NUREG/CR-3756
UCRL-53527

Seismic Hazard Characterization of the Eastern United States: Methodology and Interim Results for Ten Sites

D. L. Bernreuter, J. B. Savy, R. W. Mensing, and D. H. Chung

Prepared for
U.S. Nuclear Regulatory Commission

Lawrence
Livermore
National
Laboratory

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W. Washington, DC 20555
2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018

GPO Printed copy price: $10.00

NUREG/CR-3756
UCRL-53527

Seismic Hazard Characterization of the Eastern United States: Methodology and Interim Results for Ten Sites

Manuscript Completed: April 1984
Date Published: April 1984

Prepared by
D. L. Bernreuter, J. B. Savy, R. W. Mensing, and D. H. Chung

Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550

Prepared for
Division of Health, Siting, and Waste Management
Office of Nuclear Regulatory Research
Division of Engineering
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN Nos. A0390 and A0428

ABSTRACT

The EUS Seismic Hazard Characterization Project (SHC) is the outgrowth of an earlier study performed as part of the U.S. Nuclear Regulatory Commission's (NRC) Systematic Evaluation Program (SEP). The objectives of the SHC are: 1) to develop a seismic hazard characterization methodology for the region east of the Rocky Mountains; and 2) the application of the methodology to ten sites to assist the NRC staff in their assessment of the implications in the clarification of the U.S. Geological Survey (USGS) position on the Charleston earthquake.

As in the SEP, the fundamental characteristic of the methodology used in SHC consists in using expert opinions for all the input data. The most important improvement over the methodology used in the SEP leads to an estimate of the distribution of the hazard rather than just point estimates. An important aspect of eliciting expert opinion consists in holding feedback meetings in order to fine tune the methodology and the input data. At this point, the feedback process has not been completed. Our methodology and preliminary input from the expert panels is presented. Estimates of the hazard (PGA and spectral velocity) at ten representative sites are discussed including a sensitivity analysis and a comparison with the SEP results at four sites.

TABLE OF CONTENTS

Title | Page #

LIST OF TABLES

LIST OF FIGURES

Appendix C-B

Appendix D

LIST OF ABREVIATIONS

A	Symbol* for seismicity expert Number 10
ALEAS	Computer code to compute the BE Hazard and the CP Hazard for each seismicity expert.
B	Symbol* for seismicity expert Number 11
BE	Best estimate
BEHC	Best estimate Hazard Curve
BEUHS	Best estimate Uniform Hazard Spectrum
BEM	Best estimate map
BR	Braidwood
C	Symbol* for seismicity expert Number 12
CUS	Central United States
COMAP	Computer code to generate the set of all alternative maps and the discrete probability density of maps.
COMB	Computer code to combine BE Hazard and CP Hazard over all seismicity experts.
CP	Constant percentile
CPHC	Constant percentile Hazard Curve
CPUHS	Constant percentile Uniform Hazard Spectrum
CZ	Complementary zone
D	Symbol* for seismicity expert Number 13
EUS	Eastern United States
GMP	Ground Motion Panel
HC	Hazard Curve
LB	Lower Bound
LC	La Crosse
LI	Limerick
MI	Millstone
MY	Maine Yankee
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
PRD	Computer code to compute the probability distribution of epicentral distances to the site.
PSV	Pseudo Relative Velocity
Q1	Questionnaire 1 - Zonation
Q2	Questionnaire 2 - Seismicity
Q3	Questionnaire 3 - Regional Self Weights
Q4	Questionnaire 4 - Ground Motion Models
RB	River Bend
RP	Return Period
SEP	Systematic Evaluation Program
SH	Shearon Harris
SZP	Seismicity/Zonation Panel
UB	Upper Bound
UHS	Uniform Hazard Spectrum
VO	Vogtle
WB	Watts Bar
WC	Wolf Creek

*These symbols are used as identifiers in the figures of Section 4.

ACKNOWLEDGEMENTS

This work was supported by the United States Nuclear Regulatory Commission under a memorandum of understanding with the Department of Energy. The NRC program manager was Andrew Murphy and Jeff Kimball was the technical monitor.

Kenneth Campbell made a large contribution in the elaboration and completion of Questionnaire 4, dealing with ground motion models. A large portion of the software programming was performed by Larry Golen of the Lawrence Livermore National Laboratory Computations group and many secretarial persons spent long hours on the report. In this regard, a special thank you goes to Terry Patters and Sue Aubuchon.

SECTION 1: INTRODUCTION

The impetus for this study came from two unrelated needs of the NRC. One stimulus arose out of the need of the NRC funded SSMRP's task of simplified methods to have available the data and analysis software necessary to compute the seismic hazard at any site located in the eastern United States (EUS) in a form suitable for use in probabilistic risk assessment (PRA) analysis. The second stimulus was the result of the NRC's discussions with the U.S. Geological Survey (USGS) regarding the USGS's proposed clarification of their past position with respect to the 1886 Charleston earthquake. The USGS clarification was finally issued on November 18, 1982, in a letter to the NRC which states that:

> "Because the geologic and tectonic features of the Charleston region are similar to those in other regions of the eastern seaboard, we conclude that although there is no recent or historical evidence that other regions have experienced strong earthquakes, the historical record is not, of itself, sufficient grounds for ruling out the occurrence in these other regions of strong seismic ground motions similar to those experienced near Charleston in 1886. Although the probability of strong ground motion due to an earthquake in any given year at a particular location in the eastern seaboard may be very low, deterministic and probabilistic evaluations of the seismic hazard should be made for individual sites in the eastern seaboard to establish the seismic engineering parameters for critical facilities."

Anticipation of this letter led the Office of Nuclear Reactor Regulation to jointly fund this project along with the Office of Nuclear Regulatory Research. The objectives of this program are: (1) to develop a seismic hazard characterization methodology for the entire region of the United States east of the Rocky Mountains; and (2) the application of the methodology to selected sites to assist the NRC staff in their assessment of the implications in the clarification of the USGS position on the Charleston earthquake and of recent eastern U.S. (EUS) earthquakes in New Brunswick and New Hampshire.

This project has its roots in the SEP study (Bernreuter and Minichino, 1983), however, a new study was required for several reasons:

- o Although the entire EUS was zoned at the time of the SEP study, attention was focused on the areas around the SEP sites--mainly in the CUS and New England. The zonation of other areas was not performed with the same level of detail.
- o The peer review process both by our Peer Review Panel and other reviewers identified some areas of possible improvements in our methodology.
- o Since the SEP zonations were provided by our EUS Seismicity Panel in early 1979, a number of important studies have been completed and several significant EUS earthquakes have occurred which could impact upon the Panel members' understanding of the seismotectonics of the EUS.

In common with the SEP study, extensive use is made of expert judgment to obtain the imput seismicity data required to perform a seismic hazard analysis at any site in the EUS. We have incorporated a number of important improvements into the SEP methodology suggested by the SEP Peer Review Panel and other reviewers (Bernreuter, 1981a). The most important of these improvements are:

- The Seismicity Panel was expanded to ensure that there were regional experts from all regions of the EUS on the panel.
- Uncertainty in zonation of each expert is accounted for by considering up to 30 different combinations of zones per expert (see Section 2.4).
- Each expert provided all of the seismcity parameters needed for the hazard analysis.
- The members of the EUS Ground Motion Modeling Panel provided a ranking of the various EUS ground motion models.
- Our hazard analysis software was extensively rewritten so that a complete uncertainty analysis could be performed for each seismicity expert/ground motion expert.

As in the SEP, the analysis was performed for each seismicity expert independently of the other seismicity experts and only combined at the final step using the regional self weights supplied by our panel members.

The results in this report are preliminary in nature because we have not completed our elicitation process by feeding back the results of the analysis to our panel and at this date (Dec. 8, 1983), we have not yet received the response of one of the ground motion experts. This feedback is a necessary step since it allows the experts to "fine tune" their input. It gives them the opportunity to have a better understanding of our methodology thus making a final assessment of the impact of their input on the analysis, in the absolute sense and also relative to their peers. This report has two objectives. The first objective is to provide our panel with a written discussion of LLNL's role in the process, i.e., the assumptions we made during the analysis and the way the expert's inputs was translated into input data for the hazard analysis program. The second objective, is to provide the NRC staff an early preliminary look at our results which may assist them in so of the assessment they have to make. In addition, after review of the results, the NRC staff can better direct our work so that the final product will be of more value to them.

SECTION 2: METHODOLOGY

2.1 Overview

Our methodology differs from other studies in several ways. One of the major differences is the formal approach we use to elicit expert judgment and incorporate it into the analysis. This element is similar to the SEP methodology and discussed in Section 2.2. Another major difference between this study and most other studies is in the consideration of random as well as model uncertainty to include the uncertainty in the zonation maps and in the ground motion models. A third difference is in the way the computer programs have been structured to efficiently perform the uncertainty analysis which includes a distribution of maps from each expert, uncertainty in each of the seismicity parameters and a distribution of ground motion models for (at this time) four ground motion experts.

To understand how our hazard analysis programs have been structured, it may be helpful to first examine a simplistic description of the analysis process. A key step in the evaluation of the seismic hazard at a site is to determine the annual probability that the PGA exceeds a at the site, i.e., $P(A \geq a)$ for a given set of zones (one possible map), a set of seismicity parameters for each zone, and a given ground motion model. We can compute $P(A \geq a)$ for source zone S, for each expert, given that an earthquake has occurred in source zone S, using

$$P_s(A > a) = \int_m \int_r P(A > a \mid m,r)\, f_{S_M}(m)\, f_{S_R}(r)\, dm\, dr \quad , \qquad (2\text{-}1)$$

where $P(A > a \mid m,r)$ is the probability that the acceleration A at the site is greater than a, given that an earthquake of magnitude m has occurred at a distance r from the site in zone S. $P(A > a \mid m,r)$ is a function of the ground motion model, and $f_{S_M}(m)$ is the probability density function giving the distribution of the magnitudes (or epicentral intensities) of earthquakes in source zone S. This distribution is based on inputs provided by panel members. There is a separate distribution for each zone for each expert. $f_{S_R}(r)$ is the density function for the distribution of distances from the site in source zone S and is a function only of the source zone's shape and distance from the site. This distribution is derived from the geometry of the source zones provided by each expert. The integral is evaluated over the range $M_O \leq m \leq M_{SU}$ and the entire range of distances (r) from the site to the source S.

Evaluation of Eq. (2-1) for each source zone gives the total probability that a PGA of amplitude a will be exceeded, given an earthquake in source zone S. We assume that earthquake occurrence within a zone is a Poisson process. Thus to compute the expected number of exceedences, the probability for each source zone is multiplied by the mean activity rate for each source zone. The total expected number of exceedences is calculated as the sum of expected numbers of exceedences from each source zone. Under the Poisson assumption

$$P(A > a) = 1 - \exp [-(\text{total number of exceedences of amplitude } a)]. \quad (2\text{-}2)$$

To compute the uncertainty, these equations must be evaluated many times as different ground motion models or different choices of seismicity parameters are used. Typically, the distribution $f_{S_R}(r)$ would be recomputed for each change in parameters. This is costly--particularly, as in our case, where a Monte Carlo uncertainty analysis is being performed. To avoid this we have computed the distribution $f_{S_R}(r)$ separately and formulated all possible maps, i.e., sets of $f_{S_R}(r)$ for the zones involved for each map. As discussed in 2.3 and 2.4, this data is part of the input into the actual hazard computation. The hazard analysis is discussed in 2.5 and the combination of the seismicity experts is discussed in 2.6.

2.2 Elicitation of Expert Judgment

A variety of ways in which expert opinion may be elicited were reviewed by Mensing (1981). Our approach, inspired by Mensing, combines several different methods. It is characterized by the following key features:

- Two panels of experts were formed.
- Detailed questionnaires, which required several days to complete, were distributed to panel members.
- Panel members were generally paid.
- Follow-up discussions and a planned feedback meeting were held.
- The responses of each panel member were used in a separate hazard anaysis and combined at the last step with other experts.
- A review panel is planned.

Our procedure is based on the experience gained during the SEP study and incorporates suggestions made by both the SEP Peer Review Panel and the SSMRP Panel on Subjective Inputs as well as other reviewers' comments. Two panels have been assembled as part of this project. Fourteen well known geoscientists knowledgeable about the seismicity and tectonics of the Eastern and Central U.S. form the first panel called the EUS Seismicity Panel (see Table 2.1). Drs. Stevens and Wentworth subsequently resigned from the panel after providing us with their zonation maps. Dr. Basham resigned after providing his seismicity parameter, limited to Canada thus making his data incomplete for use in our analysis. However he participated in the zonation seismicity feedback meeting thus providing a useful input by generating discussions on the seismicity of Canada and the north east of the US with the other panel members. These experts provided input to develop the overall earthquake occurrence model. The second panel or ground motion modeling included six members (see Table 2.2). Dr. Veneziano resigned from the panel

TABLE 2-1

EUS SEISMICITY PANEL MEMBERS

Dr. Peter W. Basham[2]

Professor Gilbert A. Bollinger[1]

Mr. Richard J. Holt[1]

Professor Arch C. Johnston

Dr. Alan L. Kafka

Professor James E. Lawson

Professor L. Tim Long

Professor Otto W. Nuttli[1]&[4]

Dr. Paul W. Pomeroy[1]

Dr. J. Carl Stepp

Dr. Anne E. Stevens[3]

Professor Ronald L. Street[1]

Professor M. Nafi Toksöz[1]&[4]

Dr. Carl M. Wentworth[3]

Notes:
- (1) Also participated in the SEP Panels
- (2) Only provided zones and seismicity parameters for Canada
- (3) Only provided zonation--no seismicity parameters
- (4) Also member of the Ground Motion Panel (Table 2-2)

TABLE 2-2

EUS GROUND MOTION MODEL PANEL MEMBERS

David M. Boore(1)

Kenneth Campbell

Professor Otto W. Nuttli(1)&(2)

Professor Nafi Toksöz(2)

Professor Mihailo Trifunac(1)

Professor Daniele Veneziano

Notes: (1) Participated as a member of the SEP EUS Ground Motion Panel.

(2) Also member of the Seismicity Panel (See Table 2-1)

and Dr. Taksöz provided his answers to the questionnaire on ground motion (Q4) after the first calculation appearing in this report was performed. His response will be incorporated in the final analysis which accounts for the changes in response to the feedback questionnaire Q5 and Q6 on zonation/seismicity and ground motion.

Our goal in eliciting subjective judgment is twofold. First, it gives an accurate representation of the experts' views about parameters that affect seismic hazard. Second, it enables us to retain the diversity of opinion which exists in the scientific community. Five Questionnaires were designed and sent to the experts in order to collect all the necessary data for the analysis. They are the following:

Questionnaire 1 - Zonation Questionnaire	(Q1)
Questionnaire 2 - Seismicity Questionnaire	(Q2)
Questionnaire 3 - Regional Self Weights	(Q3)
Questionnaire 4 - Ground Motion Models Questionnaire	(Q4)
Questionnaire 5 - Feedback on Zonation/Seismicity	(Q5)

Q1, Q2, and Q3 pertain to the panel of experts on zonation and seismicity described in Table 2-1, and Q4 pertain to the Ground Motion Model Experts Panel. Q1, Q2 and Q3 are described in Appendix A and Q4 is described in Appendix C. Q5 is based on the experience gained in the feedback meeting on zonation and seismicity. It was designed to improve the input data and update the methodology in the light of the discussions which took place at that meeting. This questionnaire and the responses of the experts to it appear in a subsequent report. In the following we briefly describe the intent and highlights of Q1 and Q2. In each case we seek not only an expert's opinion regarding the "most probable value" of a parameter but also, whenever possible, a measure of his uncertainty in determining the value of the parameter. Judgmental probability distributions were arrived at through a multistep procedure. For example, for the EUS seismicity panel the first step was a questionnaire sent to each expert to obtain a graphic zonation of the EUS. Major inconsistencies and other problems arising from the responses were then resolved through personal communications. The experts' zonations were used to sort the historical earthquake data file to obtain a listing of earthquakes occurring in each zone. This data was sent along with a second questionnaire to each expert requesting seismicity parameters and their uncertainty for each zone. In the penultimate step, a formal meeting will be held to review and discuss the assumptions we made to arrive at our results and in the encoding. Finally, a final-round questionnaire will be sent out to allow panel members to review and, if they choose, to modify their initial responses.

The experts were instructed to avoid cognitive biases insofar as possible. For the EUS seismicity panel, for example, four points were emphasized:

- o Answers were to be based on experience, geologic and tectonic considerations, and all other available data.

- o The level of confidence each expert placed in his answers would be explicitly considered. Therefore, since his/her input would undergo filtering and weighting when combined with the opinion of other experts, the expert was asked not to feel reluctant to express nonclassical viewpoints.

- o The questionnaire was designed to contain redundancy, which was necessary for cross-checking and for establishing the consistency of the results. The experts were asked not to try to produce answers consistent with earlier answers, since it would defeat the purpose of redundancy.

- o The experts were urged to attempt answering all questions.

The application of this methodology to obtain the necessary input for the hazard analysis programs is discussed in Section 3.

2.3 Distribution of the Distance from the Points in a Seismic Zone to the Site

The difficulty of associating the location of most historic earthquakes which have occurred in the EUS, with some known geotectonic formations has led to several basic simplifying assumptions common to most hazard analyses. First, it was assumed that, given a zone provided by a zonation expert, earthquakes could occur uniformly at random within this zone. Second, all earthquakes were assumed to be point sources, thus neglecting the fact that earthquakes are created by the rupture of tectonic faults of finite length. Thus, as discussed in 2.1, the geometry input necessary for the hazard calculations only needs to be the density function $f_{S_R}(r)$ of of the distance from the site to any point pertaining to the seismic source zone.

This distribution is the proportion of a given zone located within specific ranges of distances to the site. In the following, this distribution of distances will be referred to as the Probability of Distances and will be abbreviated by PRD. The program module which was specifically developed for the purpose of calculating the PRDs was appropriately named PRD.

The calculation of PRD for a zone given a site is straightforward, as it is illustrated in Fig. 2.1. The proportion π_{ij} of the zone i to be bounded by distances R_{j-1} and R_j from the site is given by Eq. 2.3

$$\pi_{ij} = \frac{A_j}{\text{(total area of zone i)}} \qquad (2.3)$$

where A_j is the portion of the points of zone i at a distance r such that $R_{j-1} < r \leq R_j$.

In the process of developing the program PPD, several practical aspects led to decisions of some importance for the calculated hazard at the site. These are related to the following:

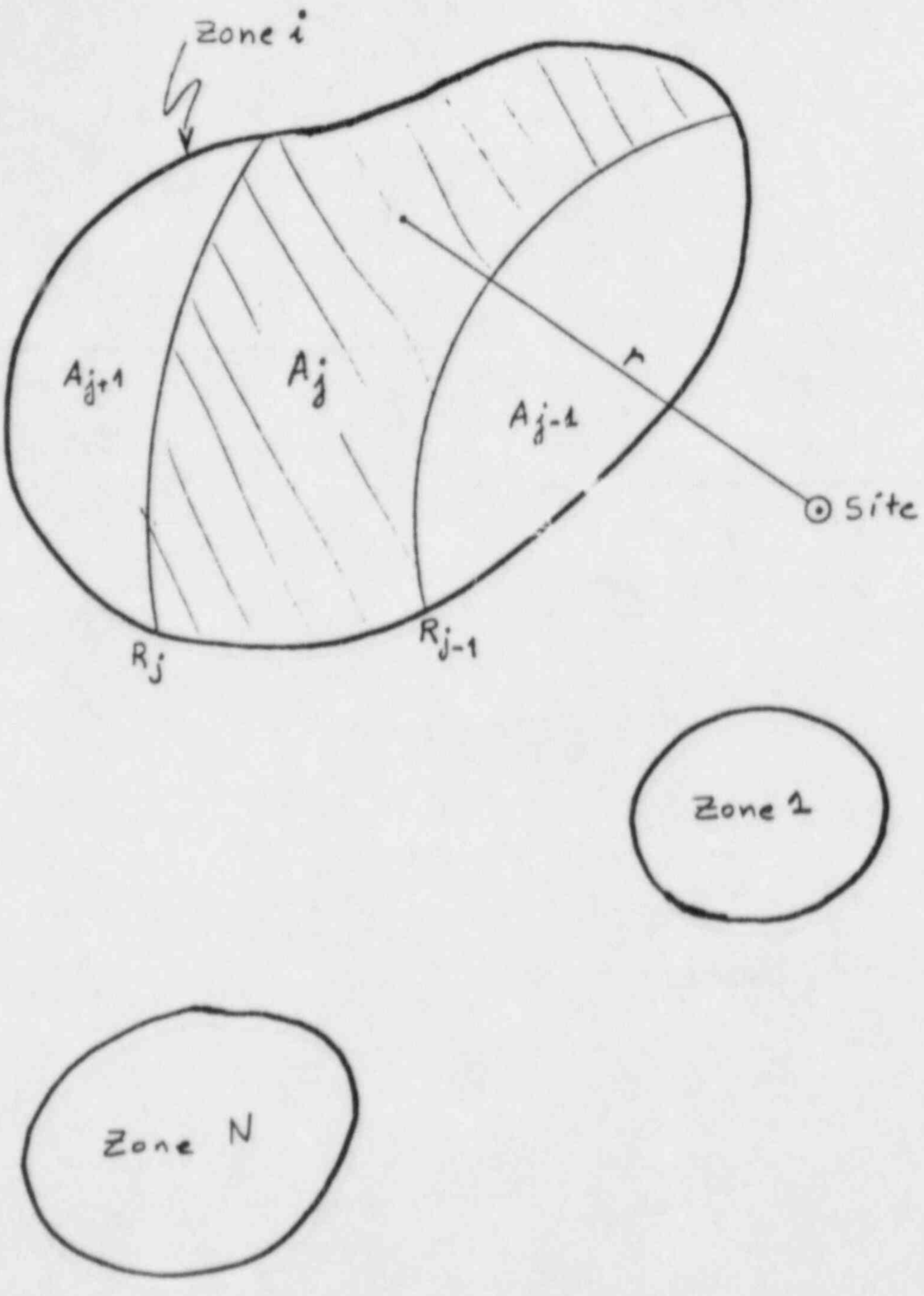


Figure 2.1 Distance Distribution for a Zone

Figure 2.2 Extent of the Complementary Zone for the EUS

(a) The format of the input zonation maps

(b) The discrete nature of the calculations and the necessity of keeping the computer time for the overall analysis within reasonable bounds

(a) The seismic zones provided by the experts had highly irregular shapes and a wide spectrum of sizes. Furthermore, most experts provided some alternatives to their best estimate zonations and in some cases there was no overall zone to model the remaining part of the EUS not specifically zoned.

The former aspect precluded the use of an analytical solution for performing Eq. 2.3 and led to a discrete solution where a zone was discretized into small quadrangles. The latter two points were resolved by creating an ad hoc zone indexing system, allowing an easy treatment of zones within zones, and an overall complementary zone (C.Z) shown in Fig. 2.2 was created when not provided by the expert. This complementary zone was meant to include all parts of the EUS not specifically zoned by the expert. Strictly speaking, if an expert thought that he/she had included all potential seismic areas into specific zones, then the seismicity of the complementary zone should be zero. However, it was clear in our individual feedback discussions with the experts that a lack of specific zonation in some areas of the EUS might reflect more a lack of knowledge rather than the conviction that these areas were aseismic. Therefore, in some cases the complementary zone may have a non zero seismicity. This is a very important point in the light of the fact that some sites are located within the complementary zone for some seismicity expert's zonations. For these sites the hazard is primarily governed by the seismicity of the C.Z.

(b) In order to get a good resolution, the size of the quadrangles mentioned above must be as small as possible, especially when computing the PRD for the portions of zone close to the site or at the location of the site. On the other hand, it is necessary to keep the dimensions of these quadrangles as large as possible to avoid prohibitive computer time uses.

Thus it was assumed that there exists a distance, from the site, beyond which the effects of earthquake occurrences is negligible at the site. This distance we called the radius of the circle of influence. Furthermore, it was assumed that the resolution in the calculations of the PRD could be a function of the distance from the site. Therefore, the size of the quadrangle was made equal to a 1 km square close to the site, up to a distance of 24 km from the site and 3 km square from 24 km to 900 km, and 20 km square from 900 km to 1250 km. The zones being entirely beyond 1250 km were not considered. These values were obtained after careful examination of sensitivity analyses where the minimum quadrangle size was as low as .1 km for the close-in zones and as large as 100 km in the remote zones. The close-in switch distance of 24 km was chosen after varying it from 5 km to 50 km.

The output of the program module PRD consists in a set of arrays of PRD's, one array per each seismic zone, for each alternative zone, and for the complementary zone if necessary. The content of each array is the set of proportions of the zone within each of the interval of distances from the site. For reason of cost, the number of these intervals was also kept to the minimum possible. The intervals start small and increase in a roughly exponential fashion. After considering several sets of intervals, the following intervals were retained for the final calculations (in km):

5,5,5,10,10,15,25,25,25,25,50,50,50,100,100,200,200,350

Thus the values of the R_j of Fig. 2.1 are:

5,10,15,25,35,50,75,100,125,150,200,250,300,400,500,700,900,1250

2.4 Set of Alternative Maps

Each expert was given the opportunity to provide a best estimate map (BEM) and a set of alternatives to express his/her uncertainty associated with the zonation. (For a more detailed discussion on the process of elicitation of responses from the experts and the data they provided, see 3.2 and Appendix A.)

The uncertainty associated with a given zonation of the experts was expressed by

a. Their level of confidence in the existence of each zone of the BEM.

b. The replacement zone that the area in question becomes if it does not exist. This replacement zone is named the "host" zone.

c. Their level of confidence in the shape of each zone or cluster of zones of the BEM.

d. The shape of the replacement zone to the zone in (c) above. This replacement zone is named the "alternate" zone.

For purposes of the analysis, all levels of confidence were normalized and treated as probability values (see Appendix D).

In order to integrate the experts' uncertainty into the hazard analysis, a simulation process was developed where each simulation draws a realization of each of the random variables from their respective distribution (this process is developed in detail in Appendix D). For the uncertainty analysis the zonations were therefore treated as random and for the purpose of the simulations, a set of all possible maps with associated probabilities were developed, based on the above information given by the experts. Thus, for each expert a discrete probability distribution of the zonation maps were developed. This was practically accomplished by the program module named COMAP. The fundamental idea used in COMAP consists in starting with the best estimate map, as a set of zones, and perform all of the following operations to generate all possible maps:

a. Remove each zone and every possible combination of zones with non-zero probability of non-existence (probability of existence non equal to 1.0) from the BEM and replace them by their respective host zone. At the same time compute the probability associated with each arrangement of the zones which constitutes these maps.

b. Remove from the BEM each zone and every possible combination of zones with non-zero probability of having an alternate shape (probability of the shape in the BEM not equal to 1.0) from the BEM and replace them by their respective alternative shape. At the same time, compute the probability associated with each of these possible cases.

c. Take each of the possible maps defined in (a) above and perform the operation (b) on the remaining zones initially in the BEM, using the convention that when a zone did not exist (i.e., was removed from the BEM), it could not be replaced by an alternate zone. Furthermore, when a cluster of zones had to be replaced by another cluster of zones, this could be performed only if all of the zones of the cluster of zones to be replaced actually existed. At the same time compute the probability associated with each of these possible cases.

In actuality, most experts had so many zones with non-zero probability of non-existence and non-zero probability of alternative shapes that in some cases the number of possible maps was very large. However, the probability associated with a map decreases very fast as the number of combinations increases.

Several assumptions were made to finally end up with a manageable number of possible maps, the effect of which was tested to determine their validity.

a. The maps (arrangement of zones as described in (a), (b), (c) above) with probability less than 1% of the BEM probability were rejected.

b. The total number of maps was set to a maximum of 30.

Since the geometry of some of the host zones changed as a result of the combinations (eliminating a zone or replacing a zone by its alternate), it was necessary to update their PRD (see Sec. 2.3). This operation was performed on the final set of 30 or less selected maps. This information and the weights (probabilities) associated with each of these maps was then used as the basic geometric input to the program module ALEAS which computes the hazard at the site. ALEAS treats this set of 30 (or less maps) and their associated probabilities as a probability function from which it draws for the simulation process.

2.5 Calculation of the Distribution of the Hazard

2.5.1 General Considerations

Many of the methods of evaluation of the seismic hazard at a site acknowledge the uncertain nature of the earthquake occurrences and of the ground motion attenuation data. In particular, the SEP study, which preceeded the present one, focussed on the integration of the above type of uncertainty which we will call the Random Uncertainty into the final hazard. There is, however, another type of uncertainty which is more likely to introduce systematic bias into the results. This we will call the systematic or model uncertainty. For example, it is associated with the choice of a zonation map and the choice of a particular ground motion attenuation equation. In the present study considerable effort went into developing a methodology which would also incorporate the systematic uncertainty into the results. The complexity of the problem made it difficult to express the systematic uncertainty by a straightforward analytical method and a simulation methodology was adopted instead. All of the formal technical details of this methodology are described in Appendix D. This section is only meant to give the reader a general understanding of the method. The overall steps, practical assumption and some of the important technical points adopted in the program module ALEAS which calculates the hazard are briefly described here.

2.5.2 Random and Systematic or Model Uncertainty

Consider a simple hypothetical ground model attenuation equation of the following form,

$$\text{Log PGA} = bM - c \text{ Log } R + E \tag{2.4}$$

In this equation b and c are constants, M is the magnitude of an earthquake, R is the distance from the source of the earthquake to the site. E is a random variable with zero mean and standard deviation e.

With this model, for a given magnitude M and distance R, the PGA can be predicted, but only in terms of a conditional probability statement of the form:

$$P\ [\text{PGA} \geq a \mid M,R] \tag{2.5}$$

Given M and R, this probability depends on the distribution of the random variable E.

In this example, the constants b, c and e are fixed and characterize the model of attenuation. The distribution of the random variable E is a model of the random uncertainty in PGA.

Similarly, given that an earthquake has occurred, there is uncertainty about the magnitude of this earthquake. The random uncertainty in M is represented by the magnitude recurrence relationship, for example, the Gutenberg-Richter equation.

Theoretically, the knowledge of the above models with the additional knowledge of the zonation and seismicity is sufficient to calculate the hazard at a site. It is associated with the models of attenuation and recurrence chosen for the analysis. However, Eqn. (2.4) is not the only ground motion attentuation model which can be used. Thus in the present study, the uncertainty in the ground motion prediction and in the magnitude (or intensity) distribution are recognized as random uncertainties. Systematic, or modeling uncertainties are recognized in the following items:

- o Many possible choices of ground motion attenuation models. This includes choices of b, c and e in the example of Eq. 2.4 above.
- o Many possible zonation maps for a given zonation expert.

- Many possible different conceptual zonations coming from the different zonation experts.

- Given a seismic zone specified by an expert, many possible models of earthquake recurrence. This is expressed by a range of values in the parameters of the recurrence equation.

- Given a seismic zone specified by an expert, many possible models of upper limit of magnitude/or intensity. This is expressed by a range of values in M_U or I_U.

2.5.3 The Method of Simulation

In this method, the hazard at the site is calculated many times, as many as necessary to describe the uncertainty in the hazard due to the uncertainties, as described above in the inputs. In each of the calculations a set of the models is chosen, and used to calculate the hazard, which for a ground motion parameter A is in the form:

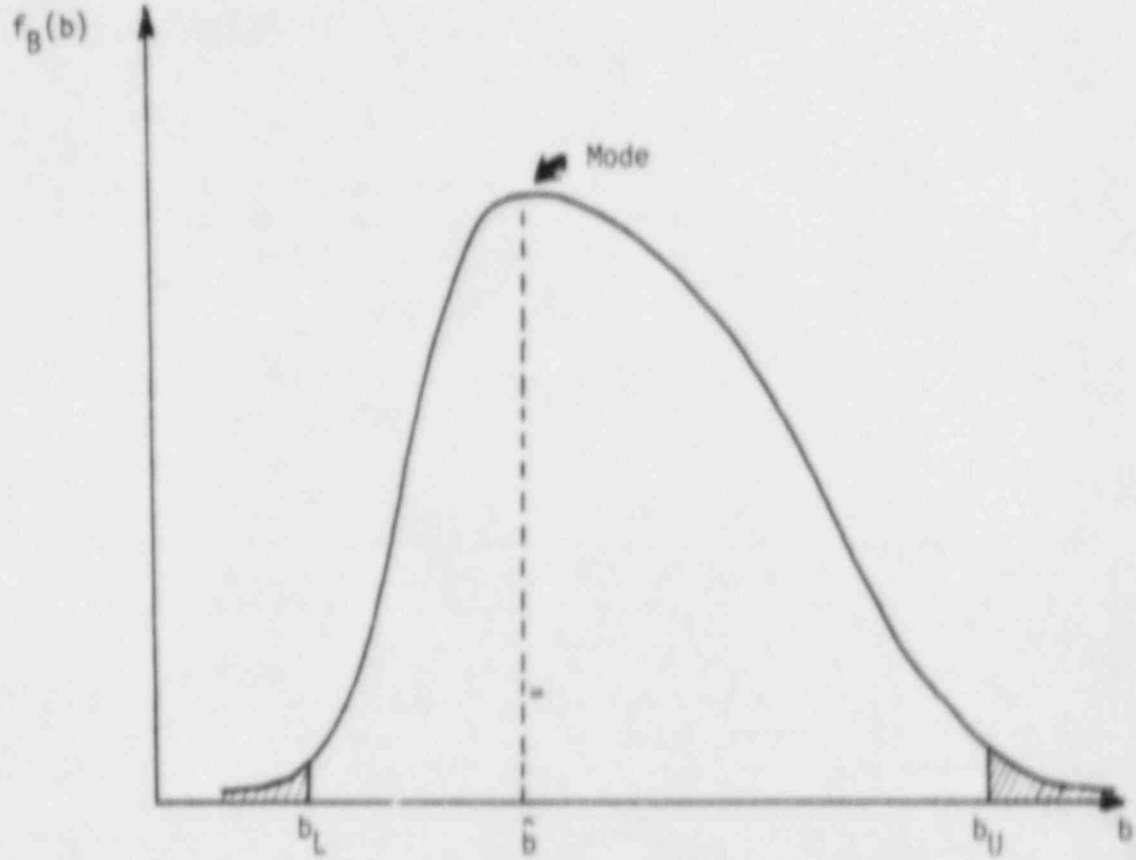
$$P\ [A > a]$$

then for each new simulation, a set of new models is chosen.

Lets assume that N_s simulations are performed for each seismicity expert. For each new simulation a zonation map is drawn from the distribution of maps described in Section 2.4, i.e., if W_{m1}, W_{m2}, ..., W_{mj}, ..., W_{mM} are the probabilities associated with maps 1, 2, ..., j, ..., M, the proportion of the times that the j^{th} map is used, is equal to N_sW_{sj}. For each simulation, a ground motion model is selected in the same manner as the maps. The distribution of ground motion models is derived from the input of the ground motion panel experts. All of the remaining model parameters are defined by continuous analytical functions and for each simulation they are drawn from their respective distribution in the usual fashion used in Monte Carlo simulations. These parameters include the earthquake upper magnitude for each zone, the coefficients of the model of earthquake occurrence and the standard deviation of the random variation associated with each ground motion model. The probability distributions are determined from the input from the seismicity and from the ground motion experts, (see Section 3 and Appendix D). Basically, each parameter is described by a best estimate, a lower bound and an upper bound. For each of the parameters a lognormal distribution function is chosen to model the systematic uncertainty, the coefficients of which are computed by equating the best estimate to the mode of the distribution and by equating the lower and upper bounds (given by the experts), to the 2.5 and 97.5 percentiles of the distribution as shown on Fig. 2.3. In the case of the upper magnitude cutoff, the bounds are considered as absolute bounds and the distribution is triangular.

2.5.4 Weighted Hazard

The Monte-Carlo simulation described above provides a set of sample points. Each point is computed for a given zonation/seismicity expert and for a given ground motion expert. Since each ground motion model is associated with a weight specified by the ground motion expert, it is necessary to select a



$P\ [b_L < B \leq b_U] = .95$

Figure 2.3 Estimation of the parameter of the probability distribution of B.

The best estimate $\hat{b}$, provided by the expert is equated to the mode. b_L is taken as the 2.5th percentile and b_U as the 97.5th percentile of the distribution, where b_L and b_U are the lower and upper bound provided by the expert.

method of combining the results. This is also true of the combination of results for the seismicity experts. Only the general concept of the method used in this analysis is presented here, the details appear in Appendix D. Two types of weights are considered.

a. Each ground motion expert has associated degrees of belief or levels of confidence to each of the seven classes of models presented in the questionnaire.

b. Each expert from the seismicity panel and from the ground motion panel have provided a self weight, which reflects how he/she perceives his/her level of expertise about the seismicity and ground motion modeling respectively.

The weights of (a) are interpreted as probabilities. They are used to define the discrete probability distribution of ground motion models for each ground motion expert. The weights associated with each possible map of the seismicity experts (see 2.4) are of the same nature. They define the discrete probability distribution of maps for a given expert.

The weights defined in (b) are of a different nature and constitute a different issue. The relative expertise of the ground motion experts is assumed to be with regard to the applicability of the ground motion attenuation models presented in the ground motion questionnaire and do not depend on the region of the EUS. In the case of the seismicity experts, four regions have been identified; as shown in Fig. 2.4. These four regions: Northeast, Southeast, North Central and South Central are in some ways related to attenuation characteristics of the EUS in the way they were defined. Their choice was based on an overall distribution of the seismicity, the large scale dominant tectonic models and considerations of attenuation characteristics, after a study by Singh and Herrmann, 1983.

Each seismicity expert was asked to provide self weights for each of the four regions. These regional self weights are used to compute a single seismicity expert weight in a way which emphasizes the weight of the expert relatively most knowledgeable about the zone which contributes the most to the hazard at the site. The problem then becomes one of combining the results over seismicity experts and ground motion experts when the weight associated with each one of them is known. Two cases have to be considered.

Figure 2.4 Identification of four regions of the Eastern U.S. based on a compilation of the seismic zonation expert maps developed in this study and a map of Q_0- contours from Singh & Herrmann (1983).

Case (a) "Best Estimate" Hazard

The term "best estimate" is actually a misnomer. In the present context, it refers to the hazard computed with all the parameters of the analysis set equal to the value defined as the best estimate by the experts. In that case the calculation is performed with the best estimate maps of the zonation expert, the best estimate upper magnitude cutoff, best estimate parameters in the definition of the earthquake occurrence and finally the best estimate model of ground motion attenuation as defined by the ground motion experts. $P\ (A_T \geq a)$ is the combination of the results over all the experts. It is simply obtained by a weighted average, as shown in Eq. 2.6, where w_{Au} is the weight for the u^{th} ground motion attenuation expert and w_s is the weight for the s^{th} seismicity expert.

$$\hat{P}_s(A_T > a) = \sum_{u=1}^{U} w_{Au}\, \hat{P}_{su}(A_T > a) \Bigg/ \sum_{u=1}^{U} w_{Au}$$

$$\hat{P}\ (A_T > a) = \sum_{s=1}^{S} w_s\, \hat{P}_s\ (A_T > a) \Bigg/ \sum_{s=1}^{S} w_s \qquad (2.6)$$

In this equation S is the total number of seismicity experts, U is the total number of ground motion attenuation experts and $P_{su}(A_T \geq a)$ is the "best estimate" hazard for a choice of seismicity and ground motion experts.

Case (b) Probability Distribution of the Hazard, Derivation of Percentiles

For each pair of seismicity and ground motion attenuation experts for which the simulation calculation of the hazard is performed, let the hazard be denoted as $p_a = P\ (A_T > a)$ (for a given s, and a given u).

The probability distribution of p_a due to the uncertainties in the expert opinions is computed as the weighted average of the individual distributions, $P_{su}\{p_a \leq p\}$ for each pair of experts (s,u). This is expressed in Eq. 2.7 where the meaning of the remaining variables is the same as in Eq. 2.6.

$$P\ \{p_a \leq p\} = \sum_{s=1}^{S} \sum_{u=1}^{U} w_s\, w_{Au}\, P_{s,u}\ \{p_a \leq p\} \Bigg/ \sum_{s=1}^{S} \sum_{u=1}^{U} w_s\, w_{Au} \qquad (2.7)$$

The different percentile levels for $P(A_T \geq a)$ are assessed from this distribution of the hazard for each a.

The above applies, in particular to the single variables PGA and PGV. In the case of the determination of the Uniform Hazard Response Spectra, the same operation is repeated for each frequency.

To produce corresponding 15th and 85th curves, which reflect the potential variation in the hazard curve at a site, the points $p_{.15}(a_i)$, $i=1,\ldots I$, are combined to form the 15th percentile curve and, correspondingly, the points $p_{.85}(a_i)$ are combined to form the 85th percentile curve.

One must be careful in interpreting the bounds as hazard curves which correspond to a specific set of input parameters. The bounds are analogous to the bounds which are used to define Uniform Hazard Spectra (UHS). The UHS is the locus of points each corresponding to the same probability of exceedence and does not represent a distinct spectrum since the inherent physical correlation between the values at different frequencies has been lost in the calculations. However, it can be interpreted as an envelope of all possible spectra. Similarly the 85th and 15th percentile hazard curves do not represent the hazard curve corresponding to a specific set of input parameters. Rather they are the locus of probabilities such that the "Probability" (due to the uncertainty of the expert's in their inputs) in the probability $P(A > a)$ being greater than .15 (85) respectively for each a. It can be interpreted as an envelope of all possible hazard curves. It is not correct to interpret the 85th percentile curve as a hazard curve which will not be exceeded by 85 percent of the hazard curves produced by the uncertain parameters. It is true, however, that for a fixed value a the value $P_{.85}(A > a)$, taken from the 85th percentile curve at a, is an estimate of the value of $P(A > a)$ which has "degree of belief" or "confidence" 0.85 that it will not be exceeded, where the "confidence" is a weighted average of the level of confidence of the individual experts.

SECTION 3: DEVELOPMENT OF INPUT DATA

3.1 Background

As indicated in Section 2, most of the data used to develop the input parameters necessary for our hazard analysis was derived by use of several questionnaires. We sent three questionnaires to our EUS Seismicity Panel and one questionnaire to our EUS Ground Motion Panel. As these questionnaires, supporting documents, and responses are rather long and involved, they are summarized in Appendix A (Seismicity Data) and Appendix C (Ground Motion Models) for ready reference. To avoid getting overwhelmed by too many details in this section, we only discuss what we consider to be the most significant features of the questionnaires and only give examples of the responses.

3.2 Zonation

The first step in a seismic hazard analysis is the definition of the areas where future earthquakes might occur. Our first questionnaire elicited this information from our EUS Seismicity Panel.

In the first section of this questionnaire the approach was outlined primarily for those panel members that did not participate in the SEP. We also provided them with an overview of the SEP (Bernreuter and Minichino, 1983). In the second part of the questionnaire we addressed source zone configuration.

We defined a source zone as a region which has homogeneous seismic characteristics in terms of rate of activity, magnitude distribution and upper magnitude. We also noted that the intent of the questionnaire was to obtain the geographic boundaries of the major seismic zones and local tectonic features, e.g., faults, which should be considered in a seismic hazard analysis. The region considered is the Eastern United States and Southeastern Canada extending west to the Rocky Mountain front or roughly 104°W. We provided the panel members with black and white copies of the appropriate section of P. King's (1969) Tectonic Map of North America (King 1969a, and 1969b). Among several possible maps, King's map was selected since it was the least likely to introduce biases in the choices of tectonic models.

The experts' uncertainty in the seismic zonation was expressed by the following considerations:

- o the existence/non-existence of an individual zone or cluster of zones, i.e., should/should not an individual zone or cluster of zones be treated as a source separate from the area surrounding it,
- o the boundary shape of an individual zone or boundaries of a cluster of adjacent zones.

To assist the panel members in understanding our questions regarding these items, we provided an example response illustrating the information we were seeking.

We first asked our panel members, using the maps we supplied, to draw their base map of potential source zones configurations, for the eastern United States. We then asked them to indicate in a table those regions in which they were not certain that they should be identified as a zone. For these zones they were asked to provide their level of confidence about their existence and indicate what region they become part of if they do not exist. Finally, we asked them to isolate the zones for which they wanted to provide alternate shapes, and to provide as many alternative boundaries as they felt necessary; and, in a table to list the alternatives and give an expression of their confidence (relative to the other alternative shapes for that zone or cluster of zones) in each alternative boundary shape.

The maps returned by our expert panel were digitized so that we would have a digital version of these maps for use in the computer program PRD discussed in Section 2.3 which computes $f_{S_R}(r)$ using Eq. (2.3). In addition, the two tables (responses to the 2nd and 3rd questions) were encoded for use in the computer program COMAP discussed in Section 2.4, which generates all possible maps for each expert. As discussed in Section 2.4, for some experts very large numbers of maps were possible so we limited the number of maps generated to a maximum of 30 per expert per site as discussed in Section 2.4.

Figures 3-1 and Tables 3-1 and 3-2 are an example of typical response from our panel members.

3.3 Seismicity Data

The seismicity data needed for our hazard analysis program, discussed in Section 2.5, was obtained from the members of the EUS Seismicity Panel in response to our second questionnaire. In this questionnaire we asked the experts to supply for each of his/her zones identified as responses to our first questionnaire the best estimates for:

- o the largest earthquake in a zone (upper magnitude cut off)
- o the expected frequency or rate of earthquakes
- o the magnitude (or intensity) recurrence relation

as well as an interval of values for each parameter to which they would associate a high degree of confidence that it contained the true value.

We indicated that unless otherwise specified by the panel members, we would treat the bounds of the interval as the 2.5th and 97.5th percentiles except for the interval bounding the largest earthquake in each zone which we said we would treat as the 100 percent bound, i.e., no larger earthquake could occur.

The experts were invited to use their own catalogue of earthquakes to derive the seismicity parameters of their zones. However for those who requested it, we provided them with a catalogue developed by LLNL. The details of this catalogue are given in Appendix B. Thus in order to assist those panel members who chose to use the LLNL catalogue in answering the questions in this questionnaire we supplied them with a list of the earthquakes which occurred in each of their zones sorted both by size and by date. We also supplied them plots of the cumulative number of events in each of their zones using the LLNL

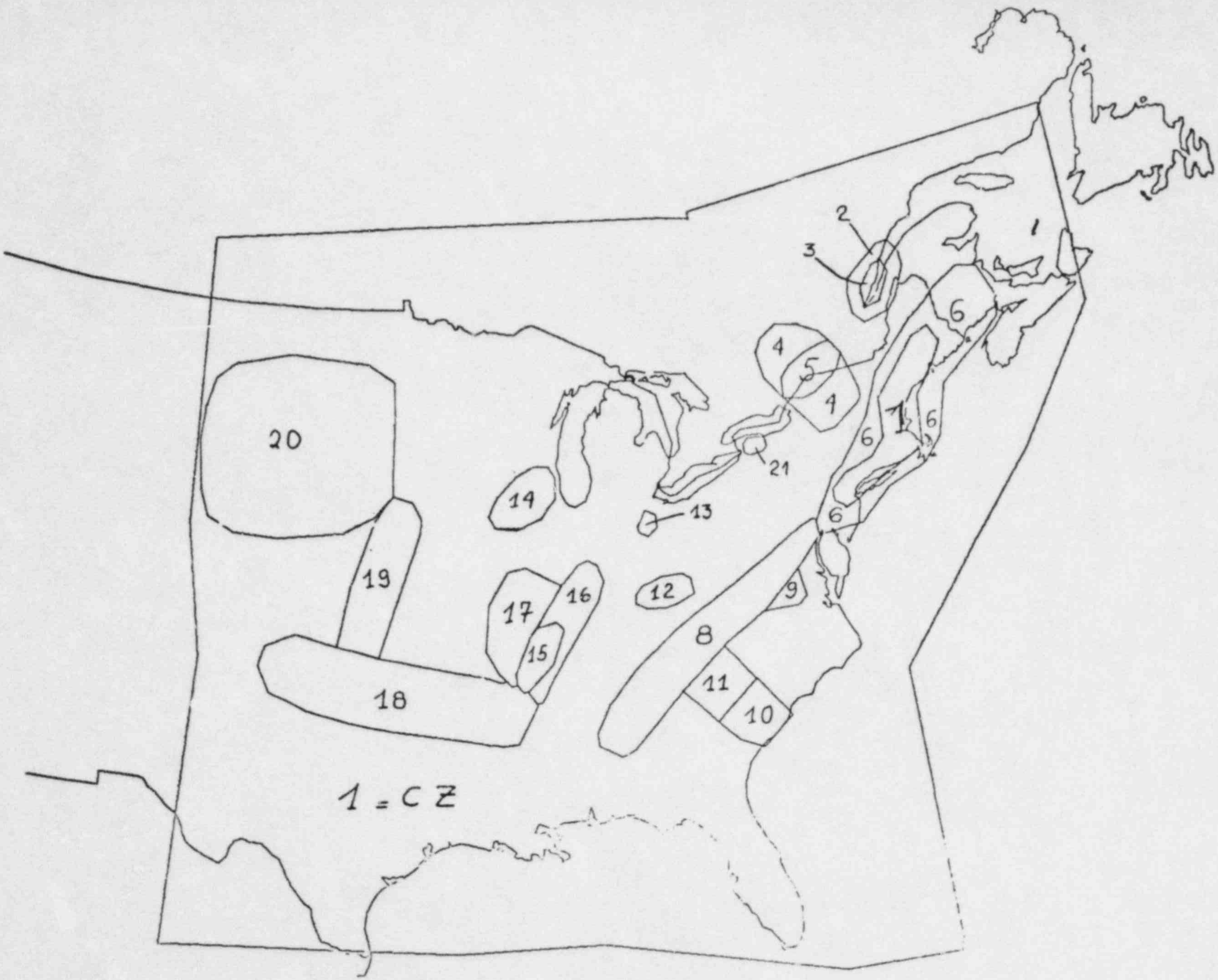


Figure 3.1a Seismic Zonation Base Map for Expert 3

Figure 3.1b Mao of Alternative Seismic Zonations for Expert 3's Base Map

TABLE 3.1

SEISMICITY DATA FOR EXPERT 3 NO. OF ZONES= 24 SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 7.0 10.0 5.0 7.0

ZONE NUMBER 1 LOC IN REG NO 4 MAP INDEX NO 1 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.3
EST. OF N	2.750	2.000	4.000
A	4.549	3.949	5.149
B	-1.100	-1.400	-.800

ZONE NUMBER 2 LOC IN REG NO 1 MAP INDEX NO 2 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.8	6.3	7.3
EST. OF N	.200	.133	.333
A	1.603	1.393	1.813
B	-.590	-.630	-.550

ZONE NUMBER 3 LOC IN REG NO 1 MAP INDEX NO 3 PROB. OF EXISTENCE= .75
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.3	6.8	7.8
EST. OF N	.267	.133	.400
A	1.223	.983	1.463
B	-.520	-.570	-.470

ZONE NUMBER 4 LOC IN REG NO 1 MAP INDEX NO 4 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.6	6.0	7.3
EST. OF N	.769	.385	1.538
A	3.586	3.016	4.156
B	-1.000	-1.130	-.870

*********** SEISMICITY DATA FOR EXPERT 3

TABLE 3.1

ZONE NUMBER 5 LOC IN REG NO 1 MAP INDEX NO 5 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.6	6.0	7.3
EST. OF N	.769	.385	1.538
A	3.586	3.016	4.156
B	-1.000	-1.130	-.870

ZONE NUMBER 6 LOC IN REG NO 1 MAP INDEX NO 6 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	5.8	7.3
EST. OF N	1.091	.727	1.818
A	4.061	3.561	4.561
B	-1.100	-1.200	-1.000

ZONE NUMBER 7 LOC IN REG NO 1 MAP INDEX NO 7 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	5.8	7.3
EST. OF N	1.091	.727	1.818
A	4.061	3.561	4.561
B	-1.100	-1.200	-1.000

ZONE NUMBER 8 LOC IN REG NO 2 MAP INDEX NO 8 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.6	5.8	7.3
EST. OF N	.800	.533	1.333
A	3.824	3.124	4.524
B	-1.040	-1.190	-.890

*********** SEISMICITY DATA FOR EXPERT 3

TABLE 3.1

****

ZONE NUMBER 9 LOC IN REG NO 2 MAP INDEX NO 8ALT PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.6	5.8	7.3
EST. OF N	.400	.267	.667
A	2.974	2.524	3.424
B	-.900	-1.000	-.800

****

ZONE NUMBER 10 LOC IN REG NO 2 MAP INDEX NO 9 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.4	7.0
EST. OF N	.167	.083	.500
A	2.855	1.925	3.785
B	-.980	-1.190	-.770

****

ZONE NUMBER 11 LOC IN REG NO 2 MAP INDEX NO 10 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.8	6.0	7.5
EST. OF N	.615	.308	1.923
A	3.116	2.516	3.716
B	-.940	-1.070	-.810

****

ZONE NUMBER 12 LOC IN REG NO 2 MAP INDEX NO 10ALT PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.0	7.5
EST. OF N	.769	.385	2.308
A	3.236	2.586	3.886
B	-.950	-1.090	-.810

*********** SEISMICITY DATA FOR EXPERT 3

TABLE 3.1

ZONE NUMBER 13 LOC IN REG NO 2 MAP INDEX NO 11 PROB. OF EXISTENCE= .85
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.3
EST. OF N	.389	.194	1.000
A	2.875	2.285	3.465
B	-.930	-1.060	-.800

ZONE NUMBER 14 LOC IN REG NO 2 MAP INDEX NO 11ALT PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	5.8	7.3
EST. OF N	.389	.194	1.000
A	3.395	2.655	4.135
B	-1.010	-1.170	-.850

ZONE NUMBER 15 LOC IN REG NO 2 MAP INDEX NO 12 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.8
EST. OF N	.300	.200	1.000
A	2.000	1.730	2.270
B	-.670	-.740	-.600

ZONE NUMBER 16 LOC IN REG NO 2 MAP INDEX NO 13 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.8
EST. OF N	.300	.200	1.000
A	2.000	1.730	2.270
B	-.670	-.740	-.600

*********** SEISMICITY DATA FOR EXPERT 3

TABLE 3.1

ZONE NUMBER 17 LOC IN REG NO 3 MAP INDEX NO 14 PROB. OF EXISTENCE= .5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.8
EST. OF N	.300	.200	1.000
A	2.000	1.730	2.270
B	-.670	-.740	-.600

ZONE NUMBER 18 LOC IN REG NO 3 MAP INDEX NO 21 PROB. OF EXISTENCE= .25
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.8
EST. OF N	.300	.200	1.000
A	2.000	1.730	2.270
B	-.670	-7.400	-.600

ZONE NUMBER 19 LOC IN REG NO 4 MAP INDEX NO 15 PROB. OF EXISTENCE= .95
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.4	6.8	7.8
EST. OF N	1.000	.667	3.000
A	3.324	2.904	3.744
B	-.910	-1.000	-.820

ZONE NUMBER 20 LOC IN REG NO 4 MAP INDEX NO 16 PROB. OF EXISTENCE= .75
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.3	7.4
EST. OF N	.357	.179	1.071
A	2.554	2.054	3.054
B	-.810	-.910	-.710

*********** SEISMICITY DATA FOR EXPERT 3

TABLE 3.1

ZONE NUMBER 21 LOC IN REG NO 4 MAP INDEX NO 17 PROB. OF EXISTENCE= .75
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.3	7.4
EST. OF N	.357	.179	1.071
A	2.554	2.054	3.054
B	-.810	-.910	-.710

ZONE NUMBER 22 LOC IN REG NO 4 MAP INDEX NO 18 PROB. OF EXISTENCE= .5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.2
EST. OF N	1.000	.500	2.000
A	4.900	4.250	5.550
B	-1.300	-1.450	-.115

ZONE NUMBER 23 LOC IN REG NO 3 MAP INDEX NO 19 PROB. OF EXISTENCE= .25
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.2
EST. OF N	1.000	.500	2.000
A	4.900	4.250	5.550
B	-1.300	-1.450	-1.150

ZONE NUMBER 24 LOC IN REG NO 3 MAP INDEX NO 20 PROB. OF EXISTENCE= .25
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.2
EST. OF N	1.000	.500	2.000
A	4.900	4.250	5.550
B	-1.300	-1.450	-1.150

EXPERT 3

Table 3.2

If Zones 2, 4, 6, 8, 10, 11, 12, 13, 14, 15, 16, 18 to 21 do not exist they become part of Zone 1.

Zone 3 becomes part of 2.

Zone 7 becomes part of 6.

Zone 9 becomes part of 8.

Zone 11 becomes part of 10.

Zone 17 becomes part of 16.

ALTERNATE BOUNDARIES

Zone Index	Level of Confidence in Boundary Shape
8	0.5
8 ALT	0.5
10	0.75
10 ALT	0.25
11	0.75
11 ALT	0.25

M_U was not limited by saturation for Expert 3.

catalogue. We also offered to supply the same data using their data base (provided it was on computer tape). Since no panel members supplied us with a tape, all panel members received a listing based on our earthquake history data tape. We emphasized that we had not applied any correction for incompleteness or possible aftershock and that they (the panel members) should correct the plots we provided them for incompleteness and aftershocks as they saw fit.

The second questionnaire, like the first questionnaire, had an introductory section explaining the type of data we were seeking. It included several groups of questions. Each group had a section defining terms and some discussion clarifying the questions and how we intended using the responses in the analyses. For example, the concept of upper magnitude cutoff, M_U, which we defined as the upper limit for the distribution of earthquake magnitude within a zone given the current tectonic and seismic conditions was discussed extensively. We also reminded the panel that some magnitude scales (most notably the m_b scale) appear to saturate. Thus, the upper limit magnitude would be limited by this saturation value. To avoid the problems of changing magnitude scales we suggested that they might want to extrapolate beyond the saturation value. For most zones this was not a problem; however, there were a few zones for which this was a problem. Generally, the panel members chose to extrapolate a little beyond the generally accepted saturation value of the m_b scale. The few departures are noted in the tables summarizing the responses given in Appendix A.

A third questionnaire was sent to the experts of the seismicity panel in order to obtain their input on their self weights for each of the four regions identified (Northeast, Southeast, North Central, South Central).

3.4 Ground Motion Models

In this analysis the ground motion model uncertainty is accounted for by considering, as much as possible, all the available models potentially applicable to the E.U.S. Thus, a straightforward method was adopted in the development of the Ground Motion Questionnaire (Questionnaire Number 4) the details of which appear in Appendix C. In this section only the highlights of the questionnaire are described and the input from the experts are presented.

Seven individuals were to participate in the evaluation of the ground motion models, two of them subsequently declined to be members of the "Ground Motion Panel." Among the five remaining experts, four have returned their responses to the questionnaire at this date. Table 3.4.1 is a list of the five experts which constitutes the Ground Motion Panel.

In the first part of the questionnaire it is explained how the ground motion models are used in the analysis. It is stated that the study is only concerned with the horizontal components of ground motion and that the measure of distance is the epicentral distance. There is some controversy as to what distance should be used in the analysis. This point was emphasized at the time of the meeting on ground motion modeling with the ground motion panel at the beginning of this project and was the object of comments from Dr. Trifunac and responses to the comments by Dr. Campbell (see Appendices C-B and C-C).

Table 3.4.1 List of Experts of the "Ground Motion Panel"

David M. Boore	(USGS)
Kenneth W. Campbell	(Tera Corp., LLNL)
Professor Otto W. Nuttli*	(St. Louis Univ.)
Professor Nafi Toksoz*	(MIT)
Professor Mihailo D. Trifunac	(USC)

*Also a member of the Zonation Panel

Our choice of the epicentral distance was based on the fact that the EUS, in general, does not exhibit any active fault traces thus making impossible the use of shortest distance or any metric based on fault length and direction. The experts were made aware of this fact in the questionnaire Q5 and were requested to consider it in their answers to the questionnaire. Then a catalog of models is presented where the different models are classified according to the way they were developed. There appears to be three general ways by which models are derived when the ground motion parameter is either Peak Ground Acceleration or Peak Ground Velocity.

1. (I) Using site intensity as an intermediate variable and relating site intensity to the ground motion parameter by using one of the following five approaches:

   - No weighting
   - Distance weighting
   - Magnitude weighting
   - Magnitude and distance weighting
   - Semi empirical

2. (D) Using the ground motions measurements directly.

3. (T) Using theoretical considerations for modeling the ground motion.

Thus the overall number of classes for modeling the PGA and the PGV is seven. Very few models are available in the case when the ground motion parameter is a spectral value (i.e. the Pseudo spectral velocity (SV), or the absolute acceleration (SA)). Thus a set of spectral shapes were chosen, which combined with a choice of PGA, PGV or PGA and PGV models, provide a larger set of spectral models to chose from.

The spectral models available were the two models developed in SEP. These models are basically intensity based, one being derived with magnitude weighting and the other with distance weighting. A third model which is also intensity based but with no weighting is the model developed by Trifunac and Anderson (1977). The three shapes of spectra (which, combined with a PGA, a PGV or both models provide the additional spectral models) are the following:

REG. Guide 1.60	:	Combined with a PGA model
NBS, 1978 - ATC	:	Combined with a PGA model
Newmark-Hall	:	Combined with a PGA and a PGV model

In order to assist the experts in their evaluation of each of the models, the main part of the questionnaire is allocated to describing all of the available models to be considered and to comparing them to one another and to the little amount of strong ground motion data available in the E.U.S. Finally, the questionnaire itself is organized as follows:

For each of the ground motion parameters (PGA, PGV or Spectra), the expert is asked to respond to the following questions, for each of the four regions of the EUS identified (Northeast, Southeast, North Central and South Central) and considering two possible measures of earthquake size (m_b and MMI).

1. Among all the ground motion models available which one is the most appropriate model i.e., the best estimate model?

2. For each class of models identified (7 classes for PGA and PGV, 3 classes of spectral shapes and 2 SEP models for spectra), which is the most appropriate model?

3. What is the confidence level that can be associated with each class. This confidence level is a number between 0 and 1 such that the sum over all classes is 1.

4. What other models should be considered?

5. Assuming that the random uncertainty has a lognormal distribution, what is the best estimate of the standard deviation on the logarithm (σ) or the coefficient of variation (cov) on the ground motion parameter? What is the interval which the expert believes, with a high degree of confidence, represents the possible range of σ or cov?

Finally in order to combine the results for several experts by the method presented in Section 2.6, the experts are asked to indicate their level of expertise with regard to assessing the worth of ground motion models.

The responses obtained for Questionnaire 4 were quite diverse. As can be seen in Table 3.4.2 "Summary of Responses", some experts chose to respond only for magnitude scale m_b and assumed all regions to be the same. One expert responded in terms of m_b and MMI and gave different models for each region.

Yet other experts (Expert Number 3 and 5) decided to select only one model for their best estimate out of one class of models and assigned a zero confidence level to all other classes. For the case of the spectra, Expert 5 did not select any of the models catalogued in the questionnaire and chose the model developed by Trifunac and Anderson (1977).

Similarly, the opinion of the experts as to the range of values to assign to σ or cov was somewhat diverse. As can be seen in the responses, the best estimate σ varied from .50 to .60 and the intervals went from [.35 - .65] to [.50 - .80] for PGA; from .55 to .76 for the best estimate of σ for PGV and from .60 to .90 for the best estimate σ for the spectral velocity models.

Figure 3.2 compares the best estimate (BE) PGA models for magnitudes of 5 and 7. Model numbers 7 and 25 are the same for both rock and soil; however, model number 27 is different for rock and soil. Both the rock (27R) and soil (27S) are shown on Fig. 3.2. It is seen from Fig. 3.2 that models numbers 7 and 25 are in reasonable agreement, however, model number 27 has a much lower attenuation than models numbers 7 and 25 and the scaling with magnitude is also significantly different. For very large earthquakes, model number 27 leads to much higher hazard curves than the other BE models. This point is discussed in Section 4.3.

Table 3.4.2 Summary of Responses to Questionnaire 4 as Input to the Analysis (1).

1. Self Weights:

Expert number	1	3	4	5
Weights	.8	.7	.8	.75

2. Ground motion parameter = PGA

A. Best estimate models

Expert ID	1	3	4	5
Best Estimate Model	7	25	7	27

Note: Same models for all regions and MMI/m_b scales.

Table 3.4.2 Summary of Responses to Questionnaire 4 as Input to the Analysis (1) continued

B. Models selected

EQK Quant. M_D-MMI	Region	Expert ID	Classes of Models 1 #	1 W	2 #	2 W	3 #	3 W	4 #	4 W	5 #	5 W	6 #	6 W	7 #	7 W
	1	1	1	.05	2	.05	3	.15		0.	5	.15	6	.25	7	.35
		3		0.		0.		0.		0.		0.	25	.70	7	.30
		4	20	.03	21	.10	22	.07	23	.13	5	.15	26	.22	7	.30
		5	27	1.		0.		0.		0.		0.		0.		0.
Mag.m_b	2	$4^{(2)}$	8	.04	9	.11	10	.08	11	.14	5	.15	26	.20	7	.28
	3	$4^{(2)}$	12	.02	13	.08	14	.05	15	.10	24	.15	26	.25	7	.35
	4	$4^{(2)}$	16	.03	17	.10	18	.07	19	.13	24	.15	26	.72	7	.30
	1	1	1	.05	2	.05	3	.10		0.	5	.10	6	.30	7	.40
		3		0.		0.		0.		0.		0.	25	.70	7	.30
		4	20	.03	21	.10	22	.07	23	.13	5	.15	26	.22	7	.30
INT.		5	27	1.		0.		0.		0.		0.		0.		0.
MMI	2	$4^{(3)}$	8	.04	9	.11	10	.08	11	.14	5	.15	26	.20	7	.28
	3	$4^{(3)}$	12	.02	13	.08	14	.05	15	.10	24	.15	26	.25	7	.35
	4	$4^{(3)}$	16	.03	17	.10	18	.07	19	.13	24	.15	26	.22	7	.30

Table 3.4.2 Summary of Responses to Questionnaire 4 as Input to the Analysis (1) continued

B. Selected models

Mag./ Intensity	Region	Expert ID	Classes of Models 1 #	1 W	2 #	2 W	3 #	3 W	4 #	4 W	5 #	5 W	6 #	6 W	7 #	7 W
		1	28	.05	29	.05	30	.15		0.	31	.15		0.	32	.60
		3		0.		0.		0.		0.		0.	46	.30	32	.70
	1	4	42	.03	43	.11	44	.08		0.	37	.18		0.	32	.60
Mag.		5 Not developed														
m_b	2	4(2)	33	.04	34	.11	35	.08		0.	31	.17		0.	32	.60
	3	4(2)	36	.02	37	.08	38	.06		0.	45	.18		0.	32	.66
	4	4(2)	39	.03	40	.11	41	.08		0.	45	.18		0.	32	.60
		1	28	.05	29	.05	30	.10		0.	31	.10		0.	32	.70
	1	3		0.		0.		0.		0.		0.	46	.30	32	.70
		4	42	.03	43	.11	44	.08		0.	31	.18		0.	32	.60
Intens.		5														
	2	4(3)	33	.04	34	.11	35	.08		0.	31	.17		0.	32	.60
MMI	3	4(3)	36	.02	37	.08	38	.06		0.	46	.18		0.	32	.66
	4	4(3)	39	.03	40	.11	41	.08		0.	46	.18		0.	32	.60

Table 3.4.2 Summary of Responses to Questionnaire 4 as Input to the Analysis (1) continued

C. Random variation

Region	Expert ID	Best Estimate σ	Lower Bound σ	Upper Bound σ
1	1	.50	.35	.65
	3	.60	.48	.72
	4	.60	.50	.80
	5	.60	.60	.60
2(5)				
3	4(4)	.55	.50	.70
4(5)				

3. Ground motion parameter = PGV.

A. Best estimate models

Expert ID	1	3	4	5
Best Estimate Model	32	32	32	N/A

Note: Same models for all regions and MMI/m_b scales.

Table 3.4.2 Summary of Responses to Questionnaire 4 as Input to the Analysis (1) continued

C. Random variation

Region	Expert ID	Best Estimate σ	Lower Bound σ	Upper Bound σ
1	1	.55	.40	.70
	3	.76	.64	.88
	4	.60	.50	.80
	5	.60	.60	.60
2(5)				
3(4)	4	.55	.50	.70
4(5)				

4. Ground motion parameter = Pseudo relative velocity (spectra)

A. Best estimate models.

Expert number	1	3	4	5
Model index	101	110	101	119

Table 3.4.2 Summary of Responses to Questionnaire 4 as Input to the Analysis (1) continued

B. Selected models.

Earthquake Quant. M_b/MMI	Region	Expert ID	Classes of Models: 1 (RS1) #	1 (RS1) W	2 (RS2) #	2 (RS2) W	3 (RS3) #	3 (RS3) W	4 (RS4) #	4 (RS4) W	5 (RS5) #	5 (RS5) W	6 (RS6) #	6 (RS6) W
	1	1	65	.10	83	.15	101	.50	47	.05	56	.15	119	.05
		3	74	.05	92	.05	110	.90		0.		0.		0.
		4	65	.12	83	.13	101	.30	47	.25	56	.20		0.
		5		0.		0.		0.		0.		0.	119	1.
m_b	2(2)													
	3	4(2)	65	.10	83	.10	101	.35	47	.25	56	.20		0.
	4	4(2)	65	.10	83	.10	101	.35	47	.25	56	.20		0.
MMI	1(2)													
	2(2)													
	3	4(2)	65	.10	83	.10	101	.35	47	.25	56	.20		0.
	4	4(2)	65	.10	83	.10	101	.35	47	.25	56	.20		0.

C. Random variation

Expert ID	Best Estimate σ	Lower Bound σ	Upper Bound σ	
1	.60	.45	.75	Same for all regions
3	.65	.53	.77	
4	.90	.70	1.40	
5	.60	.60	.60	

Table 3.4.2 Summary of Responses to Questionnaire 4 as Input to the Analysis (1) continued

Key: # = Ground motion index number. See Table 3.4.3 for correspondence with model index and equation number as they are described in Appendix C.

W = Confidence level assigned to the class of models.

Notes:

(1) Expert 2 was developed by LLNL for testing and comparisons. Not used in analysis.

(2) Except for Expert 4 all other model indeces and confidence levels same as for Region 1, m_b.

(3) Except for Expert 4 all other model indeces and confidence levels same as for Region 1, MMI.

(4) Except for Expert 4 all other model indeces and confidence levels same as for Region 1.

(5) All experts the same as for Region 1.

Table 3.4.3 Correspondence of Model Indeces in Table 3.4.2 with Models Described in Appendix C.

Ground Motion Parameter	Index in Table 3.4.2	Index of Model in Appendix C
	1	A3-G15
	2	A3-G21
	3	A3-G31
	5	G53
	6	D12
	7	D21
	8	A1-G16
	9	A1-G21
	10	A1-G31
	11	A1-G41
	12	A3-G16
PGA	13	A3-G21
	14	A3-G31
	15	A3-G41
	16	A4-G16
	17	A4-G21
	18	A4-G31
	19	A4-G41
	20	A5-G16
	21	A5-G21
	22	A5-G31
	23	A5-G41
	24	G52
	25	D13
	26	D14
	27	Trifunac-Anderson (1977)

PGV	28	A3-GV12
	29	A3-GV21
	30	A3-GV31
	31	GV52
	32	DV21
	33	A1-GV12
	34	A1-GV22
	35	A1-GV31
	36	A3-GV12
	37	A3-GV22
	38	A3-GV31
	39	A4-GV12
	40	A4-GV22
	41	A4-GV31
	42	A5-GV12
	43	A5-GV22
	44	A5-GV31
	45	GV51
	46	DV12
Spectra	47	RS4, SEP Distance weighted model
	56	RS5, SEP Magnitude weighted model
	65	RS1, REG. Guide 1.60, anchored to PGA model D21
	74	RS1, REG. Guide 1.60, anchored to PGA model D13
(SV)	83	RS2, ATC, anchored to PGA model D21
	92	RS2, ATC, anchored to PGA model D13
	101	RS3, Newmark-Hall anchored to PGA model D21 and PGV model DV21
	110	RS3, Newmark-Hall anchored to PGA model D13 and PGV model DV21
	119	RS6, Trifunac-Anderson (1977) model

Figure 3.3 shows an overlay of all soil PGA models used in the analysis for magnitudes 5 and 7. An overlay of all rock models is very similar and is not presented. As can be seen from Fig. 3.3, there is considerable diversity between the different ground motion models.

Figure 3.4 shows a comparison of the BE spectra models for rock for magnitudes of 5 and 7 at a distance of 10 km. Figure 3.5 shows the same comparison as Fig. 3.4 except the BE spectra models are for soil. Figure 3.6 shows the BE spectra for rock at 200 km for magnitudes 5 and 7. Figure 3.7 shows an overlay of all rock spectra at 10 km for magnitudes 5 and 7 and Fig. 3.8 shows the same comparison as Fig. 3.7 except the distance is 200 km. It is seen from these figures that the spectral shape changes significantly with distance and magnitude. These changes are responsible for the uncommon shapes in our best estimate uniform hazard spectra presented in Section 4.3.

3.5 Selection of Sites

The ten sites used for analysis were selected by the staff of NRC's Geosciences Branch. The criteria that was used was:

1. Provide regional coverage of all areas that are being examined in the hazard program. This should include regions such as the northeast and upper midwest which have been studied in the past and regions such as the southeast and gulf coast where little hazard information is currently available. Sites should also be chosen to provide initial (if possible) assessment of the potential impact of the USGS Charleston earthquake clarificaton letter.

2. Provide cross representation of plant vintage. The range of plant ages will allow an initial assessment to be made whether older plants may be more impacted by the hazard analysis than newer plants.

3. Provide for comparison with hazard estimates undertaken as part of Systematic Evaluation Program phase II. This will allow a direct assessment of hazard program improvements, particularly regarding how uncertainty is propagated.

4. Provide a cross representation of site conditions at test sites. This will allow an initial assessment to be made regarding the impact of site conditions on the final hazard results.

The ten sites they selected are:

1. River Bend - deep soil site; location - Gulf Coastal Plain; important issues include a region which has little or no hazard estimates.

2. Wolf Creek - rock site; partial (4 experts) hazard estimate have been completed from original program; location-west central United States; important issues include Central Stable Region and Nemaha Uplift.

3. Braidwood - treated as a rock site, review hazard estimates have been made for nearby sites including SEP Phase II at Dresden and the Zion PRA; both rock and shallow soil conditions; location-central United States; important issues include northern extent of New Madrid and seismic zones in Illinois.

4. LaCrosse - operating plant; hazard estimate made for SEP phase II; deep soil site; location-north central United States; important issues include Central Stable Region and area of low seismicity. Partial hazard estimates have been completed by consultant to licensee.

5. Watts Bar - hazard estimates made by TVA in 1978; both rock and shallow soil conditions; location-Appalachian region; important issues include possible eastern Tennessee seismic zone.

6. Vogtle - no hazard estimates have been made; deep soil site; location-Southeast United States; important issues include a region which has little or no hazard estimates and the site is within close proximity to Charleston, South Carolina.

7. Shearon Harris - no hazard estimates have been made; both rock and shallow soil condition; location-North Carolina; important issues include southeast location although somewhat removed from Charleston.

8. Limerick - no hazard estimates have been made; rock site; location-southeastern Pennsylvania; important issues include effect of Charleston on eastern seaboard plants located away from Charleston.

9. Millstone - hazard estimates made for SEP phase II; both rock and shallow soil site; location-coastal Connecticut.

10. Maine Yankee - rock site; location-Maine; important issue is that this is the closest nuclear power plant to the 1982 New Brunswick earthquake.

The locations of these sites are shown on Fig. 3.9.

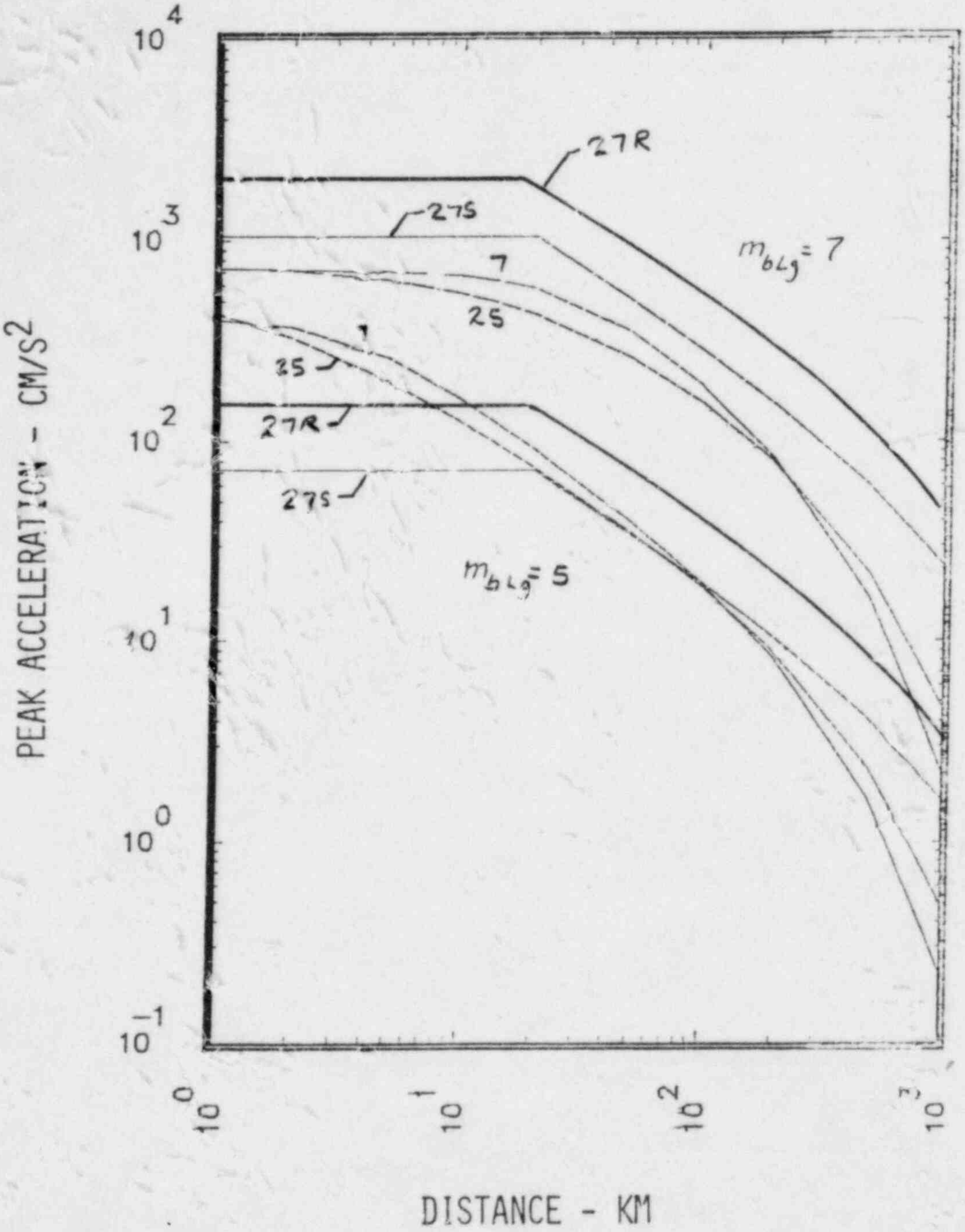


Figure 3.2 Best Estimate Ground Motion Models from Ground Motion Panel for Magnitudes 5 and 7.

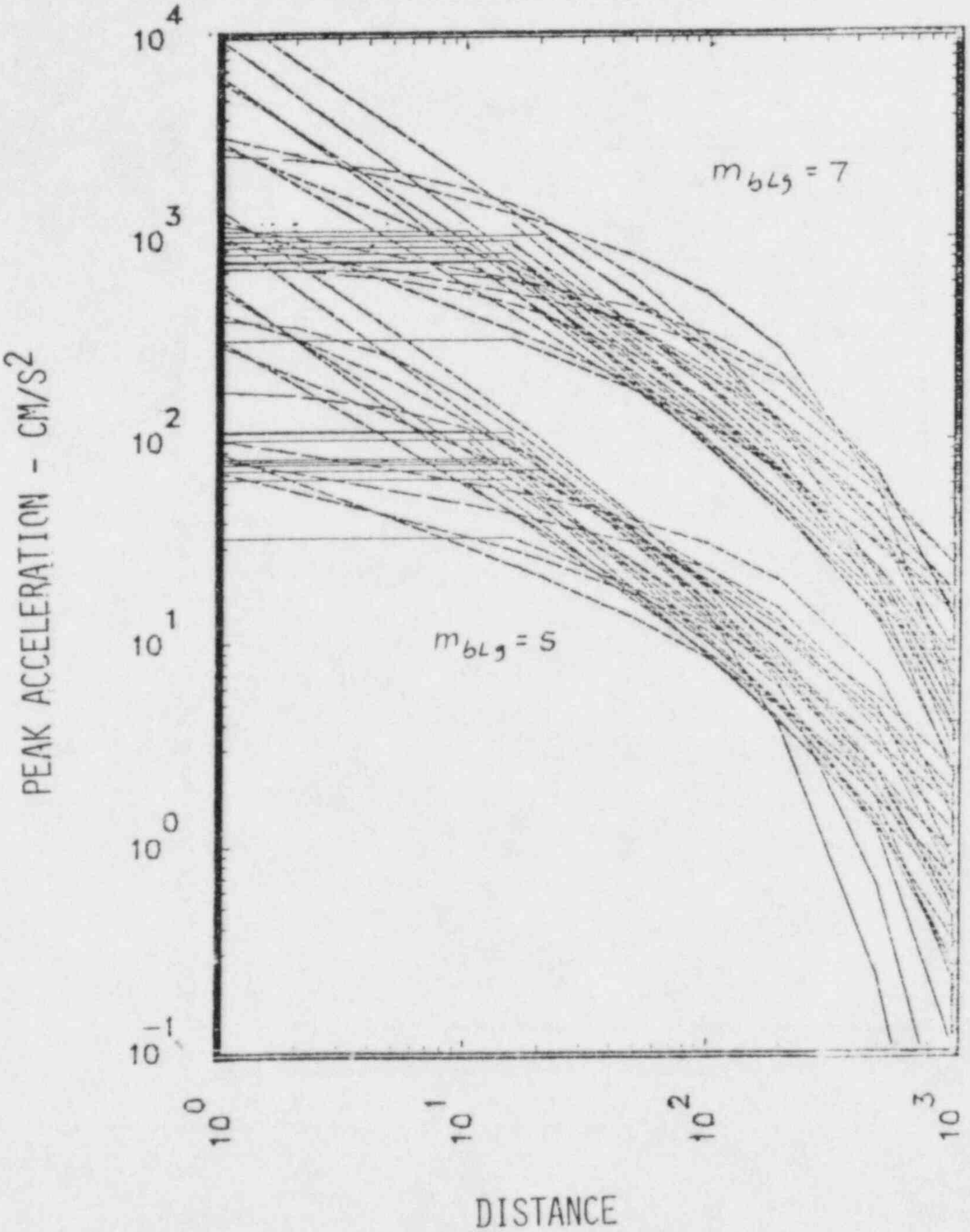


Figure 3.3 Other Models Provided by the Ground Motion Panel Members.

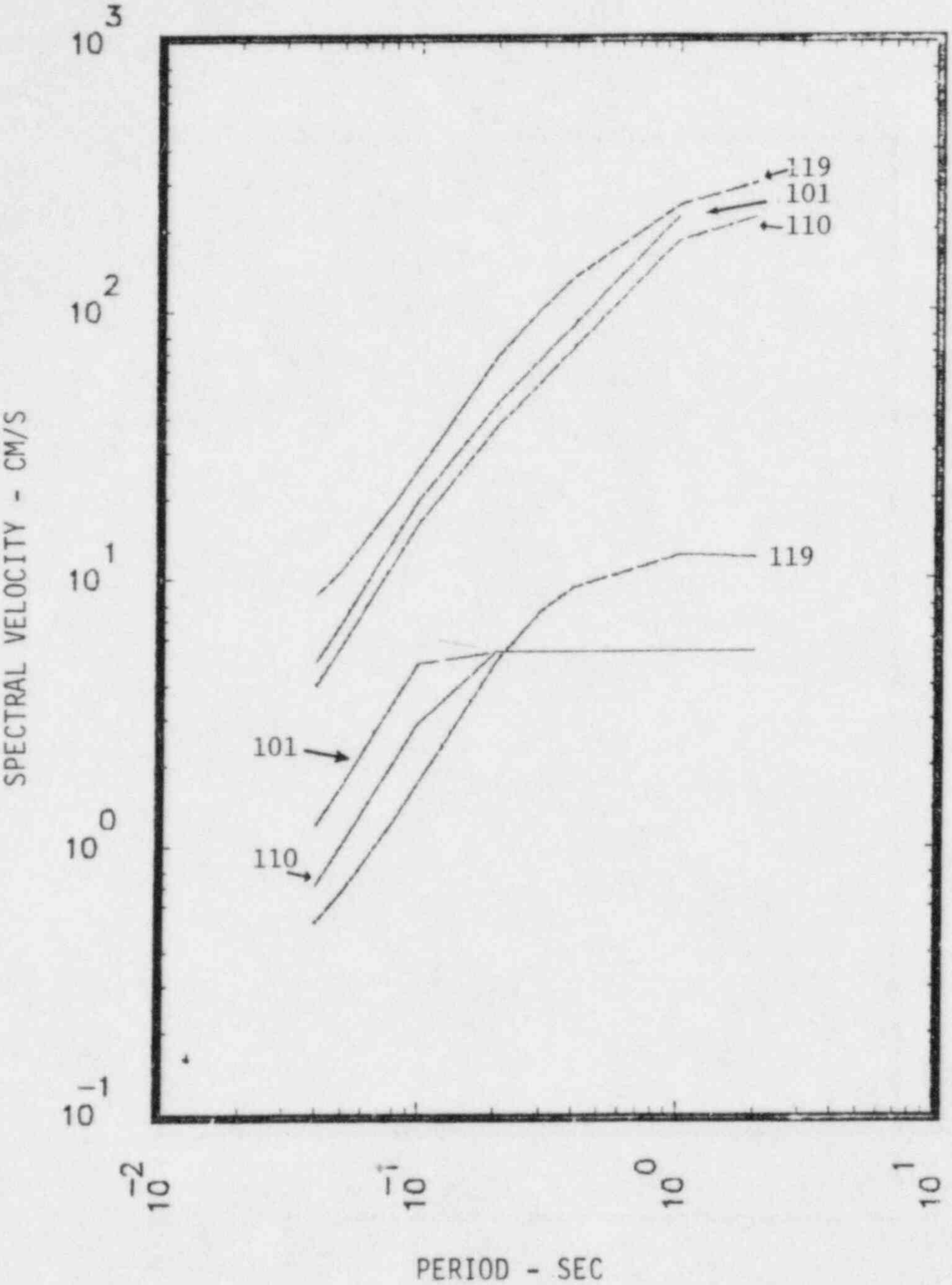


Figure 3.4 Comparison of Best Estimate Relative Velocity Spectral Models for Rock Sites - R = 10 km for Magnitudes 5 and 7.

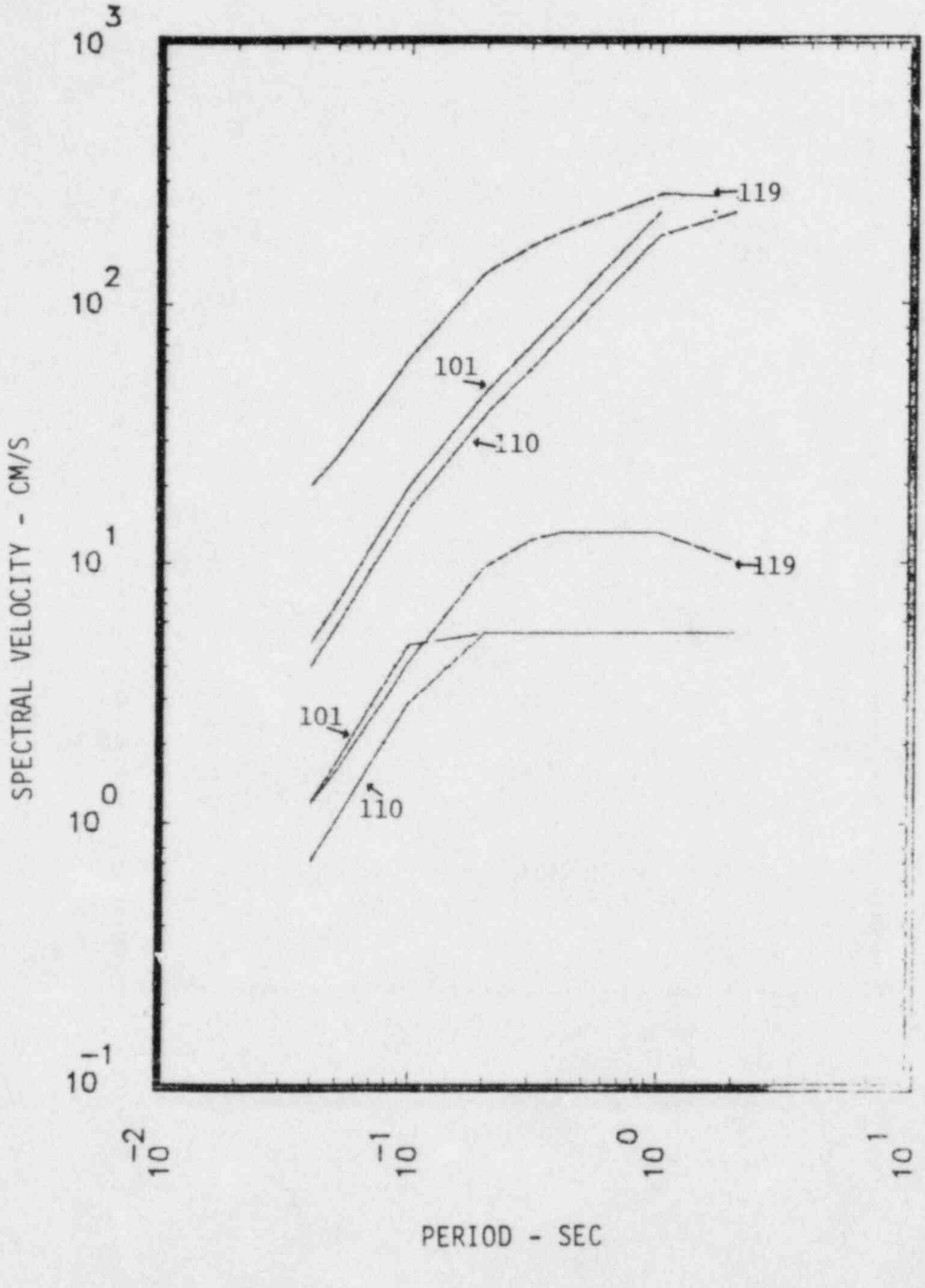


Figure 3.5 Comparison of Best Estimate Relative Velocity Spectral Models for Soil Sites - R = 10 km for Magnitudes 5 and 7.

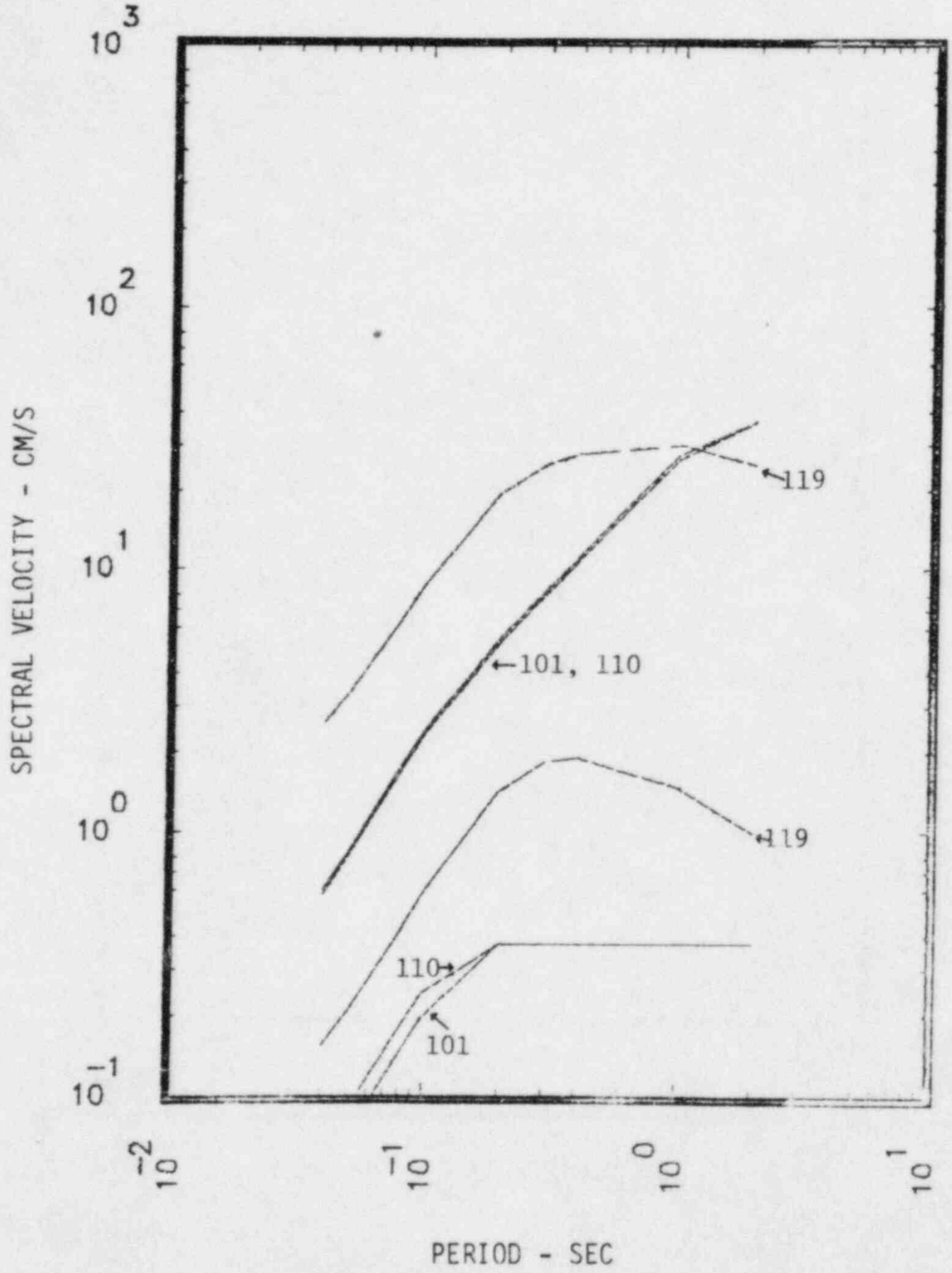


Figure 3.6 Comparison of Best Estimate Relative Velocity Spectral Models for Rock Sites - R = 200 km for Magnitudes 5 and 7.

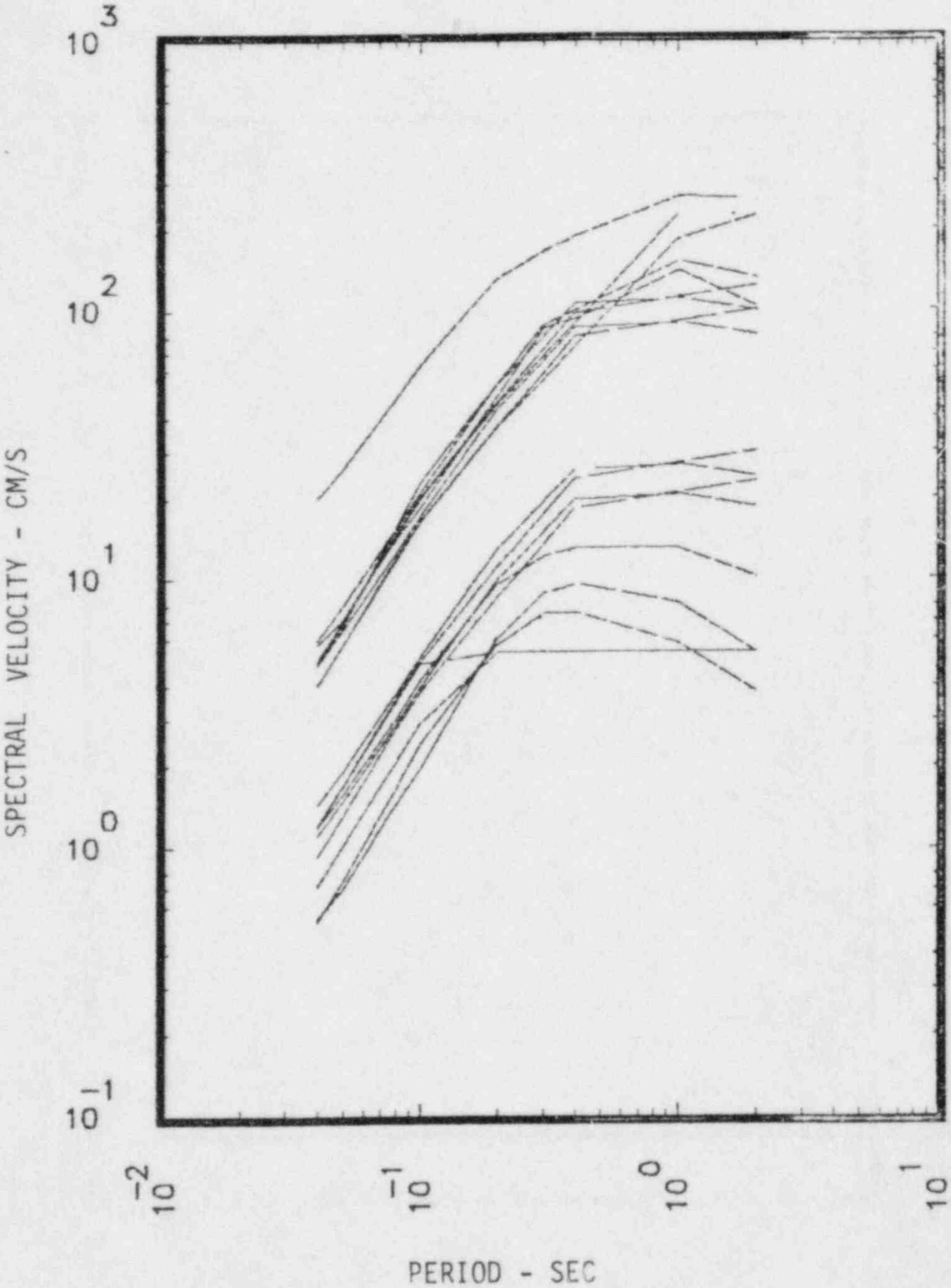


Figure 3.7 Comparison of All Relative Velocity Spectral Models Used in the Analysis for Rock Sites - R = 10 km for Magnitudes 5 and 7.

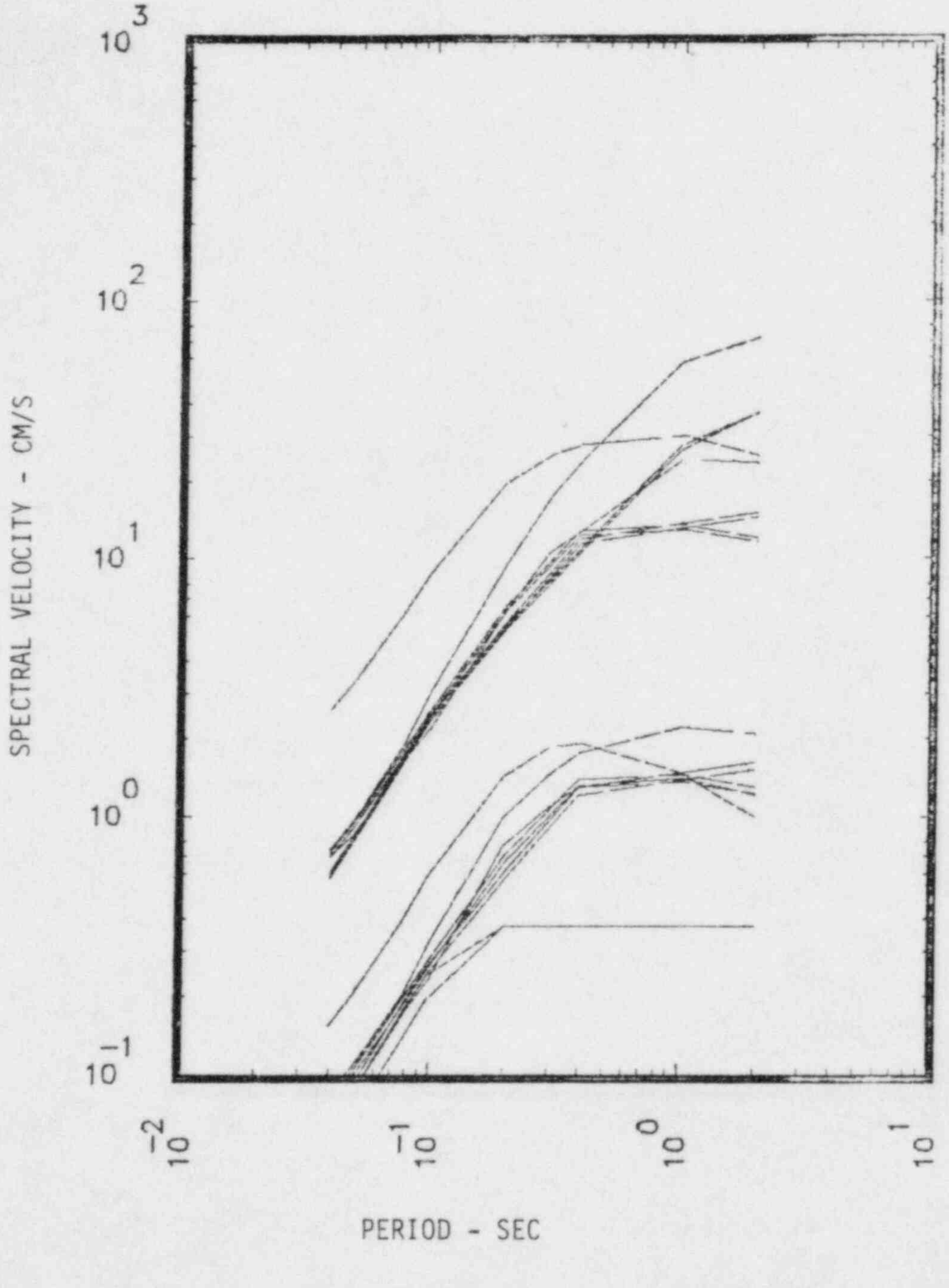
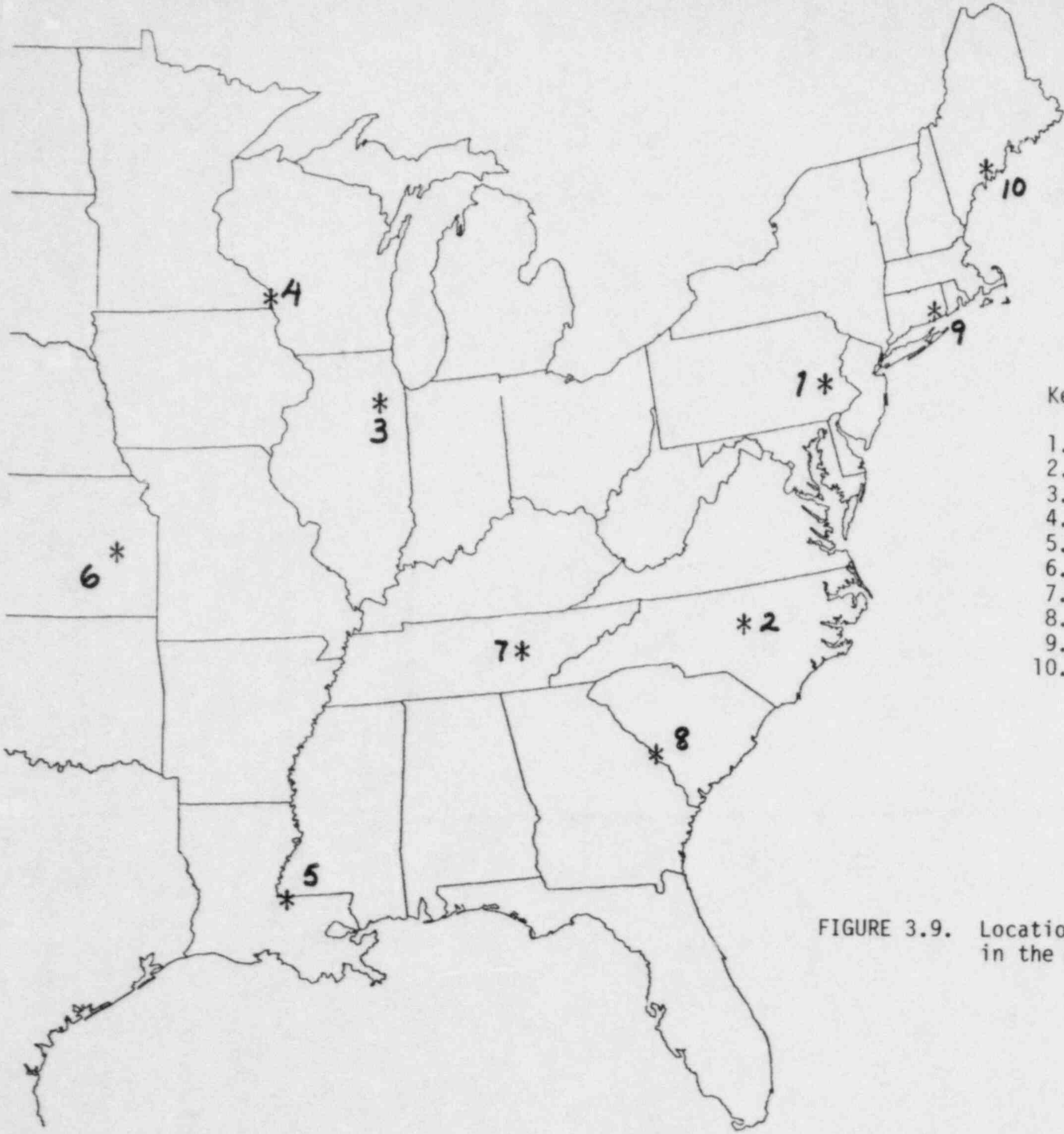


Figure 3.8 Comparison of All Relative Velocity Spectral Models Used in the Analysis for Rock Sites - R = 200 km for Magnitudes 5 and 7.



Key to Site Index Numbers

1. Limerick
2. Shearon Harris
3. Braidwood
4. La Crosse
5. River Bend
6. Wolf Creek
7. Watts Bar
8. Vogtle
9. Millstone
10. Maine Yankee

FIGURE 3.9. Location of the Sample Sites in the EUS

SECTION 4: RESULTS

4.1 Introduction

The results of the analysis for the ten sites described in Section 3.5 are presented in Section 4.3. These results must be considered as preliminary for the following reasons:

- o The feedback cycle has not been completed with the EUS Seismicity Panel.
- o One member of our Ground Motion Panel has not yet returned his answers to Questionnaire 4.
- o No feedback discussions with the Ground Motion Panel have been held yet.

It is expected that, as a result of feedback, there will be some changes in our results and this will lead to significant changes for some experts. However, the median hazard curve combined over all experts is a robust estimator and we would not expect to see this hazard curve change significantly as a result of feedback and the inclusion of the final set of ground motion models.

The results of a limited sensitivity analysis are presented in Section 4.2. The primary purpose of this section is to assist in understanding the results presented in Section 4.3. However, some of the results and conclusions are generic.

The "best estimate" hazard curves (BEHC) are presented in Sections 4.2 and 4.3. As discussed in Appendix D, what is termed BEHC for a particular expert is a hazard curve based on selecting the expert's BE map and setting all of the seismicity parameters to the BE value provided by the expert and selecting one of BE ground motion models (See Section 2.5.4 and Appendix D for more details). Thus the BEHC is not necessarily the "best estimator" to use, but is simply one possible estimator of the seismic hazard at a site. The first level of combination is to combine the BEHC resulting from using all the BE ground motions and self-weights provided by the Ground Motion Panel members. These curves for each seismicity expert are provided in Section 4.3 and referred to as BEHC for a given seismicity expert. We also combine over all seismicity experts to obtain the combined BEHC for a site using the self-weights provided by the experts. It is important to keep in mind that this combination is arithmetical so that outliers are important. We also present the constant percentage hazard curves CPHC which result from our simulation proceedure for individual experts as well as combined over all seismicity experts and ground motion experts.

In Section 4.3 we also present best estimate uniform hazard spectra (BEHUS) and constant percentile uniform hazard spectra (CPUHS). By definition the uniform hazard spectrum is a spectrum developed using probabilistic methods in such a way that each spectral amplitude has the same probability of being exceeded. In the development of the spectrum, each frequency is considered independently and correlation between the spectral amplitudes is not explicitly taken into acount. Predictions are made for one frequency at a time. All potential earthquakes, small and large, contributing to the seismicity at the site are considered, using appropriate seismicity, attenuation and exposure models. The cumulative contribution to the loading at the given frequency is computed as a cumulative distribution function of the loading.

The pseudo-spectral velocity vs. period is then plotted and the loading corresponding to the return perod of interest is used as the appropriate spectral amplitude for design at the given period. The procedure is repeated for other period within the period range of interest and the spectrum is built point by point.

Since each frequency is treated independently, the aspect of a specific spectral shape corresponding to a particular earthquake is lost in the process. Thus, the uniform hazard spectrum is not representative of any single event. For example, if the structure is subjected to a nearby small earthquake, the ground motion will be most likely rich in high frequency energy; the low frequency content of its spectrum will most probably be small. Conversely, if the event is distant, its spectrum will most probably have little energy in the high frequency range.

An important consideration in understanding the effect of the various parameters on the hazard at a given site is the relative role that the different zones play for each expert. In an attempt to display the role of the zones, Table 4.1 presents the contribution of the zones which dominate in the hazard, for each of the ten sites described in Section 3.5. The contribution factor was calculated as described in Appendix D Section D5.2. Since some zones play a different role at low hazard values than at high hazard values (or equivalently at high PGA or low PGA), the contribution factor in Table 4.1 is given for both "Low" PGA and "High" PGA. It has to be noted that this calculation is performed only once, for the best estimate case. Therfore the results of Table 4.1 have to be interpreted with caution since they are only representative of the B.E. In particular it applies only to the BE maps therefore lacking information on alternative zones or alternative boundaries. However, since in most cases the BE maps is the dominant case, the results of Table 4.1 can be used to interpret the hazard results, and keeping its limitations in mind. (Note: the zone numbers referred to in Table 4.1 are the experts' zone numbers, as they appear on the maps displayed in Appendix A).

4.2 Sensitivity Analysis

In this section we examine the sensitivity of the hazard curve to changes in various input parameters as an aid to understanding the results presented in Section 4.3. We are interested in not only how changes in the best estimate (BE) values of parameters affect the hazard curve but also how the uncertainty about the BE values influence one's assessment of the seismic hazard at a site. In particular, we examine the influence of:

1. the uncertainty individual experts have about their zonations;
2. changes in both the BE values of the a and b parameters of the magnitude recurrence relation and reduction of the uncertainty in these parameters;

Table 4.1 Proportion of the Contribution of Zones to the "Best Estimate" Hazard at Sites

Key to Table: 1st Column: "Low" = zone number/portion of contribution at low PGA level.
2nd Column: "High" = zone number/portion of contribution at high PGA levels.
Example: 7/.79 in the "Low" column for Expert 11 at Shearon Harris indicates that the expert's zone number 5 contributed 79% to the final PGA hazard in the "best estimate" case, at low levels of PGA. For this same expert at "high" level PGA, the contribution of Zone 7 was 69%.

	SITE							
Soil Condition / Location	SHEARON HARRIS Rock SE		BRAIDWOOD Rock NC		RIVER BEND Soil SC		MILLSTONE Rock NE	
Seismicity Expert Index Number	Low	High	Low	High	Low	High	Low	High
1	3/.86,1/.06 2/.06	3/.97 1/.03	19/.63,11/.21 9/.08,10/.06	19/.92 9/.04,11/.04	1/.84,9/.12 10/.02,4/.02	1/.98 9/.02	22/.84,20/.06 1/.05,21/.03, 4/.02	22/.97 1/.03
2	30/.70,CZ/.13 27/.09,29/.07	CZ/.73 30/.26	21/.56,18/.25 20/.10,CZ/.08	21/.68,18/.22 CZ/.10	CZ/.59 18/.41	CZ/.82 18/.18	31/.90,32/.07 28/.03	31/.98 32/.02
3	CZ/.52,10/.27 11/.10,8/.07	CZ/.95 10/.04	14/.69,CZ/.20 16/.05,17/.04 15/.03	CZ/.91,14/.06 16/.02,15/.01	CZ/.89,15/.09 16/.01	CZ/1.	7/.79,6/.14 1/.03,3/.02, 2/.01	7/.92,6/.05, 1/.03
4	10/.52,11/.39 9/.04,26/.03, 8/.02	11/.81,10/.19	6/.74,4/.15 3/.02,CZ/.01	6/.89,4/.09	4/.58,25/.41	25/.73,4/.24 CZ/.03	23/.76,18/.11 16/.05,19/.02 20/.02	23/.99,18/.01
5	10/.65,9/.29 8/.04,11/.01	10/.79,9/.20	CZ/.67,15/.15 13/.10,14/.04 12/.03	CZ/.76,15/.24	11/.41,CZ/.39 15/.19,17/.01	CZ.75,15/.23 11/.02	1/.92,6/.05 8/.01,3.01	1/1.
6	10/.33,CZ/.32 8/.23,17/.06 9/.05	CZ/.75,10/.17 3/.07	17/.64,23/.30 CZ/.05	17/.49,23/30 CZ/.21	CZ/.55 17/.45	CZ/.76,17/.24	4/.93,3/.05 7/.01.5/.01	4/.98,31/.02
7	CZ/.49,8/.20 9/.16,7/.10, 10/.06	CZ/.97,10/.03	CZ/.83,5/.08 6/.07,7/.01	CZ/.95,6/.05	CZ/.75,1/.14 6/.08,5/.03	CZ/.99,6/.01	24/.52,15/.34 26/.04,CZ/.03 13/.03	24/.96,15/.03, CZ/.01
10	4/.77,28/.10 15/.06, 28A/.06, CZ/.01	4/.99	26/.57,CZ/.35 12/.05,13/.03	26/.73,CZ/.27	CZ/.96,12/.04	CZ/1.	2/.56,4/.22, 22/.06,CZ/.05 23/.04,6/.01	2/.65,4/.21 CZ/.13
11	7/.79,8/.15 6/.03,5/.01	7/.69,8/.31	10/.97,CZ.02 11/.01	10/1.	14/.80,11/.12 15/.02,CZ/.02 8/.02,10/.01	14/.92,CZ/.05 11/.03	1/.71,5/.12 CZ/.07,3/.06 4/.02,1/.01	1/.93,5/.05 CZ/.01
12	3/.85,15/.10 14/.06,5/.01	3/.99,14/.01	10/.62,1/.27 11/.09,12/.02	10/.85,1/.14 12/.01	6/.87,12/.08 2/.04	6/.86,12/.14	3/.81,17/.13 18/.05,16/.01	3/.99
13	CZ/.49,9/.41 8/.09	CZ/.91,9/.09	CZ/.81,5/.09 6/.08,7/.01	CZ/.99	CZ/.88,5/.11	CZ/1.	10/.92,CZ/.04 12/.03,11/.01	10/.98,CZ/.02

Table 4.1 (Continued)

Proportion of the Contribution of Zones to the "Best Estimate" Hazard at Sites

Soil Condition / Location		SITE: VOGTLE Soil SE		MAINE YANKKE Rock NE					
		Low	High	Low	High	Low	High	Low	High
Seismicity Expert Index Number	1	1/.50,2/.35 3/.11,9/.04	1/.96,2/.04	22/.88,21/.07 20/.05	22/.96,21/.04				
	2	30/.68,29/.30 18/.02	29/.63,30/.37	31/.81,32/.19	31/.89,32/.11				
	3	10/.90,11/.06 CZ/.03	10/.98,CZ/.02	7/.76,6/.11 3/.06,2/.03	7/.92,6/.04 CZ/.03				
	4	10/.86,9/.11 4/.03	10/.96,25/.03 9/.01	20/.67,18/.27 19/.04,16/.02	20/.97,18/.03				
	5	9/.80,10/.13 8/.06	9/.65,8/.29 10/.04,CZ/.02	1/.93,6/.03 3/.03	1/.99,3/.01				
	6	10/.94,17/.05 9/.01	10/1.	4/.84,3/.14 2/.01	4/.89,3/.11				
	7	8/.73,10/.17 CZ/.08,7/.01	8/.82,10/.10 CZ/.08	24/.75,26/.14 20/.04,19/.02	24/.97,26/.02				
	10	4/.51,15/.35 28/.12,CZ/.01	4/.93,15/.06 CZ/.01	23/.45,1/.31 21/.12,8/.05 22/.02,25/.02	1/.59,23/.39 CZ/.02				
	11	8/.78,7/.19 CZ/.01	8/.97,CZ/.03	1/.77,3/.21 2/.01	1/.89,3/.11				
	12	5/.60,14/.31 3/.09	5/.75,14/.25	3/.66,17/.23 18/.09,16/.03	3/.87,18/.10 17/.02				
	13	9/.92,CZ/.07 8/.01	CZ/.54,9/.46	10/.72,CZ/.14 12/.12,11/.02	10/.57,CZ/.42 12/.01				

Table 4.1 (Continued)

Proportion of the Contribution of Zones to the "Best Estimate" Hazard at Sites

	SITE							
Soil Condition Location	LIMERICK Rock SE-NE-NC		LA CROSSE Soil NC		WOLF CREEK Rock SC		WATTS BAR Rock SC-SE	
Seismicity Expert Index Number	Low	High	Low	High	Low	High	Low	High
1	4/.95,20/.02 1/.01	4/.99,1/.01	CZ/.76,9/.12 11/.06,10/.04	CZ/.90,9/.08, 11/.01	CZ/.61,14/.14 9/.10,10/.08	CZ/.75,9/20 10/.03,14/.01	4/.88,9/.06 10/.02	4/.85,9/.15
2	28/.94,32/.02 31/.02,30/.02	28/.99	CZ/.74,18/.25	CZ/.95,18/.05	15/.67,18/.21 CZ/.05,5/.04	15/.78,18/.21 CZ/.01	27/.74,18/.19 30/.05,20/.02	27/.81,18/.18
3	6/.79,7/.08 CZ/.07	6/.93,2/.07	CZ/.72,14/.24 15/.02,17/.01	CZ/1.	CZ/.84,15/.07 17/.06,16/.02	CZ/.99	8/.82,CZ/.07 15/.04,16/.02 11/.02	8/.91,CZ/.08
4	11/.67,12/.21 16/.06,19/.01	11/.99,12/.02	6/.81,4/.15 CZ/.04	6/.86,CZ/.13	1/.73,4/.19 CZ/.05	CZ/.62,1/.20 4/.17	8/.53,4/.35 CZ/.30,9/.04 10/.03	8/.57,13/.23, 4/.20
5	1/.83,6/.14	1/1.	CZ/.74,13/.21 15/.04	CZ/.84,15/.16	CZ/.65,17/.29 15/.06	CZ/.76,15/.24	11/.86,15/.09 9/.03,14/.01	11/.84,15/.16
6	7/.86,4/.10 3/.01	7/.96,4/.03	CZ/.58,17/.35 23/.07	CZ/.78,17/.22	17/.48,CZ/.27 25/.21,22/.03	CZ/.74,17/.26	9/.79,17/.19 10/.02	9/.80,17/.20
7	13/.68,CZ/.19 23/.04,7/.04	CZ/.88,13/.11	3/.74,CZ/.11 6/.11,4/.03	3/.68,CZ/.29 6/.03	CZ/.88,5/.06 6/.05	CZ/.97,6/.03	7/.92,6/.02 5/.02,8/.02, CZ/.01	7/.98,6/.02
10	5/.59,4/.35 CZ/.04,6/.01	4/.57,5/.39 CZ/.04	CZ/.98,12/.01	CZ/1.	CZ/.94,12/.05 13/.01	CZ/.99	28/.78,26/.12 12/.06,CZ/.02	28/.96,26/.03
11	5/.93,CZ/.03	CZ/.99	CZ/.91,10/.09	CZ/1.	CZ/.73,17/.15 15/.04,10/.04 11/.04	CZ/.99,17/.01	6/.90,CZ/.03 10/.02,11/.02 8/.01	6/1.
12	3/.65,4/.24 17/.09	3/.99	CZ/.93,10/.03 20/.02,11/.01	CZ/.99	CZ/.69,9/.26 11/.04,12/.02	CZ/.82,9/.17 12/.01	2/.84,CZ/.08 11/.04,3/.02 12/.01	2/.97,CZ/.03
13	CZ/.80,10/.13 12/.02	CZ/.99	CZ/.95,5/.05	CZ/1.	CZ/.86,5/.12 1/.01	CZ/1.	8/.90,5/.04 9/.03,CZ/.02	8/.99,CZ/.01

3. changes in the BE values and reduction of uncertainty in the estimate of the upper magnitude cutoff M_U,

4. the model uncertainty in the ground motion models; on the computed hazard at a site.

It must be kept in mind that as shown in Bernreuter (1981a) the results are very site and expert dependent. Hence, there are certainly many exceptions to any conclusions reached and they should only be used as a guide for interpreting the results. Keeping this in mind, we selected four sites to explore the influence of the four items listed above to help us reach "general" conclusions. In selecting these four sites, we attempted to span the range of factors that influence the results. Thus one site, River Bend, is located in a region of low seismicity and generally simple zonation. One site (Millstone) was located in an area of complex zonation and two sites (Braidwood in the midwest and Shearon Harris in the southeast) in regions of moderate zonation complexity.

For these sites we made a number of sensitivity runs. The sensitivity analysis was performed in a non standard manner. Instead of defining the base case as the case where all variables were deterministic (i.e., without uncertainty), we defined the base case as the one where all the variables take the value and uncertainty given by the experts. Next, to analyze the influence of a given parameter, we reduce its range of variation. Thus we calculated the hazard using reduced confidence intervals for a, b and M_U. For each parameter, P, we reduced the range using the relation

$$P'_{max} = P_{BE}\,[1-R] + P_{max}\,R \qquad (a)$$

$$P'_{min} = P_{BE}\,[1-R] + P_{min}\,R \qquad (b) \qquad\qquad (4.1)$$

where R = reduction factor for the total interval P_{min}, P_{max}. Then the new interval of values considered is the initial interval multiplied by R or $\left(P'_{max} - P'_{min}\right) = R\left(P_{max} - P_{min}\right)$.

For instance, we analyzed the impact of reducing the uncertainty in the "a" parameters, to a fifth of its original value. In this case, the value of R in equation 4.1 is 0.2 and the parameter P is identified as the parameter "a". In this example, if the best estimate for a given zone, was $\hat{a} = 2$ and the lower and upper bounds were 1.5 and 2.5, respectively, then, the new bounds, given by Eq. 4.1 are:

$$\text{new } a_{max} = 2[1-.2] + 2.5 \times .2 = 2.1$$

$$\text{new } a_{min} = 2[1-.2] + 1.5 \times .2 = 1.9$$

These runs were all made using only one ground motion model - namely model No. 7 (Table 3.4.3). This model was the BE model chosen by two of our Ground Motion Panel Experts. This (#7) ground motion model as can be seen from Fig. 3.2, is very close to the BE models #25. Each run for each seismicity expert is based on 100 simulations.

4.2.1 Maps

Each expert was asked to express his/her uncertainty about both the existence of individual zones and the shape of the zone's boundary. As can be seen from a review of the tables in Appendix A, many zones shown on the maps have probabilities less than 1.0 of existence. For the uncertainty expressed by our expert about either the existence of zones or their shape to have any influence on the computed seismic hazard the site must be either within the zone or near zones that might not exist or whose boundary shape could change significantly relative to the site in question. Thus for sites like River Bend or La Crosse, which are located away from zones that might not exist, the uncertainty about the existence/nonexistence of a given zone for a given expert does not affect the answer. For sites like Millstone or Shearon Harris, which are located in regions with a number of nearby zones, then the uncertainty a given expert has about the existence or nonexistence of a given zone can have considerable impact on the computed hazard. To examine this, we fixed all the parameters at their BE values except for the maps and performed 100 simulations for each expert. Thus for each expert 100 hazard curves were computed where the only element that was changing was the maps. If all the zones around the site had probability 1.0 of existence and there was no alternative boundary shapes to influence the results, then the simulation would yield 100 identical hazard curves. If the expert was uncertain about the existence of zones, then the 100 simulations would yield several sets of hazard curves. As would be expected, map uncertainty was much more important at Shearon Harris and Millstone than River Bend and Braidwood, and more at Braidwood than at River Bend. Figures 4.1 a, b, and c are typical examples of the magnitude of the uncertainty introduced by a given expert's uncertainty about his zonation. Note that the three curves of the 15, 50 and 85th percentiles of Fig. 4.1 are degenerated to two curves. This is due to the fact that two curves are superimposed as a result of the flat distribution of the maps. It means that of the 100 simulations, more than 50 of them gave the same or almost the same results, either at the low end or at the high end. Thus the 15 and 50th (or the 50 and 85th) percentiles are equal. Not shown are the cases where no or only very little uncertainty is introduced. At Millstone it is interesting to note that for Expert 1 the BE hazard curve the loading comes primarily from zone 22. Zone 22 has a probability of existence of 1.0 but its shape (and seismicity parameters) are equally likely to be replaced by zones 38 and 39. What this means is that all maps have either zone 22 or zones 38 and 39. For Expert 13 the load is coming primarily from zone 10 which has a probability of existence of 0.6. For Expert 10 the load is coming primarily from zones 2 and 4 which have a probability of existence of 0.8. Figure 4.1d shows an extreme case of the uncertainty introduced by a given experts uncertainty in zonation for Braidwood. Zone 6 is the major contributor to the hazard but has a probability of existence of only 0.75 for Expert 4.

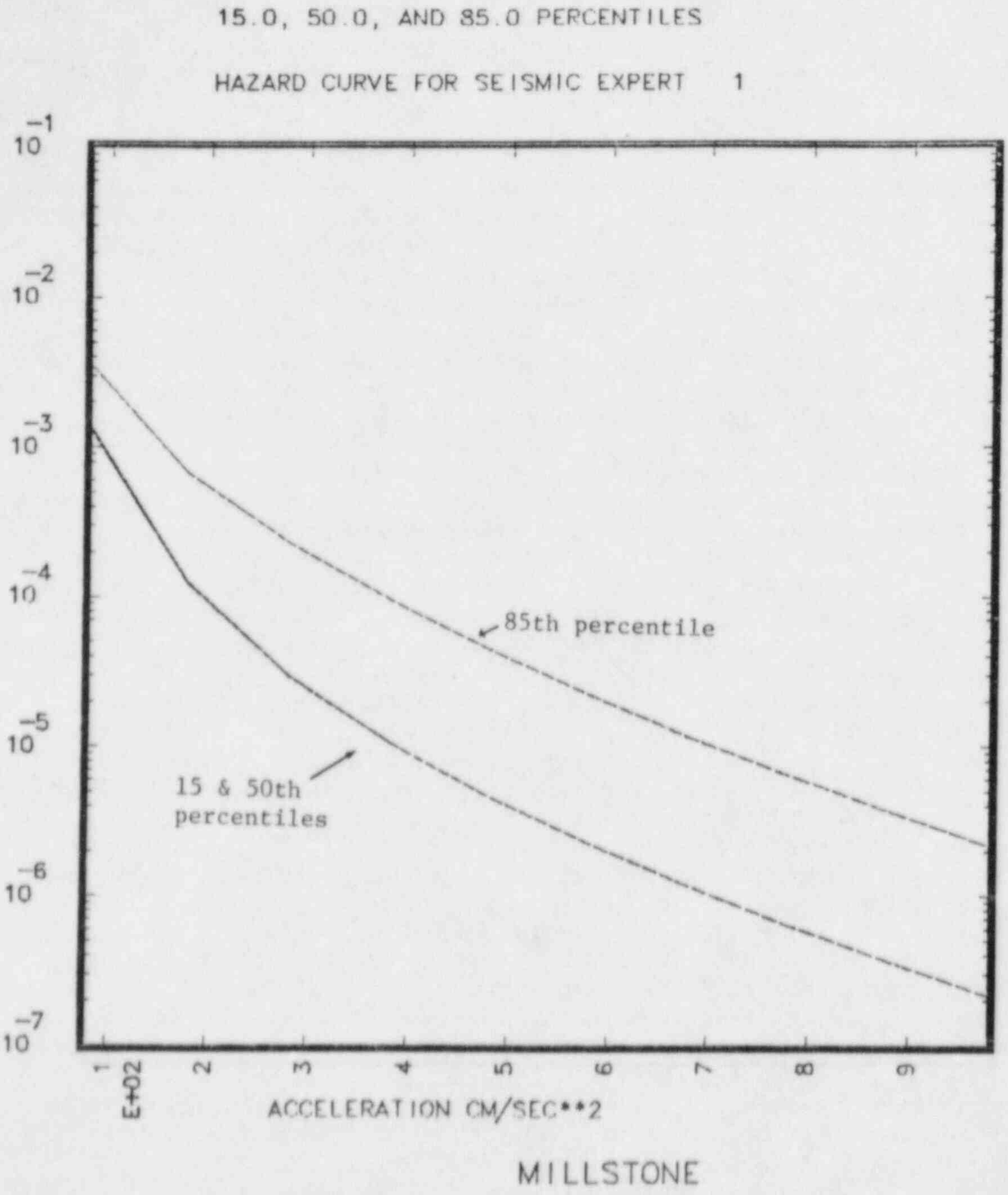
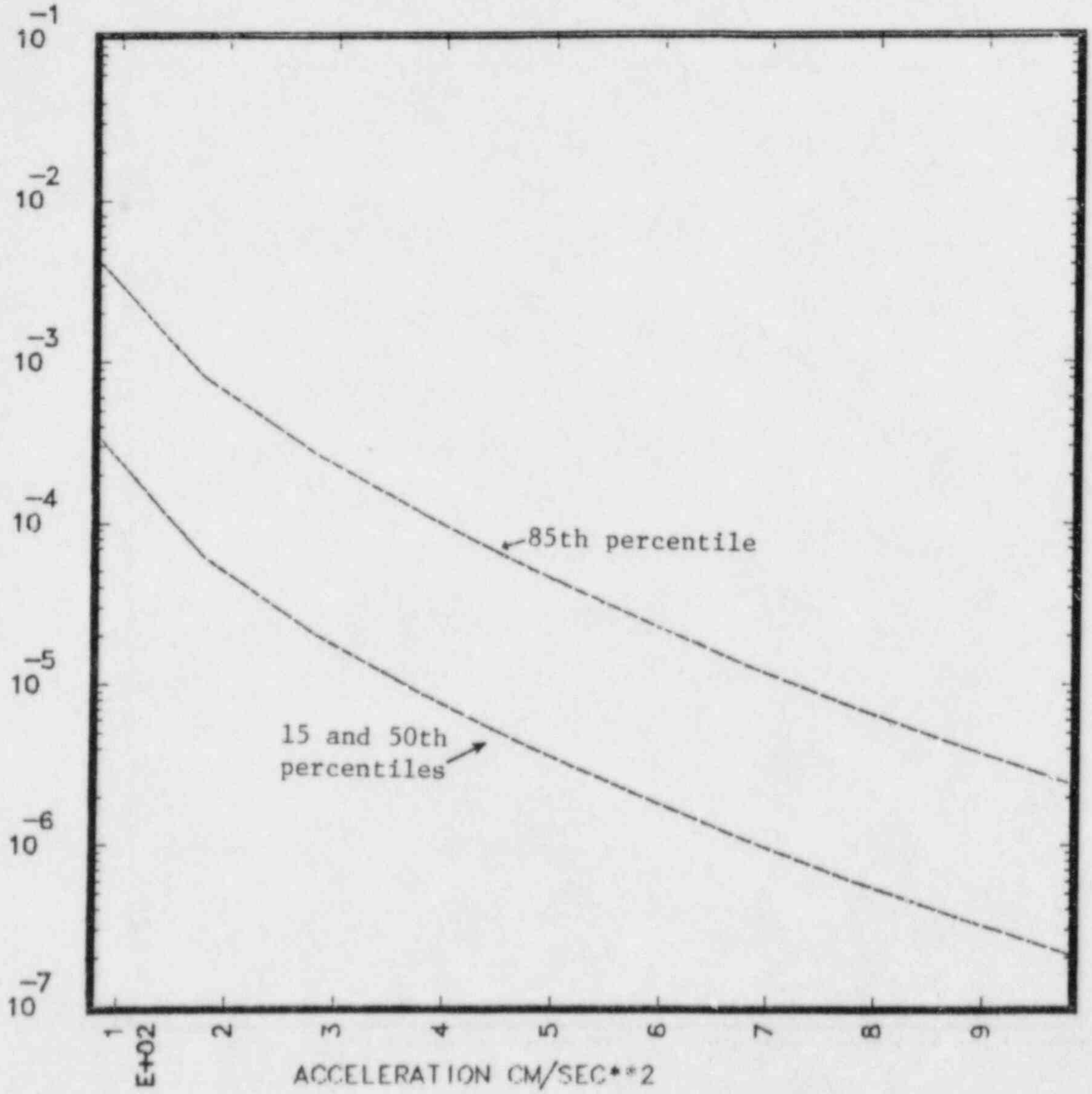

15.0, 50.0, AND 85.0 PERCENTILES
HAZARD CURVE FOR SEISMIC EXPERT 1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
85th percentile
15 & 50th percentiles
1 E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
MILLSTONE

Figure 4.1a

15.0, 50.0, AND 85.0 PERCENTILES

HAZARD CURVE FOR SEISMIC EXPERT 13

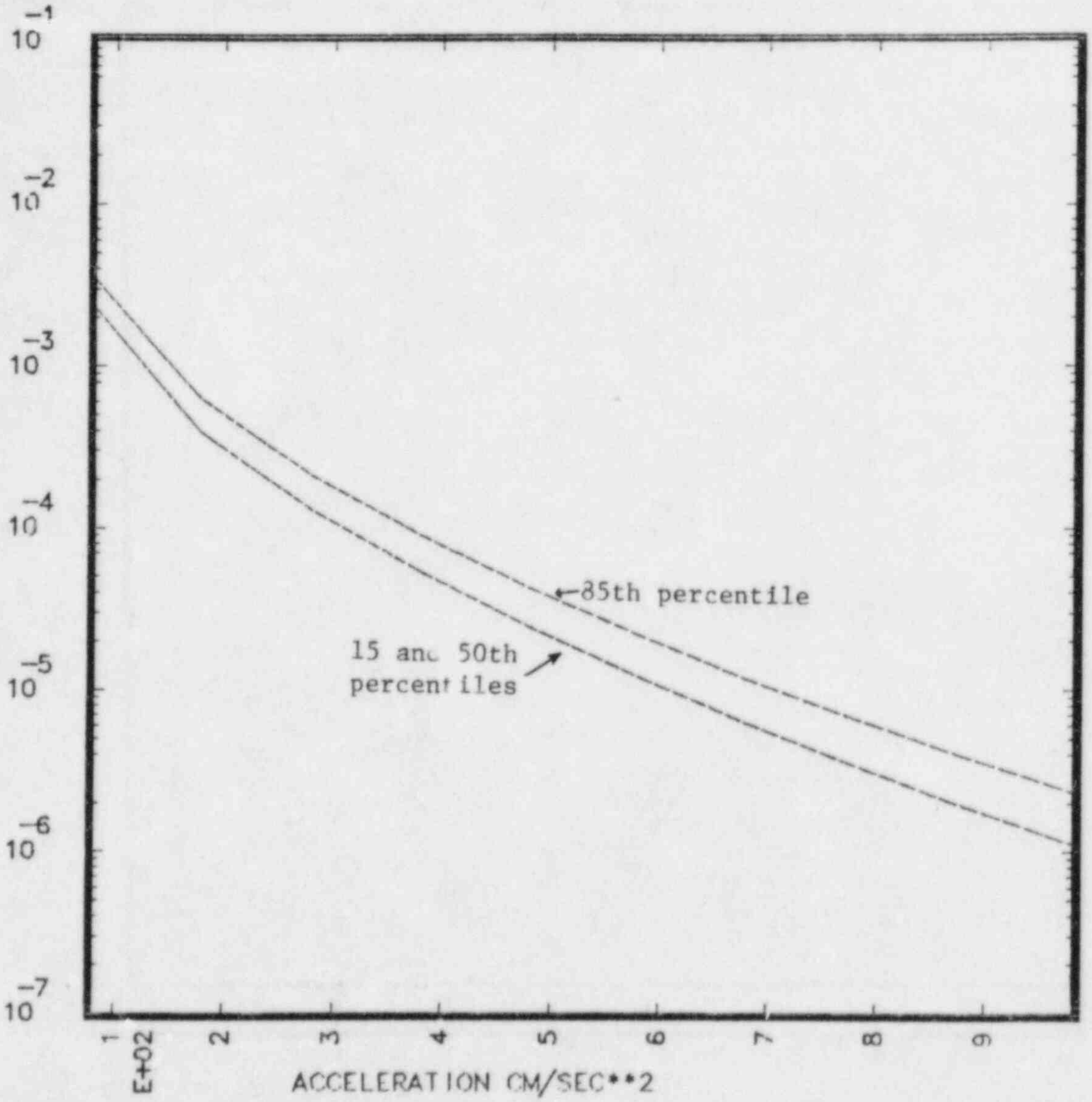


MILLSTONE

Figure 4.1b

15.0, 50.0, AND 85.0 PERCENTILES

HAZARD CURVE FOR SEISMIC EXPERT 10



MILLSTONE

Figure 4.1c

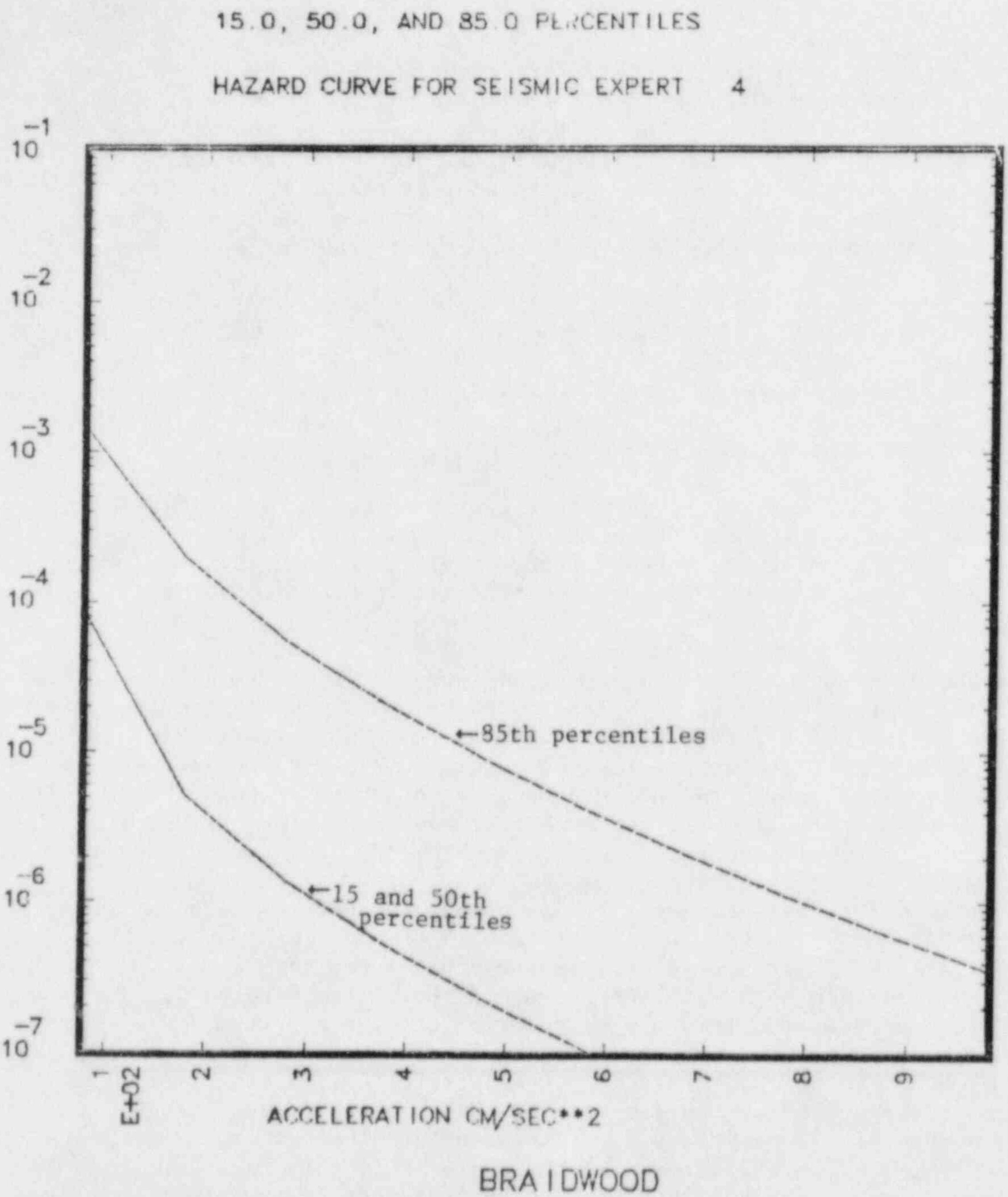

15.0, 50.0, AND 85.0 PERCENTILES
HAZARD CURVE FOR SEISMIC EXPERT 4
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
←85th percentiles
←15 and 50th percentiles
1 E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
BRAIDWOOD

Figure 4.1d

It is evident from these figures that a given expert's uncertainty about his zonation (either existence or nonexistence or boundary shapes) can be important.

4.2.2 Seismicity Parameters

In this section we examine the influence of changes in both the BE values of the a and b parameters of the magnitude recurrence and the uncertainty in the estimate of the a and b values. The influence of changes in the BE value of the "a" parameter are easily inferred from Eq. 2.2 as the a parameter is directly related to be mean rate of occurrence of earthquakes larger than M_O. Generally, only one zone is the major contributor to the hazard at a site. If this is the case, then Eq. (2.2) can be written (for small number of expected events) as

$$P[A > a] = \lambda P \qquad (4.2)$$

where λ = rate of occurrence of earthquake larger than M_O.

P = value of Eq. 2.1 for the zone

Thus it is seen that changing the rate of activity moves the hazard curve "up" (high rate) or down (lower rate) linearly with changes in the rate. Naturally, if more than one zone contributes significantly to the loading and the rates change in a complex way then the effect on the hazard curve is less predictable.

Changes in the BE value of the b parameter are more difficult to assess. This difficulty comes from two sources. First, when the b parameter is changed at what M value is the curve rotated about? Two typical choices are shown on Fig. 4.2. Curve 1 represents the original model. Curve 2 represents the case where the a parameter stays the same and only the b parameter was changed. Curve 3 represents the case where the number of events greater than M_O is kept fixed but the total number of events are changed.

Secondly, it is not as easy to get a handle on how changes in the b parameter affect the hazard curve as it was for determining how changes in the a parameter affect the hazard curve because the b parameter enters Eq. 2.1 in a more complex manner and no simple result such as Eq. 4.2 can be easily derived. The b parameter enters the calculation through the term $f_{S_M}(m)$ in Eq. 2.1, all other functions involved in the integral (2.1) remain the same. For the same number of events larger than M_O, different b values simply change the number of events in any discrete magnitude interval Δm_j. If the absolute value of b is smaller then there are relatively more large events than for the case when the absolute value of b is larger. Thus the importance of changes in the BE value of the b parameter are a function of both how much b is changed and how large M_U is. This is illustrated on Fig. 4.3 where we computed the hazard curves resulting from using b values of 0.7 and 1.1 and M_U values of 5.8 and 6.8 for a single zone which includes the site. The seismicity values are typical for the EUS.

Examination of the seismicity tables given in Appendix A indicates that the uncertainties expressed by the experts about their BE values of the a, b and M_U parameters for any particular zone are "large." Considering the important effect that changes in the value for their parameters have on the hazard curve, we investigated what impact reducing uncertainty would have on the CPHC for individual experts and on the combined CPHC for each site. One would speculate that for the reduced uncertainty case, the 15th percentile CPHC would be higher because $P_{min} > P_{min}$ and the 85th percentile curve would be lower because $P_{Max} < P_{max}$. One might hope that there would be little change in the 50th percentile curve. This is generally the case as is illustrated by Fig. 4.4 where we compare the base case (R=1.0) with the CPHC for the case with R = 0.5 in Eq. 4.1 and applied to both the a and b uncertainty ranges. This result is reasonably typical.

The problem is more complex as in some cases the uncertainty in a particular expert's zonation, e.g., Expert 4 for Braidwood, enters the picture. The 15th percentile CPHC may be controlled by a lower probability zone and the seismicity parameters for that zone in the range between P_{BE} to P_{max}. In this case, the reduced uncertainty case would have the 15th percentile curve lower than the base case. This is illustrated on Fig. 4.5.

It is of some interest to examine what effect reducing the uncertainty about the earthquake recurrence model has on the combined CPHC. This is shown on Figs. 4.6a and b which compare the combined CPHC obtained using R = 0.2 to the base case (R = 1.0) for River Bend and Braidwood. The comparisons between the base case and the reduced uncertainty case for Millstone and Shearon Harris are very similar to Braidwood. It should be noted that the use of R = 0.2 significantly reduced the uncertainty bounds; however, as can be seen from Figs. 4.6a and b it had little effect on the 50th percentile CPHC. There was a larger effect on the 15th and 85th percentile curves. Generally the maximum effect is on the 85th percentile curves. These results suggest that the combined 50th percentile CPHC is a robust estimator of the seismic hazard at a site.

4.2.3 Upper Magnitude Cutoff

It is seen from Fig. 4.3 that changing the largest event, M_U, can have considerable effect on the results. The effect increases with decreasing levels of exceedence (larger return periods). Changing M_U from 5.8 to 6.8 shows (in the range of probabilities of interest) a much greater effect than changing M_U from 6.8 to 7.8.

4.2.4 Ground Motion Models

The systematic or model uncertainty on the ground motion introduces considerable uncertainty into the estimate of the seismic hazard at a site. For any particular seismicity expert the uncertainty introduced by the ground motion models varies. Generally, it is less than the uncertainty introduced by the other parameters but in effect it is more important since it is systematically applied to all seismicity experts' models.

There are two aspects of uncertainty associated with the ground motion models. The first is the systematic uncertainty about the model itself. This is accounted for by the use of 27 different models, as shown on Fig. 3.3. It

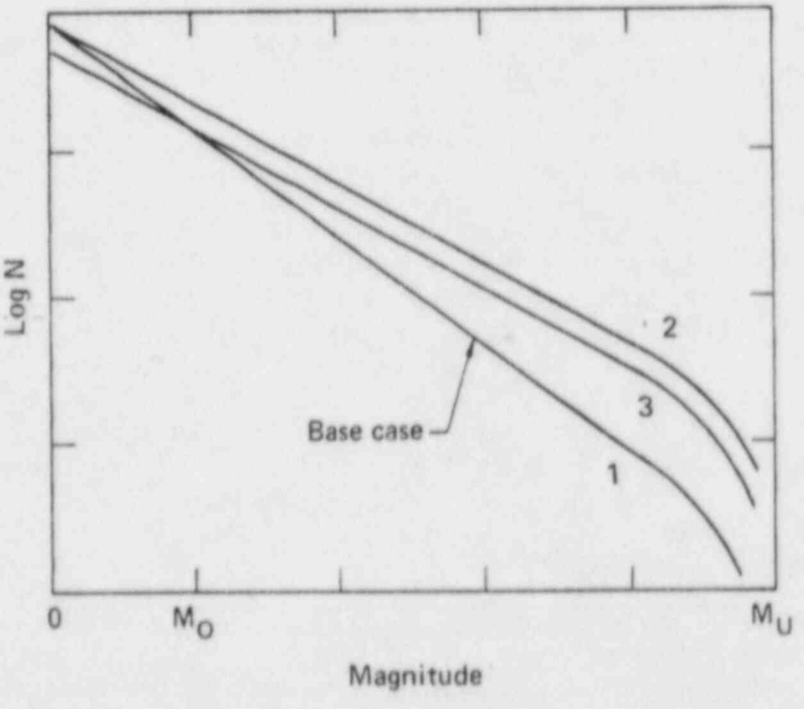


Figure 4.2 Influence of changes in the a and b parameters of the recurrence relationship.

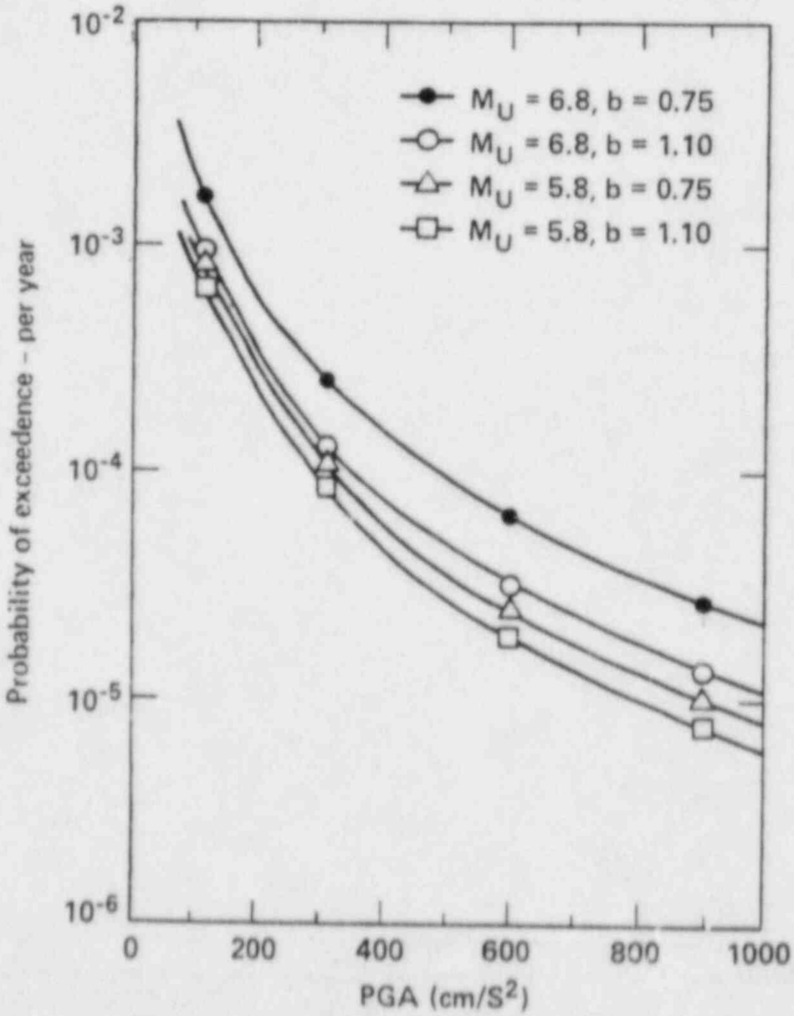
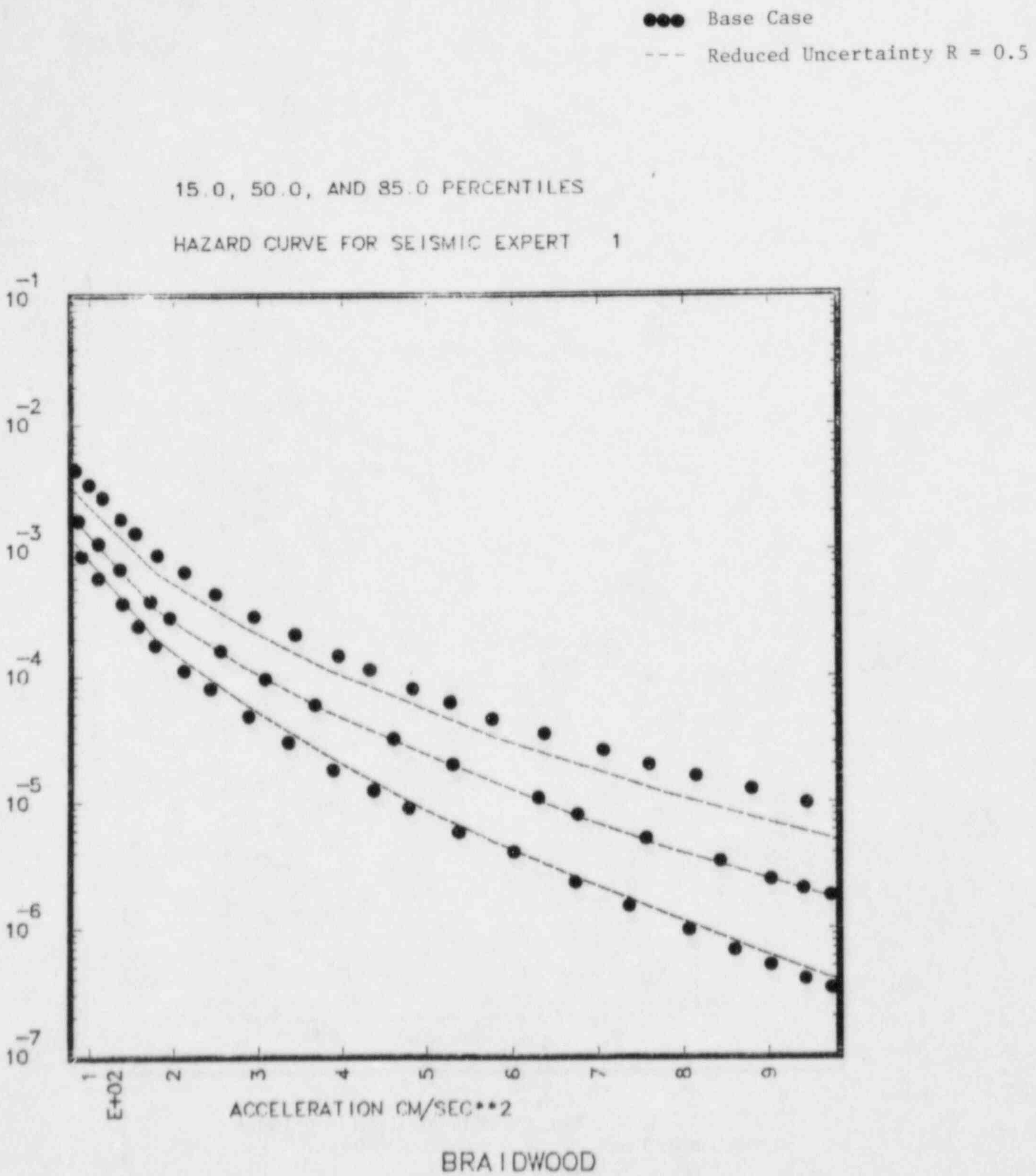
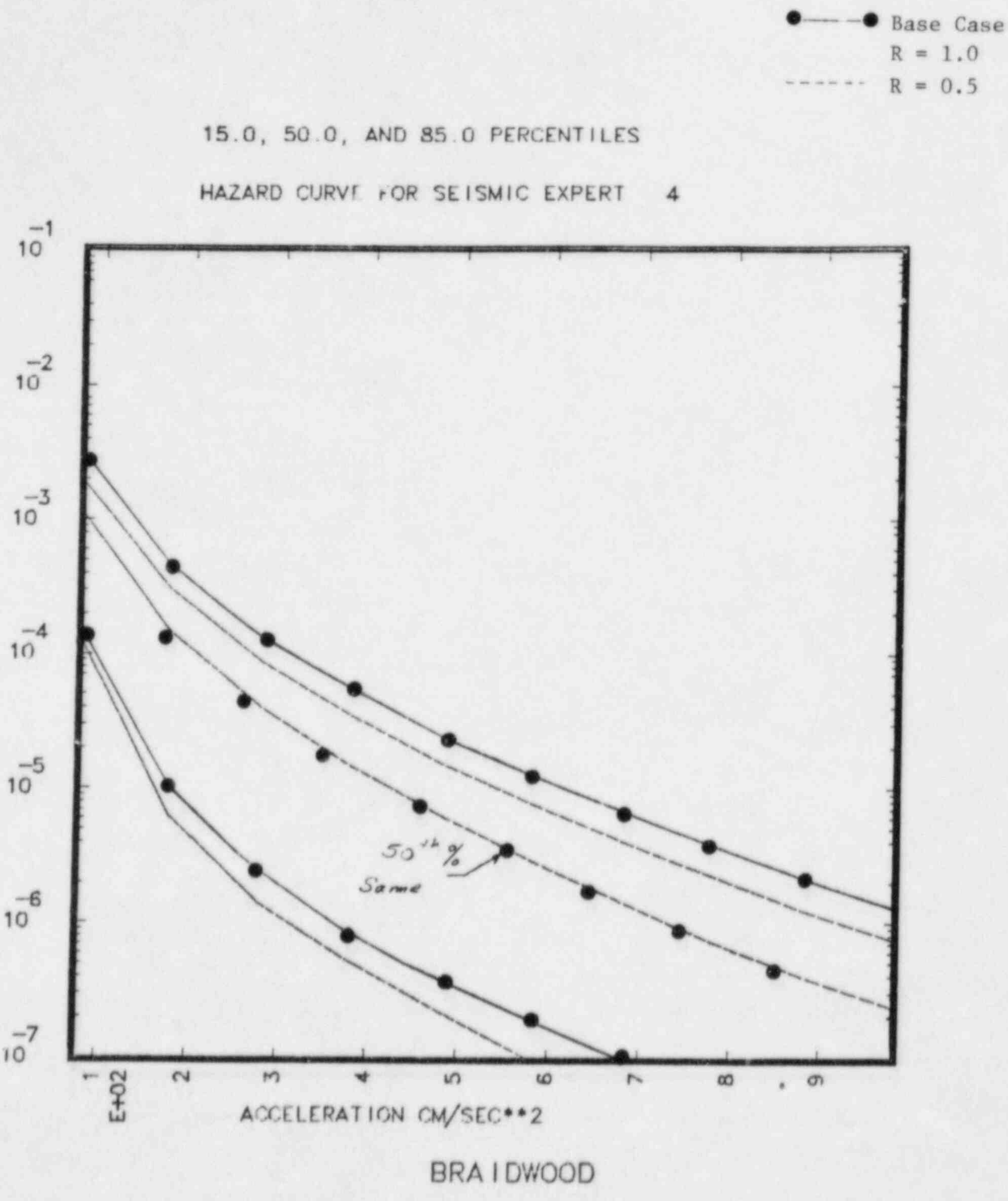


Figure 4.3 Influence of upper magnitude cutoff and of the b parameter of the recurrence relationship on the computed hazard.



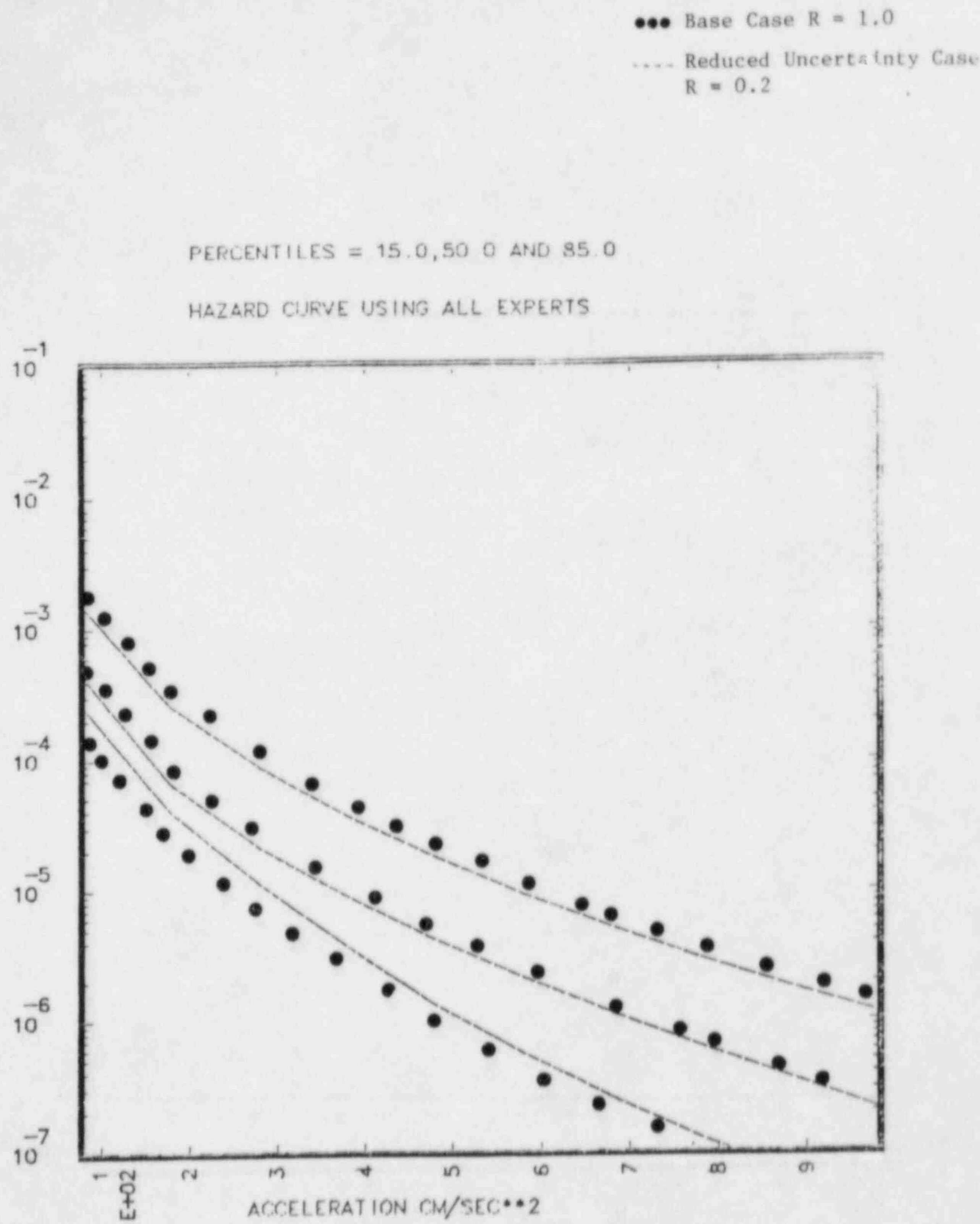
●●● Base Case
--- Reduced Uncertainty R = 0.5
15.0, 50.0, AND 85.0 PERCENTILES
HAZARD CURVE FOR SEISMIC EXPERT 1
ACCELERATION CM/SEC**2
E+02
BRAIDWOOD

Figure 4.4



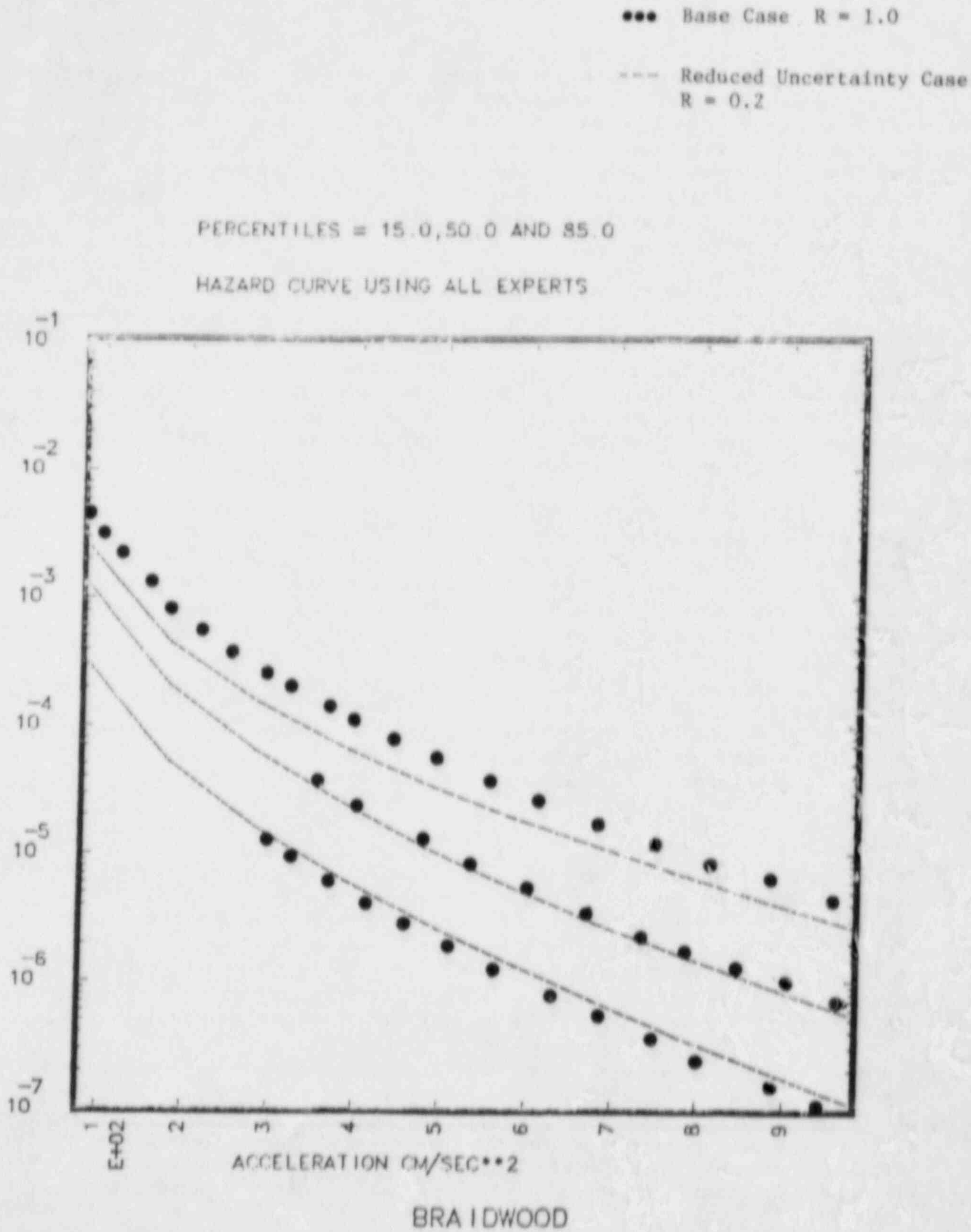
Base Case
R = 1.0
R = 0.5
15.0, 50.0, AND 85.0 PERCENTILES
HAZARD CURVE FOR SEISMIC EXPERT 4
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
50th %
Same
1 E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
BRAIDWOOD

Figure 4.5



RIVER BEND

Figure 4.6a



●●● Base Case R = 1.0
--- Reduced Uncertainty Case R = 0.2
PERCENTILES = 15.0,50.0 AND 85.0
HAZARD CURVE USING ALL EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1 E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
BRAIDWOOD

Figure 4.6b

can be seen that this uncertainty is large. The second aspect is the random uncertainty measured by the standard deviation of logarithm of the ground motion parameter (see Section 2.5.2) which is also significant (see Table 3.4.2). Both have a significant effect on the hazard. This is illustrated on Figs. 4.8. Figures 4.8a, b show the four BEHCs (one for each ground motion expert) for seismicity experts 6 and 12 at the Braidwood site for ground motion experts 1, 3, 4 and 5. For seismicity expert 6 (Fig. 4.8a) there is a significant difference between the BEHC computed using ground motion expert's 5 BE model (#27) and those using the other BE ground motion models. On the other hand, for seismicity expert 12, the BEHC are in reasonable agreement. Both are typical, that is, for many seismicity experts BE ground motion model #27 leads to much higher hazard at a site than the other BE ground motion models and for other seismicity experts ground motion model #27 (see Section 3.4 and Table 3.4.3) leads to similar or lower hazard at a site than for the other BE ground motion models. It is of some interest to compare the BEHC for ground motion experts 1 and 4. The difference between these BEHC is due solely to the value of random uncertainty assigned to the model. Ground motion expert 1 estimated $\sigma = 0.5$ and ground motion expert 4 estimated $\sigma = 0.6$. This uncertainty - while not as large as some - is significant, and because it systematically affects each hazard curve in the same way, it shows up in the final combined set of CPHC. This is illustrated on Figs. 4.9a, b, c, d where a comparison is made between the CPHC obtained using the full simulation (all seismicity experts and ground motion experts) and the CPHC obtained using all seismicity experts but only the BE ground model #7 (see Section 3. and Table 3.4.3) with $\sigma = 0.5$ for the four sensitivity sites. As expected, the use of all ground motion models greatly increases the uncertainty in the estimate of the seismic hazard at a site. It is interesting to note that the 50th percentile hazard curve is more stable than the 15th and 85th percentiles hazard curves. The difference would even be smaller if the random uncertainty for ground motion expert 4 model had been taken as 0.5.

4.3 Results

In this section we present and discuss the results of the preliminary seismic hazard analyses performed for the ten site, the location of which is shown on Fig. 3.9. We examine the results for the four sites used for the sensitivity analysis discussed in Section 4.2 in greater detail than for the other sites to illustrate the sensitivity of the hazard curve to changes in various parameters and provide insights as to which factors contribute most to the uncertainty in the estimate of the seismic hazard at any particular site.

Table 4.1 presents a summary of the zones which contribute most to the seismic hazard at each site for each seismicity expert and approximately the percent of the contribution of a given zone for the BEHC. Because the contribution of a given zone often changes as the PGA increases, we have a column for low PGA porportion and one for the high PGA porportion. The zone numbers are keyed to the maps and seismicity data files for each expert given in Appendix A.

The PGA hazard curves and the UHS for various return periods presented in this section are based on 200 simulations per seismicity expert (50 per ground motion expert) per site for PGA and 80 per seismicity expert (20 per ground motion expert) for each spectral period. Thus the CPHC for each site are based on a total of 2200 simulations and the CPUHS are based on a total of 880 simulations for each period per site. As there are 9 periods at which pseudo spectral velocities are computed, a total of 7920 simulations are required to define the CPUHS. A smaller number of simulations for each spectral ordinate than for PGA (80 as compared to 200) was used to save computer time. To define the CPUHS for each site takes over one hour 7600 CPU computer time. If we had used 200 simulations per spectral ordinate per seismicity expert, it would have taken over 5 hours per site. A sensitivity study was performed to select the number of simulations per seismicity expert required to define the 50th percentile CPUHS per seismicity expert within a few percent and the 15th and 85th percentiles within 5 to 10%. This led to CPUHS combined over all experts which were within a few percent of the curves obtained using a much larger number of simulations.

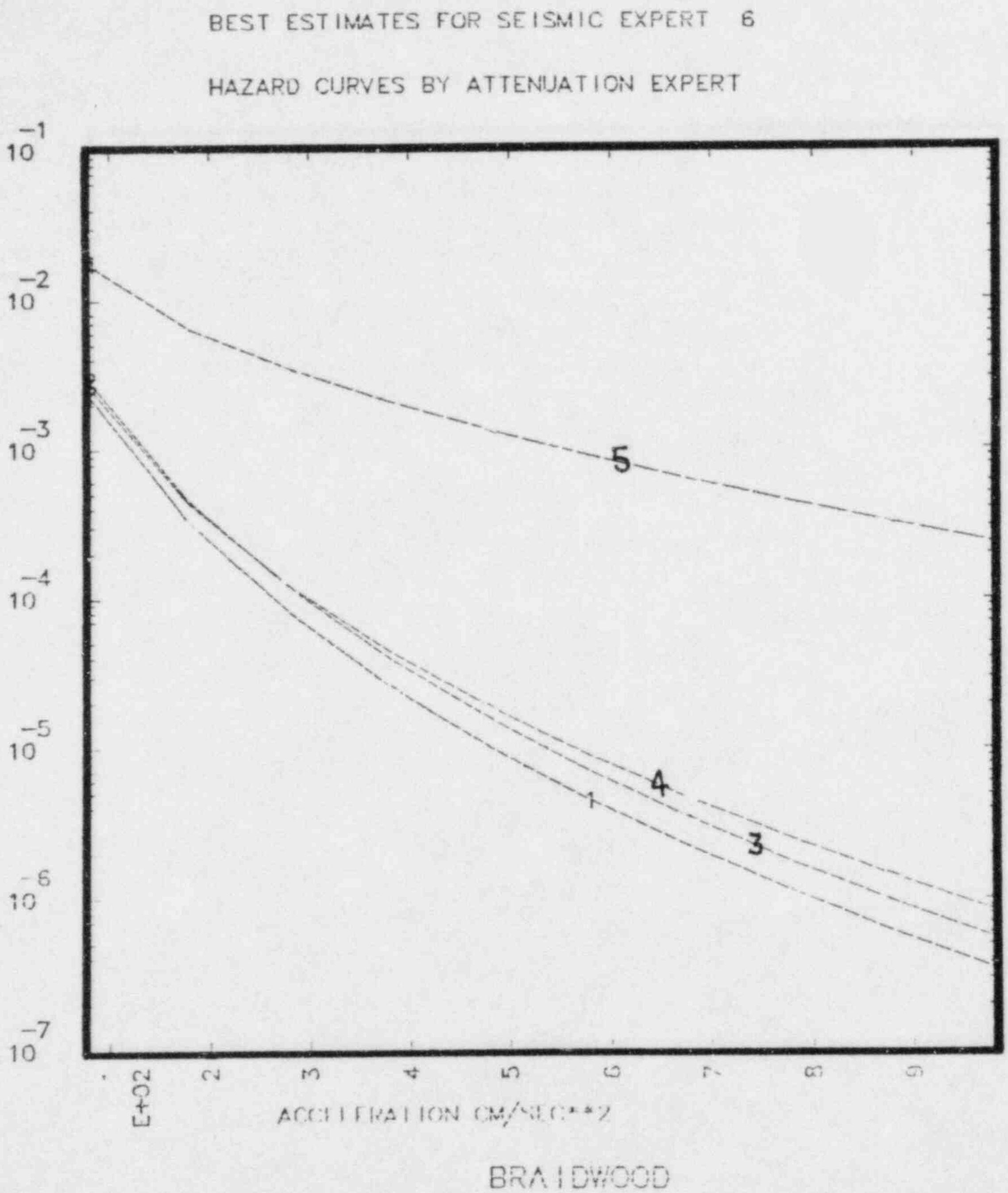
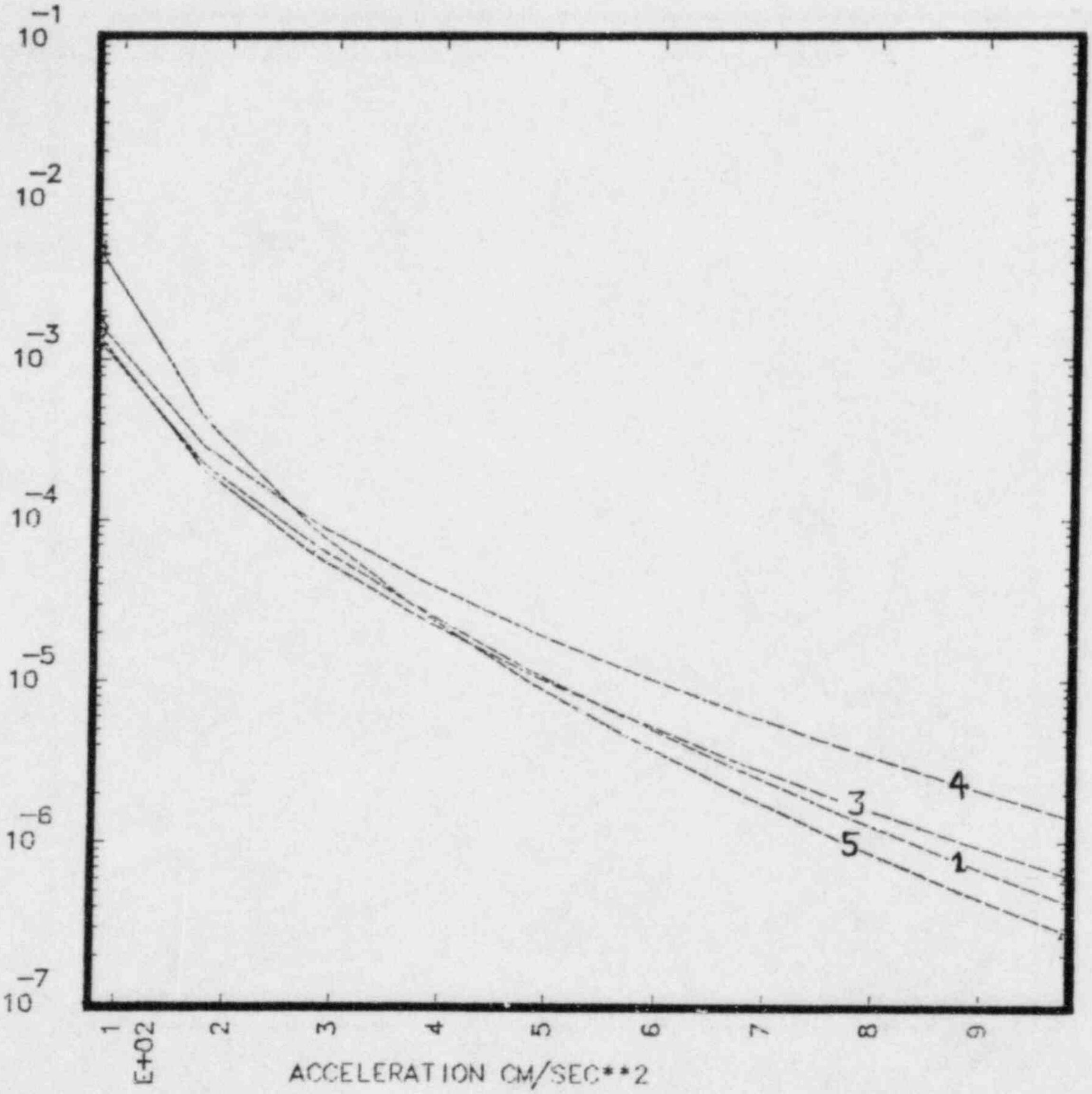

BEST ESTIMATES FOR SEISMIC EXPERT 6
HAZARD CURVES BY ATTENUATION EXPERT
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
5
4
3
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
BRAIDWOOD

Figure 4.8a

BEST ESTIMATES FOR SEISMIC EXPERT 12

HAZARD CURVES BY ATTENUATION EXPERT



BRAIDWOOD

Figure 4.8b

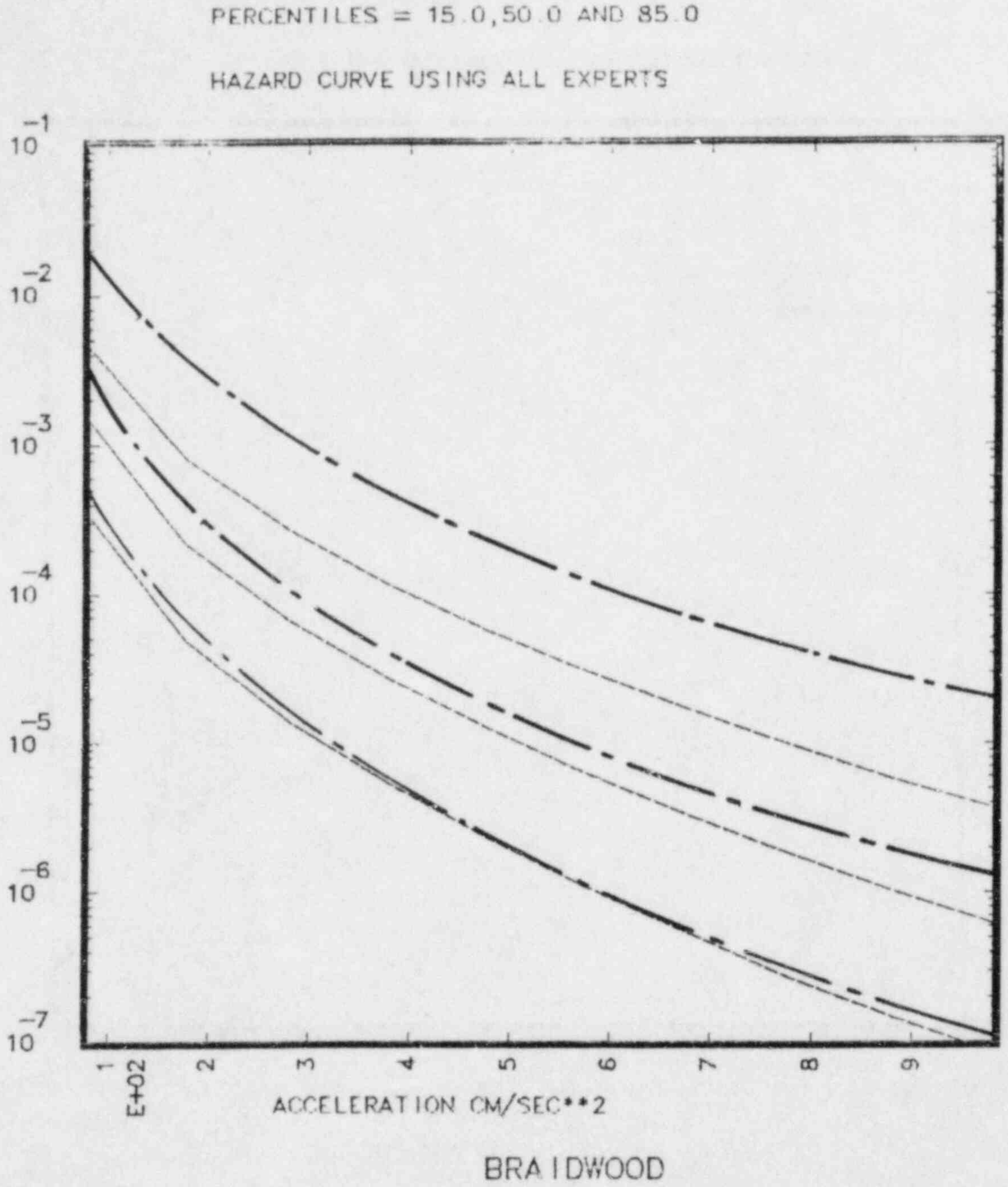
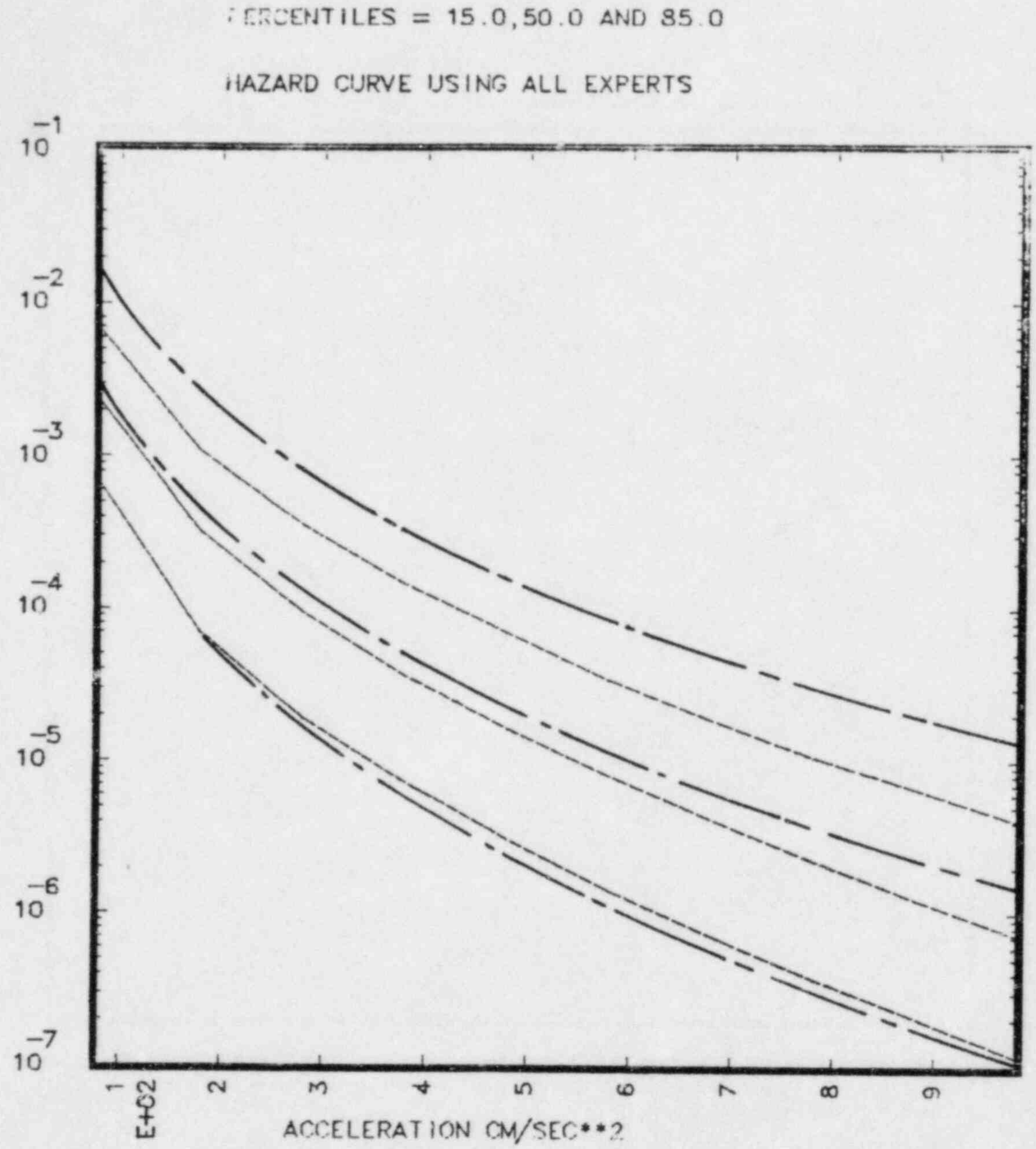
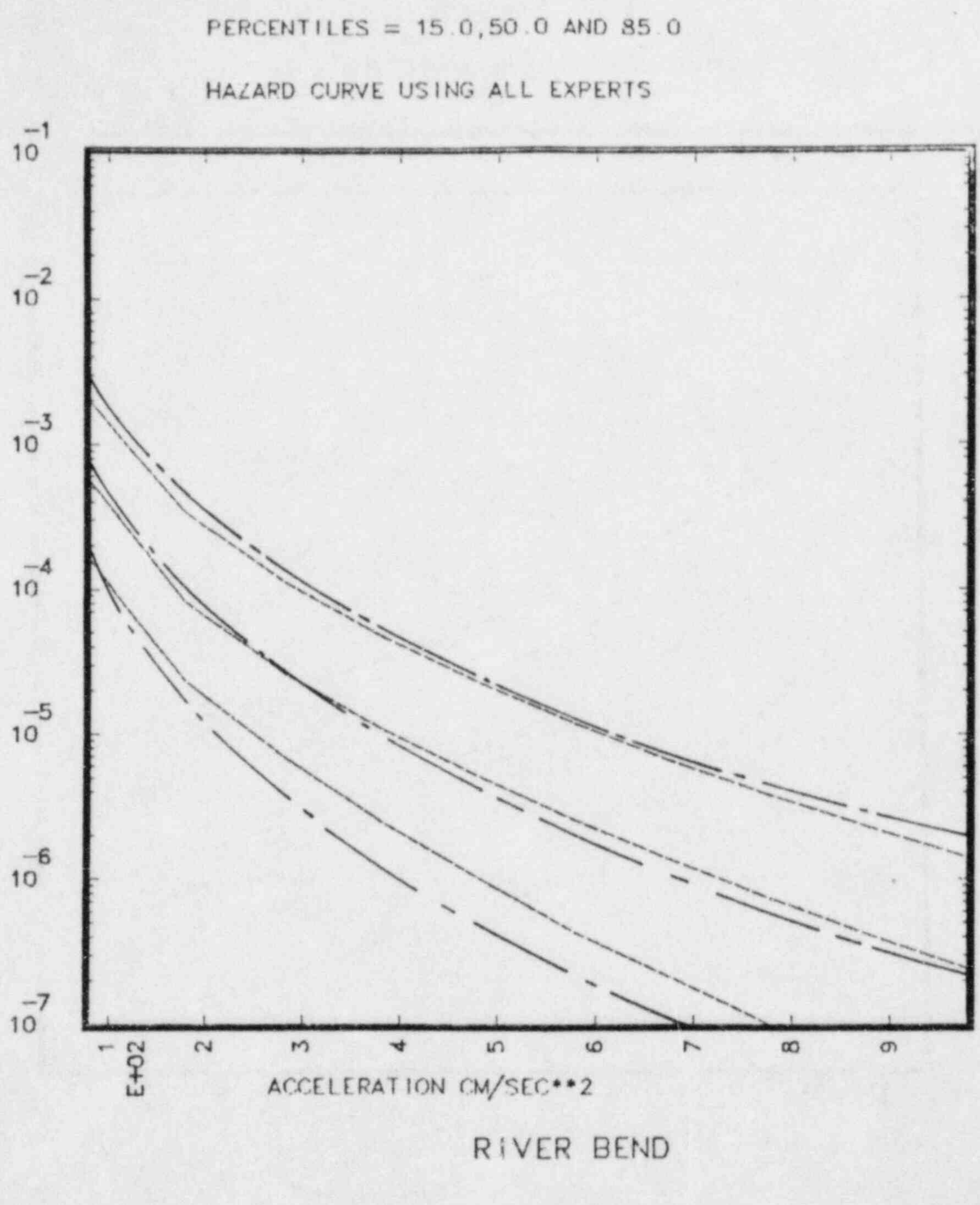


Figure 4.9a Comparison of CPHC for simulation using all ground motions (___ _ ___) and only ground motion #7 of Table 3.4.3 (_ _ _ _ _)



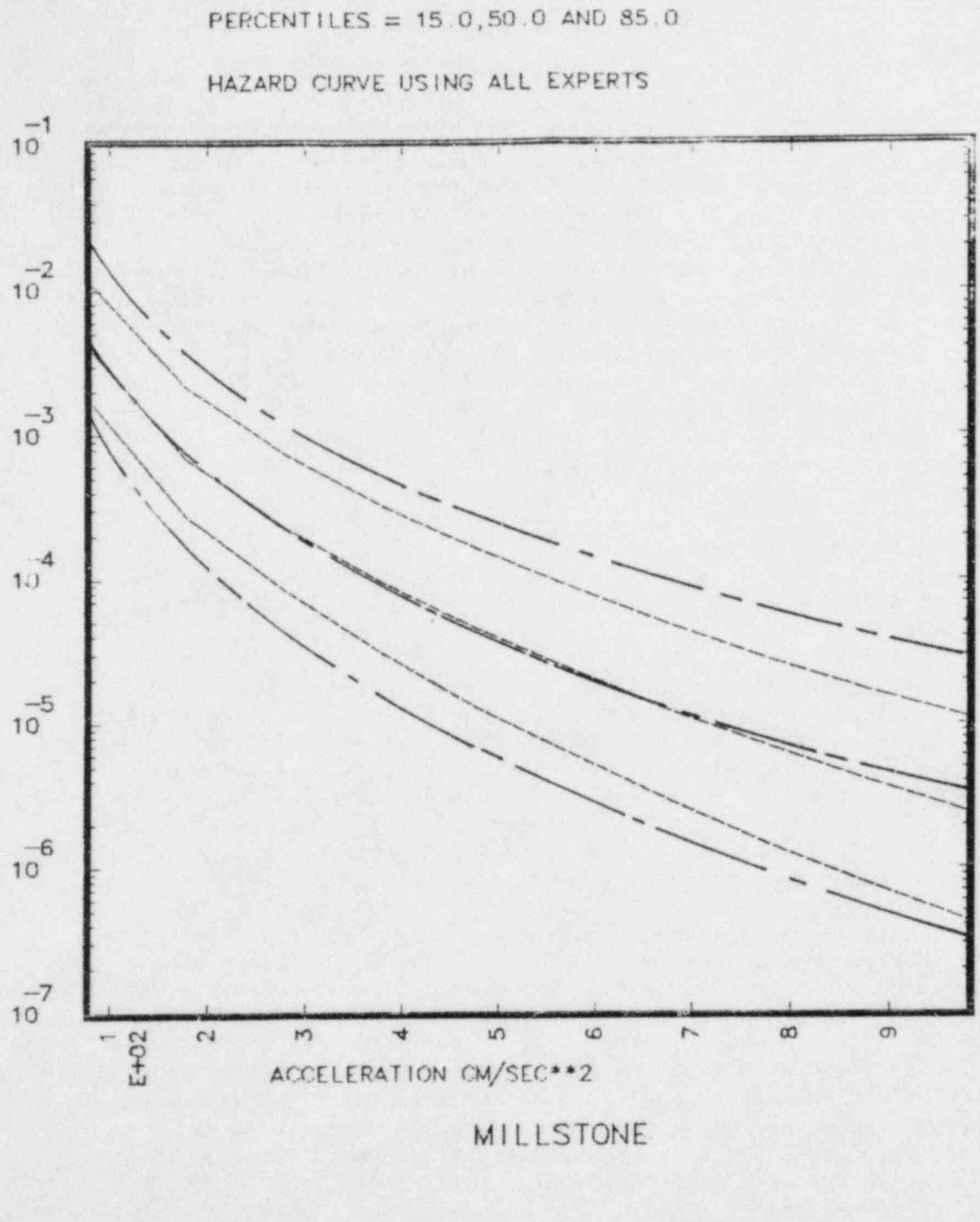
SHEARON HARRIS

Figure 4.9b



PERCENTILES = 15.0,50.0 AND 85.0
HAZARD CURVE USING ALL EXPERTS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1
2
3
4
5
6
7
8
9
E+02
ACCELERATION CM/SEC**2
RIVER BEND

Figure 4.9c



PERCENTILES = 15.0,50.0 AND 85.0
HAZARD CURVE USING ALL EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
MILLSTONE

Figure 4.9d

4.3.1 Braidwood (BR)

4.3.1.1 General

The Braidwood site is located in the north central region of the EUS. It is classified as a rock site. As can be seen from the zonation maps in Appendix A most experts put a zone within the central stable region which contains the site. Table 4.2 summarizes the seismicity parameters for these zones. It is only in the case of experts 5, 7, and 13 (D) that the site is located in the CZ. For these experts the upper magnitude cutoff in the CZ is not low by comparison with the other zones. As a result, the contribution of the CZ for experts 5, 7 and 13 is dominant in the BEHC at low and high PGA, as shown in Table 4.1. For the other experts, the effect of the sparse zonation in the NC region makes it similar to the above in the sense that the zone to which the site belongs remains dominant at low and high PGA, (see Table 4.1) with the exception of expert 3. In this latter case, the site is located inside zone 14, thus this zone is dominant at low PGA. However, zone 14 has a lower magnitude cutoff than the CZ (6.0 versus 6.5 respectively), and since zone 14 is small in area, the CZ largely dominates at high PGA, with some not quite negligible effect from the New Madrid area.

4.3.1.2 PGA Hazard Curves

The BEHC combined over all experts is shown on Fig. BR-1. Figure BR-2 privides the BEHC per individual seismicity expert but combined over all ground motion experts.

It is interesting to examine why different experts' curves plot where they do. For example, if we compare the BEHC for experts 1 and 11 we see that expert's 11 BEHC is about a factor of 5 higher than expert's 1 BEHC. We see from Table 4.2 that the main difference between expert's 11 and expert's 1 models is the rate of seismicity in the zone which contains the Braidwood site and that the activity rate is about a factor of 5 higher for expert 11 as compared to expert 1. As noted in Section 4.2.2, this would lead to the difference in BEHC observed on Fig. BR-2.

The problem is more complex when significantly different b values are involved. For example we see from Table 4.2, that a comparison of the normalized a values between expert 13 and expert 11 would only suggest about a factor of 5 difference between their respective BEHC. Hhowever, as can be seen from Fig. BR-2 there is about a factor of 10 difference at low PGA value and about a factor of 80 at high PGA. For different b values we need to compare the number of earthquakes greater than or equal to the magnitude range contributing to the loading at any given level. At PGA values of approximately 100 cm/s^2 this is for magnitudes 3.75 and greater. The ratio of the number of events greater than m_{bLg} = 3.75 is about 25, i.e., earthquakes greater than m_{bLg} = 3.75 in the zone that contains the Braidwood site are 25 times more frequent in expert's 11 zone No. 10 than in expert's 13 CZ. This would suggest that the BEHC for expert 13 is "high" compared to expert's 11 BEHC. However, from Table 4.1 we see that for expert's 13 model there is significant contribution from several other zones where as for expert 11 almost all of the loading is contributed by one zone. At the high PGA values only the expert's 13 CZ contributes most significantly to the hazard at high PGA values. The ratio of the number of earthquakes greater or equal to 6

Table 4.2

Zones in Central Stable Region Containing the Braidwood Site

Expert No	Zone No	Prob of Exist	Area (10^5 km^2)	M_{LB}	M_{BE}	M_{UB}	a_N	b
1	19	0.7	2.4	6.1	6.5	7	2.6	.93
2	21	0.5	0.5	5.5	6	6.5	2.8	.92
3	14 (1)	0.5	0.5	5	6	6.8	3.7	.67
4	6 (2)	0.75	0.6	6.3	6.5	6.7	2.8	.9
6	23 (3)	0.7	1.1	5.5	6	6.5	3.1	1.0
7	3 (4)	1.	13.6	5	5.5	6	1.8	.9
10	26	0.9	2.5	5.8	6	6.5	2.8	.94
11	10	0.9	2.3	6	6.5	6.8	3.3	.9
12	10	0.65	0.5	5	6	6.3	2.9	.95
5	CZ	1.0	65.0	7*	8*	9*	2.4	.92
13	CZ	1.0	93.1	6	6.3	6.5	2.6	1.09

*Intensity (MMI)

(1) Site is in expert's 3 control zone, zone 14 is about 25 km away.

(2) Site is at edge of boundary of zone 6 for expert 4.

(3) Site is in expert's 6 control zone, but within 5 km of zone 23.

(4) Site is in expert's 7 control zone, zone 3 is about 125 km away.

M = Upper Magnitude Cutoff

BE = Best Estimate, LB = Lower Bound, UB = Upper Bound

a_N = Best estimate normalized to areas of 10^5 km^2.

between experts 11 and 13 is about 70. This might suggest that expert's 13 BEHC is low (at the high PGA end), compared to expert's 11 BEHC; however, Table 4.2 shows that expert 11 has a larger upper magnitude cutoff then expert 13. Other zones contribute some loading as well.

The BEHC for experts 3 and 6 are interesting because they cross other BEHCs. The reason for this is that at low PGA expert's 3 zone 20 contributes most of the loading, however at high PGA most of the loading comes from the CZ which contains the Braidwood site. The rate of activity in expert's 3 CZ is much less than in the expert's zone 14 but the upper magnitude cutoff is larger in the CZ. There is also the effect of attenuation as expert's 3 zone 14 is about 25 km away from the site. It can be seen from Table 4.1 that a number of zones contribute to expert's 6 BEHC. Expert's 6 zone 17, which has a very large upper magnitude cutoff (8.0) and high seismicity, is the most important zone. As noted in Section 4.2.4, expert's 6 BEHC shown on Fig. BR-2 is strongly influenced by the choice of ground motion expert's 5 BE model.

The shape of the BEHC at high PGA levels is controlled to a large extent by the upper magnitude cutoff. Thus as the PGA increases, the BEHC for experts 1, 5, 6, 7, 13 tend to be "flatter" than for the other experts with smaller upper magnitude cutoffs.

The sparcity of the zonation mentioned above makes the analysis very sensitive to the choice of ground motion models. As a result, the dispersion in the BEHC for a single seismicity expert is great. In particular, the BE ground motion model of ground motion expert 5 is always a high outlier. This instability in the results appears clearly in Fig. BR-2 where the spread, although uniform, encompasses a factor of 10 to 13 at low PGA and as high as approximately 8 in the hazard at high PGA, with expert's 13 results representing the lowest values and the results for experts 6 and 11 being the highest. The BEHC combined over all seismicity experts in Fig. BR-1 is higher than the middle of the cluster of curves in Fig. BR-2 and is approximately equal to the BEHC for expert 1. It is no surprise to note that the uncertainty analysis leads to a large dispersion in the hazard, as shown in Fig. BR-3 (a factor of 25 to 30 at low PGA to 150 to 200 on the hazard at high PGA between the 15th and the 85th percentile curves). It is also interesting to note that the BEHC lies significantly above the 50th percentile (a factor of 3 at low PGA and close to 10 at high PGA) to come roughly in the vicinity of the 65th to 75th percentile curve from a visual inspection of Fig. BR-3.

4.3.1.3 Uniform Hazard Spectra

The BEUHS curves of Fig. BR-5 combined over the four ground motion experts show a moderate to large spread in the results per seismicity experts. The range of the pseudo velocity results is a factor of 6 at low periods (25 Hz) to 10 at higher periods (.5 Hz). The BEUHS for experts 2, 4 and 6 tend to turn upward at periods above .3 seconds approximately. This pehonemon occurs also, to a much smaller extend, for experts 5 and 7. It is caused by the interplay of the New Madrid zone (see Table 4.1) with a high magnitude or intensity cutoff with the other dominant zones when the ground motion model of ground motion expert 5 is used. Although this ground motion model carries only one fourth weight, (approximately) due to the combination method it leads to such high estimates at high magnitudes for high perids, that after combination over all ground motion experts some zonation models will present these turns upward at high periods. When combined over all experts, the BEUHS still have a slight turn upward as shown in Fig. BR-4. The BEUHS curve of seismicity experts 1 and 4 from Fig. BR-6 are the closest to the final BEUHS of Fig. BR-4. In spite of the apparent diversity of opinions among seismicity experts for the zonation around the Braidwood site, the uncertainty in the UHS is only slightly greater than the average for the other sites, and the outliers have been removed by plotting only the 15th, 50th and 85th percentiles in Fig. BR-7, BR-8 and BR-9.

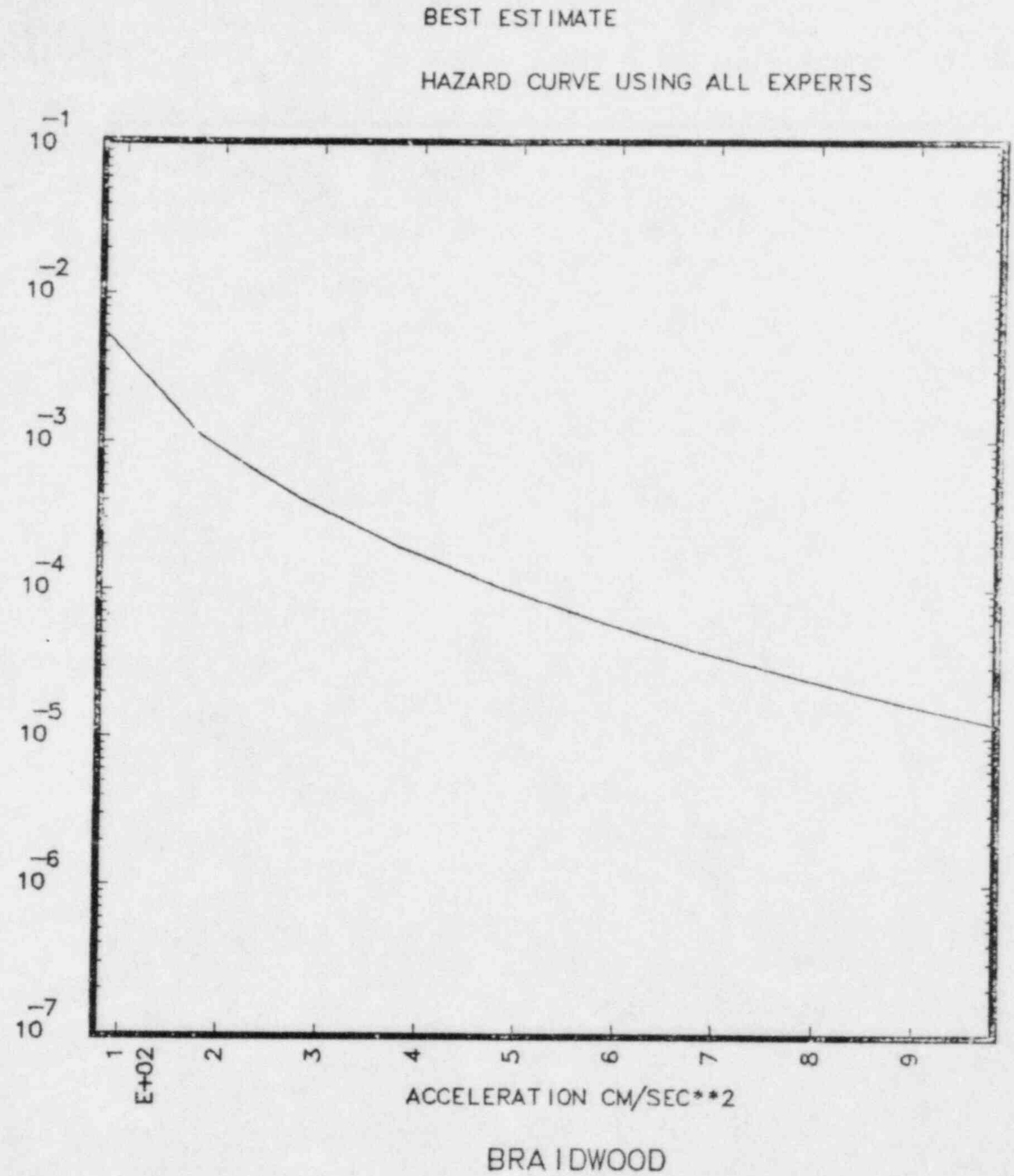

BEST ESTIMATE
HAZARD CURVE USING ALL EXPERTS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
BRAIDWOOD

Figure BR-1

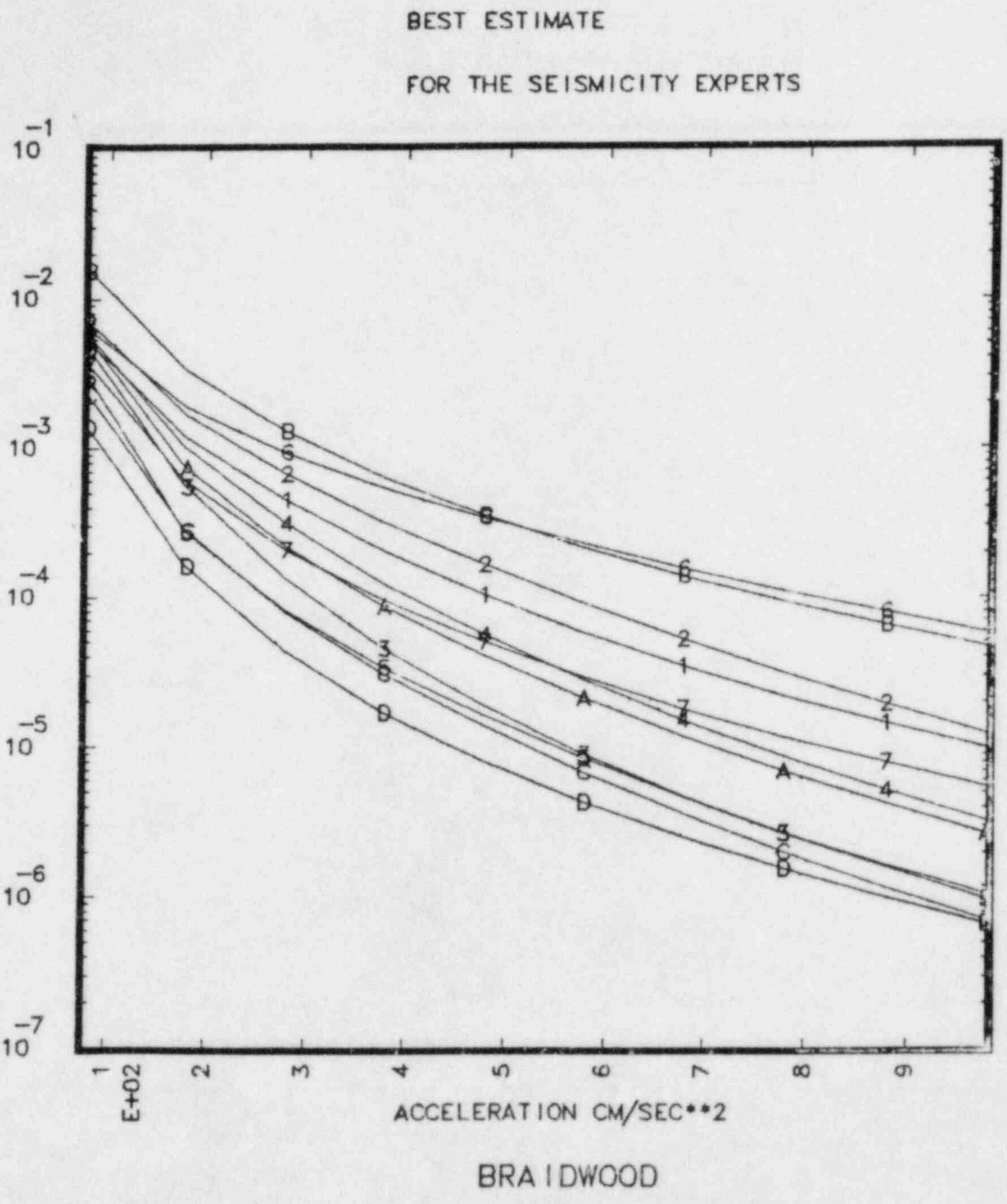


Figure BR-2 Best Estimate Hazard Curves (BEHC) per Seismicity Expert Combined Over All Ground Motion Experts.

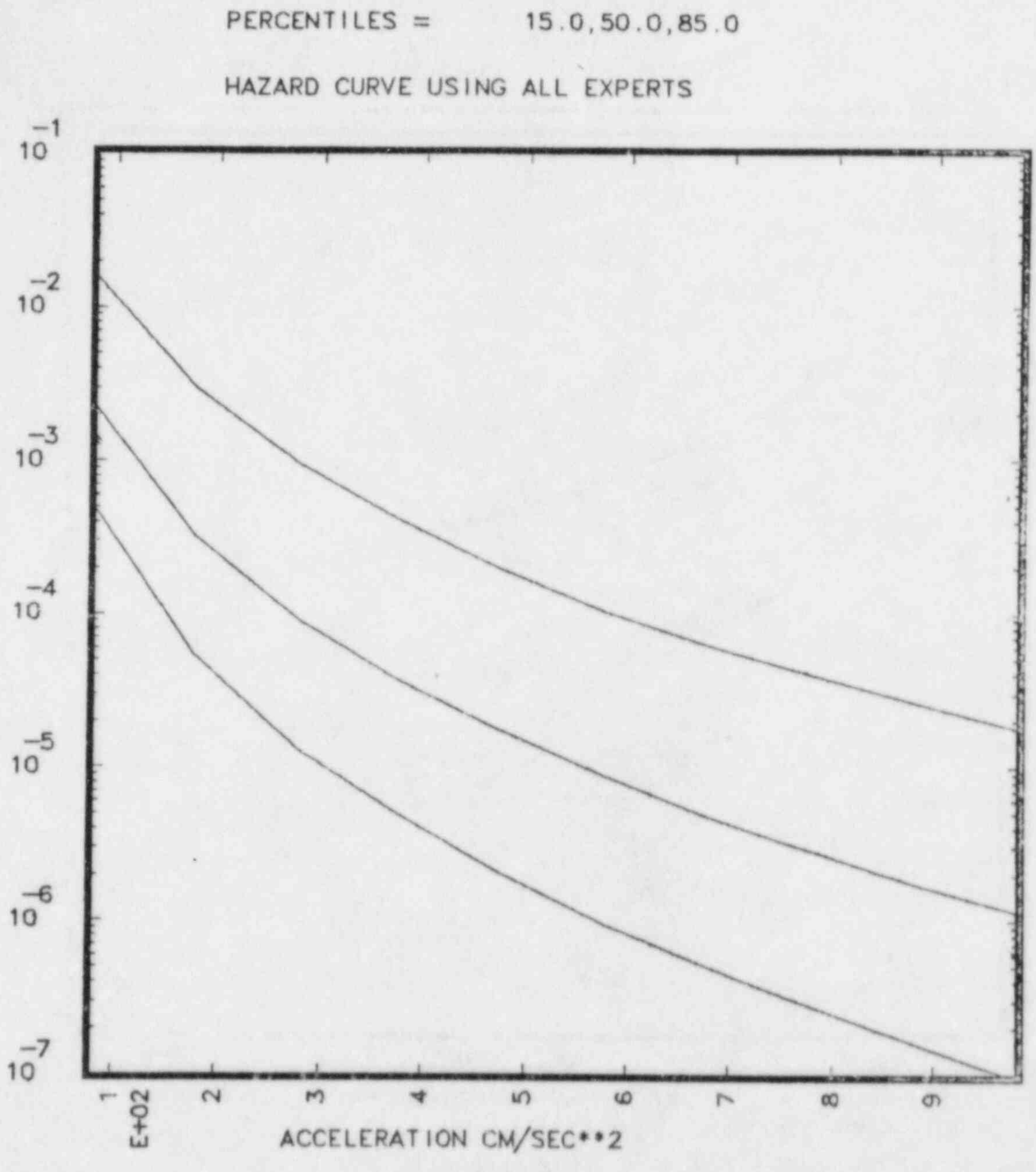


Figure BR-3 Constant Percentile Hazard Curves (CPHC) Over All Experts.

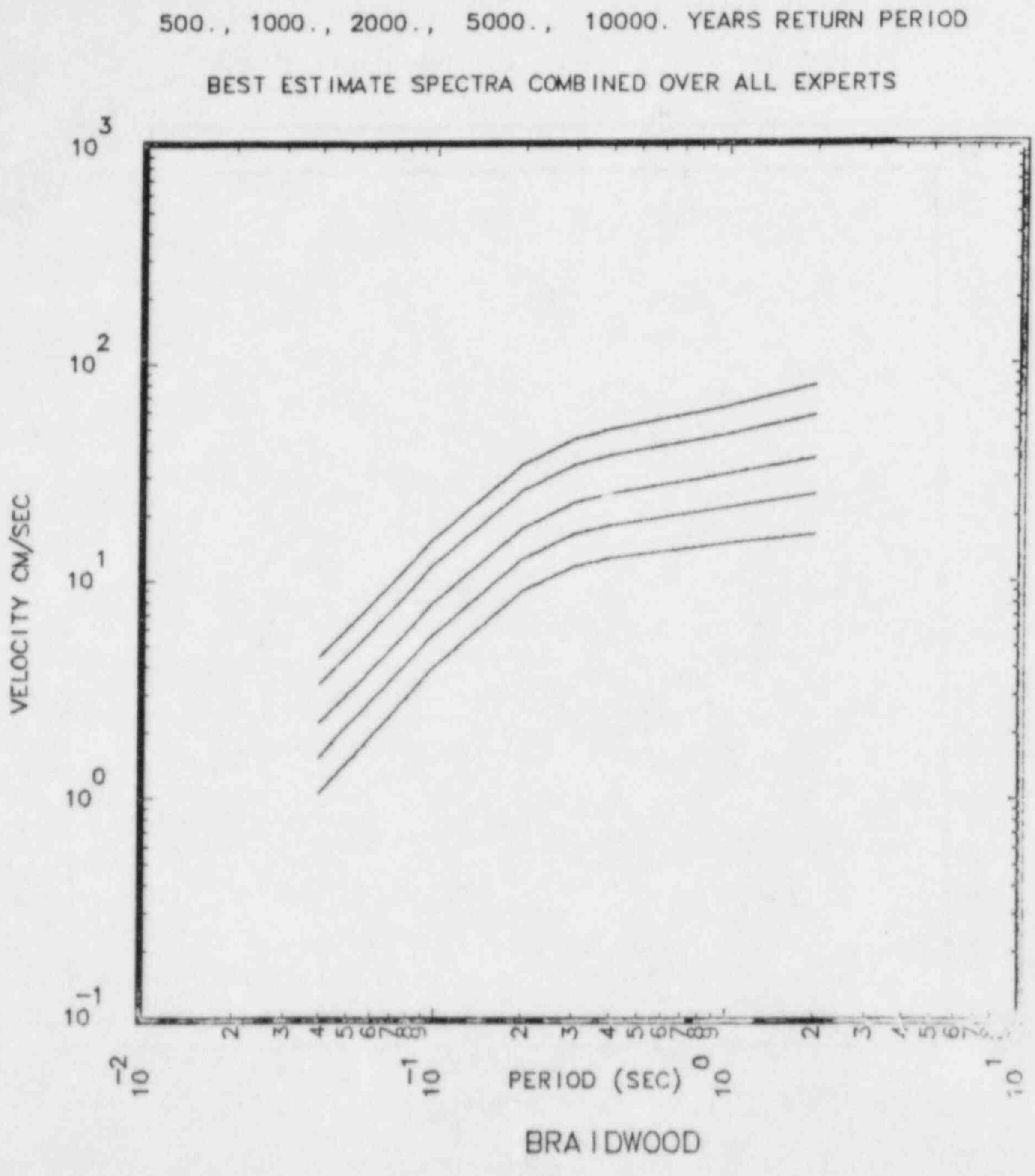

500., 1000., 2000., 5000., 10000. YEARS RETURN PERIOD
BEST ESTIMATE SPECTRA COMBINED OVER ALL EXPERTS
VELOCITY CM/SEC
PERIOD (SEC)
BRAIDWOOD

Figure BR-4

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

500. YEARS RETURN PERIOD

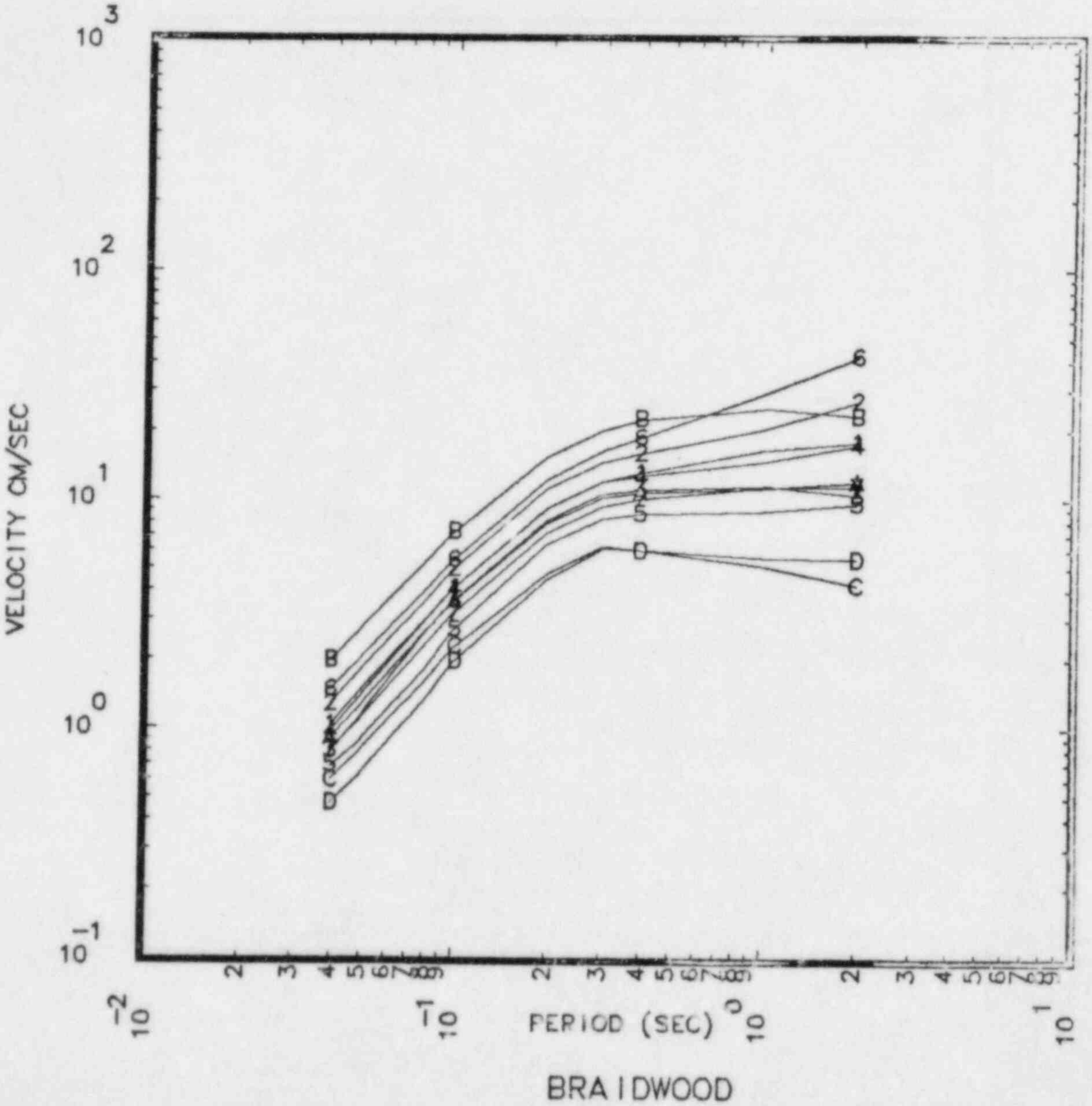


Figure BR-5

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

1000. YEARS RETURN PERIOD

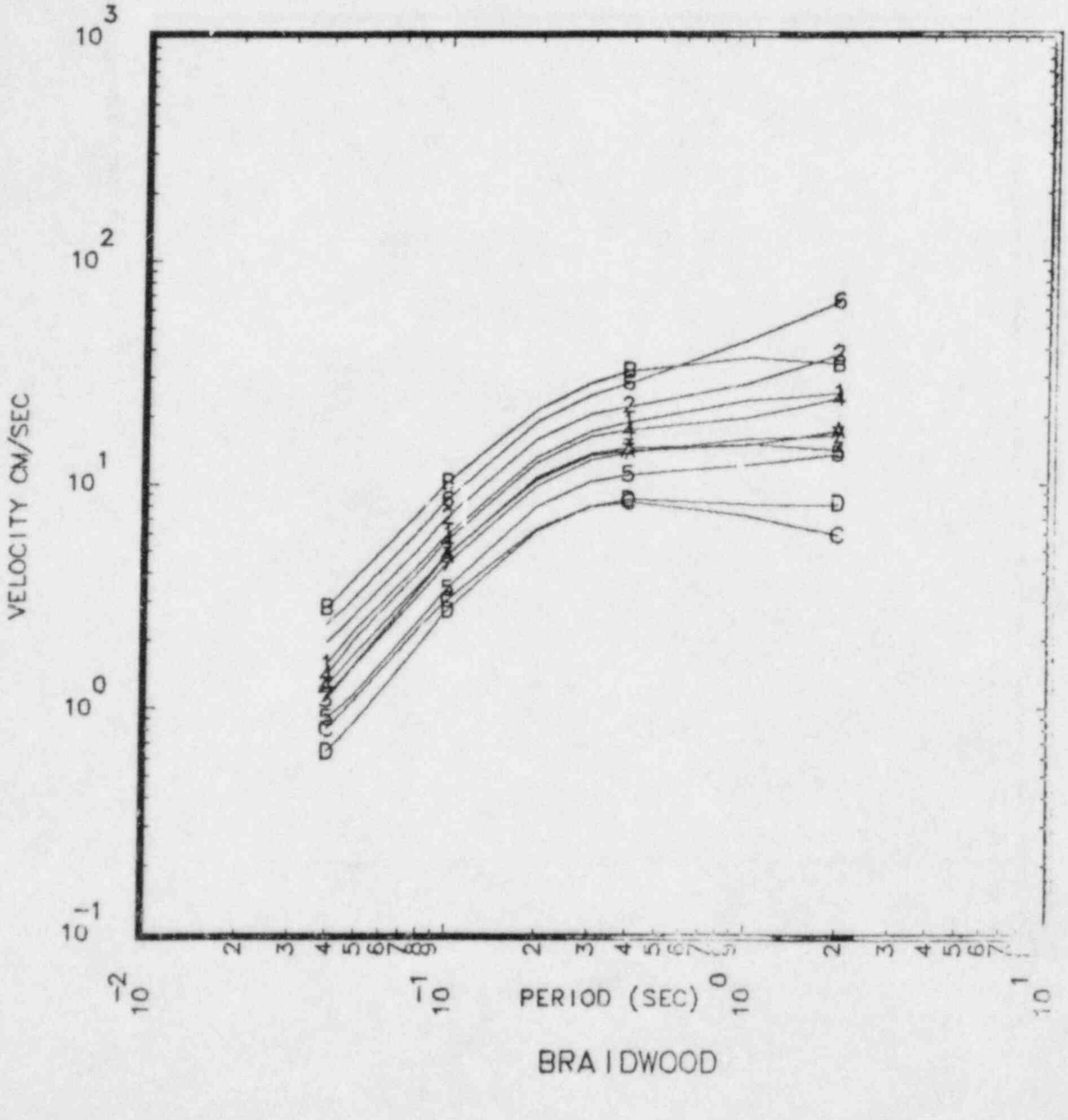


Figure BR-6

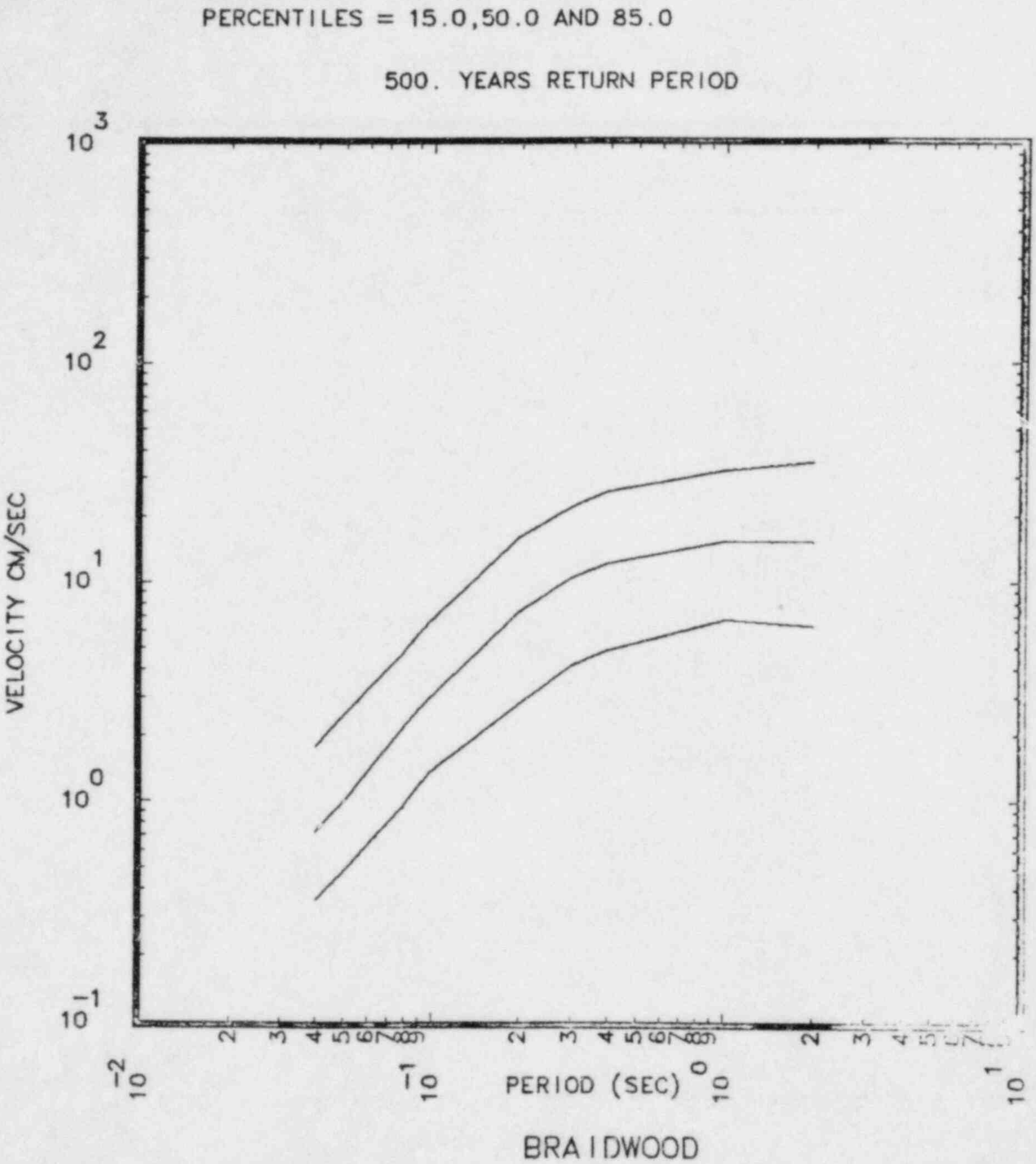


Figure BR-7 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 500 Year Return Period

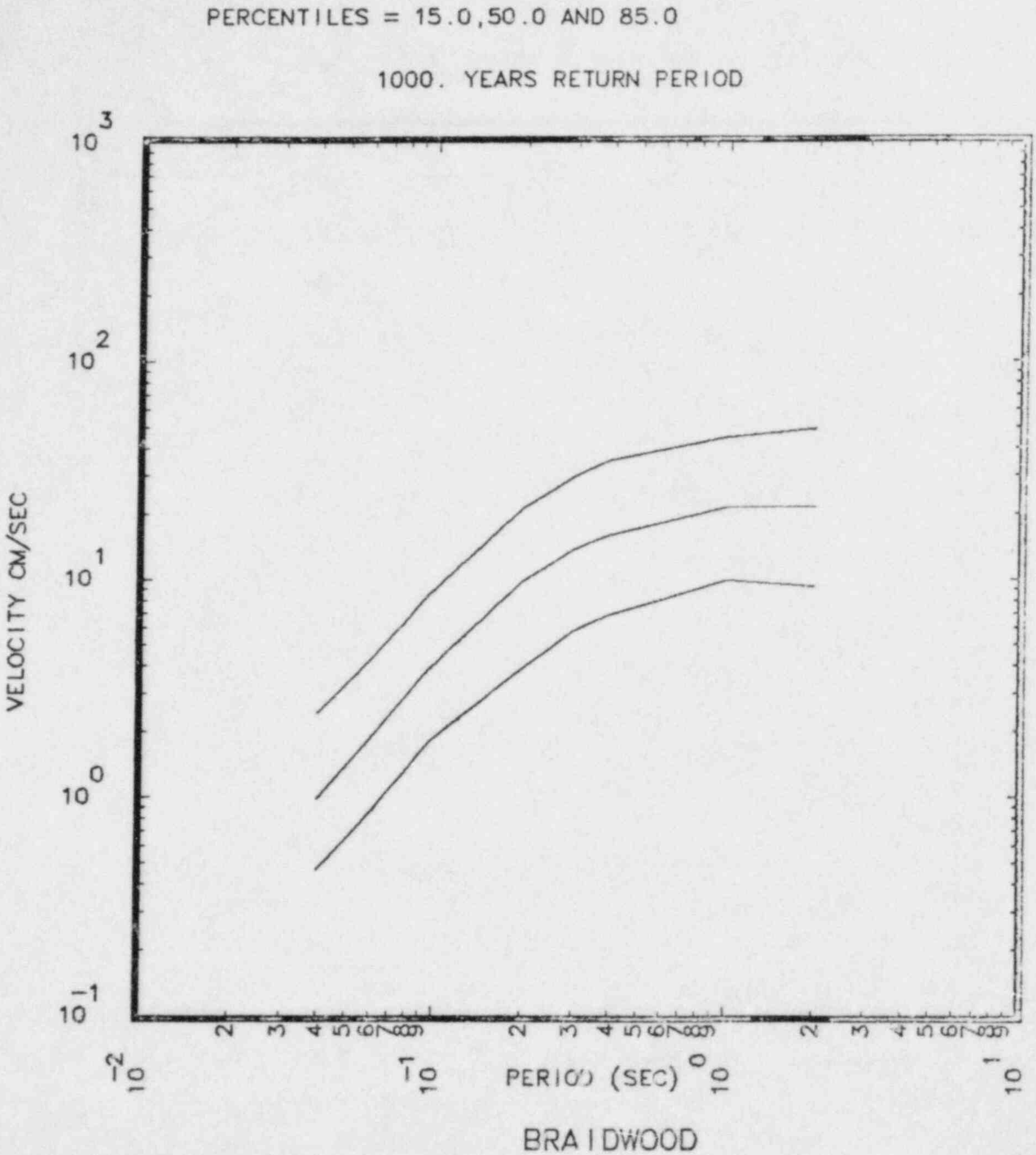


Figure BR-8 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 1000 Year Return Period

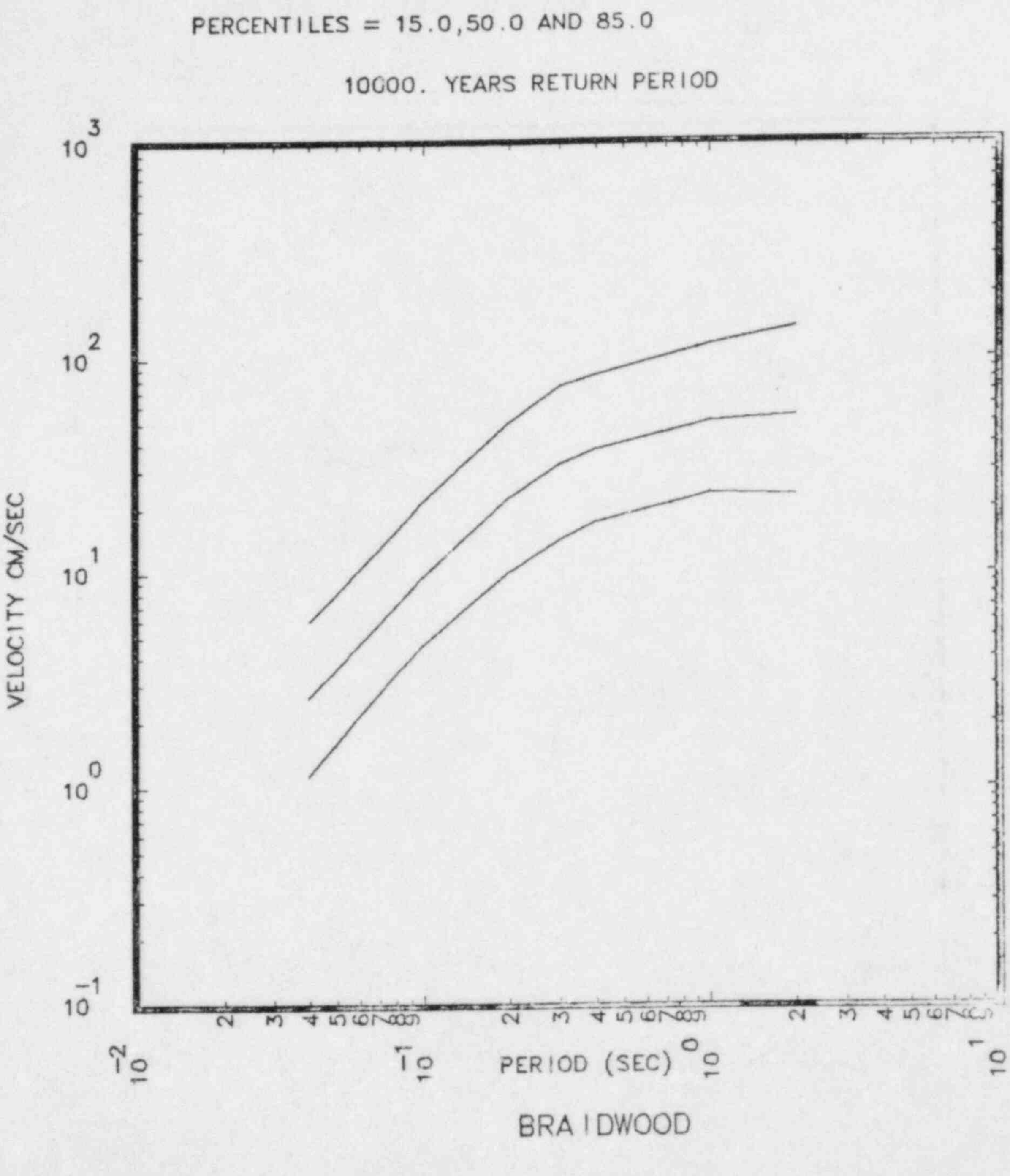


Figure BR-9 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 10,000 Year Return Period

4.3.2 Shearon Harris (SH)

4.3.2.1 General

The Shearon Harris site is located in the south east region of the EUS. It is classified as a rock site. For experts 2, 3, 6, 7 and 13, the site falls into the CZ and for the other experts it belongw to another specified zone. Since the upper magnitude cutoff for the CZ is relatively higo for the 5 experts mentioned above, in the same range of values as for the zones in which the site falls for the other experts, it is expected that the hazard curves at high PGA values behave similarly for all experts.

4.3.2.2 PGA Hazard Curves

Indeed, the BEHC per individual seismicity expert, presented in Fig. SH-2, behave in a similar fashion with the exception, perhaps, of the BEHC for experts 3 and 7. Expert's 3 BEHC is more concave than the others, leading to a hazard lower that the other BEHCs especially in the midrange values of PGA (between .2 to .6g). Experts 3 and 13 have very similar CZ in terms of seismicity and upper magnitude cutoff, thus their hazard curves converge at high PGA but the second dominant zone of expert 13 (zone 9) has more activity than the second dominant zone of expert 3 (zone 10), thus the midrange values for expert 13 are higher than for expert 3. At lower PGA values expert's 5 model tends to a higher hazard than expert's 7 model. However, the upper magnitude cutoff is much larger for expert's 7 models than for expert's 5 model. Thus at high PGA values the BEHC cross and expert's 7 model leads to a higher hazard at the Shearon Harris site. The spread between the BEHCs of Fig. SH-2 (in the order of a factor of 15 from the lower curve to the higher curve) is on the average larger than the typical spread obtained at other sites. Since this spread appears on a set of best estimate curves, it is due, in part to the diversity of expert opinions in the estimate of the BE parameters.

However, since the site is located relatively close to zones of high seismicity (BE) and high magnitude cutoffs (BE), there is a complex effect of contribution from those zones and the combined ground motion models. For example, the relative location of expert's 2 BEHC is controlled by ground motion expert's 5 BE model. When only ground motion model #7 was used, expert's 2 BEHC was the lowest (at high PGA) hazard curve for the Shearon Haris site. With the inclusion of BE ground motion model #27, expert's 2 BEHC is the highest. This effect is also apparent in Table 4.1 from the changing dominance from one zone to another between low and high PGA indicating also that the dominance is also due to a change in ground motion model.

The BEHC over all experts, shown in Fig. SH-1 falls reasonably close to the middle of the cluster of curves of Fig. SH-2 to refute the existence of outliers.

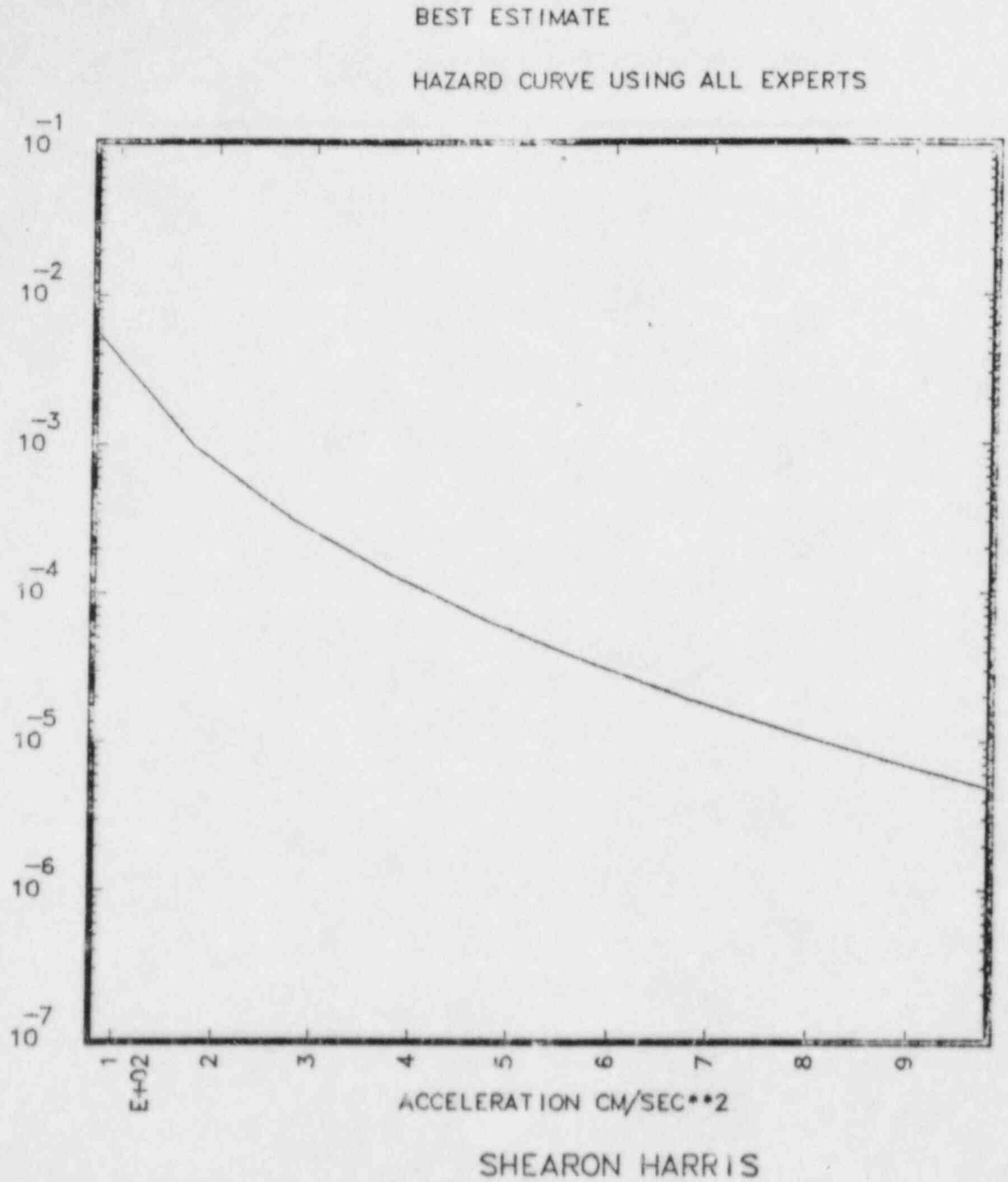
The CPHC is shown in Fig. SH-3 for all seismicity and ground motion experts combined together and for the 15th, 50th and 85th percentiles. The first comment is, again, relative to the spread between the 15th and the 85th percentile curves. A factor of approximately 24 separate these two curves at low PGA levels to become a factor of approximately 110 at high PGA levels.

Although this spread is not as high as some obtained for some sites, it is still considered as high, thus showing a wide spectrum of opinions of the experts in he zonation, seismicity and ground motion modeling for analysis of sites located in the south east of the United States. Furthermore, a large discrepancy between the BEHC of Fig. SH-1 and the 50th percentile HC emphasizes the fact that the distributions of most of the parameters dominant in the uncertainty are highly skewed. It also underlines the difference between arithmetic averaging of the curves (as performed for the BE cases) and the geometric averaging performed in the interpolation process designed to determine the CPHC (see Appendix D for details on the methods of combination).

4.3.2.3 Uniform Hazard Spectra

The BEUHS curves shown on Fig. SH-4, combined over all experts for the five return periods selected exhibit a shape close to the Newmark Hall spectrum shape. However, the 5 curves tend to diverge slightly as the period increases. An examination of Fig. SH-5 and SH-6 show that the divergence is essentially due to 3 outlying curves. The BEUHS for expert 2 is on the high side and the BEUHS for experts 3 and 12 are on the low side of the velocity, with respect to the cluster of curves for all the other experts. It is interesting to note that the dispersion in the BEUHS of Figs. SH-5 and SH-6 is very small once the outliers have been removed. Expert's 2 appears to provide the highest hazard for both the PGA hazard curve, in terms of BEHC as well as for the spectral velocity in terms of BEUHS. In the low end however, expert 3 which leads to the lowest HC in Fig. SH-2 is the lowest on Fig. SH-5 and SH-6 only at low periods. The resulting BEUHS for expert 12 (c) appears to be lower than that of expert 3 for higher periods. This is a consequence of the role that different zones play, in association with the BE ground motions and various levels of upper magnitude cutoffs and distances.

The CPUHS for the 500, 1,000 and 10,000 year return periods, combined over all experts, are presented in Figs. SH-7, SH-8 and SH-9 for the 15th, 50th and 85th percentiles. In a manner similar to the CPHC, these curves appear to be evenly spread between the 15th and the 50th percentiles, and between the 50th and the 85th percentiles over the entire range of periods considered. In this case, the 15th to 50th percentile curves are distant by a factor of approximately 2 on the pseudo relative velocity scale. This is a somewhat moderate to low dispersion by comparison with the results obtained for other sites in this section.



BEST ESTIMATE
HAZARD CURVE USING ALL EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
SHEARON HARRIS

Figure SH-1

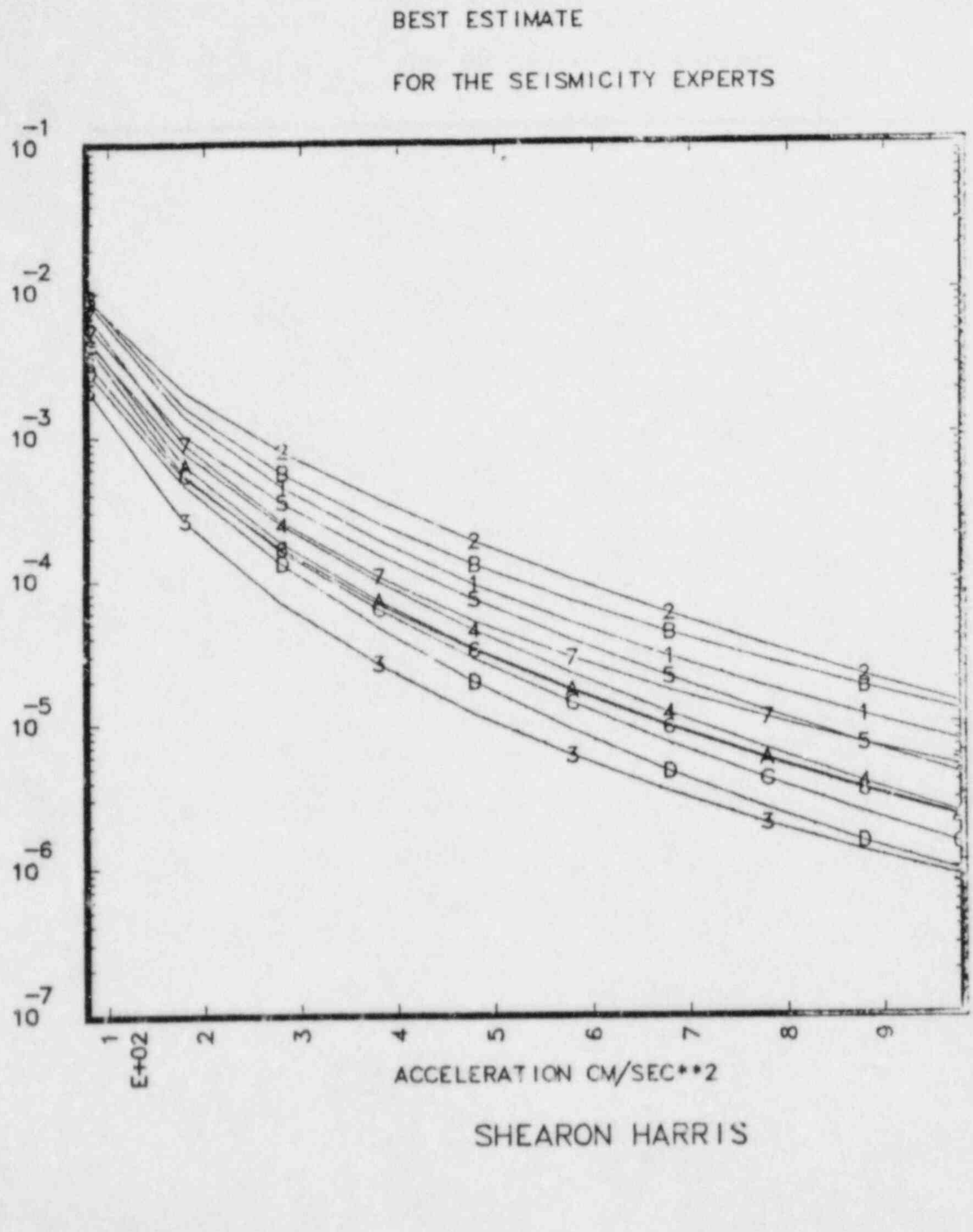


Figure SH-2 Best Estimate Hazard Curves (BEHC) per Seismicity Expert Combined Over All Ground Motion Experts.

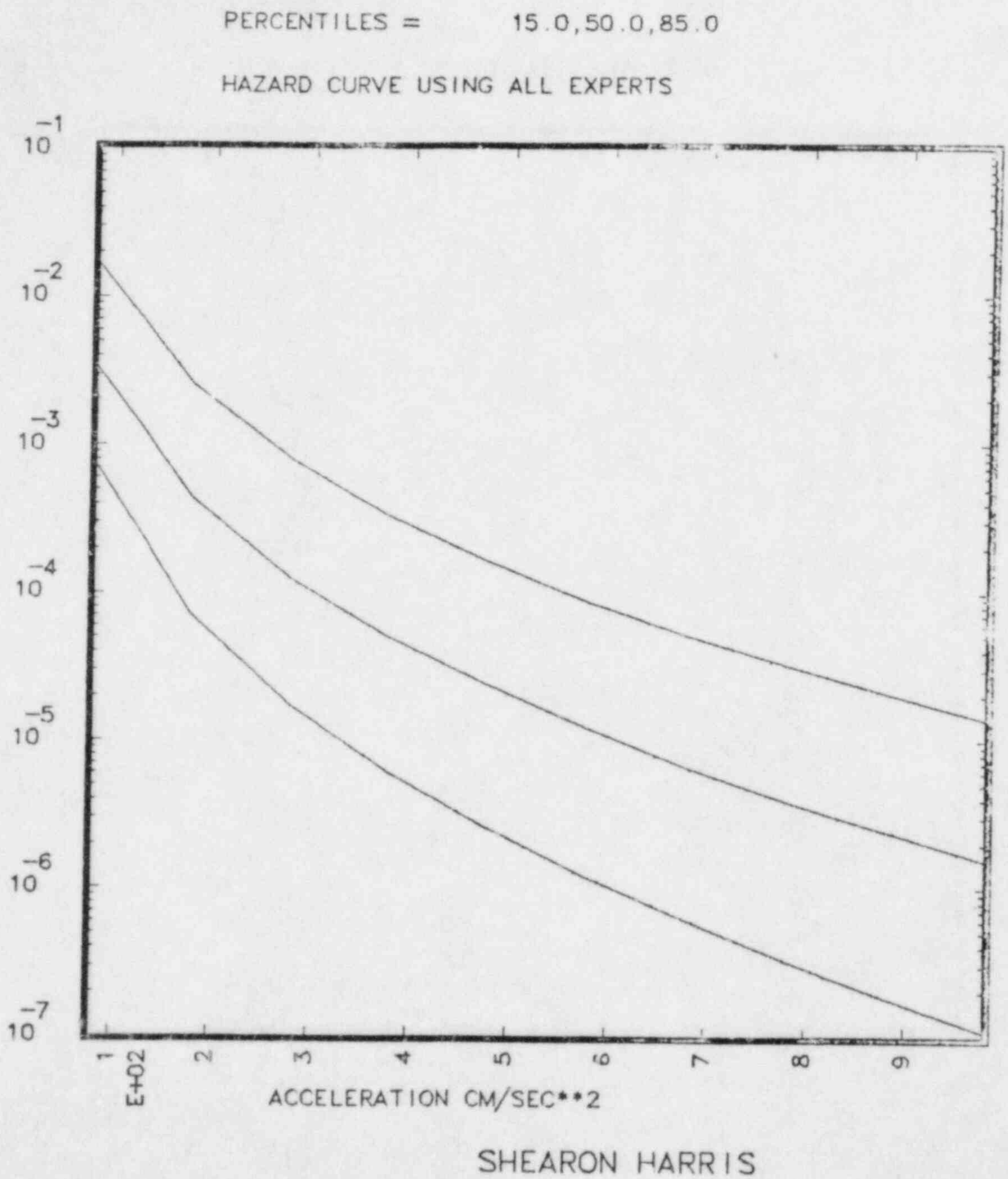


Figure SH-3 Constant Percentile Hazard Curves (CPHC) Over All Experts.

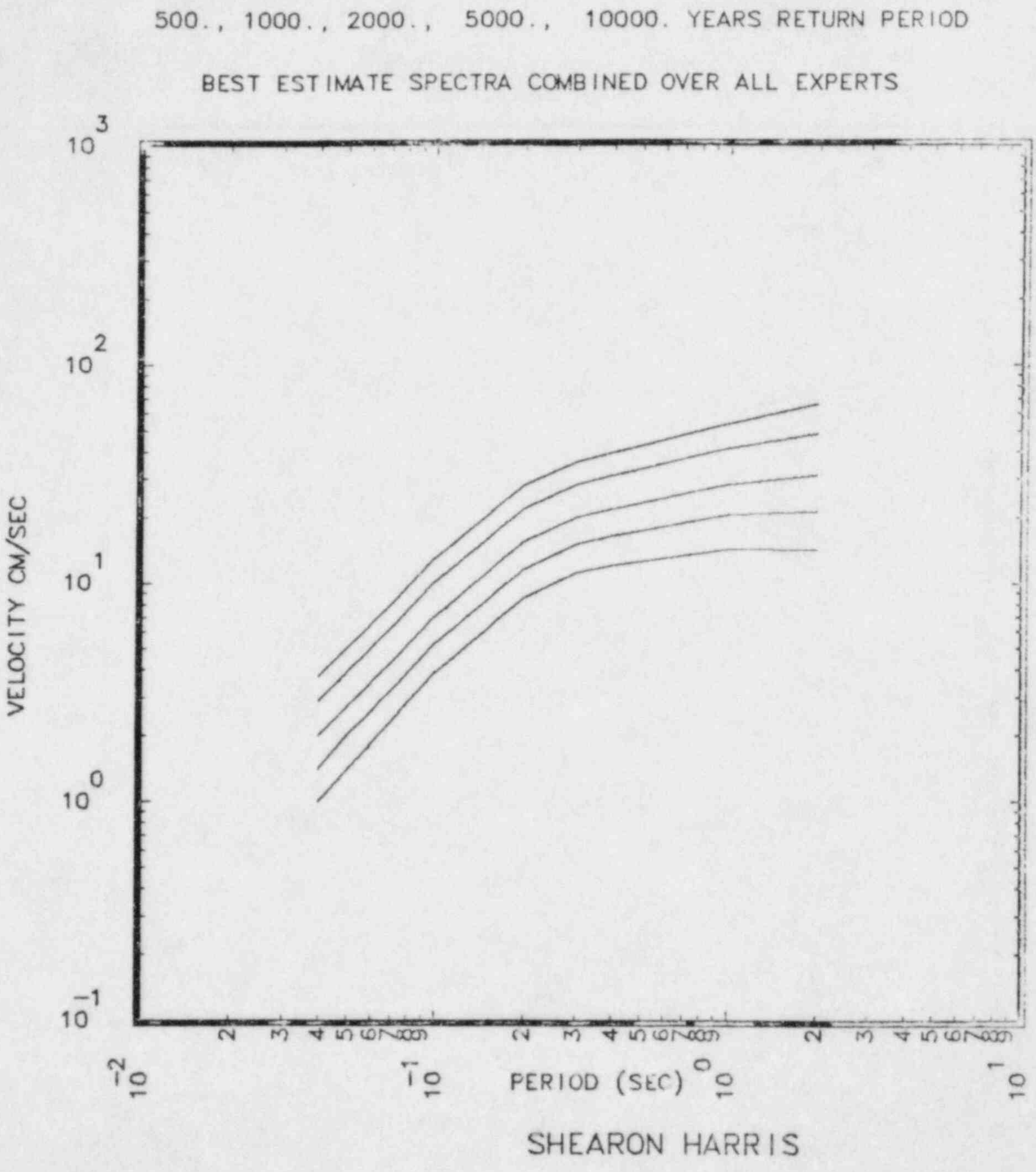

500., 1000., 2000., 5000., 10000. YEARS RETURN PERIOD
BEST ESTIMATE SPECTRA COMBINED OVER ALL EXPERTS
VELOCITY CM/SEC
PERIOD (SEC)
SHEARON HARRIS

Figure SH-4

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

500. YEARS RETURN PERIOD

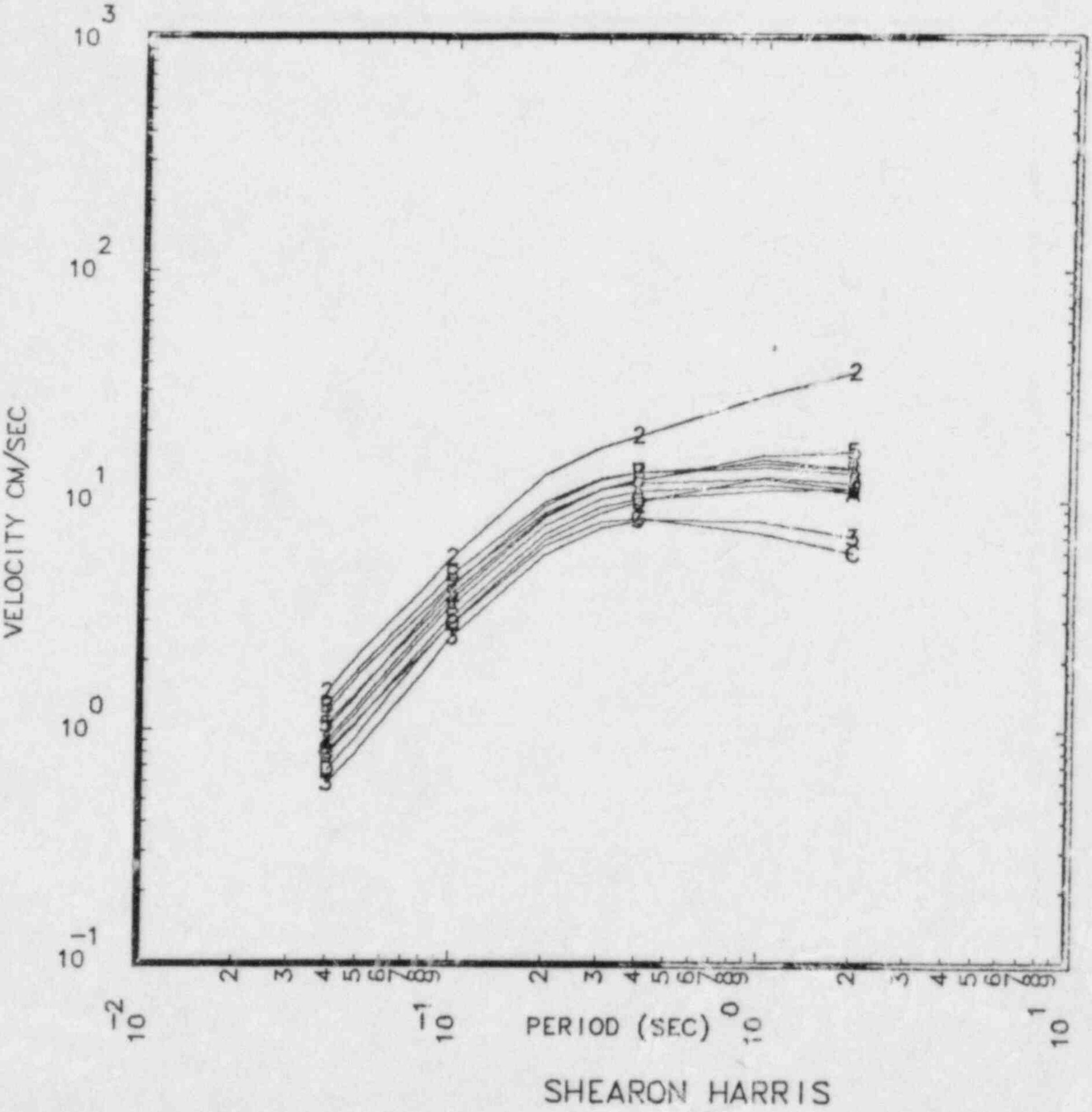
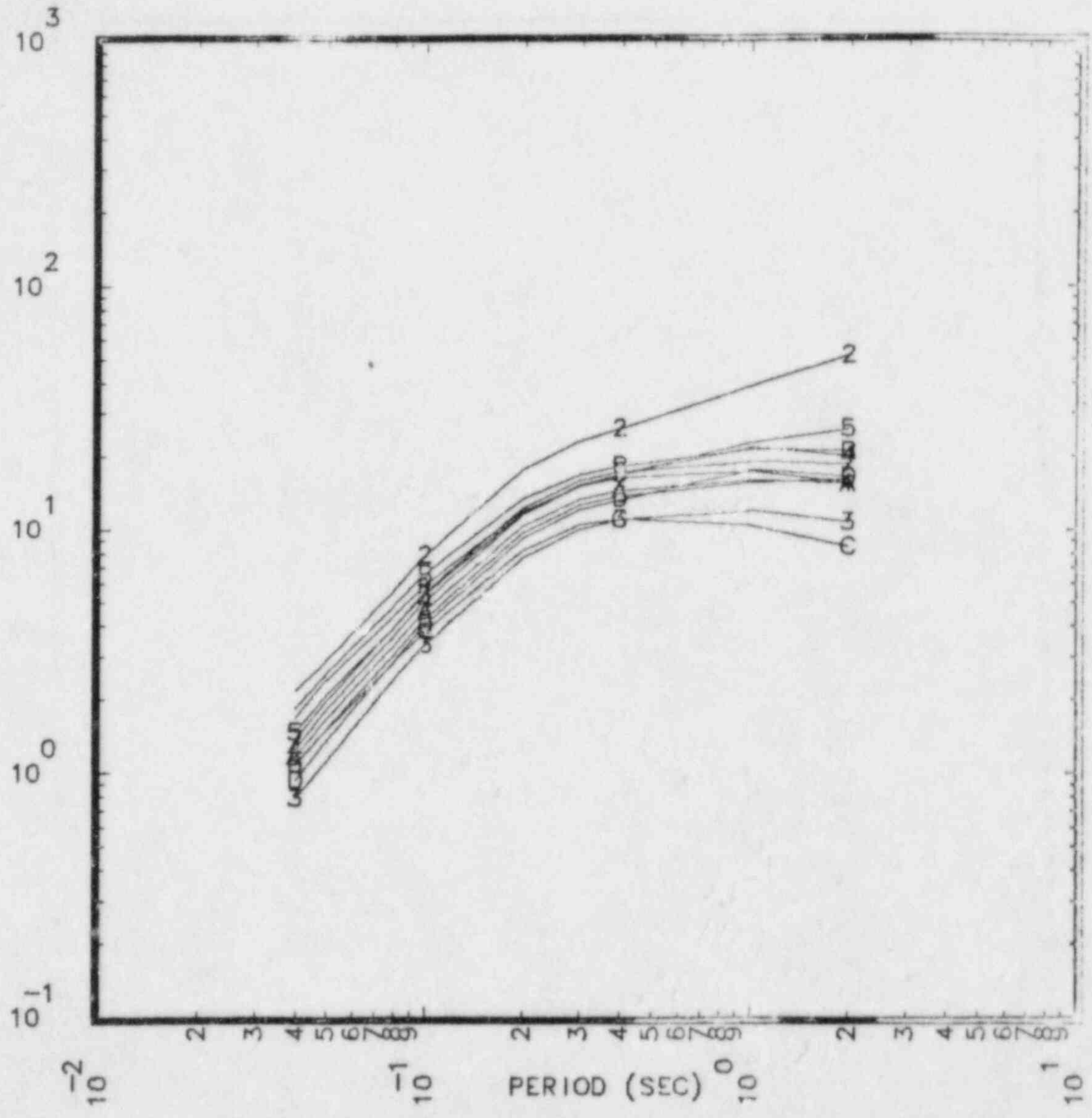


Figure SH-5

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

1000. YEARS RETURN PERIOD



SHEARON HARRIS

Figure SH-6

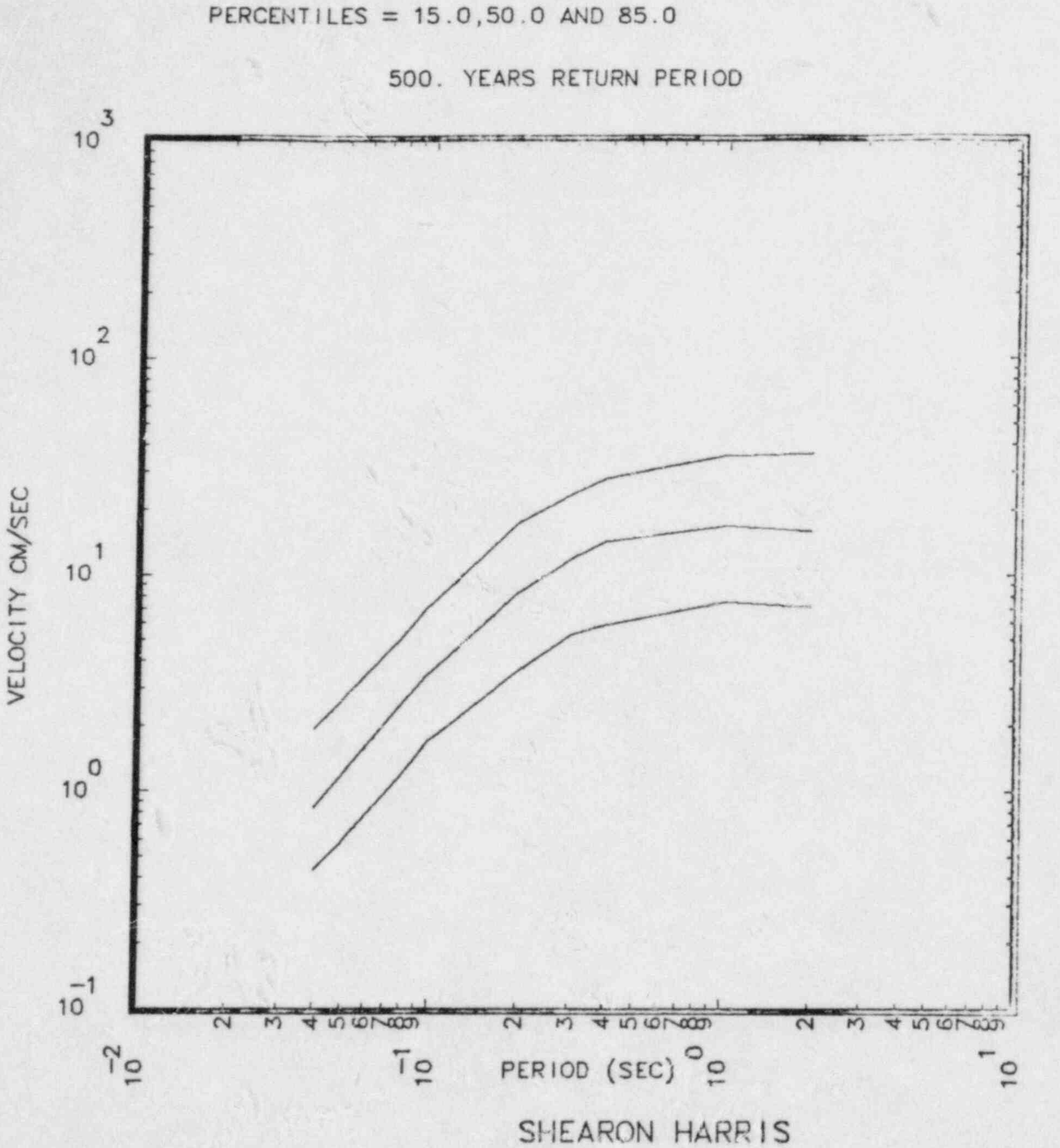


Figure SH-7 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 500 Year Return Period

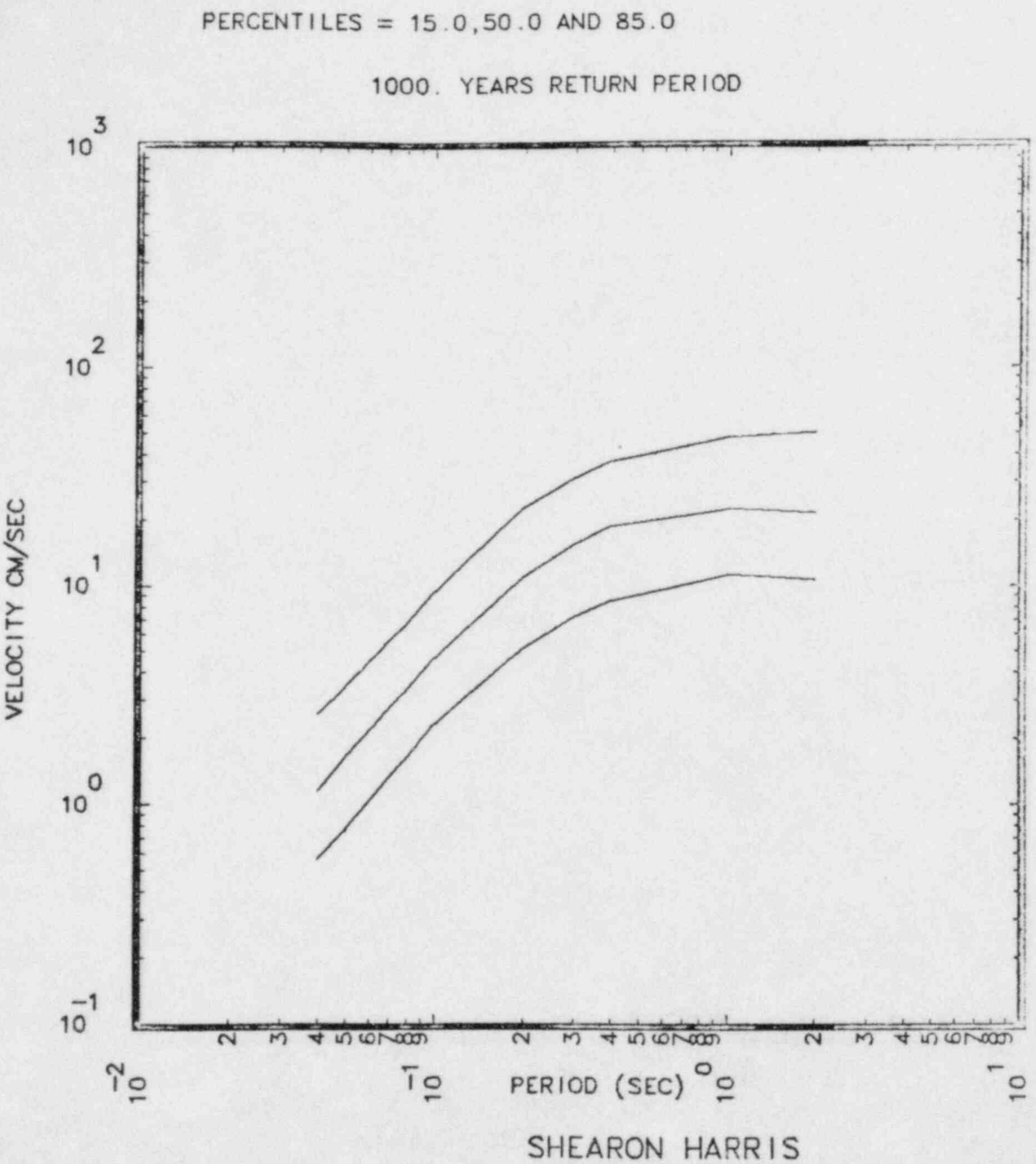


Figure SH-8 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 1000 Year Return Period

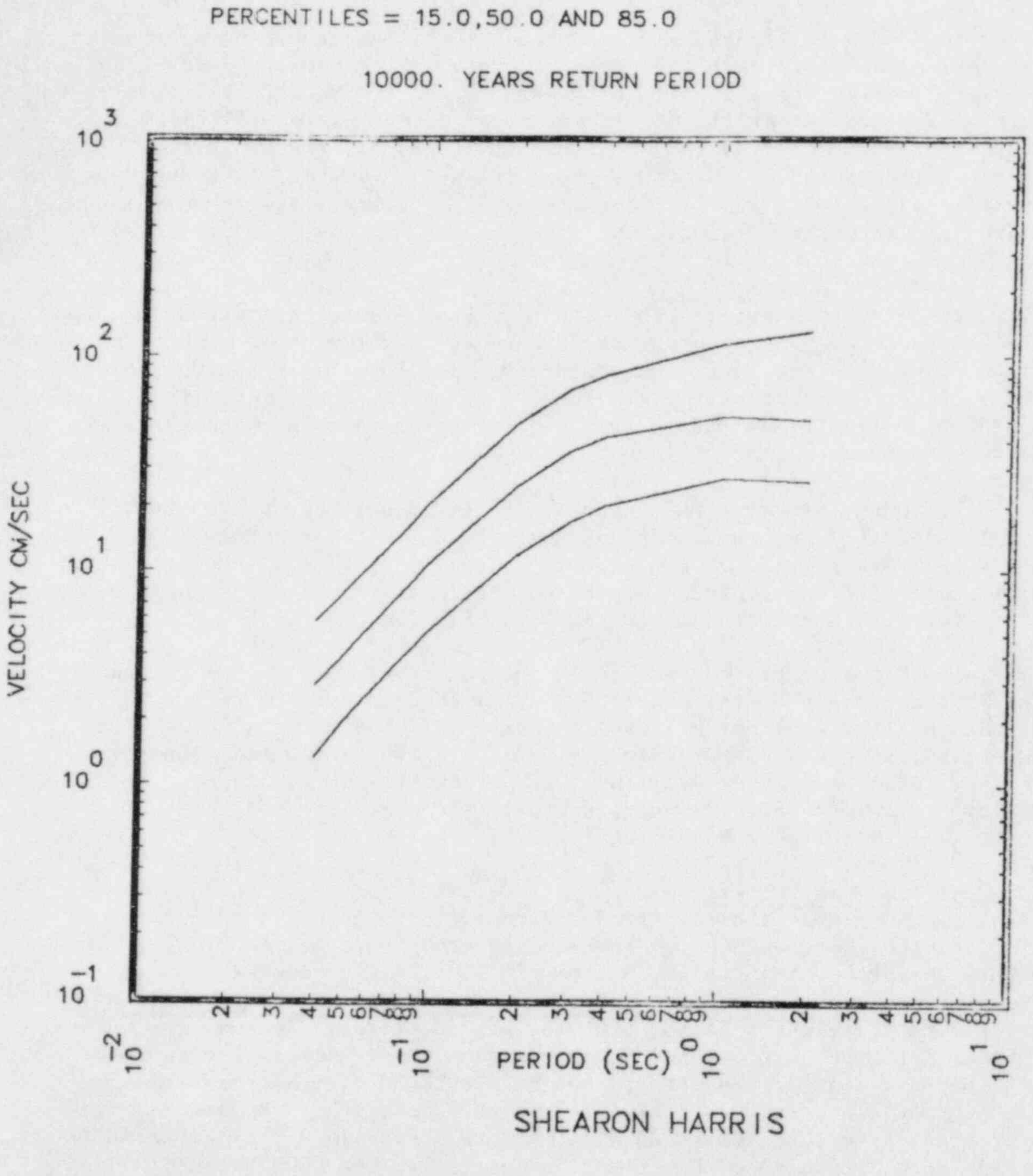


Figure SH-9 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 10,000 Year Return Period

4.3.3 River Bend (RB)

4.3.3.1 General

The River Bend site is located approximately at the boundary between the two regions defined as south east and south central. It is classified as a soil site, however, since for all seismicity experts the New Madrid area appears to be the dominant area after the CZ, it was decided to consider this site as located in the South Central (SC) region. In actuality, the CZ is the dominant zone in the BE calculations shown in Table 4.1, for all experts but for experts 1, 4, 11 and 12. For these four experts however, the dominant zones are also large zones similar to a CZ.

4.3.3.2 PGA Hazard Curves

The BEHC per seismicity expert, shown in Fig. RB-2 present all the same shape except for expert 4. For this expert, the relatively low upper magnitude cutoff (5.5) of the large zone containing the site location (zone 25) governs the shape of the curve at high PGA. The low PGA part of the curve is governed by zone 4 which is the New Madrid area and for which there is more agreement in the seismicity expert's opinions.

To the exception of expert 4 which appears to be an outlier at high PGA, experts 1 and 12 (c) are the upper and lower bound on the hazard, respectively. The spread between experts' 1 and 12 BEHC is a moderate factor of 10 over all. If one included expert 4, the interval of values would be from 8 to low PGA to a factor of 25 to 30 at high PGA.

The combined BEHC over all experts shows the relatively low hazard associated with this site. The BEHC for expert 6 in Fig. RB-2 appears to be the closest to the BEHC of Fig. RB-1 for all experts combined. The uncertainty in the hazard curves, shown by the CPHC in Fig. RB-3, is typical of the moderate uncertainty found at most sites. The 50th percentile curve, close to the BEHC at the low PGA values, diverges toward upper values at high PGA to reach a factor of 2.5 times higher hazard at 1 g level.

4.3.3.3 Uniform Hazard Spectrum

Fig. Rb-5 and RB-6 show the effect of ground motion expert's 5 model in association with the zonations and seismicity experts 2, 4, and 6. This leads to an untypical shape for the BEUHS shown in Fig. RB-4. However, the relative agreement of the experts lead to a narrow band of BEUHS at low periods (a factor of 2 to 3, versus a factor of 10 at high periods). Because the simulations for experts 2, 4, and 6 include many other models leading to more typical spectral shapes, the effect seen on the BEUHS over all experts does not appear in the uncertainty analysis. In this case, the simulated samples which created the effect mentioned above were removed since they appeared to be outside of the 15th to 85th percentile interval. The CPUHS shown in Fig. RB-7, RB-8 and RB-9 for the 500, 1000, and 10,000 year return period, therefore posesses a more response spectrum-like shape. The uncertainty in the UHS is moderate for this site; a factor of 2 at low periods and 6 at high periods between the 15th percentile curve and the 85th percentile curve.

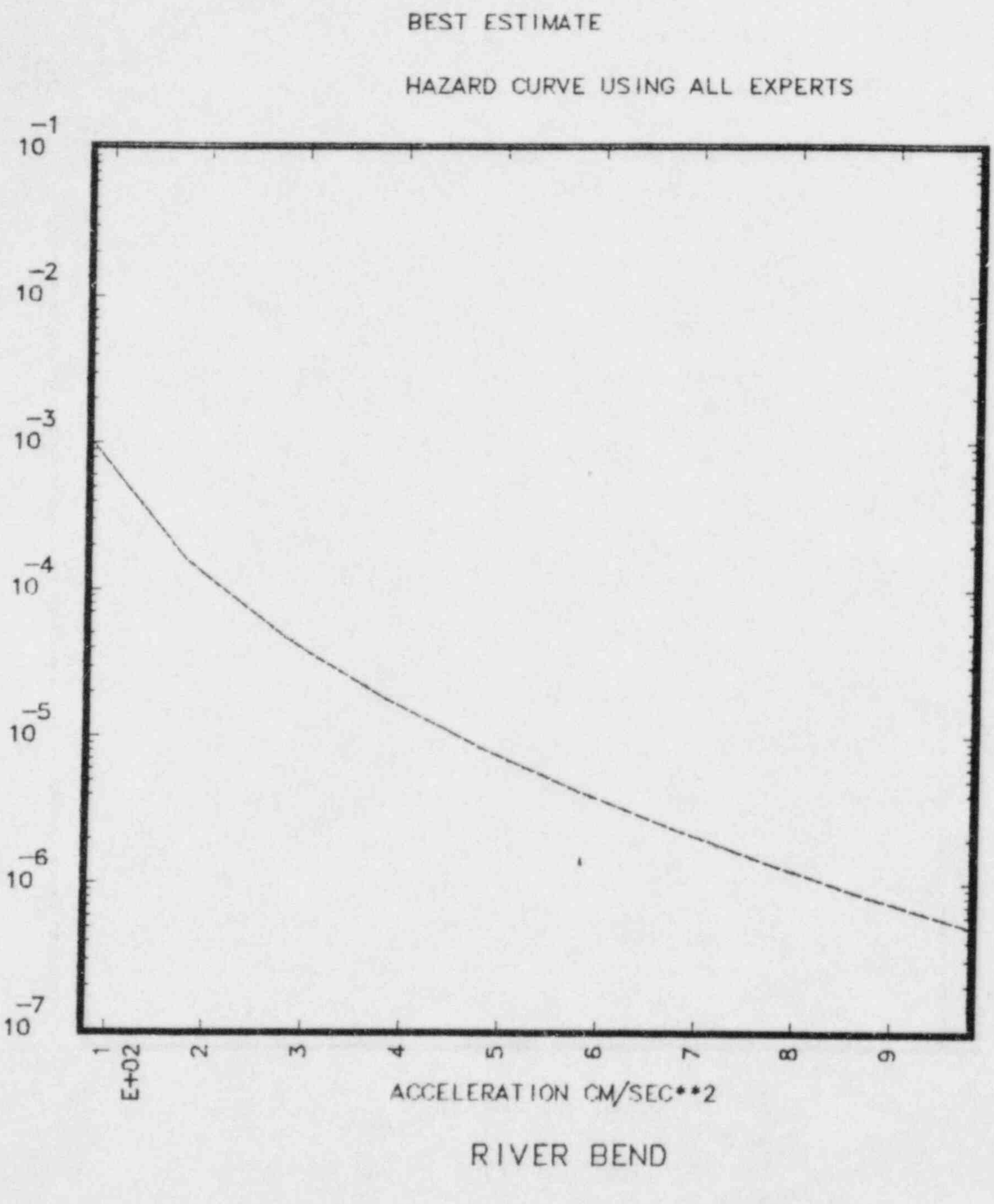

BEST ESTIMATE
HAZARD CURVE USING ALL EXPERTS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1 E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
RIVER BEND

Figure RB-1

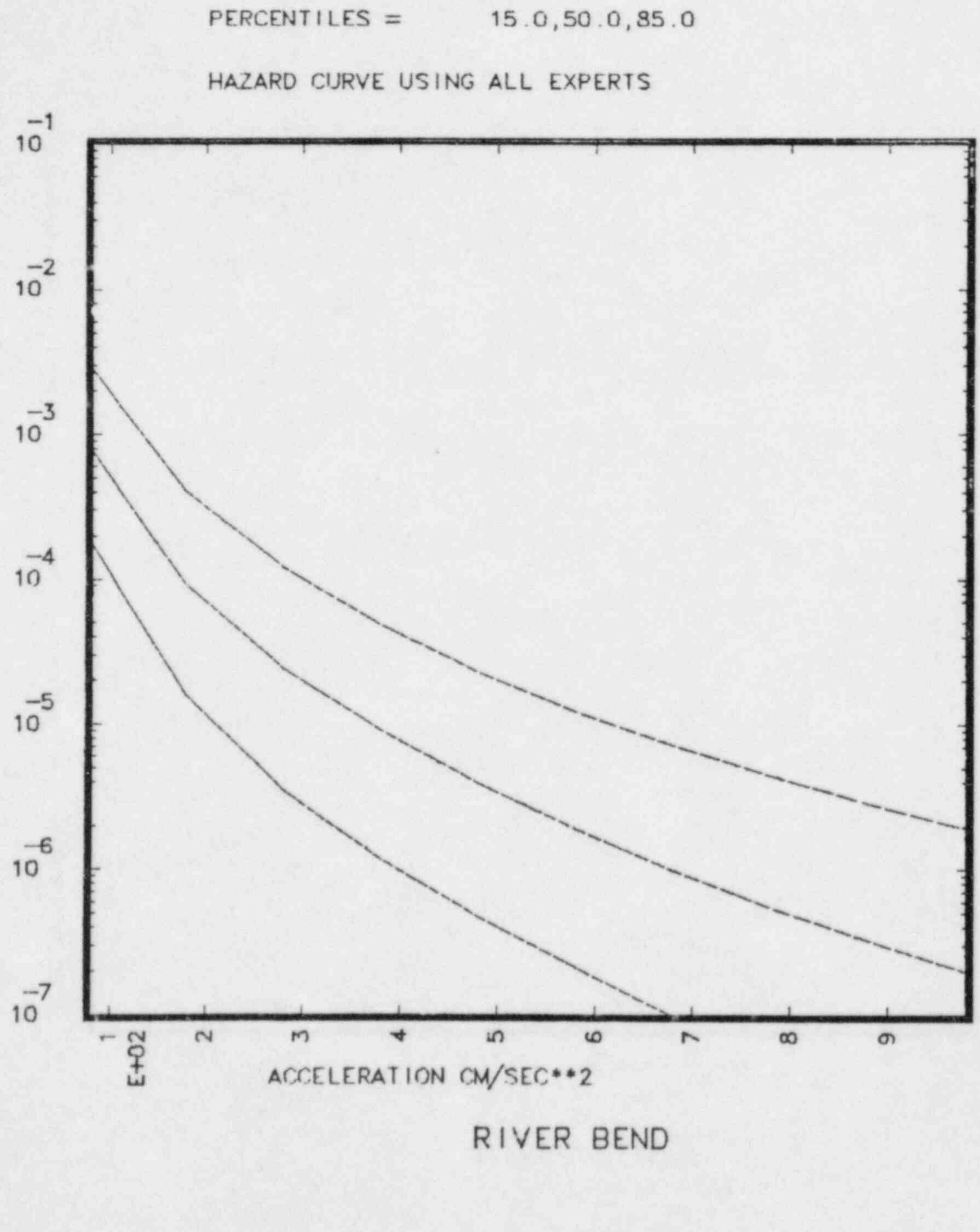


Figure RB-2 Best Estimate Hazard Curves (BEHC) per Seismicity Expert Combined Over All Ground Motion Experts.

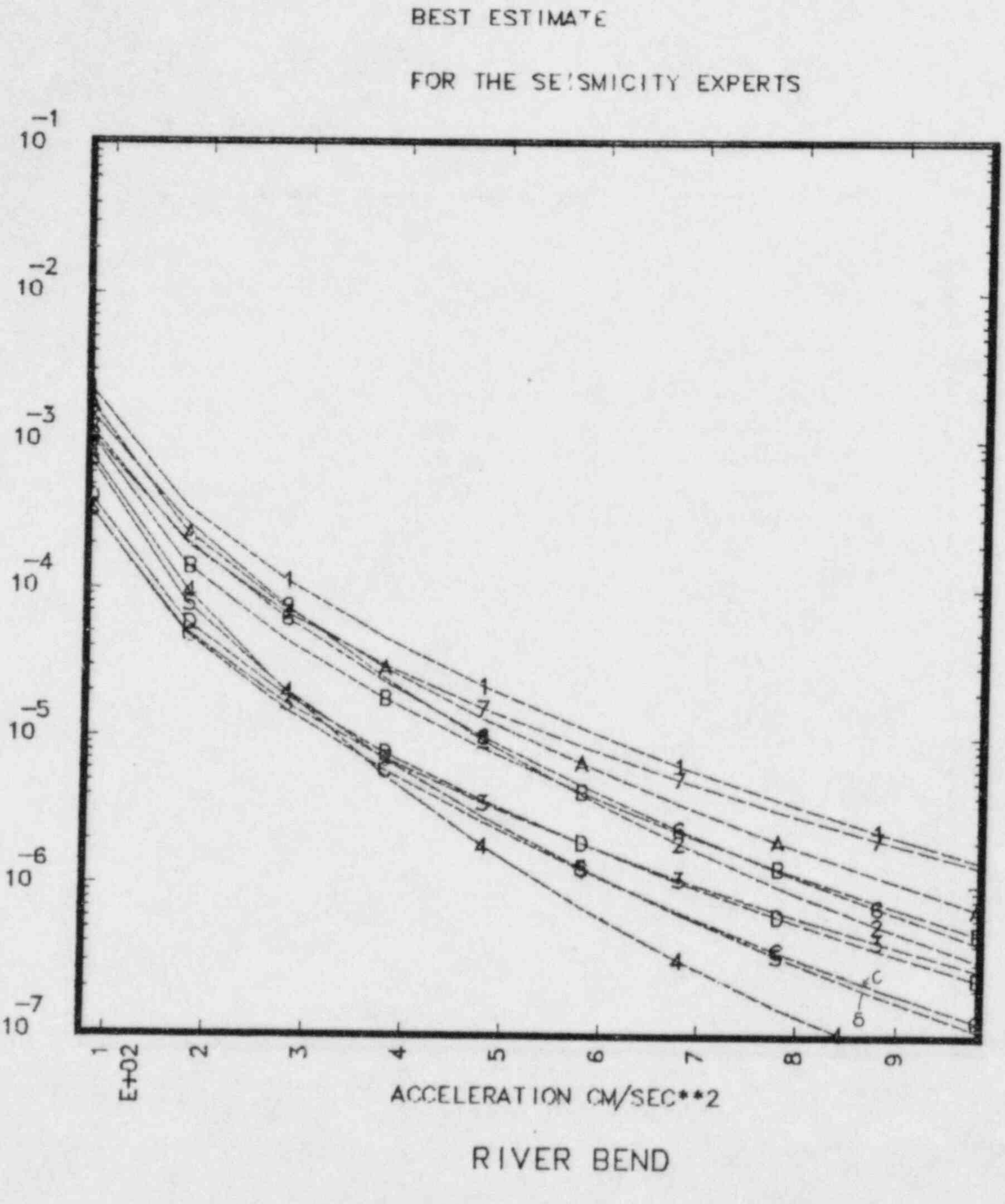


Figure RB-3 Constant Percentile Hazard Curves (CPHC) Over All Experts.

500., 1000., 2000., 5000., 10000. YEARS RETURN PERIOD

BEST ESTIMATE SPECTRA COMBINED OVER ALL EXPERTS

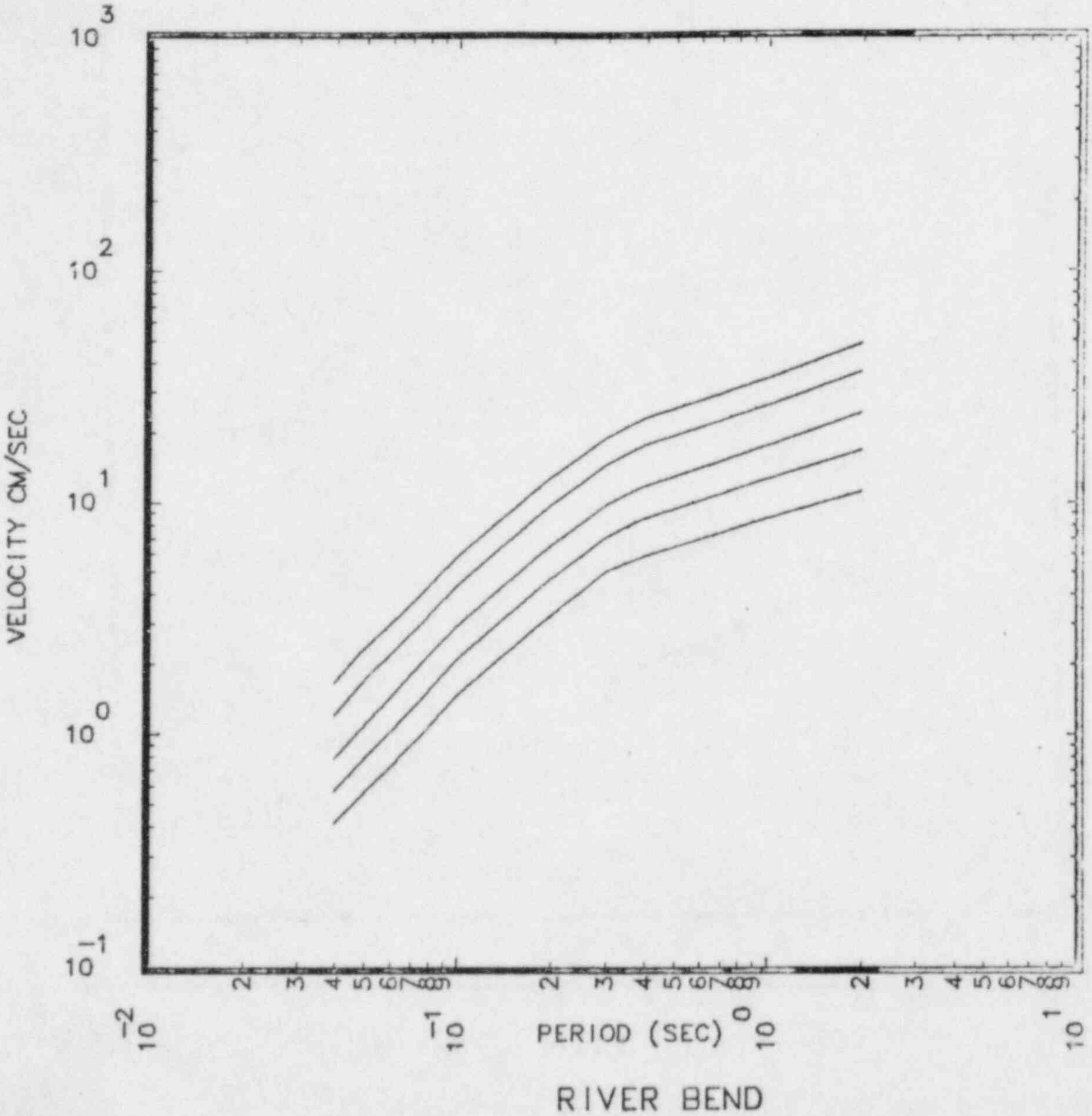


Figure RB-4

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

500. YEARS RETURN PERIOD

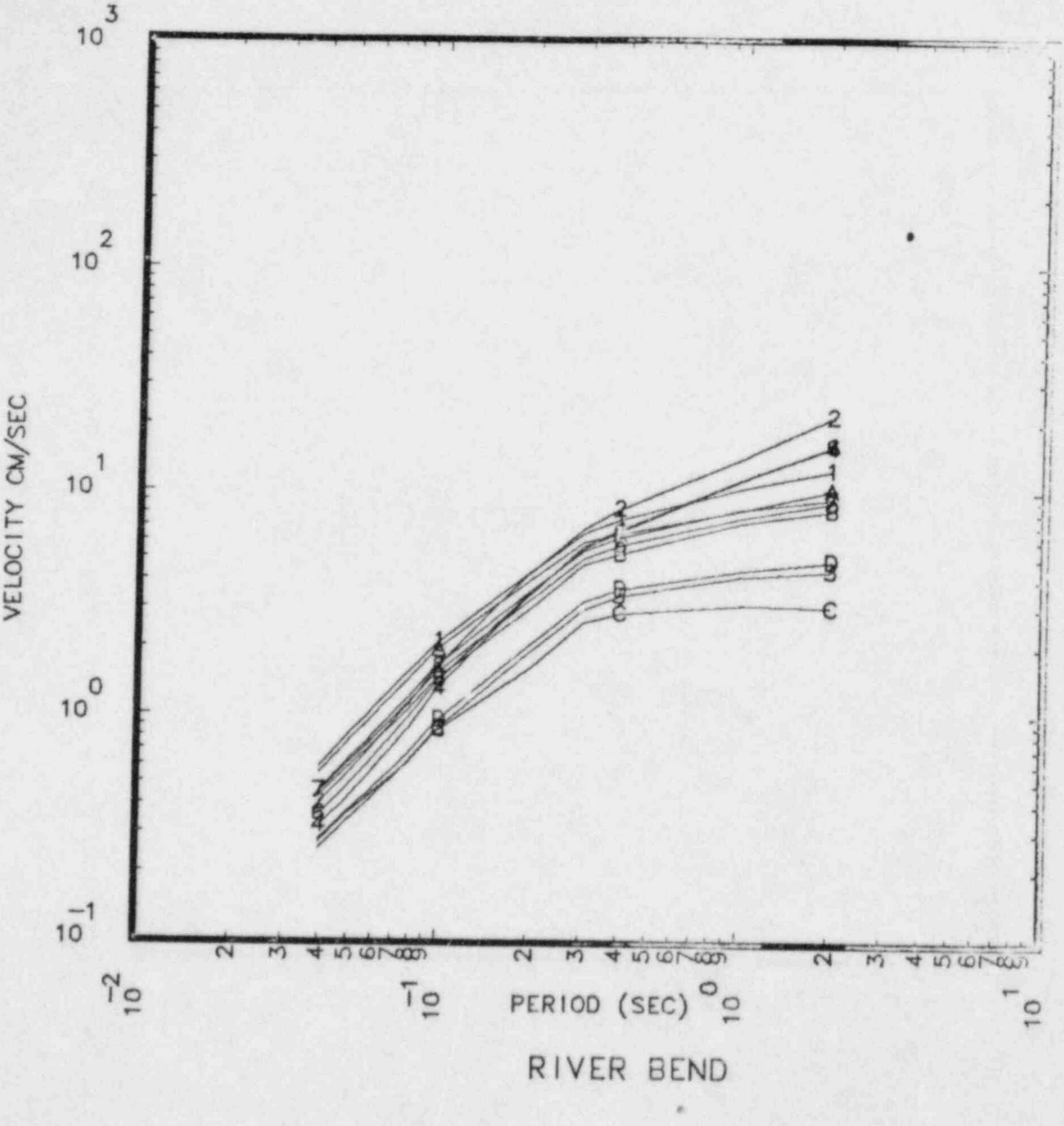
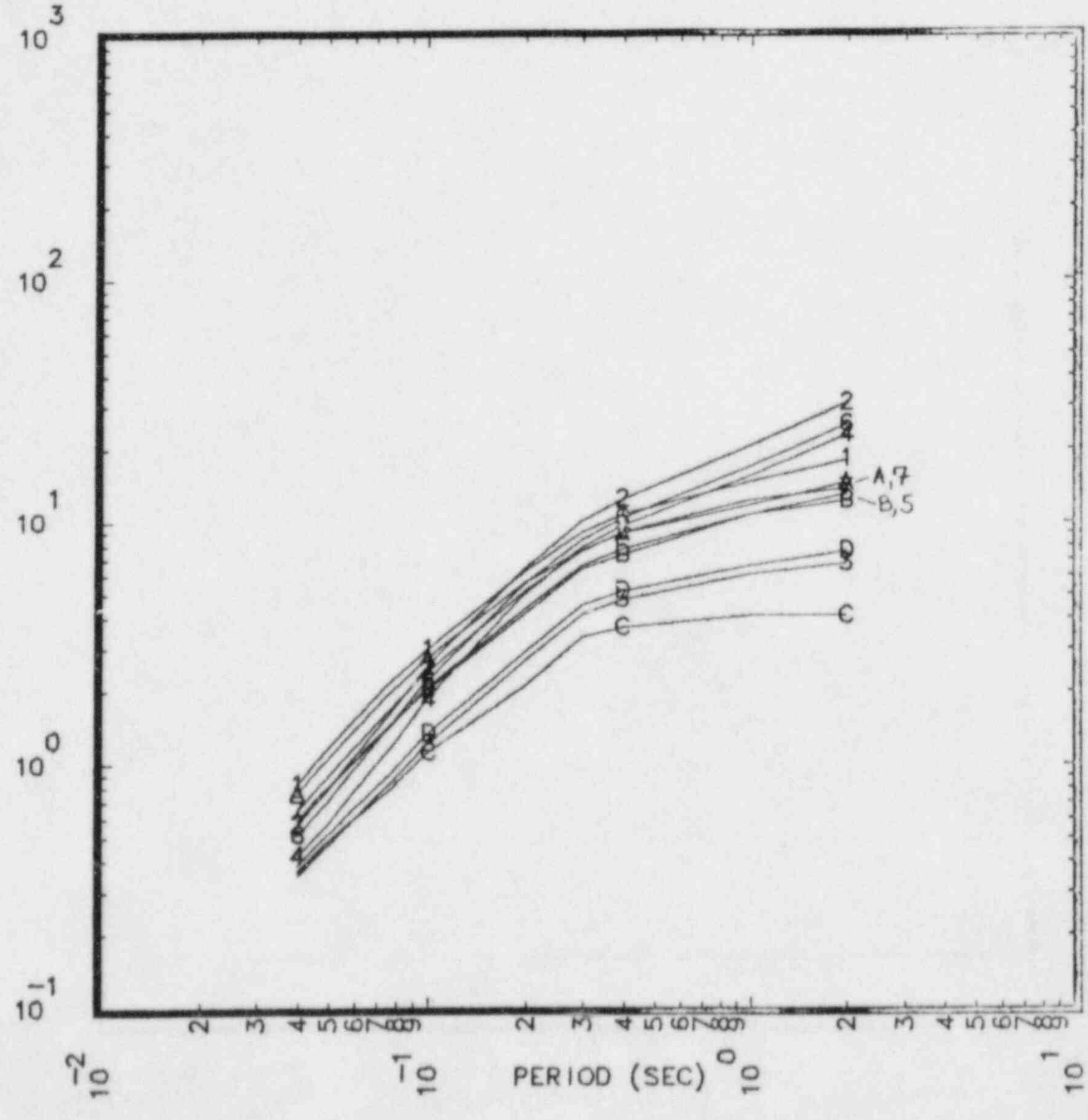


Figure RB-5

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

1000. YEARS RETURN PERIOD



RIVER BEND

Figure RB-6

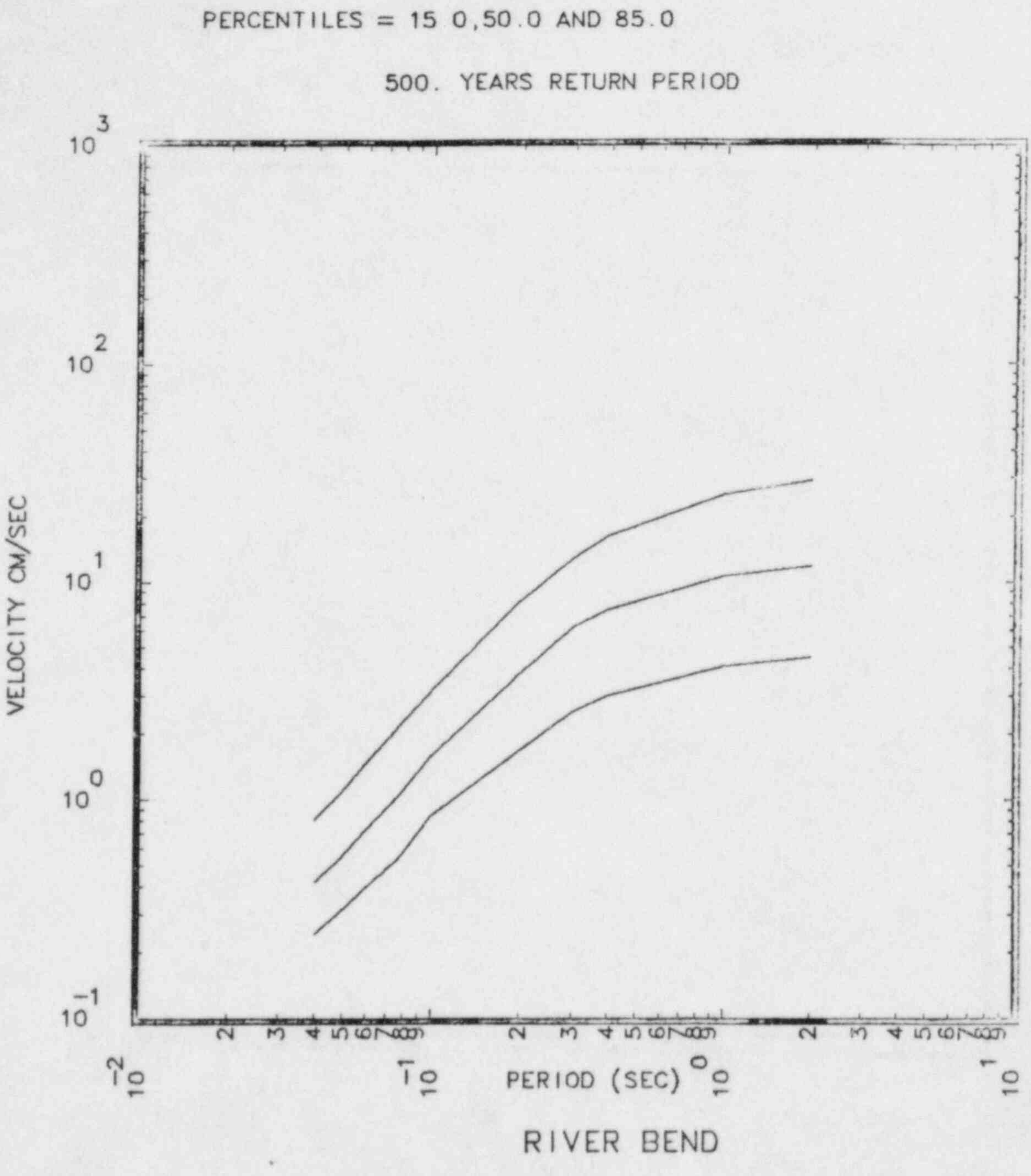


Figure RB-7 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 500 Year Return Period

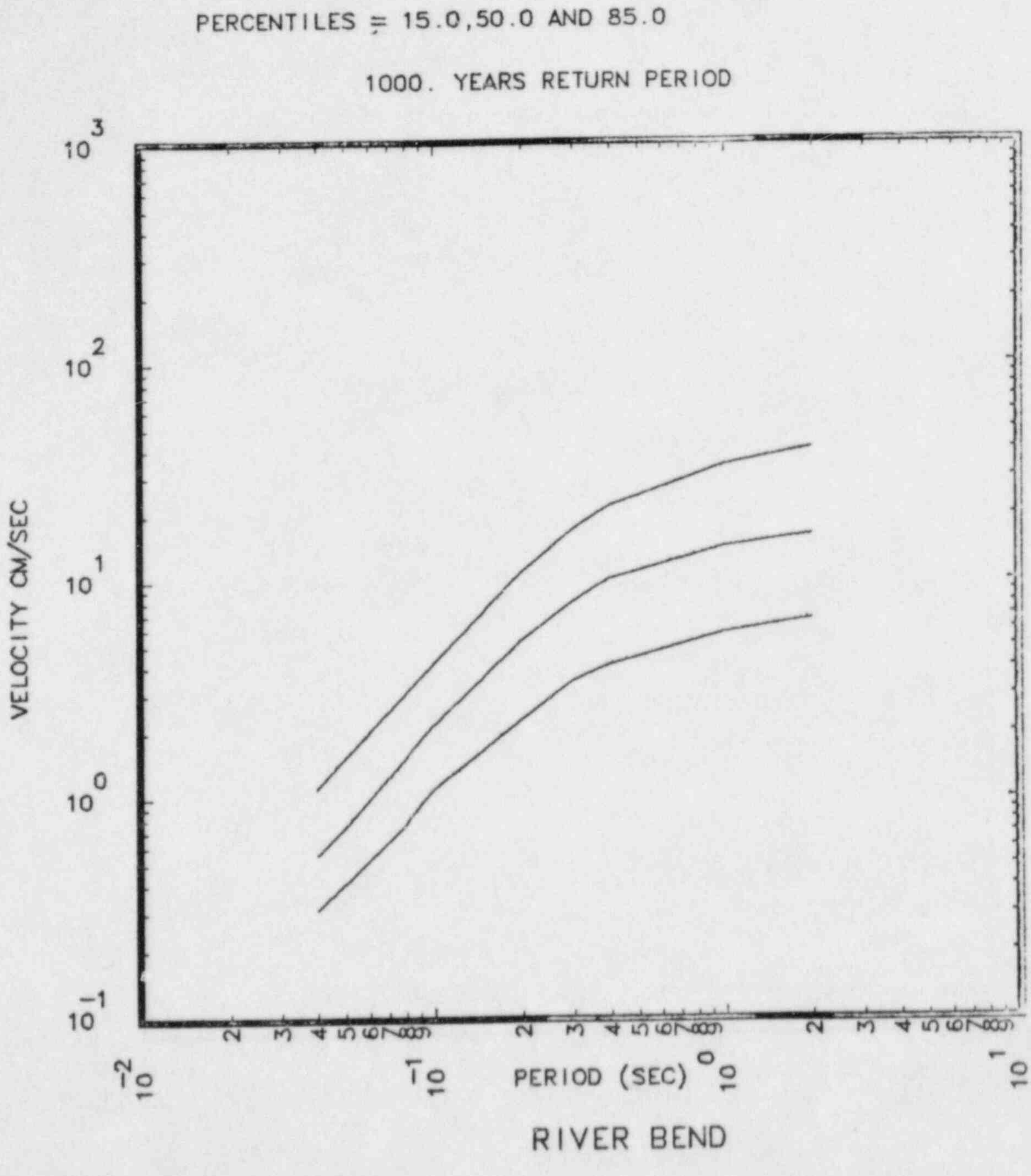


Figure RB-8 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 1000 Year Return Period

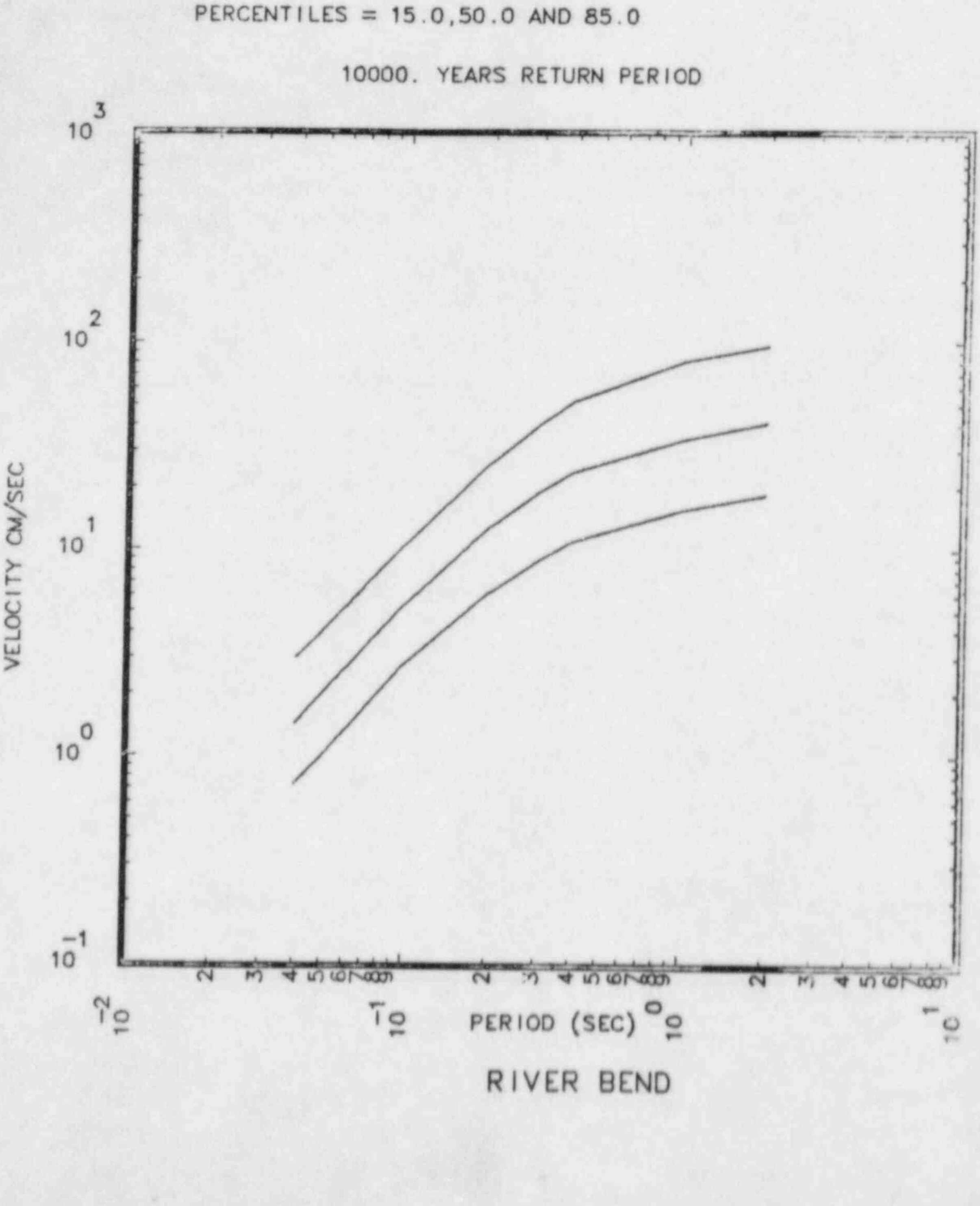


Figure RB-9 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 10,000 Year Return Period

4.3.4 Millstone (MI)

4.3.4.1 General

The Millstone site is located in the southeast portion of the north east region. It is classified as a rock site. This site is not located in the CZ for any of the experts' best estimate zonations. Because the scale of zonation is smaller for the northeast than for other regions in the experts' best estimate maps, we expect to have a wide distribution of zonation maps. On the other hand, the seismicity of this region is well constrained, in part because earthquake catalogues for New England have longer periods of complete recordings than for other regions, the uncertainty in the analysis for this site is not expected to be much larger than for other sites.

4.3.4.2 PGA Hazard Curves

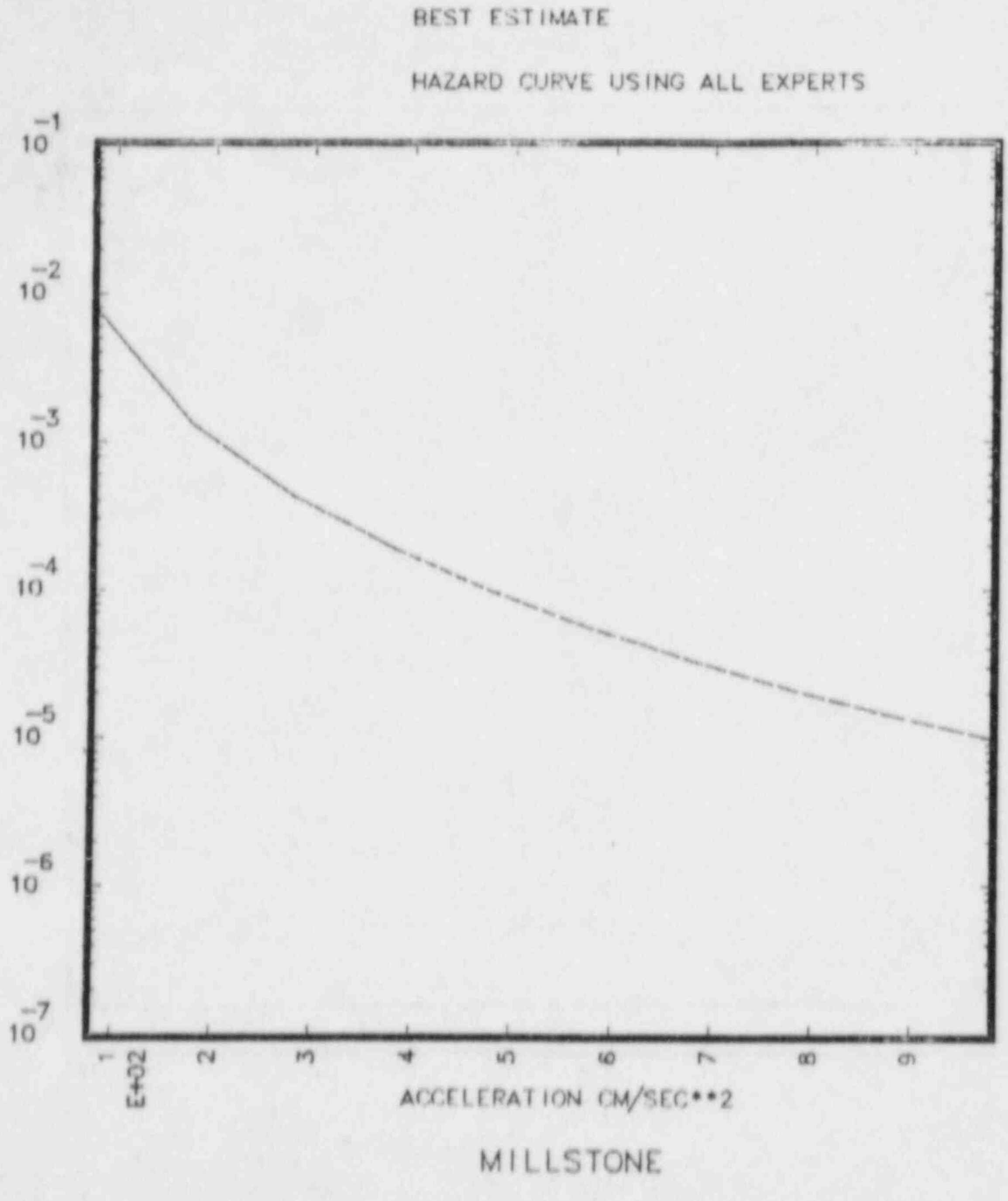
The BEHCs per seismicity expert in Fig. MI-2 display a level of diversity in the seismicity experts' opinions which is typical at low PGA and slightly higher at high PGA (a factor of 5 and a factor of 25, on the hazard, respectively). In the best estimate curves of Fig. MI-2, there appear to be two clusters of curves different from each other by a factor of approximately 3 to 5 on the hazard values. The BEHC for all experts fall in the middle of the two clusters.

The uncertainty analysis shows a moderate uncertainty in the hazard as the CPHC curves show in Fig. MI-3. However, the uncertainty at low PGA appears to be higher than typical (a factor of 20 between the 15th and the 85th percentile curves) and mostly lower than for other sites, at high PGA (a factor of 100 on the hazard between the 15th and the 85th percentiles).

4.3.4.3 Uniform Hazard Spectra

The narrow band of BEUHS, displayed in Fig. MI-4 and MI-5, shows a good agreement in the zonations and spectral ground motion models for the ranges of magnitudes considered. This is manifested by the uniform shape of BEUHS for all seismicity experts. The ratio between the highest curves (experts 6 and 7) and the lowest curves (experts 4 and 5) is approximately equal to 2, with the BEUHS combined over all experts falling roughly in the middle. In Fig. MI-7, MI-8 and MI-9, the CPUHS curves for the 50th and 85th percentiles as well as the BEUHS over all experts have similar shapes. The 15th percentile curves have a slightly different shape resulting in a lower pseudo velocity in the mid-period range of .2 to .6 seconds. Except in that period range, the uncertainty is moderate and comparable with results obtained for other sites. The ratio between the 15th and 85th percentile curves is approximately 4 at 0.4 second period, 5.5 at 4 second period and 4 at 2 second period for the 500 year return period curves.

The BEUHS is practically equal to the 50th percentile curves at low periods and lower by a factor of 1.2 at high periods, for the 500 and 1,000 return period curves of Fig. MI-7 and MI-8. The situation is reversed for the 10,000 year return period curves of Fig. MI-9. In this case, the BEUHS is equal to the 50th percentile curve in the high period ranges and lower by 25% in the low period range.



BEST ESTIMATE
HAZARD CURVE USING ALL EXPERTS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1 E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
MILLSTONE

Figure MI-1

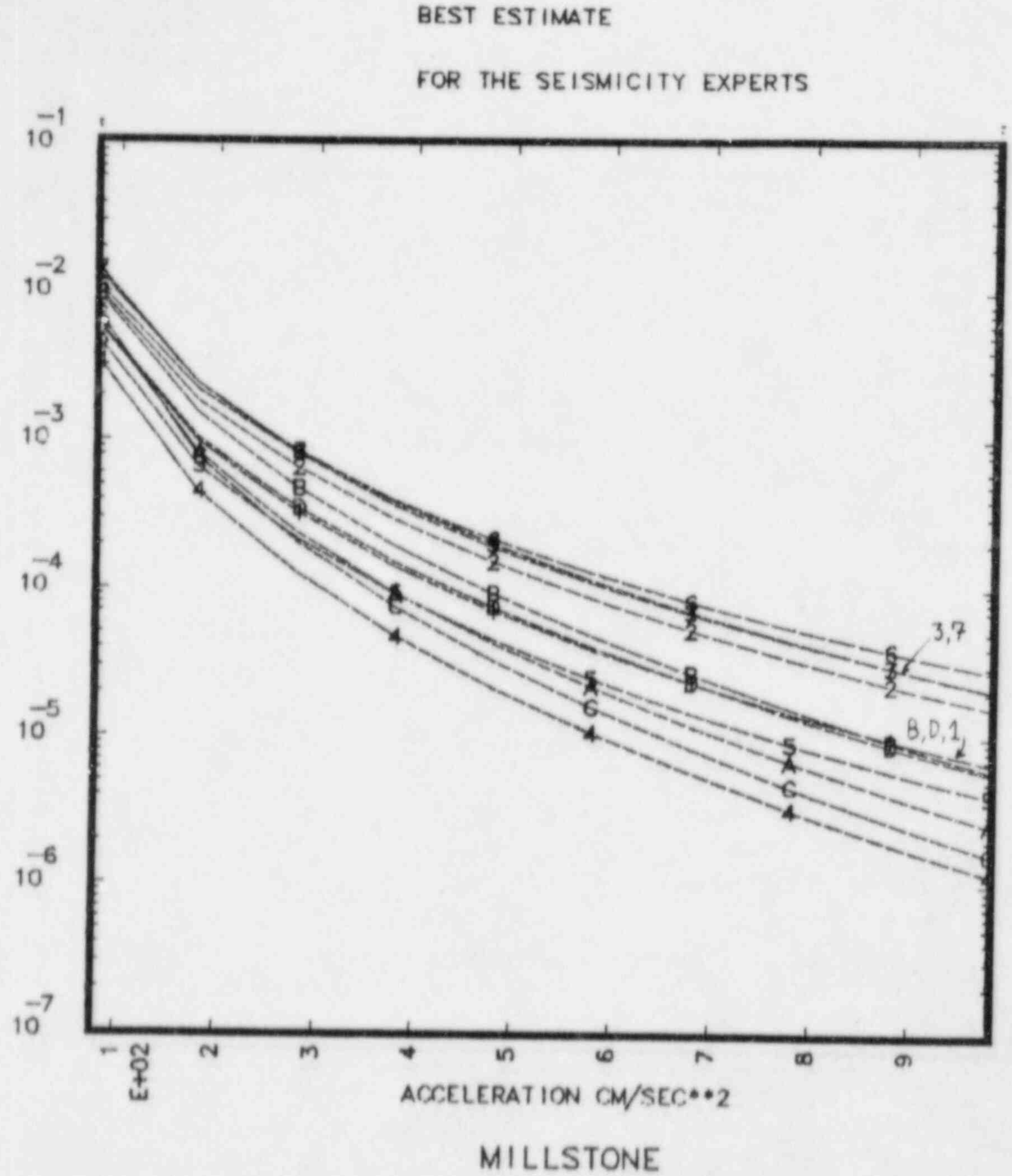


Figure MI-2 Best Estimate Hazard Curves (BEHC) per Seismicity Expert Combined Over All Ground Motion Experts.

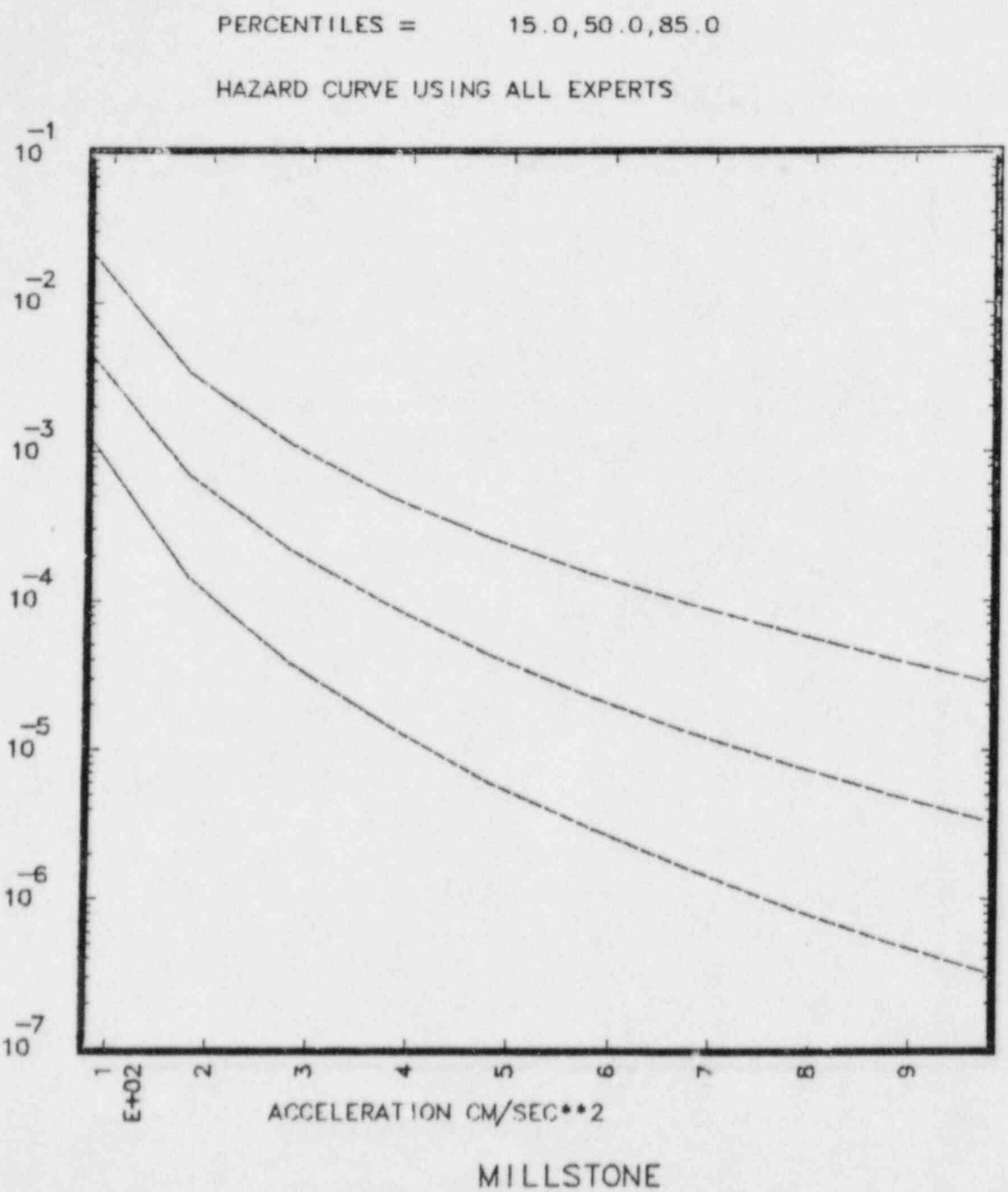
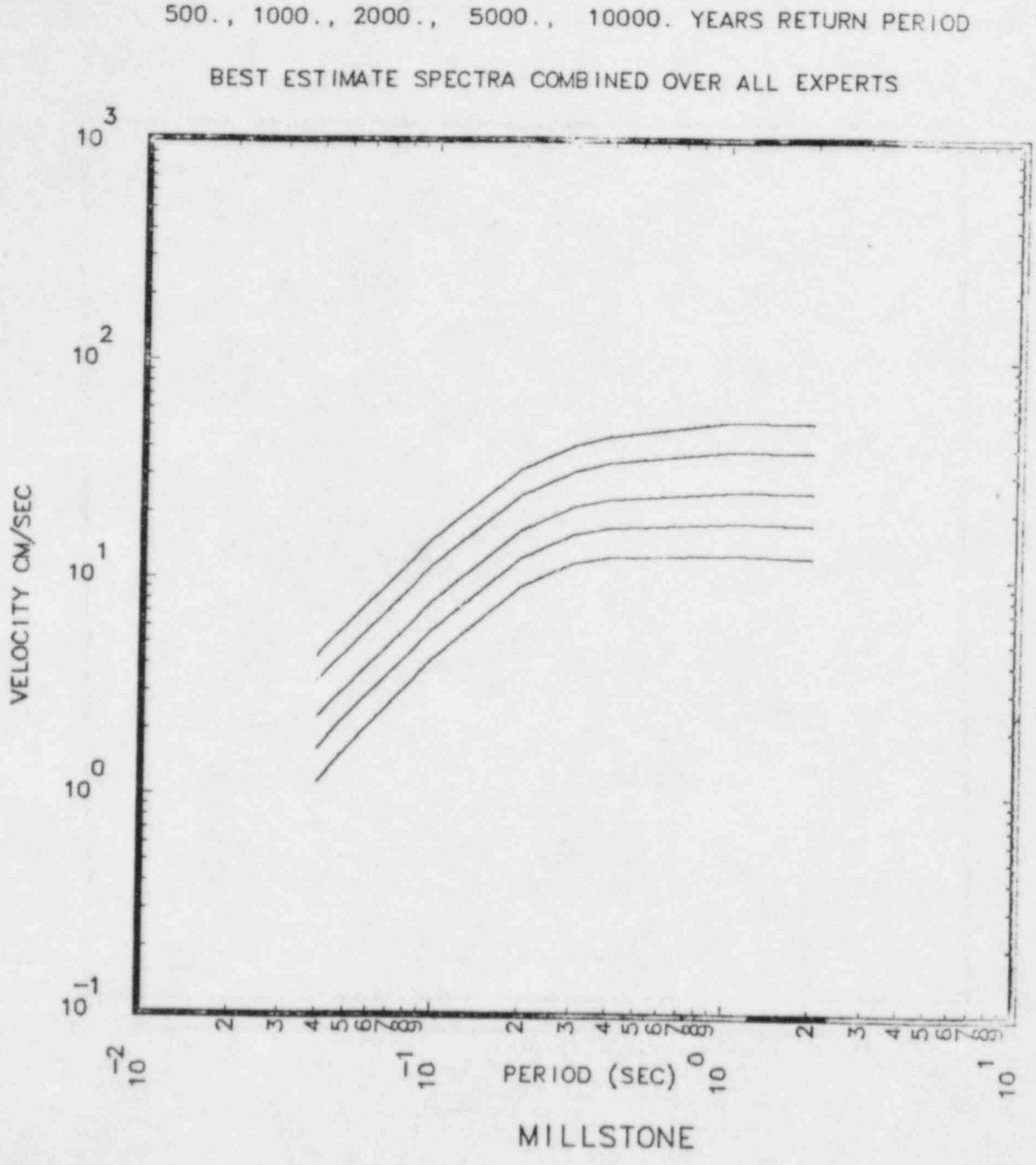


Figure MI-3 Constant Percentile Hazard Curves (CPHC) Over All Experts.



500., 1000., 2000., 5000., 10000. YEARS RETURN PERIOD
BEST ESTIMATE SPECTRA COMBINED OVER ALL EXPERTS
VELOCITY CM/SEC
PERIOD (SEC)
MILLSTONE

Figure MI-4

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

500. YEARS RETURN PERIOD

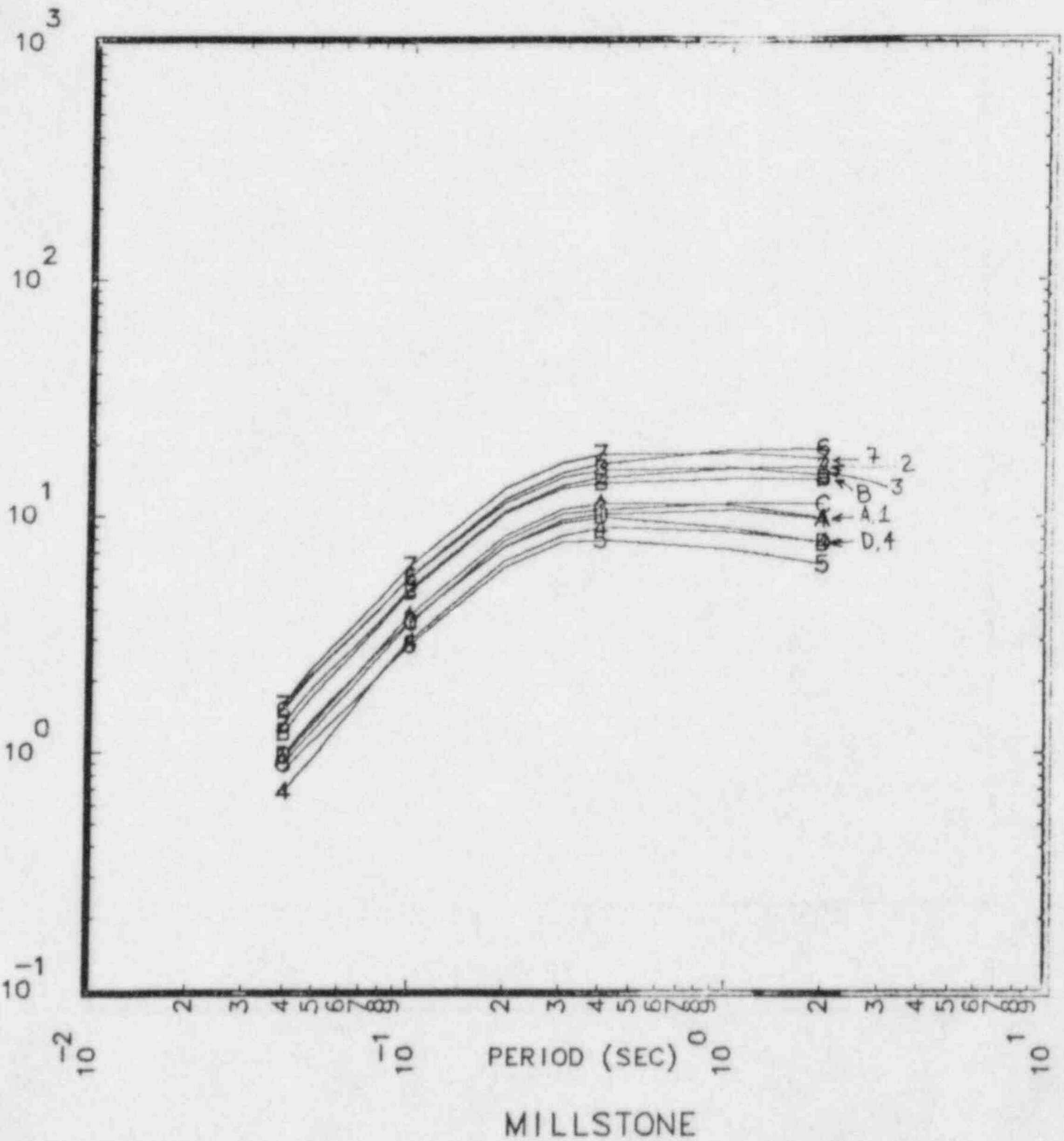


Figure MI-5

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

1000. YEARS RETURN PERIOD

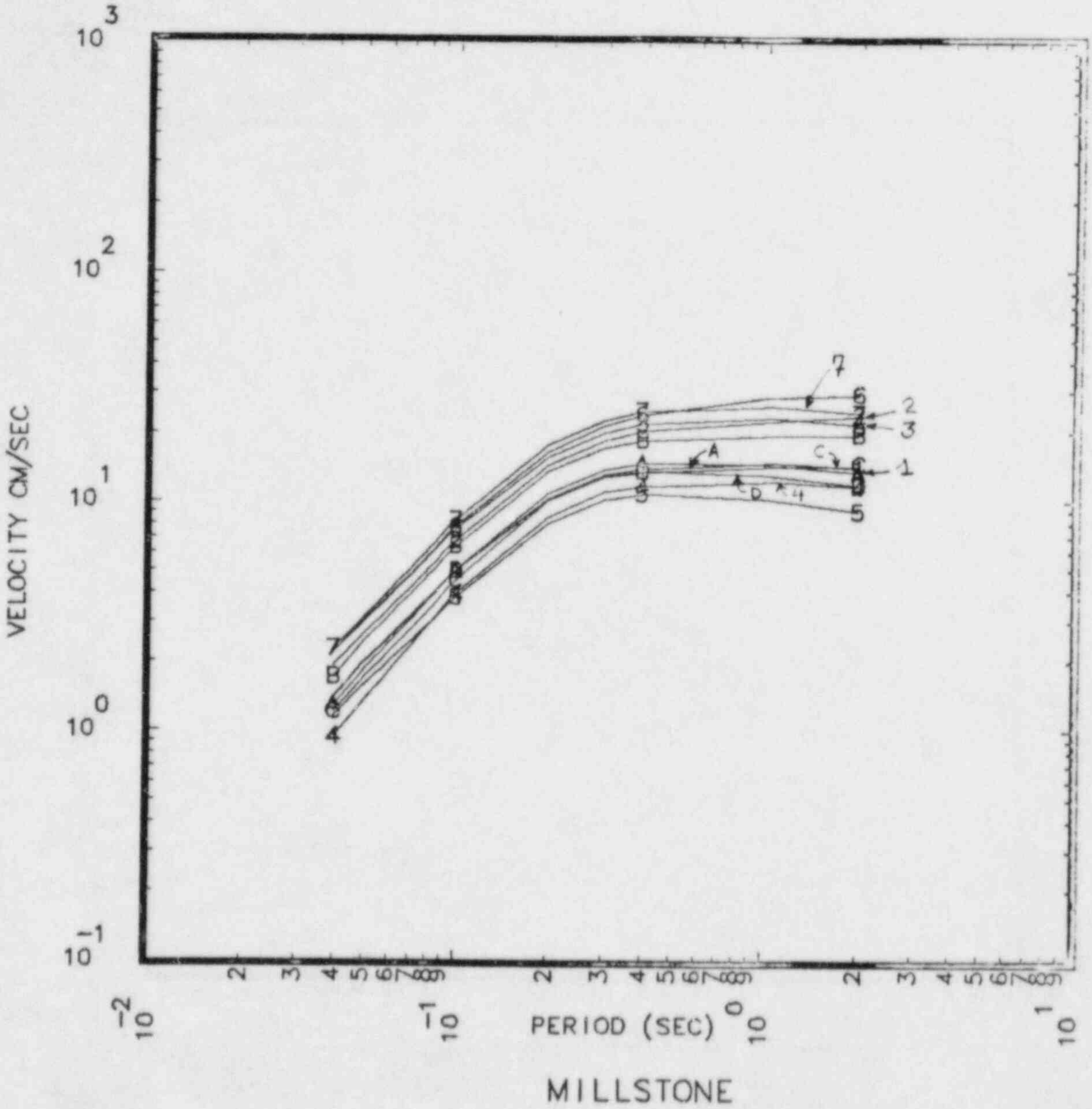


Figure MI-6

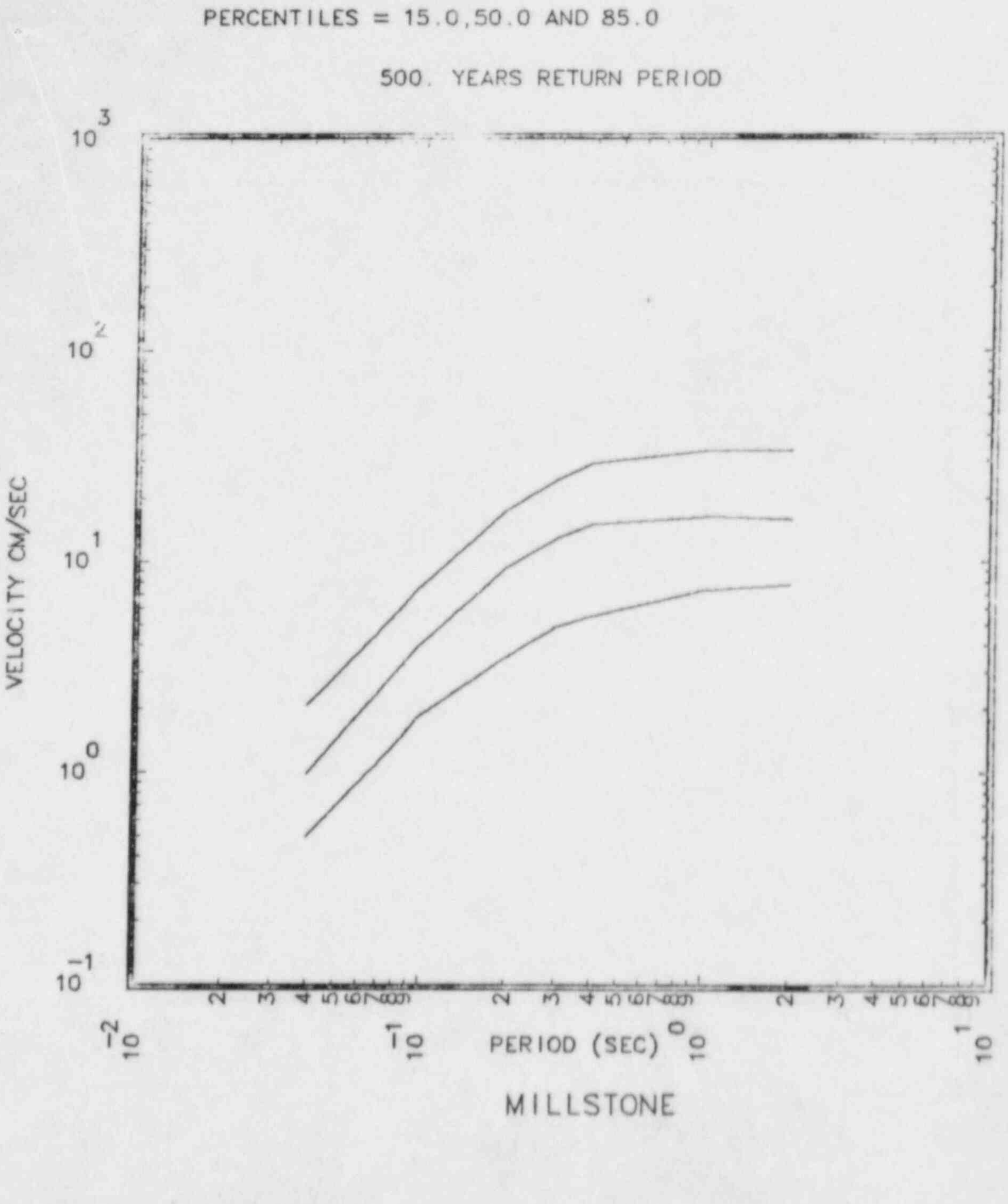


Figure MI-7 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 500 Year Return Period

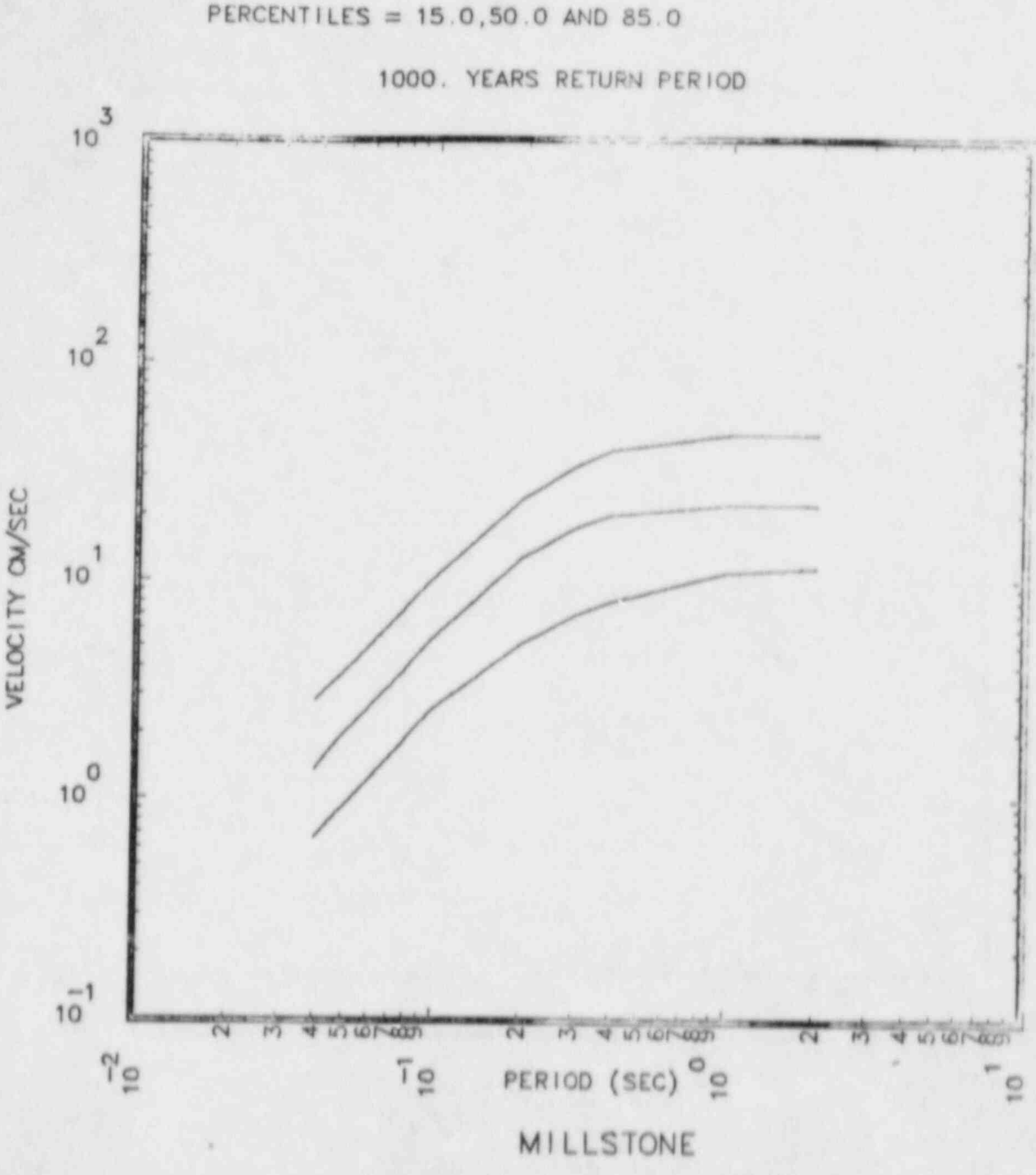


Figure MI-8 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 1000 Year Return Period

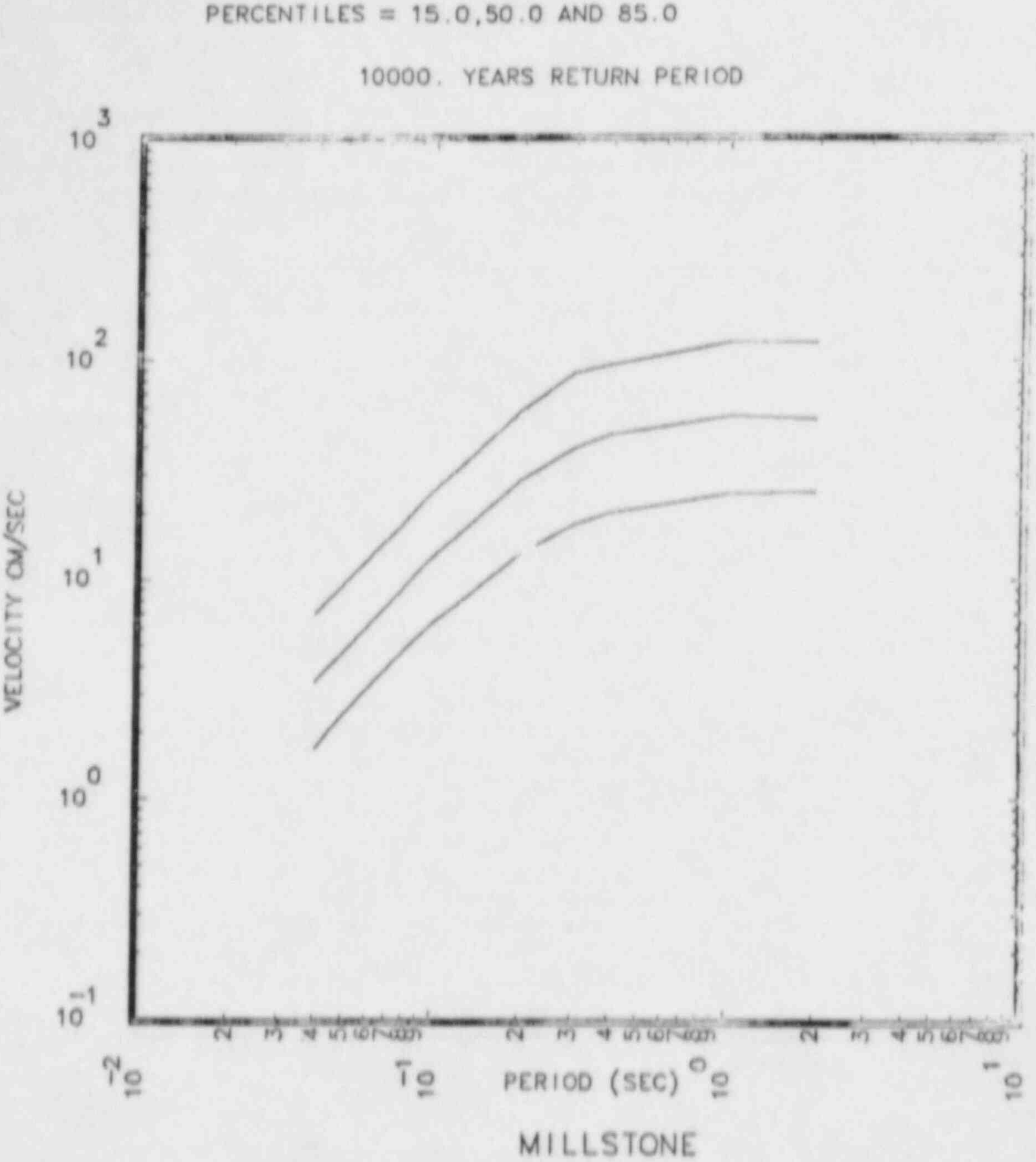


Figure MI-9 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 10,000 Year Return Period

4.3.5 Limerick (LI)

4.3.5.1 General

The Limerick site is located in the northern part of the southeast region of the EUS at the boundary with the northeast and northcentral regions. It is classified as a rock site. Only in the case of seismicity Expert 13 does the site fall into the CZ for which the best estimate upper magnitude cutoff is relatively low (6.3) as well as the a value (4.6) (relative to its size).

4.3.5.2 PGA Hazard Curves

The BEHC is presented in Fig. LI1 for the combination overall experts. Fig. LI2 shows the BEHC's for individual seismicity experts. The diversity of opinions among experts appears to be on the high side. However, the BEHC for Expert 13 (D on Fig. LI2) clearly lies outside of the cluster of results for the other experts. This is due to the fact that, as mentioned above, the CZ, which has relatively low seismicity for Expert 13, is the dominant zone. The general shape of the BEHC is very similar for all experts except for Experts 3 and 5 which are more convex than the average. This is due to the relatively high magnitude cutoff, combined with average to low a values for the dominant zones for these experts (Zone 6 for Expert 3 and Zone 1 for Expert 5). In the case of Expert 5, it is interesting to note that Zone 7 is not a dominant contributor to the hazard since its probability of existence is .3. As a result, it does not appear on the most highly weighted maps.

The CPHC is presented in Fig. LI3 for all seismicity experts combined together. The dominant part of the dispersion appears to be contributed by the large dispersion in the zonation maps for this part of the EUS. The 15th to 50th and 50th to 85th percentile curves vary by approximately one order of magnitude at 500 cm/sec^2, slightly less at low acceleration levels and slightly more around 1 g. It is interesting to note that the 50th percentile HC in Fig. LI3 is significantly lower (approximately half an order of magnitude in the value of the probability) than the BEHC of Fig. LI1. This is a manifestation of the skewness of the probability distributions of the parameters in the predominant zones, including the distribution of maps and of ground motion models. It is also due, in part, to the fact that the combination over all experts is an arithmetic averaging process and by opposition, the constant percentile curves are obtained by interpolations on a distribution on a logarithmic scale.

4.3.5.3 Uniform Hazard Spectra

The BEUHS is presented in Fig. LI4 combined over all seismicity experts for the five return periods selected. The general shape of the spectra is close to the Newmark-Hall model with some effect of the Trifunac-Anderson model. The dispersion among seismicity experts appears to be low (typically less than one order of magnitude of velocity), as shown on Fig. LI5 and LI6 for 500 years and 1,000 years return periods. For the same reasons as explained for the PGA Hazard Curves, the spectrum-hazard associated with Expert 13 is significantly lower than the rest of the experts. Expert 6 input leads also to the highest results in both cases of PGA and spectra. The three CPUHS for 500 years return period, Fig. LI7, have the same general shape as the BEUHS and the 15th-85th range is very close to the range of variation in the BEUHS for all the experts of Fig. LI5. The 50th percentile UHS appears to be only slightly higher than the BEUHS for the higher periods of .3 to 2 sec. and slightly lower in the lower period range. Figures LI8 and LI9 represent the 1000 year and 10,000 year return period CPUHS, for which the same comments as for the 500 year case apply.

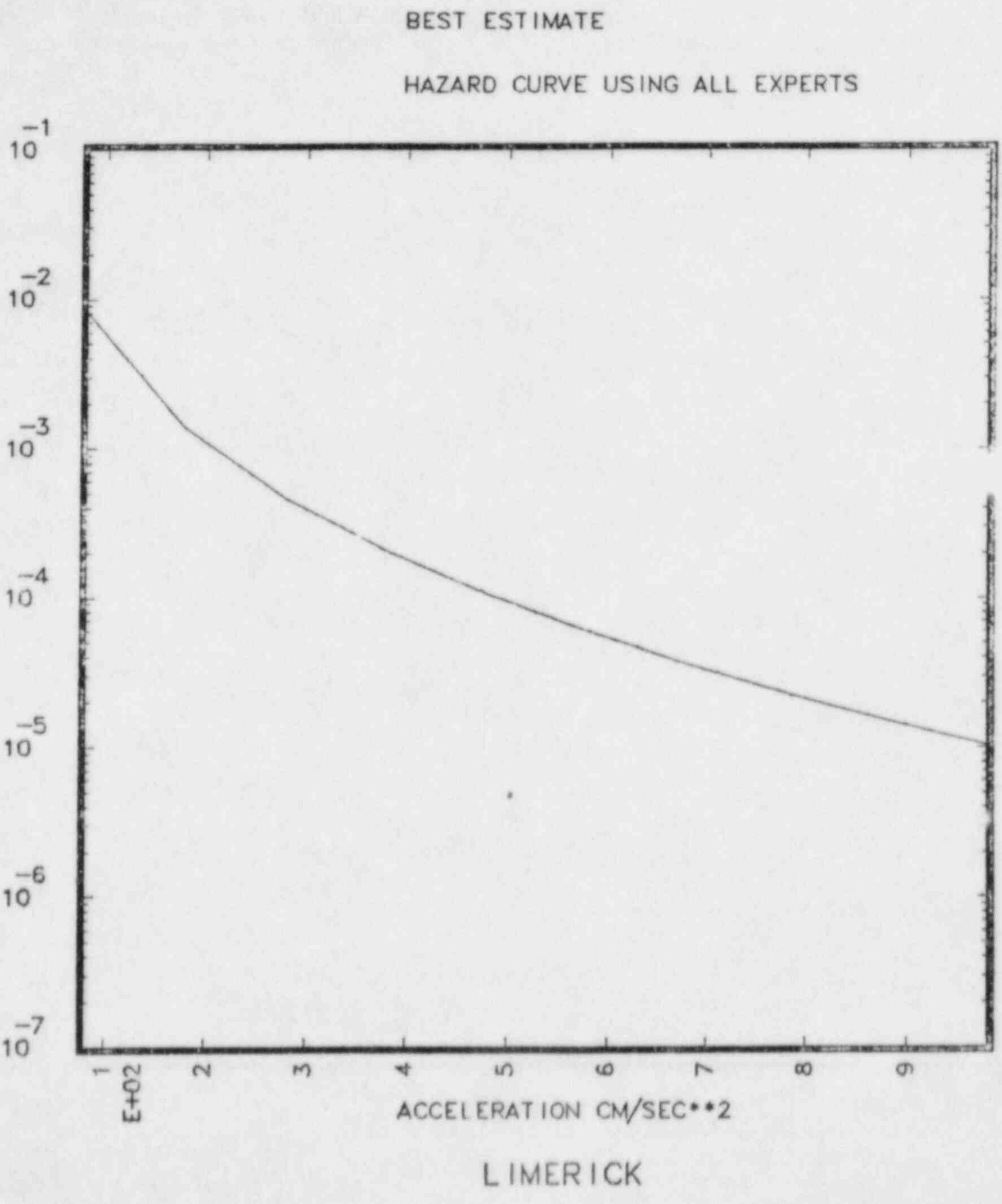

BEST ESTIMATE
HAZARD CURVE USING ALL EXPERTS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
LIMERICK

Figure LI.1

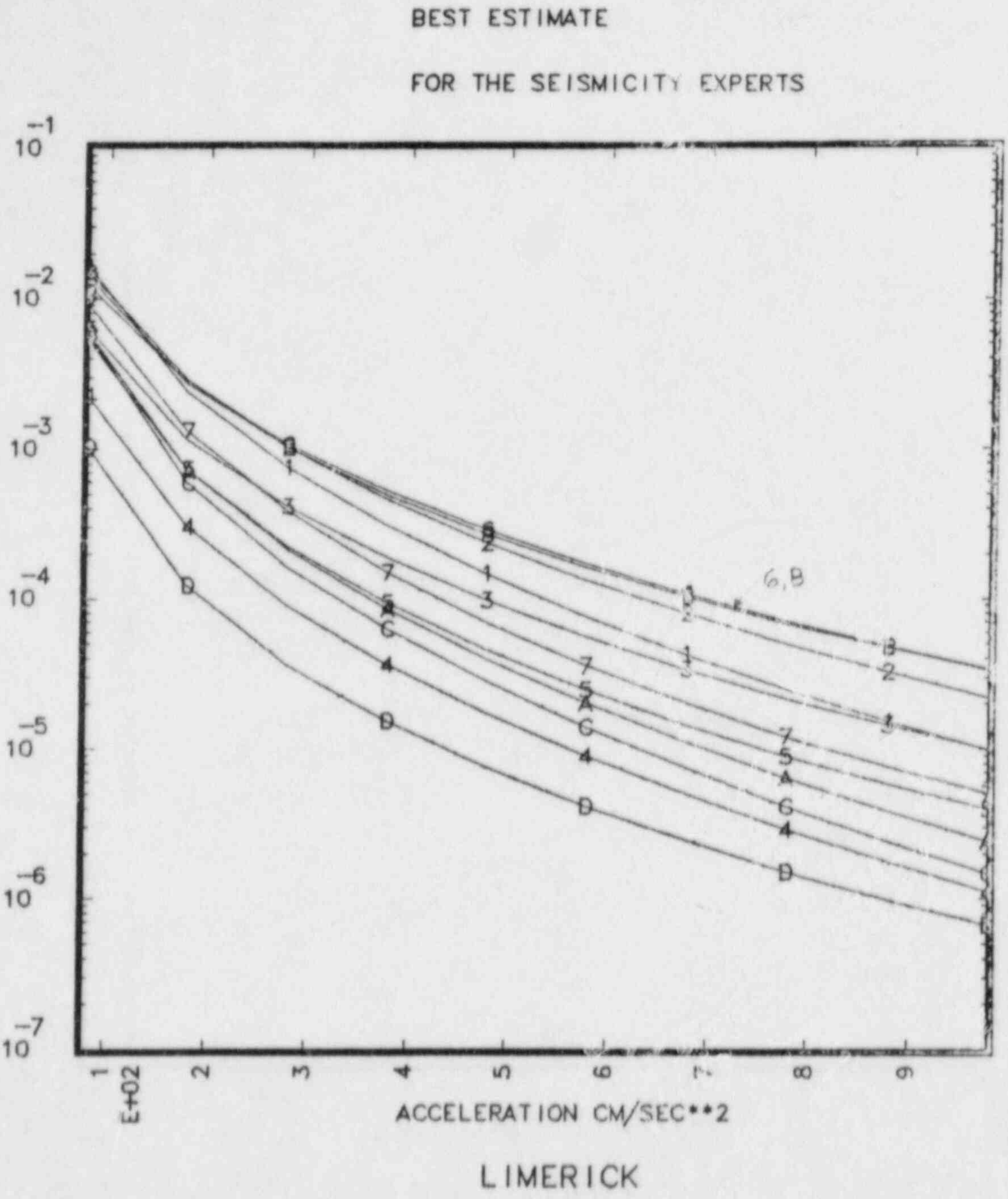


Figure LI.2 Best Estimate-Hazard Curves (BEHC) per Seismicity Expert Combined Over all Ground Motion Experts.

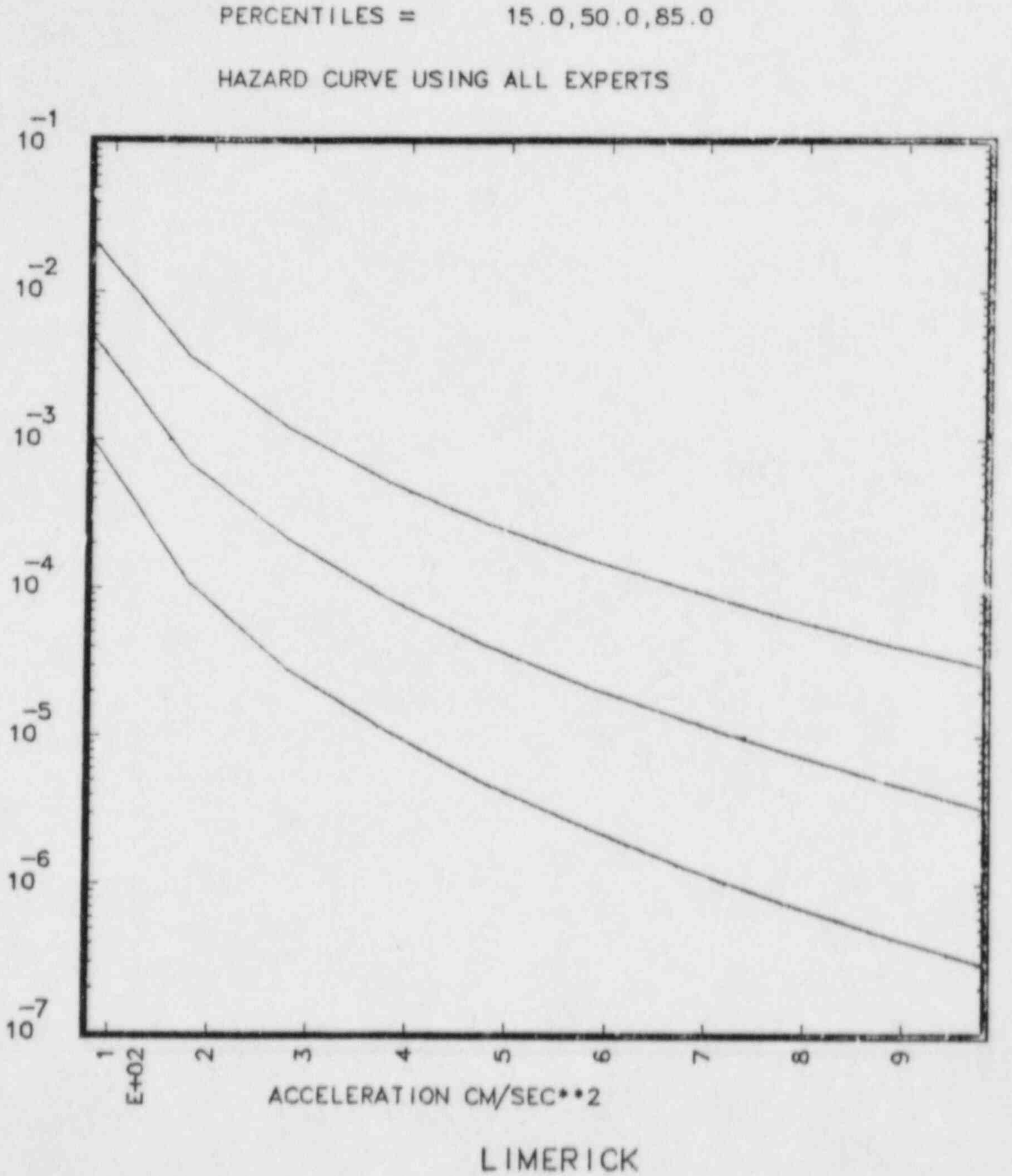


Figure LI.3 Constant Percentile Hazard Curves (CPHC) Over All Experts.

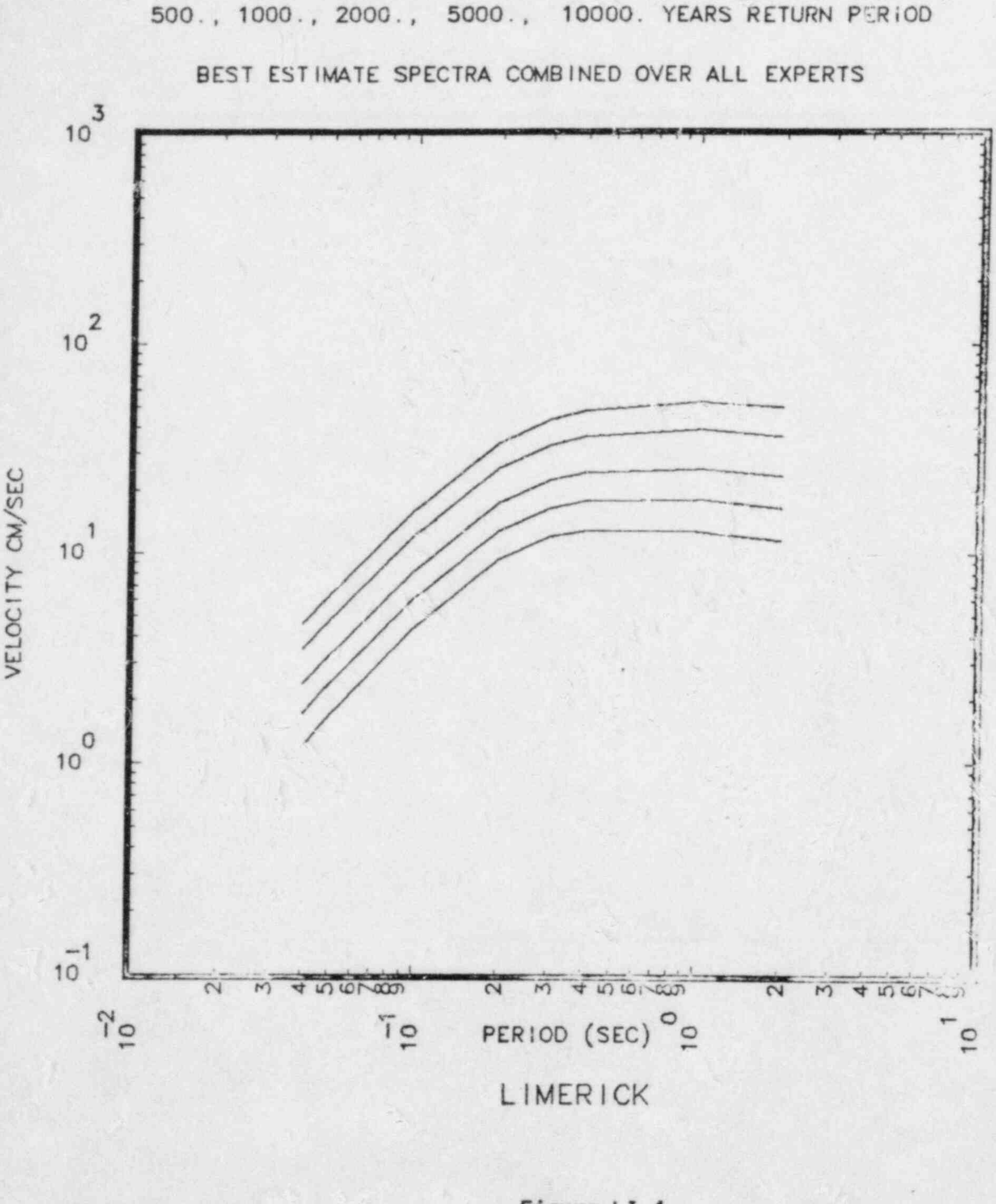
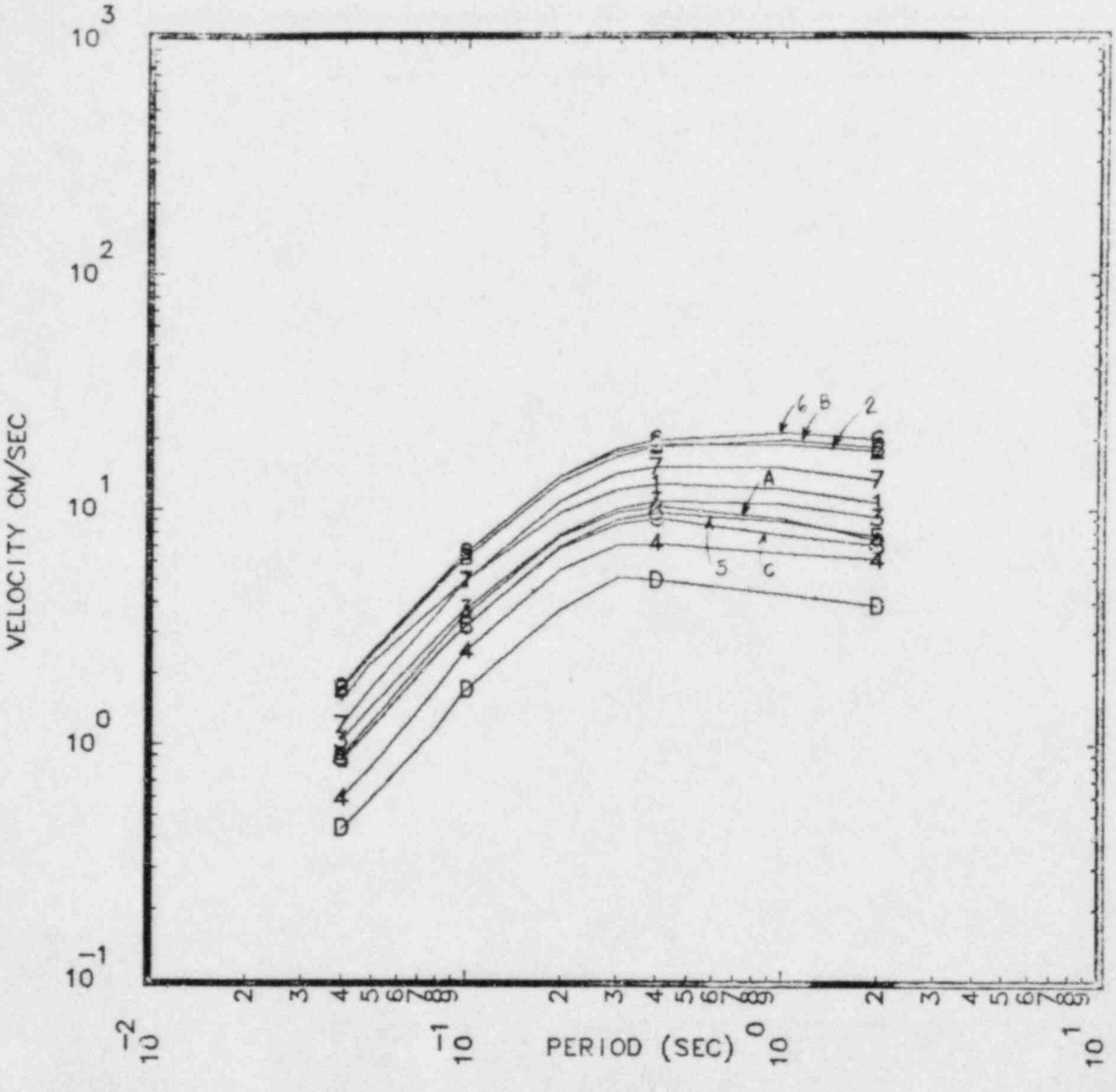

500., 1000., 2000., 5000., 10000. YEARS RETURN PERIOD
BEST ESTIMATE SPECTRA COMBINED OVER ALL EXPERTS
VELOCITY CM/SEC
PERIOD (SEC)
LIMERICK

Figure LI.4

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

500. YEARS RETURN PERIOD



LIMERICK

Figure LI.5

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

1000. YEARS RETURN PERIOD

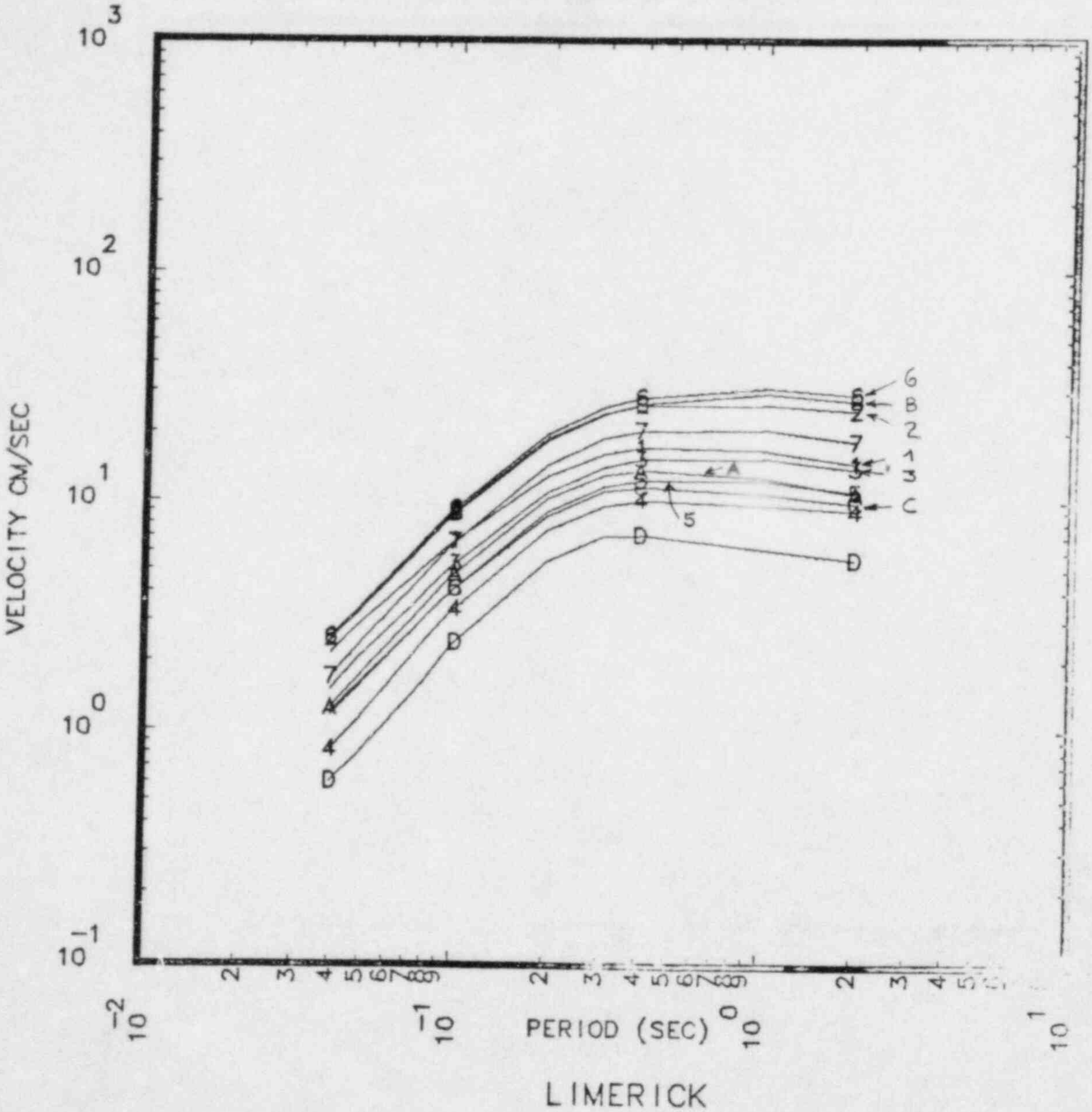


Figure LI.6

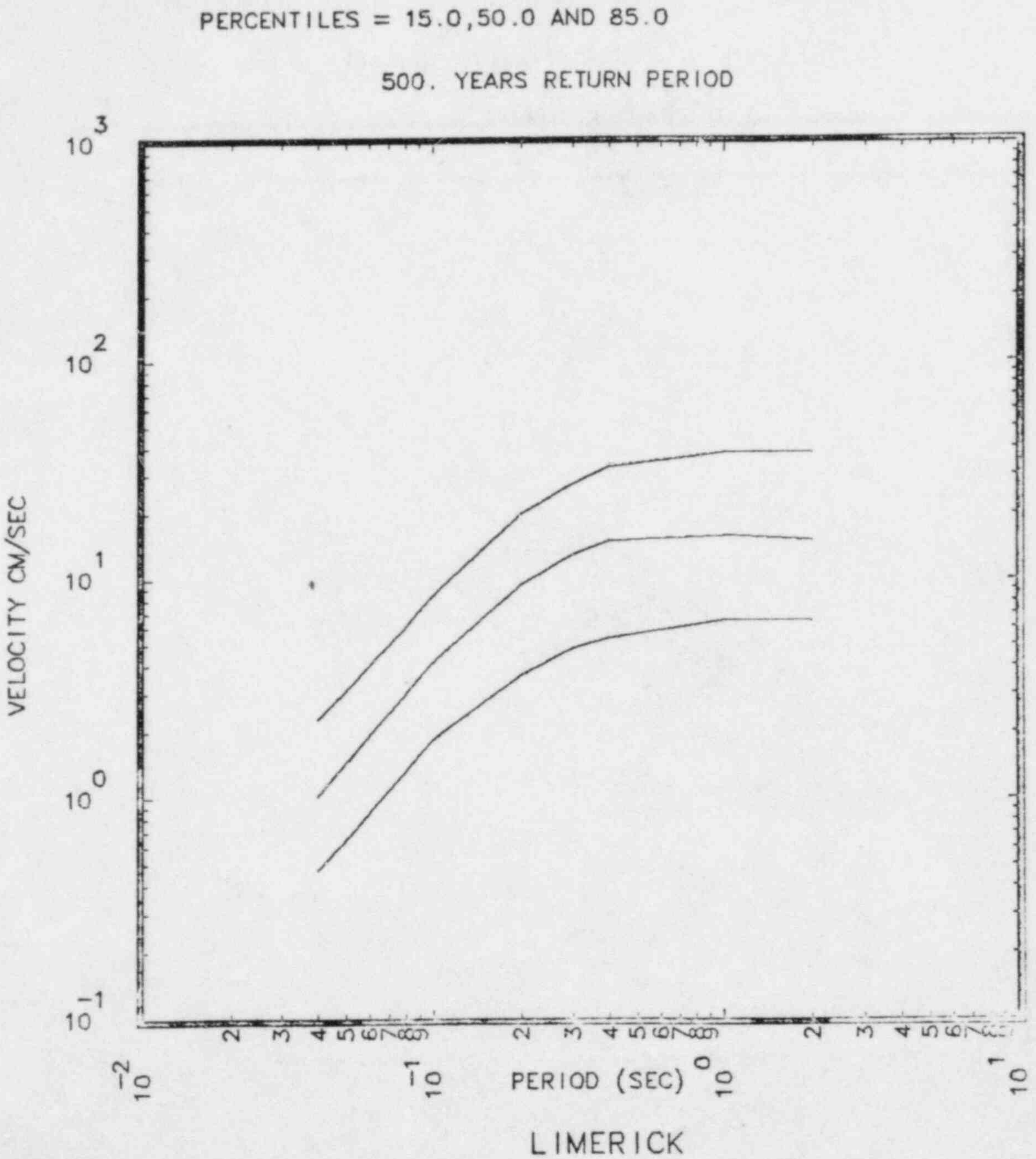


Figure LI.7 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 500 Year Return Period.

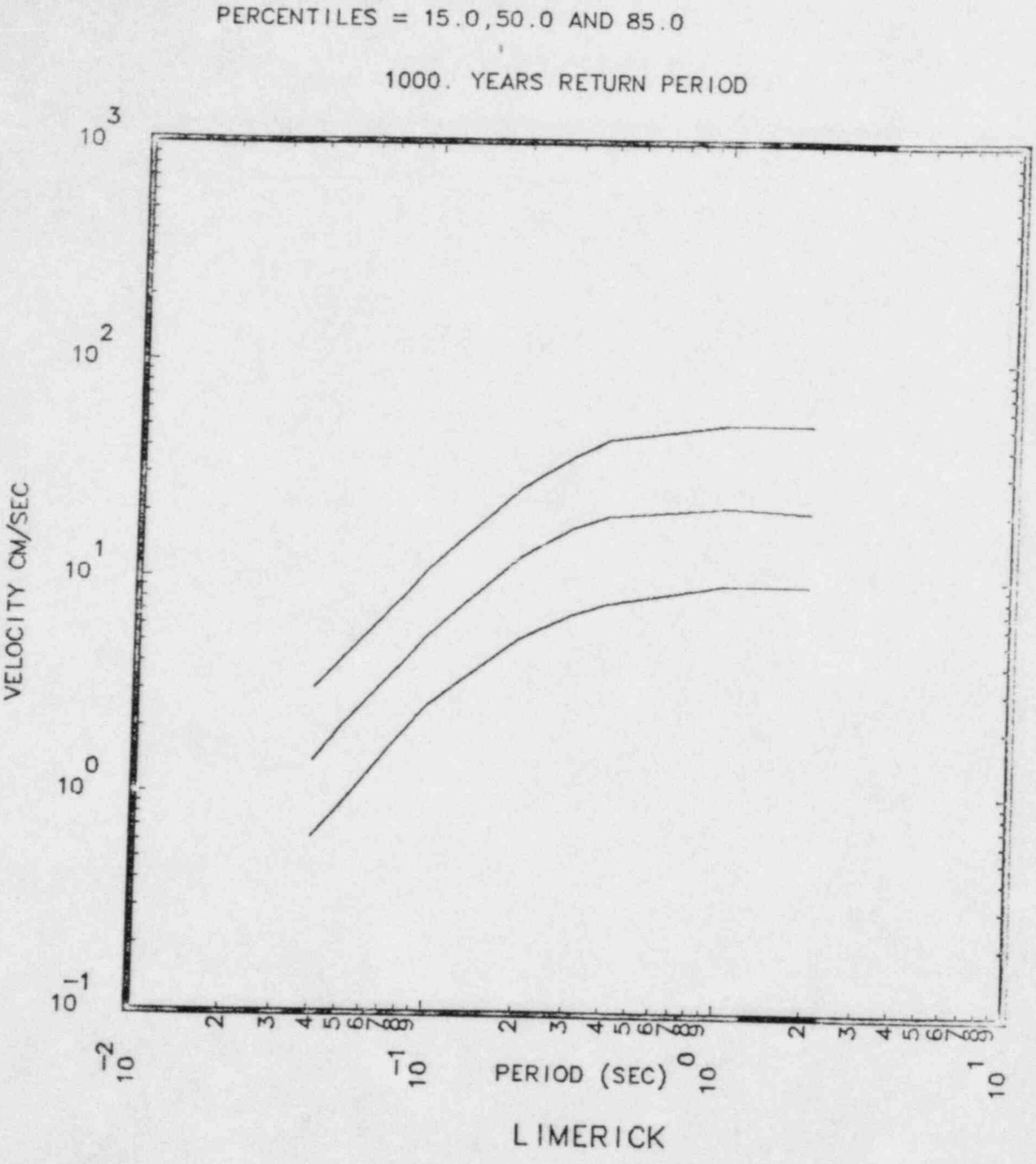


Figure LI.8 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 1000 Year Return Period.

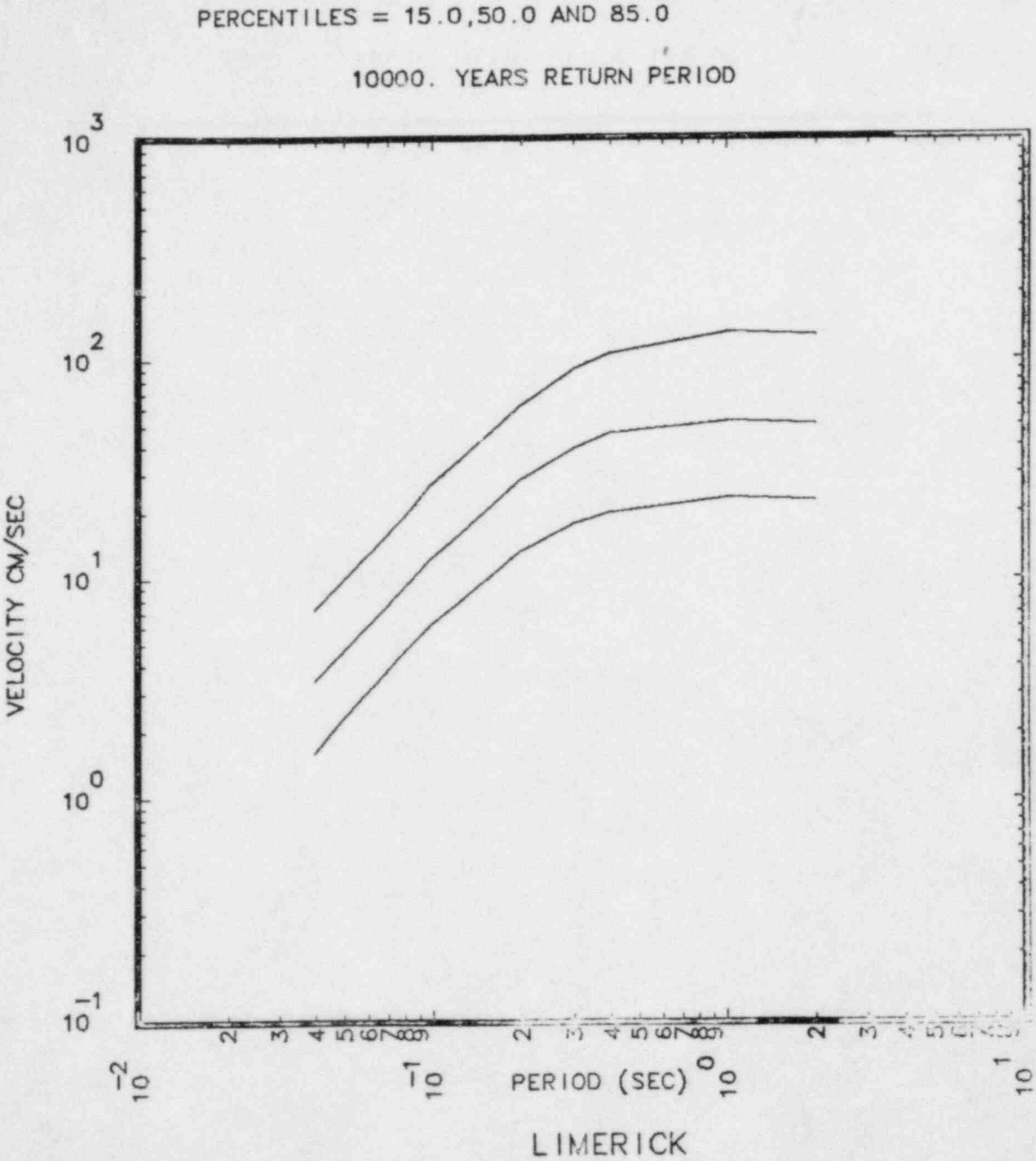


Figure LI.9 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 10,000 Year Return Period.

4.3.6 La Crosse (LC)

4.3.6.1 General

The La Crosse site is located in the middle of the north central region of the EUS. It is classified as a soil site. Only for seismicity experts 4 and 7 does the site fall in a zone other than the CZ. Therefore, the hazard at this site depends primarily on the seismicity parameters of the CZ, as shown in Table 4.1.

4.3.6.2 PGA Hazard Curves

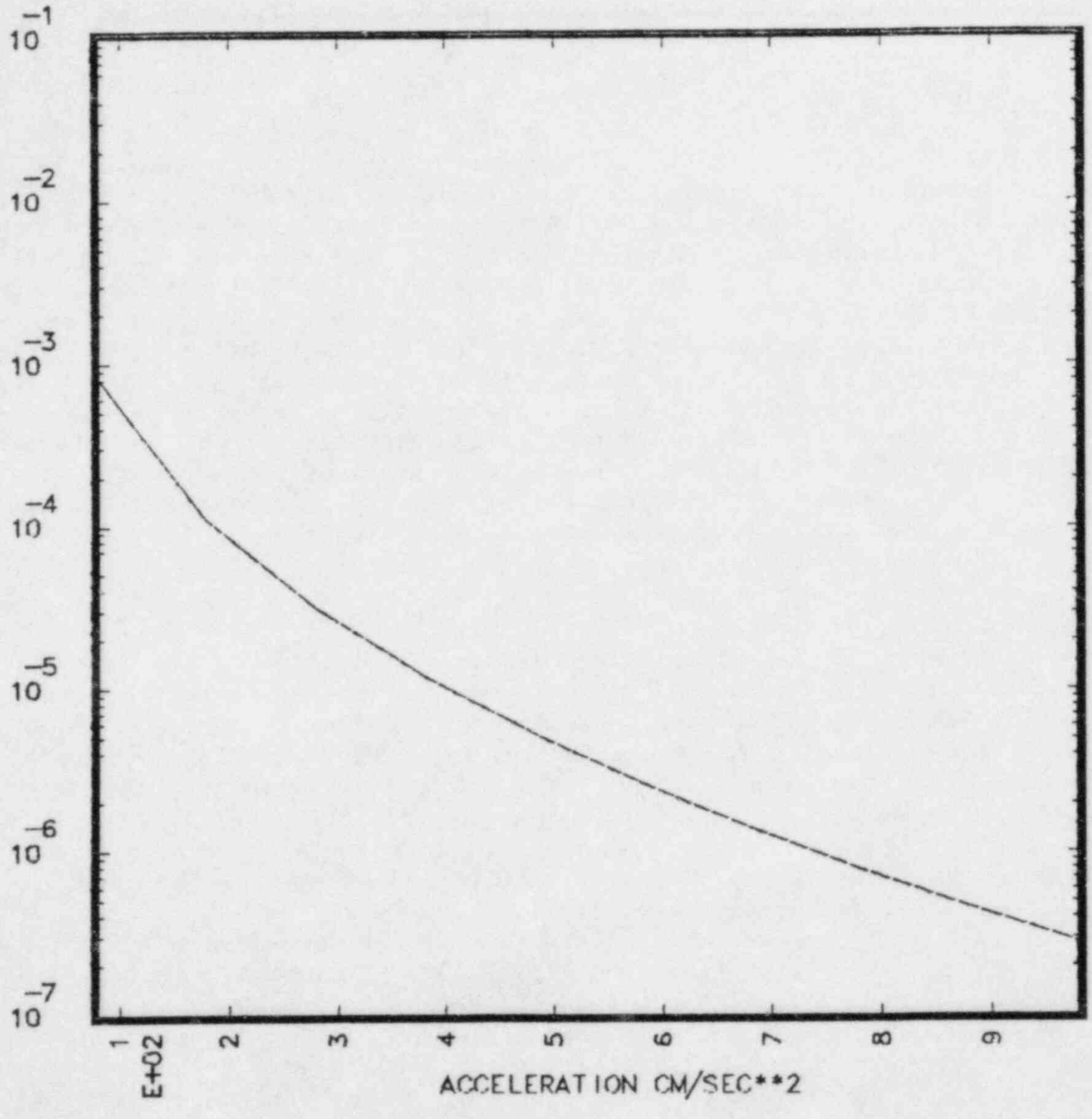
The BEHC is presented in Fig. LC1 for the combination over all experts. Figure LC2 is for the BEHC by individual seismicity expert. In spite of the fact that the hazard at this site is strongly dominated by the CZ, the best estimate results are well constrained within a rather small band, as shown in Fig. LC2. The CPHC, as shown in Fig. LC3, is not as well constrained and exhibit a rather large spread. This large dispersion comes in part from the large uncertainty in the parameters of the CZ. It is also, in part, contributed by the large spread of the distribution of the zonation maps. Since the site is located in most cases in a large dominant zone, any alternate map generates results which are significantly different from the best estimate. Although the BEHC of Fig. LC1 lies slightly higher than the 50th percentile of Fig. LC3, it does not appear to be as skewed as in the Limerick case. Also, note that the BEHC of Fig. LC1 lies approximately in the middle of the cluster of curves of Fig. LC2, thus showing that no particular seismicity expert dominates the results.

4.3.6.3 Uniform Hazard Spectra

The BEUHS is presented in Fig. LC4, combined over all experts for the five return periods selected. The final combined spectrum appears to be a combination of several spectral shapes significantly different from one another, as shown in Fig. LC5 for the BEUHS per seismicity experts. Expert's 5, 2 and 6 BEUHS, shown in Fig. LC5, do not present a plateau of velocity at high periods (low frequencies) when, by opposition, all the other expert's BEUHS present this plateau at periods above .3 to 1 sec. This phenomenon is due to the relatively high upper magnitude cutoff used by experts 5, 2 and 6 for the CZ (expert's 2 magnitude cutoff is 7.3,, expert's 5 is 6.0 and expert's 6 is 6.5). It is remarkable, however, that the spread in results from all the seismicity experts (shown on Fig. LC5) is very small, especially at low periods. As in the case of the PGA, the bounds on the UHS shown in Figs. LC7, LC8 and LC9 do not appear as constrained as the low dispersion on the best estimate results between seismicity experts would have led us to anticipate. It is believed that the same arguments as for the PGA apply here too.

BEST ESTIMATE

HAZARD CURVE USING ALL EXPERTS



LA CROSSE

Figure LC.1

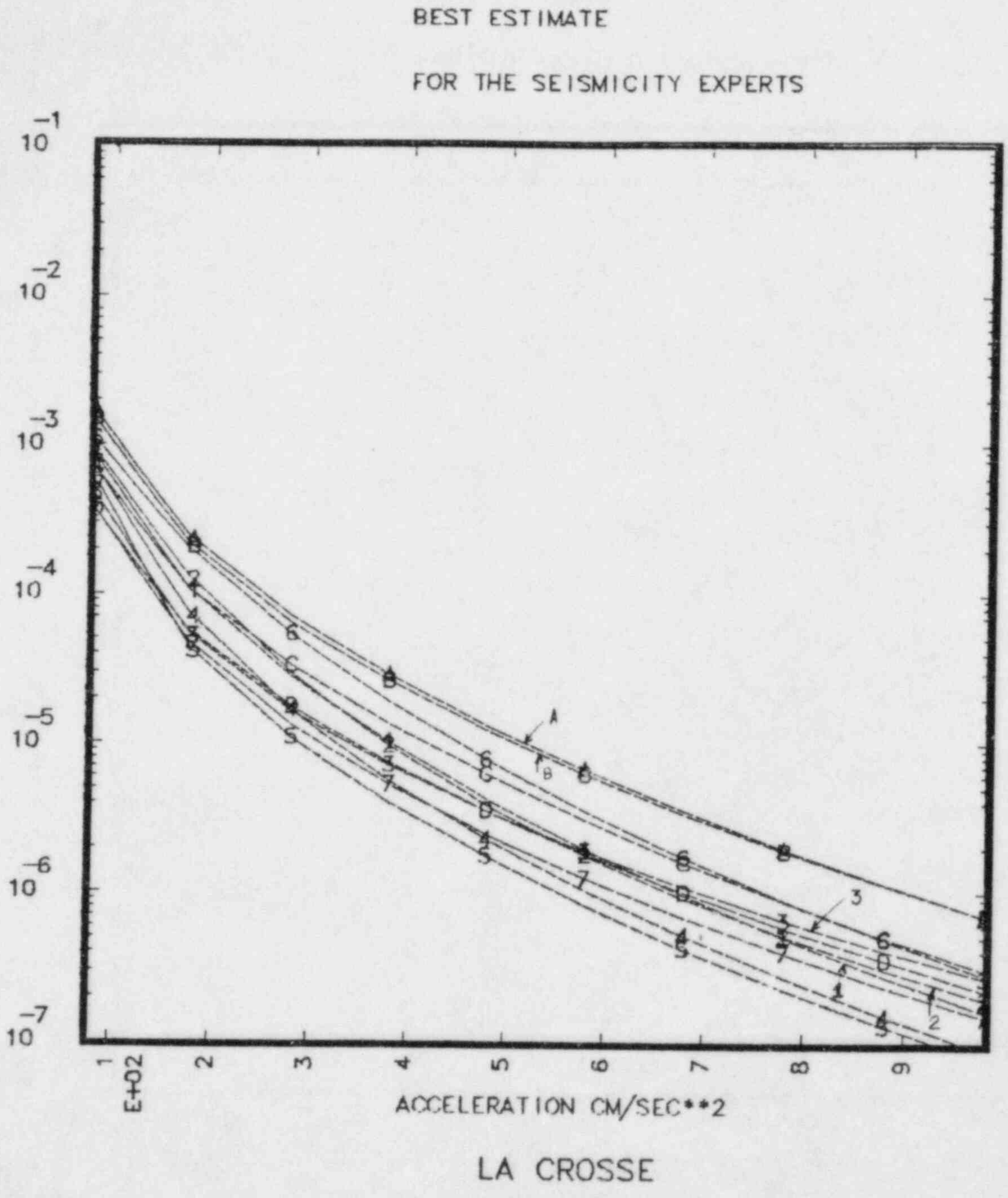


Figure LC.2 Best Estimate Hazard Curves (BEHC) per Seismicity Expert Combined Over All Ground Motion Experts.

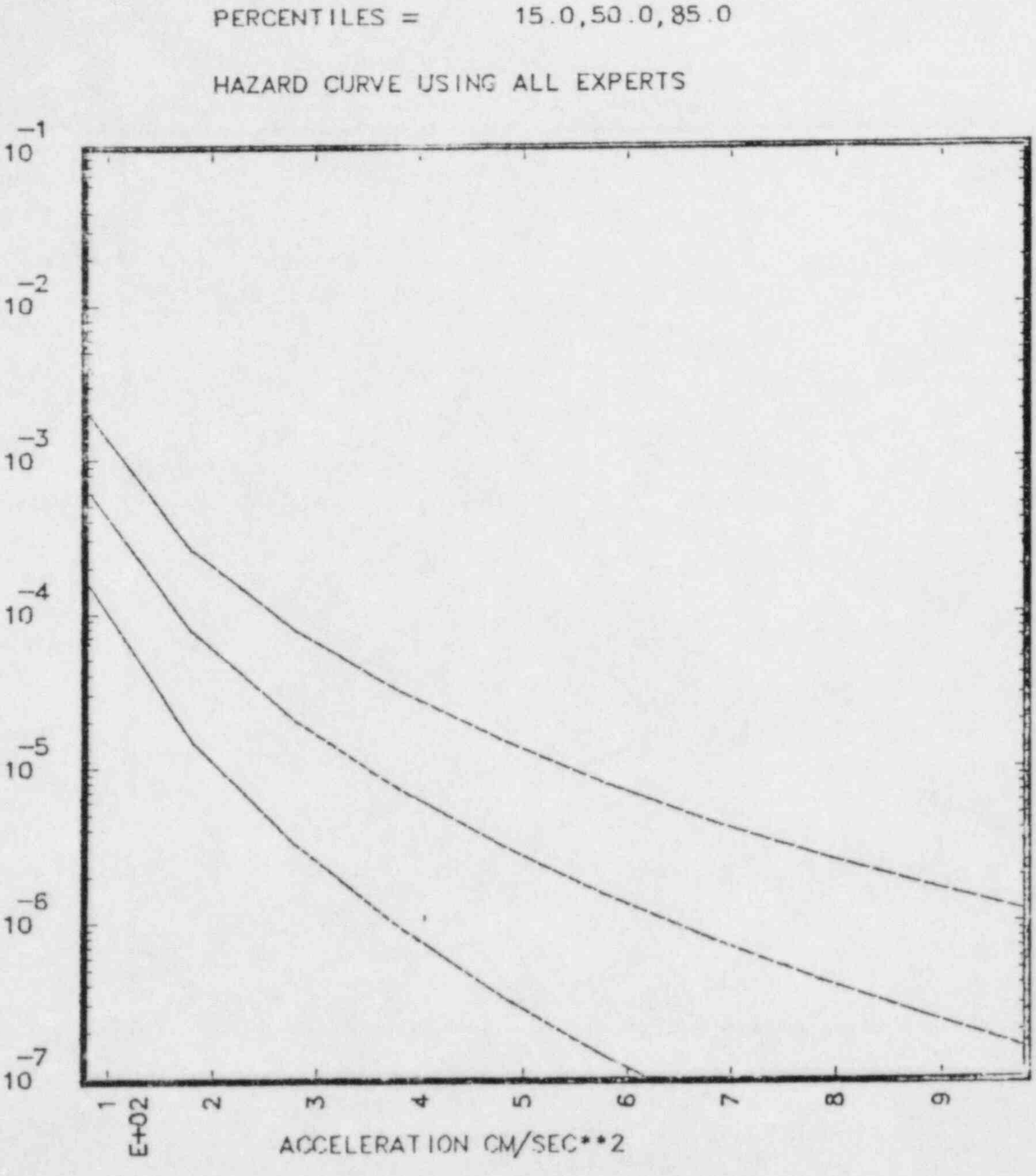


Figure LC.3 Constant Percentile Hazard Curves (CPHC) Over All Experts.

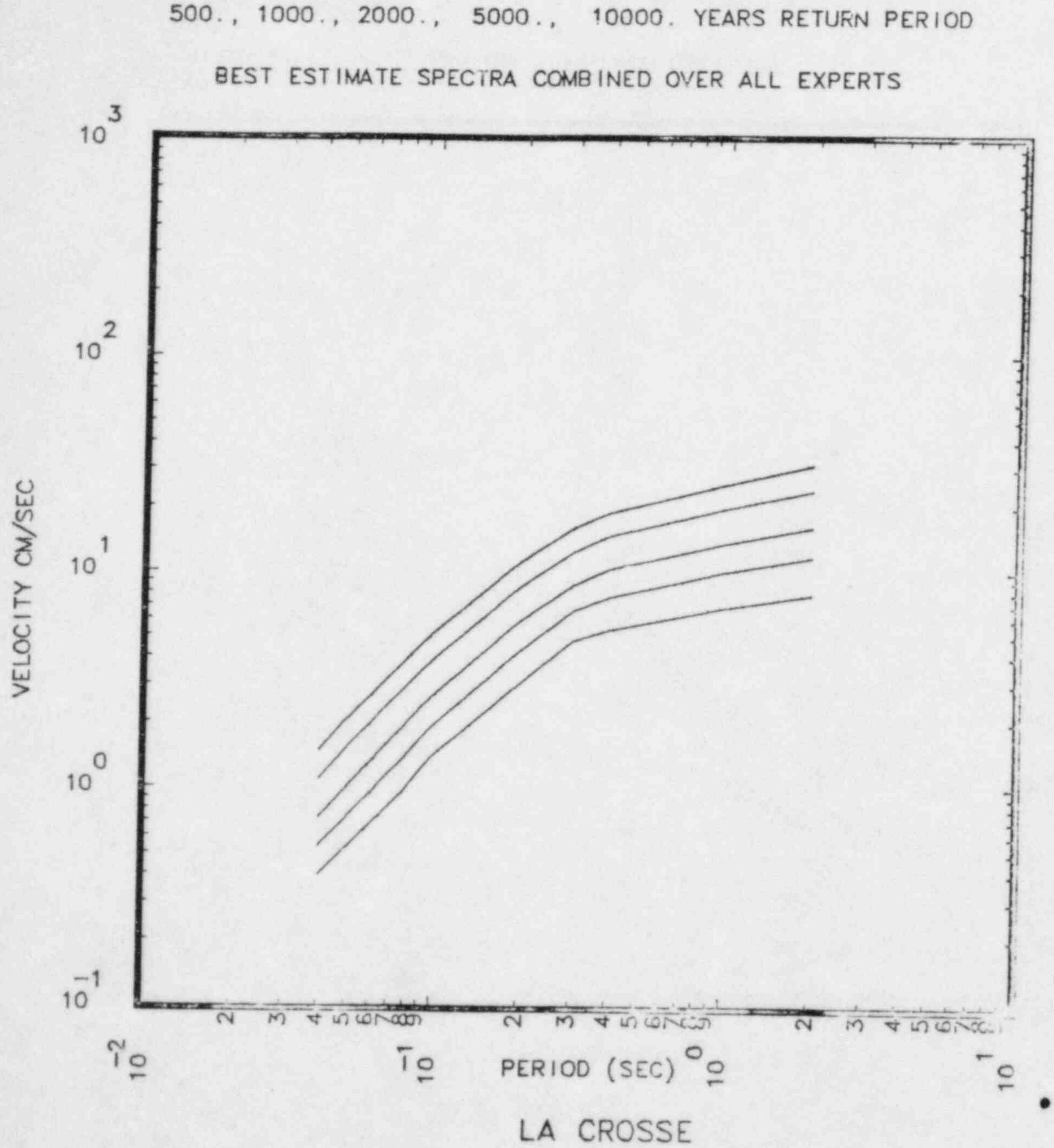

500., 1000., 2000., 5000., 10000. YEARS RETURN PERIOD
BEST ESTIMATE SPECTRA COMBINED OVER ALL EXPERTS
VELOCITY CM/SEC
PERIOD (SEC)
LA CROSSE

Figure LC.4

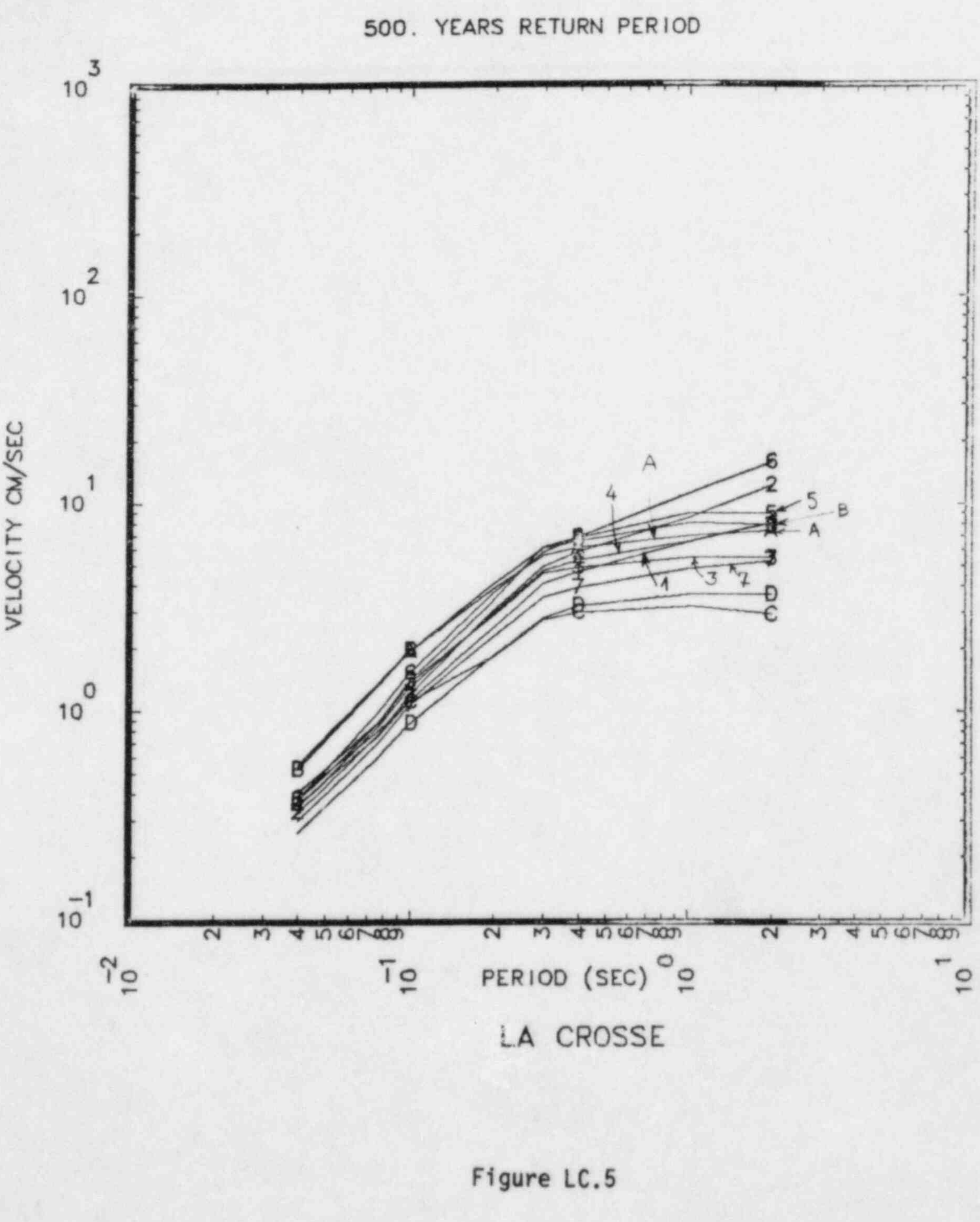
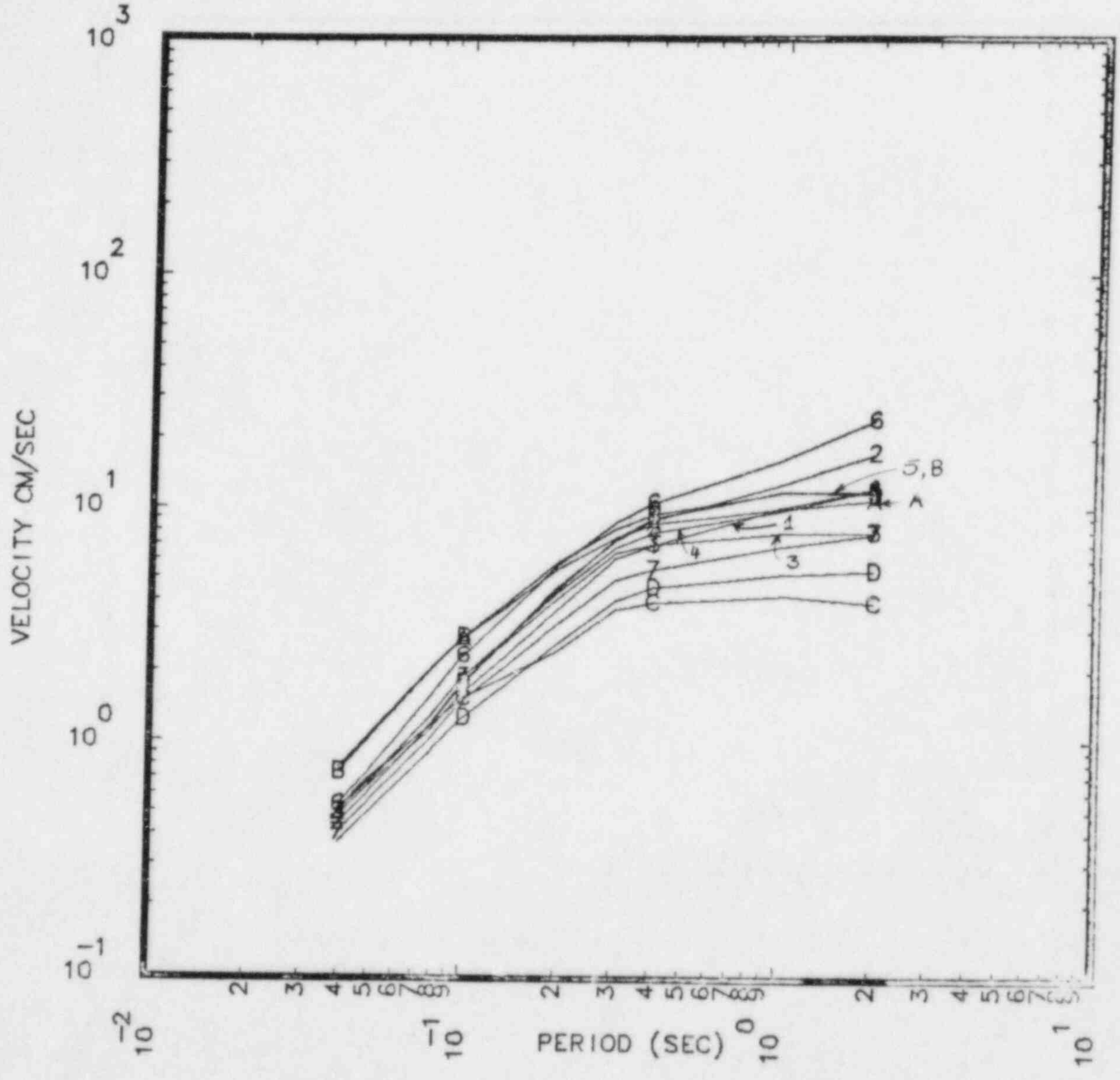

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR
500. YEARS RETURN PERIOD
VELOCITY CM/SEC
PERIOD (SEC)
LA CROSSE

Figure LC.5

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

1000. YEARS RETURN PERIOD



LA CROSSE

Figure LC.6

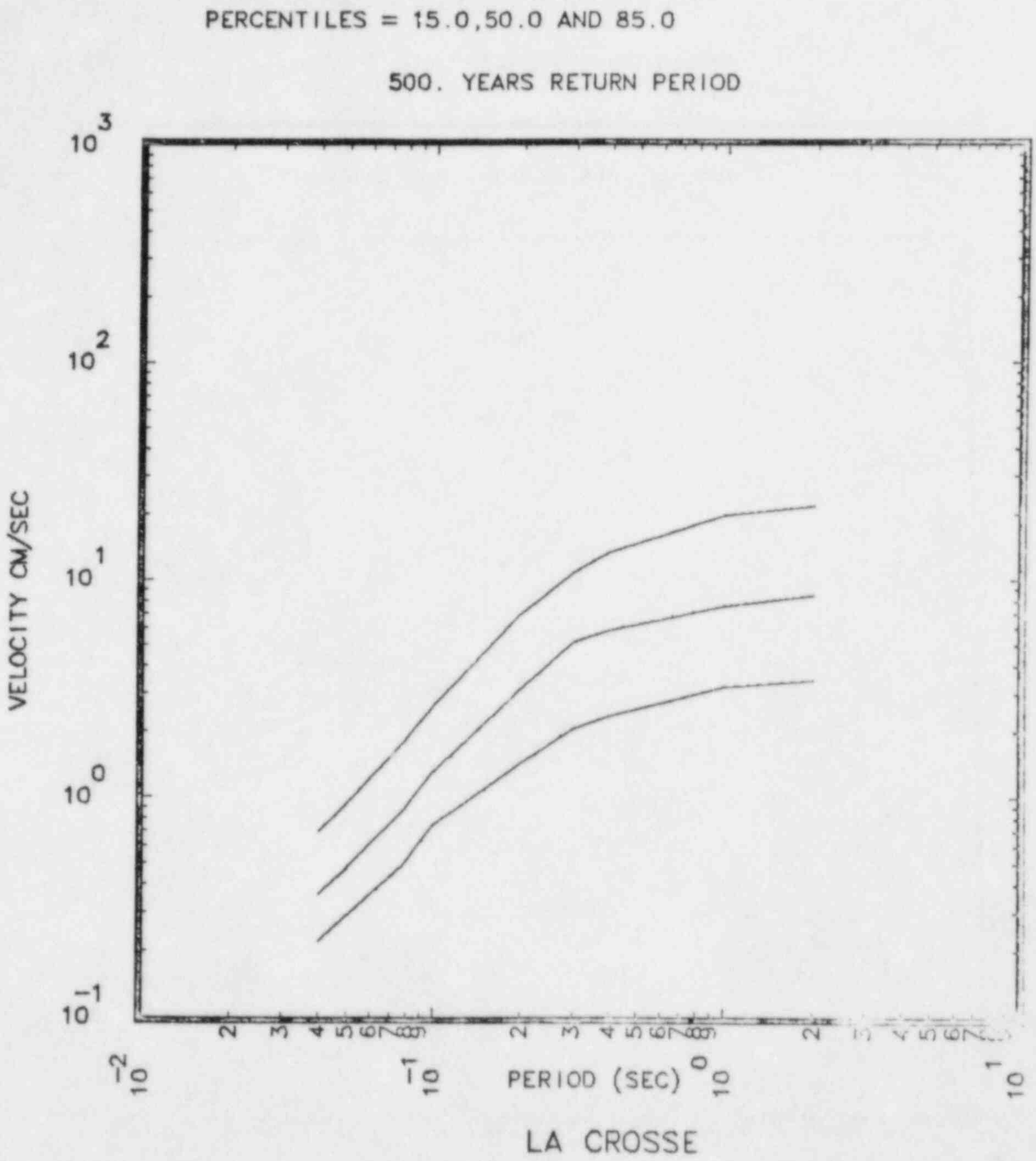


Figure LC.7 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 500 Year Return Period.

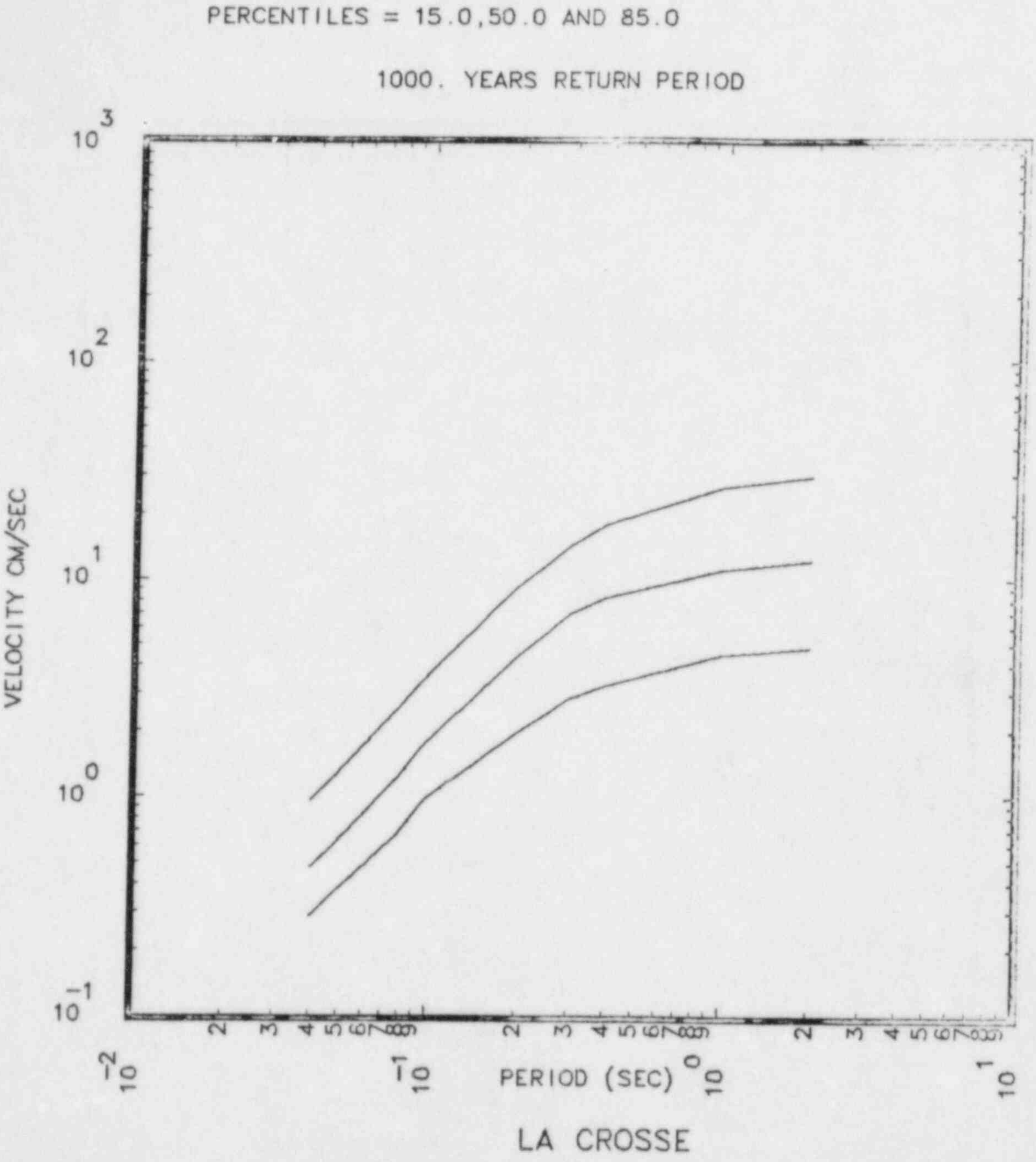


Figure LC.8 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 1,000 Year Return Period.

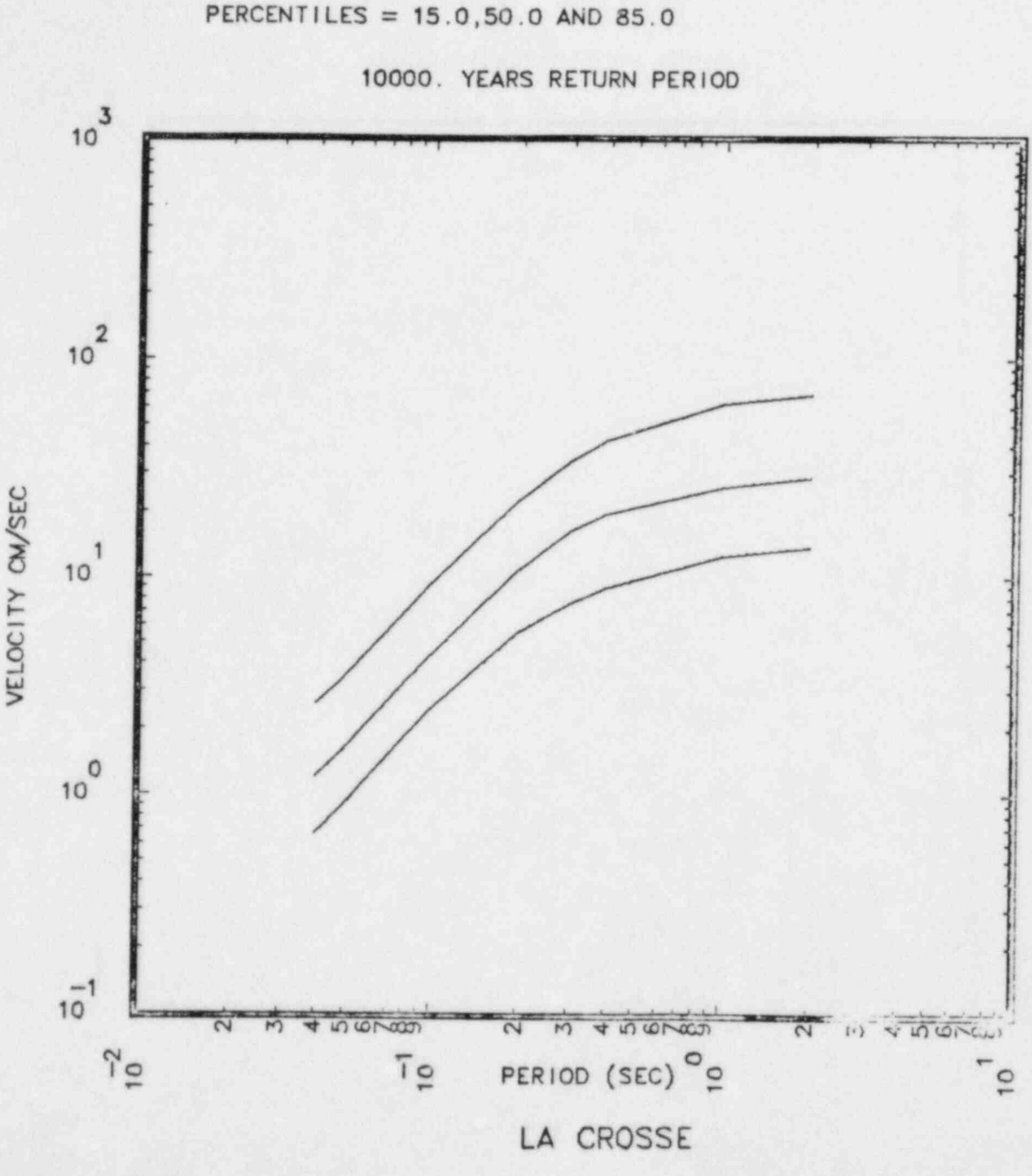


Figure LC.9 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 10,000 Year Return Period.

4.3.7 Wolf Creek (WC)

4.3.7.1 General

The Wolf Creek site is located in the south central region of the EUS. It is classified as a rock site. For eight out of the eleven seismicity experts, the site falls into the CZ. The diversity of the zonations in that part of the EUS is also an important factor, thus the distribution of the zonation maps is rather spread. Furthermore, the combination of zonations and ground motion models shifts the dominance from one zone to another between low level PGA (i.e. high hazard) to high levels of PGA (i.e. low hazard). This phenomenon is particularly apparent in the case of seismicity expert 4 (Table 4.1) for which the dominant zone is zone 1 at low levels and it is the CZ at high levels. This is also true, to a lesser extent, for seismicity expert 6.

4.3.7.2 PGA Hazard Curves

The BEHC is presented in Fig. WC1 for the combination over all experts. This curve falls in the middle of the cluster of BEHC for the 11 experts in Fig. WC2. The spread of these curves appears to be higher than the typical case. In particular, the BEHC for experts 2 and 6 and to a lesser degree expert 7 lie well above the tightly packed cluster of curves for the rest of the experts. In the case of expert 6, the high participation of zone 17 is due to its very high seismicity parameters, coupled with a very high upper magnitude cutoff of 8 (for the best estimate). As discussed in Section 4.3.1, because of the large upper magnitude cutoffs in the New Madrid zone, ground motion Expert's 4 BE ground motion model (#27) typically lead to much higher hazard at the Wolf Creek than the other ground motion models. It follows that the dispersion in the hazard results is large, as shown in Fig. WC3 where, going from the 15th to the 50th or from the 50th to the 85th percentile is typically one order of magnitude in the hazard.

In this case, the discrepancy between the BEHC and the 50th percentile is a factor of 4 to 5 at high acceleration values and 2 to 3 at low values. A large element of this difference comes from high hazard resulting from the Expert's 4 BE ground motion model and the fact that the combined BEHC is based on an arithmatical average. This shows the skewness of the probability distributions of the parameters in the dominant zones as well as the skewness in the distribution of the zonations.

4.3.7.3 Uniform Hazard Spectra

The BEUHS is presented in Fig. WC4 for all experts combined together. The spread between the 500 year and the 10,000 year return period UHS is typically less than one order of magnitude in pseudo velocity. The relatively high level of the high period (above 1 sec.) part of these UHS is due to the high estimate of experts 2 and 6, as shown in Fig. WC5. This latter figure also shows the rather small dispersion of the seismicity experts opinion, particularly for low periods. The UHS for experts 3, 12 and 13 cluster lower than the rest of the other UHS curves (on the average of 30 to 40% lower). Figure WC6, for 1000 year return period, presents the same characteristcs as Fig. WC5. The CPUHS in Figs. WC7, WC8 and WC9, on the other hand, have a shape much closer to a Newmark-Hall type spectrum, without the higher amplification at high periods, and the dispersion between the 15th and the 85th percentile is typically a factor of 5 to 6, for the 500, 1000, and 10,000 year return period CPUHS. At lower periods the BEUHS is approximately 20% higher than the 50th percentile CPUHS. At higher periods the two become practically equal; however, contrary to the BEUHS the CPUHS does not exhibit a higher amplification at periods greater than 1 sec.

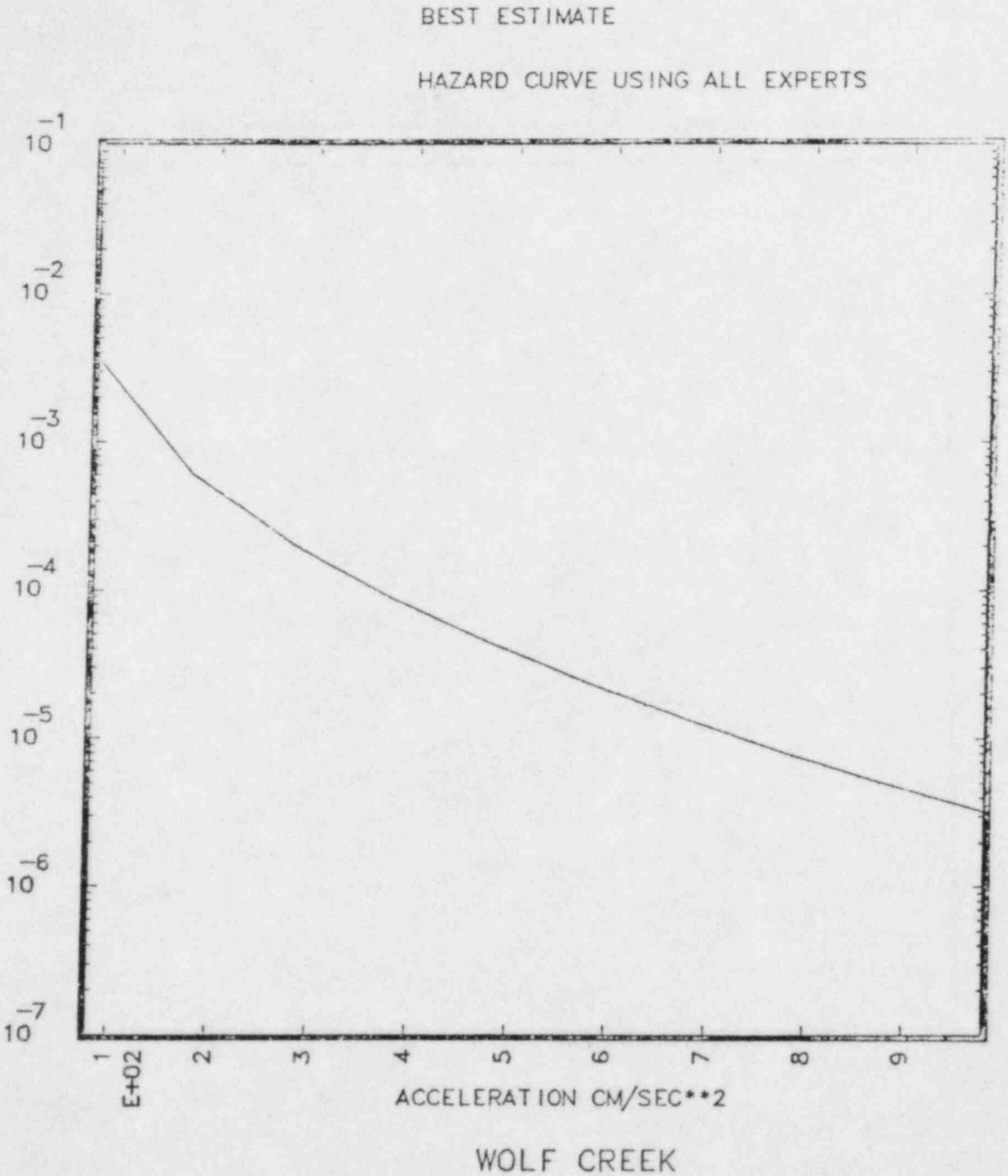

BEST ESTIMATE
HAZARD CURVE USING ALL EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
WOLF CREEK

Figure WC.1

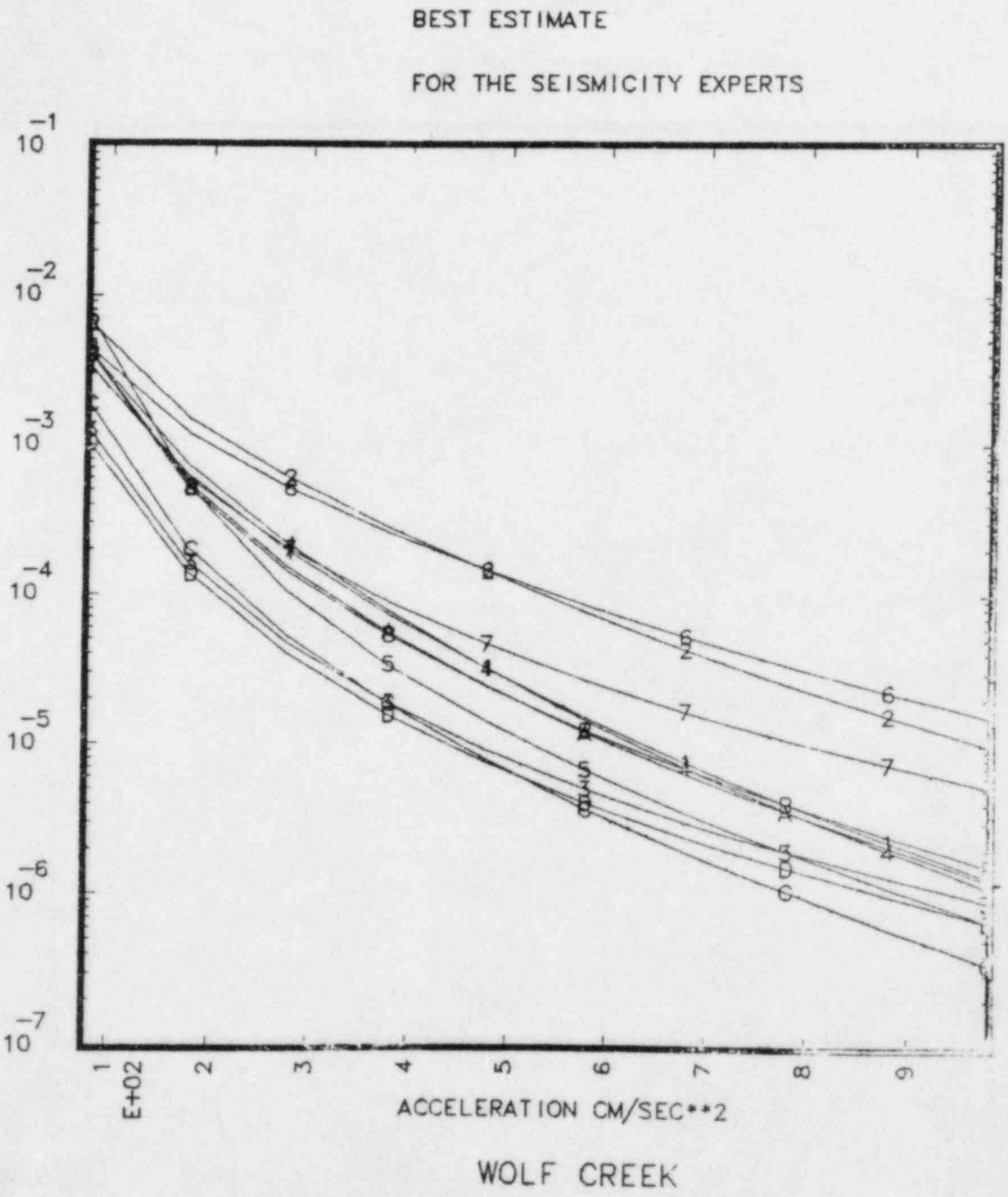


Figure WC.2 Best Estimate Hazard Curves (BEHC) Per Seismicity Expert Combined Over All Ground Motion Experts.

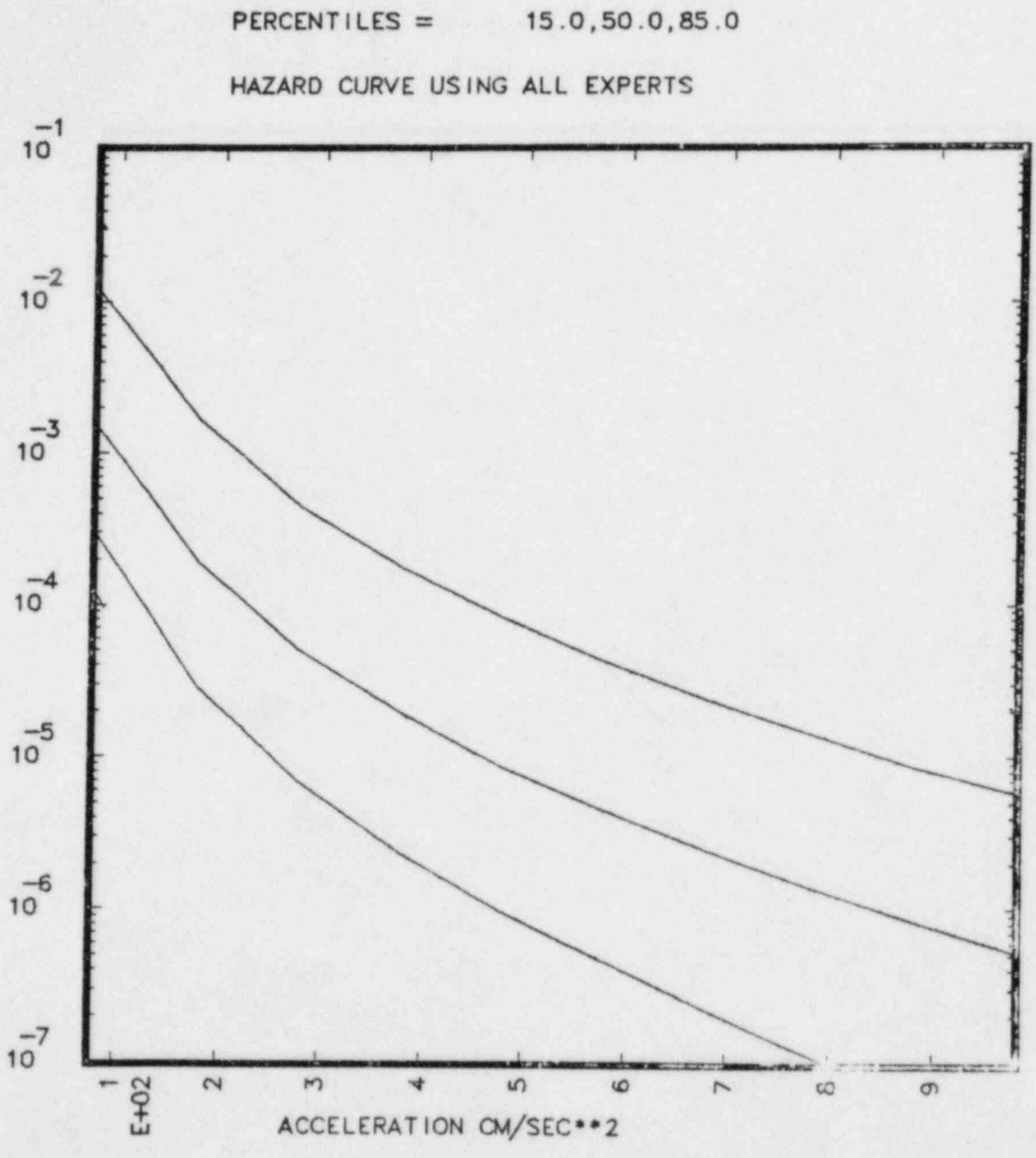


Figure WC.3 Constant Percentile Hazard Curves (CPHC) Over All Experts.

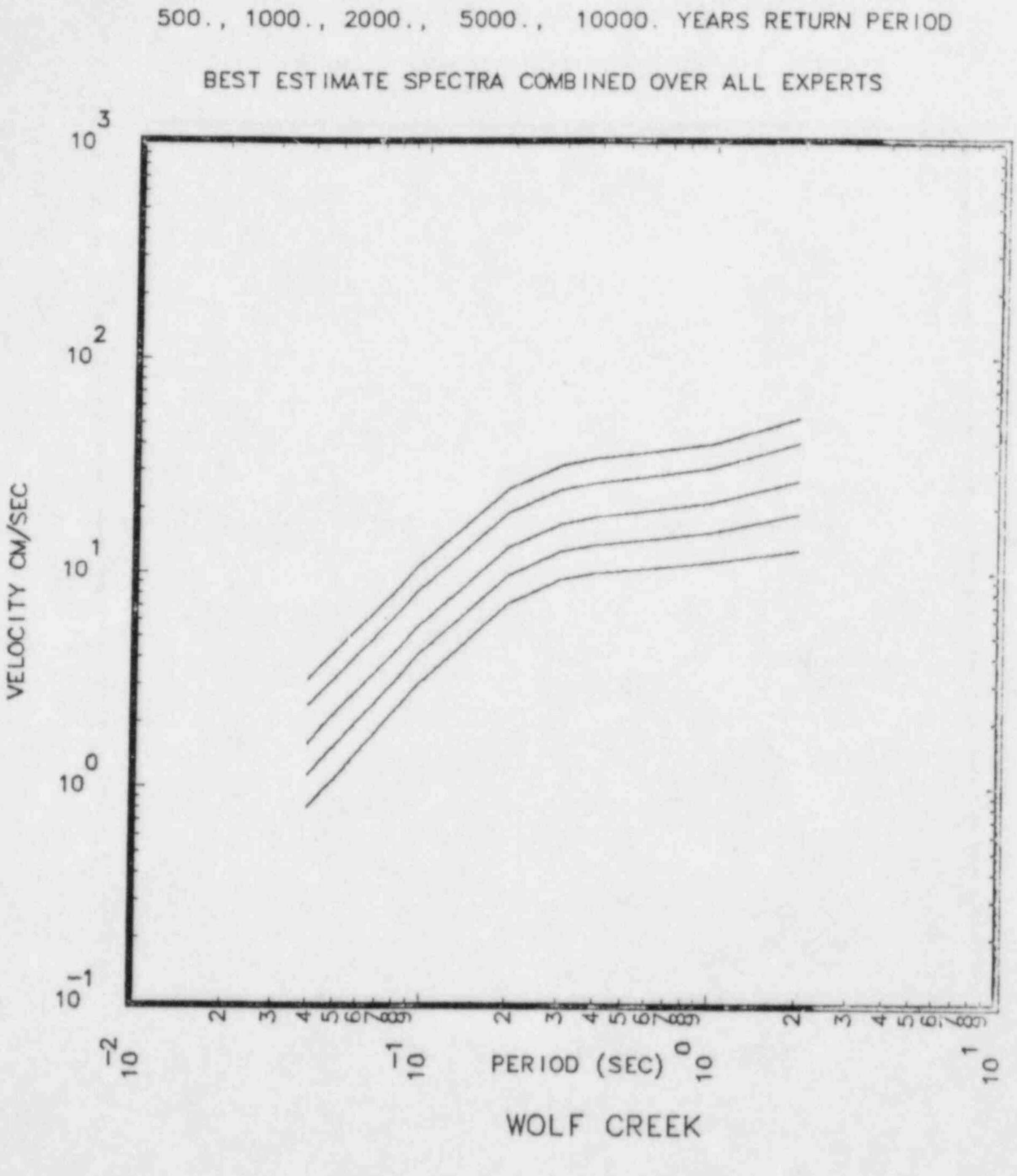
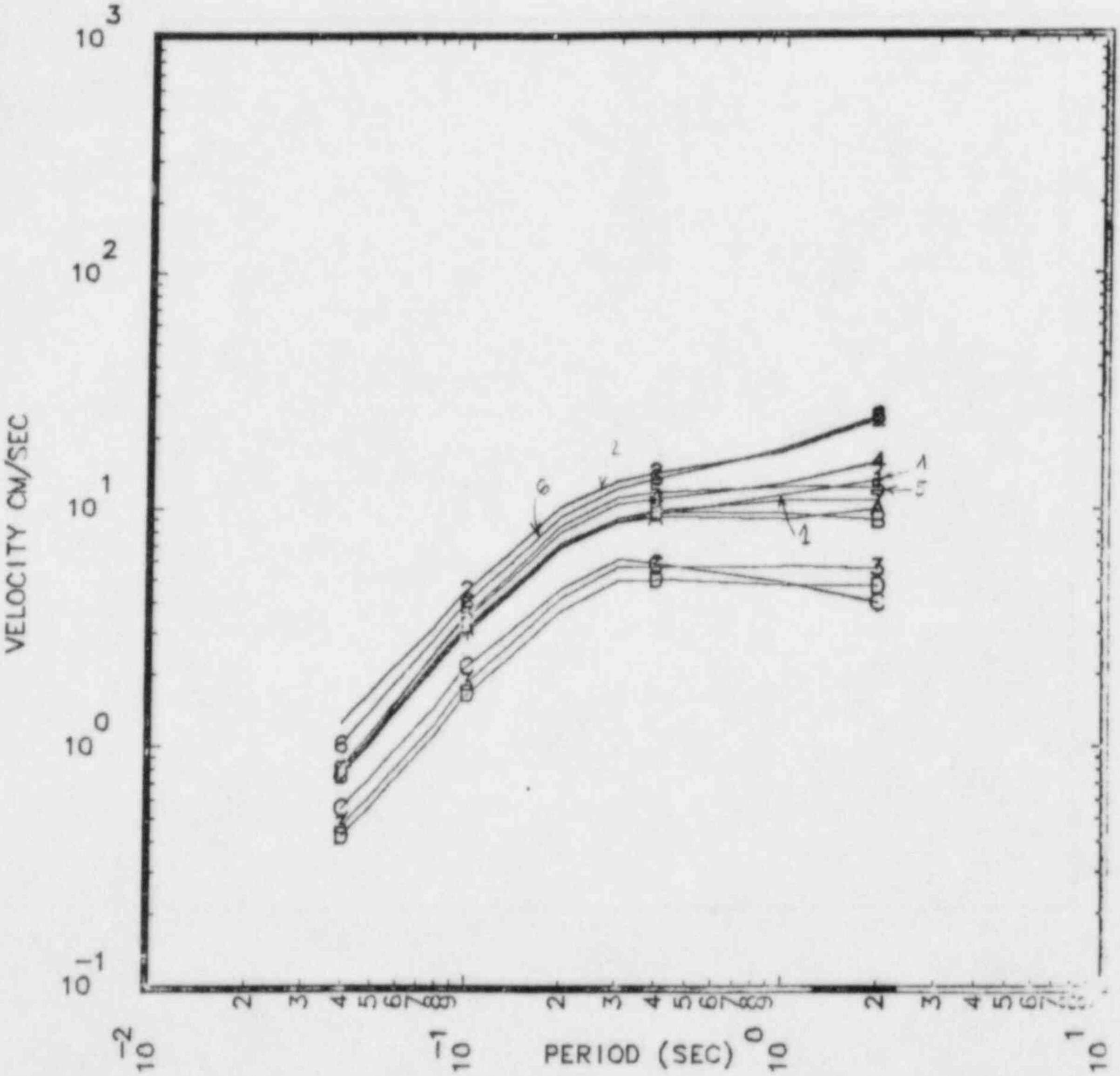

500., 1000., 2000., 5000., 10000. YEARS RETURN PERIOD
BEST ESTIMATE SPECTRA COMBINED OVER ALL EXPERTS
VELOCITY CM/SEC
PERIOD (SEC)
WOLF CREEK

Figure WC.4

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

500. YEARS RETURN PERIOD

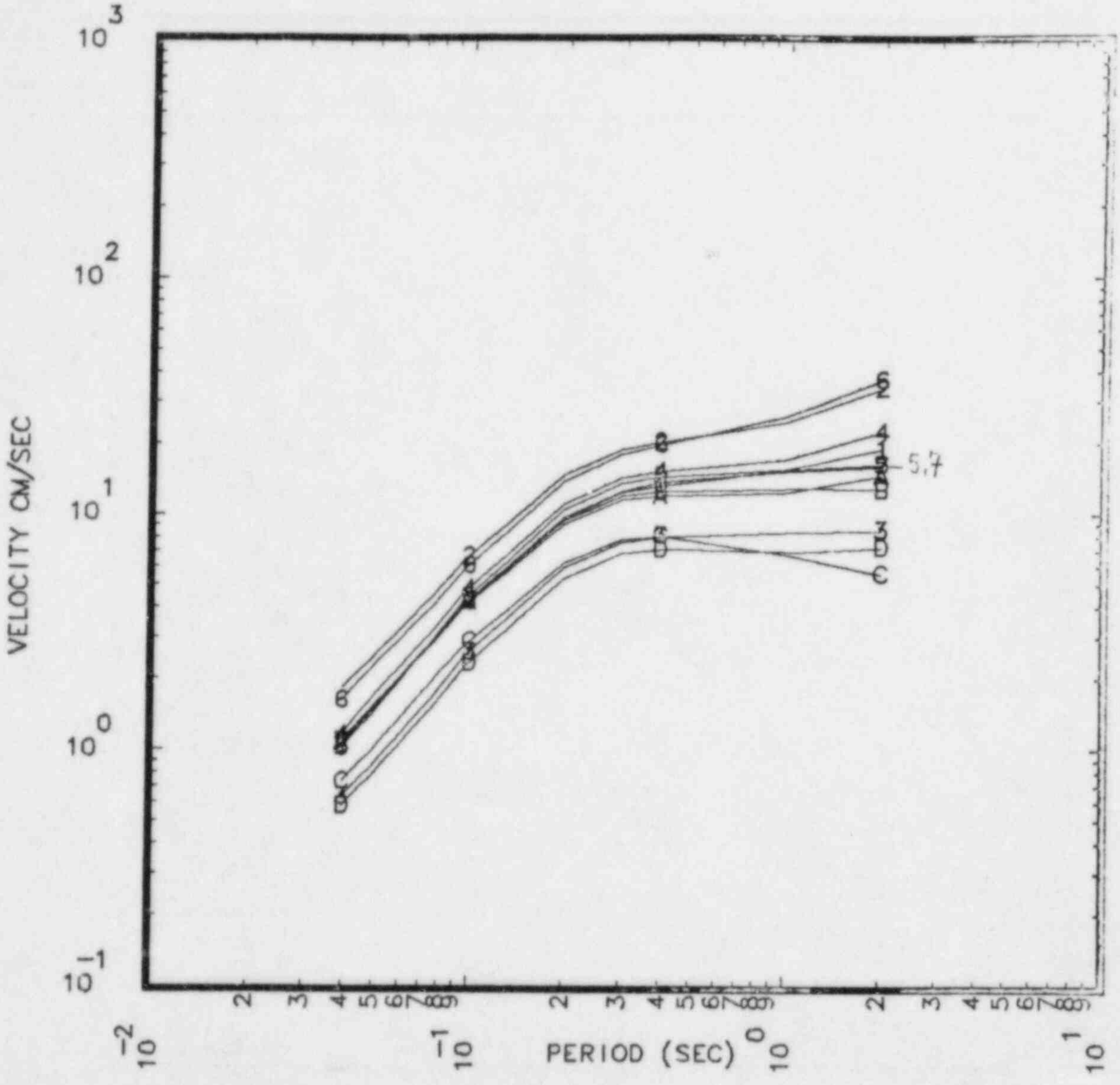


WOLF CREEK

Figure WC.5

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

1000. YEARS RETURN PERIOD



WOLF CREEK

Figure WC.6

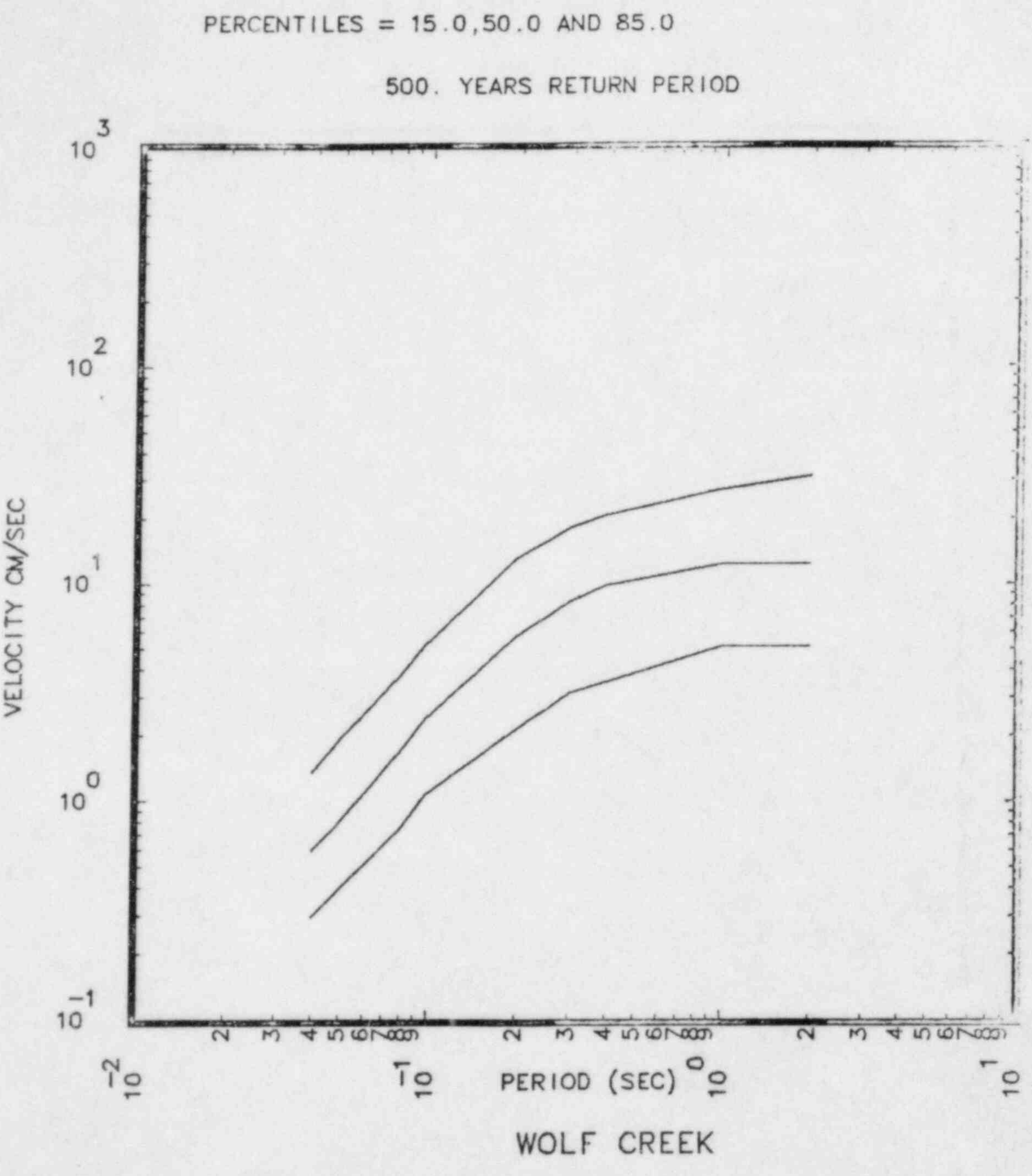


Figure WC.7 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 500 Year Return Period.

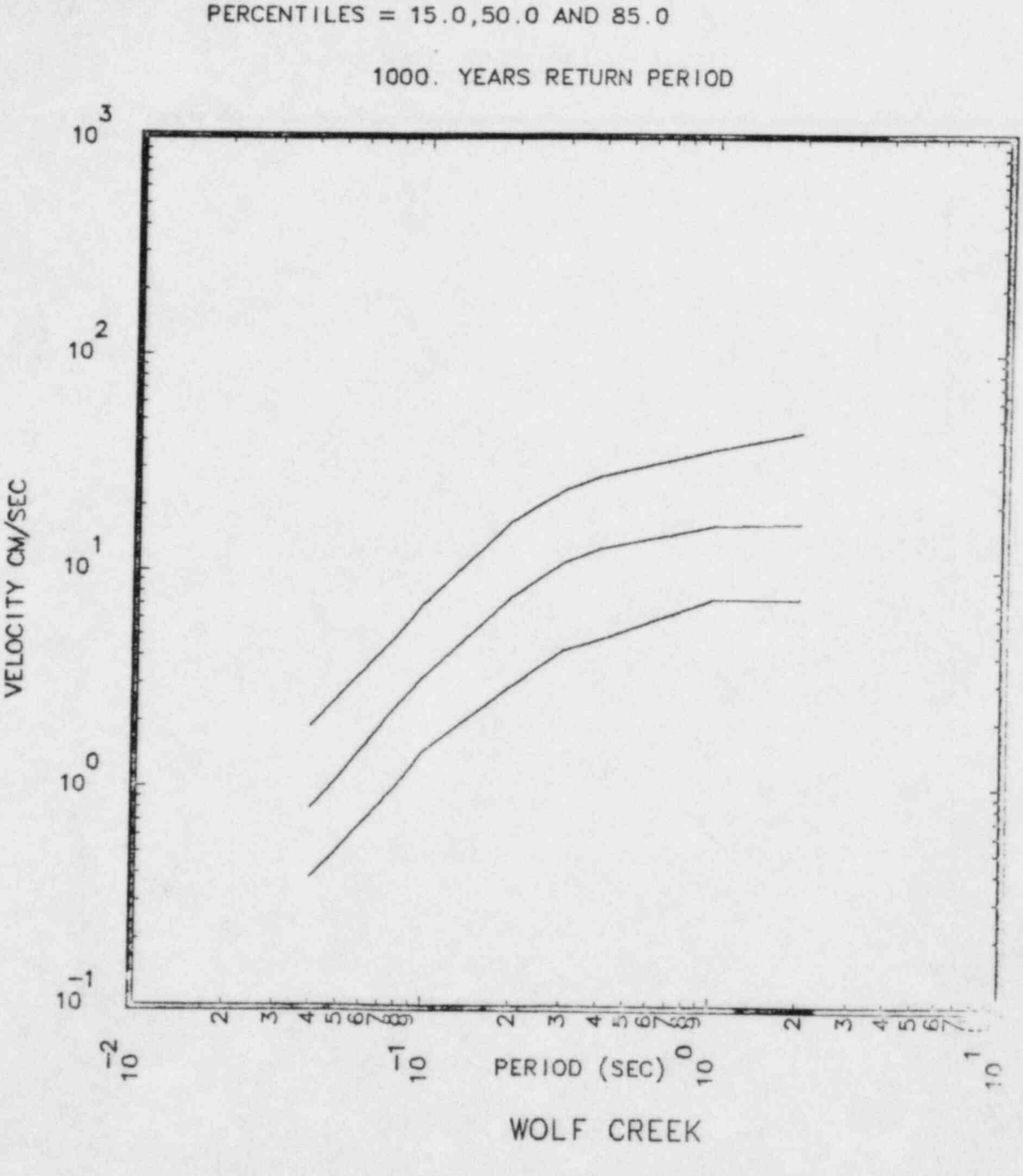


Figure WC.8 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 1,000 Year Return Period.

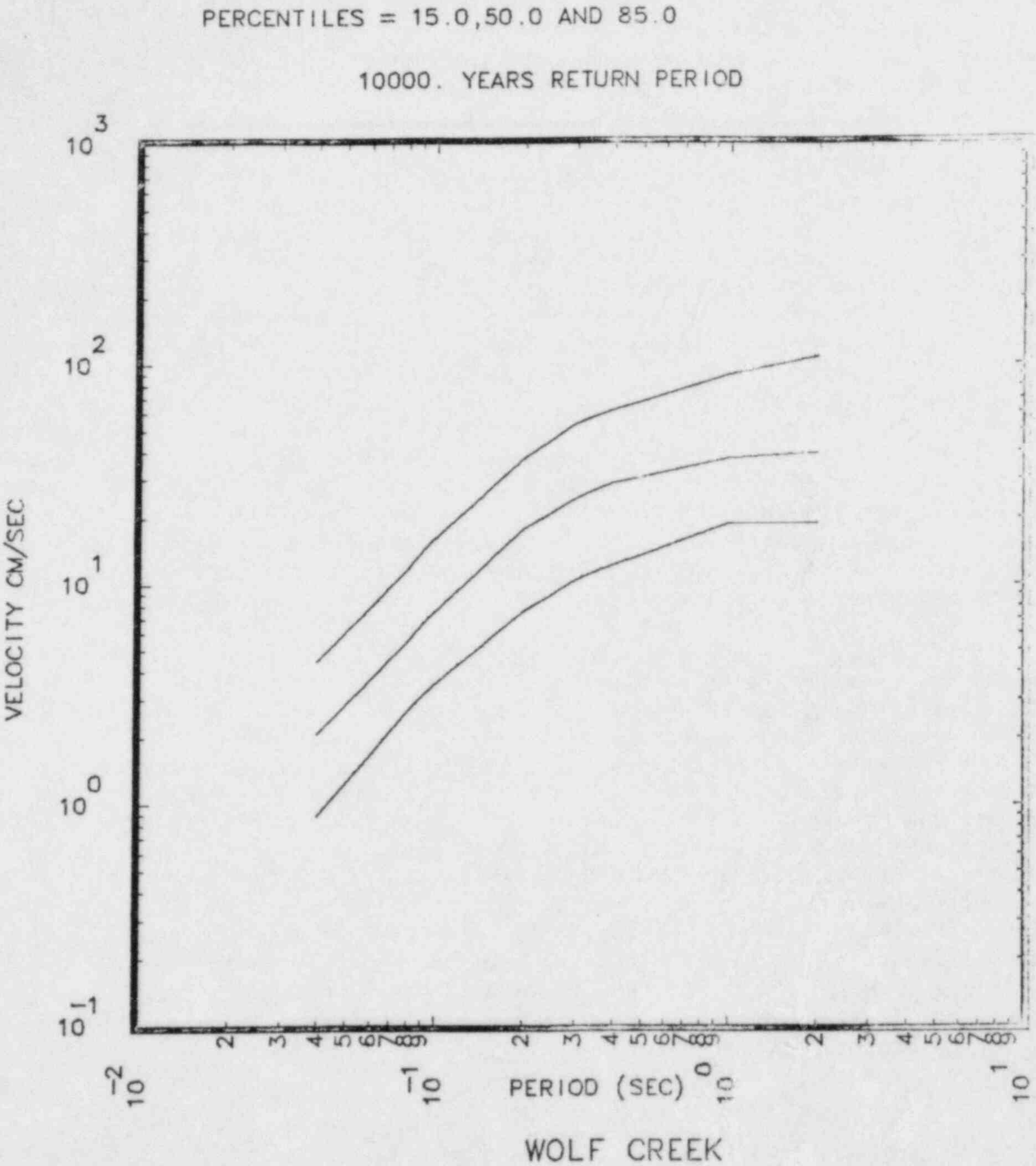


Figure WC.9 Constant Percentile Uniform Hazard Spectra (CPUHS) for the 10,000 Year Return Period.

4.3.8 Watts Bar (WB)

4.3.8.1 General

Watts Bar is located in the western part of the southeast region near the south central region. It is classified as a rock site. For all seismicity experts, this site falls into a specified zone other than the CZ.

4.3.8.2 PGA Hazard Curves

In most cases, the dominant zone is the zone where the site is located and, for some experts, the New Madrid zone contributes a little at low PGA values and becomes much more important, but never dominant, at high PGA value (see Table 4.1). As a result, the diversity of dominant zones is not as low as one could expect and the spread in results per experts, as shown in Fig. WB2, is moderate (typically a factor of 5 to 8 on the hazard) rather than small. Figure WB2 shows two distinct clusters of curves at higher PGA. One is composed of the results for experts 2, 6 and 7 on the higher side of the hazard and the other cluster is made of all the other experts, typically a factor of 3 to 5 lower than the higher cluster. Since most experts had similar views for the zonation in the region of the EUS, the differences here come rather from the diverse opinions on the seismicity values. (The upper magnitude or intensity cutoff were also all within a small interval for all experts, for the dominant zone.) The BEHC is up to a factor of 2 higher than the 50th percentile of Fig. WB3, showing that some of the distributions of the seismicity and upper magnitude bounds of the dominant zones are highly skewed.

4.3.8.3 Uniform Hazard Spectra

Figure WB4 presents the BEUHS combined over all experts for the five return periods selected. Figures WB5 and WB6 present the BEUHS per seismicity expert for the 500 year and 1,000 year return periods. From these latter two figures, it appears that the results are well constrained within a narrow band of a factor of 2 approximately at low periods, to become within a factor of 6 to 8 at periods higher than 1 sec. A careful examination, however, shows that the dispersion is primarily due to expert 12 which falls slightly lower than the custer of results, and experts 2 and 6 which lie significantly higher at periods over 1 sec. As a consequence of the arithmetic averaging technique used to combine experts' results, the UHS of Fig. WB4 present this same over-amplification at periods above 1 sec. On the contrary, this does not happen in the CPUHS of Figs. WB7, WB8 and WB9 in part due to the geometric averaging used in that case. The results are smooth spectra looking curves with a narrow dispersion, typically a factor of 3 to 4 in the range between the 15th and the 85th percentile.

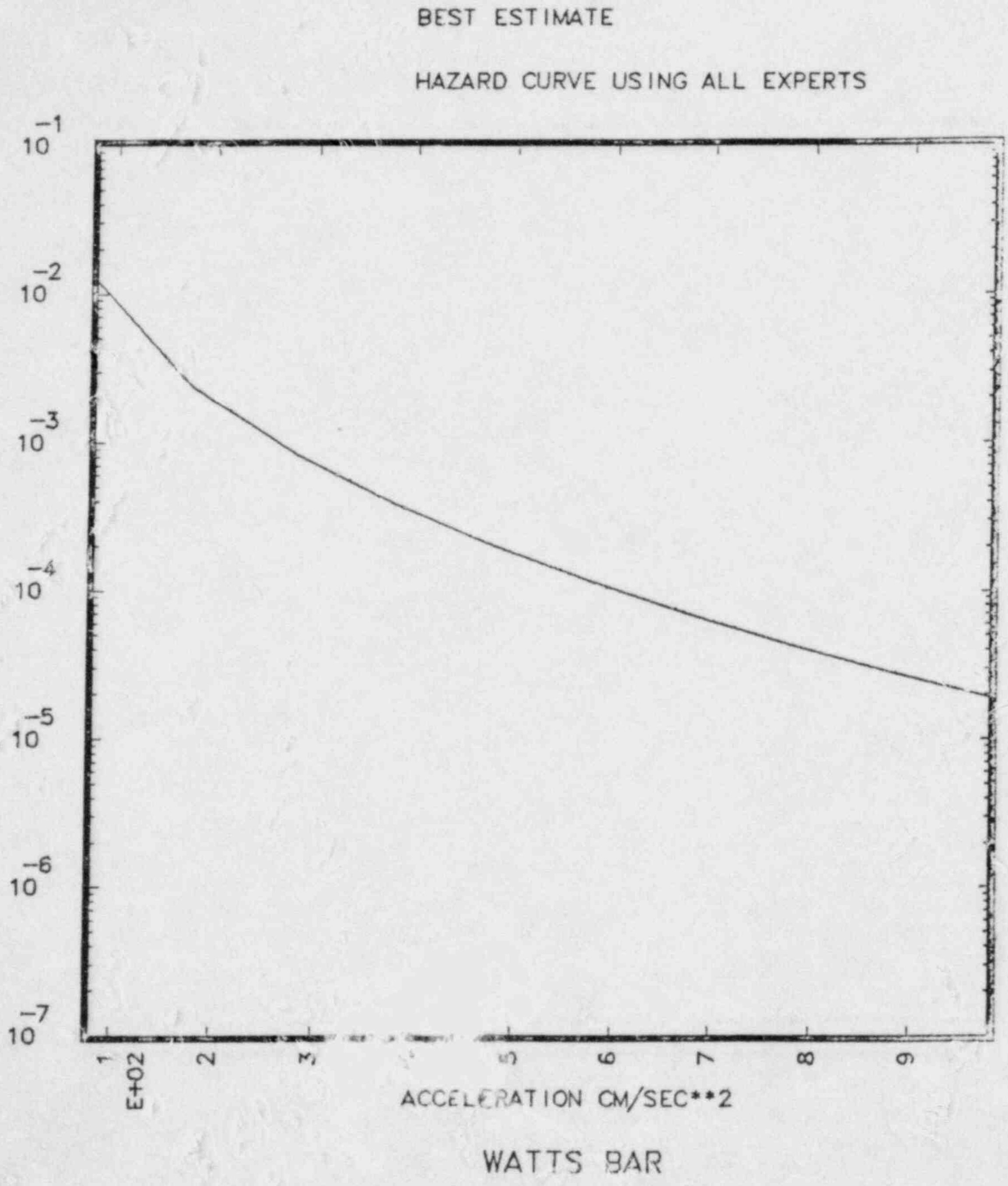
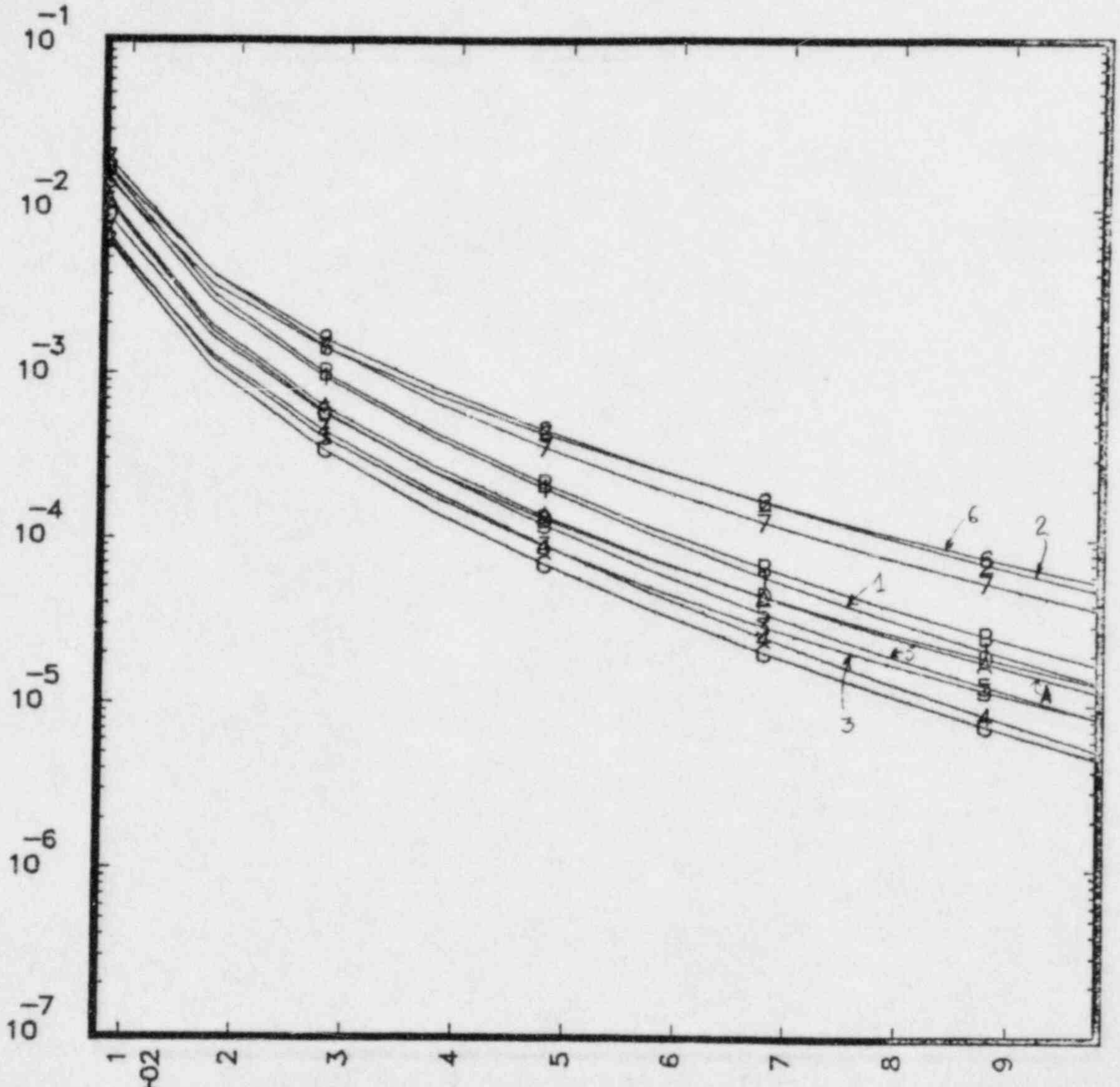

BEST ESTIMATE
HAZARD CURVE USING ALL EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
E+02
2
3
5
6
7
8
9
ACCELERATION CM/SEC**2
WATTS BAR

Figure WB.1

BEST ESTIMATE

FOR THE SEISMICITY EXPERTS



WATTS BAR

Figure WB.2

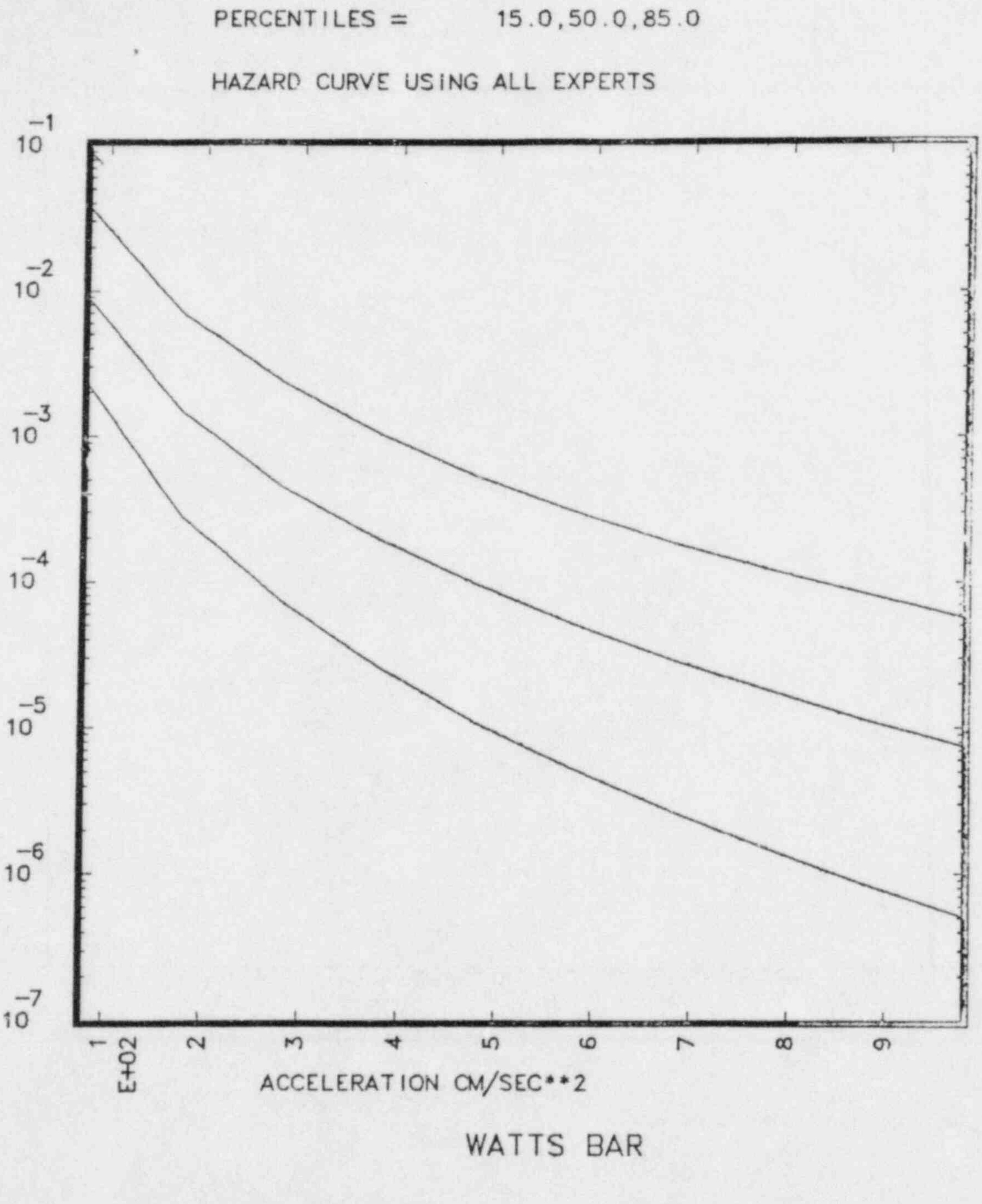

PERCENTILES = 15.0,50.0,85.0
HAZARD CURVE USING ALL EXPERTS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
WATTS BAR

Figure WB.3

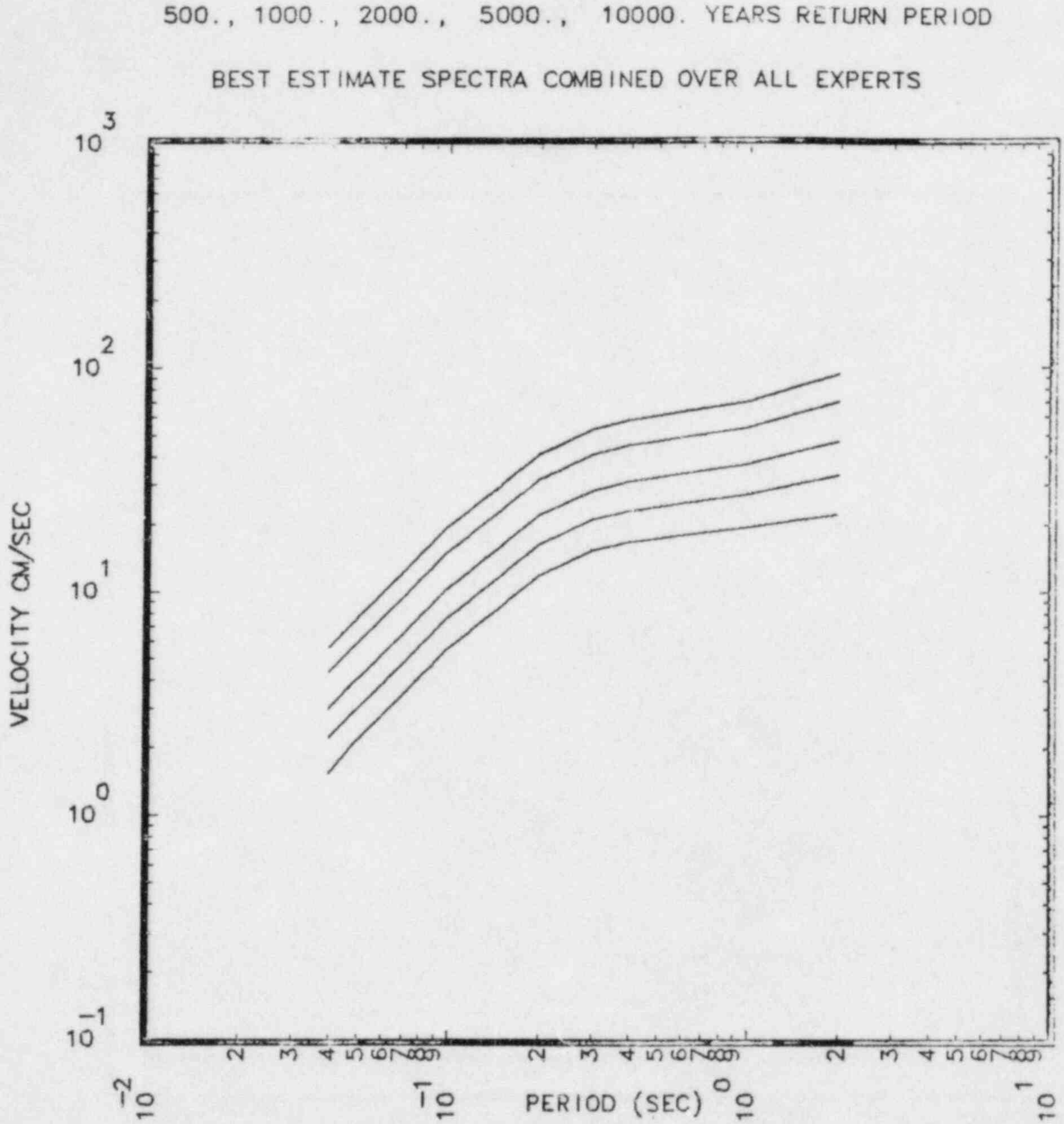

500., 1000., 2000., 5000., 10000. YEARS RETURN PERIOD
BEST ESTIMATE SPECTRA COMBINED OVER ALL EXPERTS
VELOCITY CM/SEC
PERIOD (SEC)
WATTS BAR

Figure WB.4

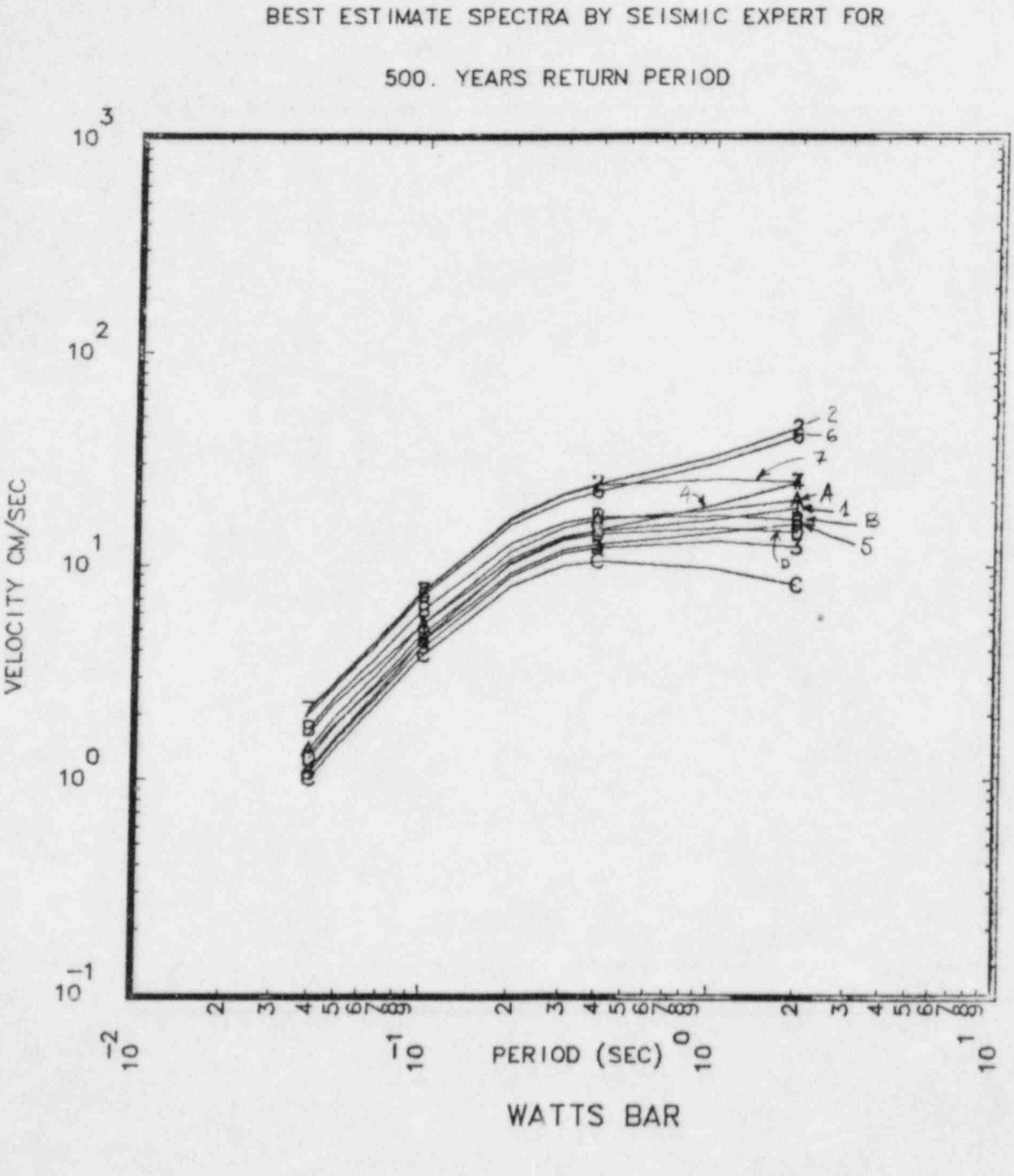
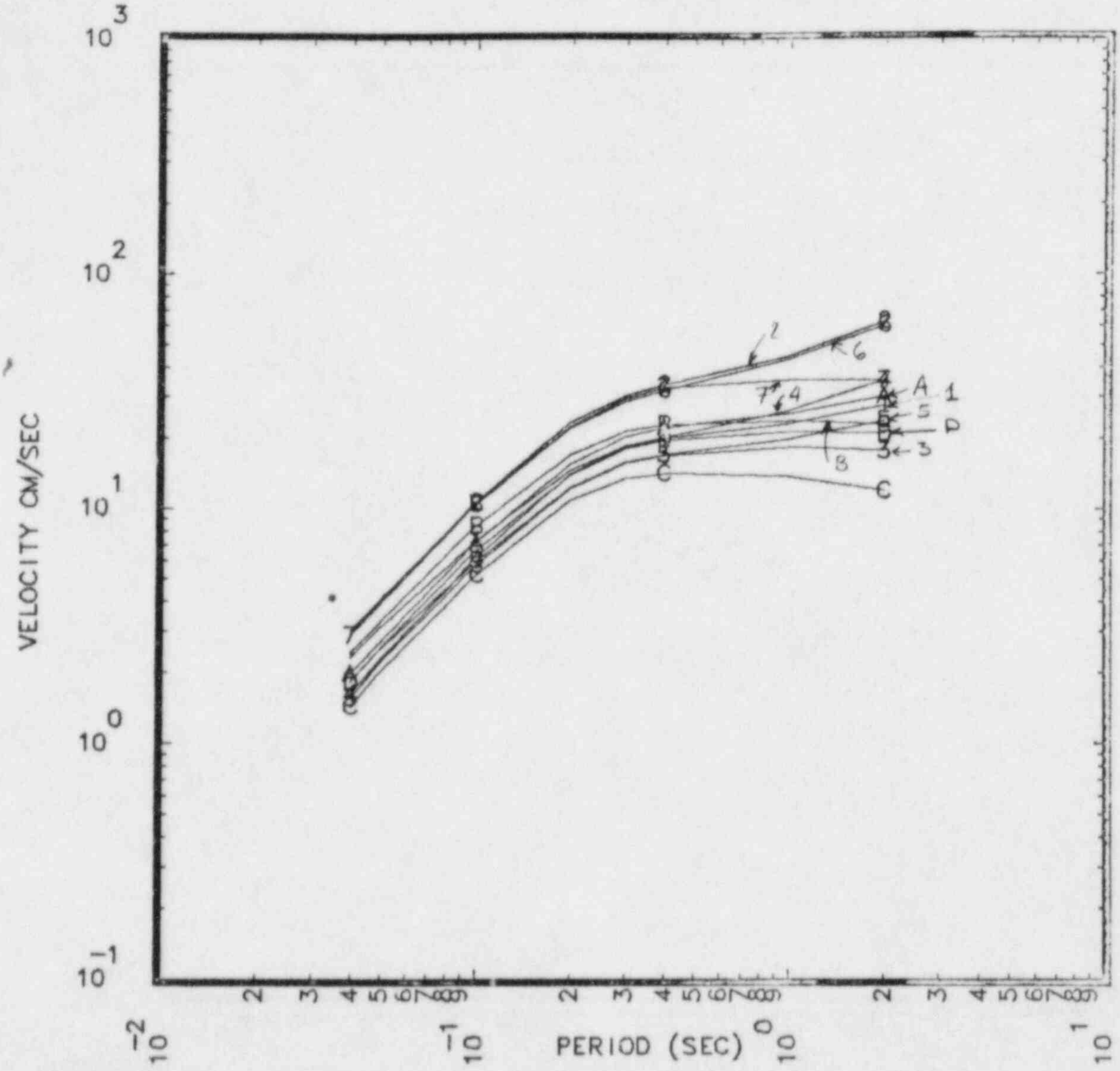

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR
500. YEARS RETURN PERIOD
VELOCITY CM/SEC
PERIOD (SEC)
WATTS BAR

Figure WB.5

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

1000. YEARS RETURN PERIOD



WATTS BAR

Figure WB.6

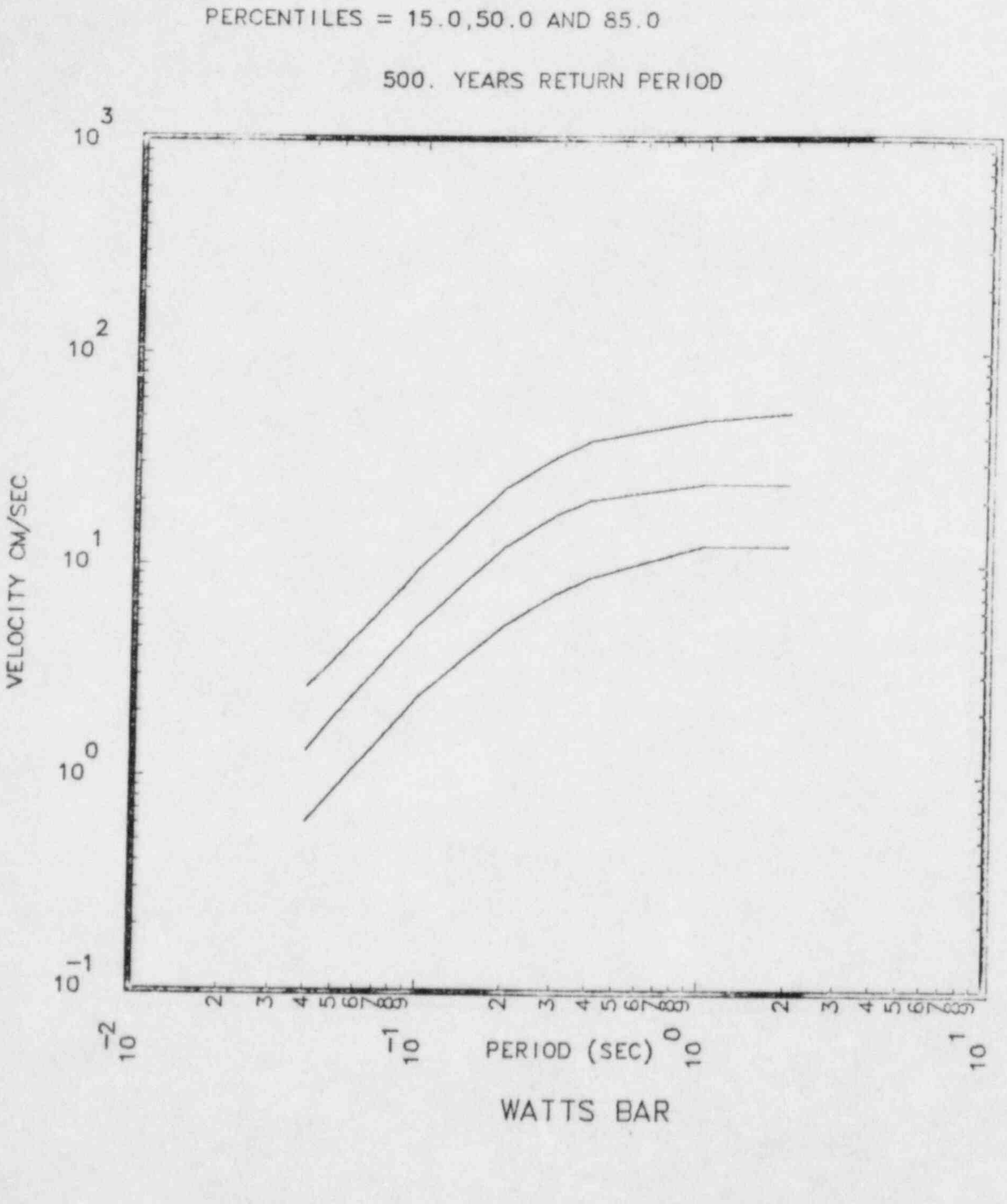

PERCENTILES = 15.0,50.0 AND 85.0
500. YEARS RETURN PERIOD
VELOCITY CM/SEC
PERIOD (SEC)
WATTS BAR

Figure WB.7

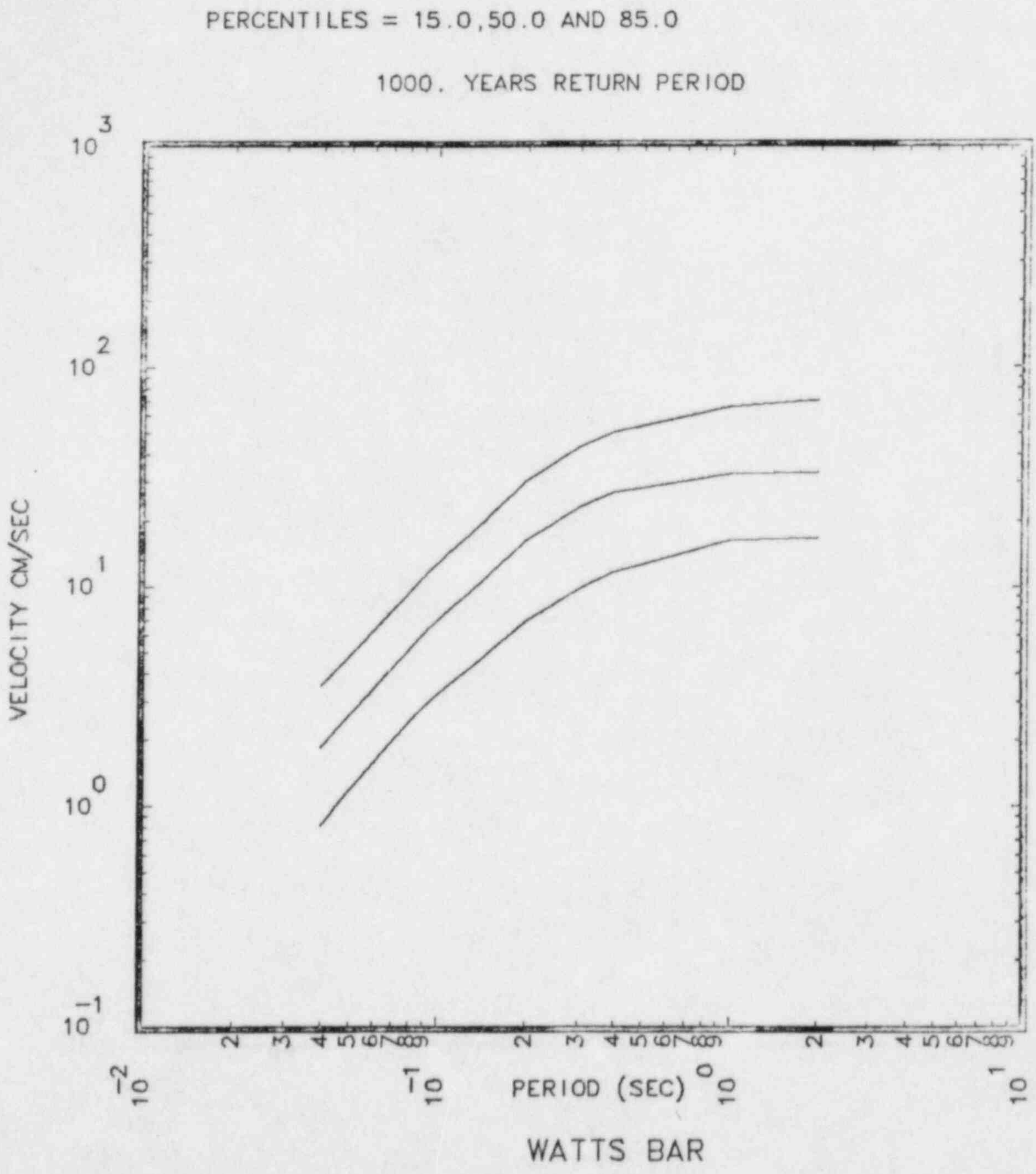

PERCENTILES = 15.0,50.0 AND 85.0
1000. YEARS RETURN PERIOD
VELOCITY CM/SEC
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-1
10^0
10^1
PERIOD (SEC)
WATTS BAR

Figure WB.8

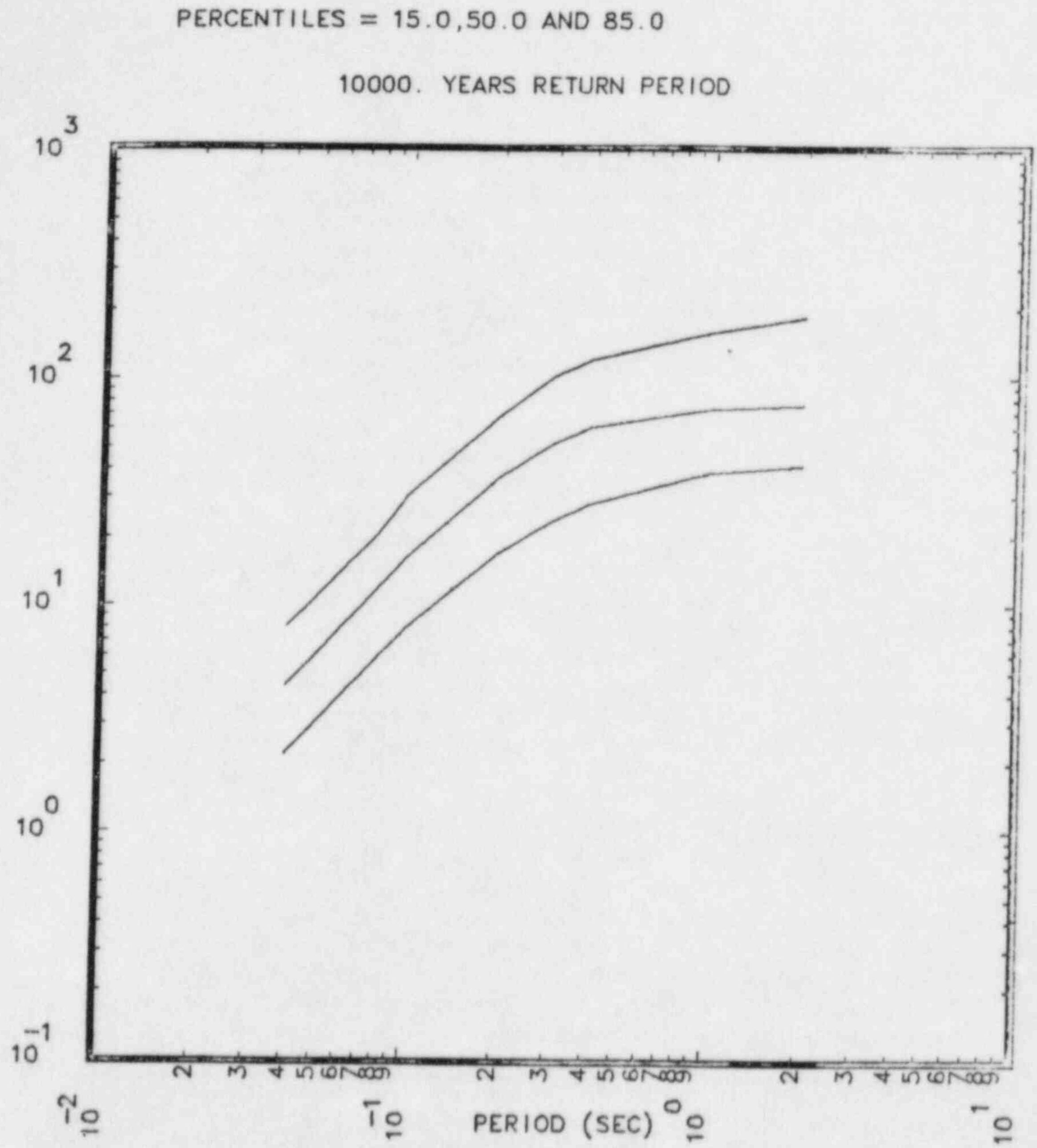

PERCENTILES = 15.0,50.0 AND 85.0
10000. YEARS RETURN PERIOD
VELOCITY CM/SEC
PERIOD (SEC)
WATTS BAR

Figure WB.9

4.3.9 Vogtle (VO)

4.3.9.1 General

The Vogtle site is located in the southeast region of the EUS. It is classified as a soil site. For none of the seismicity experts does the site fall into the CZ, but it always falls into a zone associated with the Charleston area.

4.9.9.2 PGA Hazard Curve

Table 4.1 shows that for most of the seismicity experts the dominant zone is a large area surrounding a limited Charleston zone. For Experts 1 and 2 at low PGA levels the small zone with higher magnitude/intensity cutoff dominates; and at higher PGA levels the larger zone, with also a high magnitude/intensity cutoff takes over. For experts 3, 4, 5, 6, 7, 10, 11 and 12, the site is located within a zone of high magntude/intensity cutoff which dominates the hazard at both low and high PGA levels. In the case of expert 13, the small Charleston zone dominates at low PGA levels by contributing 92% of the hazard. For this expert, high PGA levels the CZ becomes the dominant zone. The CZ has a magnitude cutoff only slightly lower than zone 9 (6.3 versus 6.8 for zone 9) which has a surface area several orders of magnitude greater than zone 9. Figure V01 presents the HC for all experts combined. The spread exhibited by the seismicity experts is rather large (a factor of 12 to 15 at low PGA and 50 to 70 at high PGA between the lowest and the highest BEHC of experts 2 and 12). The BEHC of experts 2 and 12 are the two extremes, although only expert's 12 data leads to an outlier, significantly lower than the other experts, as shown on Fig. V02. This is due in part to the relatively low seismicity and low magnitude cutoffs attributed to the zones at the site and surrounding the site. The dispersion in the hazard estimates represented by the 15th, 50th and 85th percentile curves in Fig. V03 is similar to the dispersion observed for other sites. Note, however, that the BEHC is higher than the 50th percentile (by a factor of 2 to 3).

4.3.9.3 Uniform Hazard Spectra

The BEUHS presented in Fig. V04 for the 5 selected RP's appears to be smooth, without departure at any period. This is due to the very stable shape of the curves obtained for each of the experts, shown in Fig. V05. Figure V05 shows that aside from experts 2 and 12 which appear to be clear outliers for this site, the remaining experts are constrained within a very narrow band of values; typically less than a factor of 3 between the lowest curve in the cluster and the highest curve in the cluster. The same comments apply to Fig. V06. As a result, the uncertainty analysis leads to 15th-50th and 50th-85th intervals in the same range as the ones obtained for the typical sites (i.e. moderate values) instead of much smaller values which could be obtained by removing the outliers or updating the input data of the outliers. The same comments apply for the 1,000 year and 10,000 year RP curves of Fig. V08 and V09. It is also remarkable that for these three cases the BEUHS lies practically on top of the CPUHS.

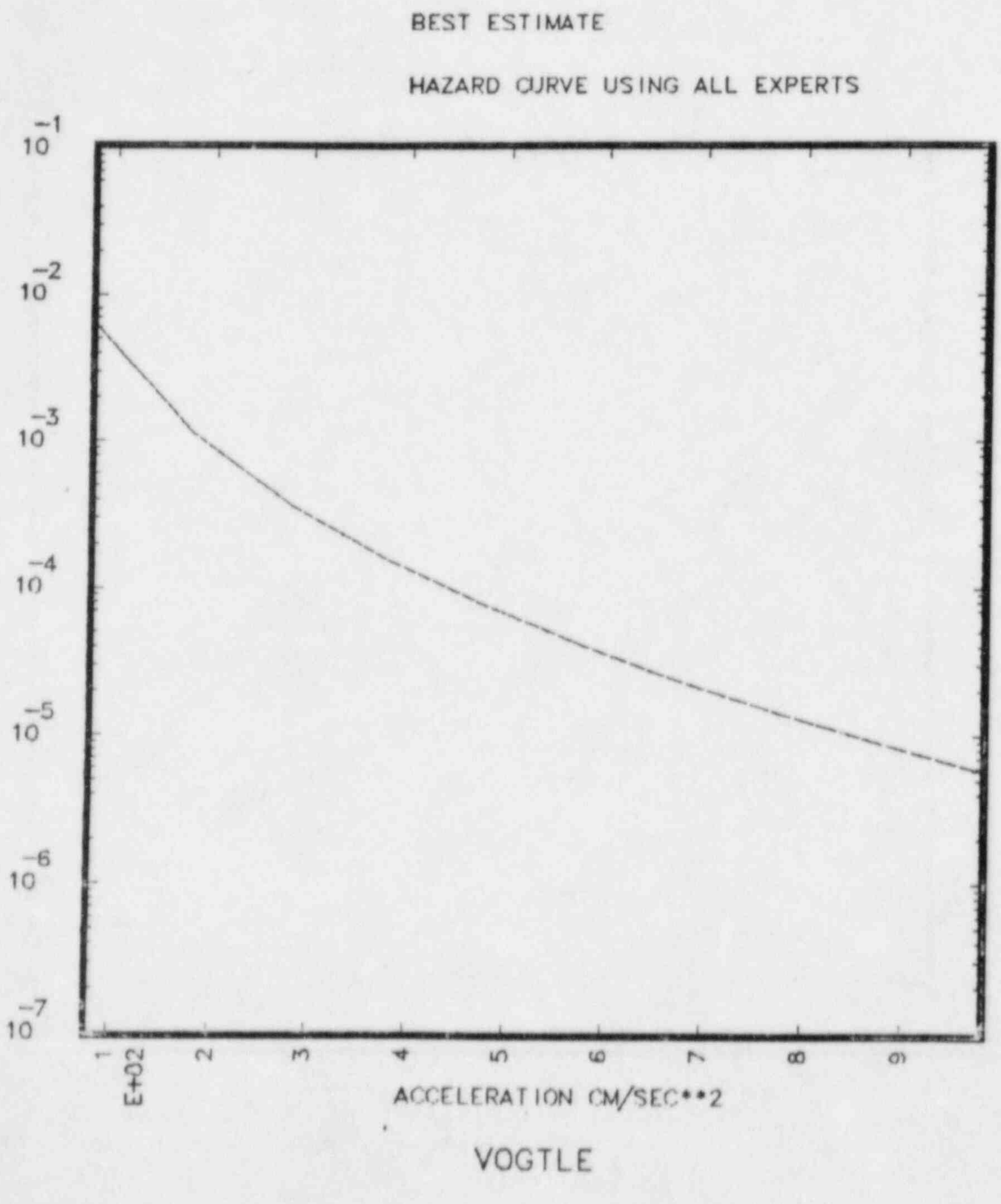

BEST ESTIMATE
HAZARD CURVE USING ALL EXPERTS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
VOGTLE

Figure V0.1

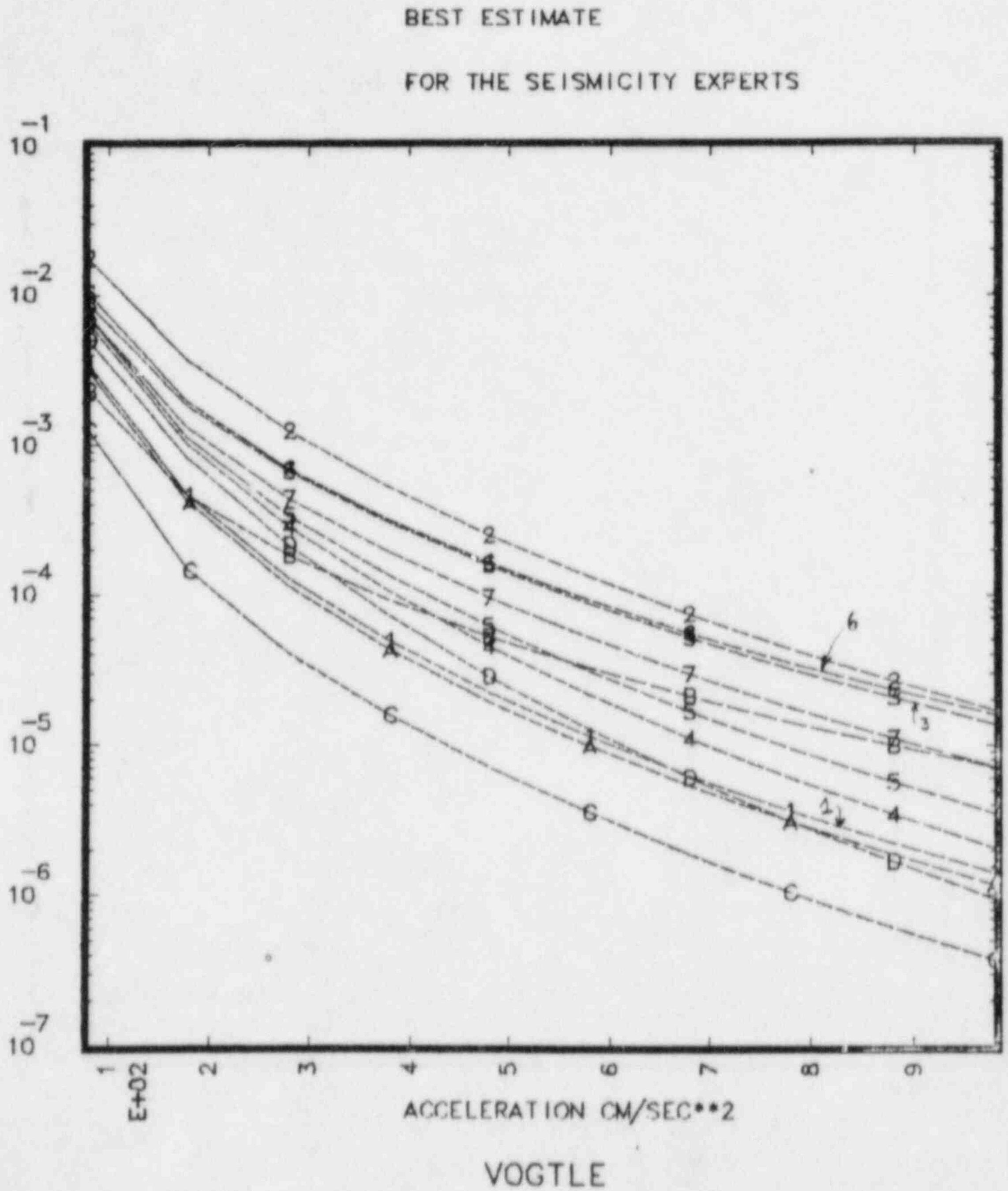
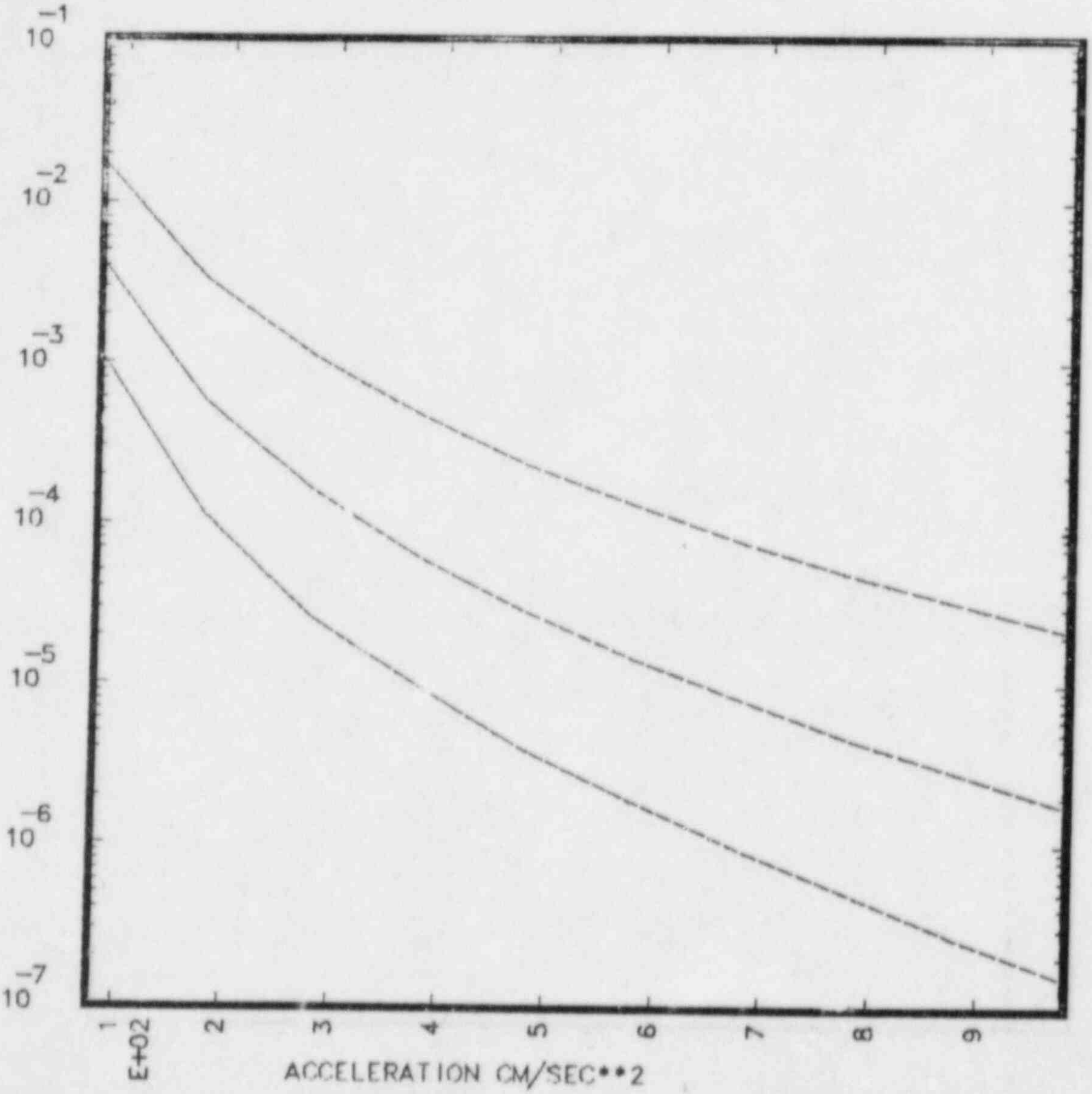

BEST ESTIMATE
FOR THE SEISMICITY EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1 E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
VOGTLE

Figure V0.2

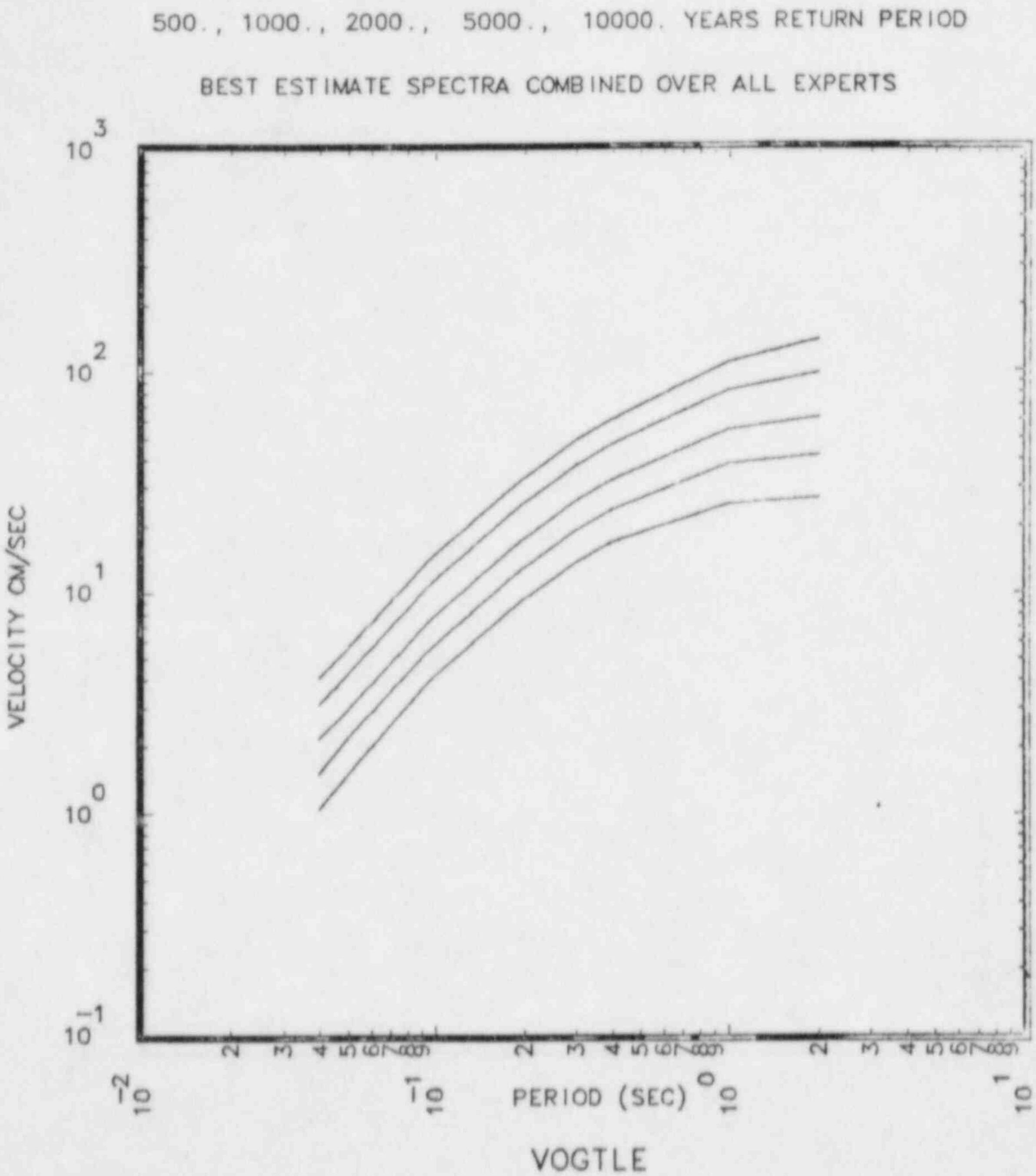
PERCENTILES = 15.0,50.0,85.0

HAZARD CURVE USING ALL EXPERTS



VOGTLE

Figure V0.3

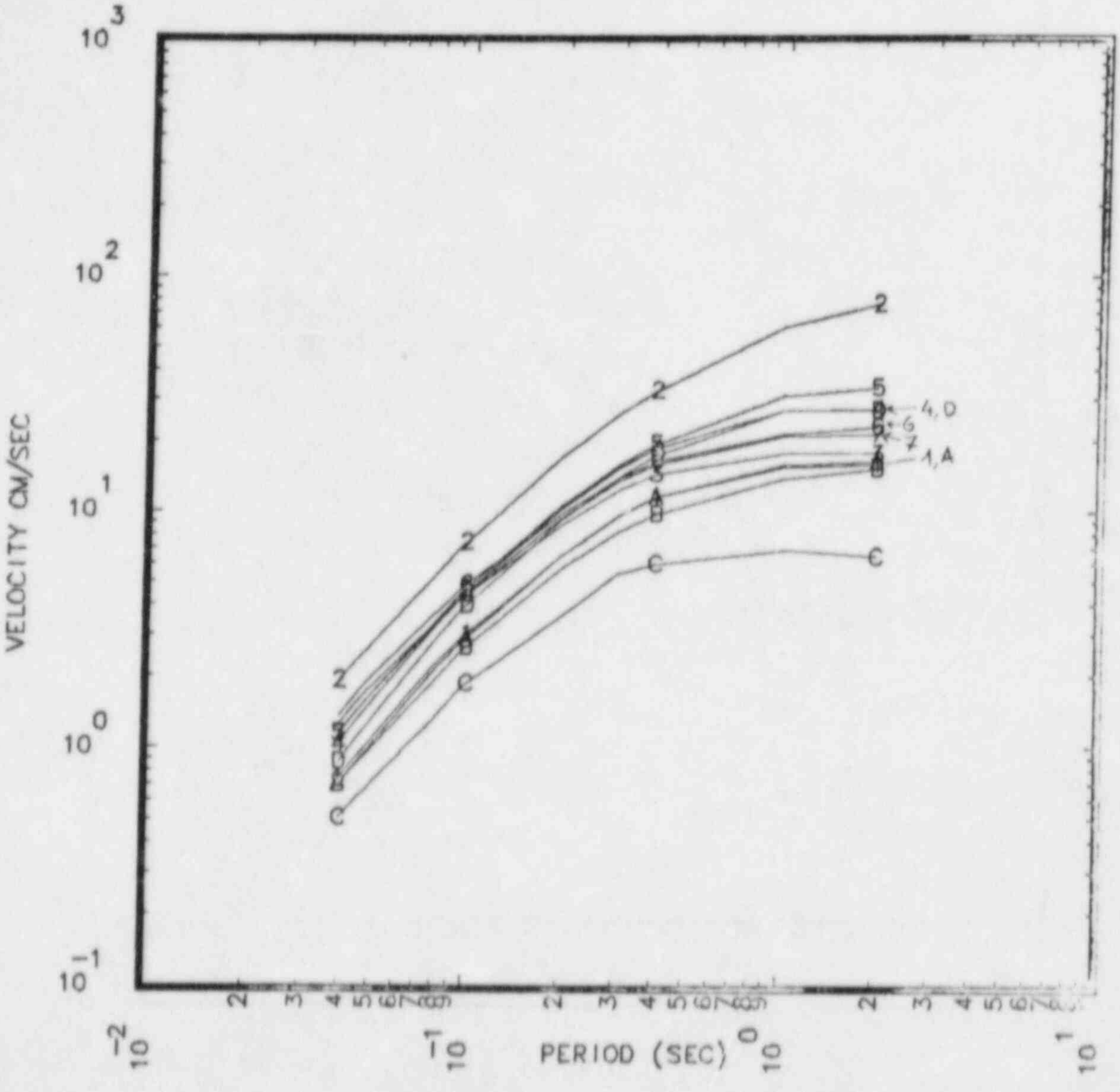


500., 1000., 2000., 5000., 10000. YEARS RETURN PERIOD
BEST ESTIMATE SPECTRA COMBINED OVER ALL EXPERTS
VELOCITY CM/SEC
PERIOD (SEC)
VOGTLE

Figure V0.4

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

500. YEARS RETURN PERIOD

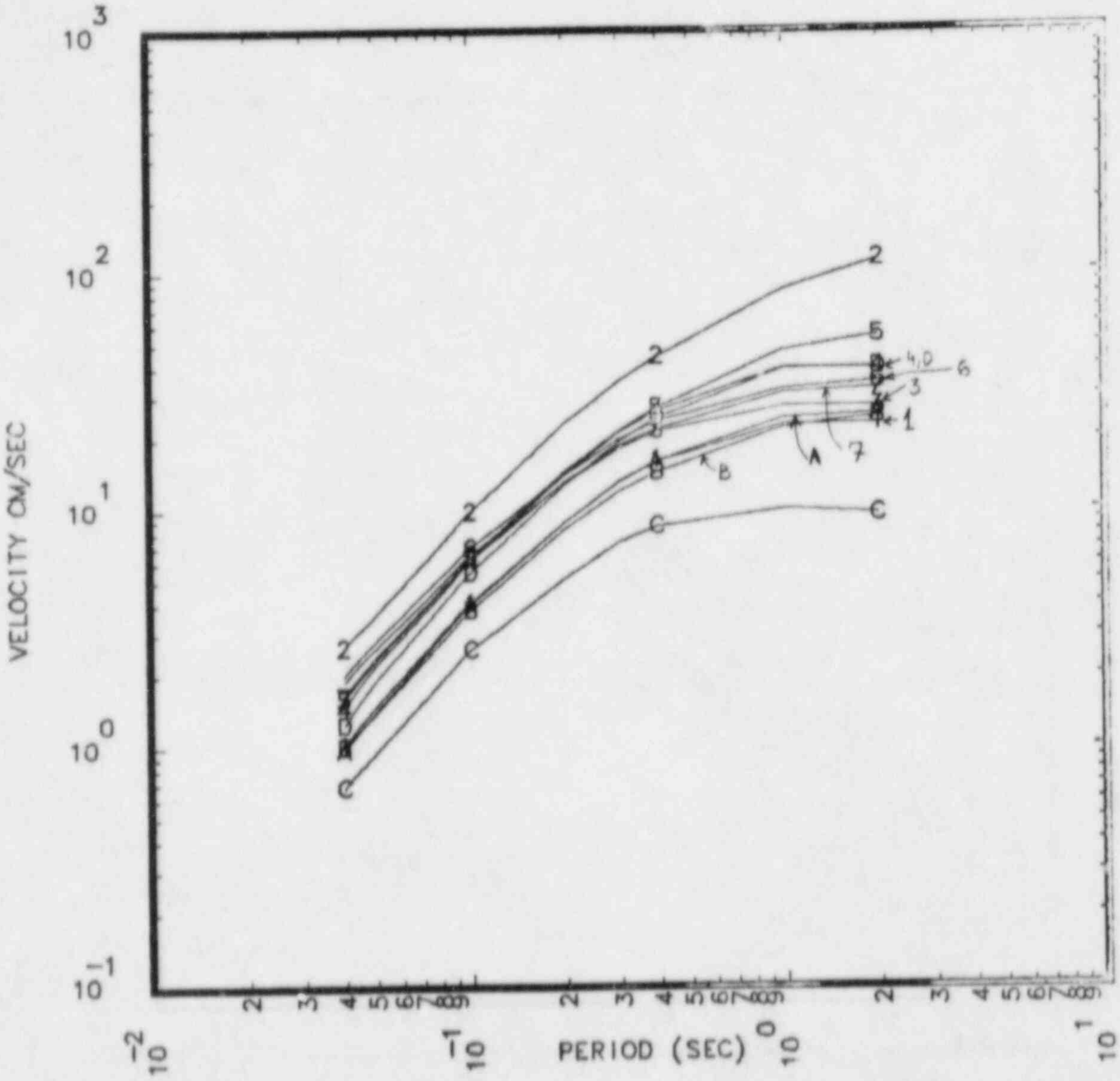


VOGTLE

Figure V0.5

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

1000. YEARS RETURN PERIOD

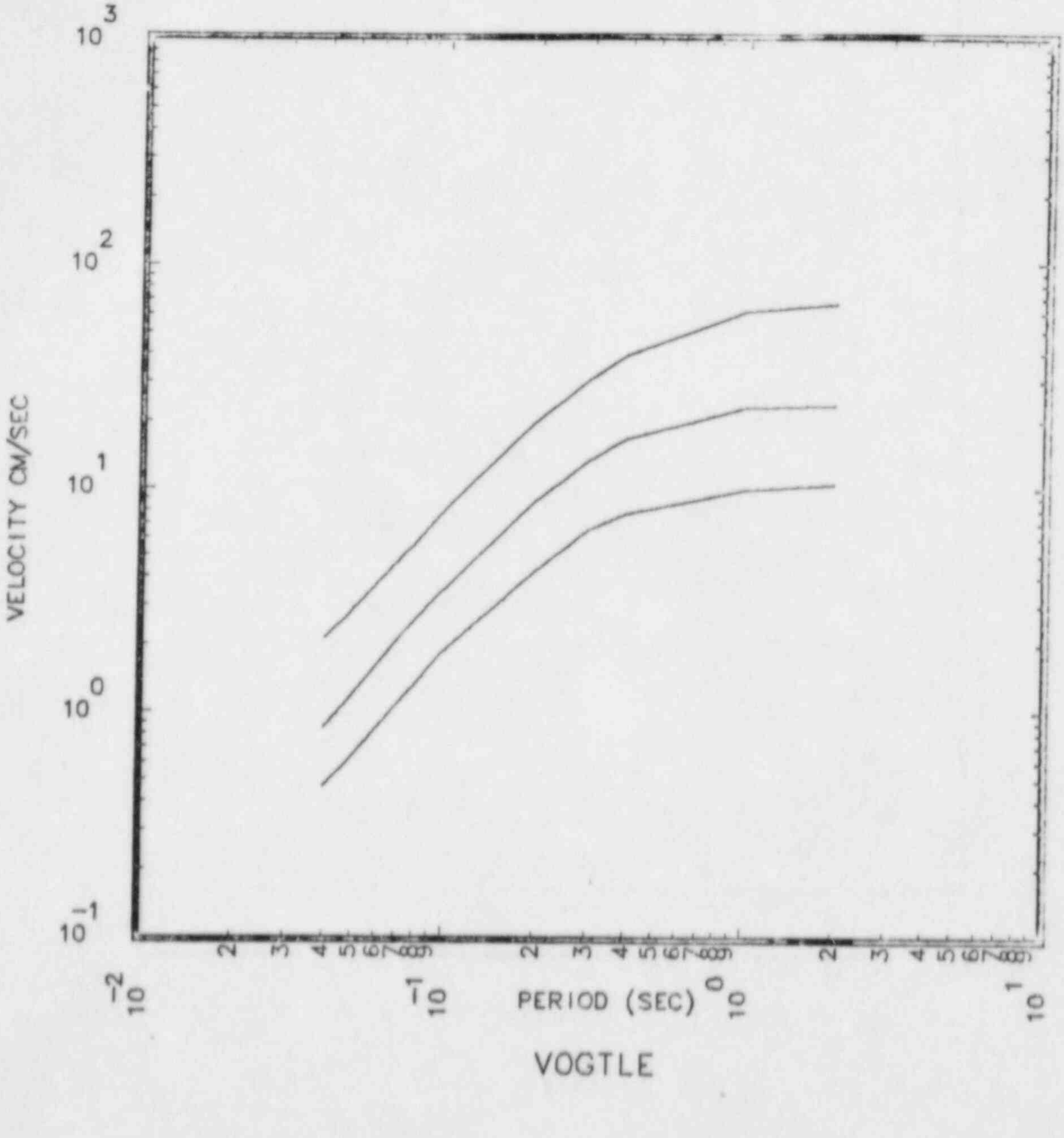


VOGTLE

Figure VO.6

PERCENTILES = 15.0,50.0 AND 85.0

500. YEARS RETURN PERIOD

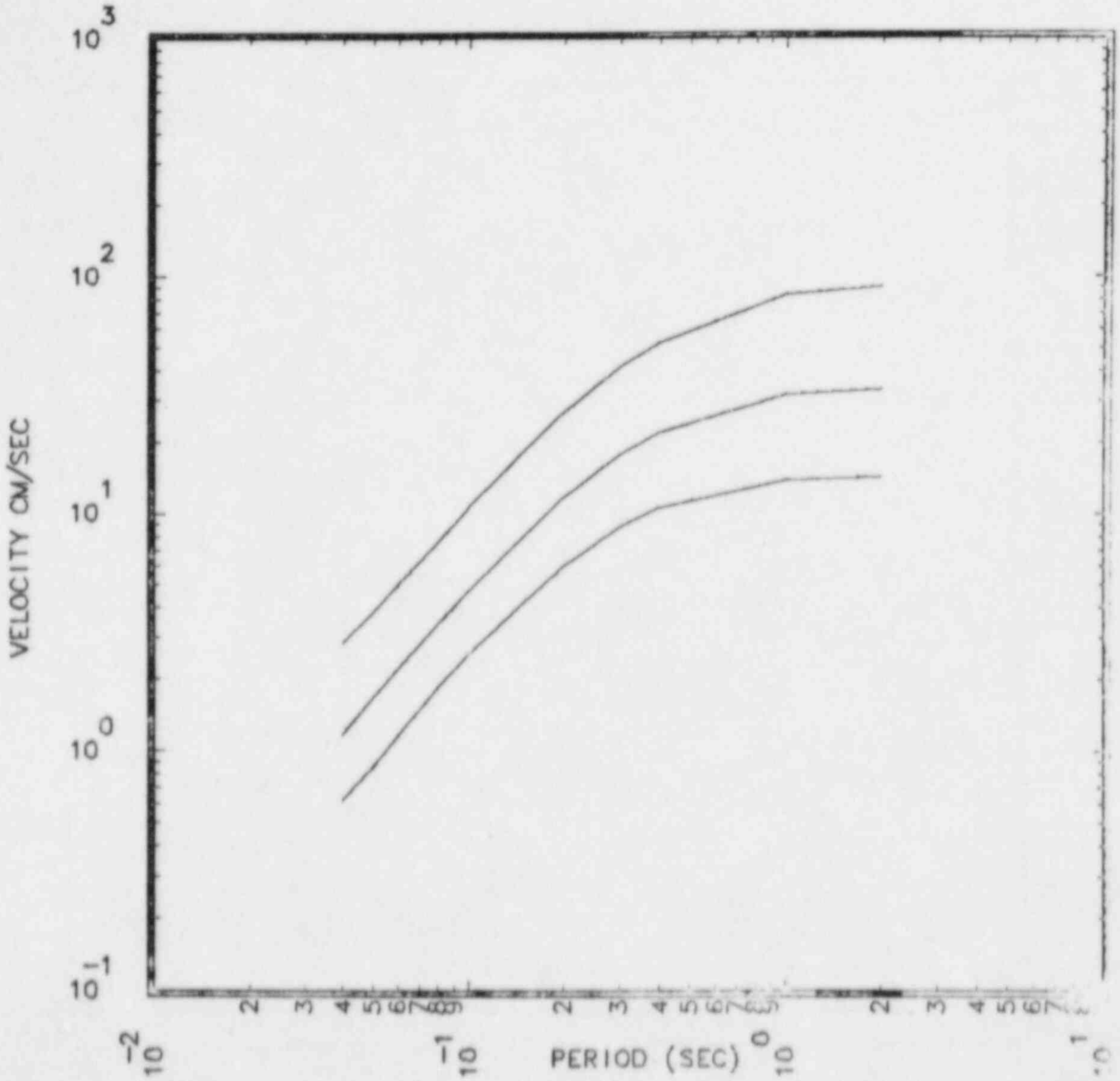


VOGTLE

Figure V0.7

PERCENTILES = 15.0,50.0 AND 85.0

1000. YEARS RETURN PERIOD



VOGTLE

Figure V0.8

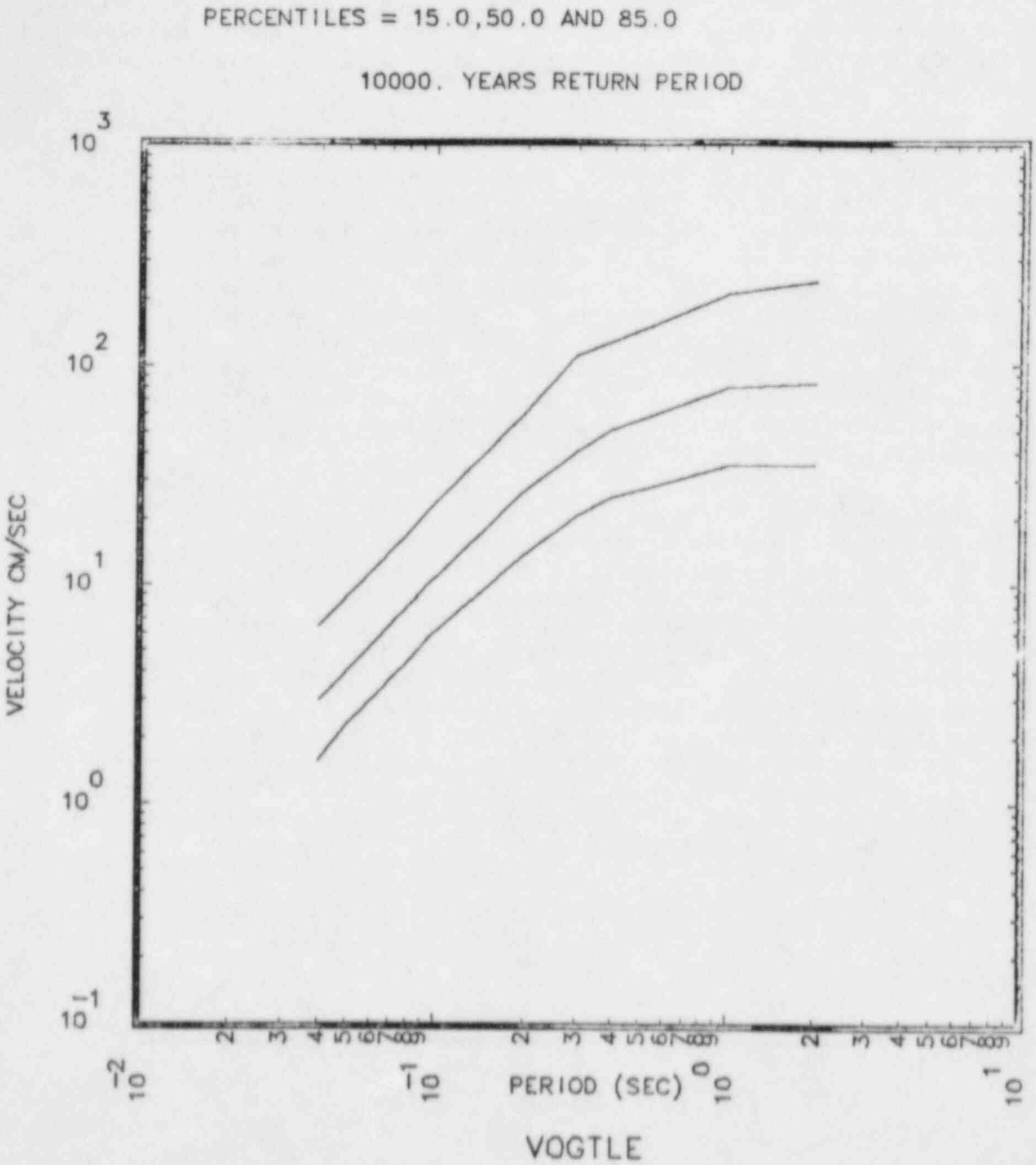

PERCENTILES = 15.0,50.0 AND 85.0
10000. YEARS RETURN PERIOD
VELOCITY CM/SEC
PERIOD (SEC)
VOGTLE

Figure V0.9

4.3.10 Maine Yankee (MY)

4.3.10.1 General

Maine Yankee is located in the middle of the northeast region of the EUS. It is classified as a rock site. For none of the seismicity experts does it fall within the CZ and thus is within a specified zone on each best estimate zonation.

4.3.10.2 PGA Hazard Curves

The BEHC is presented on Fig. MY1 for results combined over all experts, and in Fig. MY2 for results per seismicity expert. Figure MY2 does not show any outlier, but one curve in particular (HC for expert 12) exhibits a significantly different shape. At low PGA, this curve is among the highest estimates and at high PGA levels it is one of the two lowest curves. This is due to the combination of relatively high seismicity in the dominant zone 3 and low magnitude cutoff of 5.7. The experts' spread appears to be average with an interval of a factor of 3 to 4 at low PGA to 20 to 30 at high PGA. The results of the CPHC are consistent with the above with an increase in dispersion at low PGA, as shown in Fig. MY3. The BEHC falls a factor of 3 to 4 higher than the 50th percentile curve.

4.3.10.3 Uniform Hazard Spectra

The BEUHS presented in Fig. MY4 combined over all experts for the five selected RP's are smooth spectra-looking curves. The dispersion in the experts' opinions shown on Fig. MY5 is smaller than average, typically a factor of 3 to 4 from the lowest to the highest BEUHS, and there is no clear oulier in this case. The same applies to the 1,000 year RP case, with even some reduction in dispersion, of Fig. MY6. As a result of this uniformity of opinion and also as a result of the symmetry of the distribution of the parameters, the CPUHS is shown in Fig. MY7, MY8 and MY9 show a lower than average dispersion in the spectral hazard estimates. Typically, the ratio between the 15th and 50th percentile curve or between the 50th and 85th percentile curves is a factor of 2 or less, and the 50th percentile curve is practically the same as the BEUHS.

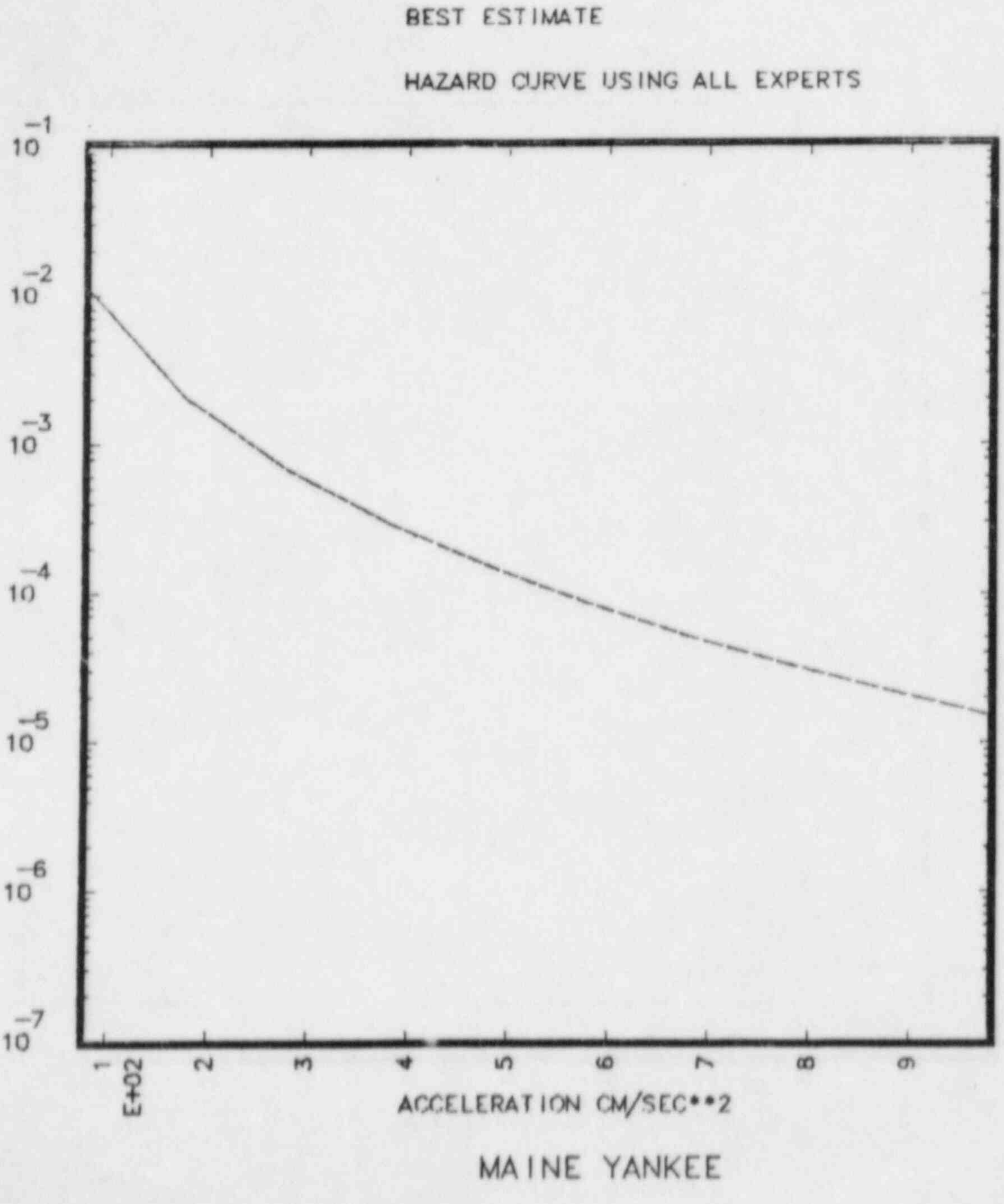
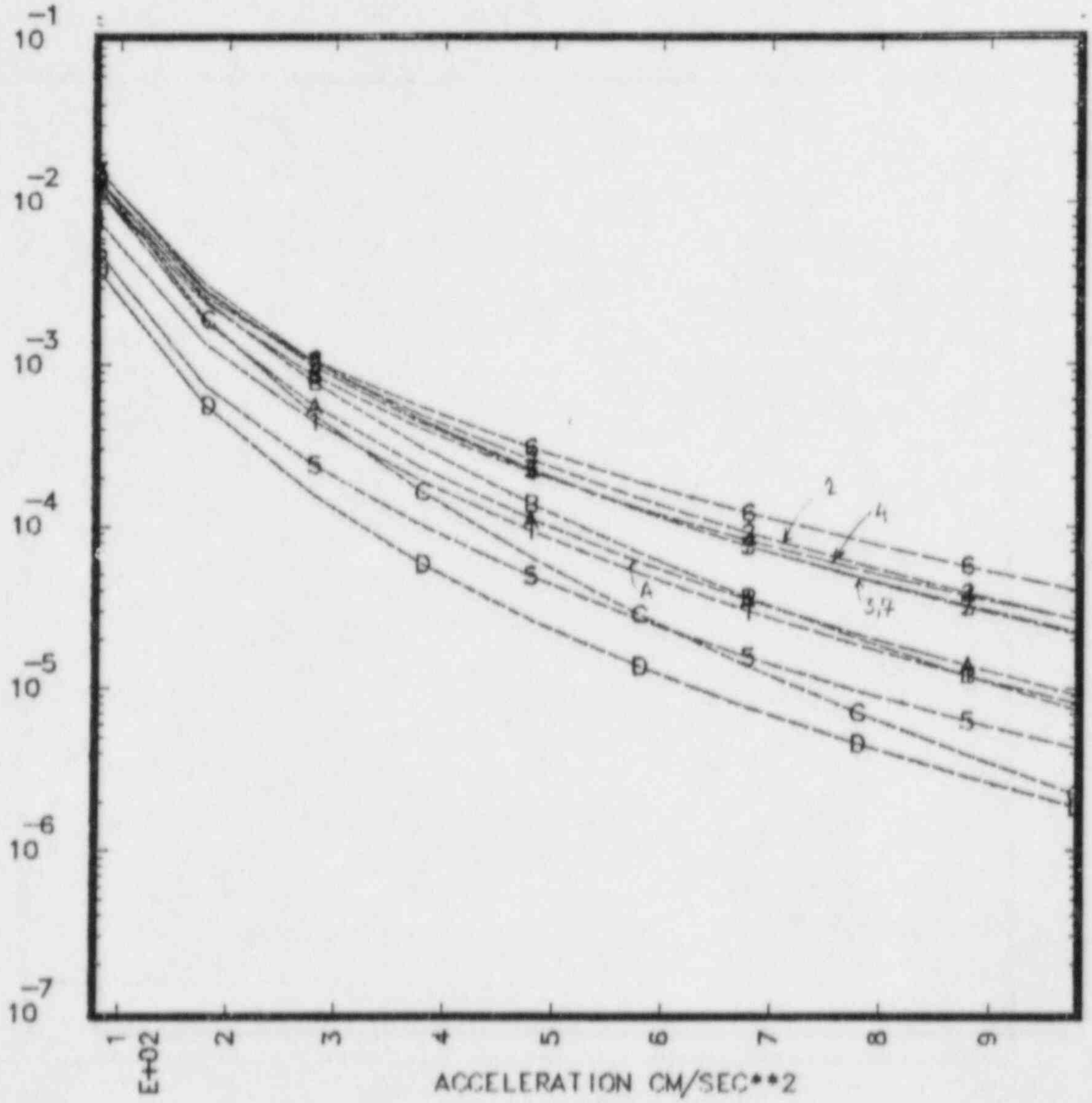

BEST ESTIMATE
HAZARD CURVE USING ALL EXPERTS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
MAINE YANKEE

Figure MY.1

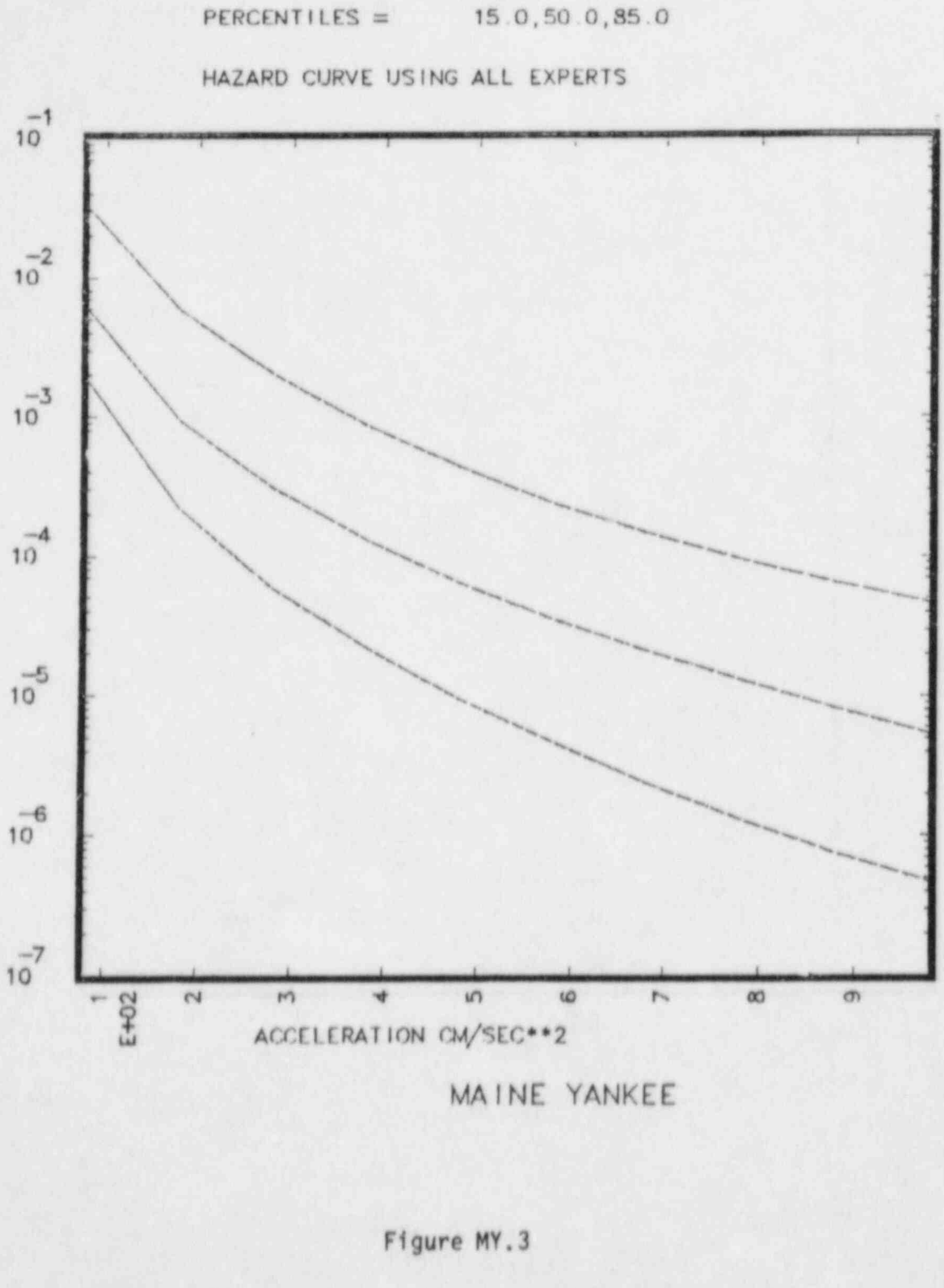
BEST ESTIMATE

FOR THE SEISMICITY EXPERTS



MAINE YANKEE

Figure MY.2

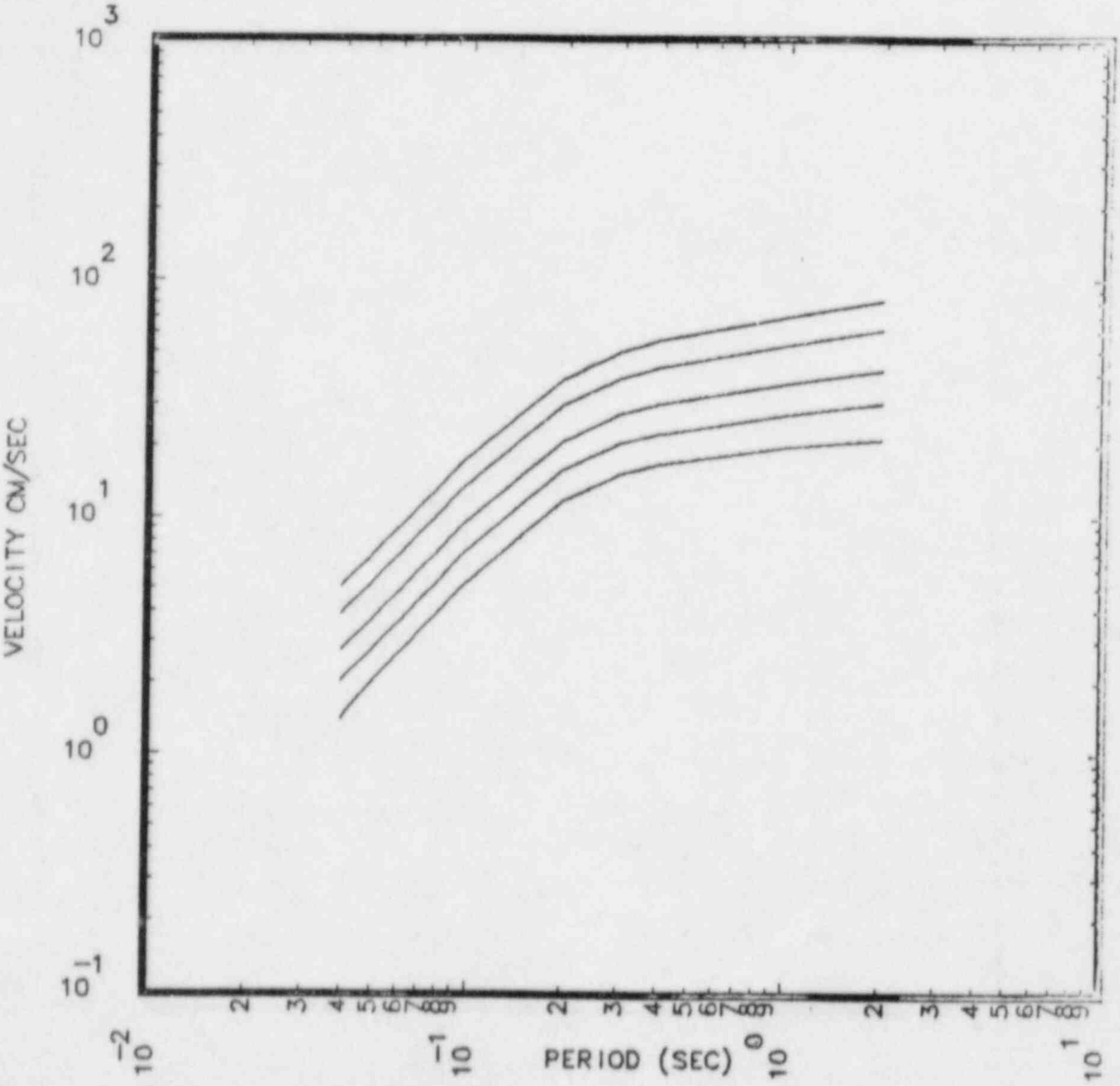


PERCENTILES = 15.0,50.0,85.0
HAZARD CURVE USING ALL EXPERTS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
MAINE YANKEE

Figure MY.3

500., 1000., 2000., 5000., 10000. YEARS RETURN PERIOD

BEST ESTIMATE SPECTRA COMBINED OVER ALL EXPERTS

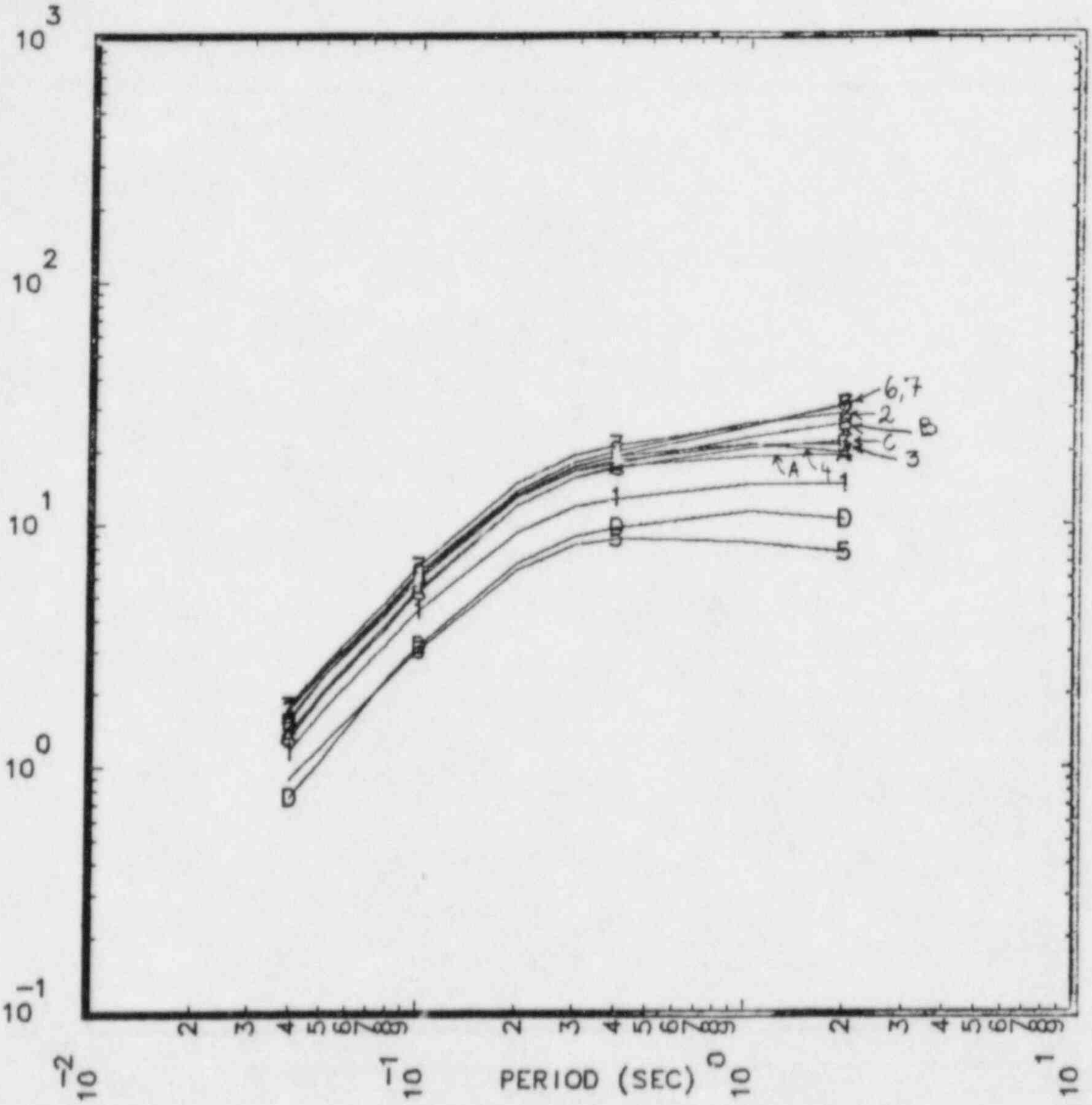


MAINE YANKEE

Figure MY.4

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

500. YEARS RETURN PERIOD

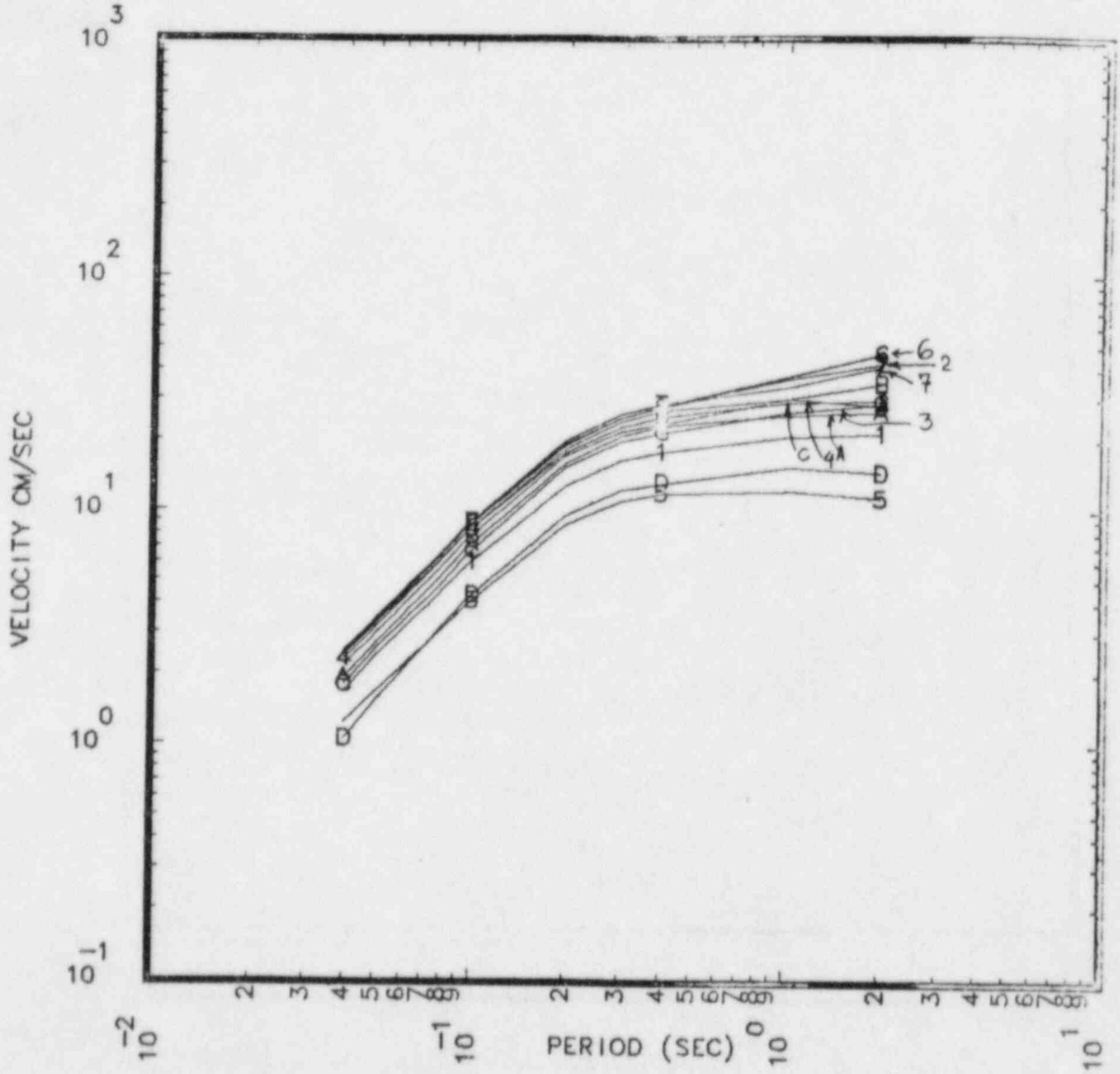


MAINE YANKEE

Figure MY.5

BEST ESTIMATE SPECTRA BY SEISMIC EXPERT FOR

1000. YEARS RETURN PERIOD



MAINE YANKEE

Figure MY.6

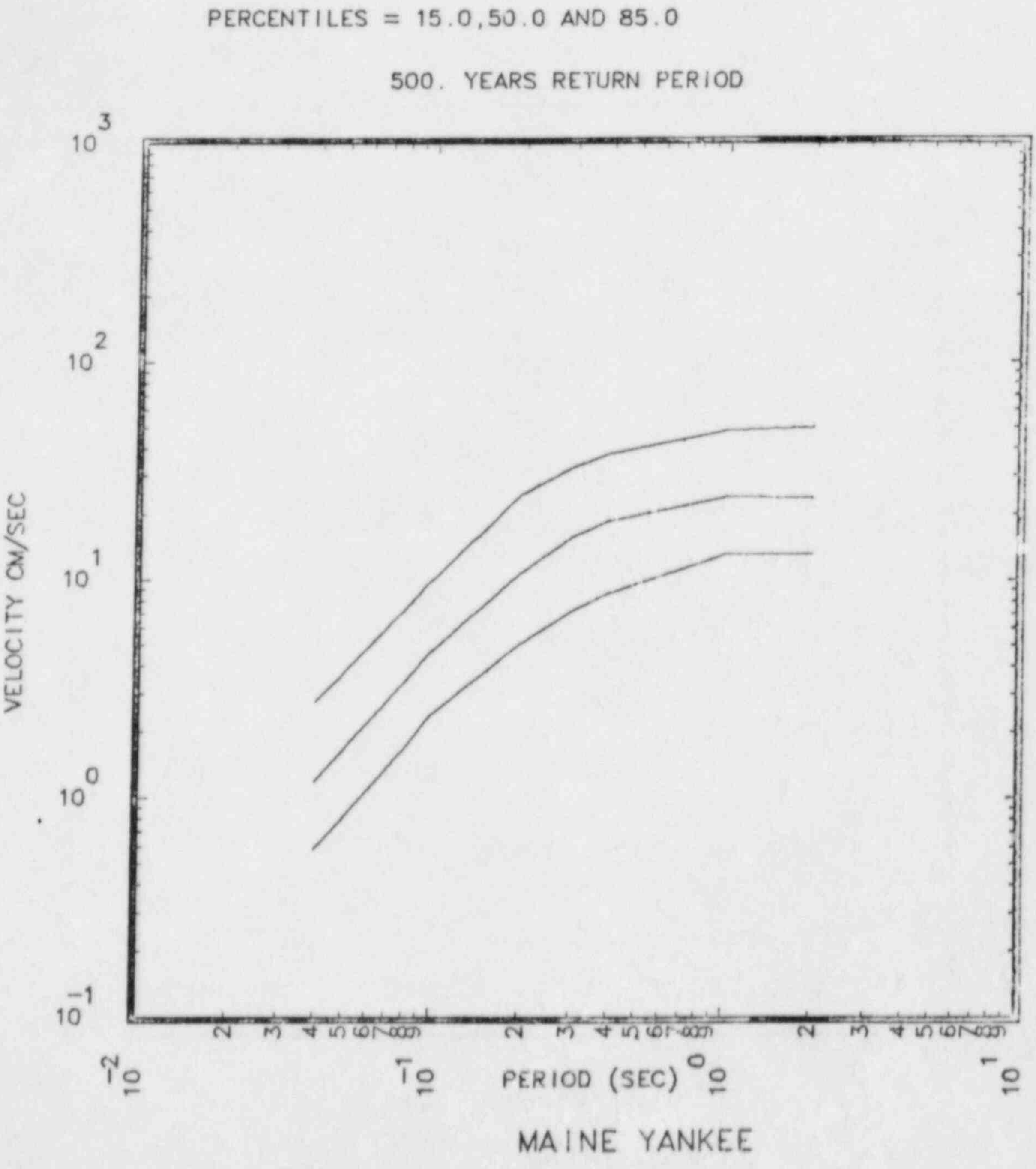
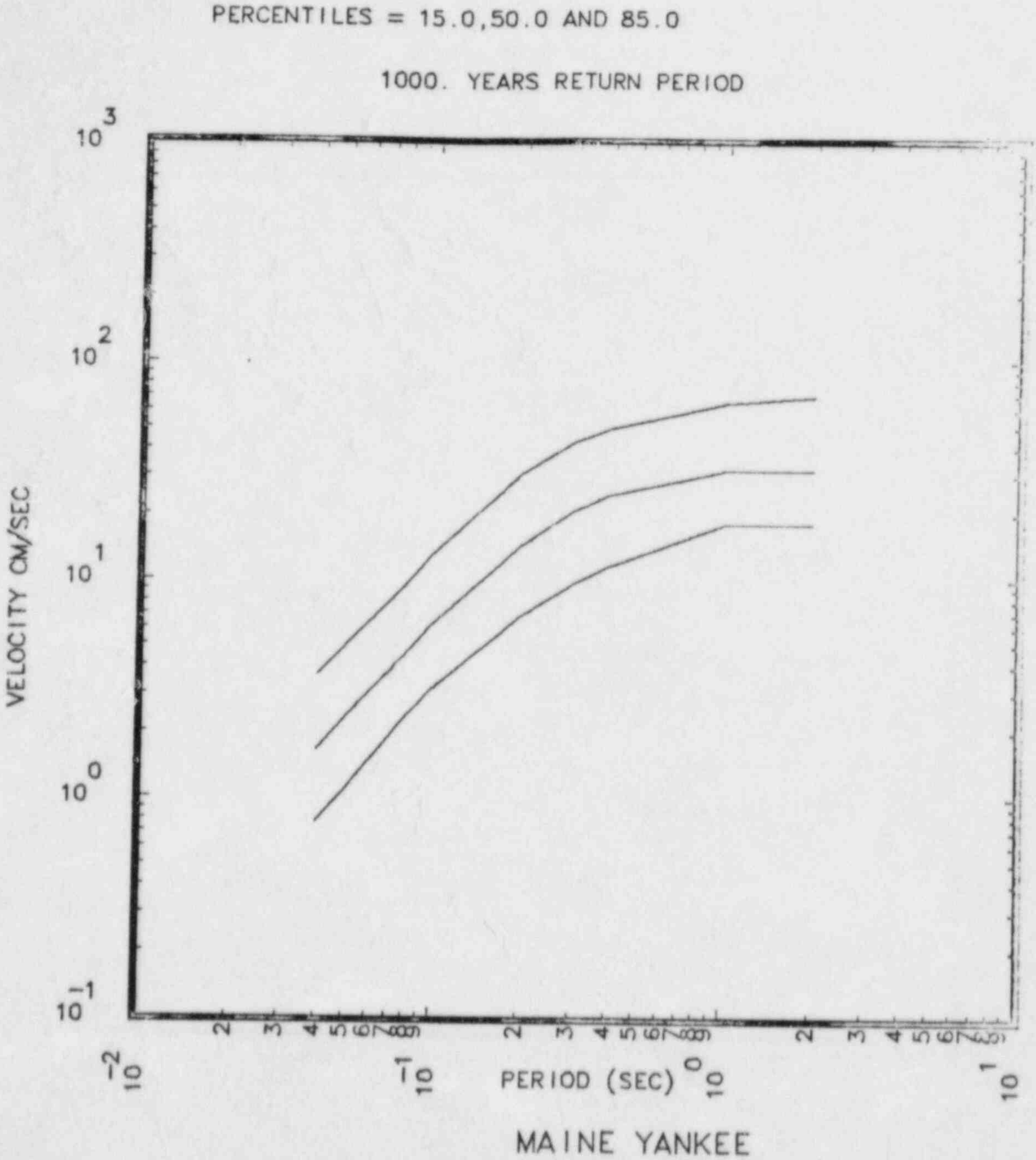

PERCENTILES = 15.0,50.0 AND 85.0
500. YEARS RETURN PERIOD
VELOCITY CM/SEC
PERIOD (SEC)
MAINE YANKEE

Figure MY.7



PERCENTILES = 15.0,50.0 AND 85.0
1000. YEARS RETURN PERIOD
VELOCITY CM/SEC
PERIOD (SEC)
MAINE YANKEE

Figure MY.8

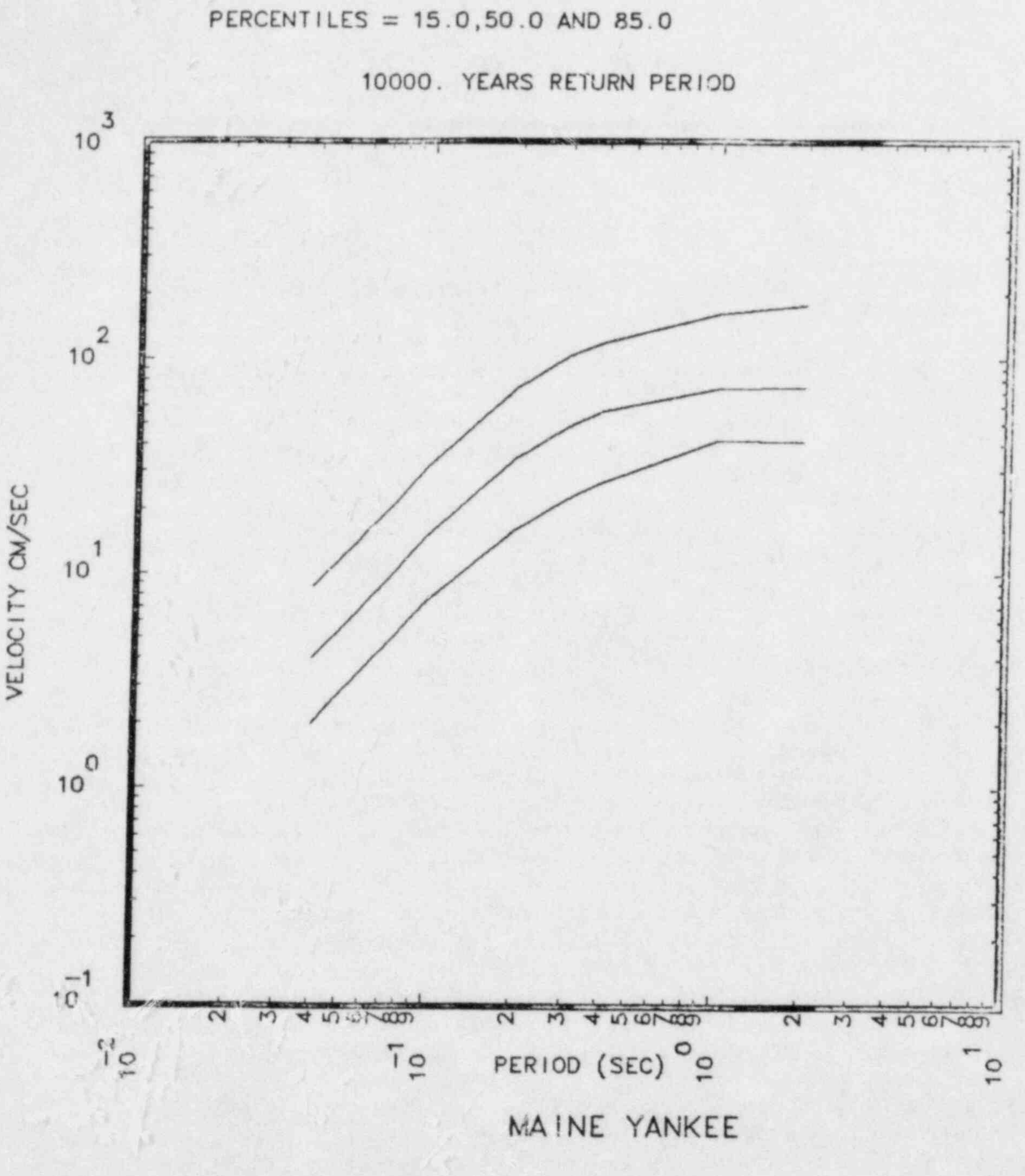

PERCENTILES = 15.0,50.0 AND 85.0
10000. YEARS RETURN PERIOD
VELOCITY CM/SEC
PERIOD (SEC)
MAINE YANKEE

Figure MY.9

SECTION 5: COMPARISON TO SEP RESULTS

5.1 Background

In Section 1 we noted that this project, The Seismic Hazard Characterization of the Eastern United States identified hereafter as simply the SHC, had its roots in an earlier study (Bernreuter and Minichino (1983)) performed as part of NRC's SEP. Six out of eleven seismicity Experts participating in this study also participated in the SEP study (see Table 5-1). This provides an excellent opportunity to examine two important questions:

1. How stable is the process of using expert judgment?

2. How different would the results be if different experts were involved?

The members of the SEP Panel provided their responses to our SEP Questionnaire between January and March, 1979 and updated their input in June-July, 1980. Although only a relatively short time has elapsed since the SEP Experts provided their input, there has been considerable activity which could have had an impact on the thinking of various panel members:

- Several major studies have been completed, e.g, the joint NRC/USGS Charleston study, the New Madrid study and the New England study.
- Several earthquakes have occurred - most notable were the 1982 New Brunswick series and the 1982 New Hampshire earthquakes.

There are a number of major differences between the SHC and the SEP studies that must be accounted for in attempting to assess the stability of results and/or the impact of additional panel members. As discussed in Section 1 of this report, we have performed a complete uncertainty analysis - whereas in the SEP study the uncertainty analysis was much more limited. Even considering the differences between the two studies it is possible to make some useful comparison. As only two sites are common between the two studies - Millstone and LaCrosse - it was necessary to expand the basis for reaching conclusions by obtaining limited results at the Braidwood and Limerick sites using the seismicity models provided by the SEP panel members. As neither of these two sites were part of the SEP the results have only limited validity because the SEP Experts were asked to focus on the nine sites under study. However, as both Braidwood and Limerick are near sites that were part of the SEP, the seismic hazard results computed for Braidwood and Limerick using the SEP models should be a reasonable extrapolation of the SEP results.

5.2 Comparisons Using Only Experts Participating in Both Studies

In this section we examine the implication of the differences between the seismicity information supplied by the Experts who participated on both the SEP Panel and as members of the SHC Seismicity Panel. As different zones are involved between the two studies it is necessary to make comparisons at the hazard curve level. It is difficult to evaluate differences in zonation that occur between the SHC and the SEP because in the SEP the Experts were asked to provide seismicity information for two pre-zoned maps, as well as, allowed to provide their own zonation. A number of the Panel Members only used the zones on the two pre-zoned maps.

TABLE 5-1

Experts Who Participated in Both the SHC and the SEP

Professor G. A. Bollinger
Mr. R. J. Holt
Professor O. W. Nuttli
Dr. P. W. Pomeroy
Professor R. L. Street
Professor M. N. Toksoz

Experts Who Only Participated in the SEP	Experts Who Only Participated in the SHC
Professor E. Chiburis	Professor A. Johnston
Dr. M. Chinnery	Professor A. L. Kafka
Professor R. B. Hermann	Professor J. E. Lawson
Professor M. L. Sbar	Professor L. T. Long
	Dr. J. C. Stepp

Table 5-2
List of the Experts Who Participated in Both the SEP and the SHC

Expert Number
1
3
4
5
7
10(A)

Note: The letters enclosed in () are the plotting symbols used for all the figures in this section.

All the hazard curves shown in this section are based on the ground motion model used in our sensitivity studies in Section 4.2 (model No. 7, Table 3.4.3). Recall that this ground motion model was chosen as the best estimate model by two of our EUS Ground Motion Experts. It is also important to remember that these are pre-feedback results.

5.2.1 Millstone

Figure 5.1a shows, for the Experts participating in both the SHC and the SEP, the BEHC per Seismicity Expert for this study for the Millstone site and Fig. 5.1b shows BEHC per SEP Seismicity Expert from the SEP study. Figure 5.1c over-plots the two sets of hazard curves. The SEP curves are denoted by the large symbols and the curves for the SHC are identified by the small symbols. For simplicity, the SEP Expert numbers are changed to agree with the Expert numbering for the SHC on the plots. Table 5-2 lists the number assigned to the Experts that participated in both studies. It is seen from Fig. 5.1c that there is general agreement between the two studies - however, there appears to be a major shift in the hazard curve for Expert 10. We also see that for the other Experts their SEP hazard curves show less dispersion than in the SHC. There are two reasons for this. First, as we have already noted our pre-zoned maps may have biased the Experts somewhat towards the same zonation. Secondly, many of the Experts in the SEP study did not provide the rate of earthquake occurrence for any of the zones. The activity rate for these zones was developed for those Experts in a uniform manner, Bernreuter (1981). In this study each Expert developed his own zonation and developed his own estimates of the rate of occurrence of earthquakes for the various zones. Thus, it is not surprising that this study shows larger differences between Experts than the SEP study.

Expert 10 was one of the few SEP Experts to provide his own rate parameters. Table 5-3 gives a comparison between the SEP response and for the SHC for Expert 10 for the zone that contributes most to the loading at the Millstone site. This is a case where the b value plays an important role. For example, the b value difference between the SEP study and the SHC leads to over a factor of 5.5 higher rate of earthquakes larger than $m_b = 4.5$ for this project than for the SEP study. This, coupled with the difference in M_U leads to the higher hazard estimate for the Millstone site for this study for Expert 10 as compared to the SEP results.

The hazard at the Millstone site for Expert 3 also shows a considerable increase between the SEP and the SHC. One of the main reasons for this is that for the SEP Expert 3 gave the best estimate of M_U as MMVII for the zone that contributes most to the hazard whereas for the SHC M_U was given as m_b = 6.5. Thus, Expert 3's M_U is significantly larger for the SHC than for the SEP. Expert 3 did not provide independent estimates for the rate of earthquake activity for the New England zones for the SEP study. There is also a significant difference between Expert 3's zones in the SEP study and the SHC study indicating that there has been some change in the opinion of Expert 3 about the zonation of New England.

Table 5-4 summarizes the significant differences between the two sets of input for each Expert that lead to differences in the hazard curves between this study and the SEP study. Overall, there is reasonable agreement between the two sets of curves shown on Fig. 5.1c.

Table 5-3
Seismicity Parameters for the Zone that Contributes Most to the Loading at the Millstone Site for Expert 10

	SEP	SHC
a	2.56	2.45
b	-1.11	-0.92
M_U	5.0	5.5

The area of the two zones is the same.

Table 5-4
Summary of Differences in the Seismic Hazard Curves
Between SEP and The SHC for the Millstone Site

SHC Number	SHC Change From SEP	Differences in Seismicity Parameter as Compared to the SEP
3	Higher	M_U increased from MMIVII to $m_b = 6.5$. Also a zonation difference
10(A)*	Much Higher	Higher M_U and much higher seismicity.
1	A Little Higher	Increase in M_U from BE of 5.75 to approximately 6.44 (MMI9.5).
5	Lower	Lower M_U and larger absolute value for b in Zone 8. In the SEP zone equivalent to Zone 8 contributed significantly to the hazard.
4	Lower	Change in zonation leading to a lower rate of seismicity for this study.
7	About Same	

*Plot Symbol

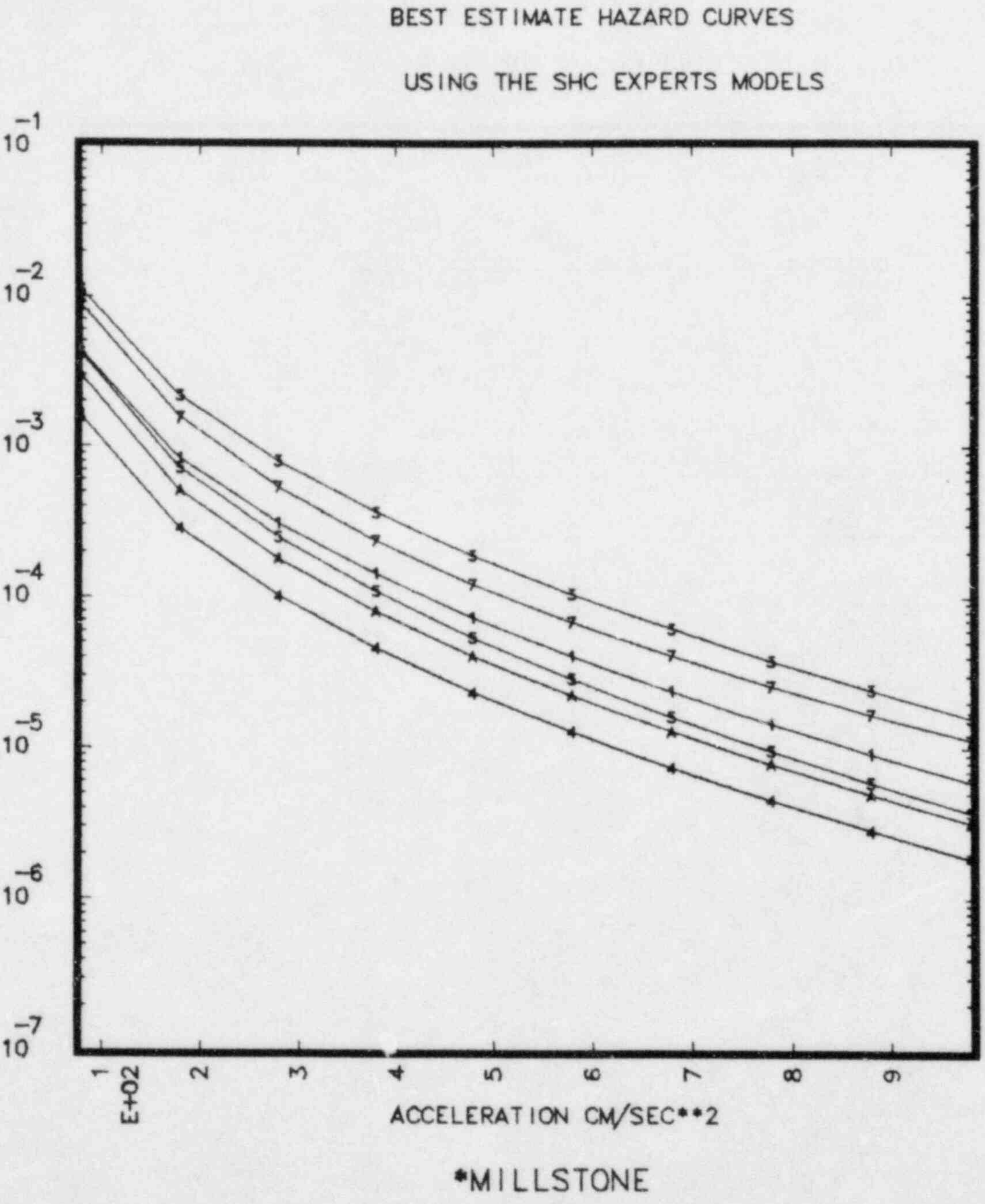
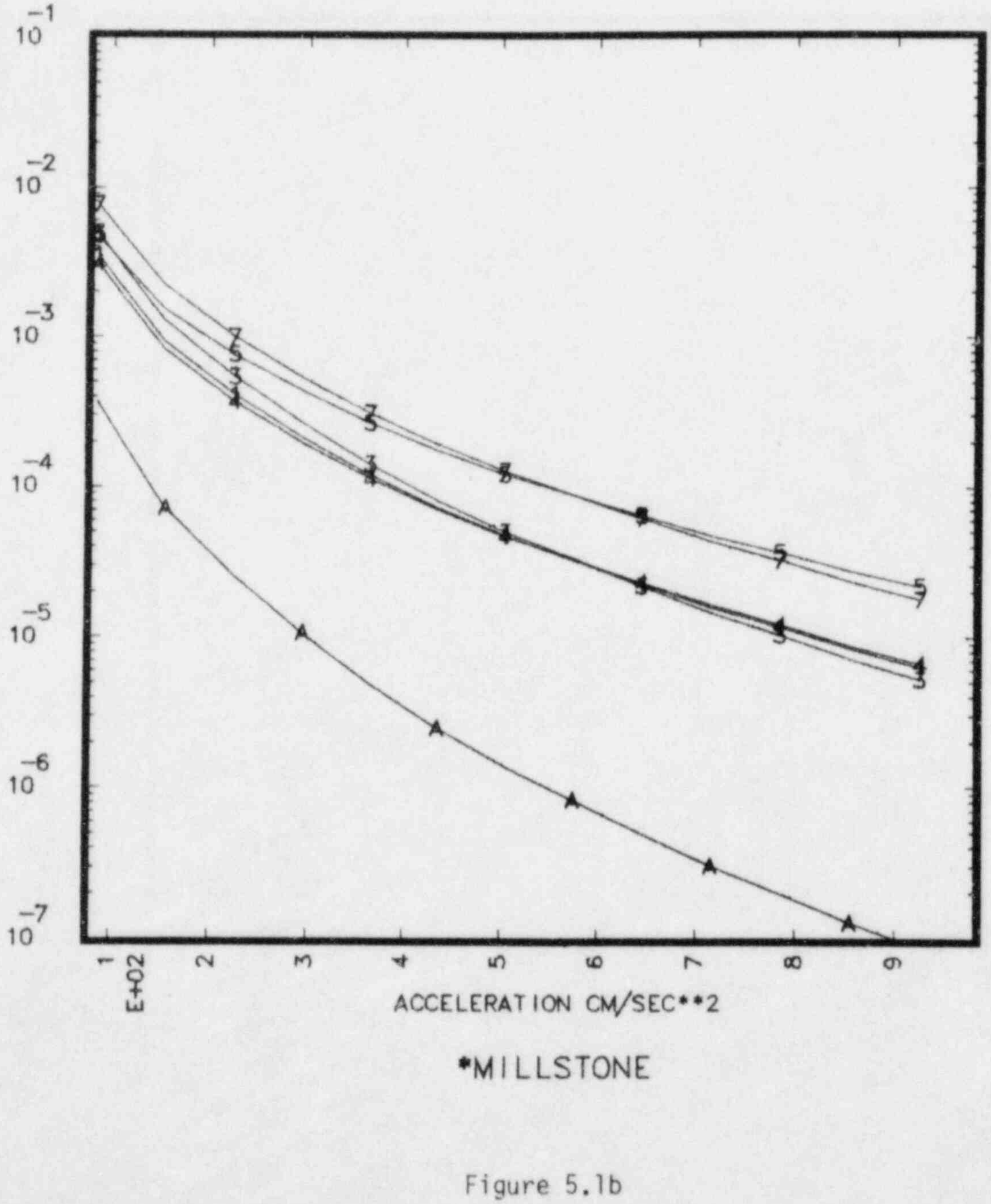


Figure 5.1a - Only Experts Participating in Both Studies

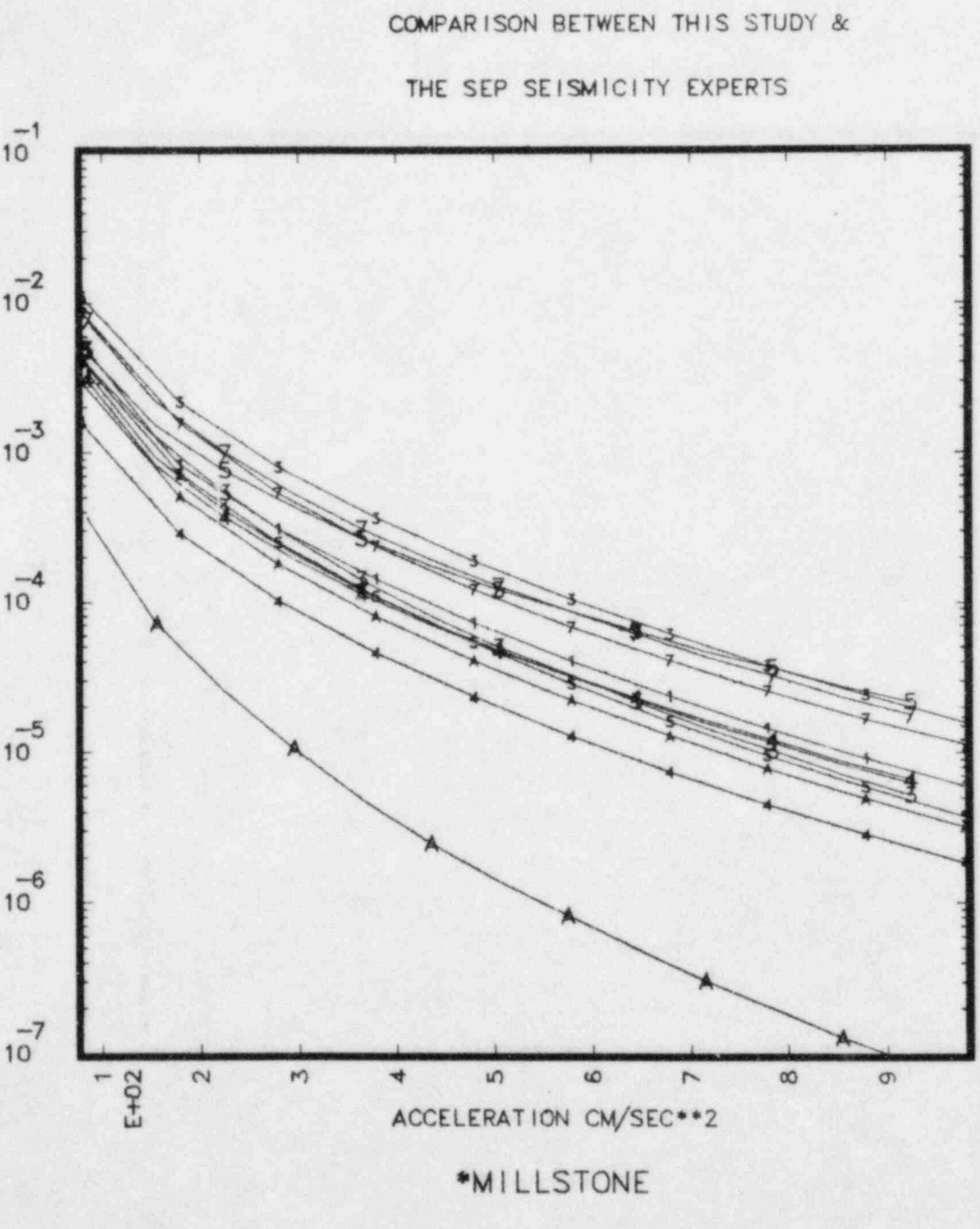
BEST ESTIMATE

FOR THE SEP SEISMICITY EXPERTS



*MILLSTONE

Figure 5.1b



COMPARISON BETWEEN THIS STUDY &
THE SEP SEISMICITY EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
*MILLSTONE

Figure 5.1c

5.2.2 LaCrosse

Figure 5.2a shows for the Experts participating in both the SHC and the SEP the BEHC per Seismicity Expert based on the zonation and seismicity parameters given in Appendix A for the LaCrosse site. Figure 5.2b shows the BEHC per Seismicity Expert based on the zonations and seismicity parameters developed for the SEP and Fig. 5.2c is an over-plot of Figs. 5.2a and b. Table 5-5 summarizes the significant differences between the two sets of input for each Expert that lead to differences in the hazard curve between the SHC and the SEP.

As can be seen from Fig. 5.2c the level of the hazard at the LaCrosse site has overall somewhat decreased for the same set of Experts in spite of one outlier. However, because only two of the Experts participating in both studies provided rate of earthquake occurrence estimates for the SEP it is not possible to draw a strong conclusion from this observation. There is reasonable agreement between the two sets of hazard curves shown on Fig. 5.2c.

5.2.3 Braidwood

Although the Braidwood site was not included in the SEP, is it located very near the Dresden site which was included in the SEP. Thus it is reasonable to use the SEP models to compute the seismic hazard at the Braidwood site. Figure 5.3a shows for the Experts participating in both the SHC and the SEP and the BEHC per Seismicity Expert based on their input for this study for the Braidwood site. Figure 5.3b shows the BEHC per Seismicity Expert based on the zonations and seismicity parameters developed for the SEP and Fig. 5.3c is an over-plot of Figs. 5.2a and b. Table 5-6 summarizes the significant differences between the two sets of input for each Expert that lead to differences in the hazard curves between the SHC and the SEP.

As can be seen from Fig. 5.3c, the level of the seismic hazard at the Braidwood site is, overall, in good agreement between the two studies, although slightly higher for the same set of Experts using the zonation and seismicity parameters they provided for the SHC as compared to the ones they provided for the SEP study. One reason for this is, as noted in Section 4.3.1, that for the SHC many Experts put a zone in Region of the Central Stable Region where the Braidwood site is located. In the SEP only one of the Experts who participated in both studies had such a zone. One other SEP Expert also put a zone in the Central Stable Region which included the Braidwood site. Generally, the net effect of this zone was to increase the rate of seismicity near the Braidwood site while generally decreasing the rate of seismicity in the CZ (larger Central Stable Region). Also, the M_U for the added zone was usually higher than for the CZ.

5.2.4 Limerick

The Limerick site is somewhat out of the region zoned with care by the SEP Experts. Thus specific conclusions cannot be drawn. However, the comparison is still of some interest. Figures 5.4a, b and c shows the results for the Limerick site. The two sets of results are in general agreement, however, there is a larger spread of results for the SHC than for the SEP. This comes in part, as discussed above, because many SEP Experts did not supply the rate of activity for the various zones. Thus the earthquake occurrence rates for many of the SEP Experts were established in a very uniform manner as contrasted to the SHC.

Table 5-5
Summary of Differences in the Seismic Hazard Curves
Between SEP and The SHC for the La Crosse Site

SHC Number	SHC Change From SEP	Differences in Input
3	Lower	Higher M_U for this study but lower rate of activity in the CZ for this Study than for the SEP.
10(A)*	Much Higher	Expert increased M_U by 0.3 units and increased the rate of activity in the CZ.
1	None	One of the few Experts to provide earthquake rates for the SEP.
5	Much Lower	Lower M_U and a different b value results in a lower number of larger events.
4	Lower	Site is located in CZ of Expert 4 for both studies. However, Expert 4's new Zonation for the CUS has most earthquakes located in various zones so that the rate of seismicity in the CZ is lower compared to SEP.
7	N/A	Did not provide seismicity parameters for CUS for SEP.

*Plot Symbol

Notes: (1) The LaCrosse site is located in the CZ of most Experts.

(2) Only Experts 10 and 1 provided rate of earthquakes occurrence for the CUS for the SEP.

Table 5-6
Summary of Differences in the Seismic Hazard Curves
Between SEP and The SHC for the Braidwood Site

SHC Number	SHC Change From SEP	Differences in Input
3	Higher at Lower Range of of PGA Levels	Zone 14 influences hazard in lower range of PGA values. Higher rate than for the SEP.
10	Much Higher	Change in zonation with much higher M_U and rate of activity. No zone in SEP.
1	About the Same	Zonation slightly different. Differences in SHC accentuated by differences in computer programs used.
5	Lower	Lower M_U and a different b value which results in a lower number of larger events.
4	Higher	Added Zone 6 with higher rate and Larger M_U.
7	N/A	Did not provide seismicity parameters for CUS for SEP.

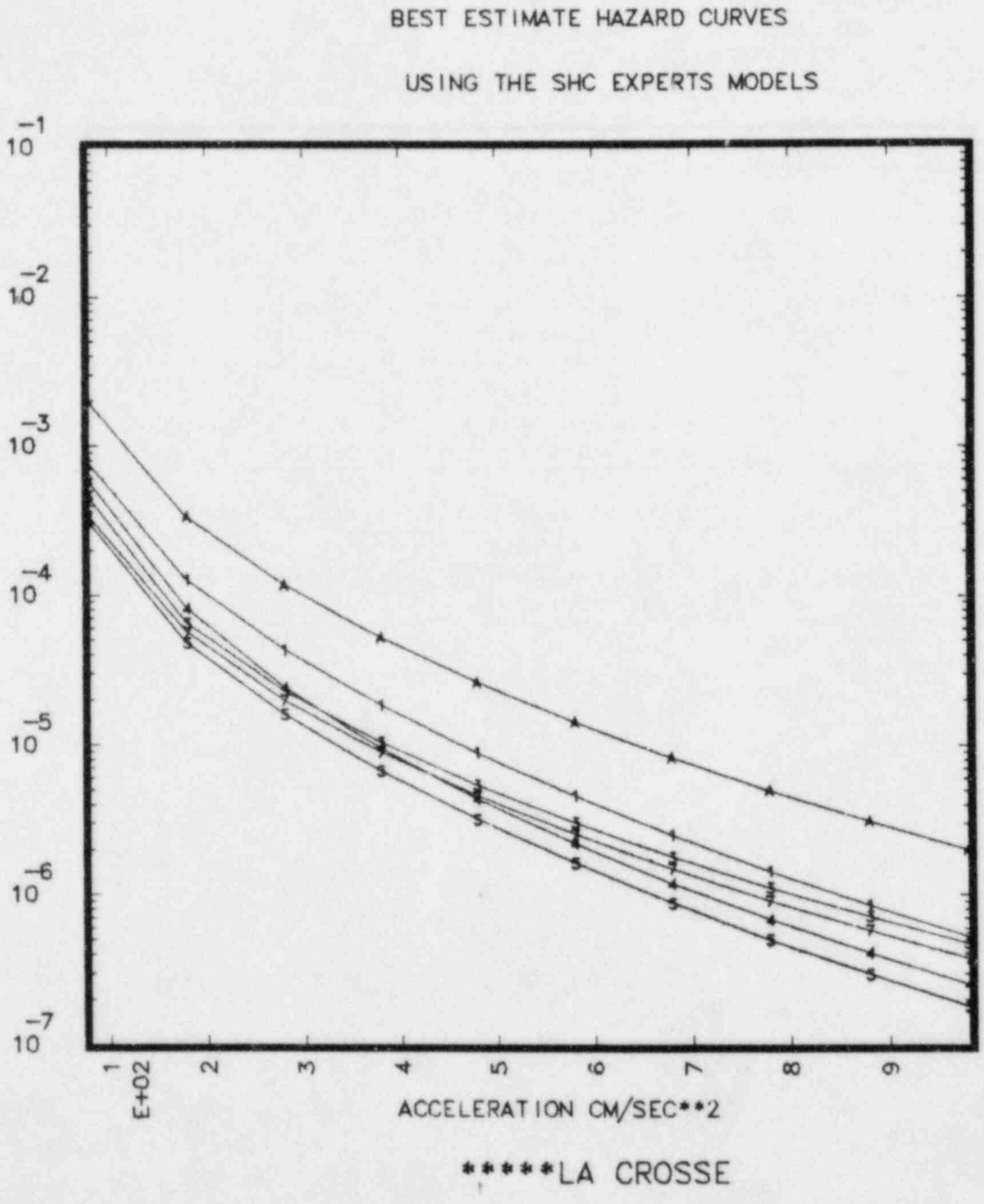


Figure 5.2a - Only Experts Participating in Both Studies

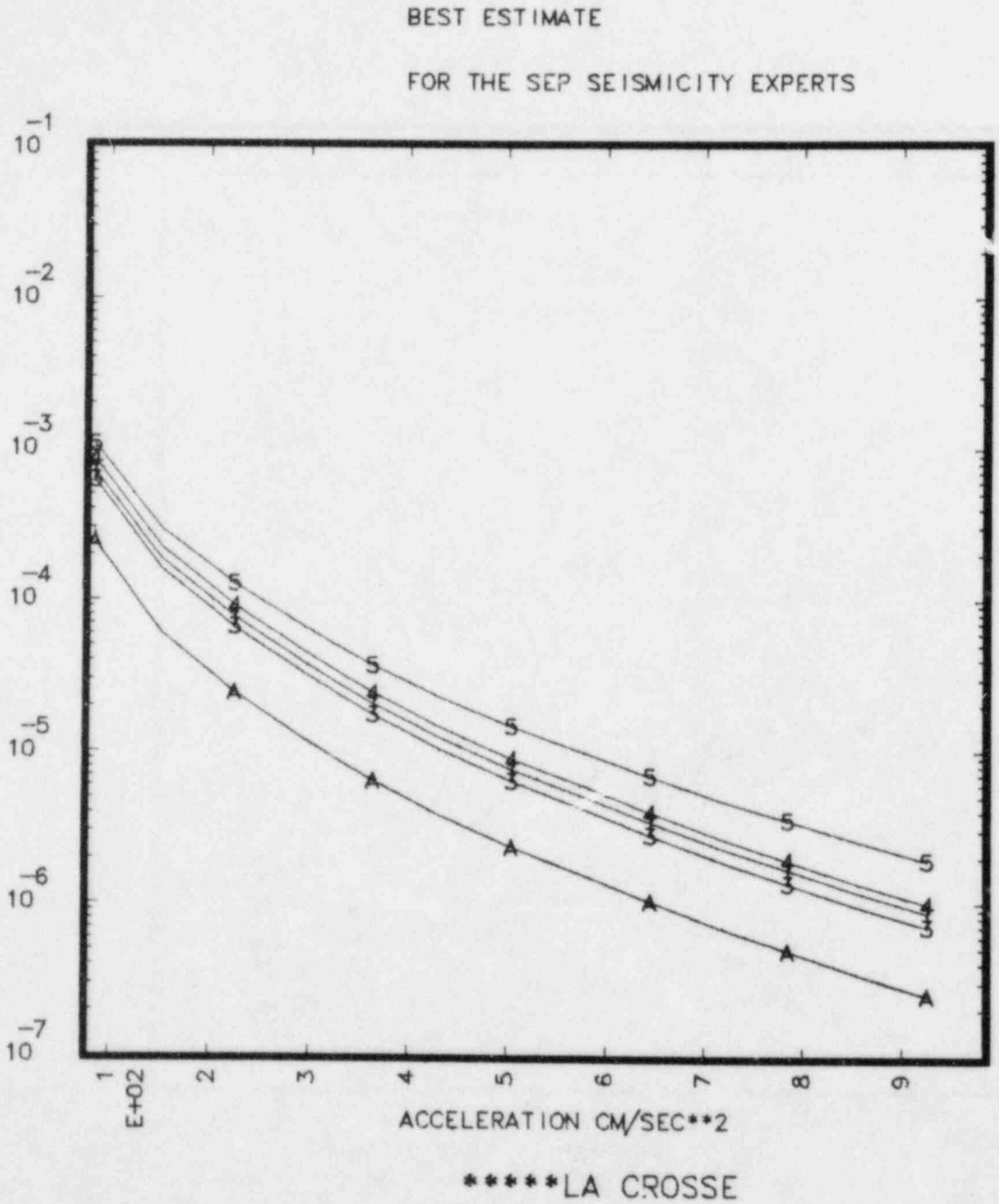
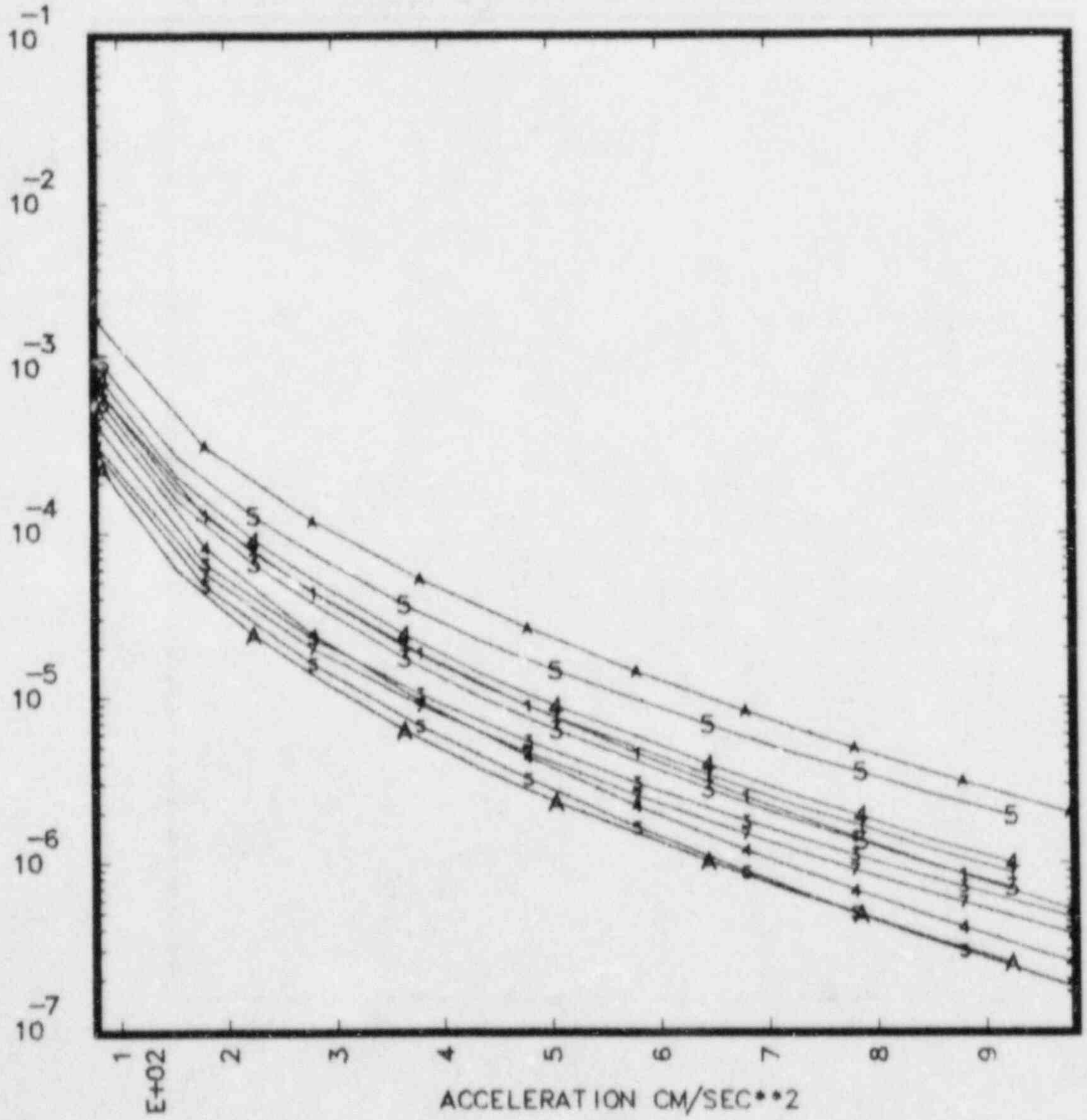

BEST ESTIMATE
FOR THE SEP SEISMICITY EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
*****LA CROSSE

Figure 5.2b

COMPARISON BETWEEN THIS STUDY &

THE SEP SEISMICITY EXPERTS



*****LA CROSSE

Figure 5.2c

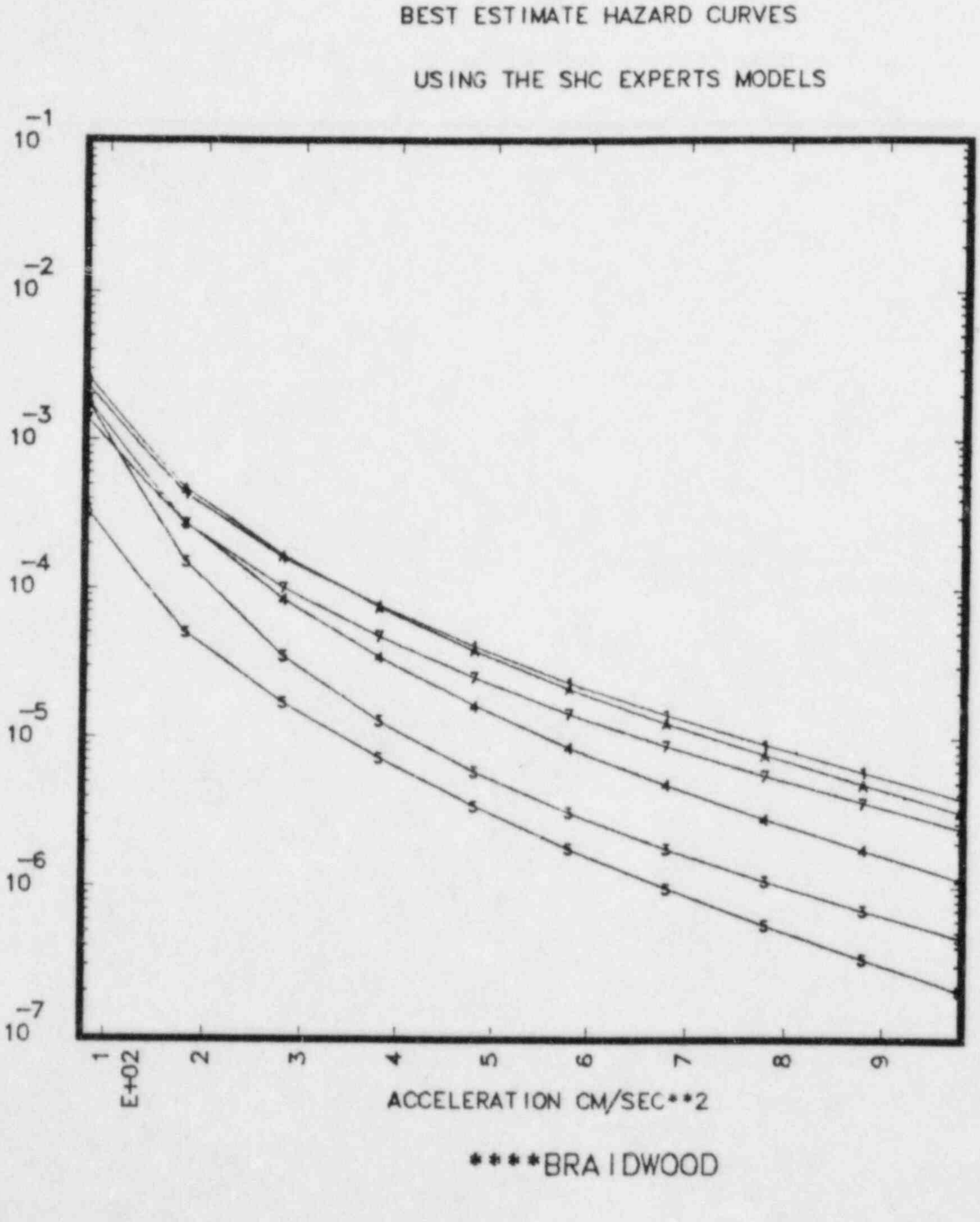
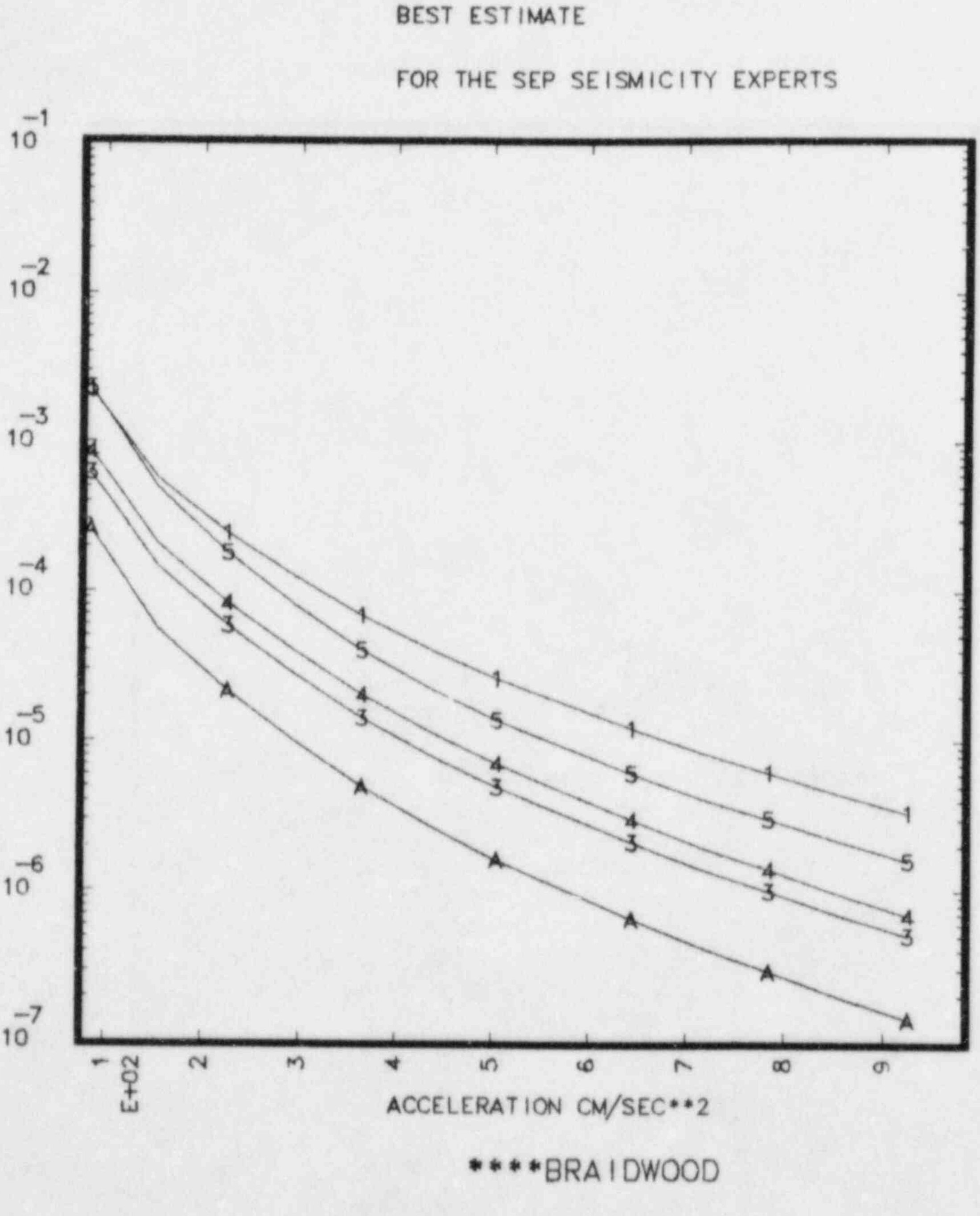


Figure 5.3a - Only Experts Participating in Both Studies



BEST ESTIMATE
FOR THE SEP SEISMICITY EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
****BRAIDWOOD

Figure 5.3b

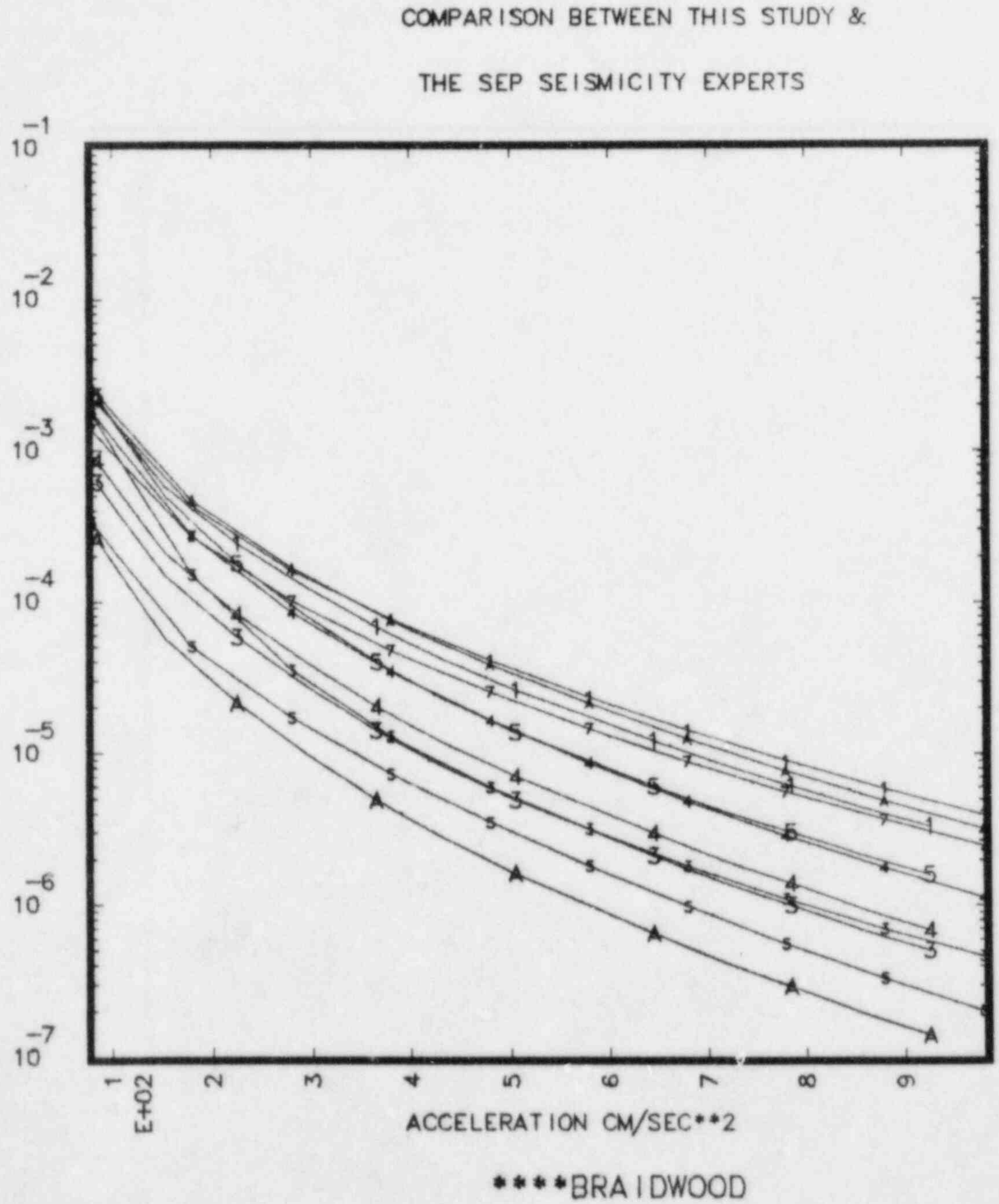

COMPARISON BETWEEN THIS STUDY &
THE SEP SEISMICITY EXPERTS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1 E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
****BRAIDWOOD

Figure 5.3c

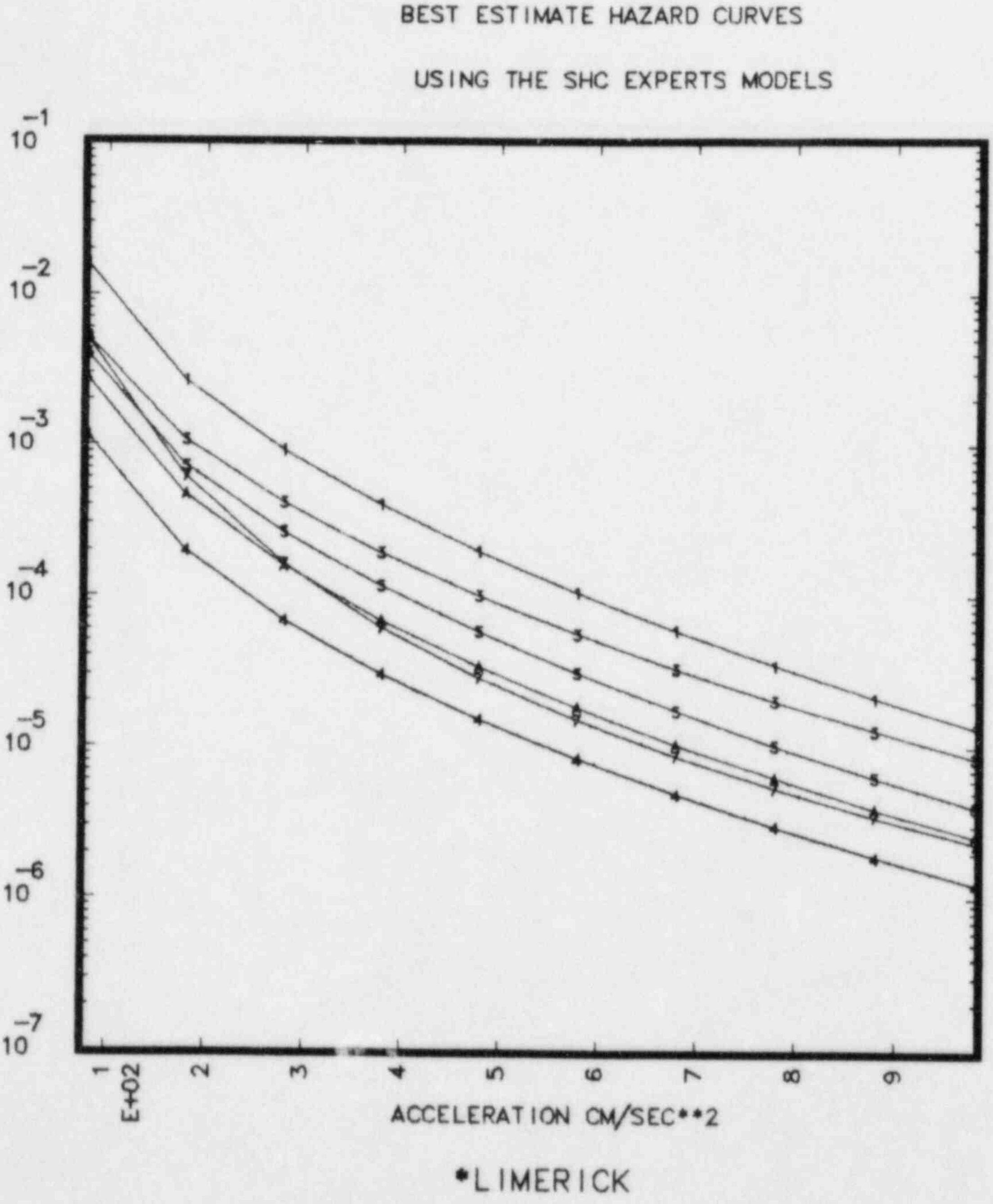
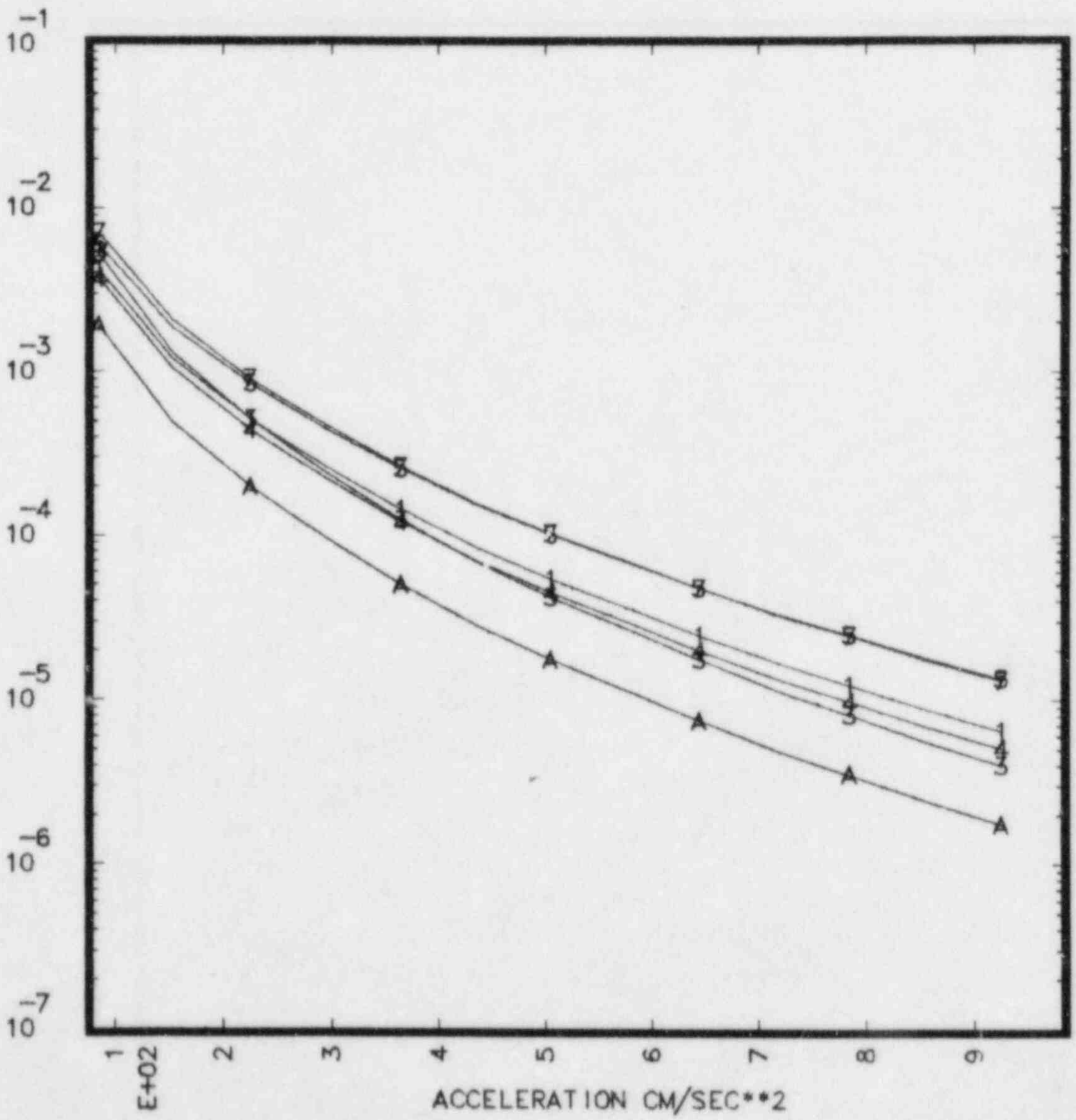


Figure 5.4a - Only Experts Participating in Both Studies

BEST ESTIMATE

FOR THE SEP SEISMICITY EXPERTS



*LIMERICK

Figure 5.4b

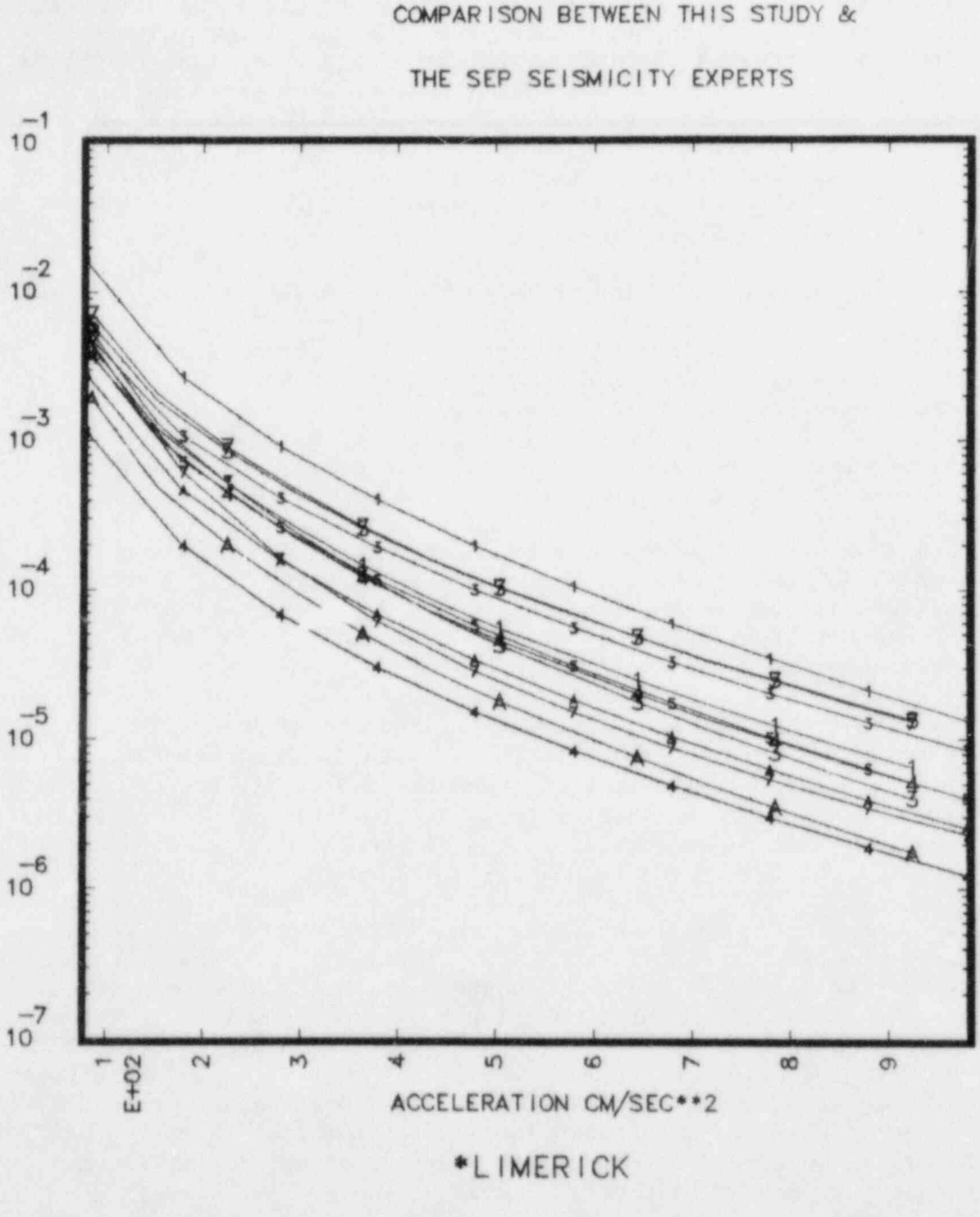

COMPARISON BETWEEN THIS STUDY &
THE SEP SEISMICITY EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
*LIMERICK

Figure 5.4c

No detailed comparisons are made between the SEP study and the SHC for the Limerick site because of the lack of detail with which the Region around Limerick was modeled for the SEP. However, it is interesting that the results between the two studies agree as well as they do for the Limerick site.

5.3 Comparisons Including All Panel Members

In Section 5.2 we examined the stability of the estimated seismic hazard at four sites using the six Experts common to both studies. We saw some changes in individual Expert's hazard curves (some higher and some lower) but overall the net estimate of the seismic hazard at the four sites was relatively stable. Table 5.1 shows that there were nine Experts (4 SEP and 5 this study) that only participated in one of the studies. It is of some interest to examine if inclusion of these additional Experts would have a significant impact on the perception of the estimate of the seismic hazard at the four sites examined in Section 5.2.

Figures 5.5-5.8 show a comparison between the PGA hazard curves obtained using the zonations and seismicity parameters developed as part of the SEP (curves marked by large symbols) and the hazard curves obtained using the zonations and seismicity parameters developed as part of the SHC (curves marked by small symbols). All hazard curves were developed using PGA ground motion model No. 7. The Experts who only participated in the SEP are identified by the large symbols B, C, D, E on the Figures. For the SHC Experts 11, 12 and 13, are identified by the small symbols B, C, D.

Figure 5.5 shows the comparison for the Millstone site. The addition of 4 SEP Experts and 5 SHC Experts does not change the character of the results. The overall dispersion of the SEP Experts' curves is somewhat larger than for the SHC. But overall the results are in good agreement showing reasonable stability for a complex Region.

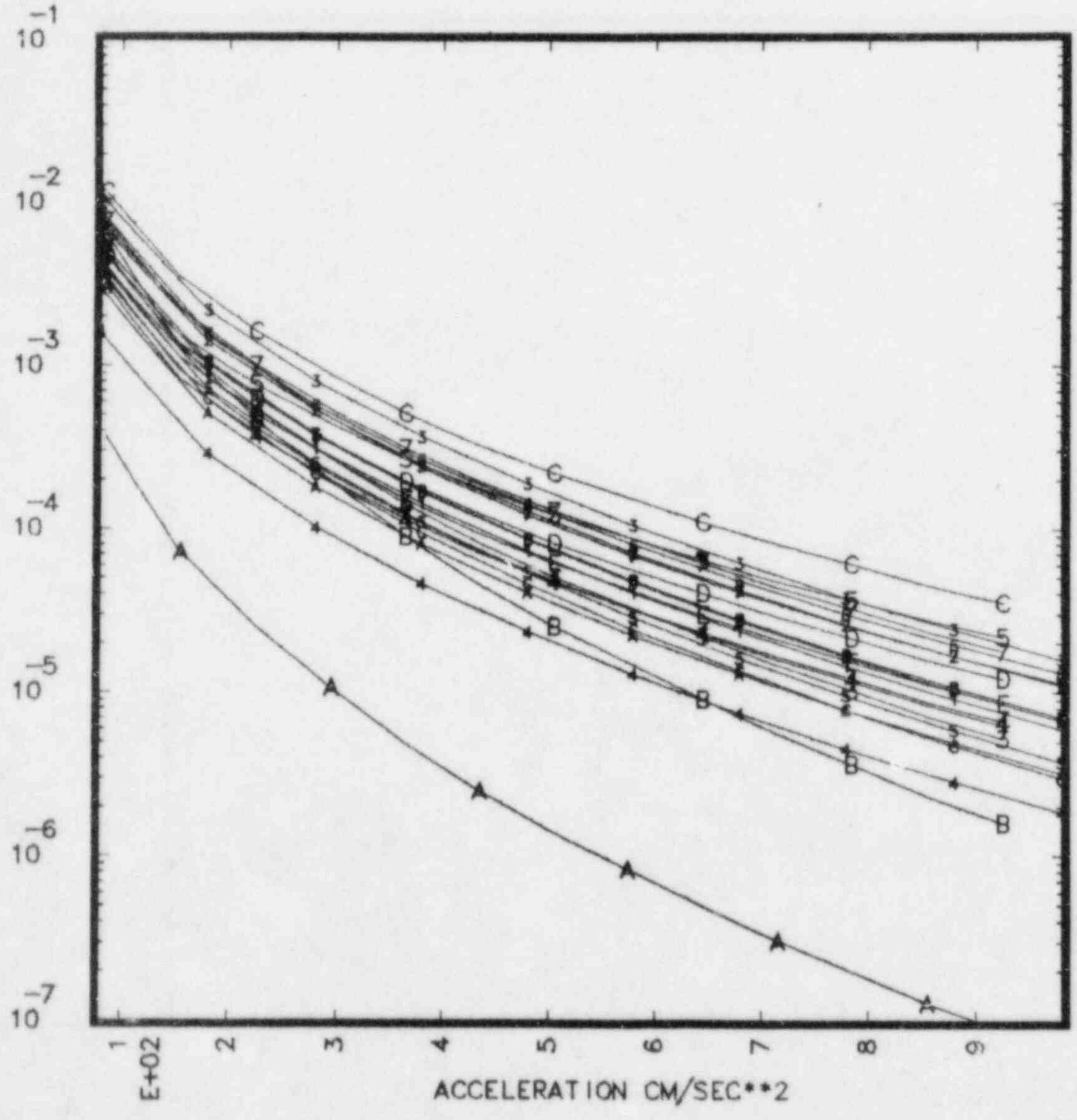
Figure 5.6 shows the comparison between SEP and the SHC for the LaCrosse site. There is very little change with the inclusion of 9 additional hazard curves. There is reasonable agreement between the two studies. The LaCrosse site is located in a Region of relative geologic simplicity - as contrasted to New England where Millstone is located. Thus at the LaCrosse site one would expect a certain stability in the results.

Figure 5.7 shows the comparison between the SEP and the SHC for the Braidwood site. Comparison of Fig. 5.7 with Fig. 5.3c shows that the hazard curve for Expert 11(B) is much higher than the rest of the Experts' curves. The reasons for this was discussed in Section 4.3.1 and is primarily due to the zonation introduced by Expert 11 for the Region around Braidwood. In general, there is good agreement between the two studies with the SHC curves lying a little higher than for the SEP. This occurs because, as noted earlier, a number of Experts in the SHC included a zone that is either near or includes the Braidwood site. However, this increase in complexity in the zonation of this portion of the Central Stable Region has not greatly increased the seismic hazard at the Braidwood site, and the estimate of the seismic hazard at the Braidwood site seems reasonably stable.

Figure 5.8 shows a comparison between SEP and the SHC for the Limerick site. It is seen by comparing Figs. 5.4c to 5.8 that the inclusion of 9 additional Experts increases the dispersion of the results. In addition, a

COMPARISON BETWEEN THIS STUDY &

THE SEP SEISMICITY EXPERTS



*MILLSTONE

Figure 5.5 - For All Experts

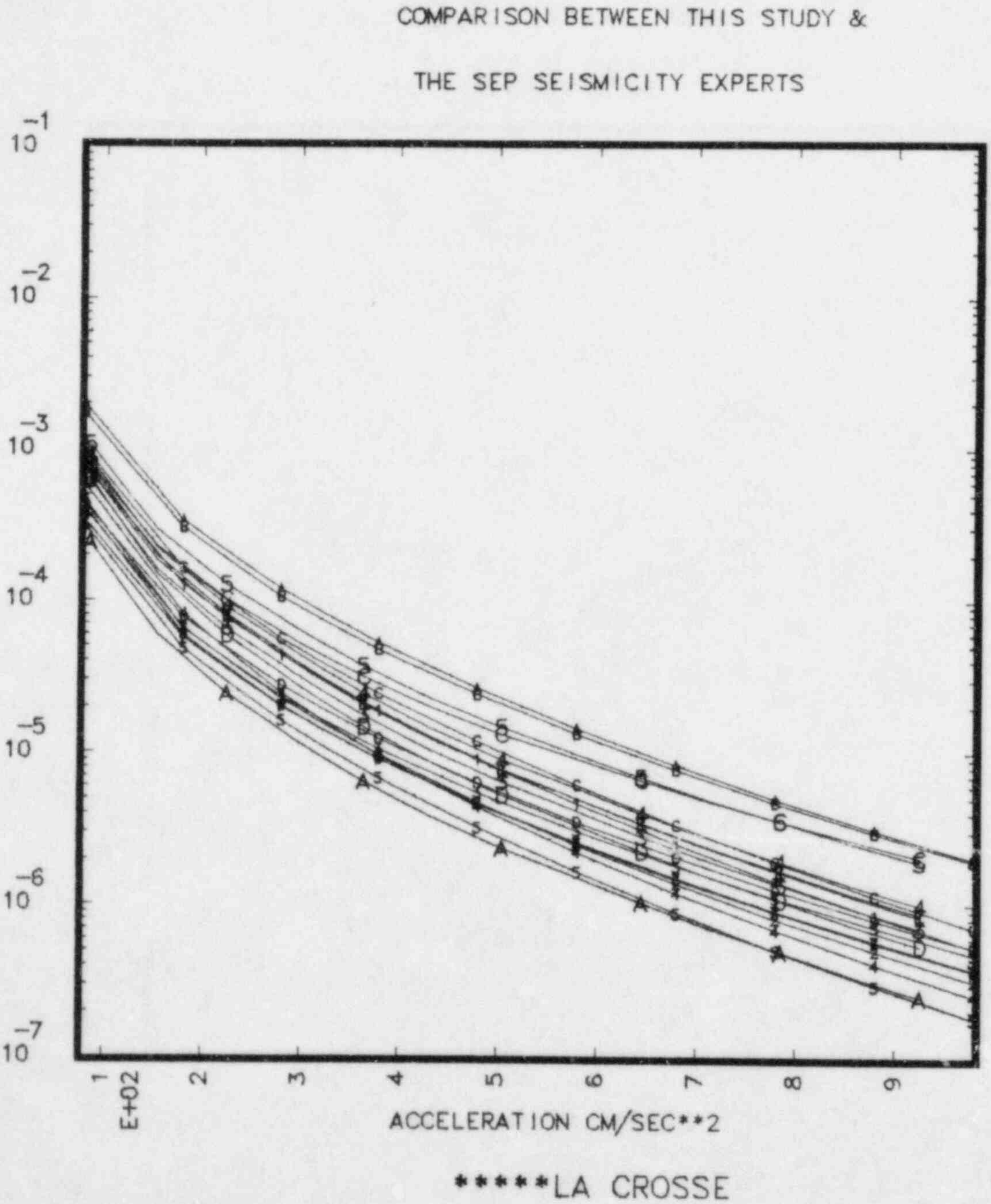


Figure 5.6 - For All Experts

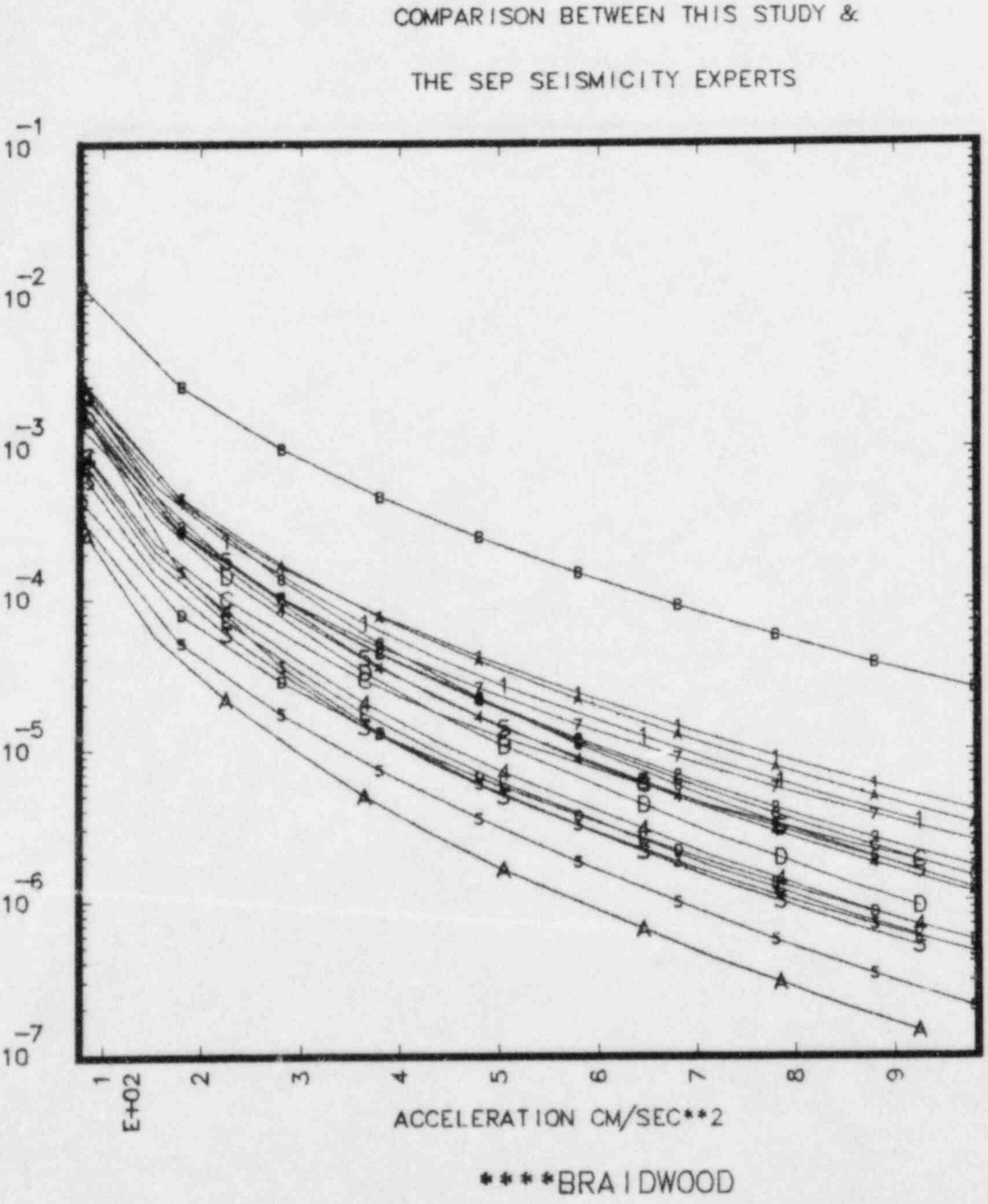


Figure 5.7 - For All Experts

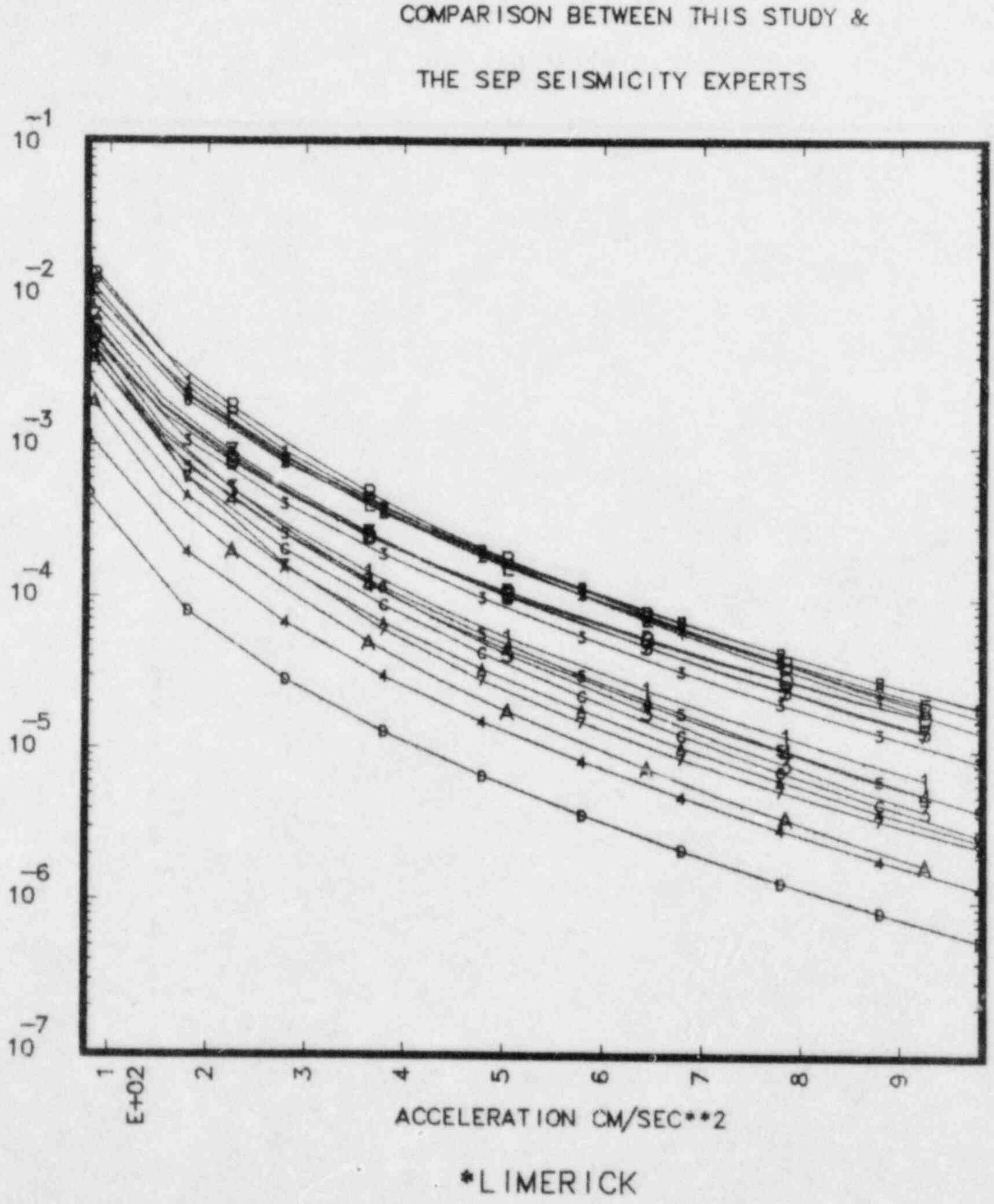


Figure 5.8 - For All Experts

number of Experts (both sets) tend to "clump" around the hazard curve for Expert 1. Overall the results of the two studies are in reasonable agreement with the results from the SHC being somewhat lower than for the SEP. However, as noted earlier, the Limerick site is on the fringe of the Region zoned with care by the SEP Panel. Considering the complexity of the zonation south of the Limerick site supplied by the Panel Members for this study, it is not surprising that there are some differences between the two studies. The fact that they are in reasonable agreement indicates that there is a reasonable stability to the approach.

5.4 Assessment of SEP Recommendations

In the previous sections we saw that for the same ground motion model and best estimate choices for the other parameters there was relatively little difference between the results obtained in the SHC as compared to the SEP. However, as noted in Section 1, one of the main differences between this study and the SEP is the manner in which the uncertainty is included in the analysis.

In the SEP, uncertainty in zonation and in the seismicity parameters was treated in simple Ad Hoc manner, see Bernreuter (1981). Also, in the SEP only a few ground motion models were used as sensitivity studies and no combination was attempted. The final SEP recommendations (Reiter and Jackson 1983) attempted to account for different ground motion models and each Expert's uncertainty in zonation in a somewhat Ad Hoc manner based on judgment. Reiter and Jackson (1983) recommended the use of the 1000 year UHS for use in the SEP. They also recommended a minimum level based on real records which was somewhat higher than the 1000 year UHS at the LaCrosse site. They also argued that the spectra that they recommended for use in the SEP were more conservative than for the 1000 year spectra and represented a reasonably uniform level of hazard at all sites studied.

In the SHC the uncertainty in the ground motion model, in each Expert's zonation and in each Expert's seismicity parameters have been systematically accounted for. In addition, the Ground Motion Panel for this study did not give high weights to the ground motion models used to develop the UHS for the SEP study. It is of some interest to see what impact these differences have relative to the recommendations made in Reiter and Jackson (1983). That is, if the recommended spectra have a return period of about 1000 years and if the relative level of the hazard is about the same at different sites as compared to the 1000 year return period CPUHS based on a complete uncertainty analysis presented in Section 4 of this report. These comparisons can only be made at two sites (Millstone and LaCrosse).

Figure 5.9 shows a comparison of the recommended UHS for the Millstone site from Reiter and Jackson (1983) to the CPUHS for the 1000 year return period. At the low frequency end of the spectrum (periods longer than 0.2 sec) there is a good agreement between UHS from the SEP study and the 50th percentile CPUHS. At the higher frequency end (periods shorter than 0.2 sec) the UHS from the SEP study falls slightly below the 50th percentile CPUHS indicating that its return period would be somewhat less than the 1000 year return period. Overall, there is good agreement between the two curves.

This difference arises because most of the loading at the Millstone site is from the zone which contains the site. The SEP spectra were based on the

"Ossippee" model, Reiter and Jackson, (1983), Bernreuter (1981). Bernreuter (1981) compares the Ossippee model to other ground motion models. Generally, for distances less than 50 km the Ossippee model gives lower ground motion estimates than the models most heavily weighted by our Ground Motion Panel Members. It is this difference that most likely leads to the differences in the 1000 year return period spectra between the SHC and the SEP.

Figure 5.10 compares the recommended UHS for the LaCrosse site from Reiter and Jackson (1983) to the 1000 year return period CPUHS developed for the SHC. It is seen that the SEP spectrum lies above the 50th percentile CPUHS for the LaCrosse site indicating that its return period is greater than 1000 years. The SEP results are more conservative at low frequencies because they are based only on one ground motion model (the Gupta-Nuttli model) which (see Appendix C or Bernreuter, 1981) has low attenuation. Therefore, long period motion is influenced by distant source zones such as the New Madrid Zone.

Considering the major differences between the way the CPUHS were developed and the way the recommended UHS were developed, indicates that there is a reasonable stability to probabilistic hazard analysis using expert judgment.

It should be noted that the reasons Reiter and Jackson (1983) cited for the SEP UHS being conservative:

1. Strong motion data sets are in many ways biased toward high values. Non-triggered instruments or low-level records receive little attention. This is also true at great distances and for longer periods where noise may be contributing significantly to observed motion.

2. The assumption that earthquakes occur randomly within a given seismic source zone is conservative for large zones of low to moderate level seismicity such as those around most SEP sites. While the sources of central and eastern U.S. earthquakes remain hidden, most seismologists conclude that damaging earthquakes will eventually be associated with specific faults.

3. The uniform spectra represent composite risk from different source zones which may effect different frequency ranges. Under certain situations, exceeding the spectra at different frequencies implies the simultaneous occurrence of earthquake in more than one source zone.

apply equally well to the results presented in this report as to the recommendations made by Reiter and Jackson.

We consider that these comparisons provide added verification of the main conclusions reached by Reiter and Jackson.

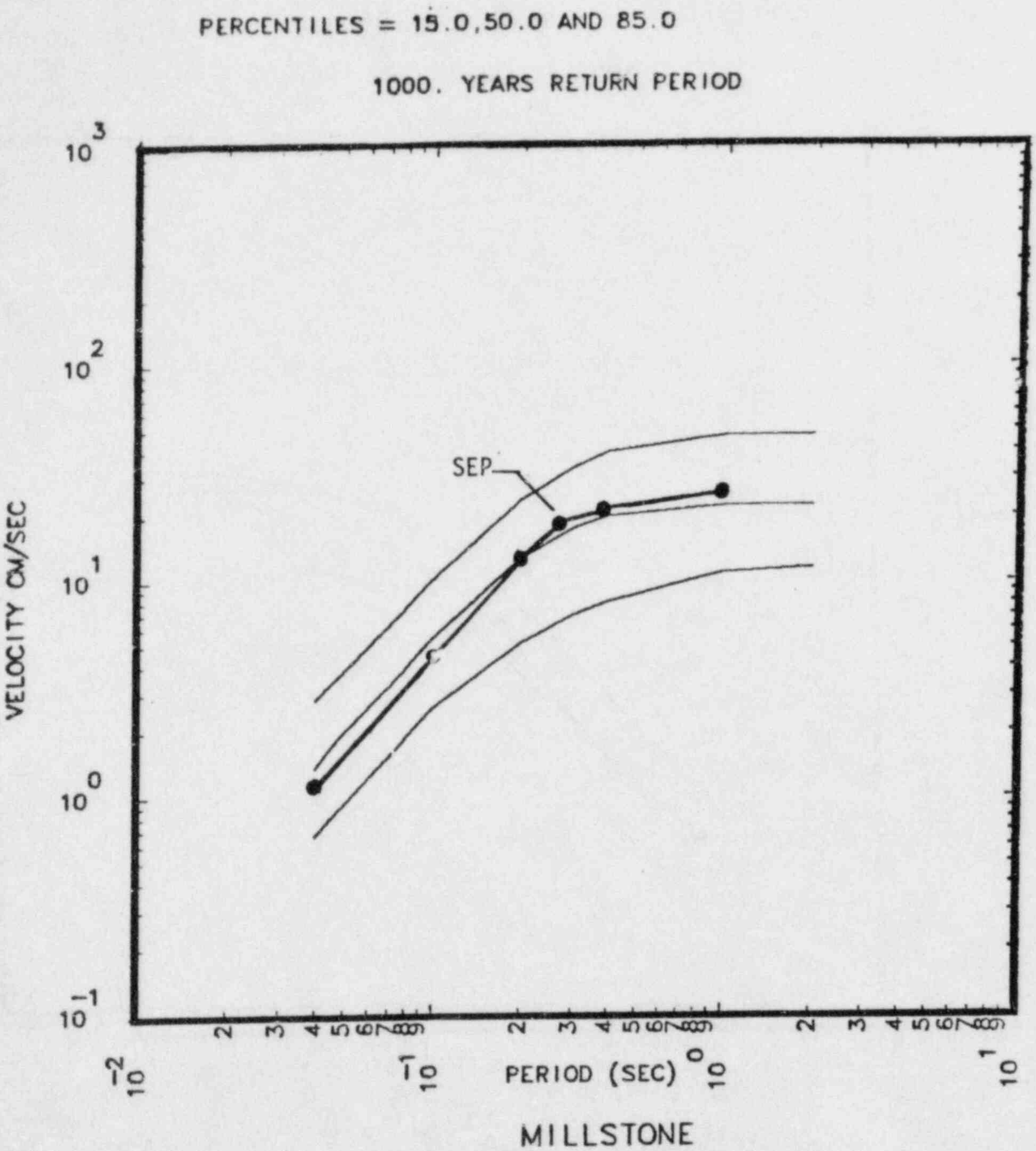


Figure 5.9 - Comparison Between the 1000 Year Return Period CPUHS and the SEP 1000 Year Return Period UHS

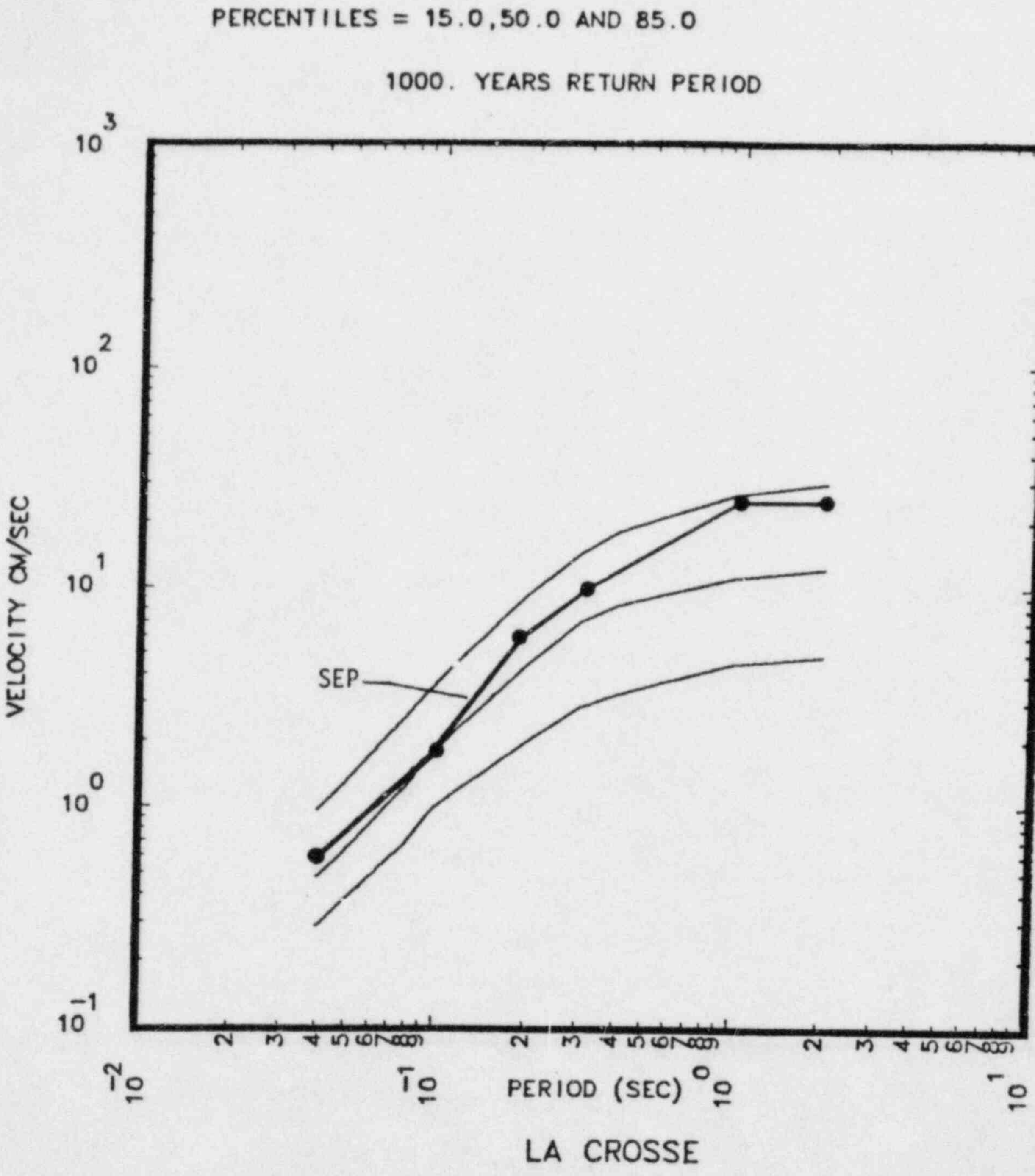


Figure 5.10 - Comparison Between the 1000 Year Return Period CPUHS and the SEP 1000 Year Return Period UHS

SECTION 6: REFERENCES

1. Bernreuter, D. L., (1981) "Seismic Hazard Analysis: Application of Methodology, Results and Sensitivity Studies", NUREG/CR-1582 (UCRL-53030, Vol. 4).

2. Bernreuter, D. L., (1981b) "Seismic Hazard Analysis: Review Panel, Ground Motion Panel, and Feedback Results," NUREG/CR-1582 (UCRL-53030, Vol. 5).

3. Bernreuter, D. L. and Minichino, C., (1983), "Seismic Hazard Analysis Overview and Executive Summary," NUREG/CR-1582, Vol. 1, UCRL-53030, Vol. 1.

4. King, P. B., (1969a) "The Tectonics of North America--A Discussion to Accompany the Tectonic Map of North America," U.S. Geological Survey, Professional Paper No. 628, U.S. Department of the Interior.

5. King, Philip B., (1969b) "Tectonic Map of North America," prepared by USGS, compiled by King, P. B.

6. Mensing, R. W., (1981) "Seismic Safety Margins Research Program Phase I Final Report--The Use of Subjective Inputs," Lawrence Livermore National Laboratory, Livermore, Calif., UCRL-53021, Vol. 10; also published as U.S. Nuclear Regulatory Commission NUREG/CR-2015, Vol. 10.

7. Reiter, L., and Jackson, R. E., (1983) "Seismic Hazard Review for the Systematic Evaluation Program - A Use of Probability in Decision Making," U.S. Nuclear Regulatory Commission, Division of Engineering, NUREG/0967.

8. Singh, Sudarshan and Hermann, Robert B., (1983) "Regionalization of Crystal Coda Q in the Continental United States," J. G. R. Vol. 88, Number B1, pp. 527-538, Jan. 10, 1983.

7. Trifunac, Mihailo D. and John G. Anderson (1977), "Preliminary Emperical Models for Scaling Absolute Acceleration Spectra," University of Southern California, Dept. of Civil Engineering Report No. CE77-03.

Appendix A

Questionnaires to the EUS Seismicity Panel and a Summary of Their Responses

A.1 Introduction

This appendix contains the complete text of the first three questionnaires sent to the EUS Seismicity Panel members and a detailed summary of their responses is given in Section A.2. The first questionnaire (Q1) elicited the individual panel member's judgement about the zonation of the EUS. The second questionnaire (Q2), given in Section A.3, elicited the individual panel member's judgement about best estimates and the uncertainty in the following parameters:

- The largest earthquake in each of the zones identified by the panel member in his answer to the first questionnaire.
- The expected frequency or rate of earthquakes in each zone.
- The magnitude (or intensity) recurrence relation for each zone.

In the third questionnaire (Q3), given in A.4, the experts were asked to provide a self weight which reflects how he/she perceives his/her level of expertise about his/her answers to Q1 and Q2.

The answers to the three questionnairs are summarized in A.5.

A.2 First Questionnaire-Zonation (Q1)

1. INTRODUCTION

1.0 Background

The purpose of this project, intiated by the U.S. Nuclear Regulatory Commission (NRC), is to "develop a seismic hazard characterization for the region of the United States east of the Rocky Mountains." One task of the project is to assess the seismicity of this region and to describe it in a form which can be used as input to a seismic hazard analysis. The seismic parameters of interest are:

- Seismo-tectonic zonation.
- Rate of earthquake occurrence.
- Distribution of earthquakes magnitudes.
- Largest earthquake, i.e. upper magnitude cutoff.

Because it is difficult, or perhaps impossible, to precisely quantify such seismic parameters using only the sparse historical record, expert judgement is crucial. Thus, a panel of experts has been assembled. The membership of the panel is:

Dr. Peter W. Basham

Professor Gilbert A. Bollinger

Dr. Michael A. Chinnery

Mr. Richard J. Holt

Professor Arch C. Johnston

Dr. Alan L. Kafka

Professor James E. Lawson

Professor L. Tim Long

Professor Otto W. Nuttli

Dr. Paul W. Pomeroy

Dr. J. Carl Stepp

Dr. Anne E. Stevens

Professor Ronald L. Street

Professor M. Nafi Toksoz

Dr. Carl M. Wentworth

As a member of the panel you have been selected based on your knowledge of the seismicity of all or part of the Eastern United States (EUS). We wish to thank you for your willingness to participate in the deliberations of the panel.

Some of you are familiar with the approach that we are taking as you participated in an earlier study. That study was limited to the assessment of the seismic hazard at the nine oldest reactor sites in the EUS. This study represents a generalization of the earlier study in that: (1) the approach is modified to incorporate methodology improvements suggested by our reviewers, and (2) the area to be dealt with is the entire EUS east of the Rocky Mountain front, including the offshore regions along the east and Gulf coastlines.

For those of you not familiar with our approach, we have enclosed the overview report from the previous study and give below a brief description of the elicitation process and analyses planned. The elicitation process will be in three stages. The first stage will be the elicitation of the seismo-tectonic zonation. This is the object of this questionnaire. You will be asked to describe a base map which identifies all potential source zones for the EUS. Since you may be uncertain about the existence and shape of some of the zones, you will be asked to provide plausible alternatives to individual features of your base map. From this information, a set of mutually exclusive zonation alternatives for the entire region can be derived. An appropriate subset of these alternative maps can be used to assess the seismic hazard at a specific site.

The second stage of this study, a questionnaire will be sent to you in order to elicit your opinion on the occurrence rate and magnitude distributions. Ideally, you should use your own set of historical seismicity data. However, if you desire, we will provide you such data in the form of a catalog of historic events. This catalog is described in Appendix 1. Specifically, for each zone in your base map as well as for the alternate zones, you will be given (1) a listing of all earthquakes in the zone having magnitudes greater than some pre-specified minimum, and (2) a table giving the number of earthquakes in the zone as a function of magnitude[1]. You will then be asked to respond to questions designed to elicit your opinion, in light of the data, regarding the earthquake occurrence rate, upper magnitude cut-off and magnitude distribution.

Your responses will then be combined and cross-checked to assure consistency in the results. Also, the results will be used to compute the seimic hazard at various locaions in the EUS. These hazard assessments will be made available to you in the third stage of the elicitation process so that you may assess the physical reasonableness of the seimic parameters elicited in the first two stages of our process.

The third stage of the process will start with a general meeting of the panel, and at that time you will have the opportunity to review results based on your input, as well as the results from the other panel members. In order to ensure anonymity, each panel member's results will be identified by some code which only that panel member will know. In addition, at the meeting we will discuss:

---

1. We use the term magnitude as a general term referring to size, not as a specific measurement.

1. the models and approximations that we introduced to put your results into a form suitable for input into our hazard analysis;

2. the parameters which contribute the most to the uncertainty in the predicted seismic loading at the selected sites and to which the results are most sensitive; and

3. those areas which may need to be more carefully considered by the panel members.

After this meeting we will formally request that you revise your original responses if appropriate.

1.2 Description of the Seismic Hazard Analysis

Given source zone configurations and seismicity information from the first two questionnaires, along with an attenuation model, we can compute a hazard curve for any site in the EUS and any time period T. The hazard curve at a site is defined here to be the probability, P(A>a), that the maximum value of peak ground acceleration, A, induced at the site by earthquakes occurring within a T-year period exceeds the value a. Graphically, a typical hazard curve, plotted on a semi-logarithm scale, is given in Figure 1.1.

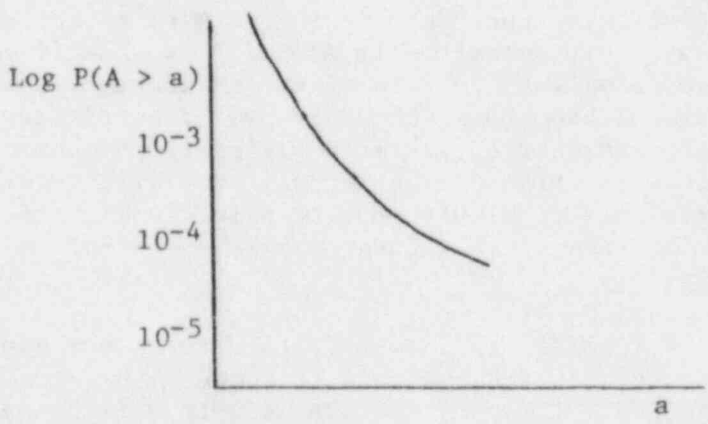


Figure 1.1 Typical Hazard Curve at a Site

To develop a hazard curve at a site, it will be necessary for us to adopt certain models to describe seismicity. From the responses to this questionnaire we will be able to develop a collection of maps (alternative source zone configurations for the EUS) for each expert. Given a map, we model the occurrence of earthquakes within each zone, where attention is restricted to earthquakes with magnitudes exceeding some pre-specified minimum, M_m. Following the standard hazard analysis practice, we assume that the occurrence of earthquakes can be approximated by a Poisson process.

You will be asked, in the second questionnaire, to estimate the space-time rate of occurrence, which is assumed constant within a zone, but which may vary from zone to zone. Given an earthquake, it is then necessary to model the magnitude distribution. You will be asked to model the magnitude-recurrence relationship for each zone and also to estimate the values of the parameters of the model (e.g., a linear model with an intercept and a slope as parameters). In addition, you will be asked your opinion about the existence of a physical upper bound on earthquake magnitudes. If you feel that you cannot give such an upper bound, or if you feel that the bound is so large as to be of no practical importance, then we will model the distribution of magnitudes with an upper limit equal to the largest observable value on your chosen measurement scale (e.g., XII on MMI scale). On the other hand, if you specify an upper magnitude cutoff, M_u, the range of the magnitude distribution will be restricted to the interval $[M_m, M_u]$. Your magnitude-recurrence model and your upper magnitude cutoff value will be combined to model the distribution of magnitudes for each zone.

Another essential ingredient in seismic hazard analyses is the attenuation model which relates peak ground acceleration at a site to earthquake magnitude and source-site distance. This portion of the project is not concerned with the choice of attenuation model. A second panel is being formed to assist in the selection of appropriate attenuation models and to estimate the parameters of the model.

The seismicity information for each expert is combined with the attenuation model to develop a "best estimate" hazard curve for each expert. Variations in the source zone configurations and uncertainty in the seismicity parameters will be combined to develop bounds for the hazard curve which reflect your level of confidence in your responses.

1.3 Discussion

Information about the seismicity in the EUS is available both in the form of recorded events (i.e., data) and in knowledge, held by individuals like yourselves, about the tectonic and geologic properties of the region which affect seismicity. Thus, it is appropriate to combine these two sources of information when characterizing seismic hazards in the EUS. Methods exist for analytically combining data with opinions, however, in this project we are relying on your abilities to assimilate the data with your knowledge in developing your responses to the questionnaires. Thus, we expect that you will review one or more catalogs of events, recognizing the shortcomings of the data (e.g., incompleteness of the catalogs). The data, in turn, should be combined with your general experience in the region, your knowledge of the geologic and tectonic features, similarities of the EUS with other regions, and other related information.

Throughout the questionnaires we will be asking you to associate a level of confidence to your responses. We will interpret your level of confidence to represent the degree to which you judge your knowledge, expertise, the historical data, etc., support a given response. In making this judgement we ask that you not be influenced by your level of expertise, for a given section of the EUS, relative to the other panel members. The latter measure of relative expertise (self-weighting) is only approproate when opinions from several individuals are combined to form a consensus. We will .e eliciting such self-weights as a separate part of the elicitation process. To illustrate, suppose you are responding to a question about the existence of a zone in a section of the EUS for which you feel your level of expertise (self-weight) on a scale of 0.0-1.0 is 0.8. Based on your knowledge, review of past-events, etc., if you are 95 percent sure the zone should be identified, then your level of confidence in the existance of the zone is 0.95, not 0.95 x 0.8 = 0.76. [If you assign confidence of 0.76 to the zones existence, this implies that your confidence in its non-existence is 0.24, rather than 0.05].

We recognize the inherent difficulty of quantifying subjective judgement. However, substantial uncertainty is an unavoidable factor in assessing seismic hazard in the EUS. Until more data becomes available expert opinion about seismicity is an important source of information. It is widely accepted that subjective probability (i.e., in our terminology, level of confidence) is the uniquely appropriate means of quantifying uncertainty. Thus, eliciting your level of confidence is an attempt to assist you in sharpening and quantifying your opinions as well as to express your uncertainty. We encourage you to be as unbiased and complete as possible in responding to the questionnaire.

Although the goal is to describe the seismicity of the entire EUS, it is recognized that some of you will not feel comfortable in responding for the entire region. However, we urge you to supply zones for all regions if possible. Large uncertainties can be reflected in the range of alternatives presented and through the level of confidence associated with a response. We want to emphasize that, in addition to assessing the best estimate hazard curve and associated uncertainty for each expert, the intent of the project is not to obtain a consensus but to present the diversity of opinion among different experts. Therefore, we urge you to express your own knowledge and beliefs in your responses. Specifically, do not be reluctant to express unconventional and/or non-classical viewpoints.

If you feel that you cannot respond to our questions for certain regions of the EUS, this is acceptable. In that case respond only to the portion of the EUS for which you are knowledgeable. However, whatever portion of the EUS you respond to, we urge you to answer all questions.

2. SOURCE ZONE CONFIGURATION

2.1 Introduction

In this part of the elicitation process we are concerned with the specification of various seismic source zones. A zone is a region which has homogeneous seismic characterictistics in terms of rate of activity, magnitude disdtribution and upper magnitude cut-off. The intent of this section is to obtain the geographic boundaries of the major seismic zones and local tectonic features, e.g., faults, which should be considered in a seismic hazard analysis. The region to be considered is the Eastern United States and Southeastern Canada extending west to the Rocky Mountain front or roughly 104°W.

We will be asking you to draw a base map of the seismic source zones for the Eastern United States and Southern Canada on one of the maps provided . The base map should:

- o Identify all potential seismioc zource zones
- o Describe your "best estimate" of the boundaries of the zones.

It is recognized that you may have alternative views about the zonation other than your initial base map. Specifically, you may be uncertain about:

- o the existence/non-existence of an individual zone or cluster of zones, i.e., should/should not an individual zone or cluster of zones be treated as a source separate from the area surrounding it,
- o the boundary shape of an individual zone or boundaries of a cluster of adjacent zones.

Thus, we will be asking you questions which will allow you to express such uncertainty.

We have provided several maps which can be used to indicate alternative source zone configurations. Please do not return your responses on any other working maps or even copies of the maps provided to you. In processing your responses, these maps will be digitized and therefore need to be all the same. If you need more maps, please do not hesitate to request them from us.

To assist you in interpreting and answering the questions for this part of the elicitation, we have included an illustration of the type of response we hope to derive from the questions in this section of the questionnaire. Please recognize that this illustration is not intended to reflect reality but only to illustrate the desired format for your responses. (In fact, the illustration was purposely done by a non-seismologist).

In the illustration, Figure A1 describes the base map, in response to Question 1-1. Each zone has been indexed. Indexing zones is necessary for later identification when one describes alternative configurations in response to later questions. In this illustration 15 zones were identified. Most of the zones are aras, except Zone 2 which is a line source. Table A1 illustrates the response to Question 1-2 on uncertainty in the existence of one or more zones identified on the base map. The zones identified in Table A1 are those for which the respondent was not sure about their existence, i.e., the need to identify a separate source zone different from the surrounding area. Two pieces of information are provided for each zone identified in Table A1:

- the respondent's <u>level of confidence</u> that a zone does exist
- if the zone is considered non-existent, the region must become part of another zone; this zone must be identified.

In the illustration, Zones 2, 3, 4, 5, 12, and 14 were considered potentially non-existent. The respondent's confidence in Zone 2 existing is 0.40 and if Zone 2 does not exist then that region becomes part of Zone 1. Similarly, the respondent has confidence 0.85 that Zone 3 must be identified as a separate source zone.

Responses to Question 1-3 on potential alternative boundary shapes for an individual zone or group of zones is illustrated in Figures A2 and A3 and Table A2. In this case, Zone 3 was considered to have two potential configurations; the elliptical shape on the original map and a triangular shape drawn on Figure A2. The respondent's confidence, conditional on the zone's existence, in the elliptical shape boundary was 0.6 and in the triangular boundary was 0.4. These are entered in Table A2. Also, in the illustration, alternative configurations for Zones 11 through 15 are drawn on Figure A2 as Zones 19 through 24. Finally, zones labeled 4 and 5 in the initial map were judged to have two additional boundary shapes. These are labeled 17 and 18 in Figure A2 and Zone 25 in Figure A3. Notice that in the latter alternative, the region originally described by two zones has been described by a single zone.

Although most of the source zones identified in the illustration represent areas, there are also relevant line and point sources, such as faults, which could be active or could otherwise serve to localize seismicity. It is important that you identify such line and point sources on your maps and treat them in your responses as another zone, indexing them, consider their existence/non-existence and possibly reshaping or relocating them on your alternative maps.

2.2 <u>Questions</u>

1-1 Using one of the maps provided, please draw your base map of potential source zones, along with their "best estimate" configurations, for the Eastern United States. Please index each zone identified on your map.

1-2 To express an uncertainty about the possible existence of an individual zone or cluster of zones, please record, by index number, in a table similar to Table A1, any regions which you are not certain should be identified as a zone. Indicate your level of confidence in its being a zone and indicate what zone that region will be part of if the zone does not exist.

1-3 To indicate possible alternative boundaries for an individual zone or cluster of adjacent zones, please isolate the zones you would like to reshape; provide as many alternative boundaries, on one or more of the maps provided, as you feel is necessary; and, in a table similar to Table 2, list the alternatives and give us an expression of your confidence (relative to the other alternative shapes for that zone or zones) in each alternative boundary shape.

As indicated in the Introduction we will provide, if you desire, a description of historical seismic activity relevant to your source zone configurations which you can use as a data base for responding to the questions on seismicity in the second stage of the elicitation process.

1-4 Do you desire to have us provide you a description of historical seismic activity in the EUS?

Yes ______ No ______

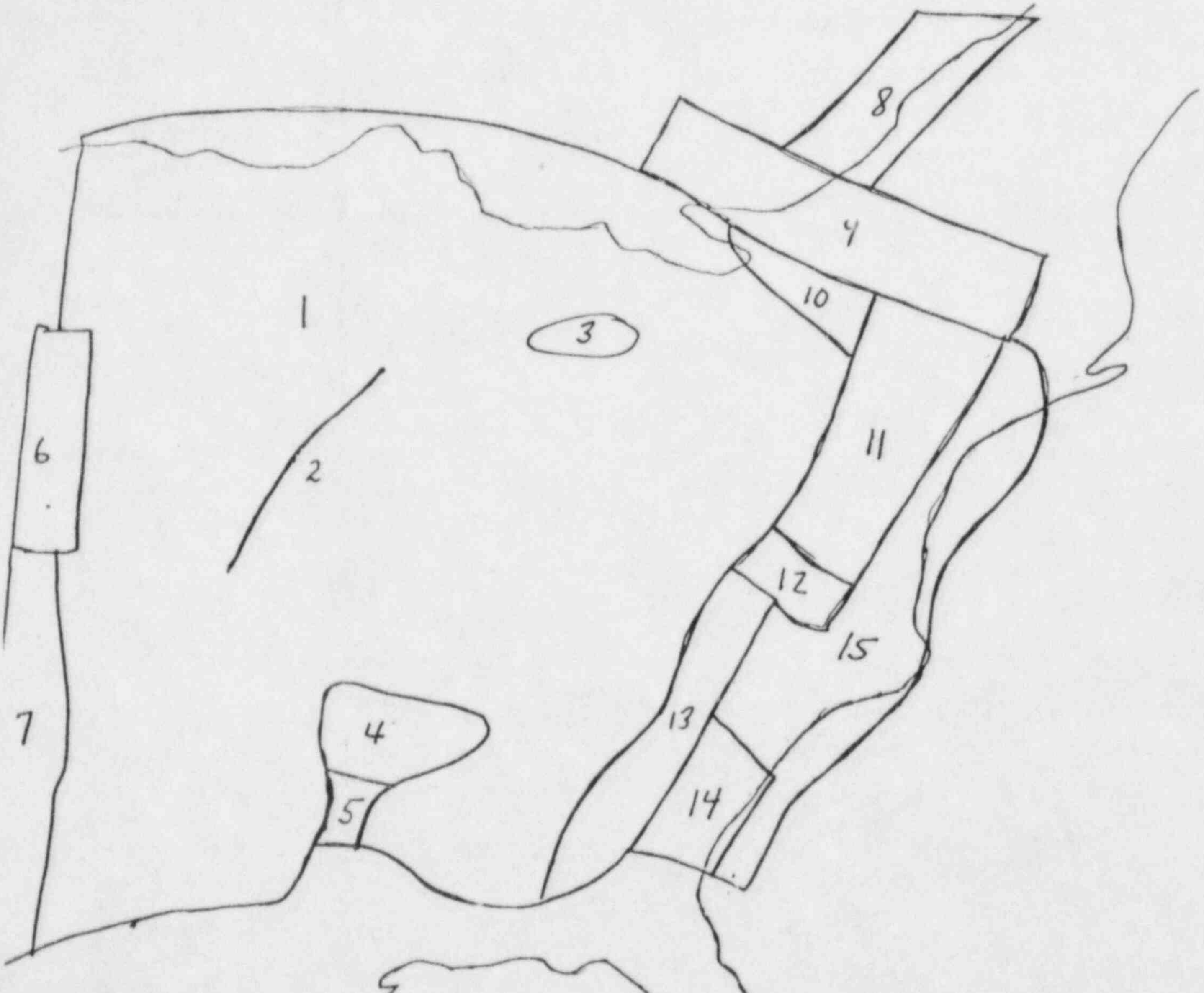


Figure A1. "Best Estimate" Source Zone Configurations

Table A1. Existence of Selected Zones

Zone Index	Level of Confidence In Existence	Non-Existent Zone Becomes Part of Zone Number
3	0.85	1
4 and 5	0.98	1
12	0.70	11
14	0.80	15

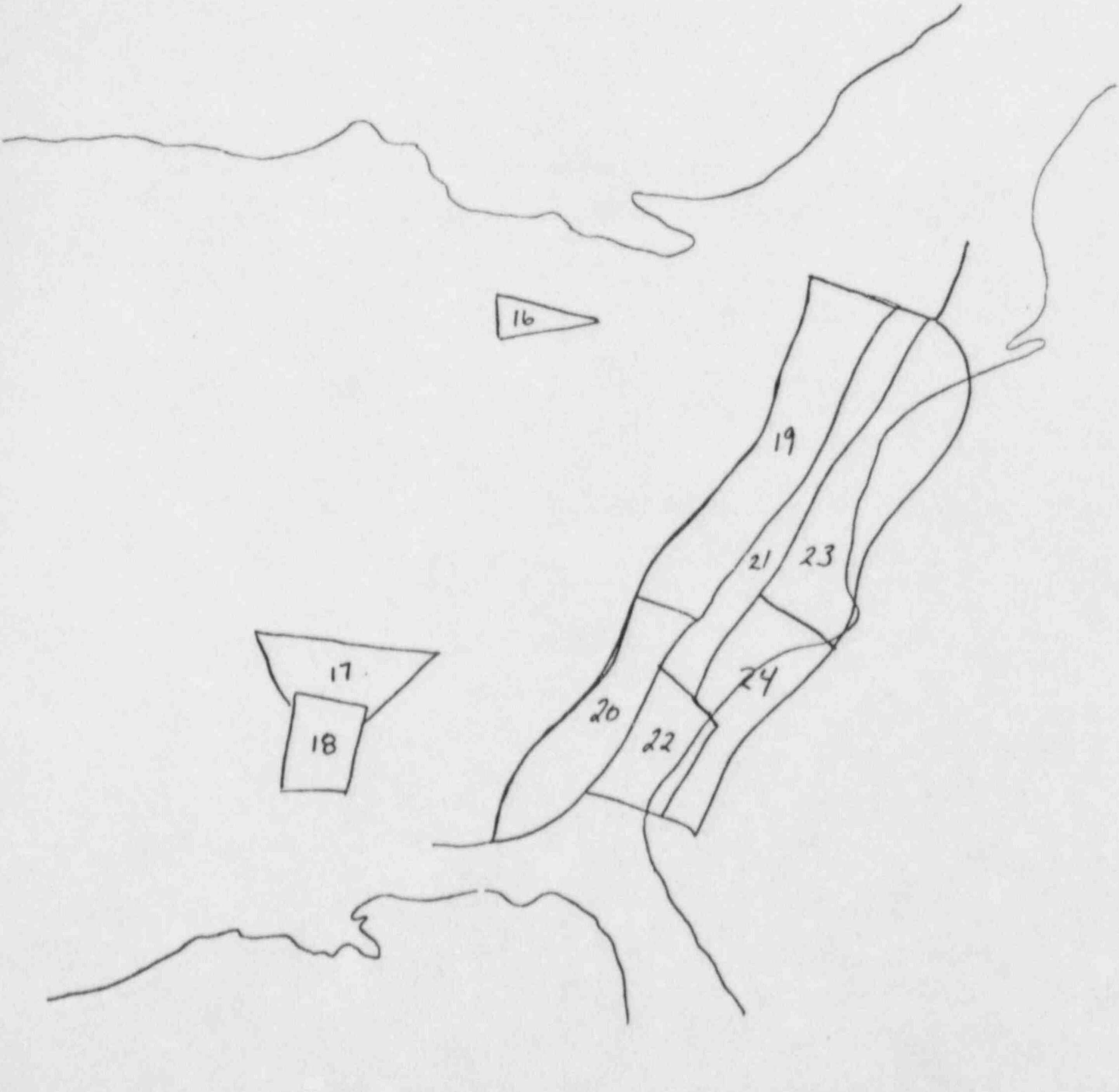


Figure A2. Alternative Source Zone Configurations

Figure A3. Alternative Source Zone Configurations

Table A2. Confidence for Alternative Boundaries

Zone Index	Level of Confidence[1] In Boundary Shape
3	0.6
16	0.4
4, 5	0.7
17, 18	0.15
25	0.15
11, 12, 13, 14, 15	0.7
19, 20, 21, 22, 23, 24	0.3

(1) Notice that for any specific region, the sum of the levels of confidence over alternative boundary shapes should be 1.0.

A.3 Second Questionnaire: Seismicity Parameters (Q2)

1. EASTERN UNITED STATES SEISMICITY

1.0 Introduction

As part of the project to develop a seismic hazard characterization of the EUS, this questionnaire is designed to elicit your opinions about the seismicity of the source zones you identified in Questionnaire 1. For each of the zones(1) identified in your zonations of the EUS we will ask questions about:

- o The largest earthquake, i.e., upper magnitude cutoff
- o The expected frequency or occurrence rate of earthquakes
- o The magnitude-recurrence relation

We are returning to you digitized versions of the maps you developed for Questionnaire 1 as well as historical seismic data, if you requested this information.

In responding to questions about seismicity we expect that you will use one or more catalogues of historical events, either those of your own choosing or the catalogue we have supplied at your request. When using the catalogues to assess the future seismicity in the EUS it is important that you consider the validity and quality of the data as well as some potential shortcomings in using the recorded events to form your opinions. One issue you should consider is the potential incompleteness of the data. The completeness of a catalogue will depend on several factors, e.g., the length of recorded history, the population density and distribution during past events. Completeness is likely to vary between catalogues as well as between regions within a catalogue. It would be appropriate for you to correct for incompleteness when using the data to form your opinions. You should also be aware of potential inaccuracies in the location and size of the past events. In addition, aftershocks are a potential source of uncertainty when using historical data. Since our analysis is based on assuming earthquakes occur as a Poisson process, one might question the inclusion of aftershocks when using the data to assess seismicity. How to treat aftershocks is left to your discretion. Aftershocks have not been culled from the data in the catalogue we provided.

The extent to which you rely on the historical data to form opinions about the future seismicity of the EUS should be based on your judgements of the data. This may be based on your knowledge of the geologic and tectonic features of the area, similarities with other regions, theoretical considerations, results of studies available to you, and any other information you feel is related to the seismicity of the EUS. Thus, your responses to questions about seismicity should reflect your assimilation of the data with your knowledge and experiences relevant to the seismicity of the EUS and your evaluation of the historical record of seismicity in the various zones.

---

(1) In using the generic term zone in this questionnaire, we are referring to all tectonic features (e.g., areas, faults) identified on your maps as potential sources of earthquakes.

For each seismic parameter used to characterize seismicity within a zone, e.g., the expected frequency of earthquakes, we will ask you to give your best estimate of the value of the parameter. In addition, we will ask you to give an interval of values for each parameter to which you associate a high degree of confidence. As discussed in the Introduction in Questionnaire 1, confidence is considered to reflect your state of knowledge regarding the seismic parameter conditional on the historical data, your knowledge about and experiences with the geologic and tectonic conditions in the EUS, and any other information relevant to the seismicity in the region. We do not ask you to associate a specific level of confidence with the interval because of the difficulty we expect you would have in distinguishing between similar confidence levels, e.g., distinguishing between 90 and 95 percent levels of confidence. However, in our analysis we will model your state of knowledge about a parameter by assigning a probability distribution to each seismic parameter. Your best estimate and confidence bounds will be used to estimate the parameters of the probability distribution. In this context we will associate a specific level (e.g., 95 percent) of confidence with your interval. This interval should represent a set of values, in which you are highly confident that it includes the true value of the parameter. The width of the interval should reflect the uncertainties you have about the seismicity within a zone.

We would like to emphasize that it is important, for the success of this project, that you respond to all questions for each of the zones identified in the first questionnaire. Thus, even if you are uncertain about one or more seismic property for a zone, we encourage you to express an opinion. Your uncertainty should be reflected in your responses to questions involving a statement of confidence. Moreover, even if you believe some seismic features (e.g., the magnitude-recurrence relation model) are similar for all zones, you should consider each zone individually in making your responses. For example, even if your best estimate of the slope of a linear magnitude-recurrence relation is the same for all zones, your uncertainty about this parameter may vary from zone to zone; one reason for this is that the quality and amount of historical data varies from zone to zone. This variation in uncertainty should be reflected in varying confidence bounds for the slope from zone to zone.

To help you understand the reasons for the questions we pose in this questionnaire as well as why we emphasize the need for you to respond to all questions, we will outline how the three items addressed in this questionnaire (frequency of earthquakes, upper magnitude cutoff, magnitude- recurrence relation) enter into the hazard analyses.

For this project, seismic hazard at a site is defined as the probability P(A a) that the peak acceleration A at the site exceeds the value a. That is, P(A a) is the probability that at least one earthquake occurs for which the peak acceleration at the site exceeds a. This probability is experessed per unit time, e.g., 2.8×10^{-3} per year. The seismic hazard curve is frequently described by a plot of the logarithm of P(A a) versus a. (See Figure 1.1 in Questionnaire 1.) The peak acceleration at a site is assumed to be functionally related to earthquake magnitude and source-to-site distance.

Hence, the hazard P(A   a) depends on the distribution of peak acceleration conditional on magnitude and source-to-site distance, as well as the distribution of magnitudes, integrated over relevant source zones. The upper magnitude cutoff is the parameter of the distribution of magnitudes which defines the largest possible earthquake for each zone. The expected frequency of earthquakes and the magnitude-recurrence relation are jointly used to describe the frequency of magnitudes between the specified minimum level M_o and the upper magnitude cutoff M_U. Our hazard analysis methodology, similar to that used in the previous study, uses your inputs about the seismicity within a zone to estimate the expected frequency of earthquakes for a finite set of magnitude intervals spanning the range between M_o and M_U. Assuming a Poisson model for the occurrence of earthquakes in each zone, we can integrate over the relevant zones to assess the seismic hazard at a site, conditional on the values of the seismic parameters.

We will combine your best estimate and interval estimates of the seismic parameters, along with your responses to the questions in Section 4, to specify a joint probability distribution for the seismic parameters. This distribution will be used to assess a best estimate hazard curve and bounds for the hazard curve which represent your uncertainties in the seismicity of the EUS. Details about the appropriate probability distributions and about how we will interpret your inputs to estimate these probability distributions are discussed in the respective sections of the questionnaire. A discussion of the precise method for assessing the seismic hazard at a site and propagating the uncertainties through the analysis are too complex to present in this introduction. Details for the complete seismic hazard analysis, including the procedures for propagating uncertainty through the analysis, will be presented for your review at the general meeting of the panel during the third stage of the elicitation process.

2. UPPER MAGNITUDE CUTOFF

2.1 Introduction

An important parameter of the magnitude distribution is the upper limit of the range of magnitude values. This limit corresponds to the largest magnitude that will occur given the current geologic and tectonic conditions within a zone. This part of the questionnaire is concerned with eliciting your opinions about this limiting magnitude value for each zone identified in your seismic zonation of the EUS.

When one considers the magnitude of the largest event that can occur in a source zone, one might imagine that this will depend on the time length to be considered. For example, if one considers periods of 150 years and 1,000 years, one might expect the magnitude of the largest event to be different for the two time periods. In fact, if one were able to record the magnitudes of all earthquakes within a source zone over two such time intervals it would not be unusual for the largest event in 150 years to be different than the largest event in 1,000 years. This would be true even if the tectonic and geologic conditions of the region remained constant over time, since the magnitude of the largest event in T years, M_T, is a random variable. Thus, values observed over the 2 time periods would be realizations from two distributions of values. It is true that the probability distributions of these random variables will depend on T. However, assuming that the seismic, tectonic, and geologic conditions of the region remain constant over time, the range of values, specifically the lower and upper limits of the distributions, will be the same for both distributions. Conceptually, the relationship between the distributions of the largest earthquake in 150, 500, and 1,000 years is shown in Figure 2.1. Notice that all three distributions have a common upper limit, denoted M_U. However, the probability that the largest earthquake has a magnitude close to M_U decreases as the time period T decreases. This common upper limit is the parameter of interest in this section of the questionnaire.

The assumption that the range of values of the distribution of magnitudes is independent of time suggests, perhaps, that the value of the upper limit must include magnitudes of events which may occur as a result of potential long term changes in geologic and tectonic conditions. This is not the case for this project. In your responses, you should not consider the consequences of a change in tectonic conditions, for example, a change of the Atlantic margin to a subduction zone. The purpose of this project is to consider the seismicity of the region as it exists today and can be expected to exist in the near geological future.

The tectonic and seismic conditions currently existing within a zone will limit the magnitude of an earthquake, should an earthquake occur. This limiting value of magnitude, determined by the physical conditions within a zone, is the upper limit of the distribution of magnitudes. We refer to this parameter as the upper magnitude cutoff.

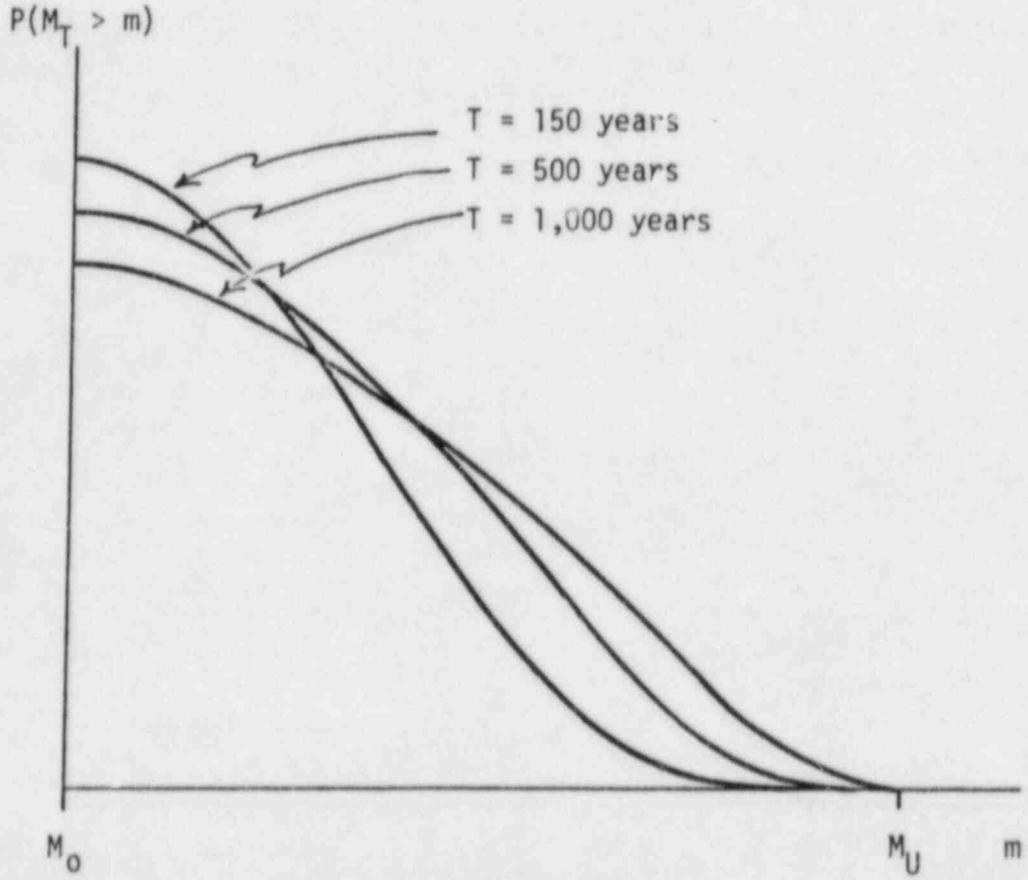


Figure 2.1 Probability that the Magnitude of the Largest Earthquake, M_T, in T Years Exceeds m.

Definition:

Upper Magnitude Cutoff, M_U - the upper limit for the distribution of earthquake magnitude within a zone, given the current tectonic and seismic conditions.

If the current tectonic and seismic conditions were to remain stationary and the magnitudes of all earthquakes were recorded for a long time, the collection of magnitudes would form a distribution of magnitudes, the upper limit of which is the parameter M_U. The parameter M_U should be distinguished from the random variable M_T discussed above.

An important consideration in the assessment of the upper magnitude cutoff is the saturation properties of the measurement scales presently used to describe the magnitude of an earthquake. For example, the Modified Mercali Intensity (MMI) scale has an upper value of XII. Thus, no matter what the total energy (or moment) associated with an earthquake, its magnitude, when measured in MMI, can never exceed XII. Similarly, the energy (or moment) - magnitude relationship, when magnitude is measured in M_{bLg} units, is described in Figure 2.2. Thus, when responding to questions concerning an upper magnitude cutoff, if one's response is expressed relative to observable magnitude values, the magnitude saturation value is an upper limit. On the other hand, when assessing the upper magnitude cutoff you may not want to be constrained by the saturation value. This can be done by expressing one's opinion in an alternative magnitude scale (e.g., in M_s). Alternatively, to avoid problems of changing magnitude scales (e.g., from M_s to M_{bLg}) and the uncertainty of the relation between scales, you may want to continue the linear portion of the moment-magnitude relation beyond the saturation value (indicated by the dashed line in the figure). To allow you as much flexibility as possible in expressing your views about the upper magnitude cutoff, you should feel free to consider or not consider the saturation of the measurement scale in your responses. We do ask you, however, in Question 2-2 to indicate if you are limited by a saturation value.

In Question 2-4 we ask you to specify an interval for the upper magnitude cutoff M_U to which is associated a level of confidence. This interval will be combined with your best estimate to describe your uncertainty about the value of M_U. In this description we will treat your best estimate as the most likely value (mode) and the endpoints of the interval as the limits of a triangular distribution similar to that shown in Figure 2.3. If you feel the triangular distribution does not adequately describe your uncertainty in the value of the upper magnitude cutoff, you should indicate an appropriate distribution in response to Question 2-5. Such a distribution can be expressed in terms of a density (relative frequency) function e.g., the uniform density function in Figure 2.4a, or in terms of a cumulative distribution function, e.g., the uniform distribution function in Figure 2.4b.

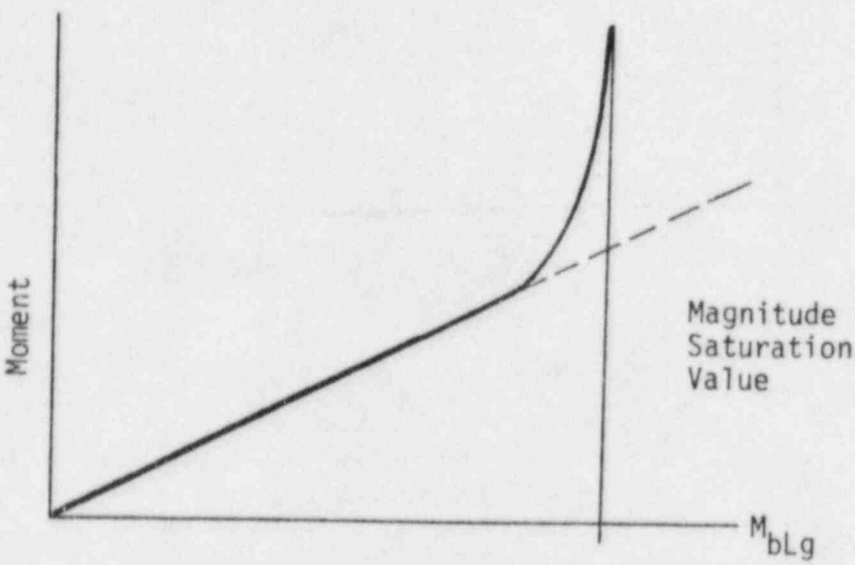


Figure 2.2 Moment - Magnitude Relationship

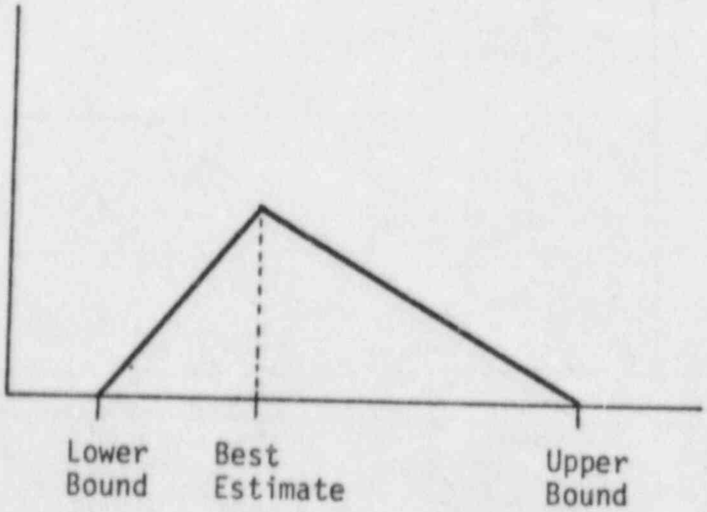


Figure 2.3 Triangular Density Function

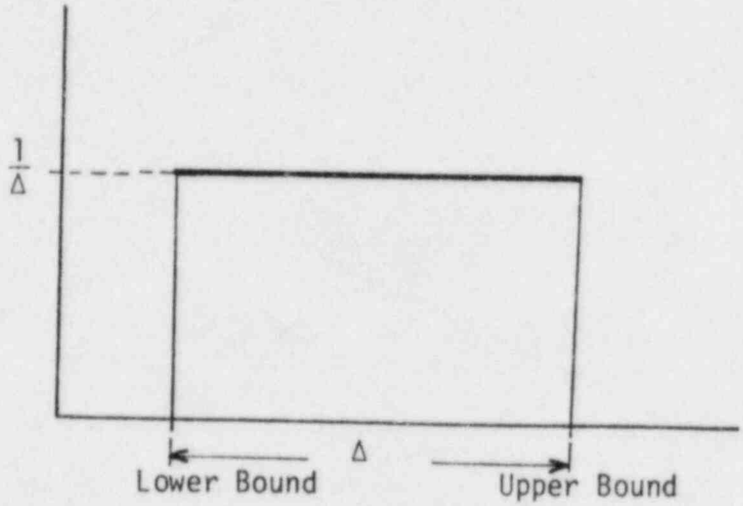


Figure 2.4a Uniform Density Function

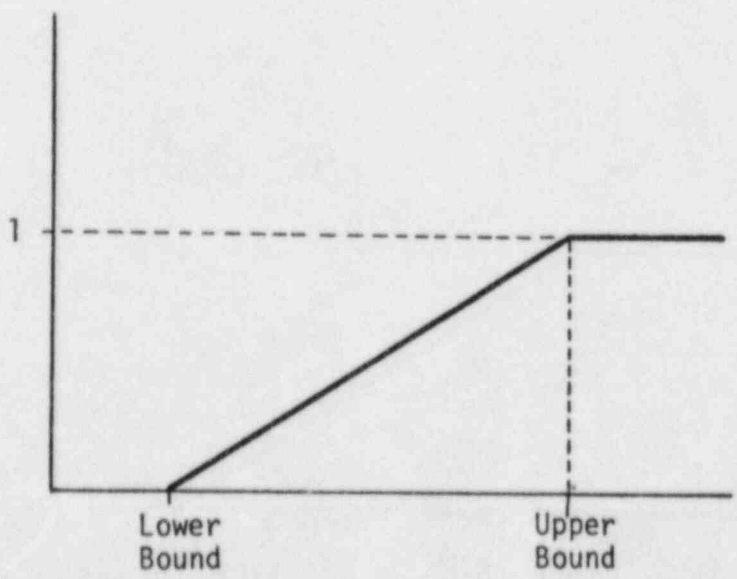


Figure 2.4b Uniform Distribution Function

2.2 Questions

For each of the seismic source zones identified on your maps of the zonation of the EUS.

2-1 What scale of measurement (e.g., MMI, M_{bLg}, etc.) for earthquake magnitude will you use for your responses to questions about the upper magnitude cutoff? (Note: It is not necessary to use the same scale for all zones; indicate, separately, the scale you are using for each zone.)

2-2 Will you, in your responses concerning the upper magnitude cutoff, be constrained by the saturation value (e.g., XII on the MMI scale) on your chosen scale of measurement? If so, what is the saturation value?

2-3 Given the current tectonic and seismic conditions for each zone, give your best estimate (most likely value) for the upper magnitude cutoff M_U for the distribution of magnitudes for the zone.

2-4 Give a lower bound M_{UL} and an upper bound M_{UU} for the value of the upper magnitude cutoff such that the range (M_{UL}, M_{UU}) is a reflection of your confidence in estimating the upper magnitude cutoff. As indicated in Fig. 2.2, the interval (M_{UL}, M_{UU}) will be treated as a 100% confidence interval for M_U.

2-5 Does the triangular distribution adequately describe your uncertainty in the value of the upper magnitude value? If not, please indicate an appropriate distribution.

3. EARTHQUAKE OCCURRENCES

3.1 Introduction

In this part of the questionnaire we elicit your opinions about the occurrence of earthquakes with magnitudes between a minimum magnitude M_o and the upper magnitude cutoff in each of the source zones identified on your maps of the zonation of the EUS. For this project, the minimum magnitude, in MMI units, is M_o = IV and, in M_{bLg} units, is $M_o = 3.75$. To elicit your opinions we ask you to respond to questions about:

1. The expected frequency (occurrence rate) of earthquakes with magnitude equal to or greater than M_o within a zone.

2. The magnitude-recurrence relation within a zone.

We recognize that by requesting your opinions about the expected frequency and the magnitude-recurrence relation, we are potentially eliciting redundant information. Specifically, for a specific time period, if the magnitude-recurrence relation is applicable at M_o then it can be used to estimate the expected frequency of earthquakes with magnitude equal to or greater than M_o. However, since the magnitude-recurrence model is usually derived from historical data, data which might be incomplete for magnitudes close to M_o, one might believe that the magnitude-recurrence model does not hold for all magnitudes. In this case, the two sets of questions are not redundant but provide needed inputs into the seismic hazard analysis. We further address the issue of the range of applicability of the magnitude-recurrence relation in Section 3.4.

By asking both questions, it provides you an opportunity to estimate the expected frequency by viewing the historical data from more than one perspective. For example, an estimate of the expected frequency can be based on only the number of earthquakes occurring over a period of time. On the other hand, the estimate from the magnitude-recurrence relation is influenced by the model used to fit the historical data. Thus, we have estimates of similar parameters based on different methods of analyzing the historical data. We recognize, of course, that you may choose to use entirely different procedures as a basis for your responses.

In any case, we request that you respond to questions about both expected frequency and the magnitude-recurrence relation. In doing such we hope that you will consider both questions separately and not derive the obvious response of one from the other. This permits us to treat your responses to both sets of questions equally in the seismic hazard analysis.

In responding to questions regarding the occurrences of earthquakes we expect you will use historical data on the seismic activity in the EUS, either your own data or the catalogue of historical events we have provided. Of course, when using this data to subjectively assess future seismicity in the EUS it is important that you use your judgment as to the validity, quality, and completeness of the data in determining how much you will rely on the data to form your opinions. If you are using the catalogue that we provided at your request, it should be recognized that no corrections for completeness have been performed on it nor have aftershocks been culled from the data. The analysis of the completeness of the catalogue and the use of aftershocks has been left to your discretion. Your judgments of the data may be based on geologic and tectonic considerations, similarities with other regions, theoretical considerations, results of your own studies or other studies available to you, or any other information which you feel influences the seismicity in the EUS.

We will ask you to provide your best estimate of the seismicity parameters and to express your uncertainty about each parameter by specifying an interval for the value of the parameter to which you associate a high degree of confidence. When modeling your uncertainty about the parameters in this section, the confidence interval is interpreted to be the set of values for which your personal confidence is 0.95 (i.e., a 95 percent level of confidence) that the true value lies within that range. As discussed earlier, the level of confidence reflects the degree to which you judge the data, tectonic and geologic conditions, etc., support a given response.

In the seismic hazard analysis, rather than imposing a parameteric model on the magnitude distribution, we take a nonparametric approach and base our analysis on the occurrence rate for each subinterval in a finite partition of the magnitude range (M_0, M_U). Your best estimates and confidence bounds for the seismic parameters are transformed into a best estimate and confidence bounds for the magnitude-recurrence relation using the functional form (e.g., linear) of the relation you supply. The best estimate and confidence bounds for the magnitude-recurrence relation will be used to specify the means, variances and covariances of the occurrence rates for the subintervals. These will, in turn, be used to determine the parameters of the joint distribution of the occurrence rates, which is modeled as a multivariate gamma distribution.

3.2 Magnitude Scale

When analyzing your responses to questions about earthquake occurrences it is important that the magnitude scale you use in making your responses be clearly identified. You are free to use whatever scale you feel permits you to best express your opinions about seismicity within a zone. The same scale need not be used for all zones. In Question 3-1 we ask you to identify the magnitude scales you will use in your responses about earthquake occurrences.

The seismic hazard analysis will be based on magnitudes in either the MMI or M_{bLg} scales. Thus, if you use any other magnitude scale it will be necessary to transform the responses in your chosen scale to statements on either the MMI or M_{bLg} scale. To make this transformation we will need to know the relationship between the magnitude scales you will be using and either MMI or M_{bLg}. To ensure the integrity of your answers, we ask you to describe this relation.

form your opinions. If you are using the catalogue that we provided at your request, it should be recognized that no corrections for completeness have been performed on it nor have aftershocks been culled from the data. The analysis of the completeness of the catalogue and the use of aftershocks has been left to your discretion. Your judgments of the data may be based on geologic and tectonic considerations, similarities with other regions, theoretical considerations, results of your own studies or other studies available to you, or any other information which you feel influences the seismicity in the EUS.

We will ask you to provide your best estimate of the seismicity parameters and to express your uncertainty about each parameter by specifying an interval for the value of the parameter to which you associate a high degree of confidence. When modeling your uncertainty about the parameters in this section, the confidence interval is interpreted to be the set of values for which your personal confidence is 0.95 (i.e., a 95 percent level of confidence) that the true value lies within that range. As discussed earlier, the level of confidence reflects the degree to which you judge the data, tectonic and geologic conditions, etc., support a given response.

In the seismic hazard analysis, rather than imposing a parameteric model on the magnitude distribution, we take a nonparametric approach and base our analysis on the occurrence rate for each subinterval in a finite partition of the magnitude range (M_0, M_U). Your best estimates and confidence bounds for the seismic parameters are transformed into a best estimate and confidence bounds for the magnitude-recurrence relation using the functional form (e.g., linear) of the relation you supply. The best estimate and confidence bounds for the magnitude-recurrence relation will be used to specify the means, variances and covariances of the occurrence rates for the subintervals. These will, in turn, be used to determine the parameters of the joint distribution of the occurrence rates, which is modeled as a multivariate gamma distribution.

3.2 Magnitude Scale

When analyzing your responses to questions about earthquake occurrences it is important that the magnitude scale you use in making your responses be clearly identified. You are free to use whatever scale you feel permits you to best express your opinions about seismicity within a zone. The same scale need not be used for all zones. In Question 3-1 we ask you to identify the magnitude scales you will use in your responses about earthquake occurrences.

The seismic hazard analysis will be based on magnitudes in either the MMI or M_{bLg} scales. Thus, if you use any other magnitude scale it will be necessary to transform the responses in your chosen scale to statements on either the MMI or M_{bLg} scale. To make this transformation we will need to know the relationship between the magnitude scales you will be using and either MMI or M_{bLg}. To ensure the integrity of your answers, we ask you to describe this relation.

Also, the hazard analysis will involve several ground motion models, some of which involve intensities and some involving magnitudes. Thus, it is necessary for us to move between the epicentral intensity $(MMI)_E$ expressed in the MMI scale and M_{bLg} scale. To do this we propose to use the relation

$$(MMI)_E = 2M_{bLg} - 3.5$$

If you do not feel that this is the best model for relating $(MMI)_E$ and M_{bLg} measurements, you can indicate such in your response to Question 3-4.

Finally, the seismic hazard analysis is based on assessing the hazard at a site in the EUS due to earthquakes with magnitudes above a minimum level. For purposes of this project, the minimum magnitude, M_o, is either $(MMI)_E$ = IV or $M_{bLg} = 3.75$. In this analysis it is assumed, from a structural standpoint, the effect on a nuclear power plant of earthquakes of magnitude below IV or 3.75 will be insignificant and hence need not be taken into consideration. If you respond to questions about seismicity in other than the MMI or M_{bLg} scales, it is important to identify the corresponding minimum level.

Questions

3-1 In your responses to questions about earthquake occurrences, please list all the magnitude scales you will use. Note: It is not necessary to use the same scale for all zones.

For any magnitude scale other than MMI and M_{bLg} identified in Question 3-1, please

3-2 Describe the relationship between that scale and either the MMI or M_{bLg} scale.

3-3 Indicate the minimum magnitude, M_o, below which the effect of the earthquake will be insignificant.

When transforming between $(MMI)_E$ and M_{bLg} scale in our analysis we propose to use the relation

$$(MMI)_E = 2M_{bLg} - 3.5$$

3-4 Do you agree with this relation? If not, please indicate the relationship you believe is more appropriate.

3.3 Expected Frequency of Earthquake

An important parameter for characterizing the seismicity of a zone is the frequency with which earthquakes occur within the zone. Since a seismic hazard analysis is based on considering the effect of earthquakes having magnitudes or epicentral intensities greater than some minimum level, we are only interested in the occurrence of earthquakes with magnitude at the minimum level or greater. The questions in this part of the questionnaire are designed to elicit information about the expected frequency of earthquakes within a zone with magnitudes at or above the min um level.

For purposes of this project the minimum magnitude, M_o, is either $(MMI)_E$ = IV or M_{bLg} = 3.75. If you are responding to questions about magnitude in any other scale, e.g., in M_s units, there is a corresponding minimum level below which the effect of the earthquake on a nuclear power plant will be insignificant.

The expected frequency can be expressed either in terms of the rate of occurrence within a zone per year, e.g., 0.313 per year, or the number of earthquakes expected to occur in a zone within a specified period of time, e.g., 47 in 150 years. The time period is left to your discretion. The period you use may depend on the catalogue of historical data you choose and your opinion about the completeness of the data. The same time period need not be used for all zones. We are interested in assessing the seismic activity in each zone under the geologic and tectonic conditions as they exist today and can be expected to exist in the near geological future. Thus, in using the historical data one must judge, in addition to the completeness of the data, how well past seismic activity reflects activity that may occur in the future under present conditions.

Questions

For each of the seismic source zones identified on your maps of the zonation of the EUS:

3-5 What scale of measurement for earthquake magnitude will you use for your responses to questions about the expected frequency of magnitudes greater than M_o?

3-6 Give your best estimate of the expected frequency, either in terms of the mean rate per year or the expected number in T years, of earthquakes with magnitude at or above M_o occurring within the zone. Indicate the time period T.

Note: The expected frequencies should be expressed as the rate (number) per zone, not per unit area.

3-7 Give an interval which you believe, with a high degree of confidence, represents the possible values of the expected frequency.

3.4 Magnitude Distribution

Conditional on an earthquake of magnitude M_o or greater occurring within a zone, the magnitude of the earthquake can be any value between M_o and M_U, the upper magnitude cutoff. Thus, given that an earthquake occurs within a zone, its magnitude is the value of a random variable drawn from a distribution of magnitudes. The purpose of this part of the questionnaire is to elicit information which characterizes this distribution.

Several methods can be used to describe the magnitude distribution. Certainly, one simple method would be to list a set of distinct magnitude values along with the frequency or relative frequency corresponding to each magnitude. However, the method most often used is based on the magnitude-recurrence relation. This is a model for the relationship between the $\log_{10} N_m(T)$ and m for magnitudes between M_o and M_U, where $N_m(T)$ is the number of earthquakes exceeding magnitude m in T years. Three such models, or magnitude-recurrence relations, are illustrated in Figure 3.1. The choice of the function , e.g., linear, quadratic, piecewise linear, as well as the values of the model parameters, e.g., a, b, c, characterize the magnitude distribution.

Another method for describing the magnitude distribution, which may be analogous to specifying a magnitude-recurrence relation, is to model the magnitude distribution in terms of a well known probability distribution, e.g., the exponential distribution. The choice of the distribution, e.g., exponential, as well as the values of the parameters of the distribution characterize the magnitude distribution. When using well known probability distributions it must be recognized that most probability distributions are defined over an infinite range, e.g., zero to infinity. Since the upper magnitude cutoff, M_U, is finite, it will be necessary to truncate the probability distribution at M_U when using such models to describe the magnitude distribution.

Although any of these methods is adequate to describe the magnitude distribution, it is most convenient for our analysis to characterize the magnitude distribution in terms of the magnitude-recurrence relation. Thus, we encourage you to respond to Questions 3-8 through 3-16 which elicit information about the magnitude distribution in terms of the magnitude-recurrence relation. However, if you feel you can better characterize the magnitude distribution using another method then please use the alternative method. In any case, it is important that the magnitude distribution be completely characterized, i.e., both functional form and parameter values, for all zones.

Questions

Questions 3-8 through 3-16 are based on characterizing the magnitude distribution in terms of a magnitude-recurrence relation. If you are using an alternative method to describe the distribution of magnitudes, skip questions 3-8 through 3-16 and go directly to Question 3-17.

3-8 What scale of measurement (e.g., MMI, M_{bLg}) for earthquake magnitude will you use for your responses to questions about the magnitude-recurrence relation?

3-9 Will you, in your responses concerning the magnitude-recurrence relation, be constrained by the saturation value on your chosen scale of measurement? If so, what is the saturation value?

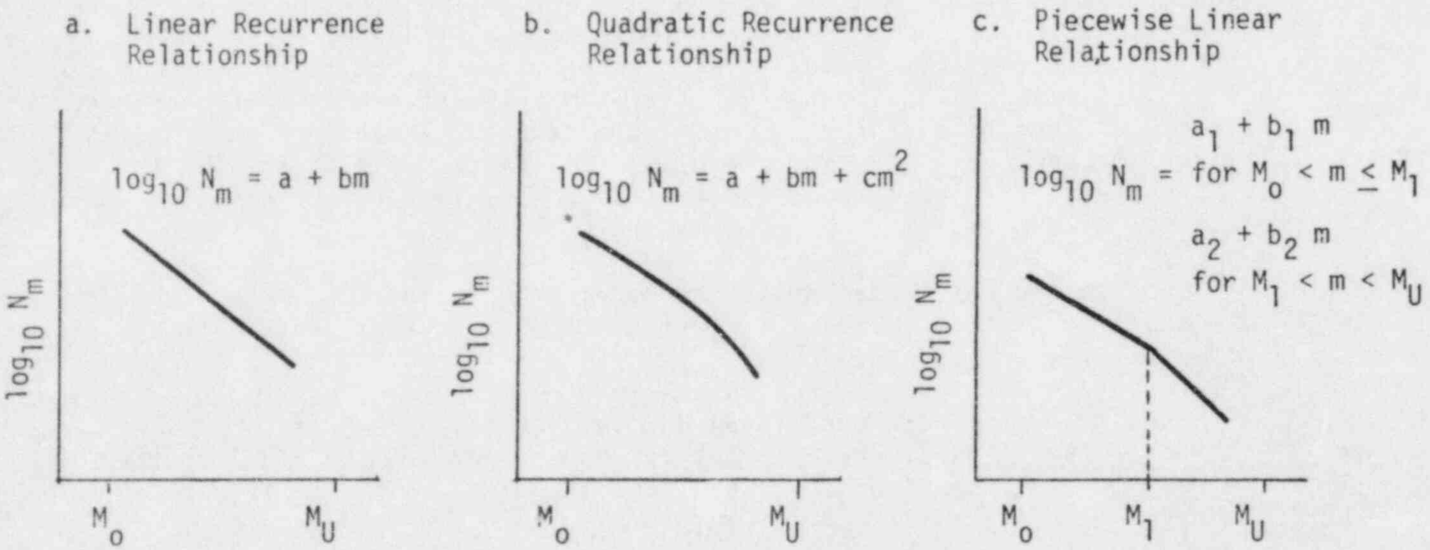


Figure 3.1 Magnitude-Recurrence Relations

In using the magnitude-recurrence relation to characterize the magnitude distribution it must be recognized that the model is an empirical relation based on historical data collected over T years. Since the entire magnitude range may not be represented in the historical data, the model derived from the data may not be applicable for all magnitudes between the minimum magnitude M_o and your maximal upper magnitude cutoff M_{UU}. We ask you to identify the range of magnitudes, denoted M_{LB}, M_{UB}, in Question 3-14. This range may vary from zone to zone.

It is necessary for the seismic hazard analyses, however, to characterize the magnitude distribution for all magnitudes including the magnitudes between M_o and M_{LB} and between M_{UB} and M_{UU}. Thus, it is necessary to extrapolate the magnitude-recurrence model beyond the range (M_{LB}, M_{UB}). You can indicate how this should be done by responding to questions 3-10 and 3-11. If you do not suggest a method we will extrapolate the magnitude-recurrence relation beyond M_{LB} and M_{UB} by a method based on assuring a continuous derivative at M_{LB} and M_{UB}, a zero derivative at M_U and a value at M_o, on the N_m scale, equal to the expected frequency of earthquakes with magnitude equal to or greater than M_o, the minimum magnitude. A graphical illustration, assuming a linear magnitude-recurrence relation, is given in Figure 3.2. Note, the vertical scale in Figure 3.2(a) is N_m rather than $\log_{10}N_m(T)$ and $\log_{10}N_m(T)$ in Figure 3.2(b). For each of the seismic source zones identified on your maps of the zonation of the EUS

3-10 Indicate the magnitude-recurrence model (e.g., linear, a + bm; quadratic, $a + bm + cm^2$) which, in your opinion, best represents the seismicity of the zone.

Notes: a. The same model need not be used for all zones.
b. If a piecewise model is chosen, part of the model is the specification of the "change points" e.g., M_1 in Figure 3.1c.

3-11 For the model chosen in Question 3-10 give your best estimate of the value of the parameters of the model (e.g., values of a, b, c).

3-12 Specify the time length, T, on which your estimates of the parameters identified in Question 3-11 are based.

3-13 Give an interval which you believe, with a high degree of confidence, represents the possible values for each parameter identified in your response to Question 3-11.

3-14 Specify the range of magnitude values, denoted (M_{LB}, M_{UB}), for which the magnitude-recurrence relation identified in Questions 3-10 and 3-11 is applicable.

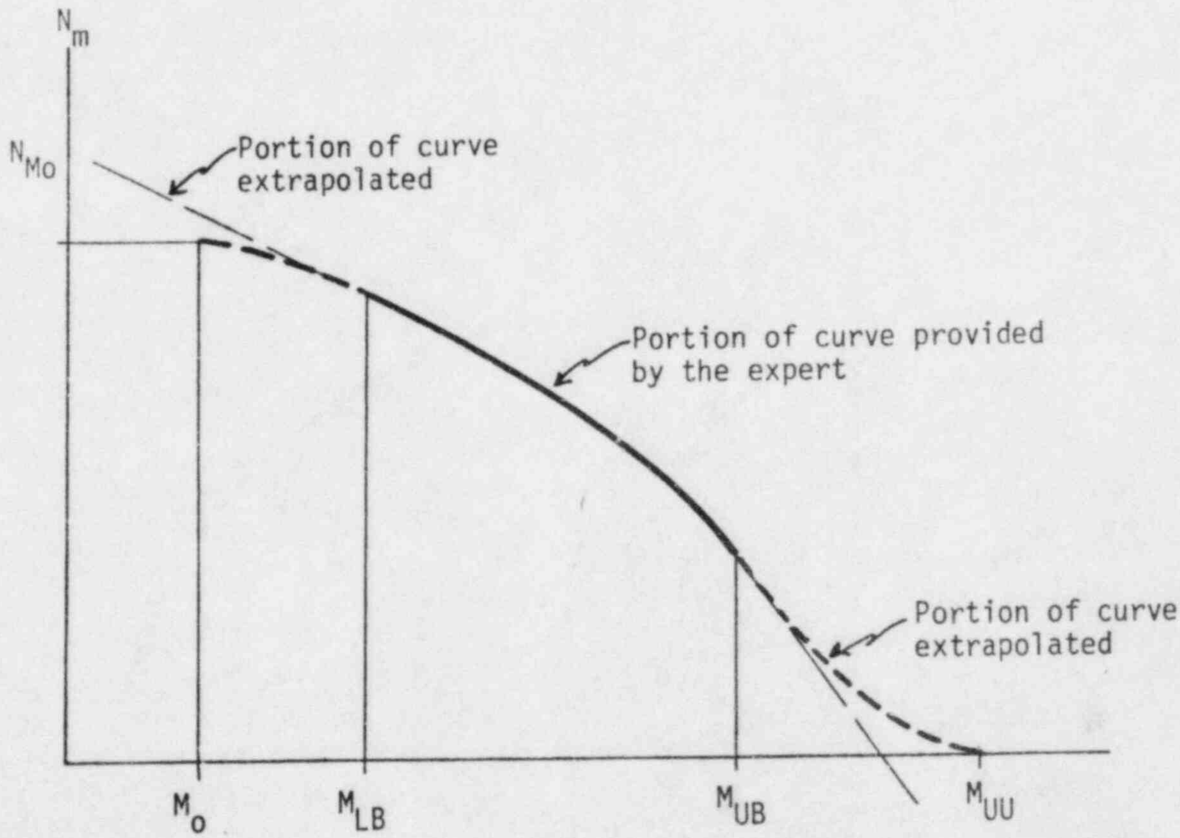


Figure 3.2(a) Extrapolation of the Magnitude-Recurrence Relation in the Number of Event versus Magnitude Space.

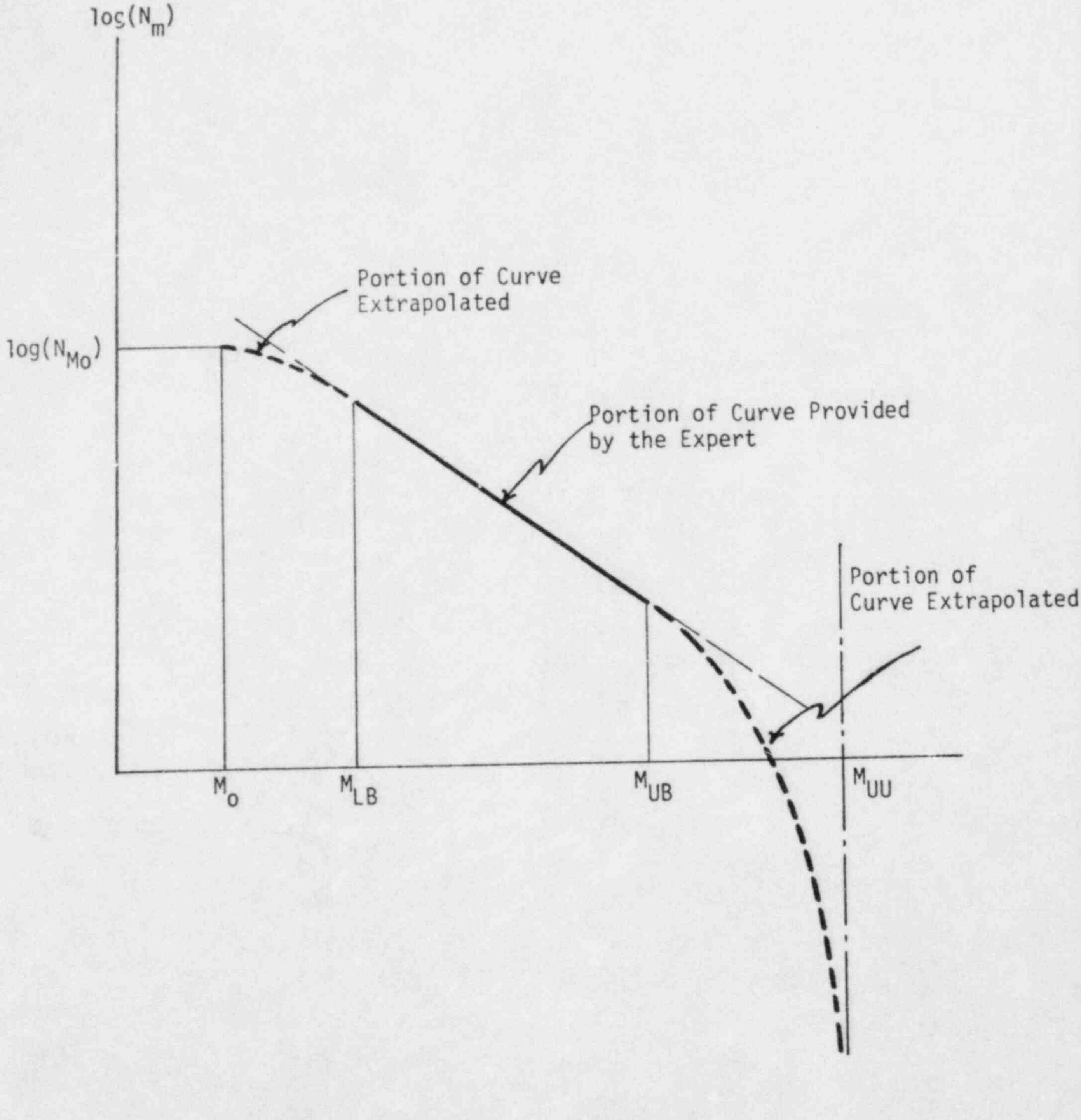


Figure 3.2(b) Extrapolation of the Magnitude-Recurrence Relation in the Logarithm of Number of Event versus Magnitude Space

If the range (M_{LB}, M_{UB}) does not coincide with the interval (M_o, M_{UU}) for some zones, it is necessary to extrapolate the magnitude-recurrence curve beyond (M_{LB}, M_{UB}) so that the frequency of earthquakes can be assessed for all magnitudes from the minimum magnitude M_o to the maximal upper magnitude cutoff M_{UU}. Extrapolation of this curve in either direction is a matter of subjective opinion. We have suggested one method for extrapolating. However, you may prefer to suggest an alternative procedure. In that case our method of extrapolation would not be applied when we analyze your inputs. Of course, when extrapolating, two restrictions on the extrapolation procedure must be recognized. Specifically, the value of N_m at $m = M_o$, the minimum magnitude, should equal the expected frequency of earthquakes with magnitudes equal to or greater than M_o and the value of N_m at M_U, the upper magnitude cutoff, should be zero. To indicate your method of extrapolation, please respond to Questions 3-15 and 3-16.

If the range (M_{LB}, M_{UB}) does not coincide with the interval (M_o, M_{UU}) for any zone and you have a method of extrapolation you feel is appropriate, please

3-15 Indicate how the magnitude-recurrence curve should be extended to magnitudes in the interval (M_o, M_{LB}).

3-16 Indicate how the magnitude-recurrence curve should be extended to magnitudes in the interval (M_{UB}, M_{UU}).

<u>If you have responded to Questions 3-8 through 3-16 for all source zones, please skip the remaining questions in this section.</u>

If you can better describe the magnitude distribution using another method (e.g., by a discrete or well known continuous probability distribution), please do so in the context of Questions 3-17 through 3-19.

3-17 What scale of measurement (e.g., MMI, M_{bLg}) for earthquake magnitude will you use in describing the probability distribution of magnitudes?

3-18 For each of the seismic source zones identified on your maps of the zonation of the EUS, specify a model for the probability distribution of magnitudes for that zone. Include in your specification your best estimate of any parameters in the model.

3-19 Give an interval which you believe, with a high degree of confidence, represents the possible values for any parameters identified in your response to Question 3-18.

4. EARTHQUAKE OCCURRENCE IN T YEARS

4.1 Introduction

As discussed in Section 2.1, the magnitude M_T of the largest earthquake in T years is a random variable. the probability distribution of this random variable is a function of earthquake frequency and magnitude distribution. Thus, your opinions about the probability distribution of the largest earthquake in T years reflect your opinions about the distribution of earthquake magnitudes.

In eliciting your opinions about the probability distribution of M_T we recognize that we are gathering more information than is absolutely necessary to analyze the seismic hazard at a site. However, use of redundant information increases the precision of our estimates and gives you the opportunity to assess seismicity from more than one perspective. We plan to develop the seismic hazard at a site based on (i) your responses to the questions in Sections 2 and 3, and (ii) your responses to Sections 2 and 3 combined with your responses to the questions in this section. This will give us an opportunity to share with you, when we discuss the output of the hazard analysis, the consequences of your assessing the seismicity of the EUS from alternative perspectives.

Since the probability distribution of M_T is related to the seismic parameters discussed in Sections 2 and 3 it would be possible to derive responses to the questions in this section directly from your responses in the preceeding sections. We prefer you did not do this but again use the historical data, the tectonic and geologic conditions of the EUS, and other relevant information to develop your opinions about the probability distribution of M_T.

To gather information about the distribution of the magnitude of the largest earthquake we consider two time periods, T = 150 years, because it represents approximately the length of recorded history in some sections of the EUS, and T = 1,000 years, because it represents a somewhat extended length of time.

As discussed previously, the distribution of M_T depends on the seismic parameters identified in Sections 2 and 3. A critical parameter is the largest magnitude possible, i.e., the upper magnitude cutoff M_U. In Section 2 we elicited your best estimate as well as an interval (M_{UL}, M_{UU}) for the upper magnitude cutoff. Since it would be impossible for you to respond to the questions in this section for all values of M_U in the range (M_{UL}, M_{UU}), we ask you to respond conditional on your best estimate, denoted M_U in the questions. Also, since your responses are conditional on M_U, you should respond to the questions in this section in the same scale of measurement as M_U.

4.2 Questions

Please respond to Questions 4-1 or 4-2 or both, and 4-3.

For each of the seismic source zones identified on your maps of the zonation of the EUS:

For T = 150 years and T = 1,000 years.

4-1 Give an estimate of the probability that the magnitude M_T of the largest earthquake in T years equals or exceeds m, conditional on your best estimate M_U of the upper magnitude cutoff, i.e., estimate

$$P\left\{M_T \geq m \mid \hat{M}_U\right\}$$

for (a) $m = \hat{M}_U - 1$, (b) $m = \frac{M_o + \hat{M}_U}{2}$, and (c) $m = M_o + 1$

4-2 Give an estimate of the median $M_T(.5)$ for the magnitude of the largest earthquake in T years, conditional on M_U. That is, estimate the value $M_T(.5)$ such that

$$P\left[M_T \geq \hat{M}_T(.5) \mid M_U\right] = P\left[M_T \leq M_T(.5) \mid \hat{M}_U\right] = 0.5$$

Information about earthquake frequency is also reflected in statements about the number of earthquakes with magnitudes exceeding a specific value. This is addressed in the next question.

4-3 Give an estimate of the expected value of the number of earthquakes of magnitude m or greater in T years, $N_m(T)$, conditional on your best estimate $\hat{M}_U$, for

(a) $m = \hat{M}_U - 1$, (b) $m = \frac{M_o + \hat{M}_U}{2}$, and (c) $m_o = M + 1$.

5. DEPTH OF EARTHQUAKES

5.1 Introduction

As described by attenuation models, the hazard at a site depends on the magnitude of an earthquake as well as the distance of the site from the earthquake source. The source-to-site distance, for some models, is a function of the surface distance of the site from a source as well as the depth of the hypocenter at the source. Thus for some models, in general, the deeper the expected depth of an earthquake, the greater the correction in the surface distance in the attenuation. In this section we elicit your opinions about the expected depth of an earthquake within each zone.

5.2 Questions

For each of the seismic source zones identified on your maps of the zonation of the EUS:

5-1 Which of the following best describes the distribution of depths at which earthquakes will occur within the zone. Earthquakes within the zone will occur:

a. at approximately the same depth throughout the entire zone

b. at only a small set of depths

c. within a "continuous" range of depths.

5-2 Give your best estimate of either

a. the single depth value

b. the set of depths and the percentage of activity attributable to each

c. the range of depths and a probability distribution describing the relative activity at depths throughout the range.

If your response to Question 5-1 is either b or c,

5-3 Do you believe that the depth at which an earthquake will occur within the zone will depend on the magnitude? If yes, what function best describes the relation between depth D and magnitude M (e.g., linear, $D = a + bM$; power function, $D = aM^b$)?

A.4 Third Questionnaire: Weights (Q3)

Lawrence Livermore National Laboratory

NUCLEAR SYSTEMS SAFETY PROGRAM

July 20, 1983
EG-83-62/1034u

Professor Gilbert A. Bollinger
604 Newman Lane
Blacksburg, Virginia 24060

SUBJECT: "Self Rating" Questionnaire
EUS Seismicity Modeling Panel
Seismic Hazard Characterization of the EUS

Dear Gil:

Enclosed please find the subject "Self Rating" questionnaire and answer sheet (three pages in all). It is important to the success of the project that you complete this questionnaire and return it to me as soon as possible. We will then incorporate your self-rating into our computational chain in strict confidence.

We are making steady and good progress in our project objectives. You will soon be informed about the extent of our progress and the time and place of our "Feedback Meeting" in October, 1983.

Thank you very much for your immediate attention, and have a good summer.

Sincerely yours,

Dae H. Chung
Principal Co-Investigator

DHC/sa

Enclosure

PS: If you have not yet submitted your bill, please send it to me indicating your consulting time. Danny

An Equal Opportunity Employer • University of California • P.O Box 808 Livermore, California 94550 • Telephone (415) 422-1100 • Twx 910-386-8339 UCLLL LVMR

bcc: D. L. Bernreuter
R. T. Langland
P. D. Smith

<u>NRC</u>

A. J. Murphy
L. Reiter/J. Kimball

Same letter sent to:

Dr. Alan L. Kafka
Weston Observatory

Mr. Richard Holt
Weston Geophysical Research, Inc.

Professor Arch Johnston
Tennessee Earthquake Information Center

Professor Tim Long
Georgia Institute of Technology

Professor James Lawson
Oklahoma Geophysical Observatory

Dr. Carl Stepp
EPRI

Professor Otto Nuttli
St. Louis University

Professor Ronald Street
University of Kentucky

Dr. Paul Pomeroy
Rondout Associates

Professor Nafi Toksoz •
MIT

Dr. Carl Wentworth
USGS

Dr. Peter Basham
Dept. of Energy, Mines, and Resources
Ottawa Canada

Dr. Anne Stevens
Dept. of Energy, Mines, and Resources
Ottawa Canada

SELF RATING

1.0 Introduction

We have been receiving your responses from Questionnaire 2 and are in the final stages of developing the software to translate your opinions regarding the zonation and seismicity of the EUS into descriptions about the seismic hazard at selected sites. We want to again express our appreciation for your participation in this project.

As part of the elicitation process, we have asked you to give us your (a) best estimate of the seismic parameters (e.g., zonation, occurrence rate, upper magnitude cutoff, etc.) as well as (b) a range of values to which you associate a degree of confidence. In this context we consider confidence to reflect the degree to which you judge the historical data, your knowledge and experiences with the geologic and tectonic conditions in the EUS, and other relevant information to support a given response.

In the discussion (Section 1.3) in Questionnaire 1, we specifically pointed out that in questions involving a statement of confidence you should not be influenced by your level of expertise relative to the other members of the panel. Thus, we are able to develop a hazard curve with bounds for each individual which reflects the degree of confidence (or level of uncertainty) associated with the responses of that individual.

However, in addition to the hazard curve developed from the responses of each expert, it is important that we combine the hazard curves over all members of the panel to develop (a) a "best estimate" hazard curve which reflects the "best estimate" responses of the entire panel and (b) bounds for the hazard curve which reflect not only the uncertainties of the individual members but also the diversity of opinions between members of the panel. We propose to combine the best estimate hazard curves from each member and the uncertainty information by a weighted averaging procedure. To do this, of course, we need to determine an appropriate set of weights.

Although there are several weighting schemes (e.g., equal weights, LLNL derived weights), one set of weights, consistent with what was done on the previous (SEP) elicitation, is based on your appraisal of your expertise, i.e. self rating. We recognize some of the weaknesses and difficulties in eliciting and using self rating and we are investigating alternative weighting techniques. However, most weighting techniques are subjective and thus involve some of the same problems as self rating. Overall, we believe self rating to be a viable means of developing weights for combining the hazard curves for all members of the panel. Thus, we would ask you to self rate yourself with regard to your level of expertise about the geologic, tectonic and seismicity of the EUS.

In contrast to the previous elicitation when you were asked to self rate yourself with regard to (a) zone configuration, (b) maximum earthquake and (c) earthquake recurrence for each zone, our weighting method only allows for a single weight, i.e. a single weight which simultaneously reflects your expertise with regard to zonation and seismicity. However, we do recognize that you may feel your level of expertise is not the same for the entire EUS. Thus, we have partitioned the EUS into four regions.

- Northeast
- Northcentral
- Southeast
- Southcentral

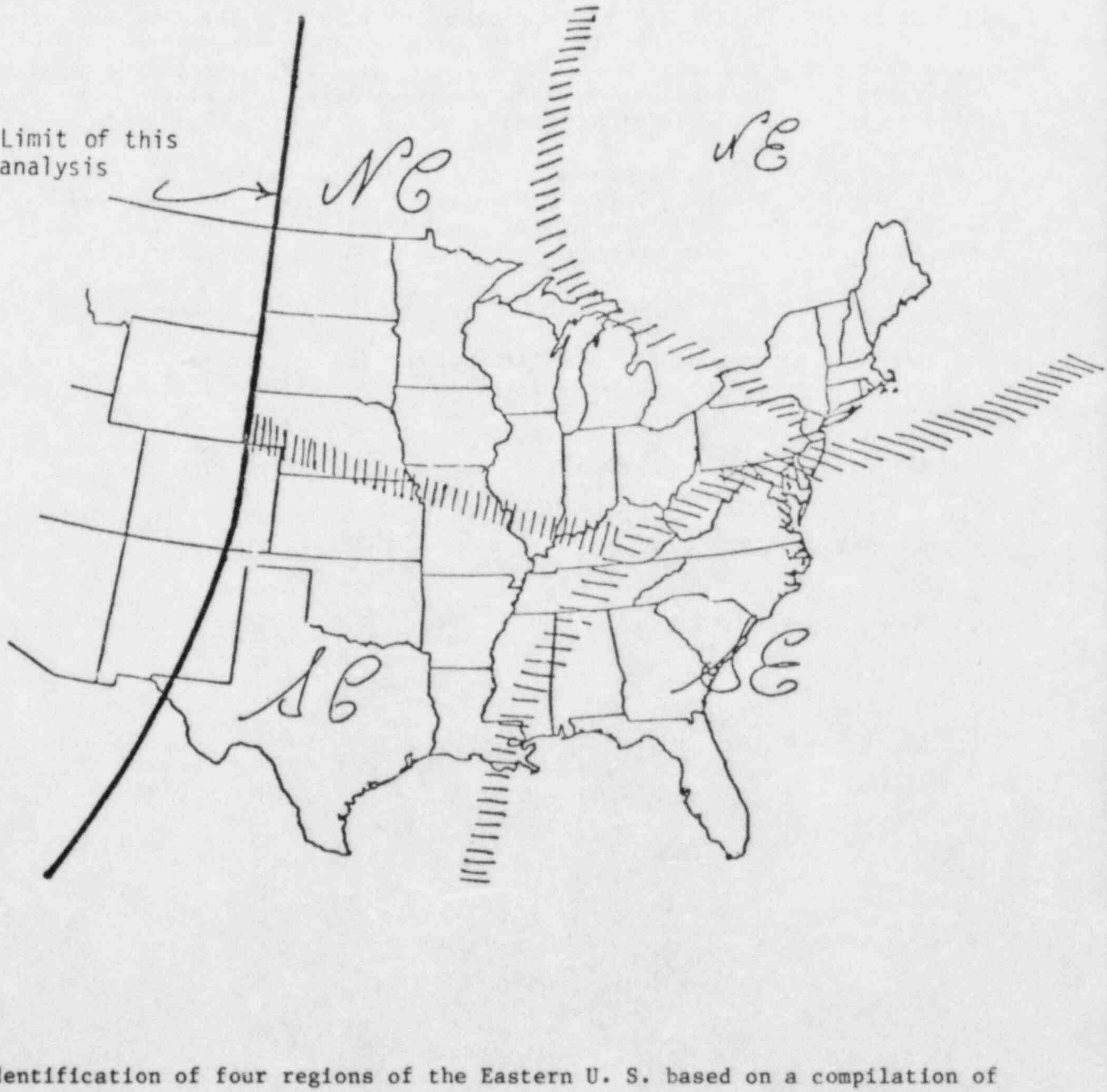
which have been labeled regions I-IV on the included map. The boundaries of the regions are also described in the following questionnaire. We would like you to self rate yourself for each of the four regions. We will combine your rating in the four regions to develop a single weight for the hazard based on your responses. The combination is based on the likelihood of the risk being initiated in a zone within each region.

In appraising your level of expertise in each of these regions, we ask that you use a 1-10 scale where low values indicate a low level of expertise and high values a high level of expertise. An integer value is not necessary, although not more than one decimal place (e.g. 7.3) is appropriate.

2.0 Question

For each of the four regions identified below, please indicate your level of expertise with regard to the geologic, tectonic and seismic characteristic within the region.

REGION	SELF RATING
I. Northeast	________
II. Northcentral	________
III. Southeast	________
IV. Southcentral	________



Identification of four regions of the Eastern U. S. based on a compilation of the seismic zonation expert maps developed in this study, combined with a map of Q_o-contours from Singh & Herrmann (1983).

A.5 Summary of the Experts' Responses

This section contains in a summary form the following seismicity experts' input:

- o Digitized versions of the map(s) provided by the expert with each zone numbered with the expert's index system.
- o Table A2 for each expert gives the response to Question 3 of the first questionnaire about alternative zones and any additional comments required for the second questionnaire.
- o Table A3 for each expert keyed to the map zones gives the responses to the third questionnaire (self weights), the responses to Question 2 of the first questionnaire giving the probability of existence of the primary source zones and the responses to the second questionnaire.

Although the layout of Table A3 for each expert is reasonably self-explanatory, some explanation is helpful. The first line gives the expert number and his self weights for the four regions shown in Figure 2.4. Then follows the data for each zone. Two zone numbers are given for each zone, the number keyed to the map is the map index number (i.e., the zone index provided by the expert). For each zone the probability of existence is given (response to Question 2 of the first questionnaire). In some cases the probability of existence is listed as "ALTBDY." This indicates that this zone is an alternative shape for some primary zone. Reference must be made to Table A2 to determine which zones replace and which zones are replaced as well as the level of confidence in the alternative set of boundaries.

All experts chose to work in either m_{bLg} or MMI and all but Expert 6 chose the recurrence model as

$$\log n = a - b\ (M \text{ or } I_o) \qquad \text{(A-1)}$$

Expert 6 chose a bi-linear model for some zones.

The second line of the data for each zone indicates whether the expert is using magnitude or intensity for his measure of earthquake energy for the zone in question. The range of validity of Eq. (A-1) is also given (Question 3-14). As discussed in the second questionnaire and in Appendix D, it is necessary to extrapolate beyond this range for some zones. The next line gives the best estimate of the upper magnitude cutoff M_u and its interval M_{UL} and M_{UU}. In most cases the experts expressed M_U in either the m_{bLG} or MMI scales. The few exceptions are given in the second table as well as the equation used to convert to either the MMI or m_{bLg} scales. The next line gives the response to questions 3-6 and 3-7 of the second questionnaire. N is the number of events <u>per year</u> greater than $m_{bLg} = 3.75$ or MMI = 4, depending upon the magnitude scale used for the zone in question. The last two lines provide the response to questions 3-11 and 3-13 (a and b values and range) on a <u>per year basis</u>.

It should be noted that the experts felt that modeling the distribution for M_u as a triangular distribution (Question 2-5) was acceptable. Table A.1 summarizes either the responses or where each response to the first three questionnaires can be found.

Table A.1

Summary of Responses or Where Response to Each Question can be Found

First Questionnaire-Zonation

(Q 1-1) See digitized maps for each expert in Fig. A1 to A20.

(Q 1-2) The probability of existence of each primary zone is given in the Table A3 for each expert. The zone(s) that a zone with probability less than one becomes part of (the host zone) of is given in the Table A2 for each expert.

(Q 1-3) Alternative boundaries are also given in the second table for each expert.

Second Questionnaire--Seismicity Parameters

(Q 2-1) Experts generally used m_{blg} or MMI except where noted in Table A2 for each expert.

(Q 2-2) Generally not a problem or experts extrapolated the m_{bLg} scale beyond saturation. Any exceptions are noted in the second table for each expert.

(Q 2-3 and 4) Given in Table A3 for each expert.

(Q 2-5) Triangular distribution acceptable to all experts.

(Q 3-1) All experts used either m_{bLg} or MMI.

(Q 3-2) Where applicable given in Table A2 for each expert.

(Q 3-3) Panel members generally agreed with the choice of M_o.

(Q 3-4) Only two panel members (Nos. 1 & 10) provided their own relationship between epicentral intensity and magnitude. These relations are given in the Table A2 for experts 1 & 10.

(Q 3-5) The experts gave their estimate of N in the same scale they used for the magnitude-recurrence relationship. This is given in the Table A3 for each expert for each zone. Note that some experts used different scales for different zones.

(Table A.5-1 - continued)

(Q 3-6 and 7)	These values are given in Table A3 for each expert and have been normalized to per year basis using the period T given by the expert.
(Q 3-8)	Same as (Q 3-5)
(Q 3-9)	Saturation of magnitude scale not generally a problem except where noted in Table A2 for each expert.
(Q 3-10)	Only Expert 6 departed from the linear magnitude-recurrence model (Eq. A.5-1) and chose a bilinear model.
(Q 3-11 and 13)	These values are given in Table A3 for each expert. The "a" values have been normalized to events per year basis.
(Q 3-14)	The range M_{LB}, M_{UB} for which the model given by Eq.(A.5-1) is given in Table A3 for each expert.
(Q 3-15 and 16)	Experts agreed with our proposed approach for extrapolation of the magnitude-recurrence relation.

The questions in Section 4 of the seismicity question have not yet been encoded. These will be provided in our final report.

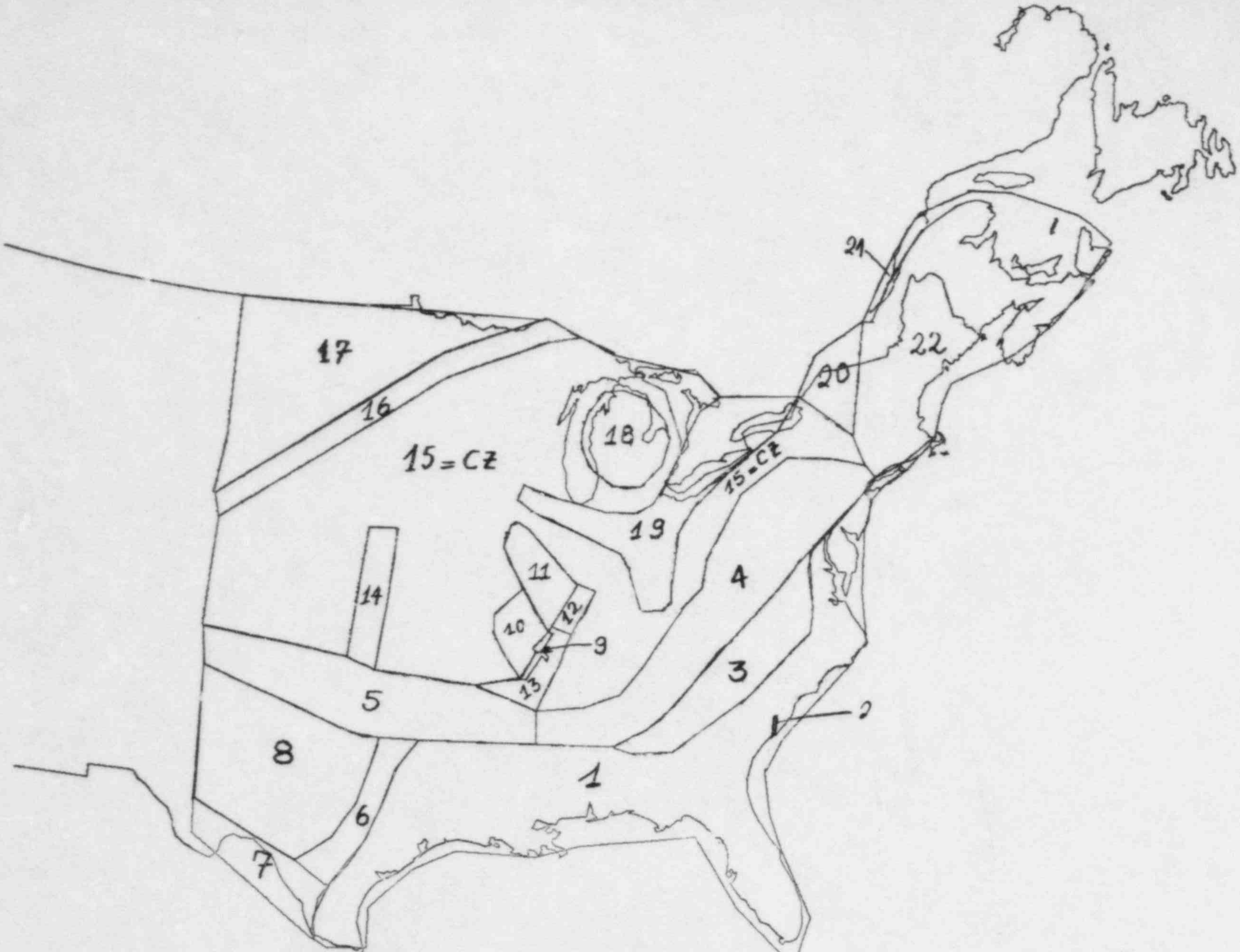


Figure A1 Seismic Zonation Base Map for Expert 1

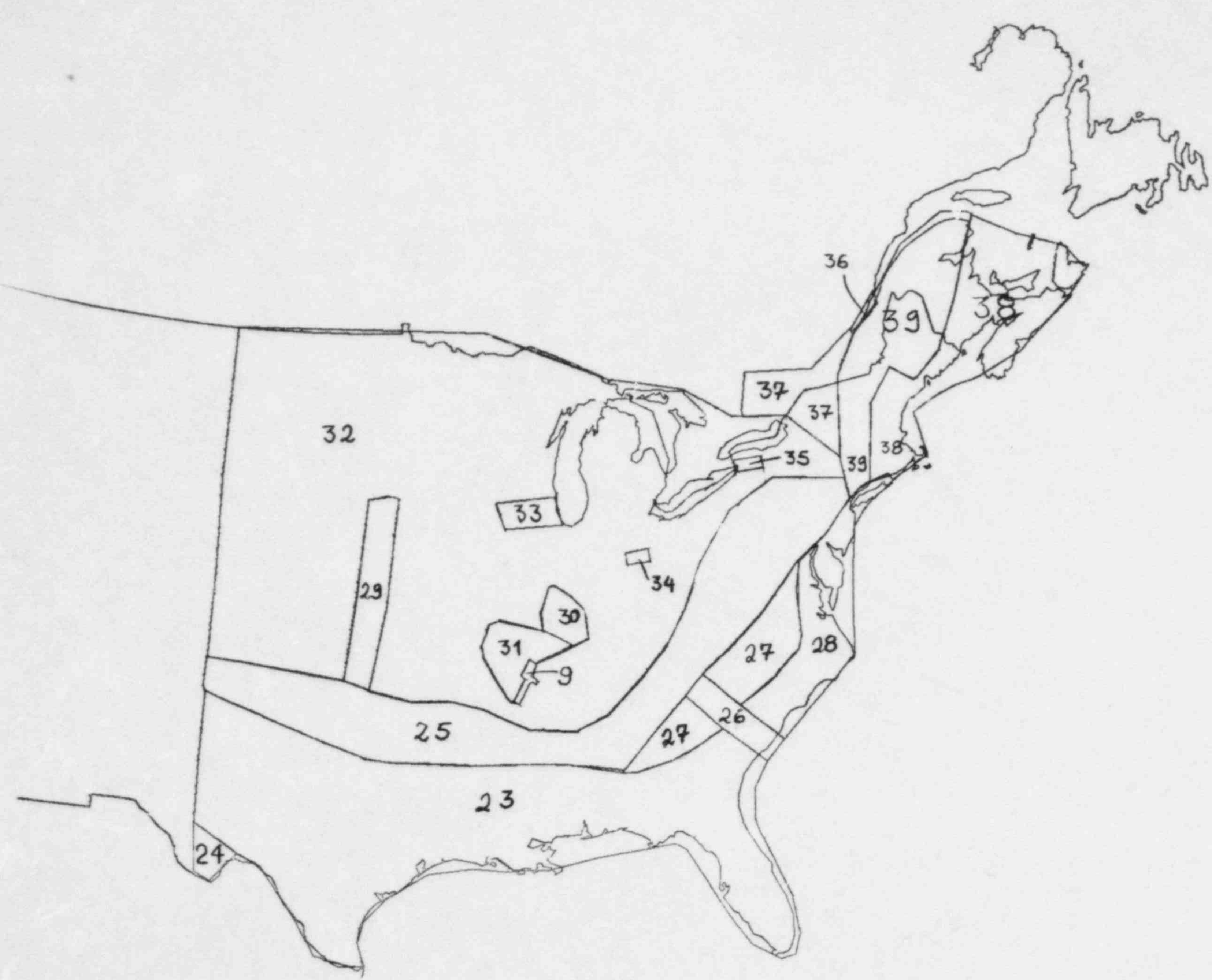


Figure A2 Map of Alternative Seismic Zonation to Expert 1's Base Map

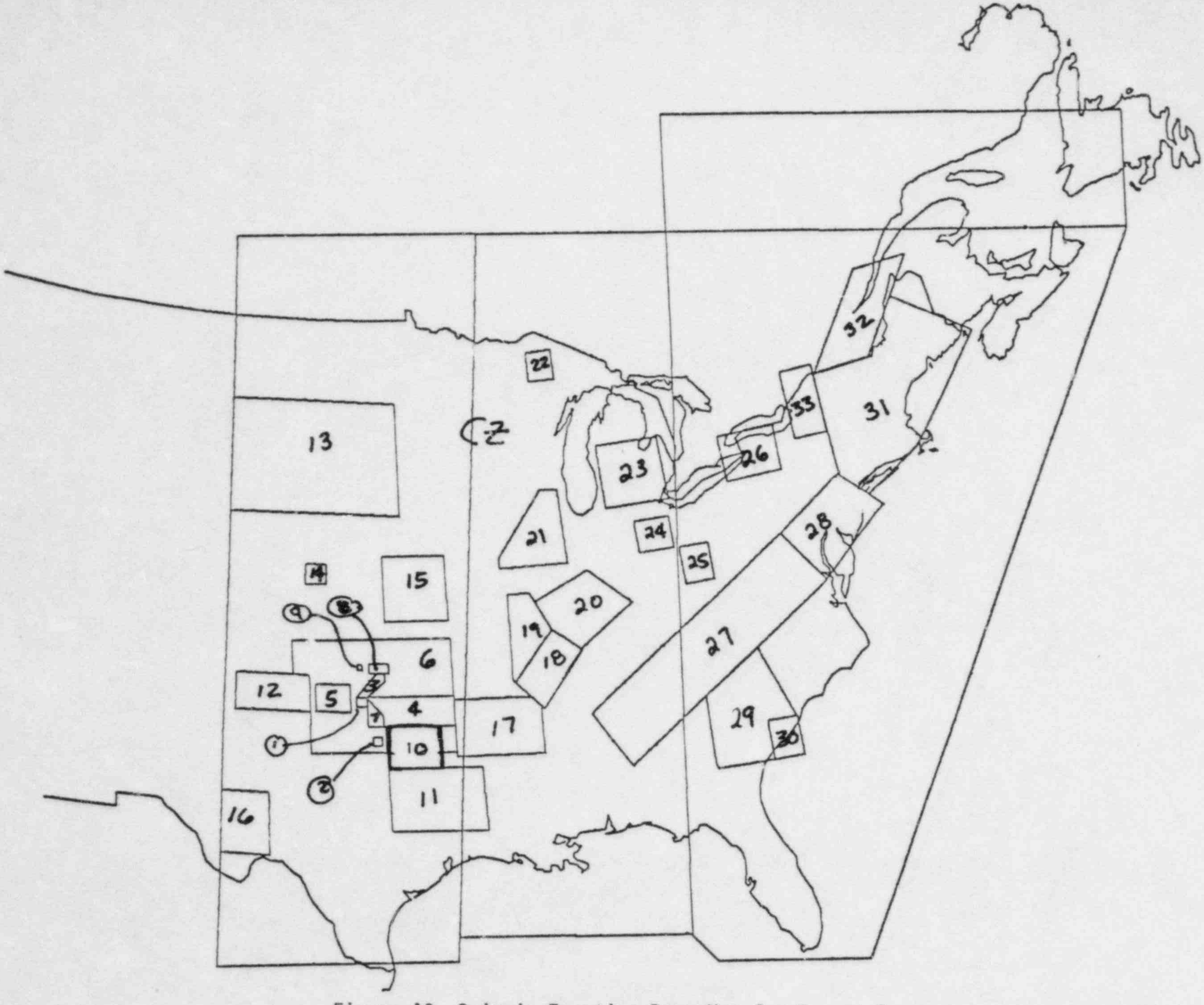


Figure A3 Seismic Zonation Base Map for Expert 2

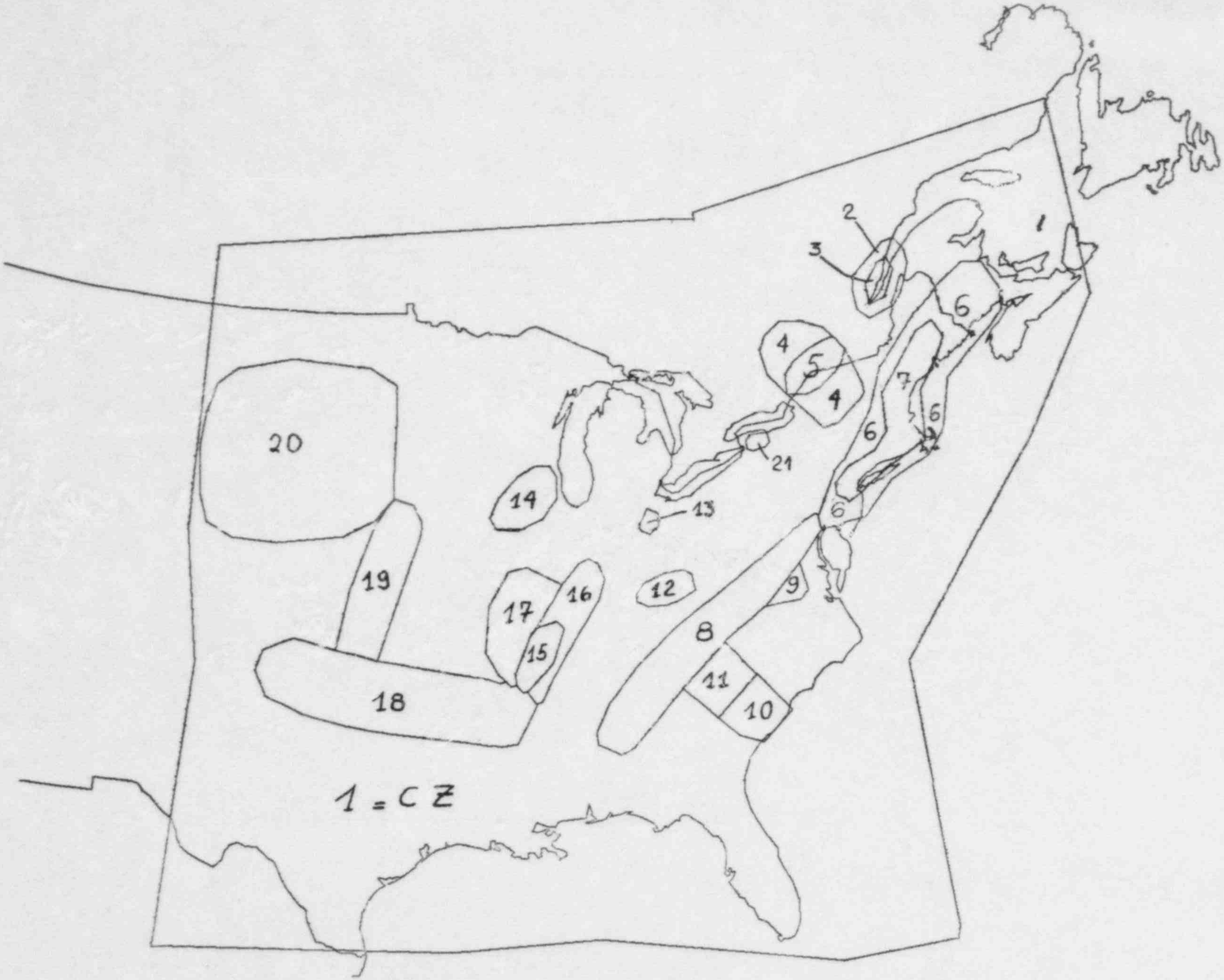


Figure A4 Seismic Zonation Base Map for Expert 3

Figure A5 Map of Alternative Seismic Zonations for Expert 3's Base Map

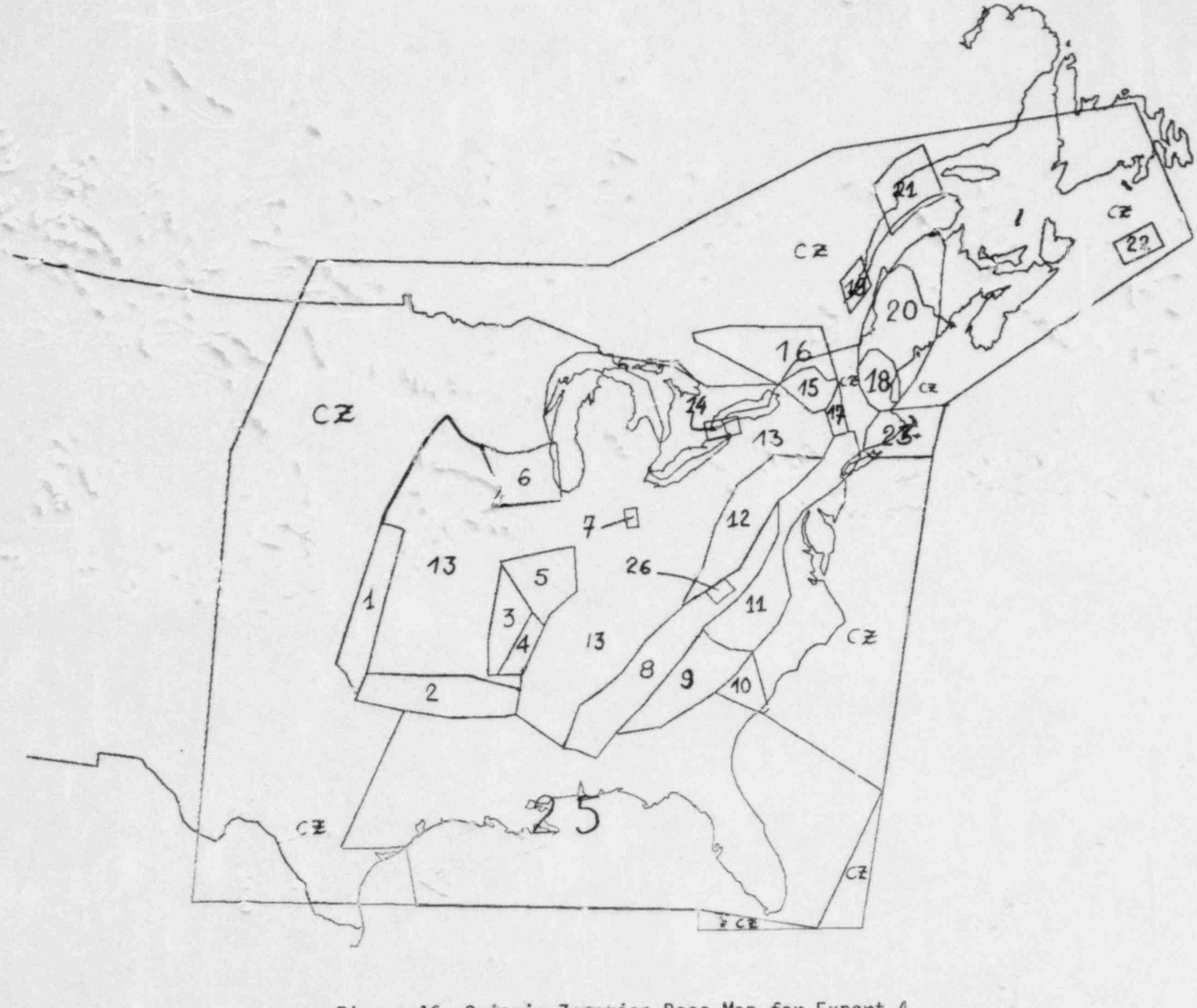


Figure A6 Seismic Zonation Base Map for Expert 4

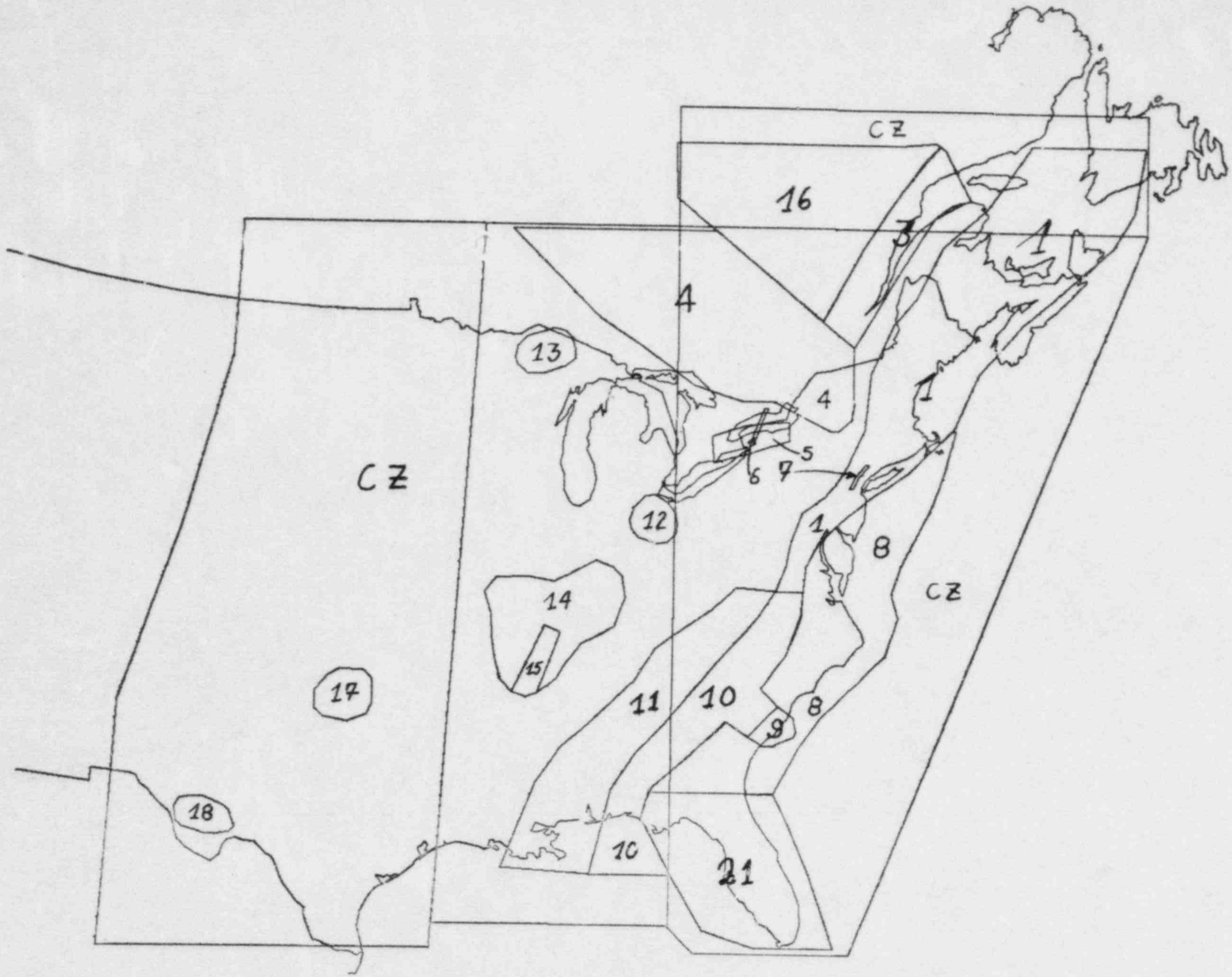


Figure A7 Seismic Zonation Base Map for Expert 5

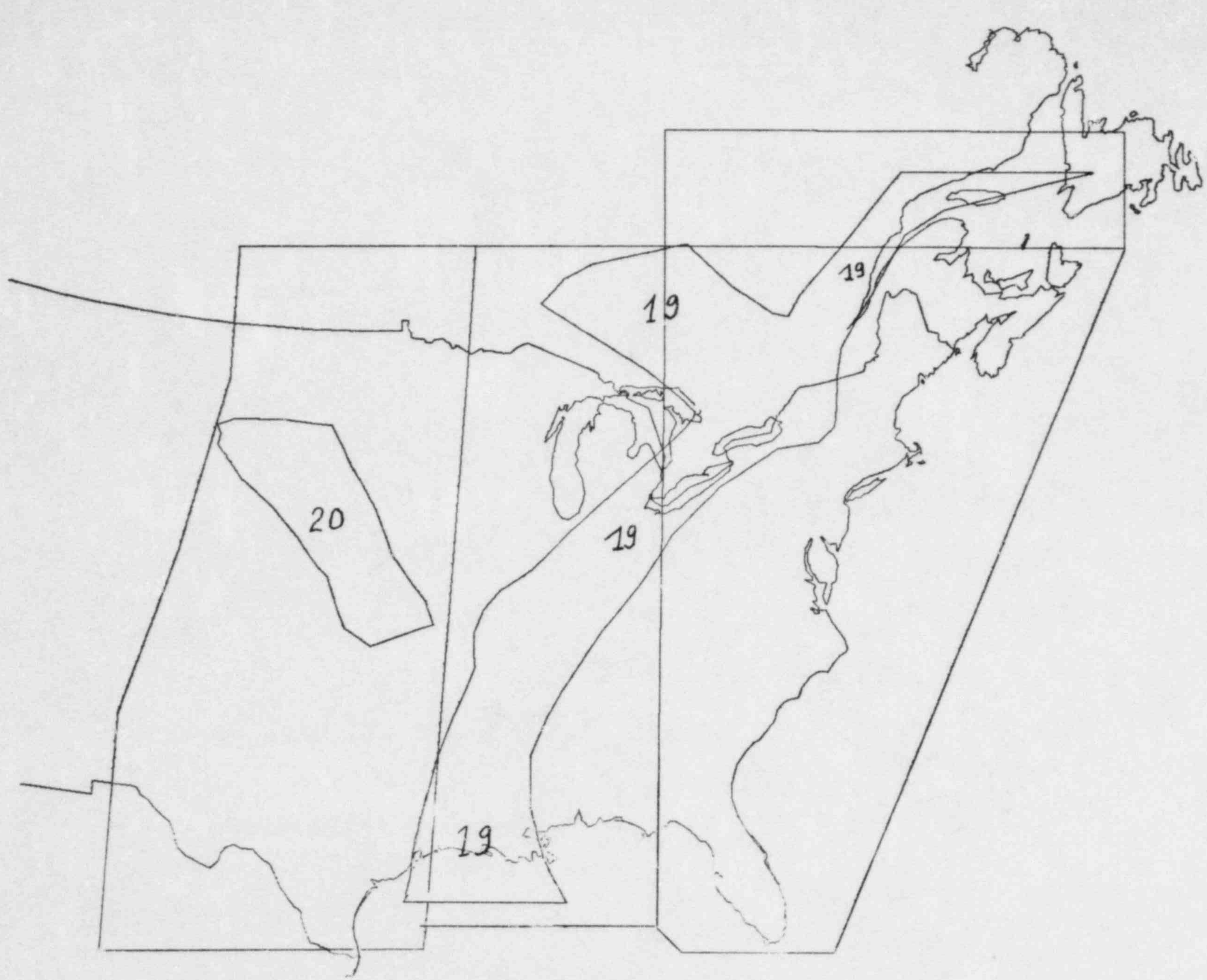


Figure A8 Map of Alternative Seismic Zonations to Expert 5's Base Map

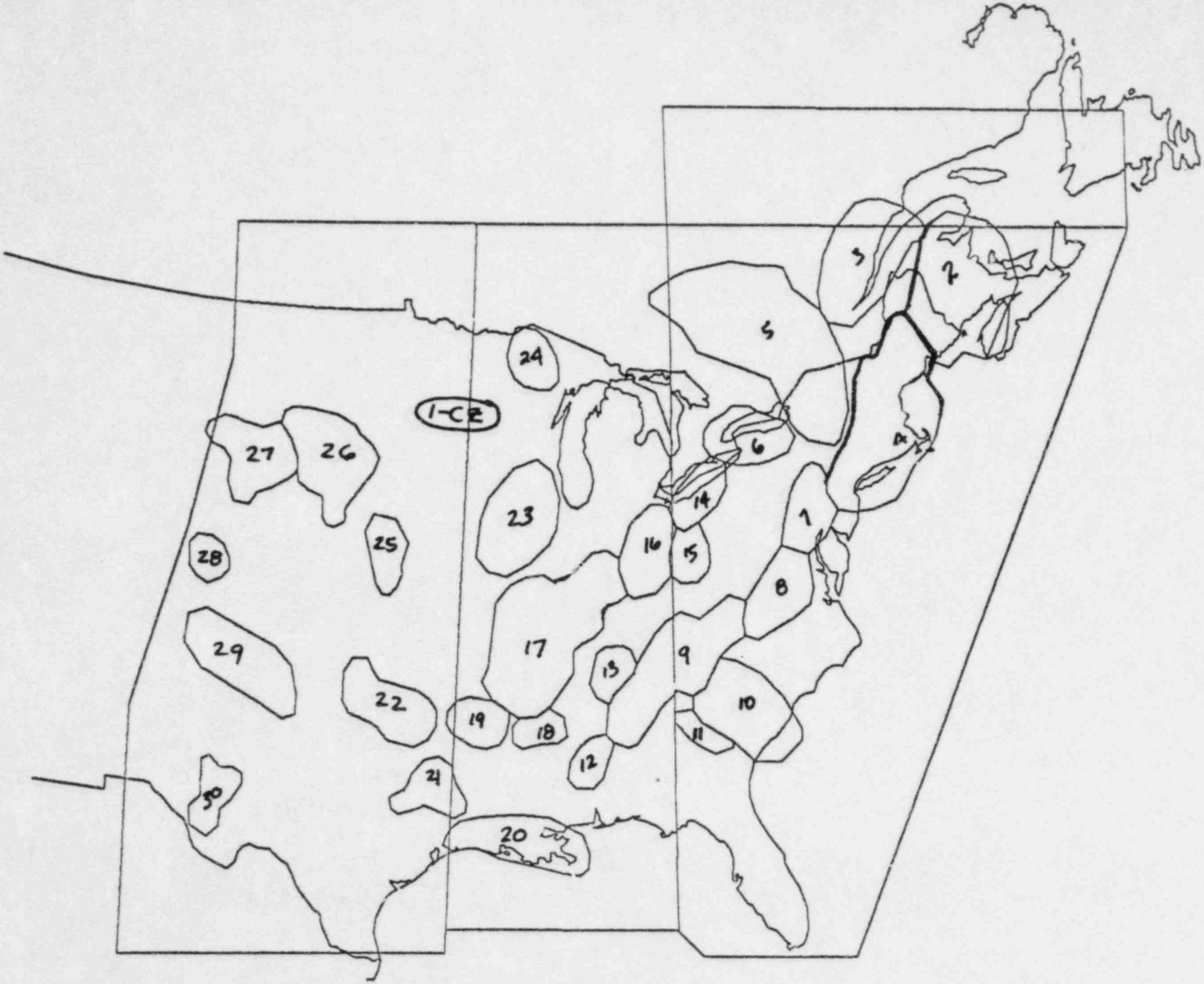


Figure A9 Seismic Zonation Base Map for Expert 6

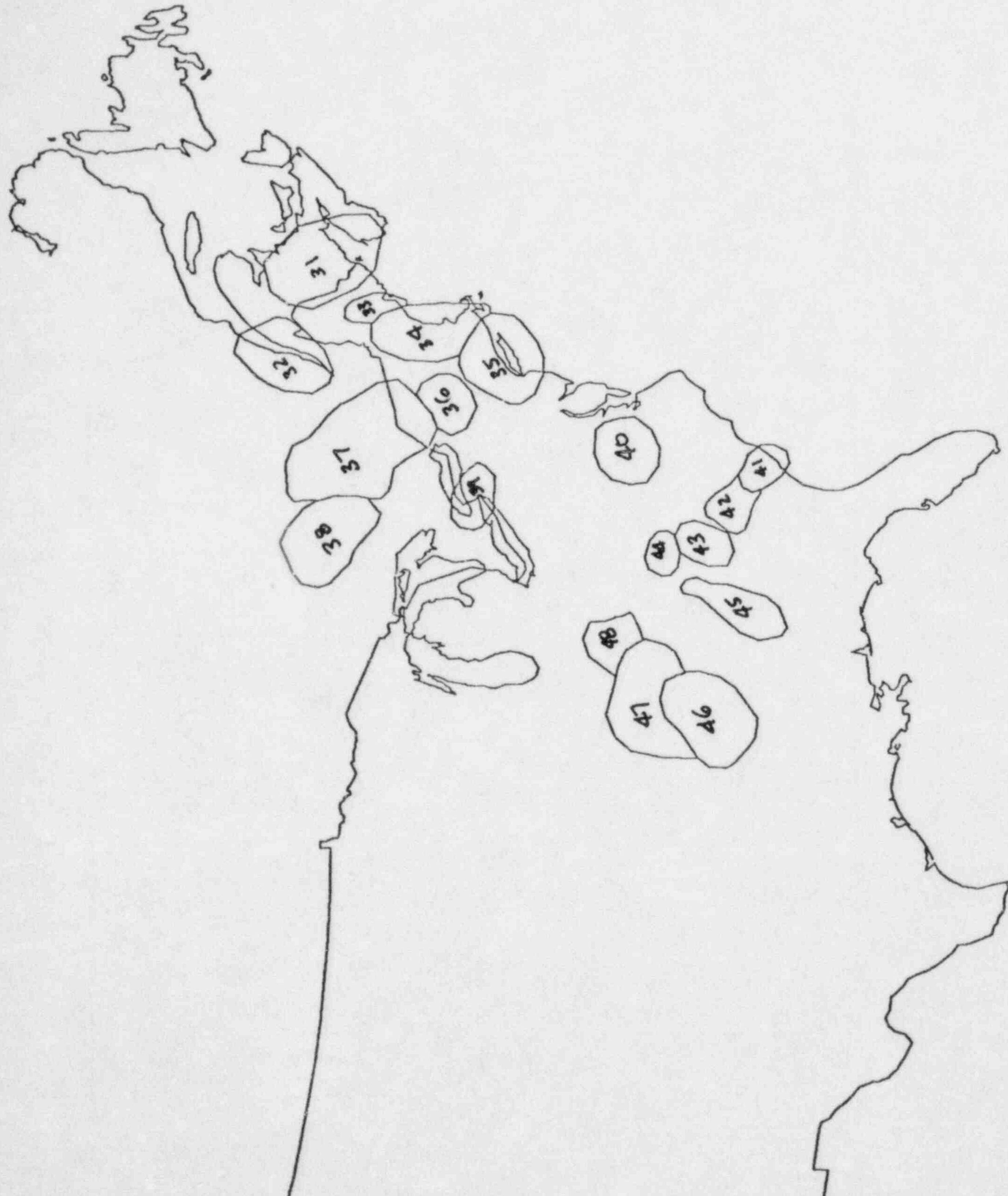


Figure A10 Map of Alternative Seismic Zonations to Expert 6's Basε Map

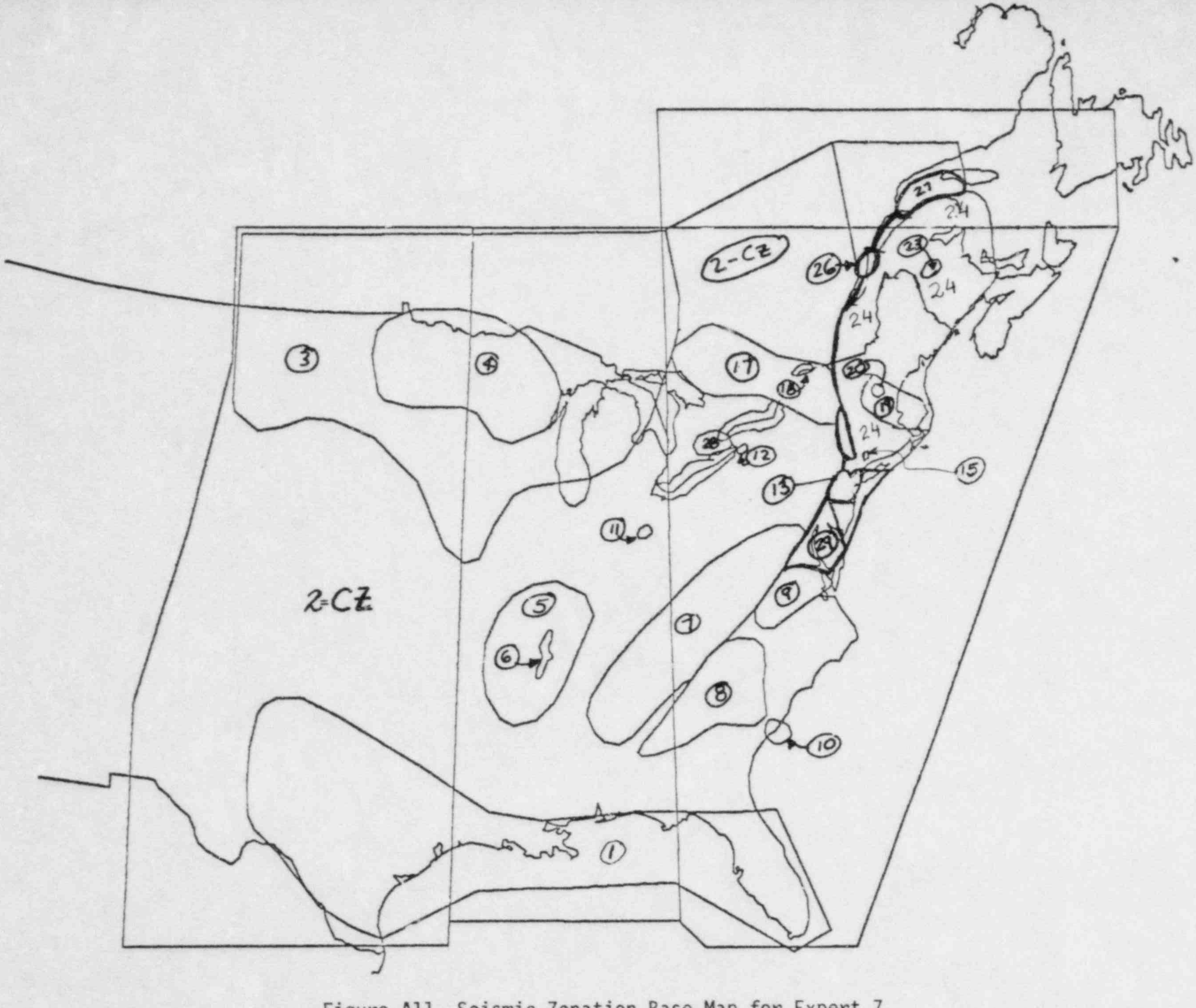


Figure A11 Seismic Zonation Base Map for Expert 7

Figure A12 Seismic Zonation Base Map for Expert 8. Expert 8 did not provide any information for regions south of the Canadian border.

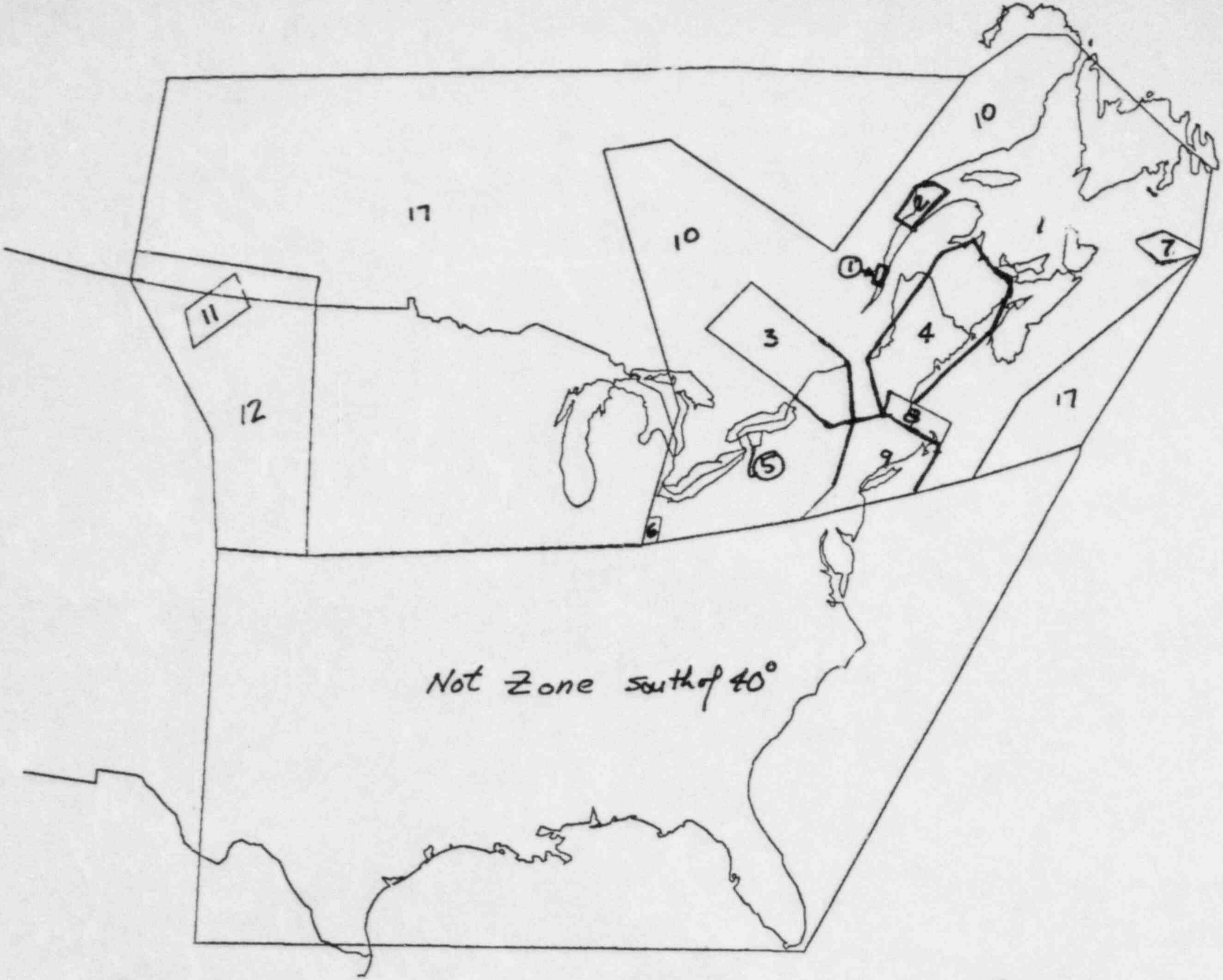


Figure A13 Seismic Zonation Base Map for Expert 9. Expert 9 did not provide any information for regions south of the 40° parallel, in his/her response to Questionnaire 1 (Zonation Questionnaire, see Appendix A).

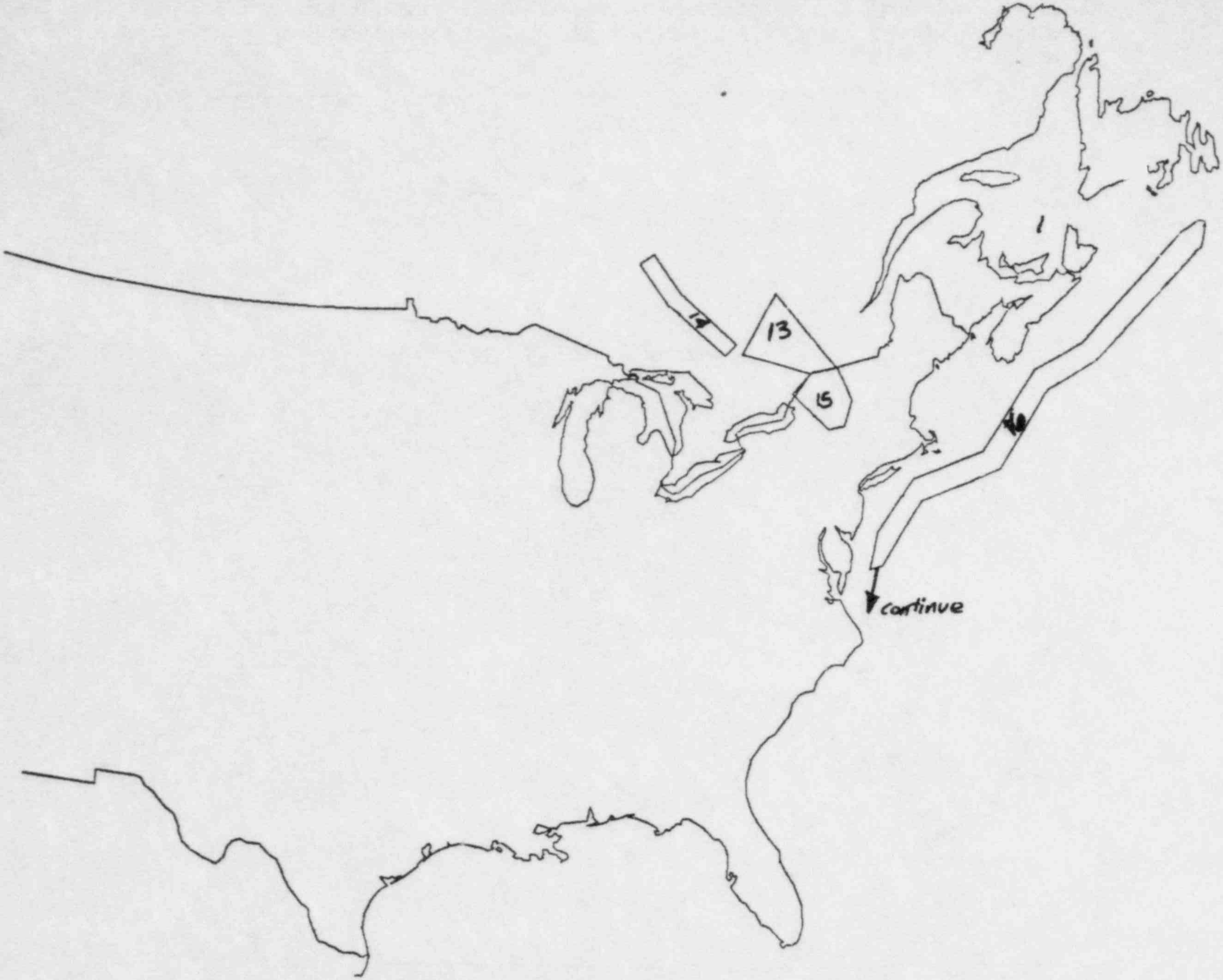


Figure A14 Map of Alternative Seismic Zonations to Expert 9's Base Map

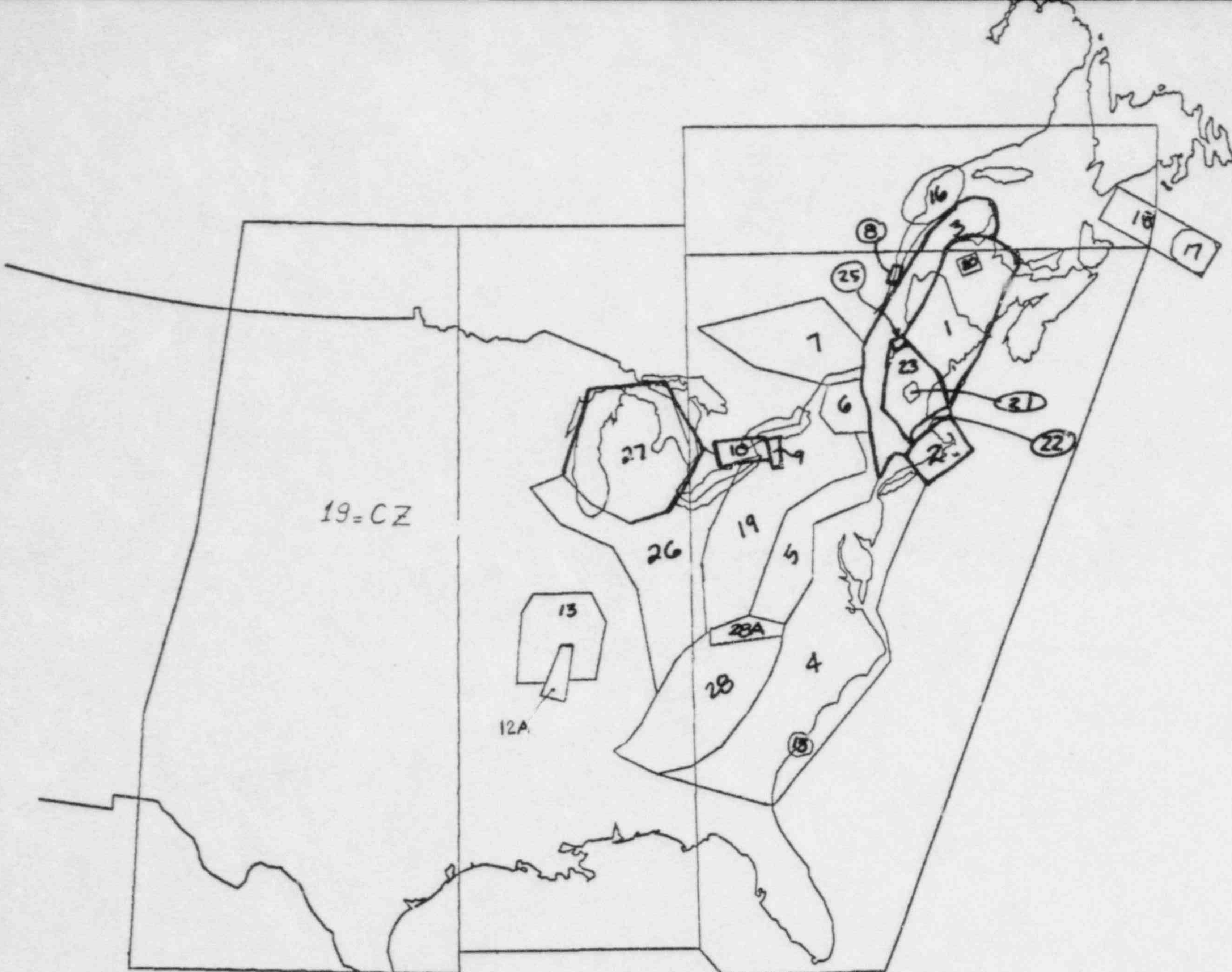


Figure A15 Seismic Zonation Base Map for Expert 10

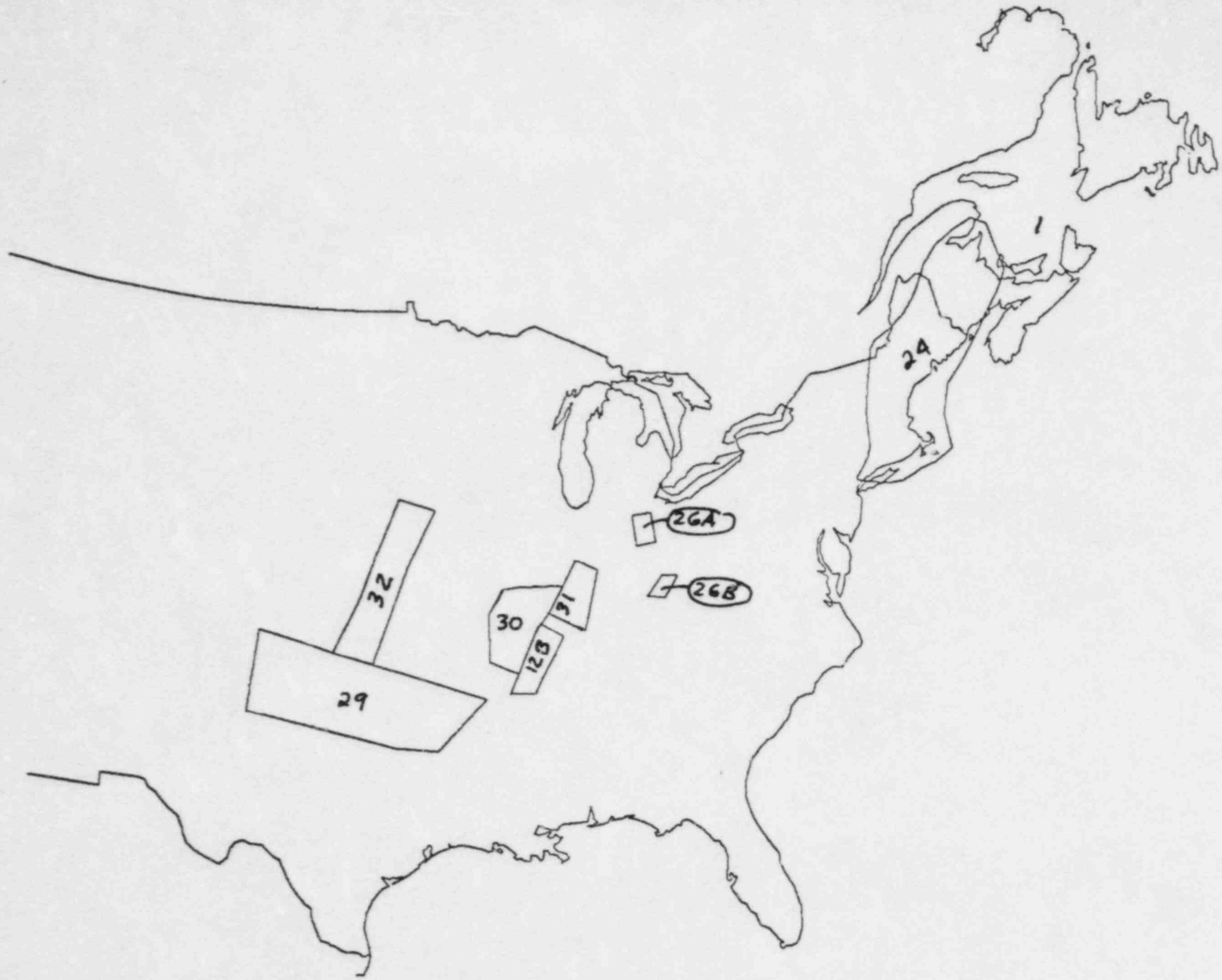
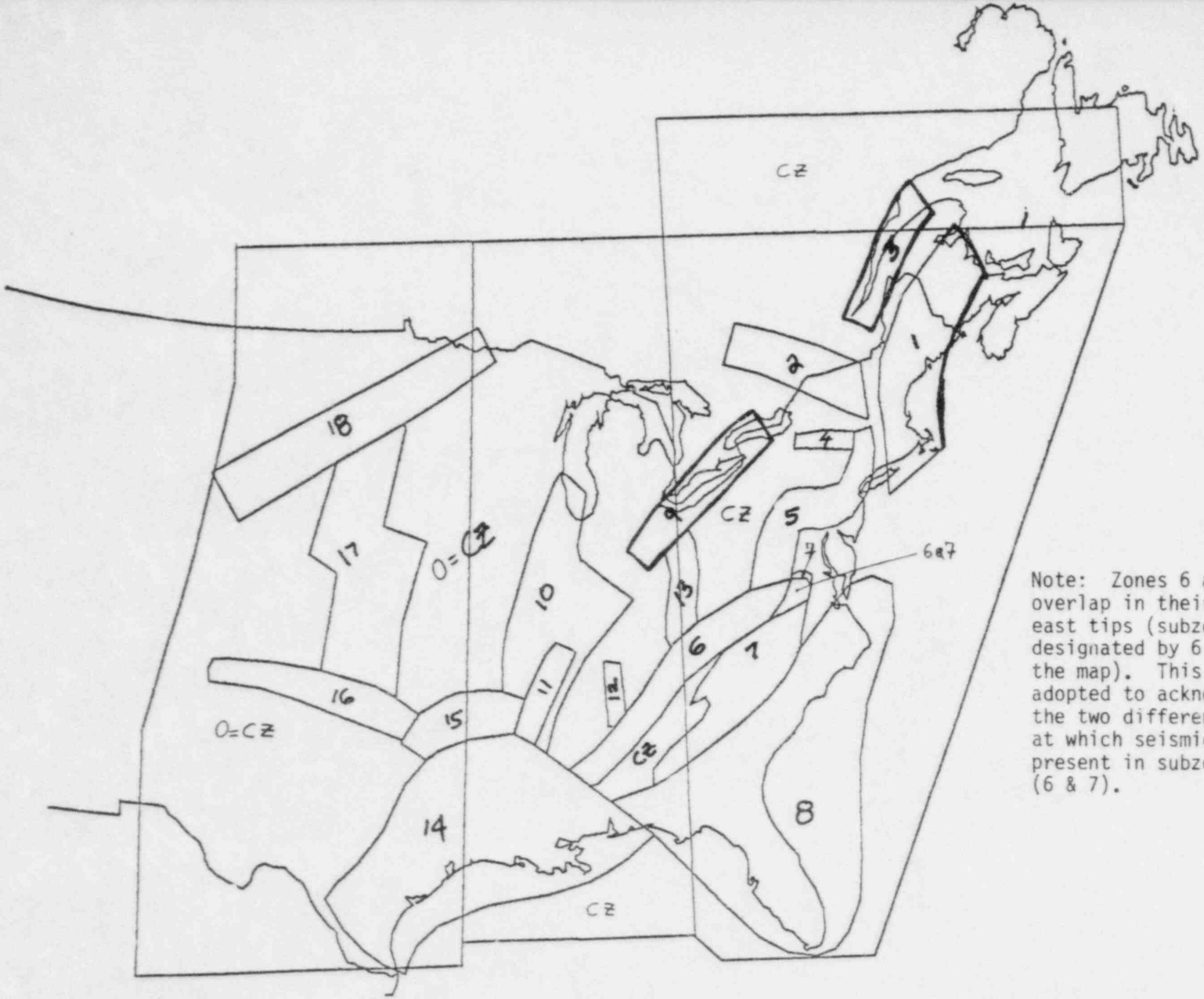


Figure A-16 Map of Alternative Seismic Zonations to Expert 10's Base Map



Note: Zones 6 and 7 overlap in their northeast tips (subzone designated by 6 & 7 on the map). This model is adopted to acknowledge the two different depths at which seismicity is present in subzone (6 & 7).

Figure A17 Seismic Zonation Base Map for Expert 11

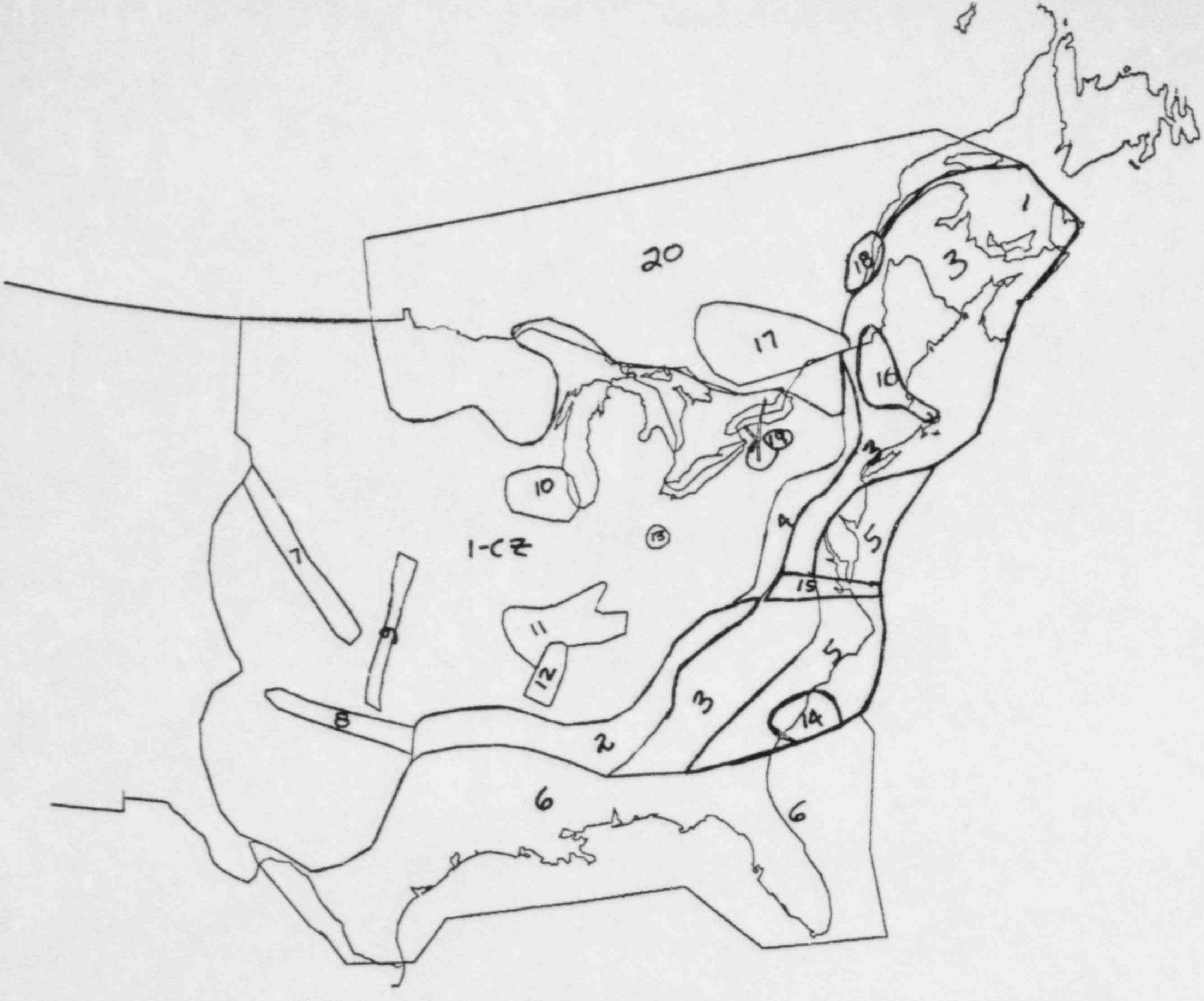


Figure A18 Seismic Zonation Base Map for Expert 12

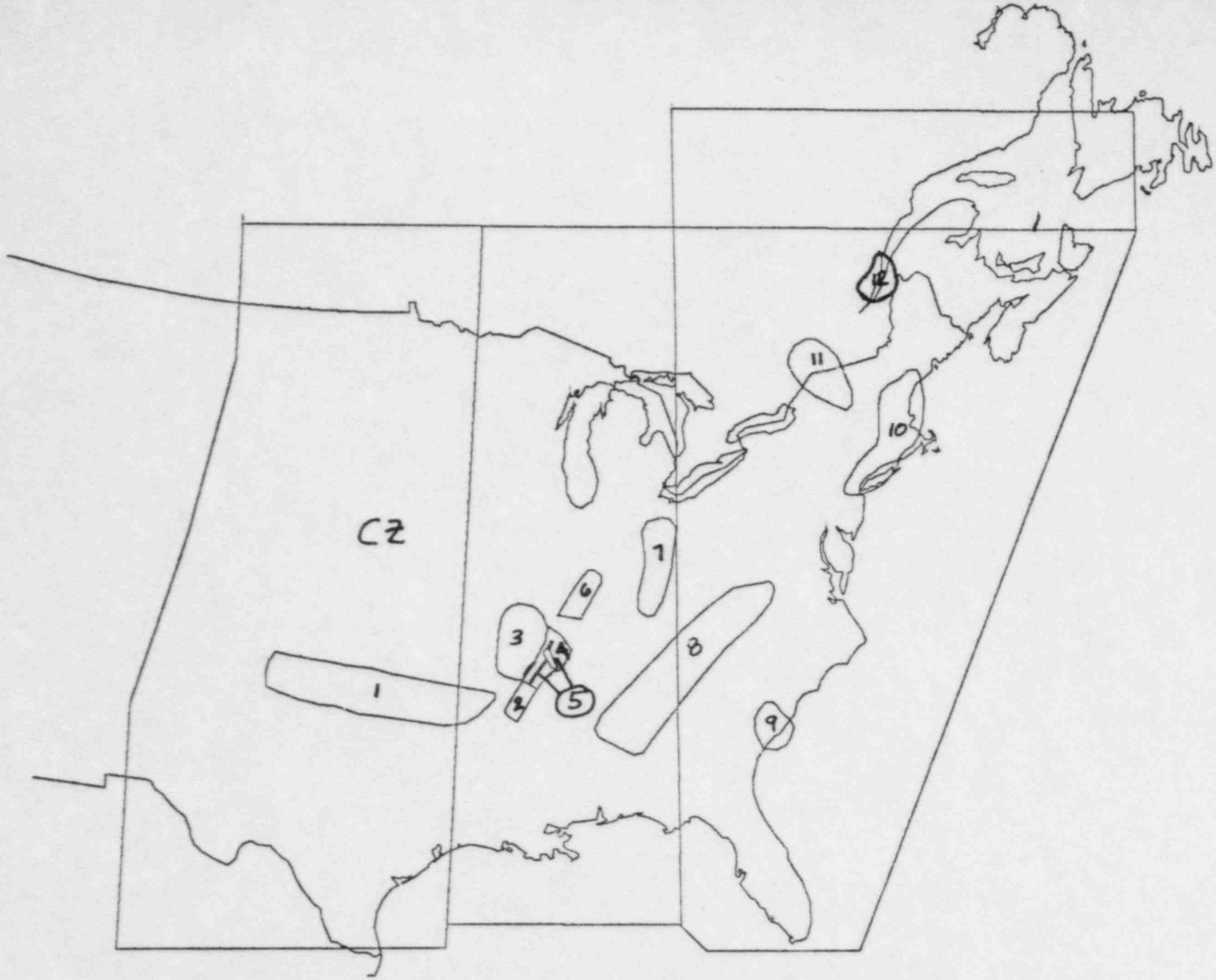


Figure A19 Seismic Zonation Base Map for Expert 13

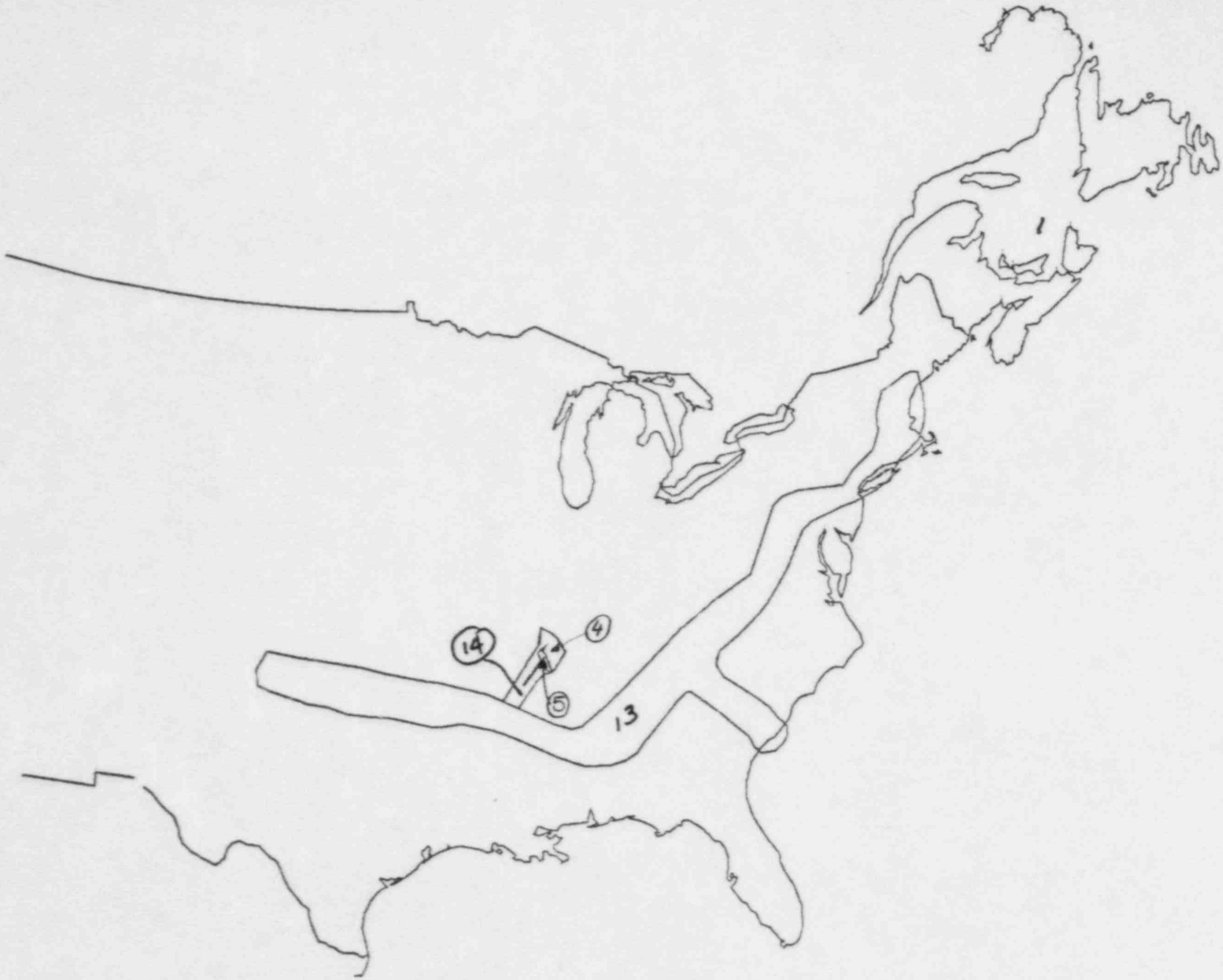


Figure A20 Map of Alternative Seismic Zonations to Expert 13's Base Map

EXPERT 1

Table A-2

If Zones 6, 8, 13, 16, 18, 19 do not exist they become part of Zone 15.
Zone 2 becomes part of Zone 1.
Zone 21 becomes part of Zone 22.

ALTERNATIVE BOUNDARIES

Zone Index	Level of Confidence in Boundary Shape
1, 2, 6, 7, 8,	0.65
23, 26, 28	0.35
3	0.65
26, 27	0.35
4, 5	0.6
25	0.4
10, 11, 12	0.7
30, 31	0.3
14	0.6
29	0.4
15, 16, 17, 18, 19	0.65
32, 33, 34, 35	0.35
20	0.5
37	0.5
21	0.6
36	0.4
22	0.5
38, 39	0.5

Expert 1 provided the relation $I_o = 2.16\ m_{bLg} - 4.4$

(Table A-2 - Expert 1 - continued)

Zones for Which M_u or M_{uu} was Limited by Saturation Value of Magnitude Scale

Map Zone No.	Saturation Value
35	12
36	12
9	7.5

EXPERT 2

Table 2

If Zones 4, 6, 11, 12, 13, 14, 15, 16, 17, 20 to 33 do not exist they become part of Zone 34.

Zones 5, 8, 9, 10 become part of 12.

Zone 7 becomes part of 4.

No alternative boundaries were given by Expert 2.

M_u was not limited by saturation for Expert 2.

EXPERT 3

Table 2

If Zones 2, 4, 6, 8, 10, 11, 12, 13, 14, 15, 16, 18 to 21 do not exist they become part of Zone 1.

Zone 3 becomes part of 2.

Zone 7 becomes part of 6.

Zone 9 becomes part of 8.

Zone 11 becomes part of 10.

Zone 17 becomes part of 16.

ALTERNATE BOUNDARIES

Zone Index	Level of Confidence in Boundary Shape
8	0.5
8 ALT	0.5
10	0.75
10 ALT	0.25
11	0.75
11 ALT	0.25

Expert 3 did not limit M_U because of saturation.

EXPERT 4

Table 2

If Zones 1, 2, 6, and 7 do not exist, they become part of Zone 13.

Zone 26 becomes part of 8.

No alternative sets of boundaries given.

M_u was not limited by saturation by Expert 4.

EXPERT 5

Table 2

If Zones 7, 8, and 10 do not exist, they become part of Zone 1.

Zone 3 becomes part of 4.

Zone 6 becomes part of 5.

Zone 9 becomes part of 8.

Zone 13 becomes part of 20 (C.Z.).

ALTERNATIVE BOUNDARIES

Zone Index	Level of Confidence in Boundary Shape
3, 4, 5, 6, 12, 14, 15	0.95
19, 20	0.05

Note

Zone 2 not used. Our zone No. 20 Map Index C.Z. was used in place of Zone 2 which covered the same area.

Zones 15 and 19 were limited by the saturation of the MMI scale at XII. The other zones were not.

EXPERT 6

Table 2

If Zones 11, 13, 18, 19, 20, 21, 22, 23, 24, 25, 27, 28, 29, 30 do not exist, they become part of Zone 1.

Zone 7 becomes part of 4.

Zone 8 and 12 become part of 9.

Zone 14 and 15 become part of 16.

ALTERNATIVE BOUNDARIES

Zone Index	Level of Confidence in Boundary Shape
2	0.7
31	0.3
3	0.6
32	0.4
4	0.8
33, 34, 35	0.2
5	0.8
35, 37, 38	0.2
6	0.6
39	0.4
8	0.6
40	0.4
9	0.7
43, 44, 45	0.3
10	0.6
41, 42	0.4
17	0.8
46, 47, 48	0.2

Note:

Expert 6 used a bilinear model for the magnitude recurrence relation in some zones.

M_u was not limited by saturation for Expert 6.

EXPERT 7

Table 2

If Zones 1, 5, 7, 8, 11, 12, 13, 15, 28, 29 do not exist they become part of Zone 2 (C.Z.)

Zone 4 becomes part of 3
Zone 9 becomes part of 7
Zone 10 becomes part of 8
Zones 16, 19, 22, 23 become part of 24
Zone 18 becomes part of 17
Zone 22 becomes part of 19

No alternative boundaries were given.

Notes

In the first questionnaire Zones 21 & 22 were identified. In the second questionnaire Expert 7 stated that Zone 21 should be incorporated in Zone 19 and 22 into Zone 24. Because the digitization was already completed, it was simpler to leave Zones 19 and 22 in the model and adjust the seismicity parameters accordingly.

M_u was not limited by saturation for Expert 7.

EXPERT 10

Table 2

If Zones 1, 2, 3, 4, 5, 6, 7, 10, 12A, 13, 16, 18, 26, 27, 28 do not exist they become part of Zone 19 (C.Z.).

Zone 20 becomes part of 1
Zone 15 becomes part of 4
Zone 9 becomes part of 10
Zone 17 becomes part of 18
Zone 21, 22, 25 becomes part of 23
Zone 23 becomes part of 1
Zone 28A becomes part of 28

ALTERNATIVE BOUNDARIES

Zone Index	Level of Confidence in Boundary Shape
12A, 13	0.6
12B, 30, 31	0.4
17, 18	0.5
29, 32	0.5
9, 10, 26, 27	
26A, 26B	
20, 1, 21, 22, 23, 25	0.6
24	0.4

Notes

Expert 10 gave a saturation value for M_U of 7.5. This limited M_U in Zones 8, 12A, 12B, 17, 18.

Expert 10 provided the relation $m_b = 0.44 + 0.67\ I_o$ which was for all zones.

EXPERT 11

Table 2

If Zones 1, 4, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18 do not exist they become part of Zone 19 (C.Z.).

Zone 2 becomes part of 3
Zone 3 becomes part of 5
Zone 5 becomes part of 6
Zone 16 becomes part of 5

No alternative boundaries given.

Notes

Expert 11 indicated a saturation for M_U of 7.0 but provided larger values for Zones 3 and 9. These larger values were used in the analysis.

EXPERT 12

Table 2

If Zones 3, 7, 8, 9, 10, 11, 12, 13, 19 do not exist they become part of Zone 1 (C.Z.).

Zones 2, 16, 4, 5, 15A become part of 3
Zones 14, 15B become part of 5
Zone 17 becomes part of 20

No alternative boundaries given.

Notes

Expert 12 gave a saturation value of 7-1/4 for M_U for Zone 12 but gave larger values for the range of M_U.

EXPERT 13

Table 2

If Zones 1, 2, 3, 6, 7, 8, 9, 10, 11, 12 do not exist they become part of 15 (C.Z.)

Zone 4 becomes part of 5

ALTERNATIVE BOUNDARIES

Zone Index	Level of Confidence in Boundary Shape
1, 8, 9, 10	0.75
13	0.25
4	0.8
14	0.2

Notes

Expert 3 used the M_s scale when responding to Q 2-2, 2-3 and 2-4 for Zone 5 and gave the relation

$$M_s = 2\ m_b - 5.65$$

which we used to compute the values given in Table 1 for Zone 5.

TABLE A3

SEISMICITY DATA FOR EXPERT 1 NO. OF ZONES= 39 SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 6.0 8.0 9.0 9.0

ZONE NUMBER 1 LOC IN REG NO 2 MAP INDEX NO 1 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 9.45

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.5	9.3	9.5
EST. OF N	1.900	1.700	2.200
A	2.680	2.600	2.940
B	-.600	-.640	-.590

ZONE NUMBER 2 LOC IN REG NO 2 MAP INDEX NO 2 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 10.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	10.0	9.5	10.5
EST. OF N	.230	.200	.290
A	.970	.900	.980
B	-.390	-.420	-.380

ZONE NUMBER 3 LOC IN REG NO 2 MAP INDEX NO 3 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 8.80

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.8	8.5	9.0
EST. OF N	1.200	1.000	1.433
A	2.604	2.374	3.144
B	-.630	-.750	-.590

ZONE NUMBER 4 LOC IN REG NO 2 MAP INDEX NO 4 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 9.10

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.1	8.9	9.5
EST. OF N	7.333	4.667	20.000
A	3.874	3.244	4.784
B	-.750	-.870	-.640

*********** SEISMICITY DATA FOR EXPERT 1

TABLE A3

ZONE NUMBER 5 LOC IN REG NO 4 MAP INDEX NO 5 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 9.80

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.8	9.1	10.2
EST. OF N	1.500	1.200	3.200
A	2.350	2.070	3.250
B	-.540	-.690	-.500

ZONE NUMBER 6 LOC IN REG NO 4 MAP INDEX NO 6 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.40

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.4	5.7	5.3
EST. OF N	.462	.403	.469
A	4.840	4.070	5.180
B	-1.480	-1.570	-1.270

ZONE NUMBER 7 LOC IN REG NO 4 MAP INDEX NO 7 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.40

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.4	5.7	5.3
EST. OF N	.137	.120	.139
A	4.310	3.540	4.[illegible]
B	-1.480	-1.570	-1.270

ZONE NUMBER 8 LOC IN REG NO 4 MAP INDEX NO 8 PROB. OF EXISTENCE= .5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.40

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.4	5.7	5.3
EST. OF N	.100	.087	.102
A	4.180	3.410	4.520
B	-1.480	-1.570	-1.270

*********** SEISMICITY DATA FOR EXPERT 1

TABLE A3

ZONE NUMBER 9 LOC IN REG NO 4 MAP INDEX NO 9 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 7.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.4	7.2	7.5
EST. OF N	.850	.825	.875
A	2.559	2.419	2.779
B	-.750	-.810	-.720

ZONE NUMBER 10 LOC IN REG NO 4 MAP INDEX NO 10 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 7.10

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.1	6.9	7.2
EST. OF N	.850	.830	.880
A	2.790	2.740	2.960
B	-.820	-.870	-.810

ZONE NUMBER 11 LOC IN REG NO 4 MAP INDEX NO 11 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.7	6.5	6.8
EST. OF N	.267	.267	.667
A	2.374	2.124	3.114
B	-.790	-.940	-.770

ZONE NUMBER 12 LOC IN REG NO 4 MAP INDEX NO 12 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.7	5.5	5.9
EST. OF N	.790	.400	1.800
A	4.510	3.390	5.960
B	-1.320	-1.630	-1.080

*********** SEISMICITY DATA FOR EXPERT 1

TABLE A3

ZONE NUMBER 13 LOC IN REG NO 4 MAP INDEX NO 13 PROB. OF EXISTENCE= .6
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.6	6.2
EST. OF N	1.300	.950	1.950
A	4.460	3.630	5.880
B	-1.240	-1.590	-1.100

ZONE NUMBER 14 LOC IN REG NO 4 MAP INDEX NO 14 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.7	5.5	6.0
EST. OF N	.613	.460	.733
A	4.234	3.434	4.904
B	-1.270	-1.420	-1.080

ZONE NUMBER 15 LOC IN REG NO 3 MAP INDEX NO 15 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.80

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.7	6.0
EST. OF N	2.667	1.867	3.267
A	5.614	4.954	6.254
B	-1.480	-1.640	-1.340

ZONE NUMBER 16 LOC IN REG NO 3 MAP INDEX NO 16 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.60

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.6	5.4	6.1
EST. OF N	1.267	.733	2.000
A	5.184	3.734	6.454
B	-1.450	-1.760	-1.110

*********** SEISMICITY DATA FOR EXPERT 1

TABLE A3

ZONE NUMBER 17 LOC IN REG NO 3 MAP INDEX NO 17 PROB. OF EXISTENCE= .5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.2	5.1	5.3
EST. OF N	.638	.511	.798
A	5.630	4.650	5.841
B	-1.670	-1.700	-1.410

ZONE NUMBER 18 LOC IN REG NO 3 MAP INDEX NO 18 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.2	5.1	5.3
EST. OF N	.162	.129	.202
A	5.041	4.061	5.250
B	-1.670	-1.700	-1.410

ZONE NUMBER 19 LOC IN REG NO 3 MAP INDEX NO 19 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.1	7.0
EST. OF N	.500	.400	.667
A	2.954	2.274	3.714
B	-.930	-1.110	-.760

ZONE NUMBER 20 LOC IN REG NO 1 MAP INDEX NO 20 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 10.10

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	10.1	9.8	10.4
EST. OF N	1.067	1.033	1.267
A	2.014	1.900	2.234
B	-.500	-.530	-.470

*********** SEISMICITY DATA FOR EXPERT 1

TABLE A3

ZONE NUMBER 21 LOC IN REG NO 1 MAP INDEX NO 21 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 11.10

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	11.1	10.7	11.6
EST. OF N	.500	.313	.700
A	1.218	.828	1.548
B	-.380	-.420	-.330

ZONE NUMBER 22 LOC IN REG NO 1 MAP INDEX NO 22 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 9.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.5	9.1	10.1
EST. OF N	2.450	1.000	4.000
A	2.829	1.999	3.429
B	-.610	-.710	-.500

ZONE NUMBER 23 LOC IN REG NO 4 MAP INDEX NO 23 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 8.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.7	8.5	8.9
EST. OF N	1.700	1.400	2.000
A	3.000	2.710	3.260
B	-.690	-.740	-.640

ZONE NUMBER 24 LOC IN REG NO 4 MAP INDEX NO 24 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 10.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	4.3	3.8	4.5
EST. OF N	.010	0.000	.010
A	-5.000	-6.000	-5.000
B	-.500	-5.000	-.500

*********** SEISMICITY DATA FOR EXPERT 1

TABLE A3

****

ZONE NUMBER 25 LOC IN REG NO 4 MAP INDEX NO 25 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 9.90

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.9	9.7	10.3
EST. OF N	12.000	10.000	21.000
A	3.830	3.540	4.370
B	-.690	-.760	-.630

****

ZONE NUMBER 26 LOC IN REG NO 2 MAP INDEX NO 26 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 10.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	10.2	9.8	10.6
EST. OF N	.700	.650	.850
A	1.690	1.520	1.940
B	-.460	-.500	-.430

****

ZONE NUMBER 27 LOC IN REG NO 2 MAP INDEX NO 27 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 8.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.7	8.4	8.8
EST. OF N	1.200	1.000	1.800
A	2.720	2.480	3.240
B	-.660	-.750	-.620

****

ZONE NUMBER 28 LOC IN REG NO 2 MAP INDEX NO 28 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 9.30

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.3	9.0	9.7
EST. OF N	.550	.450	.650
A	1.800	1.500	2.050
B	-.510	-.560	-.460

*********** SEISMICITY DATA FOR EXPERT 1

TABLE A3

****

ZONE NUMBER 29 LOC IN REG NO 3 MAP INDEX NO 29 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 8.90

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.9	8.3	9.8
EST. OF N	.580	.390	1.000
A	1.990	1.360	2.780
B	-.560	-.700	-.440

****

ZONE NUMBER 30 LOC IN REG NO 4 MAP INDEX NO 30 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 9.90

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.9	9.5	10.7
EST. OF N	.620	.410	.630
A	1.670	1.180	1.840
B	-.470	-.510	-.390

****

ZONE NUMBER 31 LOC IN REG NO 4 MAP INDEX NO 31 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 7.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.2	7.0	7.4
EST. OF N	1.200	1.100	1.600
A	2.990	2.790	3.500
B	-.830	-.940	-.790

****

ZONE NUMBER 32 LOC IN REG NO 4 MAP INDEX NO 32 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 10.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	10.2	9.6	11.2
EST. OF N	5.940	4.752	7.920
A	2.920	2.720	3.700
B	-.610	-.700	-.510

*********** SEISMICITY DATA FOR EXPERT 1

TABLE A3

****

ZONE NUMBER 33 LOC IN REG NO 3 MAP INDEX NO 33 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 10.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	10.2	9.6	11.2
EST. OF N	.060	.048	.080
A	.920	.720	1.700
B	-.610	-.700	-.510

****

ZONE NUMBER 34 LOC IN REG NO 3 MAP INDEX NO 34 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 7.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.2	7.0	7.4
EST. OF N	.170	.130	.200
A	1.340	0.000	1.620
B	-.600	-.660	-.540

****

ZONE NUMBER 35 LOC IN REG NO 3 MAP INDEX NO 35 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 11.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	11.2	9.7	12.0
EST. OF N	.220	.180	.260
A	.471	.181	.901
B	-.280	-.370	-.23[illegible]

****

ZONE NUMBER 36 LOC IN REG NO 1 MAP INDEX NO 36 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 11.40

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	11.4	11.0	12.0
EST. OF N	.325	.225	.363
A	.858	.478	1.008
B	-.340	-.360	-.280

*********** SEISMICITY DATA FOR EXPERT 1

TABLE A3

****

ZONE NUMBER 37 LOC IN REG NO 1 MAP INDEX NO 37 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 10.80

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	10.8	10.3	11.2
EST. OF N	1.100	.900	1.200
A	1.820	1.590	2.030
B	-.440	-.490	-.410

****

ZONE NUMBER 38 LOC IN REG NO 1 MAP INDEX NO 38 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 10.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	10.0	9.5	10.3
EST. OF N	1.600	1.500	2.000
A	2.330	2.180	2.740
B	-.610	-.630	-.500

****

ZONE NUMBER 39 LOC IN REG NO 1 MAP INDEX NO 39 PROB. OF EXISTENCE= ALT BRY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 9.40

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.4	9.1	9.8
EST. OF N	1.050	.800	1.250
A	2.260	1.890	2.[illegible]40
B	-.560	-.610	-.500

TABLE A3

SEISMICITY DATA FOR EXPERT 2 NO. OF ZONES= 34 SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 1.0 4.0 6.0 9.0

ZONE NUMBER 1 LOC IN REG NO 4 MAP INDEX NO 1 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 2.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.0	7.5
EST. OF N	.300	.273	1.000
A	2.584	2.474	2.994
B	-.995	-1.240	-.884

ZONE NUMBER 2 LOC IN REG NO 4 MAP INDEX NO 2 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 2.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	5.5	7.0
EST. OF N	.300	.273	.750
A	2.474	2.194	6.534
B	-.977	-3.270	-.789

ZONE NUMBER 3 LOC IN REG NO 4 MAP INDEX NO 3 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 2.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	7.0
EST. OF N	.150	.100	.300
A	1.492	1.482	2.622
B	-.819	-1.370	-.527

ZONE NUMBER 4 LOC IN REG NO 4 MAP INDEX NO 4 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 1.70 4.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	5.5	6.8
EST. OF N	.300	.273	1.000
A	2.434	2.344	2.584
B	-.906	-1.170	-.906

*********** SEISMICITY DATA FOR EXPERT 2

TABLE A3

ZONE NUMBER 5 LOC IN REG NO 4 MAP INDEX NO 5 PROB. OF EXISTENCE= 0.6
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 2.10 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.3
EST. OF N	.300	.273	.750
A	2.382	2.312	4.702
B	-.553	-1.640	-.494

ZONE NUMBER 6 LOC IN REG NO 4 MAP INDEX NO 6 PROB. OF EXISTENCE= 0.6
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 1.70 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.5	6.0
EST. OF N	.250	.227	.833
A	2.294	2.144	2.314
B	-.883	-.899	-.841

ZONE NUMBER 7 LOC IN REG NO 4 MAP INDEX NO 7 PROB. OF EXISTENCE= 0.6
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 1.50 4.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	5.5	7.0
EST. OF N	.300	.240	1.200
A	2.612	2.612	2.902
B	-1.030	-1.200	-.965

ZONE NUMBER 8 LOC IN REG NO 4 MAP INDEX NO 8 PROB. OF EXISTENCE= 0.5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 4.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.0	5.8
EST. OF N	.100	.050	.200
A	2.922	2.822	3.052
B	-1.940	-1.950	-1.900

*********** SEISMICITY DATA FOR EXPERT 2

TABLE A3

ZONE NUMBER 9 LOC IN REG NO 4 MAP INDEX NO 9 PROB. OF EXISTENCE= 0.3
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 2.00 4.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.3	5.0	5.5
EST. OF N	.100	.050	.200
A	5.272	4.812	6.112
B	-2.500	-2.860	-2.370

ZONE NUMBER 10 LOC IN REG NO 4 MAP INDEX NO 10 PROB. OF EXISTENCE= 0.4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	5.5	6.8
EST. OF N	.050	.033	.100
A	3.500	3.000	4.000
B	-1.000	-1.200	-.800

ZONE NUMBER 11 LOC IN REG NO 4 MAP INDEX NO 11 PROB. OF EXISTENCE= 0.4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.3
EST. OF N	.100	.067	.200
A	2.011	1.171	3.171
B	-.874	-1.210	-.625

ZONE NUMBER 12 LOC IN REG NO 4 MAP INDEX NO 12 PROB. OF EXISTENCE= 0.5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.200	.100	.400
A	4.899	1.249	4.899
B	-1.330	-1.500	-.577

*********** SEISMICITY DATA FOR EXPERT 2

TABLE A3

****

ZONE NUMBER 13 LOC IN REG NO 3 MAP INDEX NO 13 PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.3
EST. OF N	.500	.333	.667
A	3.317	2.971	4.171
B	-1.020	-1.200	-.800

****

ZONE NUMBER 14 LOC IN REG NO 4 MAP INDEX NO 14 PROB. OF EXISTENCE= 0.5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	4.5	5.8
EST. OF N	.100	.050	.111
A	2.301	1.301	3.101
B	-1.000	-1.200	-.800

****

ZONE NUMBER 15 LOC IN REG NO 4 MAP INDEX NO 15 PROB. OF EXISTENCE= 0.5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.100	.075	.120
A	2.959	.959	3.459
B	-1.000	-1.2[illegible]	-.800

****

ZONE NUMBER 16 LOC IN REG NO 4 MAP INDEX NO 16 PROB. OF EXISTENCE= 0.3
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.80 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.3
EST. OF N	.200	.125	.286
A	2.790	2.570	3.170
B	-.944	-1.200	-.800

*********** SEISMICITY DATA FOR EXPERT 2

TABLE A3

ZONE NUMBER 17 LOC IN REG NO 4 MAP INDEX NO 17 PROB. OF EXISTENCE= 0.3
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	5.5	6.8
EST. OF N	.133	.100	.200
A	2.576	2.076	3.076
B	-1.000	-1.200	-.340

ZONE NUMBER 18 LOC IN REG NO 4 MAP INDEX NO 18 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.50 7.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.8	7.5	8.0
EST. OF N	1.000	.857	1.500
A	2.246	1.890	2.770
B	-.621	-1.000	-.522

ZONE NUMBER 19 LOC IN REG NO 4 MAP INDEX NO 19 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	5.5	7.0
EST. OF N	.400	.267	.500
A	2.837	2.624	3.024
B	-.912	-1.000	-.800

ZONE NUMBER 20 LOC IN REG NO 4 MAP INDEX NO 20 PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	5.8	7.3
EST. OF N	.333	.250	.400
A	2.060	1.975	2.266
B	-.653	-.759	-.634

*********** SEISMICITY DATA FOR EXPERT 2

TABLE A3

****

ZONE NUMBER 21 LOC IN REG NO 4 MAP INDEX NO 21 PROB. OF EXISTENCE= 0.5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.100	.083	.125
A	2.529	2.180	2.880
B	-.923	-.959	-.887

****

ZONE NUMBER 22 LOC IN REG NO 3 MAP INDEX NO 22 PROB. OF EXISTENCE= 0.5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	5.5	6.5
EST. OF N	.120	.060	.200
A	2.597	2.097	3.097
B	-1.000	-1.200	-.800

****

ZONE NUMBER 23 LOC IN REG NO 3 MAP INDEX NO 23 PROB. OF EXISTENCE= 0.3
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.3	6.0
EST. OF N	.088	.064	.100
A	2.700	2.200	3.200
B	-1.000	-1.200	-.800

****

ZONE NUMBER 24 LOC IN REG NO 3 MAP INDEX NO 24 PROB. OF EXISTENCE= 0.4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	6.8
EST. OF N	.200	.133	.250
A	3.914	2.200	4.000
B	-1.118	-1.300	-.790

*********** SEISMICITY DATA FOR EXPERT 2

TABLE A3

ZONE NUMBER 25 LOC IN REG NO 2 MAP INDEX NO 25 PROB. OF EXISTENCE= 0.3
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.3
EST. OF N	.050	.040	.060
A	2.501	2.001	3.001
B	-1.000	-1.200	-.800

ZONE NUMBER 26 LOC IN REG NO 3 MAP INDEX NO 26 PROB. OF EXISTENCE= 0.4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.3
EST. OF N	.200	.167	.250
A	5.301	3.921	5.421
B	-1.470	-1.500	-1.000

ZONE NUMBER 27 LOC IN REG NO 2 MAP INDEX NO 27 PROB. OF EXISTENCE= 0.7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	2.500	1.819	2.858
A	4.167	2.947	5.387
B	-1.060	-1.226	-.901

ZONE NUMBER 28 LOC IN REG NO 2 MAP INDEX NO 28 PROB. OF EXISTENCE= 0.6
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.5
EST. OF N	.500	.417	.625
A	3.229	2.989	3.479
B	-.911	-.929	-.892

*********** SEISMICITY DATA FOR EXPERT 2

TABLE A3

ZONE NUMBER 29 LOC IN REG NO 2 MAP INDEX NO 29 PROB. OF EXISTENCE= 0.5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	6.8
EST. OF N	.350	.292	.438
A	2.830	2.500	3.100
B	-.676	-1.100	-.700

ZONE NUMBER 30 LOC IN REG NO 2 MAP INDEX NO 30 PROB. OF EXISTENCE= 0.7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.5	7.0	7.8
EST. OF N	1.000	.882	1.154
A	2.530	2.300	2.700
B	-.671	-.800	-.500

ZONE NUMBER 31 LOC IN REG NO 1 MAP INDEX NO 31 PROB. OF EXISTENCE= 0.7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	7.0	6.3
EST. OF N	2.000	.160	2.222
A	3.965	3.845	4.045
B	-1.030	-1.200	-.800

ZONE NUMBER 32 LOC IN REG NO 1 MAP INDEX NO 32 PROB. OF EXISTENCE= 0.7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.8	7.5	8.0
EST. OF N	1.200	.800	1.714
A	2.453	2.399	2.599
B	-.685	-.800	-.500

*********** SEISMICITY DATA FOR EXPERT 2

TABLE A3

****

ZONE NUMBER 33 LOC IN REG NO 3 MAP INDEX NO 33 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.3	7.0
EST. OF N	.200	.167	.250
A	3.224	2.844	3.604
B	-.970	-1.000	-.950

****

ZONE NUMBER 34 LOC IN REG NO 2 MAP INDEX NO 34-C.Z. PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.3	6.5	7.5
EST. OF N	5.000	3.333	10.000
A	3.500	3.000	4.000
B	-1.000	-1.200	-.800

TABLE A3

SEISMICITY DATA FOR EXPERT 3 NO. OF ZONES= 24 SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 7.0 10.0 5.0 7.0

ZONE NUMBER 1 LOC IN REG NO 4 MAP INDEX NO 1 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.3
EST. OF N	2.750	2.000	4.000
A	4.549	3.949	5.149
B	-1.100	-1.400	-.800

ZONE NUMBER 2 LOC IN REG NO 1 MAP INDEX NO 2 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.8	6.3	7.3
EST. OF N	.200	.133	.333
A	1.603	1.393	1.813
B	-.590	-.630	-.550

ZONE NUMBER 3 LOC IN REG NO 1 MAP INDEX NO 3 PROB. OF EXISTENCE= .75
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.3	6.8	7.8
EST. OF N	.267	.133	.400
A	1.223	.983	1.463
B	-.520	-.570	-.470

ZONE NUMBER 4 LOC IN REG NO 1 MAP INDEX NO 4 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.6	6.0	7.3
EST. OF N	.769	.385	1.538
A	3.586	3.016	4.156
B	-1.000	-1.130	-.870

*********** SEISMICITY DATA FOR EXPERT 3

TABLE A3

ZONE NUMBER 5 LOC IN REG NO 1 MAP INDEX NO 5 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.6	6.0	7.3
EST. OF N	.769	.385	1.538
A	3.586	3.016	4.156
B	-1.000	-1.130	-.870

ZONE NUMBER 6 LOC IN REG NO 1 MAP INDEX NO 6 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	5.8	7.3
EST. OF N	1.091	.727	1.818
A	4.061	3.561	4.561
B	-1.100	-1.200	-1.000

ZONE NUMBER 7 LOC IN REG NO 1 MAP INDEX NO 7 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	5.8	7.3
EST. OF N	1.091	.727	1.818
A	4.061	3.561	4.561
B	-1.100	-1.200	-1.000

ZONE NUMBER 8 LOC IN REG NO 2 MAP INDEX NO 8 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.6	5.8	7.3
EST. OF N	.800	.533	1.333
A	3.824	3.124	4.524
B	-1.040	-1.190	-.890

*********** SEISMICITY DATA FOR EXPERT 3

TABLE A3

****

ZONE NUMBER 9 LOC IN REG NO 2 MAP INDEX NO 8ALT PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.6	5.8	7.3
EST. OF N	.400	267	.667
A	2.974	2.524	3.424
B	-.900	-1.000	-.800

****

ZONE NUMBER 10 LOC IN REG NO 2 MAP INDEX NO 9 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.4	7.0
EST. OF N	.167	.083	.500
A	2.855	1.925	3.785
B	-.980	-1.190	-.770

****

ZONE NUMBER 11 LOC IN REG NO 2 MAP INDEX NO 10 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.8	6.0	7.5
EST. OF N	.615	.308	1.923
A	3.116	2.516	3.716
B	-.940	-1.070	-.810

****

ZONE NUMBER 12 LOC IN REG NO 2 MAP INDEX NO 10ALT PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.0	7.5
EST. OF N	.769	.385	2.308
A	3.236	2.586	3.886
B	-.950	-1.090	-.810

*********** SEISMICITY DATA FOR EXPERT 3

TABLE A3

ZONE NUMBER 13 LOC IN REG NO 2 MAP INDEX NO 11 PROB. OF EXISTENCE= .85
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.3
EST. OF N	.389	.194	1.000
A	2.875	2.285	3.465
B	-.930	-1.060	-.800

ZONE NUMBER 14 LOC IN REG NO 2 MAP INDEX NO 11ALT PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	5.8	7.3
EST. OF N	.389	.194	1.000
A	3.395	2.655	4.135
B	-1.010	-1.170	-.850

ZONE NUMBER 15 LOC IN REG NO 2 MAP INDEX NO 12 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.8
EST. OF N	.300	.200	1.000
A	2.000	1.730	2.270
B	-.670	-.740	-.600

ZONE NUMBER 16 LOC IN REG NO 2 MAP INDEX NO 13 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.8
EST. OF N	.300	.200	1.000
A	2.000	1.730	2.270
B	-.670	-.740	-.600

*********** SEISMICITY DATA FOR EXPERT 3

TABLE A3

****

ZONE NUMBER 17 LOC IN REG NO 3 MAP INDEX NO 14 PROB. OF EXISTENCE= .5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.9
EST. OF N	.300	.200	1.000
A	2.000	1.730	2.270
B	-.670	-.740	-.600

****

ZONE NUMBER 18 LOC IN REG NO 3 MAP INDEX NO 21 PROB. OF EXISTENCE= .25
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.8
EST. OF N	.300	.200	1.000
A	2.000	1.730	2.270
B	-.670	-7.400	-.600

****

ZONE NUMBER 19 LOC IN REG NO 4 MAP INDEX NO 15 PROB. OF EXISTENCE= .95
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.4	6.8	7.8
EST. OF N	1.000	.667	3.000
A	3.324	2.904	3.744
B	-.910	-1.000	-.820

****

ZONE NUMBER 20 LOC IN REG NO 4 MAP INDEX NO 16 PROB. OF EXISTENCE= .75
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.3	7.4
EST. OF N	.357	.179	1.071
A	2.554	2.054	3.054
B	-.810	-.910	-.710

*********** SEISMICITY DATA FOR EXPERT 3

TABLE A3

ZONE NUMBER 21 LOC IN REG NO 4 MAP INDEX NO 17 PROB. OF EXISTENCE= .75
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.3	7.4
EST. OF N	.357	.179	1.071
A	2.554	2.054	3.054
B	-.810	-.910	-.710

ZONE NUMBER 22 LOC IN REG NO 4 MAP INDEX NO 18 PROB. OF EXISTENCE= .5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.2
EST. OF N	1.000	.500	2.000
A	4.900	4.250	5.550
B	-1.300	-1.450	-.115

ZONE NUMBER 23 LOC IN REG NO 3 MAP INDEX NO 19 PROB. OF EXISTENCE= .25
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.2
EST. OF N	1.000	.500	2.000
A	4.900	4.250	5.550
B	-1.300	-1.450	-1.150

ZONE NUMBER 24 LOC IN REG NO 3 MAP INDEX NO 20 PROB. OF EXISTENCE= .25
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.2
EST. OF N	1.000	.500	2.000
A	4.900	4.250	5.550
B	-1.300	-1.450	-1.150

TABLE A3

SEISMICITY DATA FOR EXPERT 4 NO. OF ZONES= 26 SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 8.5 6.0 7.0 9.0

ZONE NUMBER 1 LOC IN REG NO 4 MAP INDEX NO 1 PROB. OF EXISTENCE= 0.5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.10

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.1	5.9	6.3
EST. OF N	.210	.140	.320
A	2.700	2.150	3.260
B	-.900	-1.000	-.800

ZONE NUMBER 2 LOC IN REG NO 4 MAP INDEX NO 2 PROB. OF EXISTENCE= 0.5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.60

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.6	5.4	5.8
EST. OF N	.070	.050	.110
A	2.220	1.700	2.790
B	-.900	-1.000	-.800

ZONE NUMBER 3 LOC IN REG NO 4 MAP INDEX NO 3 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.60

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.6	6.4	6.8
EST. OF N	.600	.390	.910
A	3.150	2.590	3.710
B	-.900	-1.000	-.800

ZONE NUMBER 4 LOC IN REG NO 4 MAP INDEX NO 4 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 7.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.5	7.3	7.7
EST. OF N	4.030	2.640	6.150
A	3.980	3.420	4.540
B	-.900	-1.000	-.800

*********** SEISMICITY DATA FOR EXPERT 4

TABLE A3

****

ZONE NUMBER 5 LOC IN REG NO 4 MAP INDEX NO 5 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.3	6.7
EST. OF N	.480	.320	.740
A	3.060	2.510	3.620
B	-.900	-1.000	-.800

****

ZONE NUMBER 6 LOC IN REG NO 3 MAP INDEX NO 6 PROB. OF EXISTENCE= 0.75
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.8	6.2
EST. OF N	.170	.110	.260
A	2.610	2.040	3.160
B	-.900	-1.000	-.800

****

ZONE NUMBER 7 LOC IN REG NO 3 MAP INDEX NO 7 PROB. OF EXISTENCE= 0.75
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.8	6.2
EST. OF N	.170	.110	.260
A	2.610	2.040	3.160
B	-.900	-1.000	-.800

****

ZONE NUMBER 8 LOC IN REG NO 2 MAP INDEX NO 8 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.2	6.0	6.4
EST. OF N	.260	.170	.390
A	2.790	1.860	3.720
B	-.900	-1.100	-.700

*********** SEISMICITY DATA FOR EXPERT 4

TABLE A3

ZONE NUMBER 9 LOC IN REG NO 2 MAP INDEX NO 9 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.2	6.0	6.4
EST. OF N	.260	.170	.390
A	2.790	1.860	3.720
B	-.900	-1.100	-.700

ZONE NUMBER 10 LOC IN REG NO 2 MAP INDEX NO 10 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.80

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.8	6.6	7.0
EST. OF N	.910	.910	1.400
A	3.330	2.580	4.270
B	-.900	-1.100	-.700

ZONE NUMBER 11 LOC IN REG NO 2 MAP INDEX NO 11 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.7	5.7	5.9
EST. OF N	.090	.060	.140
A	2.330	1.400	3.270
B	-.900	-1.100	-.700

ZONE NUMBER 12 LOC IN REG NO 2 MAP INDEX NO 12 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.8	6.2
EST. OF N	.170	.110	.260
A	2.610	1.670	3.540
B	-.900	-1.100	-.700

*********** SEISMICITY DATA FOR EXPERT 4

TABLE A3

ZONE NUMBER 13 LOC IN REG NO 2 MAP INDEX NO 13 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.3	5.7
EST. OF N	.060	.040	.090
A	2.150	1.600	2.700
B	-.900	-1.000	-.800

ZONE NUMBER 14 LOC IN REG NO 3 MAP INDEX NO 14 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.60

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.6	5.4	5.8
EST. OF N	.100	.070	.130
A	2.380	1.850	2.860
B	-.900	-1.000	-.800

ZONE NUMBER 15 LOC IN REG NO 1 MAP INDEX NO 15 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.60

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.6	5.4	5.8
EST. OF N	.070	.050	.110
A	2.220	1.320	3.170
B	-.900	-1.100	-.700

ZONE NUMBER 16 LOC IN REG NO 1 MAP INDEX NO 16 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.80

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.8	6.6	7.0
EST. OF N	.910	.910	1.400
A	3.330	2.960	3.900
B	-.900	-1.000	-.800

*********** SEISMICITY DATA FOR EXPERT 4

TABLE A3

****

ZONE NUMBER 17 LOC IN REG NO 1 MAP INDEX NO 17 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.3	5.7
EST. OF N	.060	.040	.090
A	2.150	1.230	3.080
B	-.900	-1.100	-.700

****

ZONE NUMBER 18 LOC IN REG NO 1 MAP INDEX NO 18 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.30

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.1	6.5
EST. OF N	.320	.210	.480
A	2.880	2.320	3.430
B	-.900	-1.000	-.800

****

ZONE NUMBER 19 LOC IN REG NO 1 MAP INDEX NO 19 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.7	6.5	6.9
EST. OF N	.740	.480	1.130
A	3.240	2.680	3.800
B	-.900	-1.000	-.800

****

ZONE NUMBER 20 LOC IN REG NO 1 MAP INDEX NO 20 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.3	6.7
EST. OF N	.480	.320	.740
A	3.060	2.510	3.620
B	-.900	-1.000	-.800

*********** SEISMICITY DATA FOR EXPERT 4

TABLE A3

****

ZONE NUMBER 21 LOC IN REG NO 1 MAP INDEX NO 21 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.10

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.1	5.9	6.3
EST. OF N	.210	.177	.320
A	2.700	1.830	3.630
B	-.900	-1.100	-.700

****

ZONE NUMBER 22 LOC IN REG NO 1 MAP INDEX NO 22 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 7.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.2	7.0	7.4
EST. OF N	2.100	1.400	3.260
A	3.700	2.770	4.640
B	-.900	-1.100	-.700

****

ZONE NUMBER 23 LOC IN REG NO 1 MAP INDEX NO 23 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.60

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.6	5.4	5.8
EST. OF N	.070	.050	.110
A	2.220	1.700	2.790
B	-.900	-1.000	-.800

****

ZONE NUMBER 24 LOC IN REG NO 4 MAP INDEX NO 25 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.3	5.7
EST. OF N	.060	.040	.090
A	2.150	1.600	2.700
B	-.900	-1.000	-.800

*********** SEISMICITY DATA FOR EXPERT 4

TABLE A3

****

ZONE NUMBER 25   LOC IN REG NO 2   MAP INDEX NO 26   PROB. OF EXISTENCE= 0.5
OCCURRENCE MODEL IN MAGNITUDE   LINEAR RANGE OF   (A-B*M)   MODEL IS   3.75   6.10

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.1	5.9	6.3
EST. OF N	.210	.090	.320
A	2.700	1.580	3.630
B	-.900	-1.100	-.700

****

ZONE NUMBER 26   LOC IN REG NO 3   MAP INDEX NO C.Z.   PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE   LINEAR RANGE OF   (A-B*M)   MODEL IS   3.75   5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.3	5.7
EST. OF N	.160	.110	.250
A	2.590	2.000	3.130
B	-.900	-1.000	-.800

TABLE A3

SEISMICITY DATA FOR EXPERT 5 NO. OF ZONES= 23 SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 10.0 8.0 7.0

ZONE NUMBER 1 LOC IN REG NO 1 MAP INDEX NO 1 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	10.0	9.0	11.0
EST. OF N	5.000	3.000	10.000
A	3.083	2.383	3.783
B	-.680	-.900	-.400

ZONE NUMBER 2 LOC IN REG NO 1 MAP INDEX NO 2 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.0	3.0	6.0
EST. OF N	.100	.050	.200
A	3.456	2.456	4.456
B	-.500	-.700	-.300

ZONE NUMBER 3 LOC IN REG NO 1 MAP INDEX NO 3 PROB. OF EXISTENCE= .6
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	11.0	10.0	12.0
EST. OF N	5.000	3.000	7.000
A	1.751	1.351	2.151
B	-.500	-.700	-.300

ZONE NUMBER 4 LOC IN REG NO 1 MAP INDEX NO 4 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.0	8.0	10.0
EST. OF N	2.000	.250	5.000
A	2.447	1.947	2.947
B	-.610	-.700	-.400

*********** SEISMICITY DATA FOR EXPERT 5

TABLE A3

ZONE NUMBER 5 LOC IN REG NO 3 MAP INDEX NO 5 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.0	7.0	10.0
EST. OF N	.200	.050	.500
A	2.528	2.028	3.028
B	-.740	-.900	-.400

ZONE NUMBER 6 LOC IN REG NO 3 MAP INDEX NO 6 PROB. OF EXISTENCE= .5
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.0	7.0	10.0
EST. OF N	.200	.050	.500
A	2.728	1.728	3.528
B	-.500	-.900	-.300

ZONE NUMBER 7 LOC IN REG NO 1 MAP INDEX NO 7 PROB. OF EXISTENCE= .3
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.0	9.0
EST. OF N	1.000	.500	2.000
A	2.678	2.178	3.178
B	-.500	-.700	-.300

ZONE NUMBER 8 LOC IN REG NO 2 MAP INDEX NO 8 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.0	9.0
EST. OF N	.300	.100	1.000
A	2.268	1.868	2.668
B	-.660	-.800	-.400

*********** SEISMICITY DATA FOR EXPERT 5

TABLE A3

****

ZONE NUMBER 9 LOC IN REG NO 2 MAP INDEX NO 9 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	11.0	10.0	12.0
EST. OF N	1.000	.200	2.000
A	2.736	2.036	3.236
B	-.540	-.800	-.300

****

ZONE NUMBER 10 LOC IN REG NO 2 MAP INDEX NO 10 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.0	9.0
EST. OF N	.500	.200	1.000
A	2.524	1.724	3.324
B	-.640	-.800	-.400

****

ZONE NUMBER 11 LOC IN REG NO 2 MAP INDEX NO 11 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.0	8.0	10.0
EST. OF N	1.800	1.000	2.500
A	4.093	2.693	4.493
B	-.820	-.900	-.400

****

ZONE NUMBER 12 LOC IN REG NO 3 MAP INDEX NO 12 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.0	8.0	10.0
EST. OF N	.300	.100	.500
A	2.591	1.991	2.991
B	-.600	-.700	-.400

*********** SEISMICITY DATA FOR EXPERT 5

TABLE A3

****

ZONE NUMBER 13 LOC IN REG NO 3 MAP INDEX NO 13 PROB. OF EXISTENCE= .5
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.0	8.0	10.0
EST. OF N	.100	.050	.200
A	3.101	2.301	3.901
B	-.480	-.700	-.300

****

ZONE NUMBER 14 LOC IN REG NO 4 MAP INDEX NO 14 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.0	8.0	10.0
EST. OF N	.500	.200	2.000
A	2.938	2.238	3.538
B	-.640	-.800	-.400

****

ZONE NUMBER 15 LOC IN REG NO [illegible] MAP INDEX NO 15 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	12.0	12.0	12.0
EST. OF N	2.000	1.000	10.000
A	2.977	2.377	3.577
B	-.560	-.800	-.400

****

ZONE NUMBER 16 LOC IN REG NO 1 MAP INDEX NO 16 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.0	9.0
EST. OF N	.200	.050	.500
A	2.721	2.221	3.221
B	-.500	-.700	-.300

*********** SEISMICITY DATA FOR EXPERT 5

TABLE A3

****

ZONE NUMBER 17 LOC IN REG NO 4 MAP INDEX NO 17 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.0	8.0	10.0
EST. OF N	.100	.020	1.000
A	3.215	2.215	4.215
B	-.500	-.700	-.300

****

ZONE NUMBER 18 LOC IN REG NO 4 MAP INDEX NO 18 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.0	8.0	10.0
EST. OF N	.100	.020	1.000
A	3.367	2.367	4.367
B	-.500	-.700	-.300

****

ZONE NUMBER 19 LOC IN REG NO 2 MAP INDEX NO 21 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	5.0	8.0
EST. OF N	.100	.020	1.000
A	3.118	2.018	4.018
B	-.920	-1.000	-.400

****

ZONE NUMBER 20 LOC IN REG NO 4 MAP INDEX NO C.Z. PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.0	9.0
EST. OF N	3.000	1.000	5.000
A	4.170	3.370	4.970
B	-.920	-1.000	-.400

*********** SEISMICITY DATA FOR EXPERT 5

TABLE A3

ZONE NUMBER 21 LOC IN REG NO 2 MAP INDEX NO 19 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	12.0	12.0	12.0
EST. OF N	8.000	3.000	12.000
A	2.103	1.803	2.303
B	-.400	-.600	-.300

ZONE NUMBER 22 LOC IN REG NO 4 MAP INDEX NO 20 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	9.0	7.0	10.0
EST. OF N	.500	.100	2.000
A	2.251	1.951	2.551
B	-.540	-.600	-.300

ZONE NUMBER 23 LOC IN REG NO 2 MAP INDEX NO ALT C.Z PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN INTENSITY LINEAR RANGE OF (A-B*I) MODEL IS 4.00 12.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	11.0	10.0	12.0
EST. OF N	3.000	1.000	10.000
A	2.783	2.583	3.183
B	-.550	-.600	-.300

TABLE A3

SEISMICITY DATA FOR EXPERT 6.   NO. OF ZONES= 48   SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 9.0 7.0 5.0 5.0

ZONE NUMBER 1 LOC IN REG NO 3 MAP INDEX NO 1 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	2.010	1.500	2.500
A	4.196	3.196	5.196
B	-1.040	-1.140	-.940

ZONE NUMBER 2 LOC IN REG NO 1 MAP INDEX NO 2 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.5	7.5
EST. OF N	.330	.200	.500
A	3.414	2.414	4.414
B	-1.040	-1.140	-.940

ZONE NUMBER 3 LOC IN REG NO 1 MAP INDEX NO 3 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 7.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.5	8.5
EST. OF N	.590	.400	.800
A	2.158	1.158	3.158
B	-.640	-.740	-.540

ZONE NUMBER 4 LOC IN REG NO 1 MAP INDEX NO 4 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.5	7.5
EST. OF N	1.500	1.200	2.000
A	4.135	3.135	5.135
B	-1.080	-1.180	-.980

*********** SEISMICITY DATA FOR EXPERT 6.

TABLE A3

ZONE NUMBER 5 LOC IN REG NO 1 MAP INDEX NO 5 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE BILINEAR MODEL USED RANGE BETWEEN 3.50 5.04 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.5	7.5
EST. OF N	.940	.800	1.200
A	3.145	2.145	4.145
B	-.850	-.950	-.750
A	5.465	4.465	6.465
B	-1.310	-1.410	-1.210

ZONE NUMBER 6 LOC IN REG NO 3 MAP INDEX NO 6 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.220	.150	.400
A	1.313	.313	2.313
B	-.670	-.770	-.570

ZONE NUMBER 7 LOC IN REG NO 2 MAP INDEX NO 7 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.210	.150	.300
A	2.280	1.280	3.280
B	-.770	-.870	-.670

ZONE NUMBER 8 LOC IN REG NO 2 MAP INDEX NO 8 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.430	.300	.600
A	4.235	3.235	5.235
B	-1.180	-1.330	-1.030

*********** SEISMICITY DATA FOR EXPERT 6.

TABLE A3

ZONE NUMBER 9 LOC IN REG NO 2 MAP INDEX NO 9 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE BILINEAR MODEL USED RANGE BETWEEN 3.50 4.79 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.5	7.5
EST. OF N	1.010	.800	1.200
A	3.110	2.110	4.110
B	-.840	-.940	-.750
A	5.786	4.786	6.786
B	-1.400	-1.500	-1.350

ZONE NUMBER 10 LOC IN REG NO 2 MAP INDEX NO 10 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.5	8.5
EST. OF N	1.130	.900	1.400
A	4.064	3.064	5.064
B	-1.070	-1.170	-.970

ZONE NUMBER 11 LOC IN REG NO 2 MAP INDEX NO 11 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.070	.050	.150
A	2.250	1.250	3.250
B	-.900	-1.200	-.700

ZONE NUMBER 12 LOC IN REG NO 2 MAP INDEX NO 12 PROB. OF EXISTENCE= .5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 4.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.060	.020	.100
A	2.200	1.200	3.200
B	-.900	-1.200	-.700

*********** SEISMICITY DATA FOR EXPERT 6.

TABLE A3

ZONE NUMBER 13 LOC IN REG NO 2 MAP INDEX NO 13 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 4.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.030	.010	.060
A	1.521	.521	2.521
B	-.900	-1.200	-.700

ZONE NUMBER 14 LOC IN REG NO 3 MAP INDEX NO 14 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.100	.040	.200
A	4.186	3.186	5.186
B	-1.400	-1.500	-1.300

ZONE NUMBER 15 LOC IN REG NO 3 MAP INDEX NO 15 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.040	.010	.060
A	1.795	.795	2.795
B	-.900	-1.100	-.600

ZONE NUMBER 16 LOC IN REG NO 3 MAP INDEX NO 16 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.200	.150	.300
A	2.761	1.761	3.761
B	-.920	-1.020	-.820

*********** SEISMICITY DATA FOR EXPERT 6.

TABLE A3

ZONE NUMBER 17 LOC IN REG NO 4 MAP INDEX NO 17 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE BILINEAR MODEL USED RANGE BETWEEN 3.50 5.38 7.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.5	8.5
EST. OF N	1.480	1.100	1.600
A	3.570	2.570	4.570
B	-.910	-1.010	-.810
A	1.315	.315	2.315
B	-.490	-1.000	-.450

ZONE NUMBER 18 LOC IN REG NO 4 MAP INDEX NO 18 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 4.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.040	.010	.080
A	2.097	1.097	3.097
B	-.900	-1.200	-.700

ZONE NUMBER 19 LOC IN REG NO 4 MAP INDEX NO 19 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 4.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.100	.020	.150
A	2.397	1.397	3.397
B	-.900	-1.200	-.700

ZONE NUMBER 20 LOC IN REG NO 4 MAP INDEX NO 20 PROB. OF EXISTENCE= .2
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.40 4.40

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.090	.020	.150
A	2.207	1.207	3.207
B	-.900	-1.200	-.700

*********** SEISMICITY DATA FOR EXPERT 6.

TABLE A3

****

ZONE NUMBER 21 LOC IN REG NO 4 MAP INDEX NO 21 PROB. OF EXISTENCE= .2
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 4.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.080	.040	.150
A	2.177	1.177	3.177
B	-.900	-1.200	-.700

****

ZONE NUMBER 22 LOC IN REG NO 4 MAP INDEX NO 22 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE BILINEAR MODEL USED RANGE BETWEEN 3.50 4.28 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.300	.150	.450
A	4.687	3.687	5.687
B	-1.410	-1.510	-1.310
A	1.047	.047	2.047
B	-.560	-1.000	-.500

****

ZONE NUMBER 23 LOC IN REG NO 3 MAP INDEX NO 23 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.210	.100	.300
A	3.097	2.097	4.097
B	-1.000	-1.100	-.900

****

ZONE NUMBER 24 LOC IN REG NO 3 MAP INDEX NO 24 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.080	.040	.150
A	2.447	1.447	3.447
B	-.900	-1.200	-.700

*********** SEISMICITY DATA FOR EXPERT 6.

TABLE A3

ZONE NUMBER 25 LOC IN REG NO 3 MAP INDEX NO 25 PROB. OF EXISTENCE= .5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.100	.050	.200
A	.900	.500	2.000
B	-.520	-.900	-.500

ZONE NUMBER 26 LOC IN REG NO 3 MAP INDEX NO 26 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.210	.100	.300
A	3.397	2.397	4.397
B	-1.110	-1.210	-1.010

ZONE NUMBER 27 LOC IN REG NO 3 MAP INDEX NO 27 PROB. OF EXISTENCE= .6
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.190	.100	.300
A	3.117	2.117	4.117
B	-1.040	-1.140	-.940

ZONE NUMBER 28 LOC IN REG NO 3 MAP INDEX NO 28 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.410	.200	.600
A	4.487	3.487	5.487
B	-1.180	-1.280	-1.080

*********** SEISMICITY DATA FOR EXPERT 6.

TABLE A3

ZONE NUMBER 29 LOC IN REG NO 4 MAP INDEX NO 29 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.180	.100	.300
A	2.397	1.397	3.397
B	-.810	-.910	-.710

ZONE NUMBER 30 LOC IN REG NO 4 MAP INDEX NO 30 PROB. OF EXISTENCE= .4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.5	7.5
EST. OF N	.100	.050	.200
A	1.577	.577	2.577
B	-.690	-.900	-.590

ZONE NUMBER 31 LOC IN REG NO 1 MAP INDEX NO 31 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.5	7.5
EST. OF N	.210	.100	.300
A	3.186	2.186	4.186
B	-1.000	-1.100	-.900

ZONE NUMBER 32 LOC IN REG NO 1 MAP INDEX NO 32 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 7.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.5	8.5
EST. OF N	.570	.300	.800
A	2.199	1.199	3.199
B	-.650	-.850	-.550

*********** SEISMICITY DATA FOR EXPERT 6.

TABLE A3

ZONE NUMBER 33 LOC IN REG NO 1 MAP INDEX NO 33 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.150	.050	.300
A	3.636	2.636	4.636
B	-1.230	-1.400	-1.030

ZONE NUMBER 34 LOC IN REG NO 1 MAP INDEX NO 34 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE BILINEAR MODEL USED RANGE BETWEEN 3.50 4.52 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.5	7.5
EST. OF N	.910	.700	1.200
A	5.610	4.610	6.610
B	-1.540	-1.600	-1.300
A	1.680	.680	2.680
B	-.670	-.900	-.570

ZONE NUMBER 35 LOC IN REG NO 2 MAP INDEX NO 35 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.460	.250	.650
A	3.638	2.638	4.638
B	-1.080	-1.180	-.980

ZONE NUMBER 36 LOC IN REG NO 3 MAP INDEX NO 36 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.210	.100	.300
A	3.140	2.140	4.140
B	-1.010	-1.210	-.810

*********** SEISMICITY DATA FOR EXPERT 6.

TABLE A3

****

ZONE NUMBER 37   LOC IN REG NO 1   MAP INDEX NO 37   PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE   LINEAR RANGE OF   (A-B*M) MODEL IS   3.50   6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.5	7.5
EST. OF N	1.040	.800	1.400
A	3.186	2.186	4.186
B	-.860	-.960	-.760

****

ZONE NUMBER 38   LOC IN REG NO 1   MAP INDEX NO 38   PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE   LINEAR RANGE OF   (A-B*M) MODEL IS   3.50   6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.5	7.5
EST. OF N	.200	.100	.300
A	1.957	.957	2.957
B	-.670	-.870	-.570

****

ZONE NUMBER 39   LOC IN REG NO 3   MAP INDEX NO 39   PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE   LINEAR RANGE OF   (A-B*M) MODEL IS   3.50   5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.190	.100	.300
A	3.414	2.414	4.414
B	-1.080	-1.280	-.880

****

ZONE NUMBER 40   LOC IN REG NO 2   MAP INDEX NO 40   PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE   LINEAR RANGE OF   (A-B*M) MODEL IS   3.50   5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.330	.150	.450
A	3.365	2.365	4.365
B	-1.030	-1.230	-.830

*********** SEISMICITY DATA FOR EXPERT 6.

TABLE A3

****

ZONE NUMBER 41 LOC IN REG NO 2 MAP INDEX NO 41 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE BILINEAR MODEL USED RANGE BETWEEN 3.50 5.00 7.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.5	8.5
EST. OF N	1.010	.800	1.200
A	4.350	3.350	5.350
B	-1.180	-1.230	-1.080
A	.950	-.050	1.950
B	-.500	-1.000	-.500

****

ZONE NUMBER 42 LOC IN REG NO 2 MAP INDEX NO 42 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.5	7.5
EST. OF N	.120	.050	.250
A	1.410	.410	2.410
B	-.640	-.840	-.540

****

ZONE NUMBER 43 LOC IN REG NO 2 MAP INDEX NO 43 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.240	.100	.450
A	3.396	2.396	4.396
B	-1.070	-1.170	-.970

****

ZONE NUMBER 44 LOC IN REG NO 2 MAP INDEX NO 44 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.120	.050	.250
A	2.091	1.091	3.091
B	-.820	-.920	-.720

*********** SEISMICITY DATA FOR EXPERT 6.

TABLE A3

ZONE NUMBER 45 LOC IN REG NO 2 MAP INDEX NO 45 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.330	.150	.700
A	2.847	1.847	3.847
B	-.900	-1.000	-.700

ZONE NUMBER 46 LOC IN REG NO 4 MAP INDEX NO 46 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 7.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.5	8.5
EST. OF N	.990	.500	1.800
A	2.025	1.025	3.025
B	-.600	-.700	-.500

ZONE NUMBER 47 LOC IN REG NO 4 MAP INDEX NO 47 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.5	7.5
EST. OF N	.410	.200	.700
A	2.975	1.975	3.975
B	-.890	-.990	-.790

ZONE NUMBER 48 LOC IN REG NO 4 MAP INDEX NO 48 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	.090	.040	.200
A	2.816	1.816	3.816
B	-1.060	-1.160	-.960

TABLE A3

SEISMICITY DATA FOR EXPERT 7 NO. OF ZONES= 27 SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 7.0 7.0 7.0 7.0

ZONE NUMBER 1 LOC IN REG NO 4 MAP INDEX NO 1 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.2	4.7	5.7
EST. OF N	.500	.400	.700
A	3.300	3.300	3.300
B	-.900	-1.100	-.700

ZONE NUMBER 2 LOC IN REG NO 4 MAP INDEX NO 2-CZ PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.7	6.2	7.2
EST. OF N	3.000	2.000	4.000
A	4.000	4.000	4.000
B	-.900	-1.100	-.700

ZONE NUMBER 3 LOC IN REG NO 3 MAP INDEX NO 3 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.0	6.0
EST. OF N	.200	.150	.400
A	2.900	2.900	2.900
B	-.900	-1.100	-.700

ZONE NUMBER 4 LOC IN REG NO 3 MAP INDEX NO 4 PROB. OF EXISTENCE= 0.75
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.0	6.0
EST. OF N	.300	.200	.500
A	3.000	3.000	3.000
B	-.900	-1.100	-.700

*********** SEISMICITY DATA FOR EXPERT 7

TABLE A3

ZONE NUMBER 5 LOC IN REG NO 4 MAP INDEX NO 5 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.00 7.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	7.0
EST. OF N	1.250	1.000	2.500
A	3.600	3.600	3.600
B	-.900	-1.000	-.800

ZONE NUMBER 6 LOC IN REG NO 4 MAP INDEX NO 6 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.00 7.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	8.0	7.5	8.2
EST. OF N	.600	.400	1.000
A	3.300	3.300	3.300
B	-.900	-1.000	-.800

ZONE NUMBER 7 LOC IN REG NO 2 MAP INDEX NO 7 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.2	5.7	6.7
EST. OF N	1.500	1.200	2.000
A	3.700	3.700	3.700
B	-.900	-1.100	-.700

ZONE NUMBER 8 LOC IN REG NO 2 MAP INDEX NO 8 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	500	.300	.800
A	3.300	3.300	3.300
B	-.900	-1.100	-.700

*********** SEISMICITY DATA FOR EXPERT 7

TABLE A3

ZONE NUMBER 9 LOC IN REG NO 2 MAP INDEX NO 9 PROB. OF EXISTENCE= 0.75
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.7	5.2	6.2
EST. OF N	.400	.200	.600
A	3.100	3.100	3.100
B	-.900	-1.050	-.750

ZONE NUMBER 10 LOC IN REG NO 2 MAP INDEX NO 10 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.2	6.7	7.5
EST. OF N	.250	.150	.400
A	3.000	3.000	3.000
B	-.900	-1.100	-.700

ZONE NUMBER 11 LOC IN REG NO 3 MAP INDEX NO 11 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 5.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.7	5.2	6.0
EST. OF N	.200	.100	.300
A	2.900	2.900	2.900
B	-.900	-1.050	-.750

ZONE NUMBER 12 LOC IN REG NO 3 MAP INDEX NO 12 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.2	5.7	6.7
EST. OF N	.200	.100	.300
A	2.900	2.900	2.900
B	-.900	-1.050	-.750

*********** SEISMICITY DATA FOR EXPERT 7

TABLE A3

****

ZONE NUMBER 13 LOC IN REG NO 2 MAP INDEX NO 13 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.2	6.3
EST. OF N	.200	.100	.300
A	2.900	2.900	2.900
B	-.900	-1.050	-.750

****

ZONE NUMBER 14 LOC IN REG NO 1 MAP INDEX NO 15 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 2.50 5.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.7	5.2	6.2
EST. OF N	.050	.030	.100
A	2.200	2.200	2.200
B	-.900	-1.050	-.750

****

ZONE NUMBER 15 LOC IN REG NO 1 MAP INDEX NO 16 PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.0	4.5	5.5
EST. OF N	.050	.030	.100
A	2.200	2.200	2.200
B	-.900	-1.050	-.750

****

ZONE NUMBER 16 LOC IN REG NO 1 MAP INDEX NO 17 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.00 6.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	1.000	.800	1.200
A	3.500	3.500	3.500
B	-.900	-1.000	-.800

*********** SEISMICITY DATA FOR EXPERT 7

TABLE A3

****

ZONE NUMBER 17 LOC IN REG NO 1 MAP INDEX NO 18 PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.2	5.7	6.5
EST. OF N	.200	.100	.300
A	2.900	2.900	2.900
B	-.900	-1.050	-.750

****

ZONE NUMBER 18 LOC IN REG NO 1 MAP INDEX NO 19 PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.2	5.7	6.7
EST. OF N	.190	.094	.280
A	2.170	2.170	2.170
B	-.900	-1.050	-.750

****

ZONE NUMBER 19 LOC IN REG NO 1 MAP INDEX NO 20 PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.5
EST. OF N	.100	.080	.150
A	2.600	2.600	2.600
B	-.900	-1.050	-.750

****

ZONE NUMBER 20 LOC IN REG NO 1 MAP INDEX NO 21(19) PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.2	5.7	6.7
EST. OF N	.012	.006	.018
A	.980	.980	.980
B	-.900	-1.050	-.750

*********** SEISMICITY DATA FOR EXPERT 7

TABLE A3

****

ZONE NUMBER 21 LOC IN REG NO 1 MAP INDEX NO 22(24) PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	6.7
EST. OF N	.005	.004	.006
A	1.170	1.170	1.170
B	-.900	-1.050	-.750

****

ZONE NUMBER 22 LOC IN REG NO 1 MAP INDEX NO 23 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.50 6.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.2	5.7	6.6
EST. OF N	.100	.080	.150
A	2.600	2.600	2.600
B	-.900	-1.050	-.750

****

ZONE NUMBER 23 LOC IN REG NO 1 MAP INDEX NO 24 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.00 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	6.7
EST. OF N	1.000	.800	1.200
A	3.500	3.500	3.500
B	-.900	-1.050	-.750

****

ZONE NUMBER 24 LOC IN REG NO 1 MAP INDEX NO 26 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 2.50 6.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.2	6.7	7.5
EST. OF N	.400	.300	.500
A	3.200	3.200	3.200
B	-.750	-.850	-.650

*********** SEISMICITY DATA FOR EXPERT 7

TABLE A3

ZONE NUMBER 25 LOC IN REG NO 1 MAP INDEX NO 27 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.00 5.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.2	5.7
EST. OF N	.450	.350	.550
A	3.200	3.200	3.200
B	-.900	-1.050	-.750

ZONE NUMBER 26 LOC IN REG NO 3 MAP INDEX NO 28 PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.2	5.7
EST. OF N	.100	.080	.120
A	2.500	2.500	2.500
B	-.900	-1.050	-.750

ZONE NUMBER 27 LOC IN REG NO 2 MAP INDEX NO 29 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.00 5.70

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.0	4.5	5.5
EST. OF N	.050	.030	.100
A	2.200	2.200	2.200
B	-.900	-1.050	-.750

TABLE A3

SEISMICITY DATA FOR EXPERT 10 NO. OF ZONES= 34 SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 7.0 7.0 7.0 7.0

ZONE NUMBER 1 LOC IN REG NO 1 MAP INDEX NO 1 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.250	.130	.400
A	3.050	2.930	3.170
B	-.950	-1.000	-.900

ZONE NUMBER 2 LOC IN REG NO 1 MAP INDEX NO 2 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.3	6.0
EST. OF N	.110	.080	.140
A	2.450	2.330	2.570
B	-.920	-.970	-.870

ZONE NUMBER 3 LOC IN REG NO 1 MAP INDEX NO 3 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.3	6.0
EST. OF N	.050	.040	.070
A	3.040	2.920	3.160
B	-1.080	-1.130	-1.030

ZONE NUMBER 4 LOC IN REG NO 2 MAP INDEX NO 4 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.8	6.8
EST. OF N	.700	.500	.900
A	3.510	3.390	3.630
B	-1.000	-1.050	-.950

*********** SEISMICITY DATA FOR EXPERT 10

TABLE A3

****

ZONE NUMBER 5 LOC IN REG NO 2 MAP INDEX NO 5 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.3	6.0
EST. OF N	.250	.150	.350
A	2.520	2.400	2.640
B	-.820	-.870	-.770

****

ZONE NUMBER 6 LOC IN REG NO 1 MAP INDEX NO 6 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.400	.300	.500
A	3.120	3.000	3.240
B	-.960	-1.010	-.910

****

ZONE NUMBER 7 LOC IN REG NO 1 MAP INDEX NO 7 PROB. OF EXISTENCE= .99
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.3	7.0
EST. OF N	1.600	1.000	2.000
A	3.480	3.360	3.600
B	-.920	-.970	-.870

****

ZONE NUMBER 8 LOC IN REG NO 1 MAP INDEX NO 8 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 7.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.8	7.5
EST. OF N	.800	.400	1.200
A	2.720	2.600	2.840
B	-.760	-.810	-.710

*********** SEISMICITY DATA FOR EXPERT 10

TABLE A3

****

ZONE NUMBER 9 LOC IN REG NO 3 MAP INDEX NO 9 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.8	6.5
EST. OF N	.080	.040	.120
A	1.730	1.560	1.900
B	-.780	-.880	-.680

****

ZONE NUMBER 10 LOC IN REG NO 3 MAP INDEX NO 10 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.8	6.5
EST. OF N	.060	.030	.100
A	2.620	2.500	2.740
B	-1.000	-1.050	-.950

****

ZONE NUMBER 11 LOC IN REG NO 4 MAP INDEX NO 12A PROB. OF EXISTENCE= .95
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 7.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.5	7.0	7.5
EST. OF N	2.000	1.400	2.600
A	3.410	3.290	3.530
B	-.870	-.920	-.820

****

ZONE NUMBER 12 LOC IN REG NO 4 MAP INDEX NO 12B PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 7.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.5	7.0	7.5
EST. OF N	2.000	1.400	2 600
A	3.590	3.470	3.710
B	-.900	-.950	-.850

*********** SEISMICITY DATA FOR EXPERT 10

TABLE A3

ZONE NUMBER 13 LOC IN REG NO 4 MAP INDEX NO 13 PROB. OF EXISTENCE= .98
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	1.500	1.000	2.000
A	4.200	4.080	4.320
B	-1.060	-1.110	-1.010

ZONE NUMBER 14 LOC IN REG NO 2 MAP INDEX NO 15 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 7.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.8	7.3
EST. OF N	.150	.100	.250
A	1.750	1.580	1.920
B	-.700	-.800	-.600

ZONE NUMBER 15 LOC IN REG NO 1 MAP INDEX NO 16 PROB. OF EXISTENCE= .75
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.600	.400	.800
A	2.820	2.700	2.940
B	-.850	-.900	-.800

ZONE NUMBER 16 LOC IN REG NO 1 MAP INDEX NO 17 PROB. OF EXISTENCE= .7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 7.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.3	7.0	7.5
EST. OF N	.340	.150	.500
A	1.690	1.520	1.860
B	-.570	-.670	-.470

*********** SEISMICITY DATA FOR EXPERT 10

TABLE A3

ZONE NUMBER 17 LOC IN REG NO 1 MAP INDEX NO 18 PROB. OF EXISTENCE= .95
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 7.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.3	7.0	7.5
EST. OF N	.340	.150	.500
A	1.690	1.520	1.860
B	-.570	-.670	-.470

ZONE NUMBER 18 LOC IN REG NO 3 MAP INDEX NO 19 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.3	6.0
EST. OF N	11.970	7.180	16.760
A	4.890	4.770	5.010
B	-1.000	-1.050	-.950

ZONE NUMBER 19 LOC IN REG NO 1 MAP INDEX NO 20 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.050	.030	.080
A	1.640	1.470	1.810
B	-.720	-.820	-.620

ZONE NUMBER 20 LOC IN REG NO 1 MAP INDEX NO 21 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.060	.030	.090
A	1.750	1.580	1.920
B	-.760	-.860	-.660

*********** SEISMICITY DATA FOR EXPERT 10

TABLE A3

ZONE NUMBER 21 LOC IN REG NO 1 MAP INDEX NO 22 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.050	.030	.080
A	1.200	1.030	1.370
B	-.700	-.800	-.600

ZONE NUMBER 22 LOC IN REG NO 1 MAP INDEX NO 23 PROB. OF EXISTENCE= .85
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.230	.150	.300
A	2.840	2.720	2.960
B	-.920	-.970	-.870

ZONE NUMBER 23 LOC IN REG NO 1 MAP INDEX NO 24 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.740	.500	1.000
A	3.640	3.520	3.760
B	-1.000	-1.050	-.950

ZONE NUMBER 24 LOC IN REG NO 1 MAP INDEX NO 25 PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.020	.010	.030
A	1.600	1.430	1.770
B	-.760	-.860	-.660

*********** SEISMICITY DATA FOR EXPERT 10

TABLE A3

****

ZONE NUMBER 25 LOC IN REG NO 3 MAP INDEX NO 26 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.8	6.5
EST. OF N	.650	.450	.850
A	3.230	3.110	3.350
B	-.940	-.990	-.890

****

ZONE NUMBER 26 LOC IN REG NO 3 MAP INDEX NO 26A PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.8	6.5
EST. OF N	.200	.100	.300
A	2.120	1.950	2.290
B	-.760	-.860	-.660

****

ZONE NUMBER 27 LOC IN REG NO 3 MAP INDEX NO 26B PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.8	6.5
EST. OF N	.030	.020	.050
A	1.450	1.280	1.620
B	-.800	-.900	-.700

****

ZONE NUMBER 28 LOC IN REG NO 3 MAP INDEX NO 27 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.3	6.0
EST. OF N	.040	.030	.050
A	2.440	2.320	2.560
B	-1.000	-1.050	-.950

*********** SEISMICITY DATA FOR EXPERT 10

TABLE A3

ZONE NUMBER 29 LOC IN REG NO 2 MAP INDEX NO 28 PROB. OF EXISTENCE= .9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.780	.550	1.000
A	3.380	3.260	3.500
B	-.920	-.970	-.870

ZONE NUMBER 30 LOC IN REG NO 2 MAP INDEX NO 28A PROB. OF EXISTENCE= .8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.220	.150	.300
A	2.610	2.440	2.780
B	-.890	-.990	-.790

ZONE NUMBER 31 LOC IN REG NO 4 MAP INDEX NO 29 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	1.000	.700	1.300
A	3.190	3.070	3.310
B	-.900	-.950	-.850

ZONE NUMBER 32 LOC IN REG NO 4 MAP INDEX NO 30 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.800	.500	1.000
A	3.140	3.020	3.260
B	-.900	-.950	-.850

*********** SEISMICITY DATA FOR EXPERT 10

TABLE A3

****

ZONE NUMBER 33 LOC IN REG NO 4 MAP INDEX NO 31 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.400	.300	.500
A	3.060	2.940	3.180
B	-.900	-.950	-.850

****

ZONE NUMBER 34 LOC IN REG NO 4 MAP INDEX NO 32 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.8
EST. OF N	.350	.250	.500
A	2.850	2.730	2.970
B	-.900	-.950	-.850

TABLE A3

SEISMICITY DATA FOR EXPERT 11 NO. OF ZONES= 21 SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 7.5 9.5 6.3 7.0

ZONE NUMBER 1 LOC IN REG NO 1 MAP INDEX NO 1 PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.4	6.1
EST. OF N	1.000	.800	1.500
A	3.750	3.600	3.900
B	-1.000	-1.200	-.600

ZONE NUMBER 2 LOC IN REG NO 1 MAP INDEX NO 2 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.4	6.1
EST. OF N	1.300	1.000	1.600
A	3.400	3.300	3.500
B	-.900	-1.200	-.700

A-145

ZONE NUMBER 3 LOC IN REG NO 1 MAP INDEX NO 3 PROB. OF EXISTENCE= 0.95
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 7.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.7	7.4
EST. OF N	1.200	1.000	1.600
A	2.300	2.200	2.400
B	-.600	-.800	-.500

ZONE NUMBER 4 LOC IN REG NO 1 MAP INDEX NO 4 PROB. OF EXISTENCE= 0.5
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.2	7.0
EST. OF N	.100	.020	.150
A	2.000	1.800	2.700
B	-.800	-1.300	-.600

*********** SEISM ITY DATA FOR EXPERT 11

TABLE A3

ZONE NUMBER 5 LOC IN REG NO 2 MAP INDEX NO 5 PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.2	7.0
EST. OF N	.900	.500	1.500
A	3.700	3.600	3.900
B	-1.000	-1.300	-.800

ZONE NUMBER 6 LOC IN REG NO 2 MAP INDEX NO 6A PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.2	7.0
EST. OF N	1.800	.600	3.000
A	4.000	3.500	4.200
B	-1.000	-1.300	-.800

ZONE NUMBER 7 LOC IN REG NO 2 MAP INDEX NO 6B PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.2	7.0
EST. OF N	.100	.020	.150
A	2.750	2.000	2.900
B	-1.000	-1.300	-.800

ZONE NUMBER 8 LOC IN REG NO 2 MAP INDEX NO 7A PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.4	6.1
EST. OF N	1.000	.600	1.600
A	3.750	3.500	3.950
B	-1.000	-1.200	-.800

*********** SEISMICITY DATA FOR EXPERT 11

TABLE A3

ZONE NUMBER 9 LOC IN REG NO 2 MAP INDEX NO 7B PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.4	6.1
EST. OF N	.050	.010	.100
A	2.500	1.800	2.800
B	-1.000	-1.200	-.800

ZONE NUMBER 10 LOC IN REG NO 2 MAP INDEX NO 8 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 7.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.7	7.4
EST. OF N	.450	.300	.800
A	2.250	2.050	2.500
B	-.700	-1.200	-.500

ZONE NUMBER 11 LOC IN REG NO 3 MAP INDEX NO 9 PROB. OF EXISTENCE= 0.7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	6.8
EST. OF N	.800	.400	1.600
A	3.650	3.350	3.950
B	-1.000	-1.200	-.700

ZONE NUMBER 12 LOC IN REG NO 3 MAP INDEX NO 10 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	6.8
EST. OF N	1.600	1.200	2.600
A	3.600	3.400	3.800
B	-.900	-1.200	-.800

*********** SEISMICITY DATA FOR EXPERT 11

TABLE A3

ZONE NUMBER 13 LOC IN REG NO 4 MAP INDEX NO 11 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 7.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.7	7.4
EST. OF N	.500	.300	.900
A	2.700	2.400	3.000
B	-.800	-1.000	-.400

ZONE NUMBER 14 LOC IN REG NO 2 MAP INDEX NO 12 PROB. OF EXISTENCE= 0.95
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.4	6.1
EST. OF N	.150	.100	.200
A	2.900	2.700	3.100
B	-1.000	-1.300	-.800

ZONE NUMBER 15 LOC IN REG NO 2 MAP INDEX NO 13 PROB. OF EXISTENCE= 0.7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.4	6.1
EST. OF N	.100	.020	.200
A	2.000	1.300	2.300
B	-.800	-1.300	-.600

ZONE NUMBER 16 LOC IN REG NO 4 MAP INDEX NO 14 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.4	6.1
EST. OF N	.700	.300	1.000
A	4.370	4.000	4.500
B	-1.200	-1.400	-.900

*********** SEISMICITY DATA FOR EXPERT 11

TABLE A3

ZONE NUMBER 17 LOC IN REG NO 4 MAP INDEX NO 15 PROB. OF EXISTENCE= 0.95
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.2	7.0
EST. OF N	.400	.300	.600
A	2.600	2.500	2.750
B	-.800	-1.100	-.500

ZONE NUMBER 18 LOC IN REG NO 4 MAP INDEX NO 16 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.4	6.1
EST. OF N	.400	.250	.700
A	3.350	3.150	3.600
B	-1.000	-1.200	-.800

ZONE NUMBER 19 LOC IN REG NO 3 MAP INDEX NO 17 PROB. OF EXISTENCE= 0.7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.4	6.1
EST. OF N	.700	.200	1.200
A	3.600	3.000	3.850
B	-1.000	-1.100	-.900

ZONE NUMBER 20 LOC IN REG NO 3 MAP INDEX NO 18 PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.4	6.1
EST. OF N	.400	.300	.600
A	3.350	3.200	3.500
B	-1.000	-1.200	-.700

*********** SEISMICITY DATA FOR EXPERT 11

TABLE A3

ZONE NUMBER 21 LOC IN REG NO 3 MAP INDEX NO 19-C.Z. PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE C/ (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	5.5	6.3
EST. OF N	7.500	5.000	10.000
A	4.250	4.050	4.450
B	-.900	-1.000	-.800

TABLE A3

SEISMICITY DATA FOR EXPERT 12 NO. OF ZONES= 21 SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 7.5 7.5 8.5 8.5

ZONE NUMBER 1 LOC IN REG NO 3 MAP INDEX NO 1-C.Z. PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.0	4.8	5.3
EST. OF N	4.630	2.550	4.730
A	5.311	4.601	5.851
B	-1.280	-1.400	-1.150

ZONE NUMBER 2 LOC IN REG NO 2 MAP INDEX NO 2 PROB. OF EXISTENCE= 0.85
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.8	6.3	5.7
EST. OF N	1.570	1.210	1.670
A	3.636	3.116	4.116
B	-.950	-1.050	-.850

ZONE NUMBER 3 LOC IN REG NO 1 MAP INDEX NO 3 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.25 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.7	5.6	5.8
EST. OF N	4.440	1.650	4.540
A	3.614	3.044	4.044
B	-.960	-1.050	-.850

ZONE NUMBER 4 LOC IN REG NO 2 MAP INDEX NO 4 PROB. OF EXISTENCE= 0.85
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.0	4.7	5.3
EST. OF N	.520	.420	.620
A	2.763	2.143	3.793
B	-.800	-.950	-.700

*********** SEISMICITY DATA FOR EXPERT 12

TABLE A3

ZONE NUMBER 5 LOC IN REG NO 2 MAP INDEX NO 5 PROB. OF EXISTENCE= 0.85
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 5.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.0	4.8	5.2
EST. OF N	.360	.250	.460
A	2.388	1.848	3.498
B	-.800	-.950	-.700

ZONE NUMBER 6 LOC IN REG NO 2 MAP INDEX NO 6 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.00 4.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.0	4.8	5.1
EST. OF N	1.050	.580	1.150
A	1.701	1.541	2.931
B	-.640	-.950	-.600

ZONE NUMBER 7 LOC IN REG NO 3 MAP INDEX NO 7 PROB. OF EXISTENCE= 0.65
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.3	5.0	5.8
EST. OF N	.120	.070	.220
A	2.166	1.766	2.366
B	-.900	-.950	-.800

ZONE NUMBER 8 LOC IN REG NO 4 MAP INDEX NO 8 PROB. OF EXISTENCE= 0.98
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 4.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.3
EST. OF N	.210	.100	.310
A	2.586	2.066	3.066
B	-.950	-1.050	-.800

*********** SEISMICITY DATA FOR EXPERT 12

TABLE A3

ZONE NUMBER 9 LOC IN REG NO 3 MAP INDEX NO 9 PROB. OF EXISTENCE= 0.98
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.0	6.3
EST. OF N	.330	.220	.430
A	2.886	2.286	3.286
B	-.950	-1.050	-.800

ZONE NUMBER 10 LOC IN REG NO 3 MAP INDEX NO 10 PROB. OF EXISTENCE= 0.65
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.3	5.0	5.3
EST. OF N	.170	.070	.270
A	2.586	1.986	2.986
B	-.950	-1.050	-.800

ZONE NUMBER 11 LOC IN REG NO 4 MAP INDEX NO 11 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.2	6.5
EST. OF N	1.100	.750	1.200
A	3.571	2.911	4.041
B	-.950	-1.050	-.800

ZONE NUMBER 12 LOC IN REG NO 4 MAP INDEX NO 12 PROB. OF EXISTENCE= 0.98
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.4	7.3	7.5
EST. OF N	1.810	1.030	1.910
A	3.811	3.231	3.981
B	-1.000	-1.050	-.900

*********** SEISMICITY DATA FOR EXPERT 12

TABLE A3

ZONE NUMBER 13 LOC IN REG NO 3 MAP INDEX NO 13 PROB. OF EXISTENCE= 0.65
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.3	5.2	5.5
EST. OF N	.230	.130	.330
A	2.651	2.051	3.051
B	-.950	-1.050	-.800

ZONE NUMBER 14 LOC IN REG NO 2 MAP INDEX NO 14 PROB. OF EXISTENCE= 0.95
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.7	7.2
EST. OF N	.520	.420	.620
A	3.580	3.020	3.700
B	-1.020	-1.050	-.900

ZONE NUMBER 15 LOC IN REG NO 2 MAP INDEX NO 15A PROB. OF EXISTENCE= 0.6
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.6	6.2
EST. OF N	.300	.200	.400
A	2.459	2.159	3.359
B	-.800	-1.050	-.750

ZONE NUMBER 16 LOC IN REG NO 2 MAP INDEX NO 15B PROB. OF EXISTENCE= 0.6
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 4.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.6	6.2
EST. OF N	.070	.020	.170
A	1.629	1.459	2.509
B	-.800	-1.050	-.750

*********** SEISMICITY DATA FOR EXPERT 12

TABLE A3

ZONE NUMBER 17 LOC IN REG NO 1 MAP INDEX NO 16 PROB. OF EXISTENCE= 0.85
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.0	6.8
EST. OF N	.630	.530	.730
A	2.899	2.399	3.399
B	-1.000	-1.100	-.900

ZONE NUMBER 18 LOC IN REG NO 1 MAP INDEX NO 17 PROB. OF EXISTENCE= 0.98
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.50 6.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.2	6.8
EST. OF N	1.600	.880	1.710
A	4.201	3.311	4.311
B	-.950	-1.050	-.850

ZONE NUMBER 19 LOC IN REG NO 1 MAP INDEX NO 18 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.6	7.2
EST. OF N	1.200	.500	1.300
A	2.180	1.670	2.670
B	-.640	-.750	-.550

ZONE NUMBER 20 LOC IN REG NO 3 MAP INDEX NO 19 PROB. OF EXISTENCE= 0.85
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 4.25 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.3	5.0	5.8
EST. OF N	.100	.050	.150
A	2.586	2.186	2.986
B	-.950	-1.050	-.850

*********** SEISMICITY DATA FOR EXPERT 12

TABLE A3

****

ZONE NUMBER 21   LOC IN REG NO 1   MAP INDEX NO 20   PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE   LINEAR RANGE OF   (A-B*M) MODEL IS   4.00   5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.5	5.3	5.8
EST. OF N	1.850	1.260	1.950
A	3.186	2.736	3.736
B	-.840	-.950	-.750

TABLE A3

SEISMICITY DATA FOR EXPERT 13 NO. OF ZONES= 15 SELF WEIGHTS FOR REGIONS 1,2 ,3 &4 ARE 5.0 8.0 6.5 9.0

ZONE NUMBER 1 LOC IN REG NO 4 MAP INDEX NO 1 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.7
EST. OF N	.530	.430	.630
A	4.300	3.400	5.000
B	-1.200	-1.500	-.900

ZONE NUMBER 2 LOC IN REG NO 4 MAP INDEX NO 2 PROB. OF EXISTENCE= 0.4
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 4.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.0	7.3
EST. OF N	.240	.120	.360
A	3.940	2.740	5.140
B	-1.200	-1.200	-1.000

ZONE NUMBER 3 LOC IN REG NO 4 MAP INDEX NO 3 PROB. OF EXISTENCE= 0.8
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.00

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.6
EST. OF N	.450	.350	.550
A	4.600	4.000	5.200
B	-1.300	-1.500	-1.100

ZONE NUMBER 4 LOC IN REG NO 4 MAP INDEX NO 4 PROB. OF EXISTENCE= 0.9
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 4.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.0	7.3
EST. OF N	.460	.230	.690
A	4.220	3.020	5.420
B	-1.200	-1.200	-1.000

*********** SEISMICITY DATA FOR EXPERT 13

TABLE A3

ZONE NUMBER 5 LOC IN REG NO 4 MAP INDEX NO 5 PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 1.60 6.20

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.3	7.1	7.4
EST. OF N	.860	.560	1.330
A	3.270	3.190	3.350
B	-.890	-.930	-.850

ZONE NUMBER 6 LOC IN REG NO 4 MAP INDEX NO 6 PROB. OF EXISTENCE= 0.6
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.50

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.7
EST. OF N	.210	.080	.340
A	2.300	1.800	3.000
B	-.790	-1.000	-.590

ZONE NUMBER 7 LOC IN REG NO 3 MAP INDEX NO 7 PROB. OF EXISTENCE= 0.7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.7
EST. OF N	.190	.060	.320
A	2.500	2.000	3.000
B	-.860	-1.100	-.660

ZONE NUMBER 8 LOC IN REG NO 2 MAP INDEX NO 8 PROB. OF EXISTENCE= 0.85
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.5	6.2	6.7
EST. OF N	.990	.600	1.300
A	3.820	3.400	4.300
B	-1.020	-1.170	-.870

*********** SEISMICITY DATA FOR EXPERT 13

TABLE A3

ZONE NUMBER 9 LOC IN REG NO 2 MAP INDEX NO 9 PROB. OF EXISTENCE= 0.7
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.8	6.6	6.9
EST. OF N	.490	.350	.640
A	2.540	2.200	3.600
B	-.760	-.880	-.700

ZONE NUMBER 10 LOC IN REG NO 1 MAP INDEX NO 10 PROB. OF EXISTENCE= 0.6
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	5.9	5.8	6.2
EST. OF N	.440	.300	.600
A	4.000	3.500	4.500
B	-1.160	-1.300	-1.000

ZONE NUMBER 11 LOC IN REG NO 1 MAP INDEX NO 11 PROB. OF EXISTENCE= 0.85
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 5.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.0	5.5	6.3
EST. OF N	.260	.120	.400
A	2.300	2.000	3.200
B	-.760	-.950	-.650

ZONE NUMBER 12 LOC IN REG NO 1 MAP INDEX NO 12 PROB. OF EXISTENCE= 0.85
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.8	6.6	6.9
EST. OF N	.200	.100	.350
A	1.500	1.400	2.500
B	-.580	-.850	-.500

*********** SEISMICITY DATA FOR EXPERT 13

TABLE A3

ZONE NUMBER 13 LOC IN REG NO 2 MAP INDEX NO 13 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.9
EST. OF N	1.220	.400	2.000
A	3.900	3.000	5.000
B	-1.020	-1.220	-.800

ZONE NUMBER 14 LOC IN REG NO 4 MAP INDEX NO 14 PROB. OF EXISTENCE= ALT BDY
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 4.75

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	7.0	6.0	7.3
EST. OF N	.700	.350	1.050
A	4.400	3.200	5.600
B	-1.200	-1.200	-1.000

ZONE NUMBER 15 LOC IN REG NO 3 MAP INDEX NO 15-C.Z. PROB. OF EXISTENCE= 1.0
OCCURRENCE MODEL IN MAGNITUDE LINEAR RANGE OF (A-B*M) MODEL IS 3.75 6.25

PARAMETER	BEST ESTIMATE	LOWER LIMIT	UPPER LIMIT
UP MAG CO	6.3	6.0	6.5
EST. OF N	3.250	2.500	4.500
A	4.600	3.800	5.400
B	-1.090	-1.180	-.990

APPENDIX B

Earthquake Catalogs

The basic information for the seismic data base used in this study was developed for NUREG/CR-1577: An Approach to Seismic Zonation for Siting Nuclear Electric Power Generating Facilities in the Eastern U.S. This catalog is discussed in detail in NUREG/CR-1577. A brief description is provided below along with the changes we have introduced:

1. WES-A catalog of seismic events in the northeastern United States and adjacent areas compiled by Prof. Chiburis of Western Observatory of Boston College, Weston, Massachusetts. The catalog consists of information on 2,567 events which occurred from 1534 through 1977. The areal coverage of the catalog is approximately 38°N to 60°N and 48°W to 81°W.

2. BOL-A catalog of seismic events in the southeastern United States and adjacent areas compiled by Prof. Bollinger of the Virginia Polytechnic Institute and State University at Blacksburg, Virginia. The catalog consists of information on 667 events which occurred from 1698 to 1974. The areal coverage of the catalog is approximately 31.5°N to 39.7°N and 76.2°W to 88.0°W.

3. SEU-A catalog of seismic events in the southeastern United States and adjacent areas published by the Southeast United States Seismic Network and edited by Prof. Bollinger. The catalog consists of information on 33 events which occurred from 1977 to 1978. The areal coverage of the catalog is approximately 32°N to 39.6°N and 78°2W to 89.3°W.

4. SLU-A catalog of seismic events in the central United States and adjacent areas compiled by Prof. Nuttli of Saint Louis University, St. Louis, Missouri. The catalog consists of information on 1,113 events which occurred from 1811 to 1975. The areal coverage of the catalog is approximately 30°N to 48°N and 80°W to 104°W.

5. EQH-A catalog of seismic events in the east and central United States and adjacent areas provided by Mr. Von Hake of the National Geophysical and Solar-Terrestrial Data Center, NOAA, Environmental Data Service in Boulder, Colorado. The catalog is a subset of the input data to the Earthquake History of the United States and consists of 926 events which occurred from 1638 to 1977. The areal coverage of the catalog is approximately 24°N to 50°N and 66°W to 106°W.

6. EUS-A catalog of seismic events in the east and central United States and adjacent areas provided by Mr. Tarr of the United States Geological Survey, Golden, Colorado. The catalog is itself a composite of many of the above catalogs and consists of 2,248 events which occurred from 1534 to 1974. The areal coverage of the catalog is approximately 29°N to 50.2°N and 65.8°W to 96.4°W.

7. To make the data set complete in Canada, we added the Canadian Earthquake Epicenter File to 1980 which covers Canada and adjacent areas of the northern U.S. provided by Dr. Peter Basham and Dr. Anne Stevens of the Department of Energy, Mines and Resources. This catalog is itself a composite of some of the above catalogs as well as Canadian sources such as Earth Physics Branch, Department of EMR, University of British Columbia, etc. Only the Canadian data sources were retained.

The basic data from all of the above catalogs were merged. Because of the space and time overlap between the different catalogs, this resulted in multiple entries for the majority of the earthquakes listed. To edit the catalog, the following criteria were applied.

1. The entry from the local investigator was considered the most reliable and therefore, retained in the listing (e.g., for an event in southern Illinois, the SLU entry was retained while for an event in southern New Hampshire, the WES data were used).

2. In border regions (e.g., between the SLU and BOL areas and SLU an WES areas), the SLU data were accepted.

3. For remaining events, if there was an EQH listing, that data was retained.

4. There was a significant number of events ramaining with a listing in the EUS catalog only. Each of these events was examined separately. If the evidence indicated that the event should have been contained in other catalogs (e.g., an intensity VII in a populated area) and it was not, the earthquake was removed from our composite catalog. This still left a number of EUS events, (usually low intensity) the existence of which could not be confirmed. These events were retained in the catalog.

5. For the northeastern U.S., we adopted the magnitude estimates developed by Street and Lacroix (BESSA, Vol. 69 pp. 159-176) and changed the appropriate entries in the catalog.

DEVELOPMENT OF EASTERN UNITED STATES GROUND MOTION MODELS
LAWRENCE LIVERMORE NATIONAL LABORATORY

1.0 BACKGROUND

We use the term Ground Motion Model to identify the equation used to estimate the ground motion at a particular site as a function of the "magnitude" of seismic energy released by an earthquake, the appropriate distance between the site and the source of energy released, and some factor to account for local site conditions. Typically, the ground motion model takes the functional form:

$$\ln(GMP) = C_1 + C_2 E + C_3 A(R) + C_4 S + (\text{Error term}) \qquad (1\text{-}1)$$

where GMP = ground motion parameter of interest; e.g., PGA or PGV
C_i = constants
E = measure of seismic energy release - usually some magnitude measure or epicentral intensity.
R = appropriate distance measure
A(R) = attenuation term - typically $A(R) = \ln R - C_5 R$
S = site factor term, e.g., S = 0 soil
= 1 rock

The error term accounts for the fact that the ground motion at a site due to a specific earthquake is a random variable, being affected by many more parameters than can be represented in a mathematical model such as Eq. (1-1). For example, the ground motion generating potential of an earthquake may be governed by dynamic stress drop and the area of release of energy in addition to the earthquake magnitude. Furthermore, ground motion is likely to be affected by the radiation pattern as well as "fine" details of the local site geologic column. Thus, the model in Eq. (1-1), less the error term, is intended to represent the "expected" or average ground motion at a site and the error term accounts for the random variation about that average value attributable to specific earthquakes.

In addition to the inherent random variation in ground motion about the average value, another source of uncertainty associated with ground motion models is attributable to the choice of parameters included in the model and the data base used to estimate the values of the coefficients $C_1, \ldots C_4$ in Eq. (1-1). These uncertainties, which we call modeling uncertainties, contribute to the uncertainty associated with the hazard analysis methodology. Modeling uncertainties are discussed in more detail in Section 2.4.

The ground motion model and the associated magnitude of the random variation have a direct effect on the hazard analysis. The estimates of the probability of exceedance are strongly correlated with the ground motion model. Changes in the model significantly affect the estimates of the hazard at a site. Thus, it is important that we select the most appropriate ground motion models for use in the hazard analysis.

The development of a ground motion model for the Eastern United States (EUS) is a difficult task for several reasons:

- o There are few data on strong ground motion from EUS earthquakes.
- o It is generally agreed that one cannot make direct use of a ground motion model developed from the Western United States (WUS), as data from a number of different sources indicate that the attenuation of seismic energy in the EUS is much different from that in the WUS.
- o Recent work by Nuttli (1983b) suggests that the seismic source spectrum scales differently for EUS earthquakes than for WUS earthquakes.

In spite of these difficulties, given the paucity of strong ground motion data in the EUS, it is necessary to make use of WUS ground motion data and models and make corrections for the known differences between the WUS and EUS. The ground motion parameters (GMP) chosen for this analysis are the horizontal components of peak ground acceleration (PGA), peak ground velocity (PGV), and several spectral ordinates (SA) at frequencies ranging from 0.5 to 25 Hz.

In our earlier program for the Systematic Evaluation Program (SEP) we took what might be termed a "best estimate" approach; i.e., for a given site we developed a single best estimate hazard curve for each expert of the EUS Seismicity Panel. In keeping with this approach we only sought a best estimate model from our first EUS Ground Motion Panel. We did not achieve this objective and in the end we handled the ground motion model in an ad hoc fashion, primarily relying on sensitivity studies to demonstrate differences between models.

In our current effort, one of our objectives is to incorporate the improvements suggested by our reviewers into our overall approach. Two of the main areas for improvement are in the treatment of uncertainty and the manner in which the ground motion model is treated. This time we are concerned not only with a best estimate hazard curve but a detailed study of the uncertainty in the estimate of the hazard. We also want our results to be suitable for use in performing probabilistic risk assessments (PRA). Suitable input for a PRA requires a complete specification of the uncertainty in the hazard curve.

To achieve these objectives, it is necessary to put the current EUS Ground Motion Model Panel on the same footing as the EUS Seismicity Panel. This requires the identification and weighting of all ground motion models for the EUS which the Panel members deem sufficiently reliable to be included in the analysis.

Because it is possible to develop a large number of different models, we have attempted to provide in this report a framework for selecting from all possible models those which we feel are sufficiently reliable or credible to be used in the hazard analysis. To assist us in choosing the most appropriate models we ask the panel (see questionnaire, Section 7) to provide several pieces of information. For the short term, we ask you to select from seven categories of already existing models the best model in each category and to provide your relative degree of belief in each. We also ask you to select from all the models the one which, in your opinion, provides the best overall estimates for the EUS. (Note: These models can change regionally.) For the long term, if in your opinion some new model could be developed or existing models improved by some additonal work, we ask you to provide a prescription of how to develop your "best estimate model" (or models if several are almost equally likely in your judgment). We may also have overlooked some models that you feel should be included. These should be added. In the feedback phase we will ask you to provide weights for all models. We will also address how best to deal with local site effects. Initially, we had planned to address this issue in this document, however, it would appear best to delay it until after the USGS workshop in July.

When making selections there are several considerations regarding how the models will be used that may affect choice and ranking of the various ground motion models. The first consideration is the choice of strong-motion components. Since our study is concerned with the horizontal components of ground motion, we have excluded any models based on the vertical component. In fact, there are very few such models available. Because there are two horizontal components, one must decide how they are to be used in the analysis. Models can be developed using the maximum or minimum component, the mean of the two components, the vector combination of components, or both components. In our analyses we will be using the mean of the parameters established from the two horizontal components . Since it is relatively simple to relate predictions based on other definitions to estimates of the mean, the particular definition used should not affect your choice or ranking of models. However, your choice of the value of uncertainty to be associated with these predictions should take this into consideration. The use of the mean of the two horizontal components has been found to result in a smaller standard error than the use of either the maximum component or both components.

The second consideration is the definition of the source-to-site distance. The way the hazard analysis is performed, earthquakes are essentially modeled as point sources at the surface of the earth. This is consistent with the definition of epicentral distance. Therefore, ground motion models utilizing epicentral distance as the measure of source-to-site distance are the most appropriate models to be used with the hazard code. A problem arises when a ground motion model uses a distance measure other than epicentral distance. Three such models, two by Campbell (1981b, 1982) and one modified from Joyner and Boore (1981), referred to as the SSMRP model, are offered for your consideration. Their use of closest distance to the fault rather than epicentral distance has substantially reduced the standard errors associated with these models. While this suggests that models based on fault distance are better predictors of strong ground motion than epicentral models, one must consider their use before making such a decision. For example, such models, when used with a hazard analysis based on epicentral distance, will tend to underestimate the ground motion expected at the site for distances close to the source (see Appendices C-B and C-C for a more complete discussion). This should be kept in mind when selecting and ranking the various ground motion models and when specifying an appropriate value for the uncertainty to use in the analyses. If the panel members feel the use of epicentral sources in the hazard code is a severe limitation to their selection of the best models, they are asked to indicate this in the questionnaire.

The last consideration is in regards to the strong-motion parameter to be used. The parameter of interest for our study is pseudo-relative velocity representing frequencies of 0.5 to 25 Hz (periods of 0.04 to 2 sec.). However, there are very few EUS ground motion models available that predict this parameter directly. The current state-of-practice is to develop response spectra from peak acceleration and/or peak velocity and standard spectral shapes. For this reason, we require ground motion models based on peak acceleration and peak velocity. Because there are fewer velocity models than acceleration models, the unavailability of certain models may also affect your choice of the "best model" in a particular category. Each of these parameters will be ranked separately. Several factors will have to be considered when selecting and ranking spectral models. One factor is whether the model is based on a regression of individual ordinates or based on a spectral shape. A second factor is the relative appropriateness of the various spectral shape models. Another factor is whether the spectral shape model requires estimates of both peak acceleration and peak velocity and whether both are available.

In Section 2 we describe the framework we have selected to categorize the different ground motion models. In Section 3 we provide a generic evaluation of the different categories defined in Section 2. In Section 4 we provide specific examples and comparisons between the acceleration models. In Section 5 we discuss velocity and spectral models. In Section 6 we discuss the available EUS strong-motion data. Section 7 contains the questionnaire.

2.0 INFERRING EASTERN U.S. GROUND MOTION

There are at least three general approaches that could be used to develop EUS ground motion models:

1. Those that use site intensity as an intermediate variable (I),

2. Those that use ground motion measurements directly (D), and

3. Theoretical modeling (T).

2.1 Intensity Based Models

This category includes all models developed in a formal manner by combining a MM intensity-attenuation relation, such as

$$I_s = C_1 + C_2 I_o + C_3 \ln R + C_4 R \qquad (2\text{-}1)$$

with a relation between site intensity (I_s) and various ground motion parameters (e.g., PGA), to get a relation between GMP, source size and distance.

For each intensity-attenuation relation there are a number of different ways that the relation between site intensity and ground motion parameters can be developed and combined with the intensity-attenuation relation. To organize our discussion we will sort all such approaches into one of five basic methods:

(I-1) No weighting
(I-2) Distance weighting
(I-3) Magnitude weighting
(I-4) Magnitude and distance weighting
(I-5) Semi-empirical

The following discussion will briefly describe each of these approaches and the basic assumptions required for each. We will also attempt to describe the inferences involved in these assumptions regarding the prediction of ground motion in the EUS. The reader may then compare these inferences regarding EUS ground motion with what he believes to be the true conditions prevailing in the EUS to help him decide which models are more appropriate.

Method I-1 (No Weighting). This method simply relates site intensity to ground acceleration, ground velocity, and/or the response spectrum, as obtained from existing strong ground motion records. Thus,

$$\begin{aligned} I_s &= F(I_o,R) && \text{based on EUS data} \\ GMP &= G(I_s) && \text{based on WUS data} \end{aligned} \qquad (2\text{-}2)$$

This method assumes that ground motions are the same for the same site intensity in both regions, regardless of the size or distance associated with this intensity. Thus, differences in the attenuation of I_s between the two regions (i.e., differences in the relation $I_s = F(I_o,R)$) require that predictions of GMP in the EUS for fixed I_s be associated with predictions in the WUS based on data obtained at shorter distances or from larger magnitudes. This will result in ground motion models for the EUS that predict higher amplitudes than similar models in the WUS for similar magnitudes and distances. Because this approach results in predictions in the EUS that represent WUS data of higher magnitudes or shorter distances, inferences regarding the effect of this approach on spectral shape and duration of strong ground motion in the EUS are not clear. While higher magnitude data will be associated with longer durations and relatively higher low frequency content, data obtained at shorter distances will be associated with shorter durations and relatively greater high frequency content. This would imply that on the average predictions of GMP in the EUS will probably be associated with ground motions of about the same duration and spectral content as those in the WUS.

Method I-2 (Distance Weighting). This method relates the ground motion parameter to site intensity and distance, assuming that the ground motions are the same for a similar site intensity and distance in the two regions. Thus,

$$I_s = F(I_o,R) \quad \text{based on EUS data} \qquad (2\text{-}3)$$
$$GMP = G(I_s, R) \quad \text{based on WUS data}$$

This method, which can be called "distance weighting," requires that predictions of GMP in the EUS for fixed I_s and R be associated with predictions in the WUS based on data obtained from larger magnitude earthquakes in order to accommodate differences in the attenuation of I_s between the two regions. This will result in ground motion models for the EUS that predict higher amplitudes than similar models in the WUS for similar magnitudes and distances. Because this approach results in predictions in the EUS that represent WUS data of similar distances but higher magnitudes, we may infer that EUS predictions will be associated with ground motions having longer durations, greater low frequency content, and about the same amount of dispersion as WUS predictions at the same magnitude and distance. The enhanced low frequency content will result in a "broader" predicted response spectrum in the EUS.

Method I-3 (Magnitude Weighting). This method relates the ground motion parameter to site intensity and magnitude, assuming that the ground motions are the same for a similar site intensity and magnitude in the two regions. Thus,

$$I_s = F(I_o,R) \quad \text{based on EUS data} \qquad (2\text{-}4)$$
$$GMP = G(I_s, M) \quad \text{based on WUS data}$$

This method, which we refer to as "magnitude weighting," requires that predictions of GMP in the EUS for fixed I_s and M be associated with predictions in the WUS based on data obtained at shorter distances in order to accommodate differences in the attenuation of I_s between the two regions. This will result in ground motion models for the EUS that predict higher amplitudes than similar models in the WUS for similar magnitudes and distances. Because this approach results in predictions in the EUS that represent WUS data of similar magnitudes but shorter distances, we may infer that EUS predictions will be associated with ground motions having shorter durations, greater high frequency content, and less dispersion than WUS predictions at the same magnitude and distance. The enhanced high frequency content will result in a "narrower" predicted response spectrum in the EUS.

Method I-4 (Magnitude and Distance Weighting). This method relates the ground motion parameter to site intensity, magnitude and distance. Thus,

$$I_s = F(I_o, R) \quad \text{based on EUS data} \qquad (2\text{-}5)$$
$$GMP = G(I_s, M, R) \quad \text{based on WUS data}$$

This method requires the assumption that the ground motions are identical for the same I_s, M, and R in the WUS and EUS. Thus, in order to accommodate differences in intensity attenuation between the two regions, predictions of GMP in the EUS will be associated with WUS data exhibiting higher than average site intensities for a given magnitude and distance. These data will tend to be associated with relatively rare properties of the source, path or site that result in higher than normal amounts of damage. This will result in ground motion models for the EUS that predict higher amplitudes than similar models in the WUS for similar magnitudes and distances. This method infers that EUS predictions will be associated with ground motions of either higher amplitudes, longer durations, enhanced frequency content, or some combination of these as compared to WUS predictions. Because this approach results in predictions in the EUS that represent WUS data at similar distances, they will represent ground motions having similar dispersion characteristics.

Method I-5 (Semi-Empirical). All of the above methods are based on a formal substitution of the results of a regression analysis between the GMP and site intensity (using WUS data) into a relation between site intensity, epicentral intensity and distance (EUS data) to get a relation between GMP, epicentral intensity and distance for the EUS. There are alternative approaches; e.g., Nuttli and Herrmann (1978) used Method I-4 but included a free parameter which they evaluted using judgment and some EUS ground motion data. Battis (1981) assumed that the ground motion in the epicentral region would be similar in all regions for earthquakes of the same epicentral intensity, and that PGA at the limit of the felt area is equal to 6 cm/sec^2.

2.2 Direct Models

Under this category we include all the approaches that derive ground motion models directly from the data without the use of site intensity as an intermediate variable. For the WUS, typical models of this class are those developed by Joyner and Boore (1981) and Campbell (1981a). Unfortunately, for the EUS there isn't sufficient data to perform such regression analyses. Thus, for the time being, one must resort to a semi-empirical approach to arrive at a model for the EUS.

There are many possible ways of developing semi-empirical models. For ease of discussion we separate them up into two major subcategories, D-1 and D-2. Category D-1 includes all those models where it is assumed that the ground motion "near" the source of energy release is the same in the EUS and WUS, and that at larger distances the differences in the ground motion between the two regions is due solely to differences in anelastic attenuation. Nuttli (1979) and Campbell (1981b) have developed models based on this assumption.

Category D-2 includes those semi-empirical models for which it is assumed that, in addition to differences in anelastic attenuation between the EUS and WUS, the ground motion scales differently in the EUS than in the WUS with source size (i.e., the basic source parameters of the earthquake are on the average different between the two regions). Nuttli's most recent models (Appendix A) fall into this category.

2.3 Theoretical Models

This category includes the approaches that rely on numerical modeling techniques, making use of some simple or complex theoretical model to compute the ground motion at a site. Examples of models in this category are: Herrmann and Goertz (1981), Savy (1979, 1981), and Apsel et al. (1982). This is a very large category which undoubtedly would have a number of subcategories. However, at this time it does not appear to us that any of the methods or results are sufficiently advanced to use in the type of hazard analysis required for this project. Although such methods show promise, they are not yet advanced to a state that one can use them without excessive computation costs. In addition, in view of the lack of correlation between earthquakes and known tectonic structures in the EUS, it is not possible to develop with any degree of accuracy the necessary source parameters for such models. Thus, in what follows, very little will be said about theoretical models and such models will not be included unless specifically proposed by one of the Panel members.

2.4 Modeling Uncertainties

Given an earthquake of magnitude M and distance R from a site, the ground motion model represents a statistical description of the ground motion at a site. In the case of an earthquake, the actual motion of the site is not likely to be exactly as predicted by the model. Although there are several reasons for this, they can be summarized as follows:

- o The model is only a mathematical representation of the physical world which cannot capture all of the details of reality. It is unlikely that all relevant parameters have been included in the model. Furthermore, the values of the coefficients in the model are based on a limited sample of earthquakes. Thus, for a specific earthquake, the model cannot be expected to predict the exact ground motion value. Since for the EUS the coefficients are determined by use of data from other regions and/or theoretical or semi-empirical considerations, there is an added degree of uncertainty in modeling EUS ground motions.

o Even if the mathematical model was an exact representation of ground motion characteristics, it only represents an average or expected motion at a site for a specified magnitude and distance. Due to random variations in source, path, and site characteristics, it cannot predict the actual ground motion for a specific earthquake.

Both types of variation contribute to the uncertainty in predicting the ground motion for a specific earthquake. We believe it is important to distinguish between these uncertainties which we label modeling and random. The latter variation is, of course, the inherent random variation that occurs in the physical world. In the hazard analysis this type of variation is recognized by assuming that the ground motion has a distribution about the predicted value. We describe this distribution, in our hazard analysis, by a lognormal distribution, the median of which is estimated by the ground motion model. A complete specification of the distribution requires some measure of the variation in the ground motion parameter about its median value. A convenient way of expressing this variation is in terms of the standard deviation of the natural logarithm of the GMP. However, data necessary to assess this variation (i.e., ground motion data at the same location from several earthquakes of similar magnitude and distance from the site) are not available for the EUS. Thus, it is necessary to elicit expert opinion about this variation. The former variation is what we call modeling uncertainty. It arises because we have very limited data sets and an imperfect understanding of the functional form and parameterization of the ground motion model. This uncertainty will be included by the use of several ground motion models together with subjective weights assigned by panel members.

3.0 EVALUATION OF APPROACHES

3.1 General Discussion

Of the many possible models that can be developed, which one is "best"? The absence of actual data makes it impossible to give an unqualified answer. Thus, we must rely on expert judgment to help us select the best models.

At least three major factors must be considered when developing an EUS ground motion model. These three factors represent differences between the EUS and WUS relative to:

1. Regional attenuation of strong ground motion,
2. Scaling of ground motion with earthquake magnitude, and
3. The variability in ground motion between earthquakes of the same magnitude introduced by source, path and site effects.

The selection and ranking of ground motion models from those available should be based in part on an assessment as to how well they account for the above items. For example, all of the general approaches outlined above include differences in regional attenuation but in different ways. The approaches which use intensity data make the assumption that strong ground motion in the EUS attenuates at a rate proportional to that of intensity, this proportion being the same as that in the WUS. The semi-empirical approaches generally introduce a correction based on regional measurements of the attenuation of low energy seismic waves.

Evaluation of the general approaches outlined above is difficult because it is possible to develop many specific models for each class. However, there are some general comments that can be made which may be of use in comparing one model to another.

3.2 Intensity Based Models

We noted that there were at least five possible methods which use intensity to make estimates of the ground motion. However, in general, there seems to be no method free of theoretical deficiencies for using intensity data from the WUS to estimate ground motion in the EUS. One problem is that, in estimating one random variable (z) from another (x), introduction of a third random variable (y), used as an intermediary, results in both a bias in the mean estimate of z and a larger modeling uncertainty in estimating z than would be the case if z were to be estimated directly from x. In the case of estimating ground motion, the procedure of estimating site intensity from epicentral intensity, then estimating ground motion amplitudes from site intensity, results in amplitudes that are less dependent on earthquake size and distance than would be the case if ground motion were to be estimated directly. Such procedures can work well if there is a strong correlation between the variables. Such does not appear to be the case. This is not surprising as the intensity scale was not developed with such correlations in mind.

Inclusion of a distance or magnitude term in the correlations of GMP to site intensity (I_s),

$$GMP = G(I_s, R) \quad (3\text{-}1)$$

or

$$GMP = G(I_s, M) \ , \quad (3\text{-}2)$$

tends to increase the dependence of GMP on M and R (i.e. it affects the relationships in the correct manner), making such correlations appear to be better than relationships of the type GMP = $G(I_s)$. However, inclusion of M or R does not ensure that unbiased estimates will be made. In fact no intermediary parameter can do that, unless it is perfectly correlated with the first parameter (in this case I_s) or with the last (GMP).

For the intensity based approaches, regional scaling of ground motion with earthquake magnitude is primarily accounted for by the way site intensity at some distance R scales with epicentral intensity, the regional relation between epicentral intensity and magnitude, and, as discussed in Section 4 (see Eq 4-19), how the various GMPs are related to site intensity. This last factor (I_s GMP relation) is of concern because it is obtained from data in the WUS. The magnitude weighting approach introduces a secondary correction for magnitude scaling; however as discussed in Bernreuter (1981), this additional weighting is not introduced to account for regional differences in scaling of ground motion with magnitude, but rather help account for regional differences in attenuation and the fact that the same intensity occurs at much greater distances for large earthquakes as compared to smaller earthquakes. Battis (1981) argued that making the assumption that ground motion was the same in different regions at the same epicentral intensity allows for a regional correction for scaling with magnitude to be introduced through the relation between magnitude and epicentral intensity.

3.3 Direct Models

The most reliable ground motion model to use in a seismic hazard analysis, at least at this time, would be one obtained by direct regression on the data. For such results to be valid, one needs sufficient data from a number of earthquakes to be able to obtain reliable estimates for the coefficients of the model. Such data are not currently available in the EUS, requiring a semi-empirical approach to develop such models.

Semi-empirical models D-1 and D-2 are difficult to assess as a group because many diverse assumptions can be made. Many of the semi-empirical models introduce a correction for regional attenuation based on regional measurements of the attenuation of low energy seismic waves. In general, such models have a higher rate of attenuation at larger distances than the intensity based models. Most such models rely heavily on strong motion data from WUS earthquakes.

One key element in our classification is the question of the differences in average source parameters between EUS and WUS earthquakes and the implication this has on ground motion. The basis for such differences is discussed by Nuttli (1983a b). The impact of these hypothesized differences lies in the way GMP scales with magnitude. Semi empirical approaches in category D 2 introduce a regional correction for scaling of ground motion with magnitude. These corrections are generally based on theoretical considerations.

3.4 Other Factors

For several of the proposed categories we need to know the magnitudes of the earthquakes in the EUS and WUS on a scale which allows them to be directly compared at frequencies of 1 Hz and greater. The m_b scale appears to be well suited for this, but there are problems. First, the M_L scale rather than the m_b scale is commonly used for WUS earthquakes. Furthermore, m_b values for WUS earthquakes, as determined by the USGS, are often unreliable because they are usually based on P-wave amplitudes at distances of less than 2500 km. At these short distances two problems must be faced: the large variation of P-wave amplitude due to variations in upper-mantle structure and the known difficulties with the Gutenberg-Richter calibration function. (The latter problem can be reduced by using the Veith-Clawson calibration function used by DARPA.) For the larger WUS earthquakes ($m_b > 5.5$), there are sufficient P-wave observations at distances greater than 2500 km to overcome these problems. But some seismologists who have studied the amplitudes of P waves from underground nuclear explosions at the Nevada Test Site conclude that anomalous upper-mantle structure causes m_b values for WUS events to be underestimated by about 0.3 m_b units. Using such data, Chung and Bernreuter (1981) and Herrmann and Nuttli (1982) conclude that the two scales (m_b in the EUS and M_L in the WUS) are approximately equivalent in the M_L=5 range. Using standard measurements, an M_L of about 5.0 for a WUS earthquake would be comparable to an m_b of about 4.6 for an EUS earthquake.

In addition to the corrections for differences in regional attenuation and magnitude scaling, there may be a need to correct for possible regional differences in the variability in ground motion between earthquakes of the same magnitude. This random variability arises due to differences in the rupture process, complexity of the travel path, and local site geology. For example, there is some evidence that earthquakes of the same magnitude are more similar in mid-plate areas, such as the EUS, than along plate margins. If this is true, we would expect to see less source induced random variability in the ground motion in the EUS than in the WUS. In addition, the travel path is certainly less complex in the EUS than along plate margins which would also lead to less variability. For this study the variability in the estimate of the ground motion for a given magnitude and distance is generally measured by the standard deviation of the natural logarithm of the parameter, σ_{lnGMP}. Thus, for the EUS ground motion model we might expect contributions of source and propagation path variability on σ_{lnGMP} to be smaller than for the WUS. However, there are not sufficient data in the EUS to evaluate such an hypothesis.

The value of σ_{lnGMP} is a measure of the total uncertainty including the fact that the data used to develop the ground motion model was obtained from a number of different sites with very different site geology. There have been only a few studies which have attempted to sort out the relative contribution to the variability in the ground motion from these factors (Bernreuter, 1979, McCann and Boore, 1982). At this stage we are only addressing standard "rock" and "soil" sites. Nevertheless, it should be kept in mind that, in general, near-surface rock is more competent (e.g., higher V_s, V_p, ρ) in the EUS than in the WUS. Also the soils in many areas of the EUS are significantly different (e.g., Glacial Deposits) than those at sites that make up the existing strong motion data base. These factors need to be kept in mind when providing estimates for σ_{lnGMP} in the question- naire. As noted in the introduction, we will address shallow soil sites and other anomalous site conditions as special cases.

4.0 REVIEW OF ACCELERATION MODELS

4.1 Intensity Based Models

Intensity Attenuation Relations

Development of an intensity attenuation model requires a relation of the form,

$$I_s = F(I_o \text{ or } M, R) \quad (4\text{-}1)$$

The first consideration in the development of such a relation is whether $F(I_o,R)$ is to be derived from intensity data of a single well recorded earthquake, assuming all earthquakes of intensity I_o are the same, or from more limited data of several earthquakes. If one uses a single well recorded event, questions arise as to the appropriateness of the data in representing the attenuation characteristics of other earthquakes and how to scale the ground motion between earthquakes. If data from a number of earthquakes with sufficient variation in epicentral intensity is used, then these problems are taken care of. Unfortunately, this latter alternative is not viable at present, because even though considerable intensity data exists, very little of it is in a form that can be used to develop the required relations. Only a few studies have been made of individual earthquakes to develop the required equations, and no study that we are aware of has used individual intensity reports from a number of earthquakes to correctly estimate the coefficients of Eq. (4-1). Because of the large variation in intensities, considerable data are required--particularly at the lower intensity levels. Typically, such data are not available.

Because individual intensity data are seldom available, the coefficients of Eq. (4-1) are more commonly computed using an equivalent or average distance for each intensity. This "Equivalent-R" approach is convenient if, in place of intensity reports, one works with isoseismals. Isoseismals are useful because they have been developed for a number of earthquakes, including most of the significant historic earthquakes. Results based on the two approaches can be considerably different as illustrated by Fig. 4-1 taken from a study by Weston Geophysical Corp. as documented in Bernreuter (1981b). The curve labeled 1 was obtained by direct regression on the data for the Ossippee earthquake and the curve labeled 3 was obtained using distances to isoseismals. The triangles represent the individual intensity reports. As can be seen from Fig. 4-1, Eq. (4-1) is poorly constrained by the data.

Figure 4-2 shows the fit of the equation

$$I_s - I_o = C_1 + C_2 \ln R + C_3 R \quad (4\text{-}2)$$

to the individual intensity data from each earthquake listed in Table 4-1. While no one has combined such data from a wide range of earthquakes to develop the required coefficients of Eq. (4-2), several investigators have used isoseismals to develop generic relations. Included in Fig. 4-2 is such a relation developed by Gupta and Nuttli (1976). Since the Gupta-Nuttli relation was based on isoseismal data rather than individual intensity reports, we have reduced the C_1 coefficient by 0.5 intensity units to make it compatible with the other expressions in Fig. 4.2. We will refer to this relation later as the modified Gupta-Nuttli relation.

GMP - Site Intensity Relations

To complete the intensity based ground motion models, one also needs a relation between site intensity and ground motion. As discussed in Section 2, there are several functional forms this relation can take. Also, there are several data sets that can be used. For example, Fig. 4-3 shows the data base developed by Cal Tech and Fig. 4-4 shows the data base developed by Murphy and O'Brien (1977) for NRC. (Note: only the U.S. data are shown in Fig. 4-4.) Each investigator has "customized" his data set. Nevertheless, Figs. 4-3 and 4-4 give an indication of how much data exists and how little data there are to define the relation between the GMP and site intensity at the more important higher intensity levels.

TABLE 4-1
Summary of Earthquakes Used in the Intensity Data Base

Name	Date	Maximum Intensity	Analysis Source
Southern Illinois	11/9/1968	VII	G. A. Bollinger
Ossippee	11/20/1940	VII	R. J. Holt
Giles County	5/31/1897	VII-VIII	G. A. Bollinger
Charleston	8/31/1886	X	B. A. Bollinger

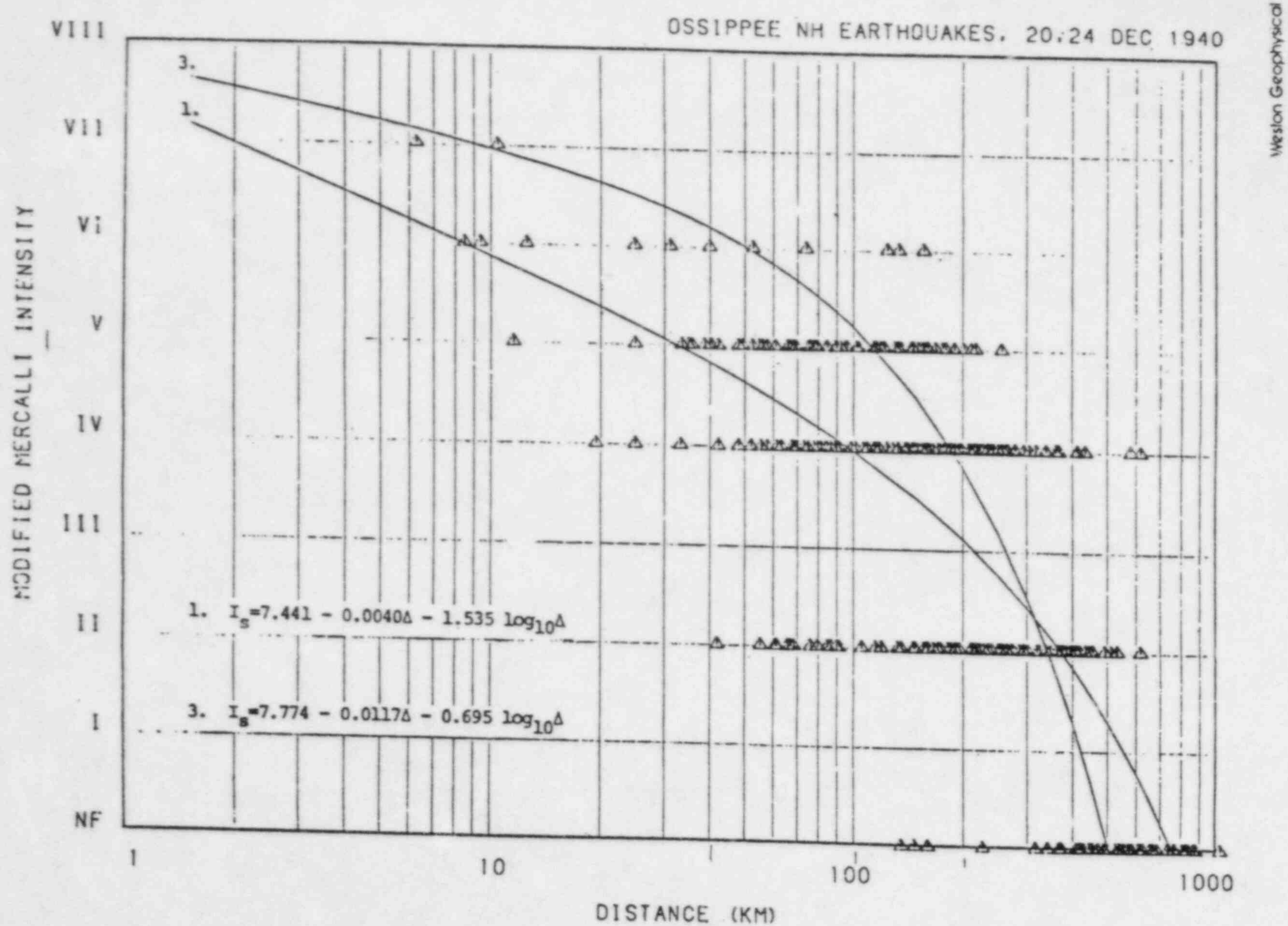


Fig. 4.1 Site intensity versus distance for the Ossippee N.H., earthquake of December 1940. Taken from Weston Geophysical Company

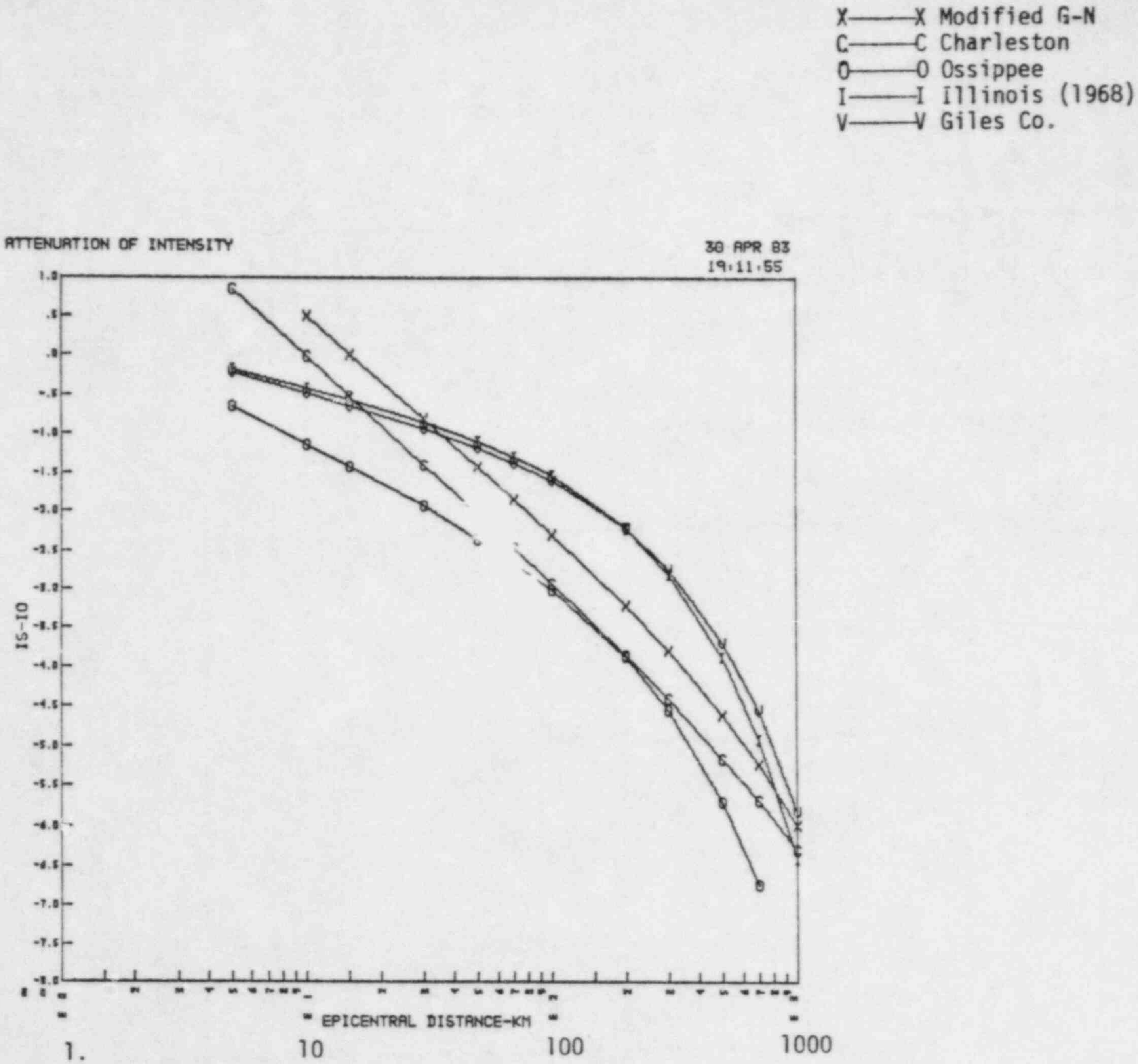


Fig. 4.2 Comparison of the "modified" Gupta-Nuttli relations with available data.

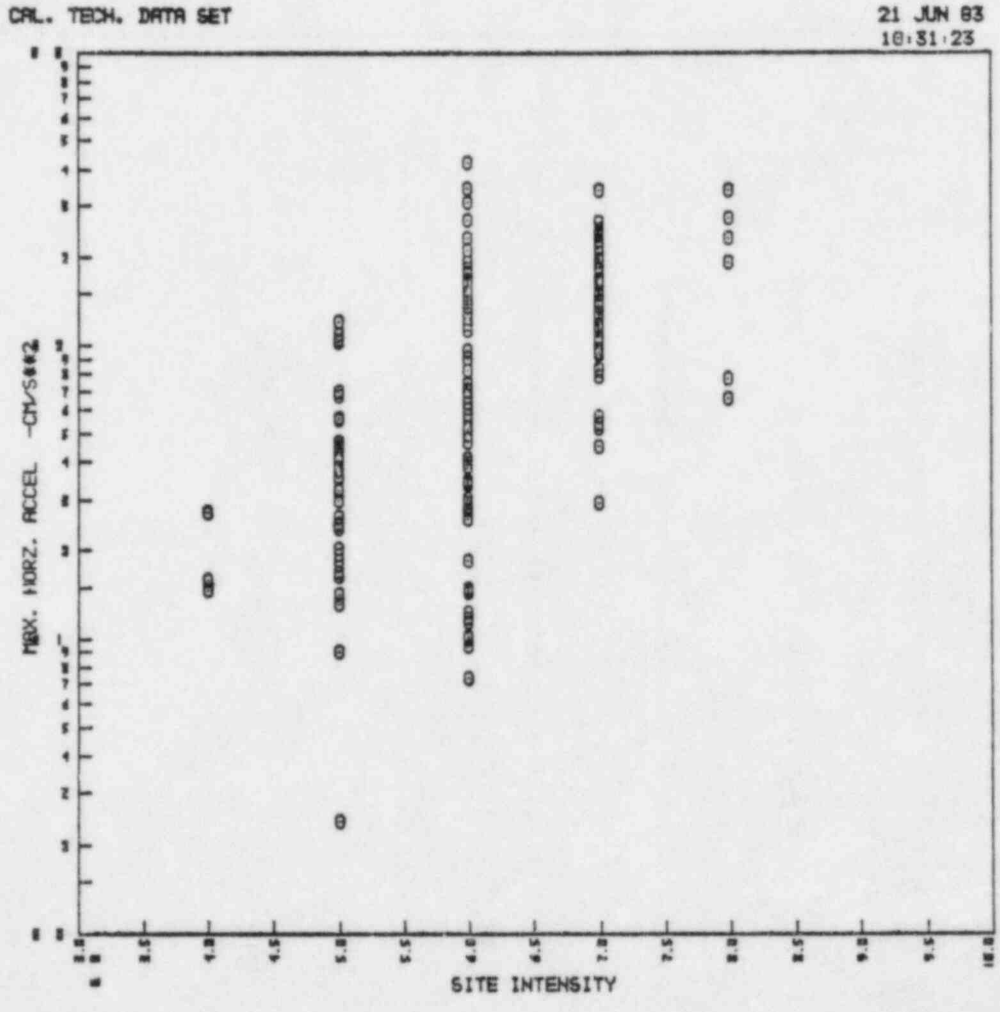


Fig. 4.3 Cal tech data base of acceleration versus site intensity.

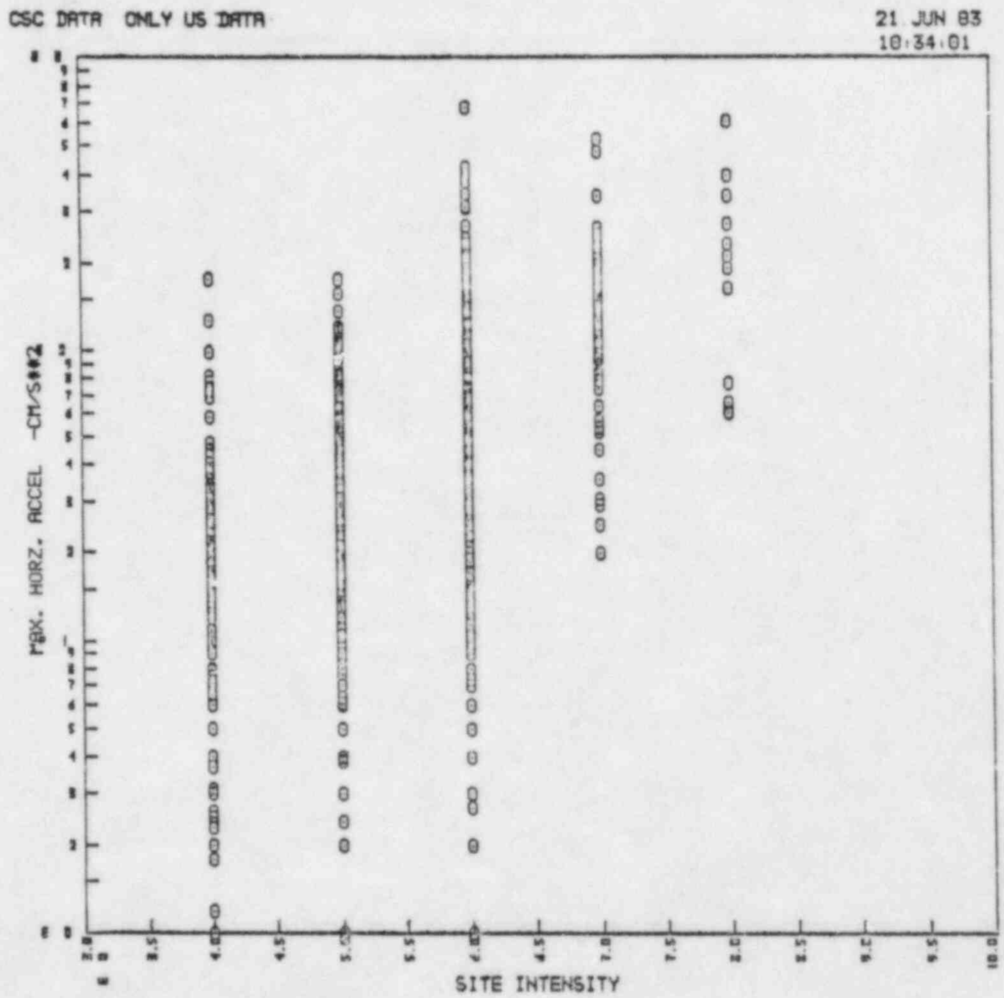


Fig. 4.4 Murphy and O'Brien data base of acceleration versus site intensity.

In addition to different data sets, there are a number of different ways the regression analysis can be performed to obtain estimates of the coefficients of the model. For example, McGuire (1977) found for medium sites

$$\ln(a) = -0.83 + 0.85\ I_s \qquad (4\text{-}3)$$

and Trifunac (1976) found

$$\ln(a) = -0.19 + 0.67\ I_s + 0.33S \qquad (4\text{-}4)$$

McGuire and Trifunac used approximately the same data set, however, the forms of the regression were different. McGuire separated his data into two sets (soft and medium sites) and performed separate regression analyses on each data set. Trifunac introduced a site variable S which has a value of 0, 1, or 2 depending upon the site type (see Sec. 7 for a definition of s). Trifunac and Brady (1975) used the same data set as Trifunac, but performed regression analyses on the logarithm of the mean acceleration for each intensity level, independent of site type. Their resulting expression was

$$\ln(a) = 0.032 + 0.69\ I_s \qquad (4\text{-}5)$$

Murphy and O'Brien (1977) found by using a more extensive data set not segregated by site type

$$\ln(a) = 0.58 + 0.58\ I_s \qquad (4\text{-}6)$$

Murphy and O'Brien used just the peak horizontal component, whereas McGuire, Trifunac, and Trifunac and Brady used both components.

Site type can have a significant effect on the derived relation. For example, McGuire found for soft sites

$$\ln(a) = 0.27 + 0.6\ I_s \qquad (4\text{-}7)$$

which is significantly different than his expression for medium sites (Eq. 4-3). This dependence on site type may be an important consideration in the selection of the "best" relation between the GMPs and site intensity as these expressions should be derived in a manner consistent with Eq. (4-1). All of the available intensity attenuation relations were derived without regard to site type, because site data is not generally available for the intensity reports. In addition, it is doubtful in our opinion that the value of intensity assigned to each PGA value (a in the above expressions) in the various data bases can be said to be truly representative of the intensity at the recording site. For these reasons, one might prefer GMP-I_s relations that are developed without regard to site type.

An even more significant problem involves the use of low intensity data in the regression analysis. For example, the Cal Tech Data set used by Trifunac, McGuire, and Trifunac and Brady includes MM IV and V data. However, the ground motion data for these intensities may not be representative because the data set was developed using only digitized accelerograms. The criteria for selecting accelerograms to be digitized required that the level of ground shaking be "significant" or that the records be associated with an earthquake with "significant" damage. In our view, such a selection process would tend to bias the data towards high PGA records, particularly at the lower intensity levels. In the least squares fitting process this would tend to reduce the coefficient of the I_s term, thereby reducing the estimate of PGA at high intensity levels.

The data set developed by Murphy and O'Brien also has some bias. Although the set of MM IV and V data is more complete than the Cal Tech set, in order to be included, the accelerograph had to trigger, the records read, and the values reported. Such values are often only reported if the level of acceleration is at least 0.05g (this is standard practice for the USGS). Thus, The MM IV and V set of Murphy and O'Brien is probably also biased towards higher values of PGA. Eq. (4-6) suffers from a further bias because in performing their regression analysis Murphy and O'Brien <u>only</u> included PGA levels greater than 10 cm/sec^2.

To assess the impact of incompleteness at the lower intensity levels, we have recomputed the coefficients of Eq. (4-6) using U.S. data without the 10 cm/sec^2 cutoff. We found

$$\ln(a) = -1.69 + 0.86\ I_s \qquad (4\text{-}8)$$

if MM IV-X data are included and

$$\ln(a) = -2.32 + 0.96\ I_s \qquad (4\text{-}9)$$

if only MM V-X data are used.

Equations (4-3), (4-4), (4-6), (4-7) and (4-9) are compared in Fig. 4-5. Also shown on Fig. 4-5 are the mean log acceleration levels for MM V-VIII level based on the Murphy and O'Brien data for the U.S. shown on Fig. 4-4. A value of 1000 cm/sec^2 was chosen for MM X.

As seen by the scatter of data at each intensity level, the correlation between PGA and site intensity is poor. Different methods have been proposed to improve this correlation. For example, studies show that the residuals of GMP-I_s relations are strongly correlated with distance. This leads naturally to regressions of the form

$$\ln(a) = C_1 + C_2 \ln R + C_3\ I_s \qquad (4\text{-}10)$$

which we have denoted as "distance weighted" models. For medium sites, McGuire (1977) found

$$\ln(a) = 1.45 - 0.359 \ln R + 0.68\ I_s \qquad (4\text{-}11)$$

X E(Log A) for each intensity level (CSC data ∿ only USA)

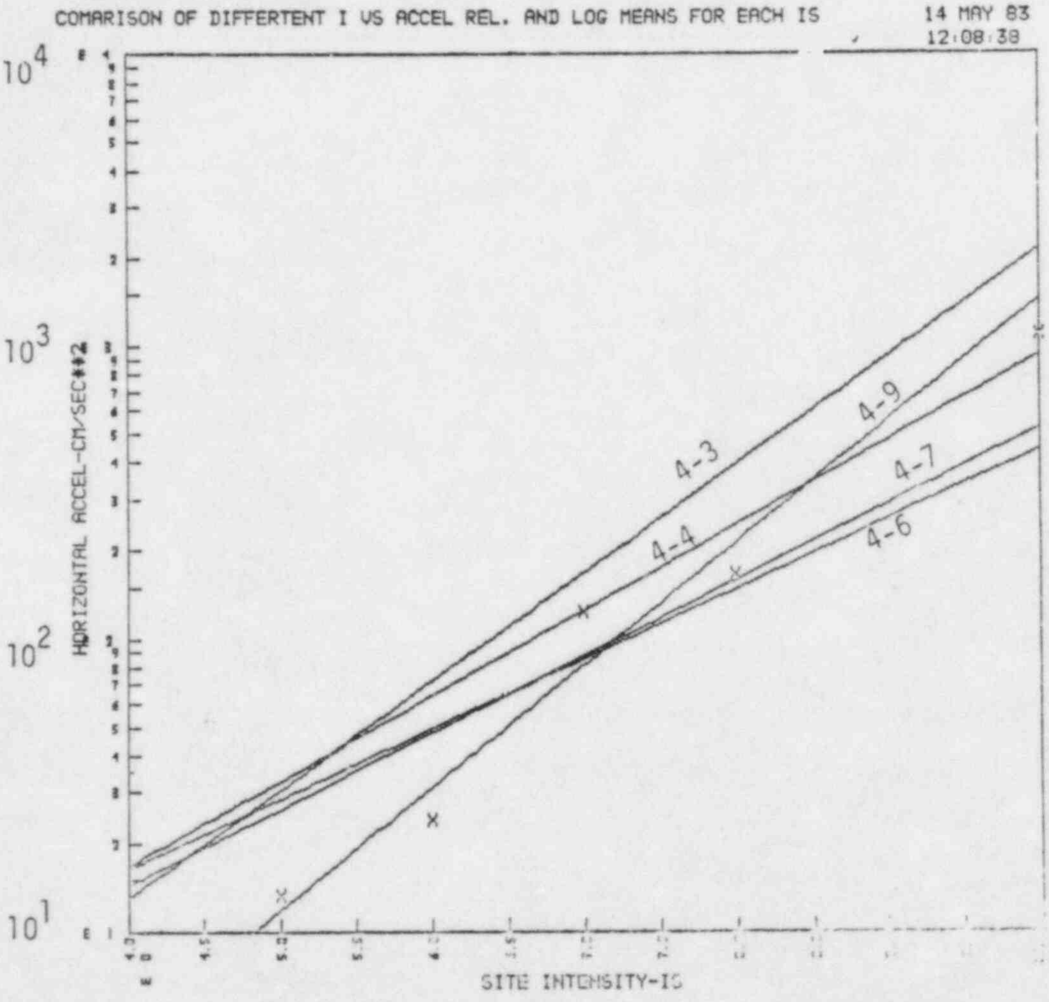


Fig. 4.5 Comparison of several accelerations versus site intensity equations.

and for soft sites

$$\ln(a) = 2.01 - 0.313 \ln R + 0.51 I_s \tag{4-12}$$

In our earlier study (Bernreuter 1981a) we found

$$\ln(a) = 1.79 - 0.323 \ln R + 0.57 I_s \tag{4-13}$$

Eq. (4-13) was obtained using the Cal Tech data set without regard to site type. It is in general agreement with McGuire's results, falling somewhere between his predictions for soft and medium sites. Neither Murphy and O'Brien, Trifunac, nor Trifunac and Brady considered a regression of the form of Eq. (4-10).

Our earlier study (Bernreuter 1981a) appears to be the only case which has considered a "magnitude-weighted" model of the form

$$\ln(a) = C_1 + C_2 M + C_3 I_s \tag{4-14}$$

We evaluated the coefficients of Eq. (4-14) using a modification of the Cal Tech data set and a weighted regression analysis to obtain

$$\ln(a) = 0.96 - 0.13M_L + 0.63 I_s \tag{4-15}$$

In addition to Eq. 4-6, Murphy and O'Brien also developed a relation of the form

$$\ln(a) = C_1 + C_2M + C_3 \ln R + C_4 I_s$$

They found for U.S. accelerations greater than 10 cm/sec^2

$$\ln(a) = 1.38 + 0.55M - 0.68 \ln R + 0.32I_s \tag{4-16}$$

The magnitude used is assumed to be M_L.

Battis (1981) introduced a different approach for using intensity data to develop a relation between GMP and site intensity. Battis assumed that the radius of the felt area of earthquakes could be defined by a constant level of acceleration equal to 6 cm/sec^2. This value was based on his extrapolation of the results of Trifunac and Brady (1975).

Combined Models

To get the required relation between the GMP, magnitude, and distance applicable in the EUS, we must combine an intensity attenuation relation with an expression relating GMP to I_s. As outlined above, there are a number of such combinations - each with their own assets and liabilities. The difference between the different intensity attenuation relations was illustrated in Fig. 4-2. To evaluate the difference between the various GMP-I_s relations we chose the modified Gupta-Nuttli curve shown in Fig. 4-2. It more or less represents an "average" between the different intensity attenuation relations. We combine the modified Gupta-Nuttli relation with Eqs. (4-3), (4-6) and (4-9) to develop three relations which approximately bound the different regression analysis results and assumptions. That is, we combine the different relations of the form

$$\ln(a) = C_1 + C_2 I_s \tag{4-17}$$

with the modified Gupta-Nuttli relation

$$I_s - I_o = 3.2 - 0.0011R - 1.17 \ln R \tag{4-18}$$

for $R \geq 15$ km

to obtain

$$\ln(a) = C_1 + C_2(I_o + 3.2 - 0.0011R - 1.17 \ln R) \tag{4-19}$$

Figure 4-6 shows this comparison for epicentral intensities of V, VII and IX. This figure indicates that the choice of the GMP-I_s relation has an important effect on both the rate of attenuation and how the ground motion scales with earthquakes of larger epicentral intensity - both being controlled by the coefficient C_2 of the I_s term in Eq. (4-17). To a large extent the coefficient C_2 is controlled by what data is included or excluded in the lower intensity ranges.

To illustrate the impact of "unweighted", "distance weighted" and "magnitude weighted" relations, we have compared the results using the modified Gupta-Nuttli attenuation model with the GMP-I_s acceleration relations given by Eqs. (4-4), (4-13), and (4-15). We use this set because all three regressions were performed using approximately the same data base. In making the required substitutions, we obtain

$$\ln(a) = C_1 + C_3 \ln R + C_4 M_L + C_2 [I_o + 3.2 - .0011R - 1.17 \ln R] \tag{4-20}$$

where the coefficients C_i are obtained from the regression between site intensity and PGA.

A problem occurs here in making a comparison between Eq. (4-15) and either Eq. (4-13) or Eq. (4-4) because Eq. (4-15) uses M_L while the other two relations are in terms of epicentral intensity. Some relation must be used to translate M_L into the appropriate I_o in the EUS. This is normally done in a two

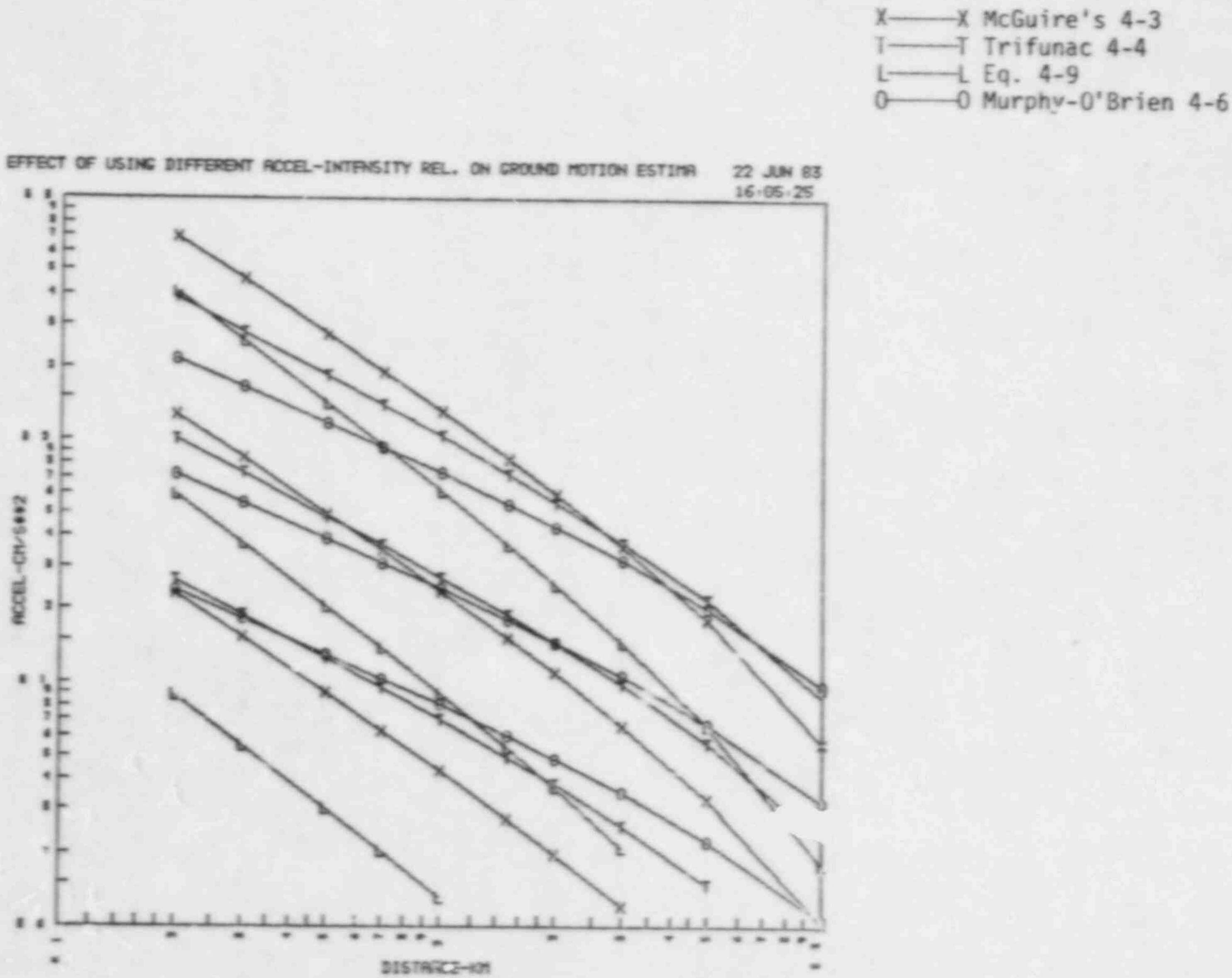


Fig. 4.6 Comparison of several combined models for intensities V, VII and IX.

step process. First the M_L is converted to an equivalent EUS m_{bLg} and then the m_{bLg} is converted to an equivalent I_o. As discussed earlier, it appears that

$$M_L \sim m_{bLg}$$

and in the past the relation

$$I_o = 2m_{bLg} - 3.5 \qquad (4\text{-}21)$$

has been widely used in the EUS. Figure 4-7 shows the comparison of the unweighted, distance-weighted and magnitude-weighted models made by combining Eqs. (4-4), (4-13) and (4-15) with Eq. (4-18), the modified Gupta-Nuttli attenuation relation. In the distance-weighted model, the R in Eq. (4-13) is assumed to be the same as the R in Eq. (4-18). This, as discussed earlier, is not strictly true.

The last set of models we need to compare are the intensity based semi-empirical models. These models form a somewhat disjoint set. One of the earliest semi-empirical models was developed by Nuttli and Herrmann (1978). They combined the relation

$$I_s - I_o = 3.1 - 1.07 \ln R \qquad (4\text{-}22)$$

which they felt approximates the Gupta-Nuttli relation, with Eqs. (4-16) and (4-21) and a free parameter. The use of Eq. (4-16) makes this essentially a "magnitude-and distance-weighted" approach. The free parameter was evaluated using judgment and available EUS data to obtain

$$\ln(a) = 1.47 + 1.2\, m_{bLg} - 1.02 \ln R; \; R > 15 \text{ km} \qquad (4\text{-}23)$$

Battis (1981) assumed the model

$$\ln(a) = C_1 + C_2 M + C_3 \ln(R + 25) \qquad (4\text{-}24)$$

M = appropriate magnitude scale
R = epicentral distance

To evaluate the coefficients in Eq. (4-24), Battis assumed that in the "near field" (i.e., R = 10 km) the ground motion is the same for all regions for the same epicentral intensity. In the "far field," at the limit of the felt area, he assumed that the ground motion is the same for all regions and sizes of earthquakes, using a value of 6 cm/sec^2. To obtain relations for both the central U.S. and the WUS, he used McGuire's (1974) relation to get PGA estimates at R = 10 km as a function of M_L. He used the relation between M_L and m_b derived by Brazee (1976) for California,

$$m_b = 1.28 + 0.75\, M_L, \qquad (4\text{-}25)$$

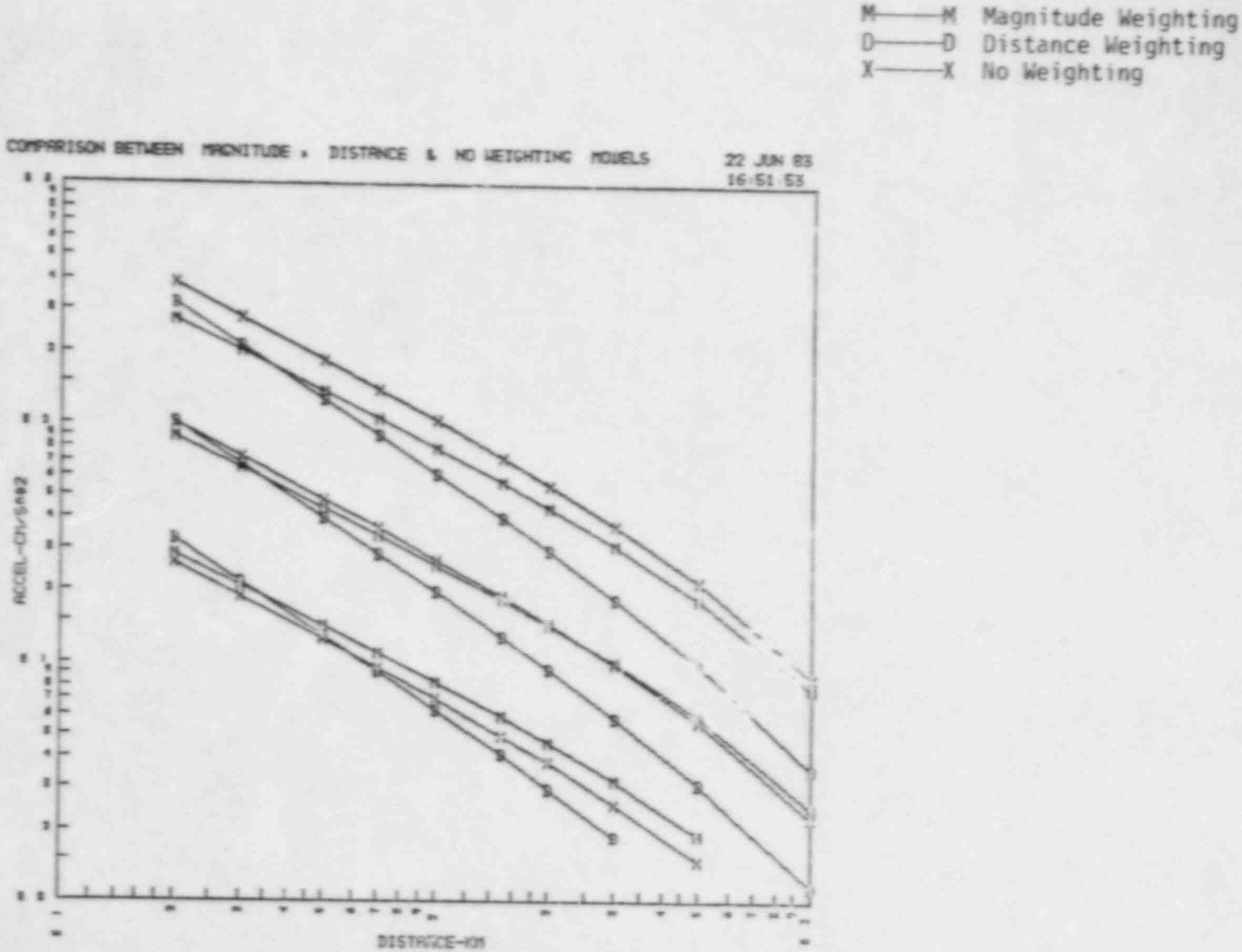


Fig. 4.7 Comparison of the magnitude weighted attenuation equations with the distance weighted and no weighting equations, for magnitudes 4.25, 5.25, and 6.25 (i.e., approximately source intensity $I_o \sim$ V, VII and IX).

and Brazee's relation between m_b and I_o,

$$m_b = 2.89 + 0.37\ I_o, \tag{4-26}$$

to relate the parameters M_L, m_b and I_o for the WUS.

Battis developed an approximate relation for the radius of felt area for the WUS. For the Central U.S., he used the relation

$$m_b = 2.6 + 0.34\ I_o \tag{4-27}$$

and determined the distance of the felt area using Nuttli and Zolweg's (1974) relation between the felt area and m_b

$$\ln R_f = -6.23 + 3.41\ m_b - 0.2\ m_b^2 \tag{4-28}$$

He evaluated the coefficients of Eq. (4-24) using a least squares process and obtained

$$\ln(a) = 3.16 + 1.24\ m_b - 1.24\ \ln(R + 25) \tag{4-29}$$

for the Central US. Fig. 4-8, taken from Battis, compares Eq. (4-29) to his result for the WUS,

$$\ln(a) = 5.83 + 1.21\ m_b - 2.08\ \ln(R + 25) \tag{4-30}$$

At 10 km the difference between Eqs. (4-29) and (4-30) arises because of the differences between Eqs. (4-26) and Eq. (4-27). For example at I_o = VII Eq. (4-26) results in m_b values that are about 0.5 units larger than those given by Eq. (4-27).

Weston Geophysical Corporation, Inc. (WGC) has proposed a model for New England. WGC based the attenuation of intensity on four New England earthquakes ranging in magnitude from 3.5 to 5.8. WGC used Eq. (4-11) (distance weighting) to convert from site intensity to ground motion. They noted that because of the small range of magnitudes of the earthquakes involved that the scaling with magnitude determined by the regression analysis was unreliable. To account for this, they changed the coefficient of m_b from the value of 0.7 determined from the regression to 1.1 and readjusted the constant so that the model with the 1.1 slope agreed with the 0.7 slope model at m_b = 4.875. Their resultant model is given by

$$\ln(a) = 1.47 + 1.1\ m_b - 0.88\ \ln R - 0.0017R \tag{4-31}$$

The Nuttli-Herrmann model, Eq. (4-23), the Battis model, Eq. (4-29), and the WGC model, Eq. (4-31), are compared in Fig. 4-9. Also shown in Fig. 4-9 for comparison is the magnitude-weighted model, Eqs. (4-15) and (4-20) expressed in terms of m_b through Eq. (4-21),

$$\ln(a) = 0.77 + 1.13\ m_b - 0.0007R - 0.74\ \ln R \tag{4-32}$$

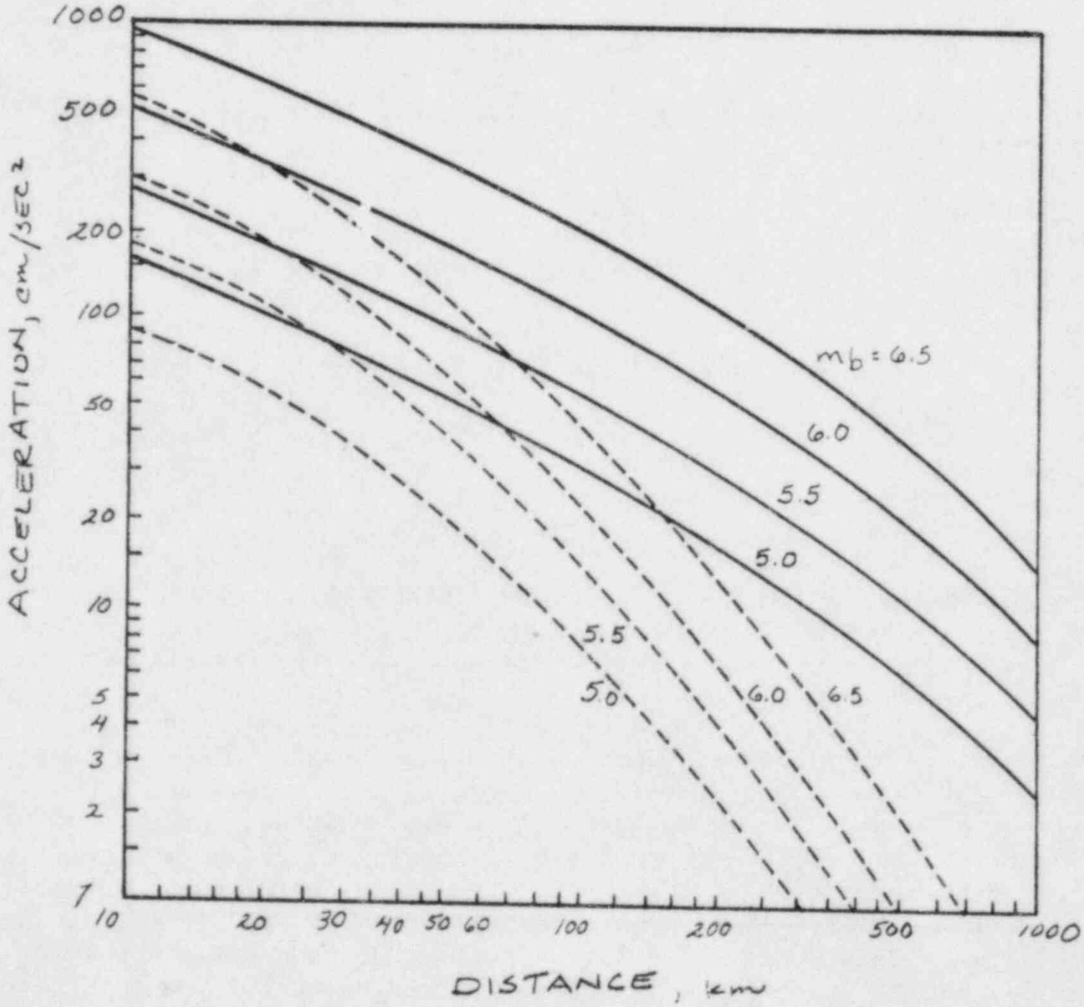


Figure. 4-8 Comparison of derived peak acceleration attenuation functions for the Central United States (solid curves) and California (dashed curves). Battis's Model.

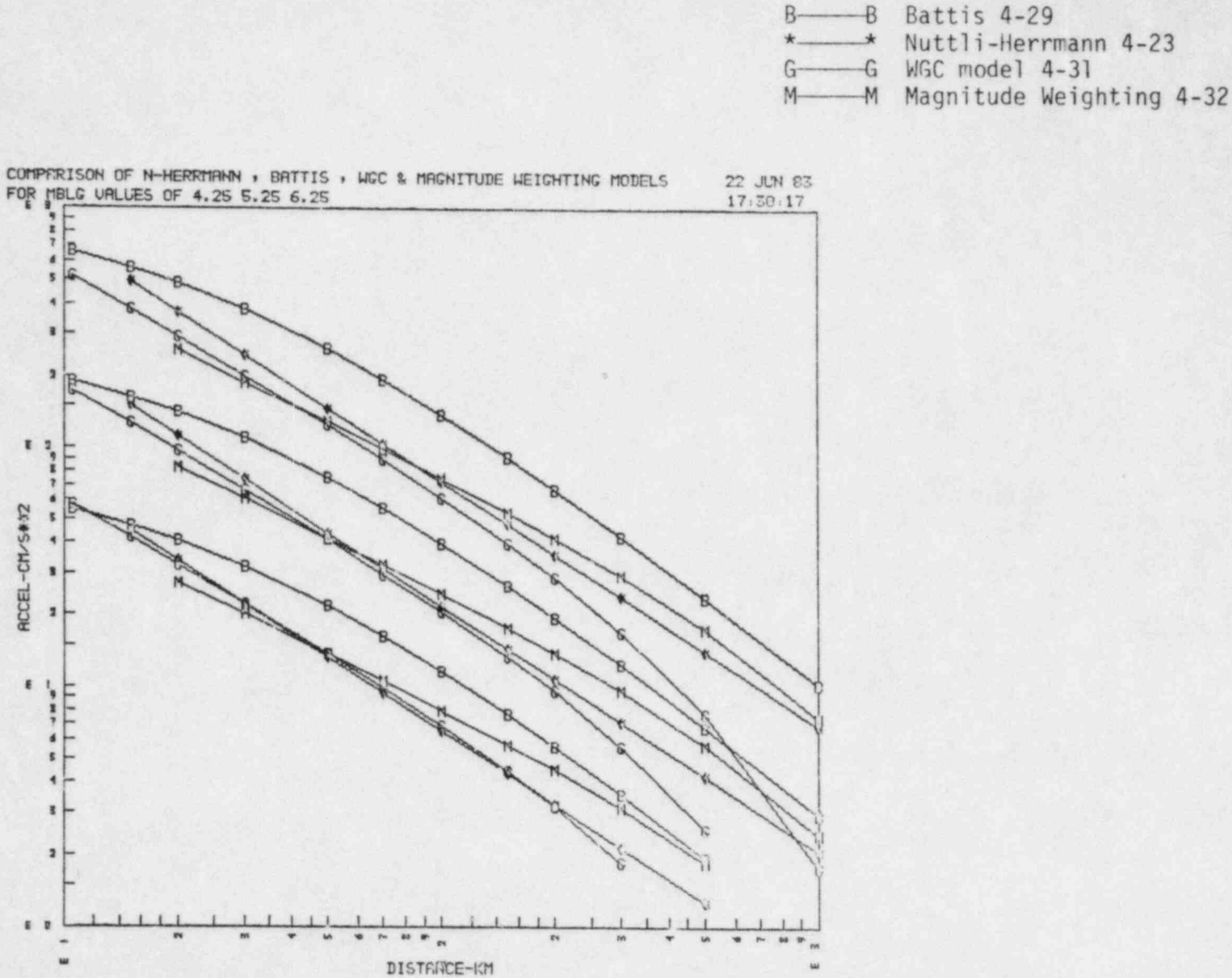


Fig. 4.9 Comparison of the magnitude weighting mdoel (M, Eq. 4-39) with Battis' model (B, Eq. 4-29), the Nuttli-Herrmann model (*, Eq. 4-23) and the Weston Geophysical model (G, Eq. 4-31).

4.2 Direct Models

Although there are many possible models in the categories referred to as D-1 and D-2, in fact, only a few have been formally developed. Recall that category D-1 includes those semi-empirical models that do not use site intensity as an intermediate variable and assume that differences between the ground motion from EUS and WUS earthquakes are only related to the differences in attenuation between the two regions. Category D-2 includes those models which assume that in addition to attenuation differences between the two regions there are also differences in magnitude scaling.

Nuttli (1979) assumes that

$$GMP\ (R) = A_o R^{-5/6} \exp(-\gamma R) \qquad (4\text{-}33)$$

where γ is a regional absorption coefficient. Eq. (4-33) is a theoretical attenuation curve for Lg waves.

Nuttli further assumes that

$$\log A_{max} \propto 0.5 m_b$$

$$\log V_{max} \propto 1.0 m_b \ .$$

In addition, he assumes that the source spectra of EUS earthquakes are the same as for WUS earthquakes, so that the ground motions observed in the near-source region are the same for both areas. Nuttli also assumes that the predominate frequency of the ground motion for identical magnitude earthquakes is the same between the two regions.

The constant A_o in Eq. (4-33) was assumed to be proportional to m_b as given in the above relations and calibrated using the San Fernando earthquake. The appropriate absorption coefficient for the central US was taken from Nuttli and Dwyer (1978). Nuttli's (1979) model is given by the following equations:

$$\ln(a) = 1.481 + 1.15\ m_b - \gamma R - 5/6\ \ln(R) \qquad (4\text{-}34)$$

$$\text{where } \gamma = 0.0136 - 0.00172\ m_b$$

In addition to Nuttli's (1979) model we are aware of four other models that fall into category D-1, one that we developed for SSMRP, Campbell's (1981b) and (1982) models, and the model used by Algermissen and Perkins (1976). We exclude the model by Algermissen and Perkins because it is nonanalytical and would be difficult to use in the hazard analysis. The model is based on the relation of Schnabel and Seed (1973) with a regional correction for attenuation. Figure 4-10 taken from Algermissen et al. (1982) compares this model to that of Nuttli and Herrmann (1981). Aglermissen et al. do not indicate what relation they used to go from m_b to M_s.

In developing the SSMRP model we started with Nuttli's (1979) suggestion that

$$GMP = A_o(m_b)\ R^{-5/6}\ \exp(-\gamma\ R) \tag{4-35}$$

Nuttli suggested that $A_o(m_b)$ could be determined from WUS data using the assumption that the only difference between WUS and EUS earthquakes is a difference in regional attenuation. To develop the SSMRP model we repeated the regression analysis on the data set of Joyner and Boore (1981) ($M_L \geq 5.0$) using an approach similar to theirs. However, in our analysis the coefficient of geometrical attenuation was taken to be -5/6 (in agreement with Nuttli's model) rather than the value of -1 assumed by Joyner and Boore. The purpose of this change was to put the model in the same form as assumed by Nuttli when he determined the regional absorption coefficients for the EUS and WUS. In addition, a value of m_b appropriate for the EUS (or an estimate of this value) was used for the measure of the size of the earthquakes. We determined the best fit relation

$$\ln(a) = 3.99 + 0.59\ m_b - 5/6\ \ln R - 0.007R \tag{4-36}$$

where

$$R^2 = [d^2 + h^2]^{1/2}$$
$$h = 5.3$$

and d is the shortest distance between the site and the surface projection of the fault rupture plane.

Nuttli (1979) obtained a similar estimate for γ in the WUS. For the central U.S. (CUS) Nuttli (1982) estimates $\gamma = 0.003$. If indeed the ground motion from CUS earthquakes scales the same with magnitude as WUS earthquakes, we can convert the above relation into a CUS ground motion model simply by replacing γ with an appropriate value for the CUS. This gives

$$\ln(a) = 3.99 + 0.59\ m_b - 5/6\ \ln R - 0.003\ R \tag{4-37}$$

where

$$R^2 = [d^2 + h^2]^{1/2}$$
$$h = 5.3$$

Campbell (1981b) uses a different functional form than that used by Nuttli (1979) or Joyner and Boore (1981). He takes as his relationship for modeling the attenuation of peak acceleration with distance the expression

$$\ln(a) = a + bM - d\ \ln[R + C(M)] - \gamma R \tag{4-38}$$

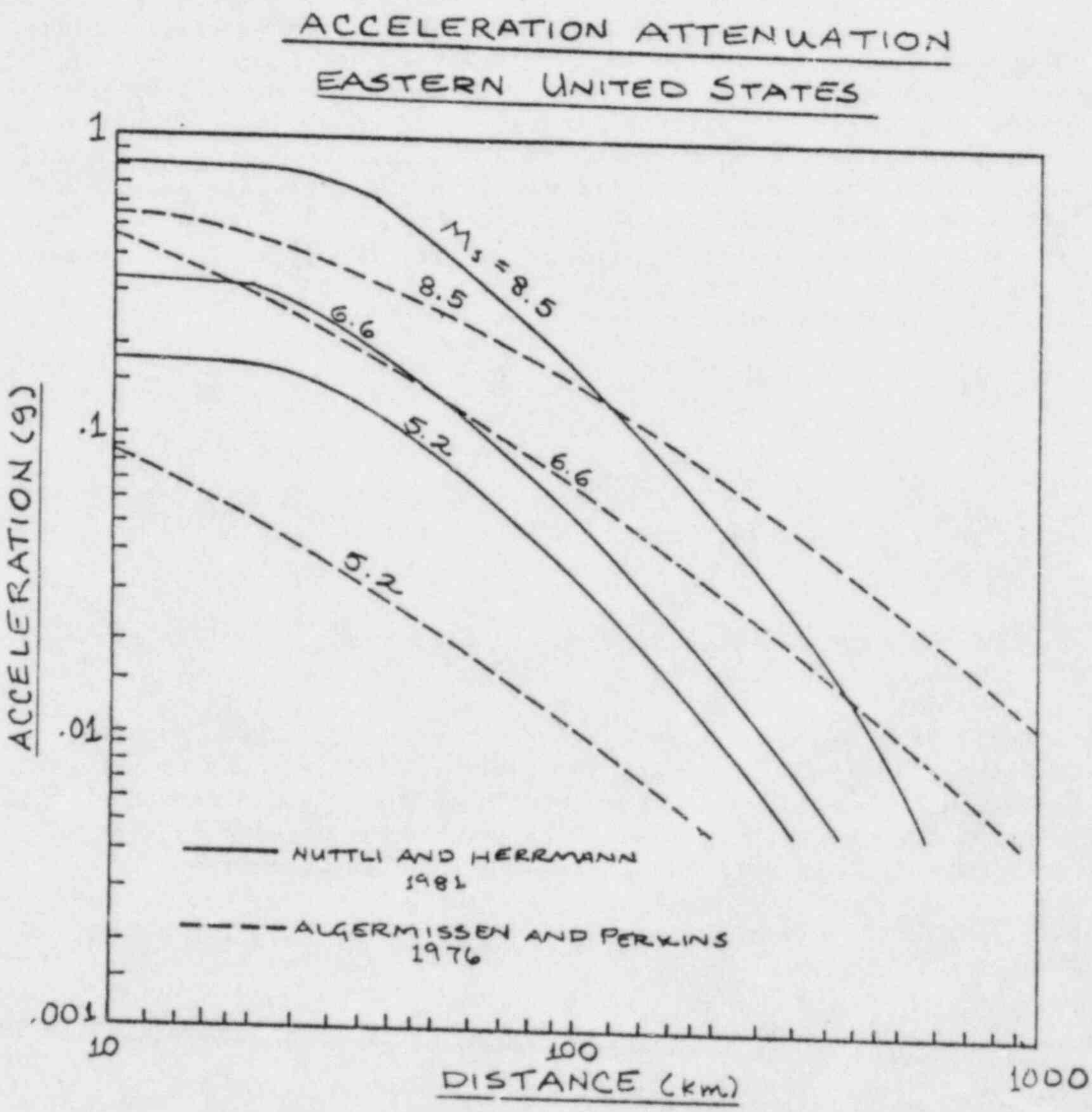


Figure. 10 Comparison of Algermissen and Perkins (1976) and Nuttli and Herrmann (1981) Acceleration Attenuation Curves for the Eastern and Central United States.

Campbell selected this functional form because it is capable of modeling nonlinear magnitude and distance scaling effects in the near field that may be supported by the data. The far-field properties of this relationship are characterized by the coefficient b which controls magnitude scaling, the coefficient d which controls the geometrical attenuation rate, and the coefficient γ which controls the rate of attenuation due to absorption.

C(M) modulates the attenuation of acceleration at distances close to the source where little geometrical attenuation is expected (Hadley and Helmberger, 1980). Since the distance at which the transition from far-field to near-field attenuation occurs is probably proportional to the size of the fault rupture zone, and since fault rupture dimensions scale exponentially with magnitude, Campbell used the following relationship to model C(M):

$$C(M) = C_1 \exp(C_2 M) \tag{4-39}$$

Eq. (4-38) differs from Nuttli's relationship (Eq. 4-34) in two ways. The first is that the geometrical attenuation term d is not fixed but rather was determined from the regression analysis. The second is the addition of the C(M) parameter. Both of these differences are required to accommodate the near-source effects of extended fault rupture in the case of large earthquakes and accommodate the depth of the source in the case of small events.

He based his analysis on the near-source data base of Campbell (1981a). Earthquakes were selected only if their magnitude was equal to or greater than 5.0. Distances were restricted to be no further than 30 km from the fault rupture plane for $5.0 \leq M < 6.25$ and no further than 50 km from the fault for $M \geq 6.25$. Analyses were conducted separately for two definitions of distance: the closest distance to the fault rupture surface, referred to as fault distance, and epicentral distance. He considered peak acceleration to be regionally invariant at the source (i.e., at R = 0). He used the values of absorption proposed by Nuttli (1979) in the WUS to establish γ, from which he developed the relation

$$\gamma_{WUS} = 0.042 - 0.009M + 0.00057M^2 \tag{4-40}$$

Using a weighted regression analysis similar to that of Campbell (1981a) he found the following expression for the median (50th-percentile) value of peak acceleration in cm/s^2 in terms of <u>fault distance</u>:

$$\ln(a) = 2.64 + 0.79M - 0.862 \ln [R + 0.0286 \exp(0.778M)] - \gamma R \tag{4-41}$$

with a standard error of ln(a) of 0.409.

The results of the regression analysis for <u>epicentral distance</u> yielded the following expression for the median value of peak acceleration:

$$\ln(a) = 4.39 + 0.922M - 1.27 \ln [R + 25.7] - \gamma R \tag{4-42}$$

where C_2 was found to be equal to zero. The standard error of ln(a) was found to be 0.548.

Since the standard measure for earthquake size in the CUS is m_b, Campbell's application of Eqs. (4-41) and (4-42) to this region required a conversion from m_b to M, the magnitude scale used in the development of these relationships. The magnitude scale used in the above equations was defined as M_s when both M_s and M_L were larger than 6.0 and M_L when both were below this value. Campbell used the relationships between magnitude scales developed by Nuttli (1979) and his definition of M to develop the following conversion relation

$$M = \begin{cases} 1.64\ m_b - 3.16 & (m_b \geq 5.59) \\ 1.02\ m_b + 0.30 & (m_b < 5.59) \end{cases} \qquad (4\text{-}43)$$

An appropriate ground motion model for the CUS was obtained by substituting values of γ for the CUS proposed by Nuttli (1979) using the expression

$$\gamma_{CUS} = 0.023 - 0.0048M + 0.00028\ M^2 \qquad (4\text{-}44)$$

This analysis was later revised by Campbell (1982) using a frequency dependent expression for γ of the form

$$\gamma = \frac{\pi T^{\eta}}{Q_o T_o^{\eta} TU} \qquad (4\text{-}45)$$

where T is the period of the wave, U is the group velocity, Q_o is a reference value for the quality factor Q, T_o is a reference value for period, and η is defined by the expression

$$Q = Q_o \left(\frac{T_o}{T}\right)^{\eta} \qquad (4\text{-}46)$$

The predominant period of PGA for sites located on rock was modified from a plot given by Seed et al. (1969), resulting in the relation

$$T = \begin{cases} -0.229 + 0.0650M + (0.000556M - 0.00172)R & (M \geq 7.0) \\ -0.043 + 0.0382M + (0.000556M - 0.00172)R & (M < 7.0) \end{cases} \qquad (4\text{-}47)$$

An expression for γ appropriate for California was obtained by substituting the values $Q_o = 150$, $\eta = 0.55$, $U = 3.5$ km/sec and $T_o = 1$ sec. into Eq. (4-45) based on the regionalization of Q for the United States by Singh and Herrmann (1983). Using this expressionfor γ and the relation for period given by Eq. (4-47), the analysis of Campbell (1981b) was revised, resulting in the following expression for peak acceleration (g):

$$\ln(a) = -4.290 + 0.777M - 0.797\ \ln[R + 0.012\ \exp(0.898M)] - \gamma R \qquad (4\text{-}48)$$

where R is fault distance as defined previously. The standard error for ln(a) in this analysis was 0.405.

While Campbell only applied Eq. (4-48) to the estimation of PGA in the northcentral Utah region, this expression may be applied to other regions of the U.S. by selecting an appropriate value for Q_o and η from Singh and Herrmann (1983) (or some other source if appropriate) and selecting an appropriate value or relation for the predominant period of PGA. Then γ may be estimated from Eq. (4-45) and substituted into Eq. (4-48) to estimate PGA. A conversion between M and m_b may be taken from Eq. (4-43) or from more current relations proposed by Nuttli (1983 a,b).

Figure 4-11 compares Campbell's Eqs. (4-41) and (4-42) and the SSMRP model given by Eq. (4-37) for an m_b of 4.25, 5.25, and 6.25. In making this plot several items need to be noted. First, Eq. (4.37) is plotted as a function of the distance R. This is consistent with the distance R in Eq. (4-38) for EUS earthquakes where earthquakes do not rupture to the surface. In Fig. 4-11 the epicentral distance R in Eq. (4-42) is different than either of the other two definitions, but it is plotted as R for reference. For a discussion of the differences in the definition of distance as it relates to the prediction of strong ground motion, the reader is referred to Appendices B and C and Shakal and Bernreuter (1981). Second, it should be noted that we have extrapolated beyond the data to plot the curves for $m_b = 4.25$. However, as an extended data set is not readily available, it is not possible at this time to revise these models using smaller magnitude data. At some point in your response to us you should note if it is necessary for us to extend these models.

As can be seen from Fig 4-11 there is a considerable difference between all three models. One notable difference is how the ground motion scales with magnitude. For Eqs. (4-41) and (4-42) the m_b was converted to the magnitude M used by Campbell based on Eq. (4-43).

This is believed to contribute to the differences in the magnitude scaling properties of Eq. (4-37) and Eqs. (4-41) and (4-42). In the SSMRP model it was assumed that $M_L = m_{bLg}$, whereas for the Campbell models M was determined using the magnitude conversion relations developed by Nuttli (1979) resulting in an m_b approximately 0.3 to 0.4 units smaller than M_L. In order to see what impact this might have on the results we replot Campbell's models on Fig. 4-12 using $M = m_b$ (Note: this is only strictly valid for $M < 6.0$ where $M = M_L$). As seen from Fig. 4-12 the scaling of PGA with magnitude is still significantly different between all three models. We may conclude from these comparisons that the relations used to convert between scales is an important consideration in the development of a ground motion model in the EUS.

We only know of one model that falls into Category D-2. This is the latest version of the model of Dr. Nuttli and is part of a long developmental process. Appendix C-A gives the details of the model and some other reflections on the questions before this panel by Dr. Nuttli. Figure 4-13 compares Nuttli's (App. C-A) model with his 1979 model given by Eq. (4-34).

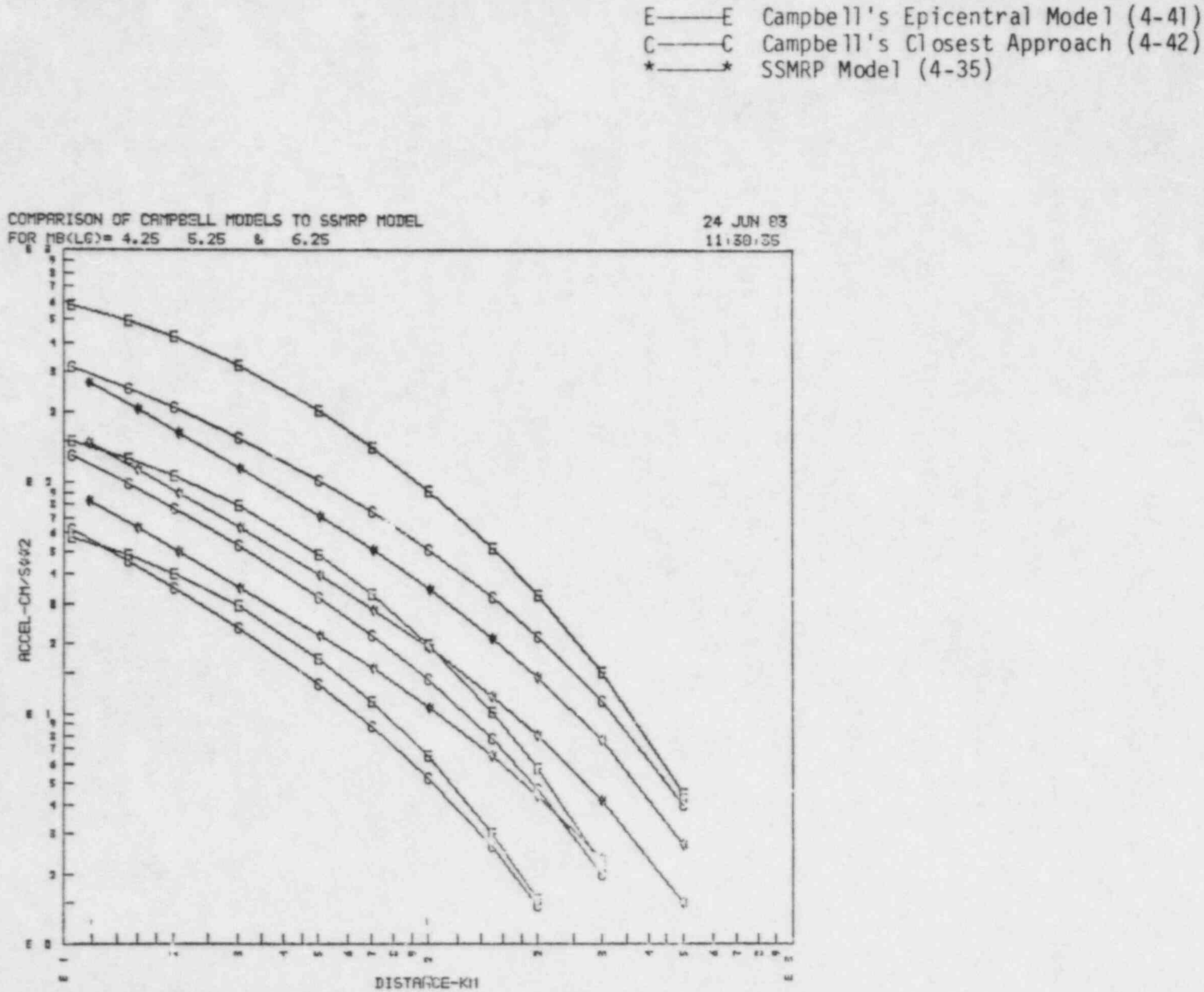


Fig. 4.11 Comparison of Campbell models to SSMRP model.

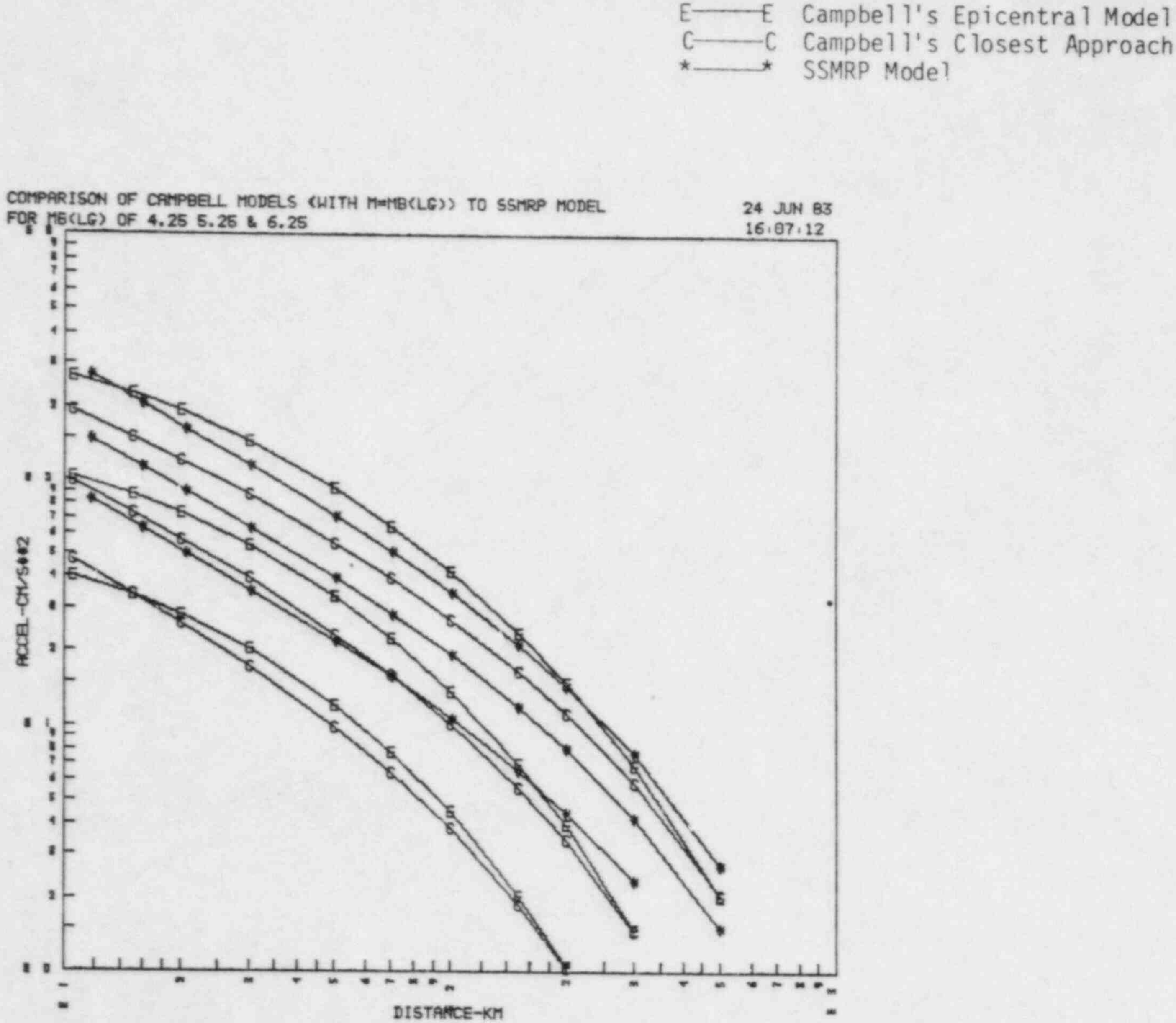


Fig. 4.12 Comparison of Campbell models to SSMRP model.

N———N (83) Model
X———X (79) Model

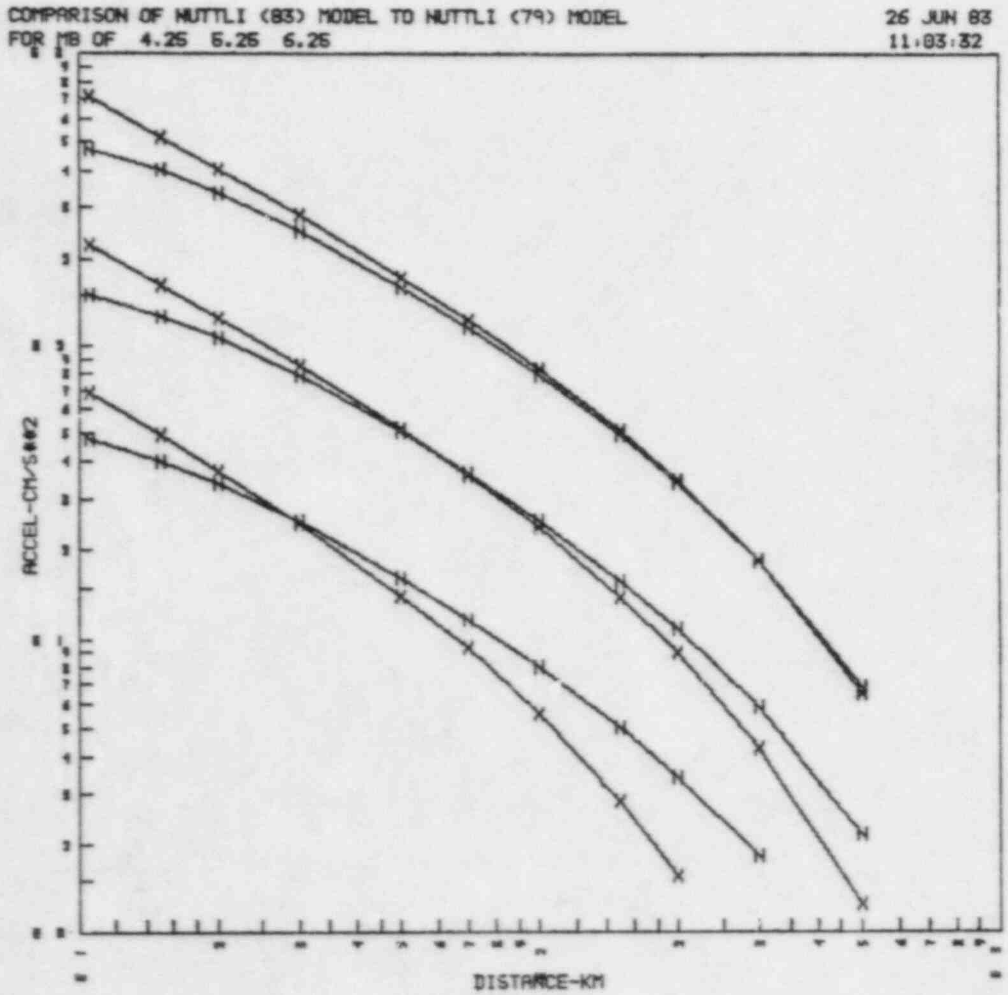


Fig. 4.13 Comparison of Nuttli model (83) to (79) model.

To make this plot we assume a depth of h = 12 km in his App. C-A model and take the distance R in both models to be the same. The models are found to be very similar--the differences arise primarily from the inclusion of the depth term and the change to a constant value for anelastic attenuation in the App. C-A model.

Figure 4-14 compares Campbell's epicentral model, Eq. (4-42), the SSMRP model, Eq. (4-37), Nuttli's App. C-A model and the Intensity Based Magnitude-Weighted Model, Eq. (4-32). The models of Campbell and Nuttli are very similar, except for differences in anelastic attenuation at the smaller magnitudes. The SSMRP model exhibits substantially less magnitude scaling and the magnitude-weighted model exhibits substantially less attenuation than the other models.

To facilitate making additional comparisons we have provided you with clear overlays of several of the key figures.

E——E Campbell's Epicentral Model
L——L SSMRP Model
N——N Nuttli's 83 Model (Appendix A)

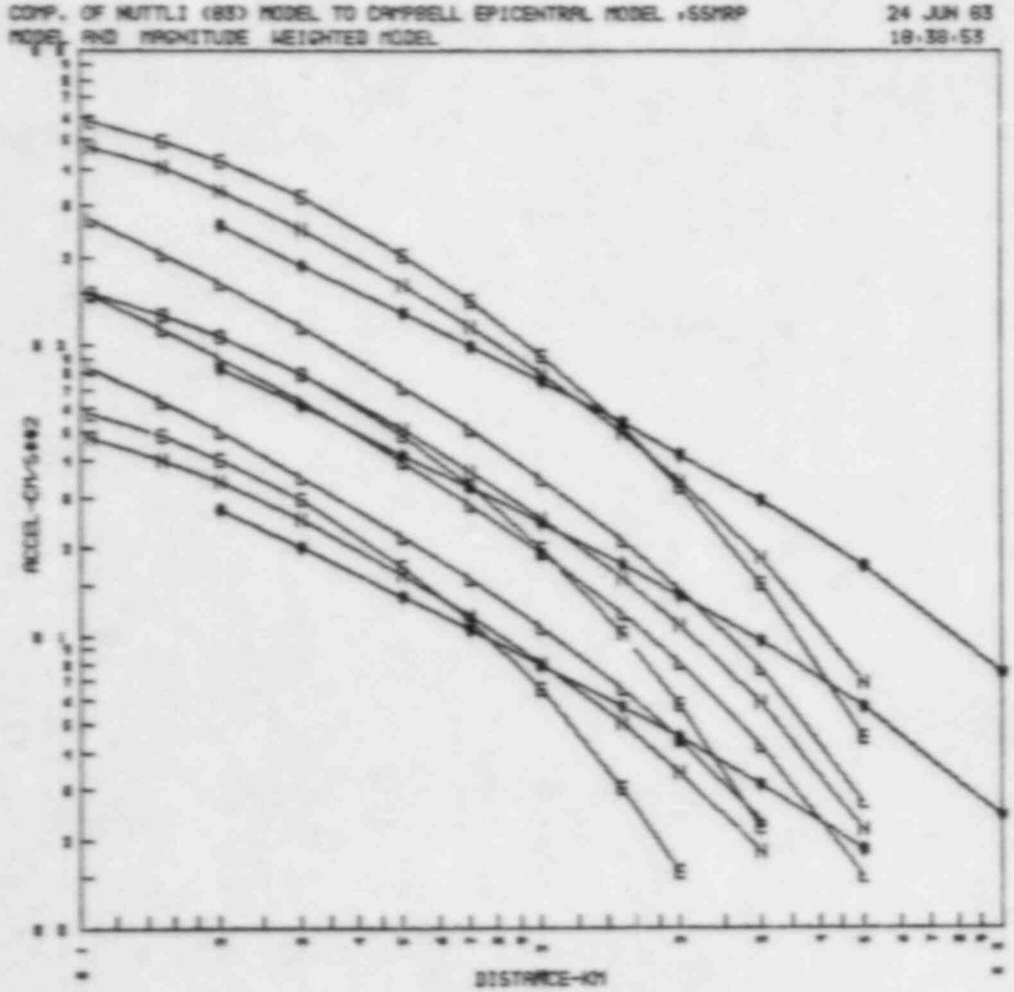


Fig. 4.14 Comparison of Campbell's epicentral model, SSMRP model and magnitude weighted model.

5.0 REVIEW OF VELOCITY AND SPECTRAL MODELS

Only a few of the investigators referenced in Section 4 have developed scaling relationships for peak velocity and response spectral ordinates. This creates a dilemma, since it is the probabilistic prediction of response spectra that is ultimately required for the characterization of seismic hazards in the EUS.

Since a discussion of peak velocity relations would be very similar to the previous discussion on peak acceleration, no presentation of actual models will be made here. Rather, the reader may refer to the Questionnaire Section 7 for a list of available models.

Of all the investigations referred to in Section 4, only three present models for response spectral ordinates. Two of these, the "distance-weighted" and "magnitude-weighted" intensity models of Bernreuter (1981b), were developed for the previous SEP study. The only other available model is a "no-weighted" intensity model based on the approach taken by Trifunac and Brady (1975) to develop similar relations for peak ground motion parameters. Because of the importance of response spectra, we feel it necessary to augment these limited models with models based on standard response spectral shapes.

Three spectral shapes will be considered; these are (1) the shape recommended by the Nuclear Regulatory Commission for the seismic design of Nuclear Power Plants (USAEC, 1973), (2) the shape recommended by the Applied Technology Council for the seismic design of buildings (NBS, 1978), and (3) the shape recommended by Newmark and Hall (1982) for the seismic design of all types of buildings (although originally developed for the design of nuclear power plants). While other spectral shape models exist, these three comprise those commonly used in practice. Of course, if you feel another model should be considered, you may indicate so in the Questionnaire. The following is a brief discussion of each model.

5.1 Nuclear Regulatory Commission

The response spectral shape recommended by the Nuclear Regulatory Commission (NRC) for the design of nuclear power plants is described in U. S. Atomic Energy Commission Regulatory guide 1.60 (USAEC, 1973). This shape is based on a statistical analysis of response spectra of strong-motion earthquakes as described by Newmark et al. (1973a). It is a broad-band spectrum, encompassing earthquakes of various sizes and distances. The NRC regulatory staff has determined this shape to be acceptable for defining the Design Response Spectra representing the effects of the vibratory motion of the Safe Shutdown Earthquake (SSE), one-half the SSE, and the Operating Basis Earthquake (OBE) for sites underlain by either rock or soil deposits and covering all frequencies of interest. They further indicate that this shape should not be used for sites that are relatively close to the epicenter of an expected earthquake or have physical characteristics that could significantly affect the spectral pattern of input motion, such as being underlain by poor soil deposits.

The spectrum shape recommended in Regulatory Guide 1.60 was selected to represent an 84th percentile spectrum when anchored to a median value of PGA. This makes this spectrum incompatible with the requirements of our project, which is designed to estimate a median or "best estimate" spectrum for a given probability of exceedance and to specify appropriate confidence limits. The 50th percentile (median) spectral shape consistent with Regulatory Guide 1.60 was obtained from Newmark et al. (1973a). To meet the program objectives the median amplification factors for each frequency control point was estimated from the ratio of the 84.1% and 50% amplification factors given in the original studies used to establish the amplification factors for each control point. This resulted in 5%-damped median amplification factors that are 23% and 26% lower in the acceleration domain (control points at 9 Hz and 2.5 Hz, respectively) and 31% lower in the displacement domain (control point at 0.25 Hz) than the corresponding 84.1% amplification factors. This median spectral shape will be referred to as the Modified Regulatory Guide 1.60 spectrum.

The spectrum based on an 84th percentile shape is shown in Fig. 5.1 for damping values of 0.5, 2, 5, 7 and 10% and a peak horizontal acceleration of 1g. The spectrum may be adjusted to any other value of PGA by linearly scaling Fig. 5-1 in proportion to the desired value of peak acceleration. Thus, the shape remains independent of magnitude, distance, and site characteristics. The applicable amplification factors and control points used to construct the spectrum for a specified PGA is given in Table 5-1.

5.2 Applied Technology Council

The response spectral shapes recommended by the Applied Technology Council (ATC) for the seismic design of buildings is described in National Bureau of Standards Special Publication 510 (NBS, 1978). Spectral shapes representative of different soil conditions were selected on the basis of a statistical study of the spectral shapes developed on such soils close to the seismic source zone in past earthquakes (Seed et al., 1976; Hayashi et al., 1971). They represent smoothed spectral shapes for the following three soil profiles.

Soil Profile Type S_1: Rock of any characteristic, either shale-like or crystalline in nature (such material may be characterized by a shear wave velocity greater than 2500 ft/sec); or stiff soil conditions where the soil depth is less than 200 ft and the soil types overlying rock are stable deposits of sand, gravels, or stiffer clays.

Soil Profile Type S_2: Deep cohesionless or stiff clay soil conditions, including sites where the soil depth exceeds 200 ft and the soil types overlying rock are stable deposits of sands, gravels, or stiff clays.

Soil Profile Type S_3: Soft-to-medium stiff clays and sands, characterized by 30 ft or more of soft-to-medium-stiff clay with or without intervening layers of sand or other cohesionless soils.

TABLE 5-1

SPECTRUM AMPLIFICATION FACTORS FOR HORIZONTAL
ELASTIC RESPONSE

(Taken in Part from Newmark et al., 1973 a)

Damping % Critical	One Sigma (84.1%) Accel. 33 Hz	9 Hz	2.5Hz	Displ. 0.25 Hz	Median (50%) Accel. 33 Hz	9 Hz	2.5 Hz	Displ. 0.25 Hz
0.5	1.0	4.96	5.95	3.20	1.0	3.11	3.84	2.11
2.0	1.0	3.54	4.25	2.50	1.0	2.53	2.93	1.67
5.0	1.0	2.61	3.13	2.05	1.0	2.01	2.32	1.41
7.0	1.0	2.27	2.72	1.88	1.0	1.91	2.09	1.32
10.0	1.0	1.90	2.28	1.70	1.0	1.62	1.73	1.21

Note: Maximum ground displacement is taken proportional to maximum ground acceleration, and is 36 in. for ground acceleration of 1g.

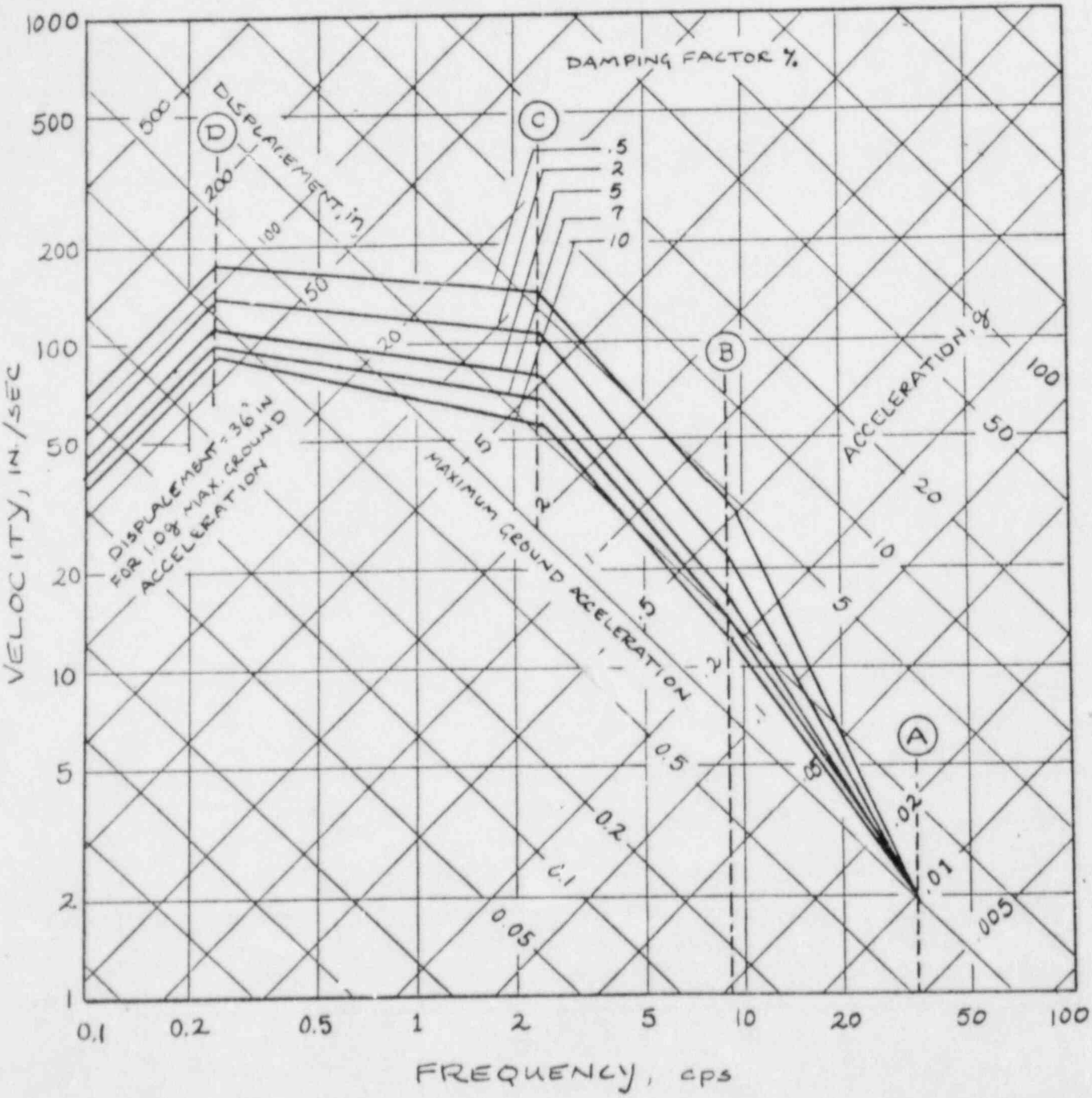


FIGURE 5-1. Horizontal design response spectra-scaled to 1g horizontal ground acceleration (USAEC, 1973).

The spectral shapes are used by ATC in conjunction with two indeces - A_a, a parameter numerically equal to Effective Peak Acceleration (specified in units of g), and A_v, a parameter related to Effective Peak Velocity--in defining a design response spectrum. However, the similarity of the spectral shapes to those recommended by Seed et al. (1976) suggests that they may be used in conjunction with PGA to adequately represent ground motion spectra for use in our project. Spectra for an Effective Peak Acceleration of 0.4g (A_a=0.4) and 5% damping are shown in Fig. 5.2. The value of A_a for Soil Profile Type S_3 has been reduced by 20% as recommended by ATC. This would not be required when anchoring the spectral shapes to PGA, as this parameter would already contain the effects of site characteristics. The spectra may be adjusted to any other value of A_a or PGA by linearly scaling Fig. 5-2 in proportion to the desired value of acceleration. However, for relatively large distances where $A_v > A_a$, ATC recommends that the velocity portion of the spectra (the horizontal portion in Fig. 5-2) be multiplied by the ratio of A_v to A_a and the remainder of the spectra extended to maintain the same overall form. This takes into account the change in spectral shape that has been observed to occur at large distances. However, the shapes remain independent of earthquake magnitude.

5.3 Newmark-Hall

The response spectral shapes recommended by Newark and Hall for the seismic design of buildings is described in a Monograph published by The Earthquake Engineering Research Institute (Newmark and Hall, 1982). The development of these shapes has been an evolutionary process, but has been primarily based on the statistical studies of Newmark et al. (1973 b), Hall et al., (1976) and Newmark and Hall (1978). They recommend that appropriate regions of the spectra be scaled by peak acceleration, peak velocity, and peak displacement. This enables the shape to vary with magnitude, distance, and site characteristics in accordance with the variation in these peak parameters.

While Newmark and Hall give amplification factors for both median and 84th percentile shapes, the median values are of interest in our study. Table 5-2 presents these amplification factors for various values of damping. The factors labeled A, V and D represent amplification factors based on peak acceleration, peak velocity and peak displacement, respectively. These domains are defined in fig. 5-3 which gives the 84th percentile, 5%-damped spectrum for a peak acceleration of 0.5g, a peak velocity of 61 cm/sec, and a peak displacement of 45 cm. The corresponding median spectrum would be reduced by 22% in the acceleration domain (A), 28% in the velocity domain (V), and 31% in the displacement domain (D) with respect to the 84th percentile spectrum.

Newmark and Hall recommend that, lacking other information, values of peak velocity (v) may be estimated from peak acceleration (a) by taking a v/a ratio of 48 in/sec/g for competent soil conditions and a v/a ratio of 36 in/sec/g for rock. Peak displacement (d) may be estimated by taking the ratio ad/v^2 to equal about 6.0. The recommendation concerning v/a will be followed when

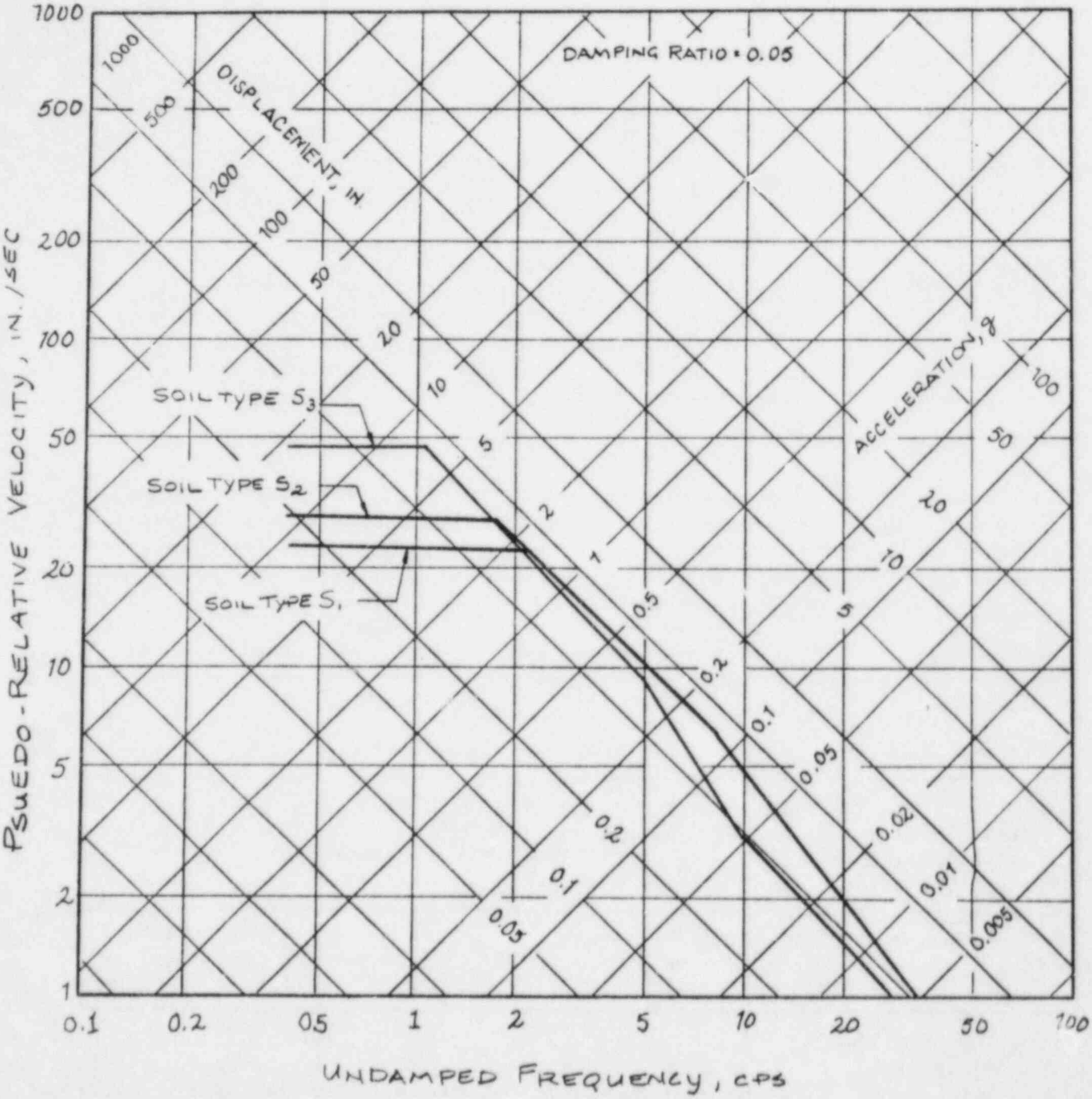


FIGURE 5-2. Ground motion spectra for Map Area 7 (A α = 0.4), (NBS, 1978).

ground motion models for peak velocity are not available. Since we are not interested in frequencies less than 0.5 Hz, it will not be necessary to estimate peak displacements.

A comparison of the three median spectral shapes for a PGA of 1g, and a damping value of 5% may be found in Fig. 5-4 for competent soil conditions and Fig. 5-5 for rock. These figures indicate that the only major disagreement among the models is for frequencies greater than 10 Hz, where the ATC shape exhibits more high-frequency content than the other two. The effect of rock is to reduce the spectral ordinates in the velocity domain for those spectra incorporating site conditions. The site-independent shape represented by the Modified Regulatory Guide 1.60 spectrum tends to fall between the soil and rock spectra of the Newmark-Hall and ATC studies. Because of the classification of stiff soil with rock in the ATC study, spectra representing both stiff soils (S_1) and deep soils (S_2) appear in Fig. 5-4. The ATC spectra are found to bracket both the site-independent Modified Reg. Guide 1.60 spectrum and the soil spectrum of Newmark-Hall.

TABLE 5-2

SPECTRUM AMPLIFICATION FACTORS FOR HORIZONTAL ELASTIC RESPONSE

(Newmark and Hall, 1982)

Damping,	One Sigma (84.1%)			Median (50%)		
% Critical	A	V	D	A	V	D
0.5	5.10	3.84	3.04	3.68	2.59	2.01
1	4.38	3.38	2.73	3.21	2.31	1.82
2	3.66	2.92	2.42	2.74	2.03	1.63
3	3.24	2.64	2.24	2.46	1.86	1.52
5	2.71	2.30	2.01	2.12	1.65	1.39
7	2.36	2.08	1.85	1.89	1.51	1.29
10	1.99	1.84	1.69	1.64	1.37	1.20
20	1.26	1.37	1.38	1.17	1.08	1.01

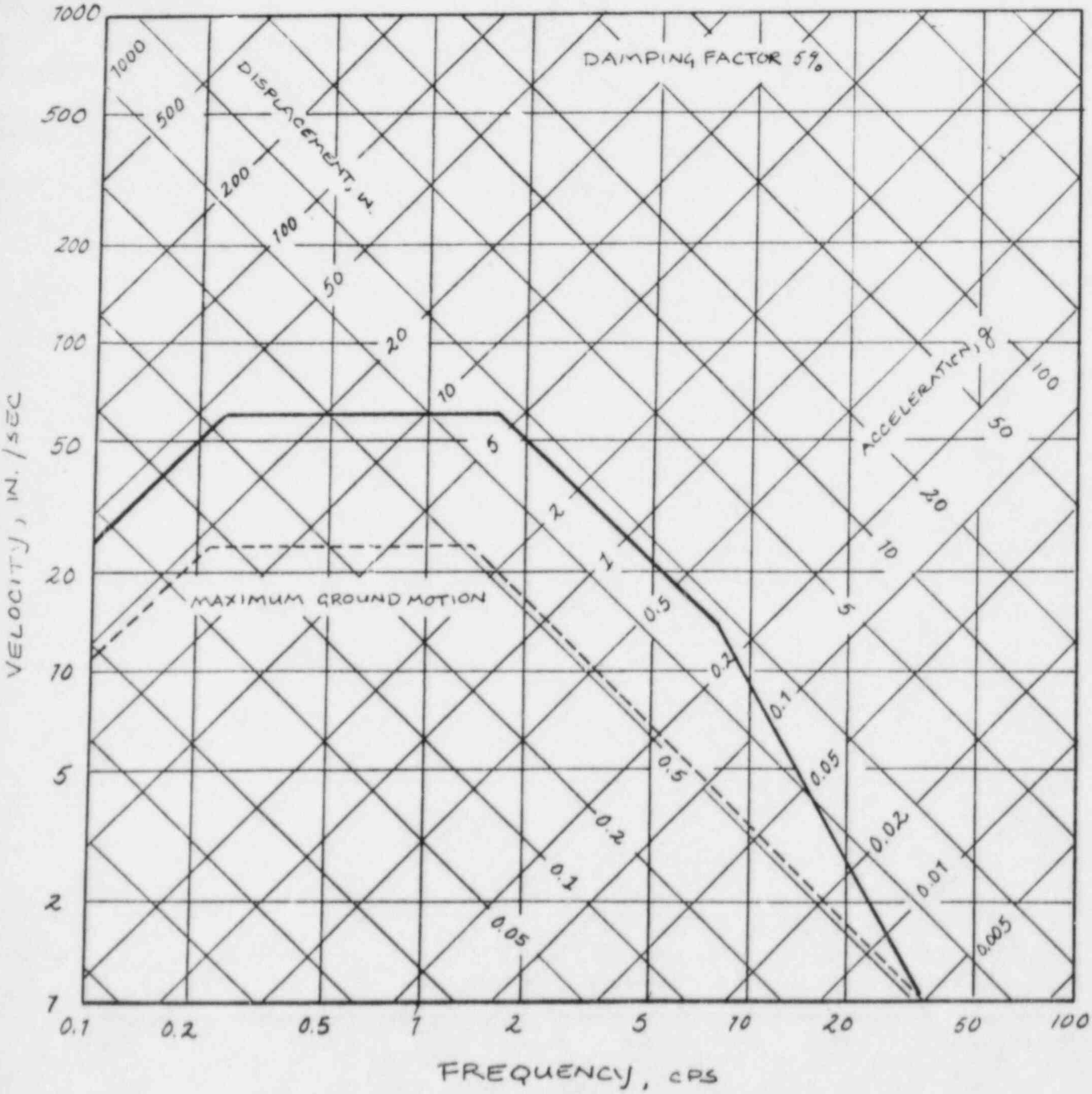


Fig. 5-3. Elastic design spectrum, horizontal motion, for 0.5g maximum acceleration, 5% damping, one sigma cumulative probability (Newmark and Hall, 1982).

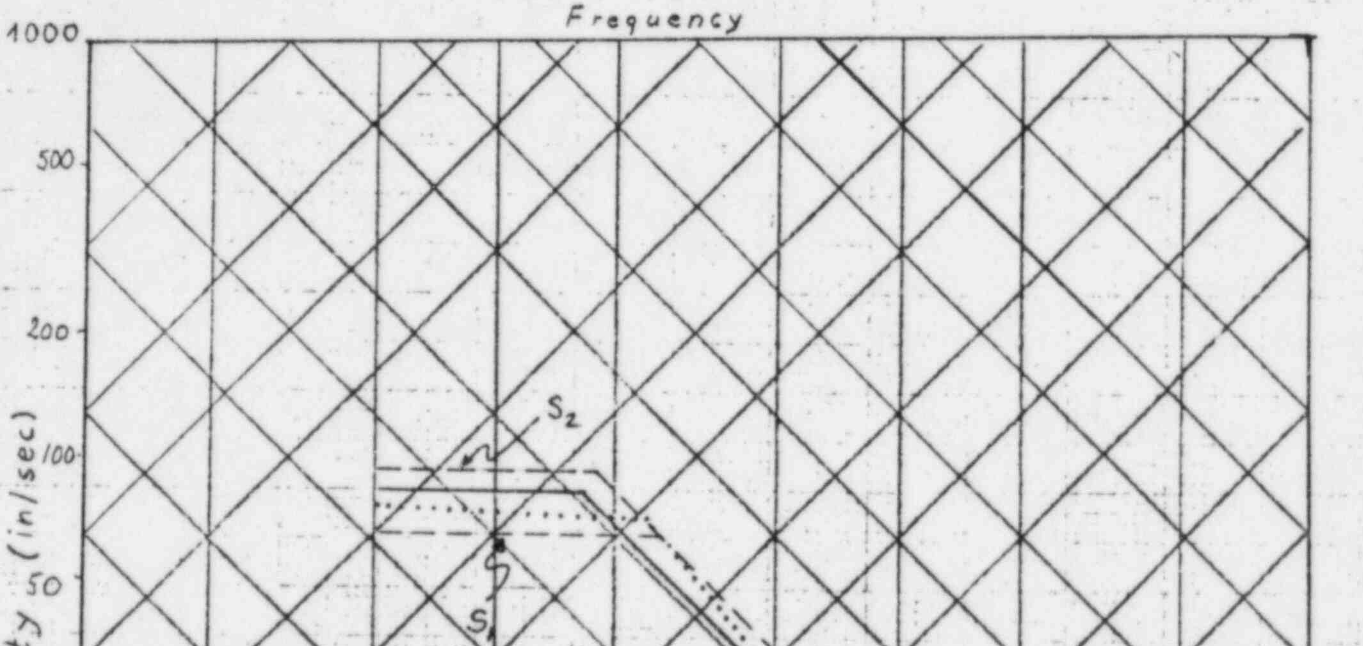


Fig. 5.4 Comparison of median spectral shape models for competent soil conditions (PGA = 1g, Damping = 5%)

——— Newmark-Hall
– – – ATC
· · · · · Modified Reg. Guide 1.60

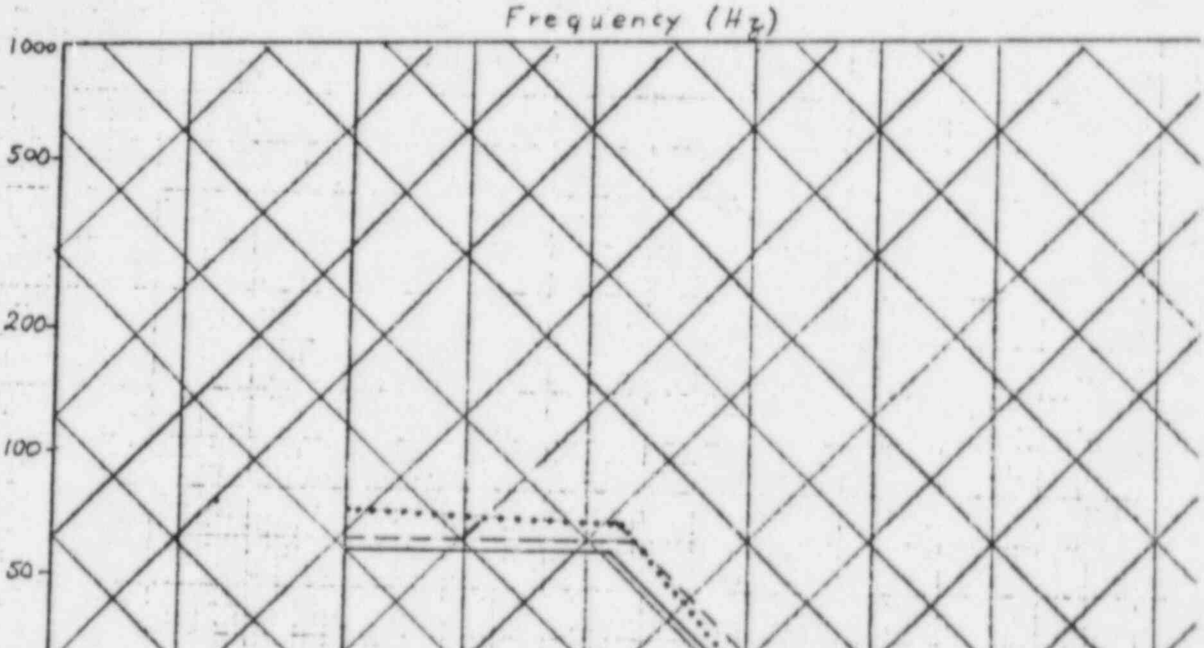


Fig. 5.5 Comparison of median spectral shape models for rock (PGA = 1 Damping = 5%)

——— Newmark-Hall
– – – ATC
······ Modified Reg. Guide 1.60

6.0. EASTERN U.S STRONG-MOTION DATA

There is very little strong-motion data available in the EUS. Table 6-1 summarizes what data are currently available for earthquakes of $m_b \geq 3.0$. The recent New Brunswick aftershocks and Gaza, New Hampshire earthquake have substantially increased this data set from the three earthquakes that had been recorded prior to 1983.

In Figures 6-1 to 6-3, we compare selected maximum values of horizontal PGA, listed in Table 6-1, with the ground motion model of Nuttli App. C-A. Fig. 6-1 presents data from the New Brunswick aftershock of March 31, 1982 (m_b=4.8), Fig. 6-2 presents data from the Gaza, N.H., earthquake (m_b = 4.7), and Fig. 6-3 presents data from four New Brunswick aftershocks of m_b = 4.0-4.6.

To facilitate further comparisons, horizontal PGA data listed in Table 6-1 are plotted in groups of one-half magnitude units in Figures 6-4 to 6-7. These groups represent magnitude ranges of 3.0-3.4, 3.5-3.9, 4.0-4.4, and 4.5-5.0. These plots are drawn at the same scale as those displaying the ground motion models in Section 4. We have included clear copies of these data plots so that they may be easily overlain on any plot in Section 4 to facilitate comparison of the various ground motion models with these data.

Table 6-1

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
6/13/75	New Madrid	4-4.25	6	S83W	43		Herrmann (1977)
New Madrid Area		D=9		Down	31		
				S02E	64		
3/25/76	Arkabutla	5.0	99	S28W	41		
0041 UT	Dam, Ms			Down	10		
	Toe	D=12		S62E	22		
	Crest		99	S79W	21		
				Down	6		
				S62E	10		

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	Right abut.		99	S28W	11		
				Down	6		
				S62E	11		
	Tiptonville TN		130	S70W	11		
				Down	12		
				S20E	17		
	New Madrid MO		131	S88W	13		
				Down	10		
				S03E	11		

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	Wappapello	5.0	150	S38W	10		
	Dam Mo	D=12		Down	5		
	Rt. Toe			S52E	12		
	Right		150	S38W	6		
	Crest			Down	5		
				S52E	6		
3/25/76	Arkabutta	4.5	99	S28W	10		
0100 UT	Dam			Down	4		
	Left Toe	D=14		S62E	5		

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
3/31/82	Holmes	4.8	6	L	178	1.3	Weichert et al (1982)
New Brunswick	Lake			V	151	0.5	
				T	340	1.4	
	Mitchell		4	L	149	1.8	The acceleration
	Lake Rd.			V	571	2.9	values given are
				T	230	1.9	corrected values and are often significantly
	Loggie		6	L	292	1.8	higher than the raw
	Lodge			V	302	1.8	uncorrected records.
				T	564	4.1	

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	Indian		3	L	417	2.7	
	Brook			V	144	0.9	
				T	405	3.11	
	Bear Lakes		12	L	58	0.4	These are shallow
				V	-	-	earthquakes with
				T	138	1.1	depths of 0--4 km
4/2/82	Mitchell	4.3	4	L	66	0.3	Late trigger
New Brunswick	Link			V	54	0.3	Missed Most
	Road			T	77	0.5	of record

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	Bear Lakes		12	L	-	-	
				V	-	-	
				T	44	0.4	
4/11/82	Bear Lakes	4.1	12	T	77	0.5	Late Trigger
4/28/82	Holmes Lake	3.4	6	L	74	0.3	Late Trigger
				V	41	0.2	
				T	56	0.3	

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
5/6/82	Holms	4.0	6	L	42	0.3	Weichert et al. (1982)
New Brunswick	Lake			V	24	0.2	
				T	71	0.7	Late Trigger
	Mitchell		4	L	54	0.4	
	Lk. Rd.			T	176	0.6	
				V	33	0.2	
	Loggie		7	L	115	1.4	
	Lodge			V	66	0.7	
				T	146	1.8	

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
7/28/82	Indian Brook	3.7	1	L	300		
				V	180		
				T	230		
6/16/82 New Brunswick	Mitchell Lake Rd.	4.6	25	L	48	0.3	
				V	26	0.2	
				T	10	0.08	
	Indian Brook		27	L	15	0.2	
				V	27	0.2	
				T	17	0.1	

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
New Brunswick	7A	3.5	8	V	83	0.4	Cranswick et. al
1/17/82		D=3.5		H1	83	1.2	(1982)
13:33:56.2GMT				H2	60	0.9	A number of recordings
	8A		10	V	18	0.1	were made for small
				H1	18	0.2	earthquakes. Only the
				H2	14	0.2	largest for which an
							estimate of the
							magnitude is
							available, is listed
1/19/82	Franklin	4.7	8	L	288		Toksoz (1982) and
Gaza, NH	Falls Dam	D=5		V	173		digitized records
	Abut.			T	540		obtained from the NRC
	Franklin		8	L	141		
	Falls Dam			V	271		
	Downstream			T	378		

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	Franklin Falls Dam Crest		8	L	124		
				V	114		
				T	307		
	Union Village Dam Down-stream		60	L	37		
				V	29		
				T	23		
	Abutment		60	L	9		
				V	6		
				T	8		
	Crest		60	L	22		
				V	23		
				T	25		

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	North Hart Dam Abut.		61	L	11		
				V	4		
				T	7		
	Crest		61	L	37		
				V	16		
				T	38		
	N. Springfield Dam Downstream		76	L	31		
				V	14		
				T	23		
	Crest		76	L	24		
				V	22		
				T	22		

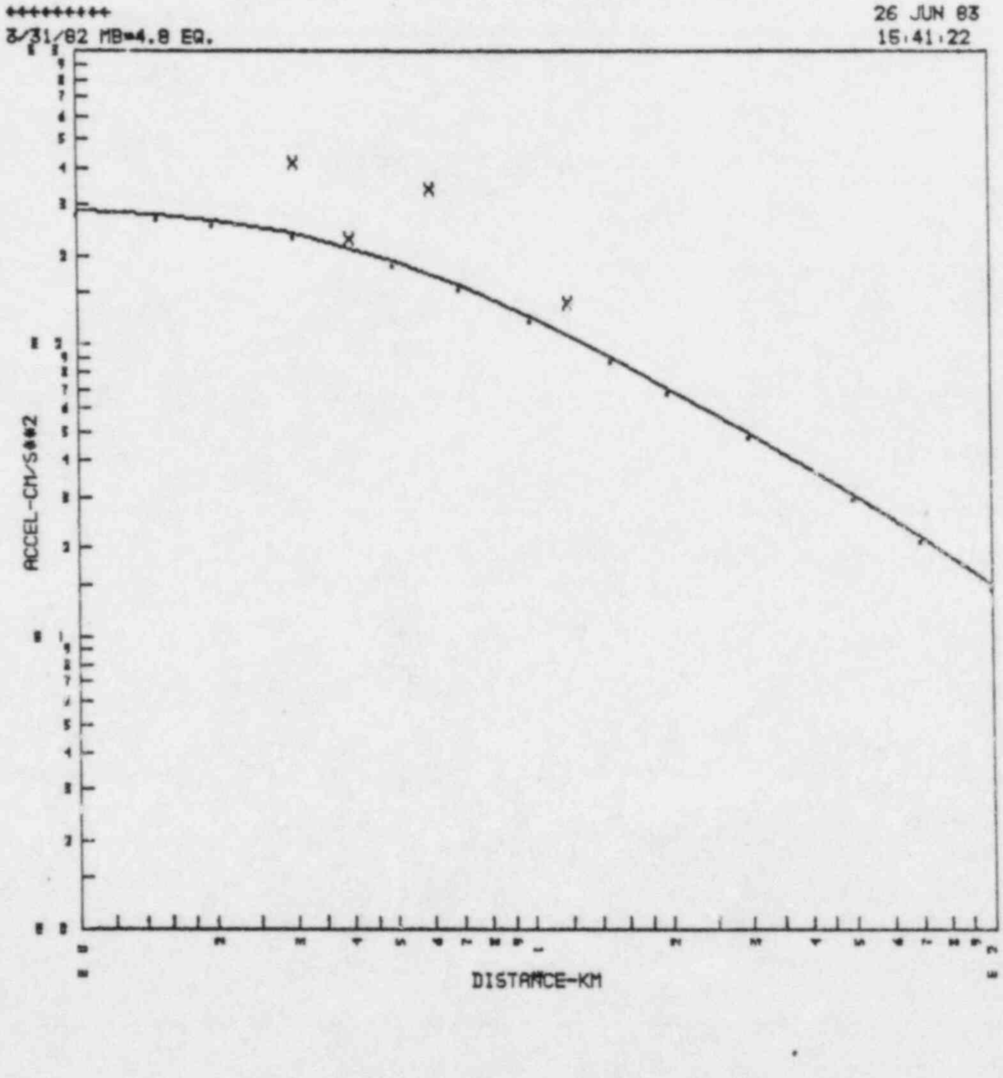


Figure 6-1 Nuttli's (App. C-A) model compared to data from the New Brunswick aftershock of 3/31/82 (m_b = 4.8).

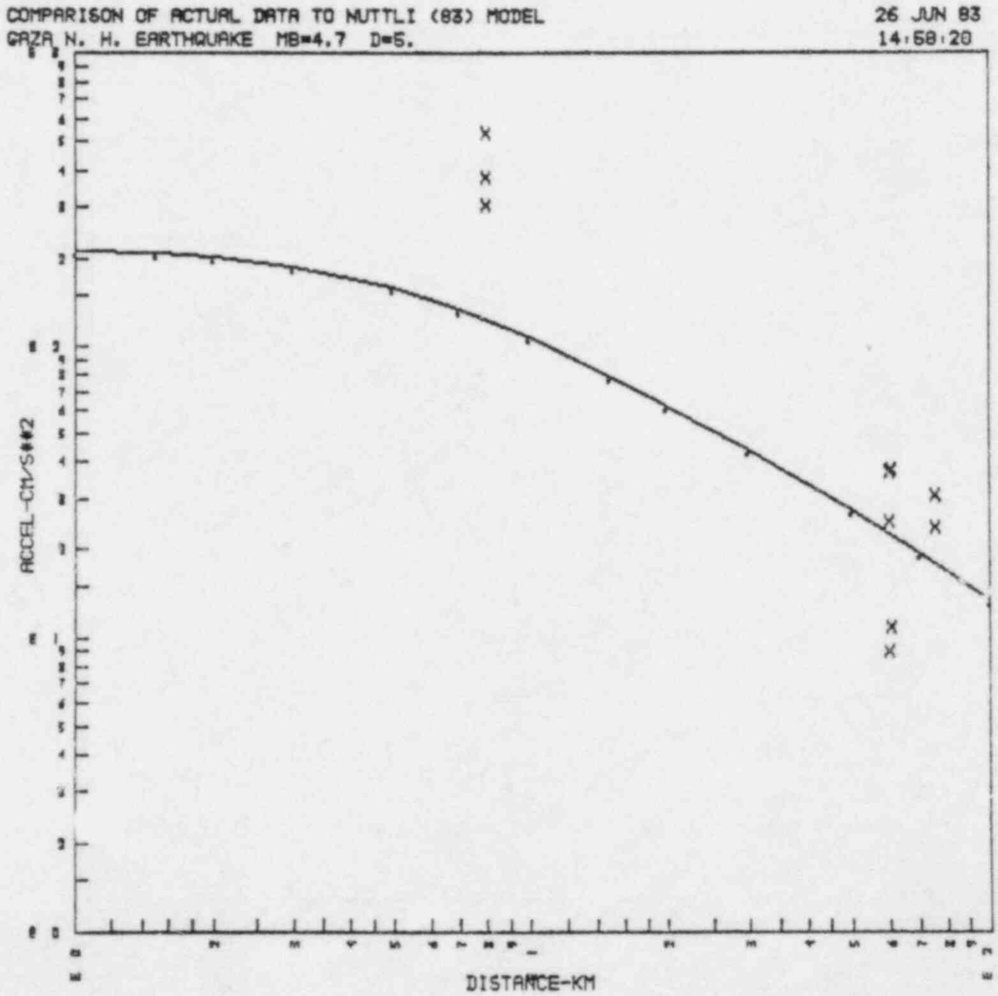


Figure 6-2 Nuttli's (App. C-A) model compared to data from the Gaza, N.H., earthquake ($m_b = 4.7$).

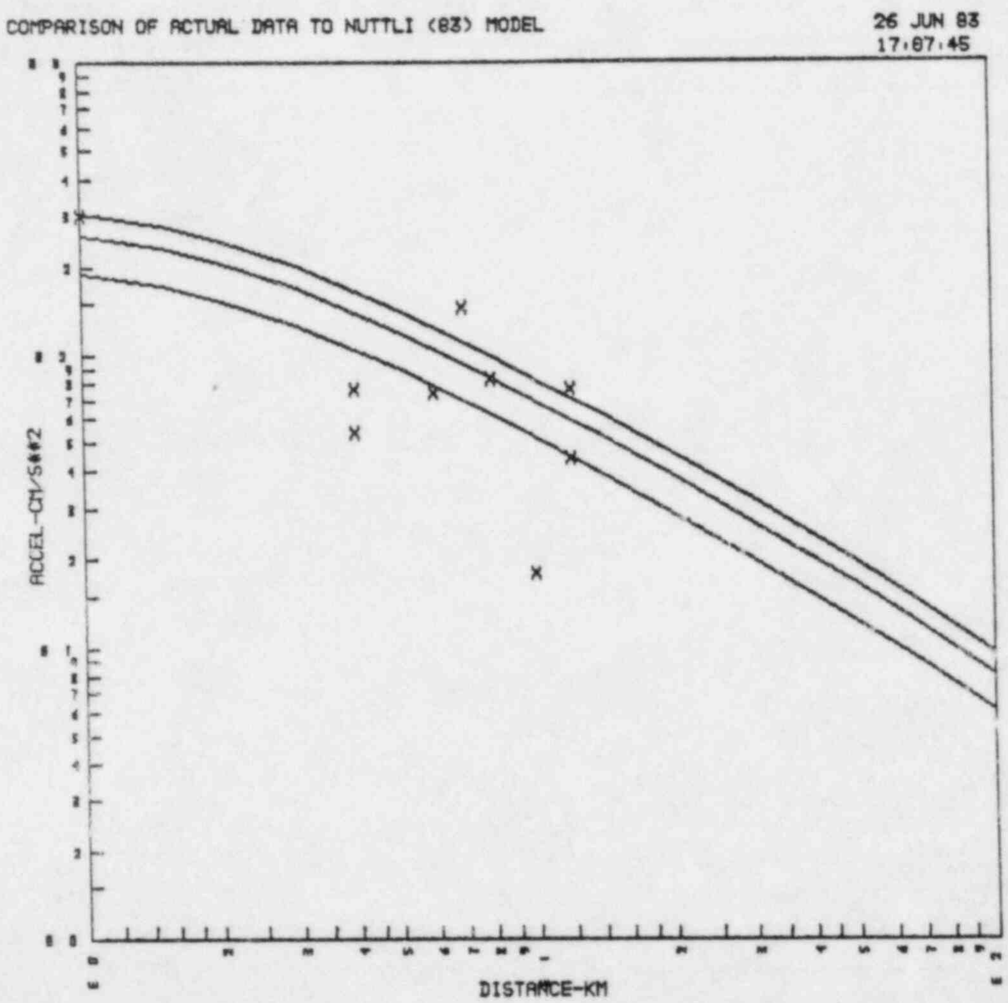


Figure 6-3 Data from New Brunswick aftershocks (m_b = 4.0 - 4.6) compared to Nuttli's (App. C-A) model for m_b = 3.5, 4.0, 4.3 D=2km.

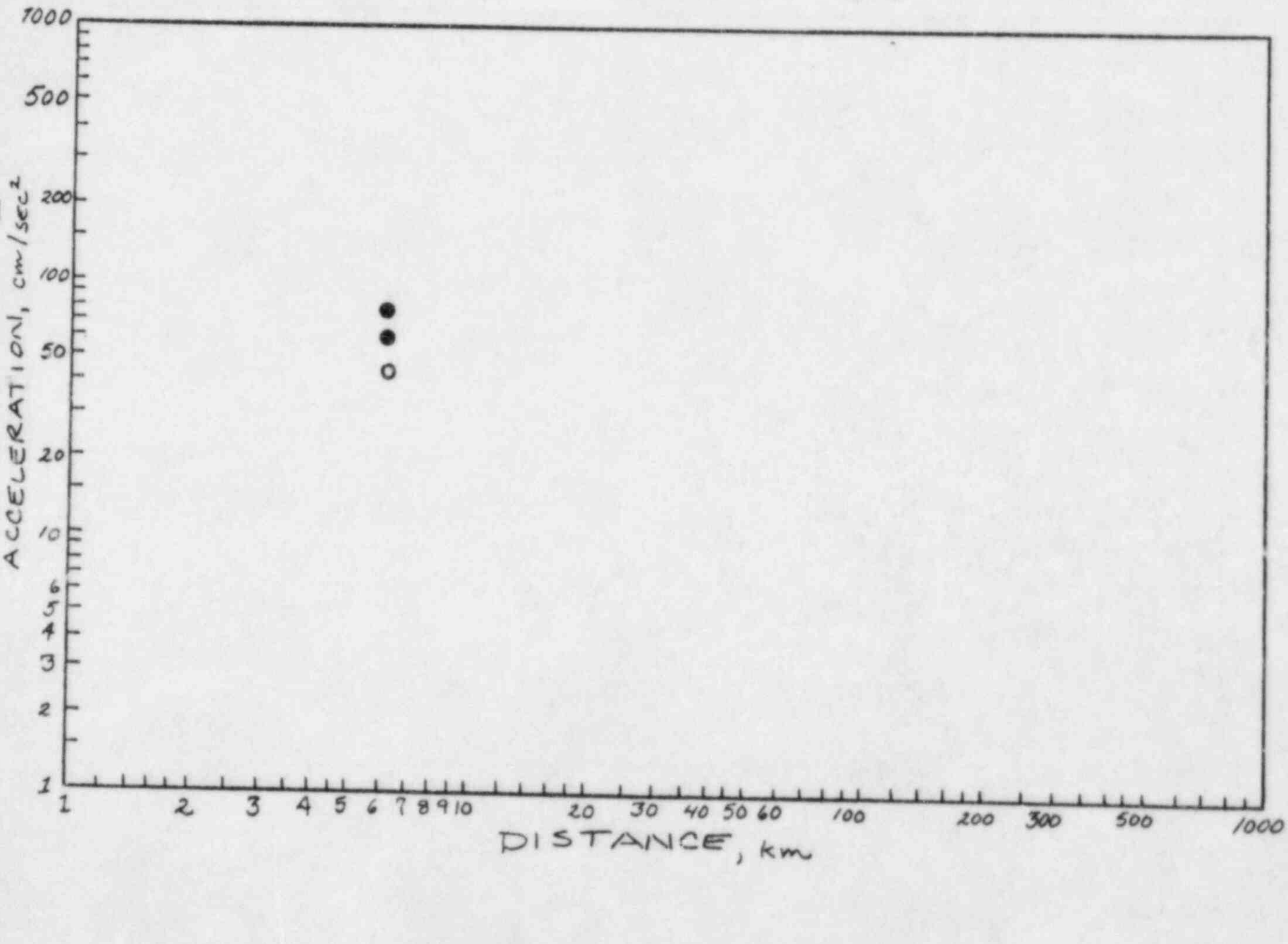


Figure 6.4 EUS strong motion data from earthquakes of m_b = 3.0 - 3.4.

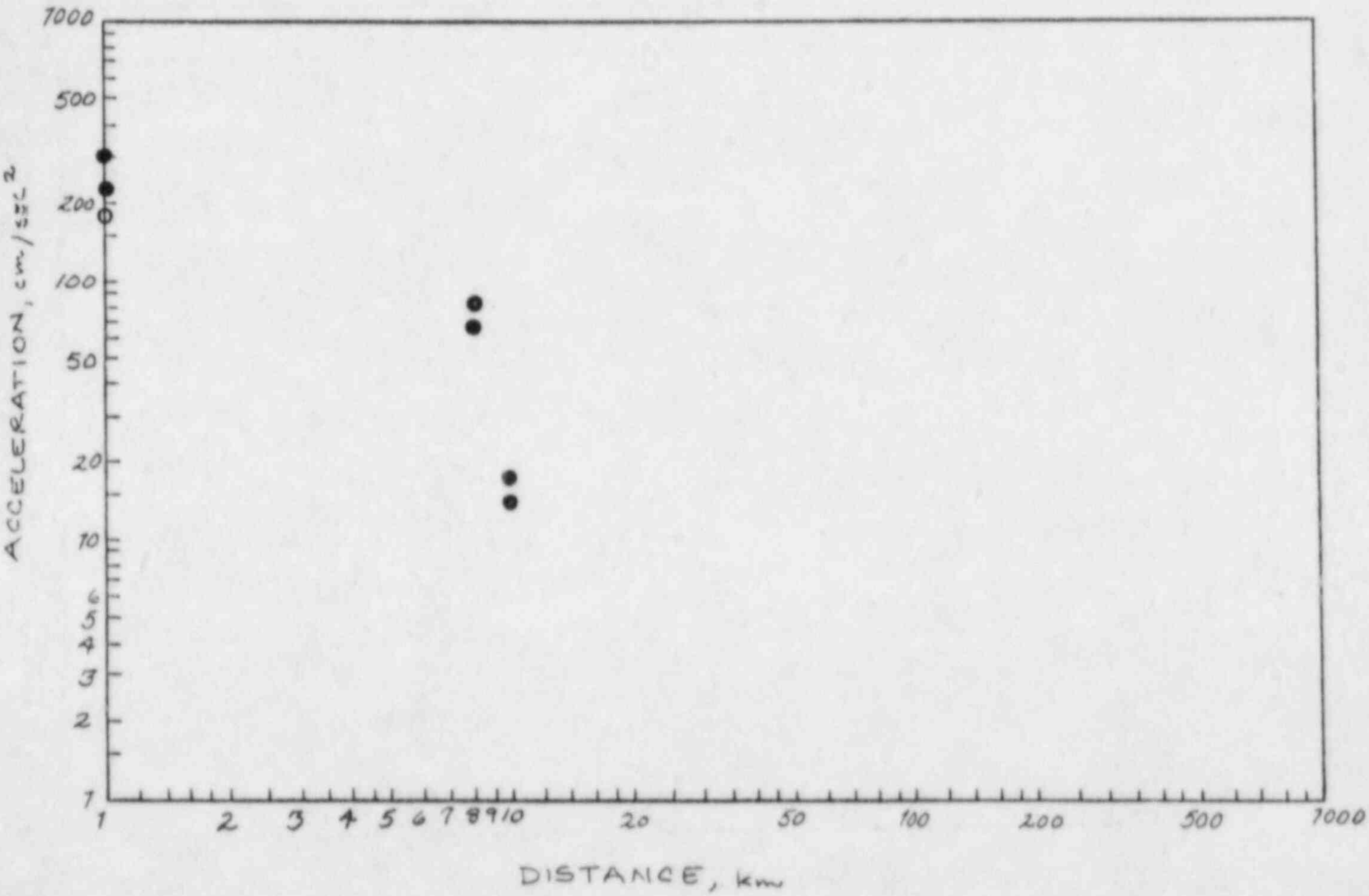


Figure 6.5 EUS strong motion data from earthquakes of m_b = 3.5 - 3.9.

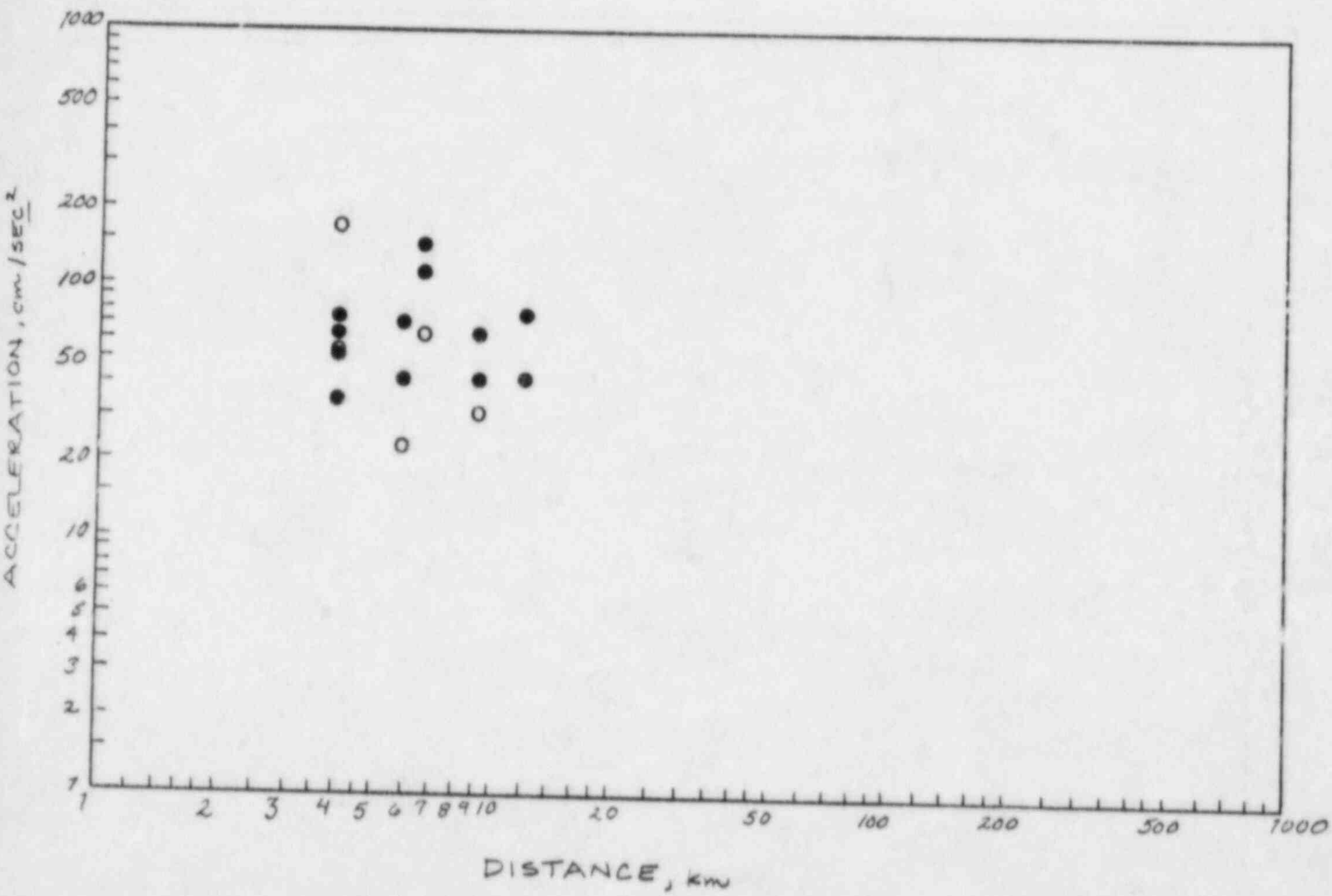


Figure 6.6 EUS strong motion data from earthquakes of m_b = 4.0 - 4.4.

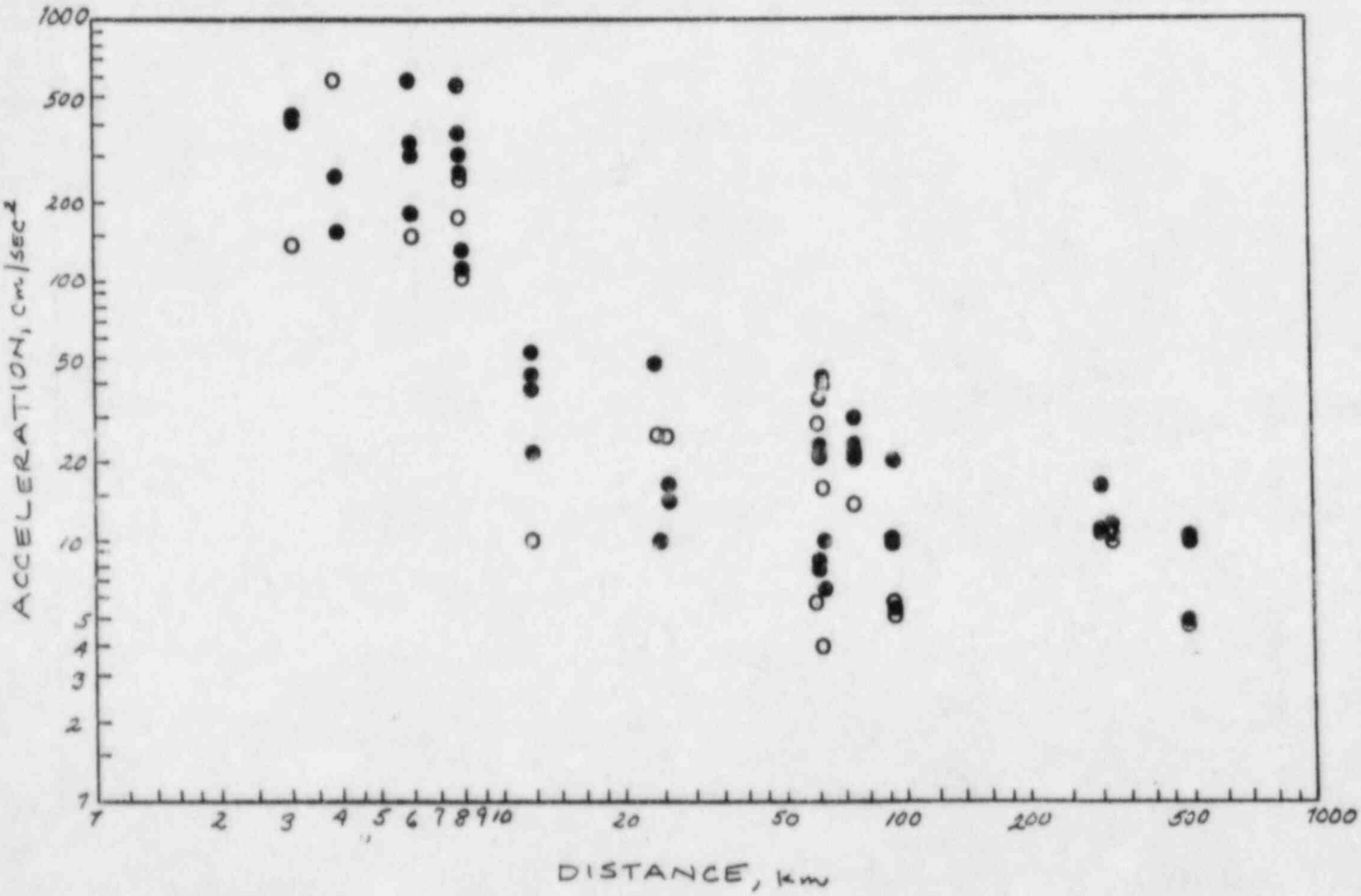


Figure 6.7 EUS strong motion data from earthquakes of m_b = 4.5 - 5.0.

7.0 QUESTIONNAIRE

7.1 INTRODUCTION

As part of the seismic hazard characterization of the Eastern United States, it is necessary to select an appropriate set of ground motion models to be used in assessing the seismic hazard at a specified site. This questionnaire is designed to elicit your opinion about the selection of the most appropriate models.

The previous sections contain a general discussion, based primarily on PCA, of EUS ground motion models which we would like you to consider in making your recommendations for the most appropriate models. We also will ask you to provide additional models if you feel they are needed. The collection of models chosen for your consideration were based on the discussion during the meeting of the panel, January 11-13, 1983, our review of the literature, and our judgment of the validity of the models to describe the attenuation of seismic energy and the ground motion at locations throughout the EUS.

As discussed in the previous sections, we have found it appropriate to partition the available ground motion models into two major categories:

1. Intensity Based Models

   Models based on using intensity as an intermediary variable to model ground motion as a function of the earthquake parameters. Most such models involve a combination of

   - o an intensity-attenuation relation, $I_s = F(I_o,R)$, which relates site intensity to source intensity, and

   - o a ground motion parameter-site intensity relation, GMP = $G(I_s,M,R)$ which relates ground motion parameters to site intensity and, perhaps, other earthquake characteristics such as magnitude and distance.

2. Direct Models

   Models based on using available data to model directly the ground motion parameter in terms of the earthquake parameters such as magnitude and source-to-site distance. Such models are generally based on the "theoretical attenuation curve"

   $$GMP = K(M)R^{-a} \exp(-\gamma R)$$

   where γ is the absorption coefficient and K(M) is a scale factor which is often expressed as a function of magnitude.

The former category, the Intensity Based Models, have been subdivided into five subcategories:

1-1. <u>No Weighting</u>: model combinations

$$I_s = F(I_o,R)$$
$$GMP = G(I_s)$$

in which the ground motion parameter is related to site intensity only.

1-2. <u>Distance Weighting</u>: model combinations

$$I_s = F(I_o,R)$$
$$GMP = G(I_s,R)$$

in which the ground motion parameter is related to site intensity and source-to-site distance.

1-3. <u>Magnitude Weighting</u>: model combinations

$$I_s = F(I_o,R)$$
$$GMP = G(I_s,M)$$

in which the ground motion parameter is related to site intensity and source magnitude.

1-4. <u>Magnitude and Distance Weighting</u>: model combinations

$$I_s = F(I_o,R)$$
$$GMP = G(I_s,M,R)$$

in which the ground motion parameter is related to site intensity, source magnitude, and source-to-site distance.

1-5. <u>Semi-Empirical</u>: models

$$GMP = H(M,R)$$

relating the ground motion parameter to earthquake magnitude and distance, but based on using intensity as an intermediary variable.

Note that subgroups 1-1 through 1-4 involve a pair of models which, in our hazard analysis, will be combined to relate the ground motion parameter to the earthquake parameters M and R. Since the intensity-attenuation model is derived independently of the ground motion parameter-site intensity model, any one of a number of intensity models can be combined with any of the ground motion parameter models.

The latter category group, the Direct Models, have been subdivided into two subcategories, based on the parameters which are expected to vary between the WUS and the EUS:

- o models in which only the absorption coefficient γ (or the quality factor Q) is assumed to be different for WUS and EUS;
- o models in which both the absorption coefficient γ and the scale parameter K(M) varies between the WUS and EUS.

Considering all possible combinations, we have identified 59 models for the peak ground acceleration PGA. Ideally, for each of these there would be a corresponding model for PGV and a corresponding set of spectra models. Unfortunately, not all PGA models have a corresponding model for PGV and there are only a few spectra models. Ideally, the same type of model would be used for all 3 parameters in the hazard analysis. However, to give you as much flexibility as possible in choosing the most appropriate models we will ask you to rank the models separately for PGA, PGV and spectra.

In characterizing the seismicity within a zone, the earthquake size is expressed in either magnitude or epicentral intensity. To estimate the hazard at a site it is necessary to assess the hazard based on each of the ground motion models. Since some ground motion models are expressed in terms of epicentral intensity and others in magnitude, a conversion of magnitude scales is required at some level. After consideration of the alternatives, we have chosen to make this conversion at the ground motion level. Thus, it is necessary to express each ground motion model in terms of both epicentral intensity and magnitude. To accomplish this conversion, we asked each member of our EUS Seismicity Panel to provide the proper conversions between scales. Since you may not feel that a ground motion model expressed in epicentral intensity to be as appropriate when converted to a model involving magnitude or vice versa, we will be asking you to select a separate set of models for intensity and magnitude.

Another issue which must be addressed in the selection of ground motion models is the question of the distance measure. Our hazard analysis is based on treating earthquakes as point sources so that the distance R in the ground motion model is treated as an epicentral distance. It must be recognized that some of the ground motion models are based on fault distance rather than epicentral distance. Thus, our treatment of R as epicentral distance may influence your choice of appropriate models. See Section 1.0 for additional discussion on this issue.

Finally, as discussed in Section 2.4, the choice of the ground motion model has a direct influence on the outcome of the hazard analysis. This influence is a function of the model as well as the extent of the random variation in the ground motion parameter (GMP). For purposes of the hazard analysis, we are approximating the random variation in the ground motion parameter by a lognormal distribution for which the ground motion model describes the expected value of the logarithm of GMP, given the earthquake parameters. Random variation is the inherent variation in GMP about its expected value due to a lot of unidentifiable factors. The extent of the random variation in GMP is described by the standard deviation of the logarithm of GMP (which is approximately the coefficient of variation of GMP). We will be asking you to estimate this standard deviation. In making an estimate it is important to recognize that the standard deviation associated with a specific ground motion model usually has both a random variation component as well as a modeling uncertainty component (see Section 2.4 of the accompanying report). It is the random component of this uncertainty that is of interest in this study. The modeling uncertainty is accounted for in the use of several models.

7.2 SELECTION PROCESS

We have identified four regions in the EUS, shown in Fig.7.1, for which it may be appropriate to change the values of some of the model coefficients, e.g., γ in the direct models. Also, a particular ground motion model may be appropriate for one region but not applicable in another. Thus, we will be asking you to select appropriate models for each of the four regions. We recognize that the actual physical situation is much more complex and the boundaries cannot be simply drawn, however, at this stage of the analysis we will limit the complexity of our model by partitioning the EUS into the four identified regions.

We have limited our analysis to the use of two "magnitude" scales, intensity (MMI) and body wave magnitude (m_b). It should be noted that (as discussed in Section 3.4) we are assuming m_{bLg} and m_b to be essentially equivalent. For simplicity we use the term m_b even though most of the magnitudes in the catalogs are in fact m_{bLg}.

Weighing the merits of using all the models available to describe ground motion versus (1) our capability to handle a large number of models in the hazard analysis and (2) your ability to reasonably distinguish between the models so as to rate them for their appropriateness has led us to the following method for eliciting your opinion about the ground motion models.

We have divided the ground motion models into seven subcategories identified in Section 7.1, five subgroups of Intensity Based Models and two subgroups of Direct Models. The models in each subcategory are catalogued in Section 7.3. For each of the two magnitude scales in each of the four regions (a total of 8 combinations) we would like you to:

For peak ground acceleration and peak ground velocity,

- o Select from among all the models the one model which you consider the most appropriate. This is labeled the Best Estimate Model. (Note: if this model is an Intensity Based Ground Motion Model, the Best Estimate would consist of 2 models, an attenuation model and a GMP model.)

- o For each of the seven (7) classes of models identified above, select the most appropriate model within the subcategory. Assign a relative "level of confidence" to each of the models. (Note: the sum of the confidences over the seven subcategories should equal 1.0.)

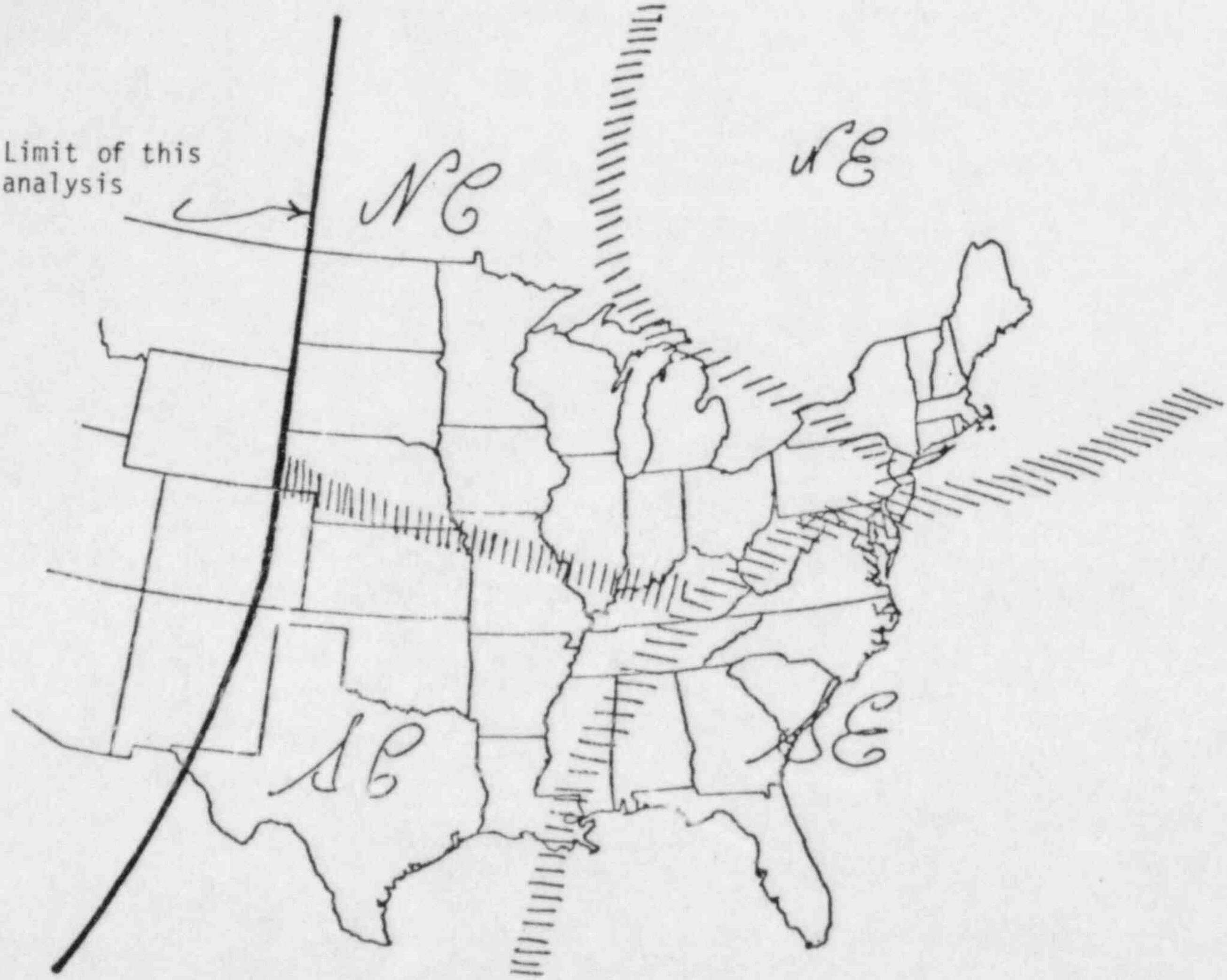


Fig. 7.1 Identification of four regions of the Eastern U.S. based on a compilation of the seismic zonation expert maps developed in this study, combined with a map of Q_o-contours from Singh & Herrmann (1983).

The "level of confidence" we ask you to express for each model is considered to reflect your degree of belief that the data, the modeling process, your knowledge of seismic attenuation and ground motion and any other relevant information supports the use of the specific model to describe ground motion within the given region. We expect that your "level of confidence" will reflect, to some degree, your opinions about the use of each of the different types of models (based on different modeling philosophies) for modeling ground motion. At a later date we will ask you to provide weights for all of the models (including any that different panel members may suggest).

For the spectra models,

- o Select the set (one for each frequency) of models which you consider most appropriate.
- o Assign a relative "level of confidence" to each of the models (Note: a zero level of confidence is acceptable).

7.3 MODELS

7.3.1 Peak Ground Acceleration

I. Intensity Based Models

Except for the models in Subcategory I-5, a ground motion model is a combination of (a) an intensity-attenuation model and (b) a ground motion parameter-site intensity model. The latter models form the basis of the Subcategories I-1 through I-4 The former models are:

A1. Bollinger (Charleston, South Carolina earthquake)

$$I_s = 2.87 + I_o - 0.00052R - 1.25 \ln R \quad , R \geq 10$$

$$I_s = I_o \quad , R < 10$$

A2. Bollinger (Giles County, Virginia earthquake)

$$I_s = 0.35 + I_o - 0.0038R - 0.34 \ln R$$

A3. Modified Gupta-Nuttli (Central U.S.)

$$I_s = 3.2 + I_o - 0.0011R - 1.17 \ln R \quad , R \geq 15$$

$$I_s = I_o \quad , R < 15$$

A4. LLNL (Southern Illinois earthquake)

$$I_s = 0.35 + I_o - 0.0046R - 0.31 \ln R$$

A5. Weston Geophysical Corporation (Ossippee earthquake)

$$I_s = 0.441 + I_o - 0.004R - 0.67 \ln R$$

Subcategory I-1. No Weighting (Equation number from Section 4)

G11. LLNL (1983) (Eq. 4-8)

$$\ln(a) = -1.69 + 0.86\ I_s$$

G12. LLNL (1983) (Eq. 4-9)

$$\ln(a) = -2.32 + 0.96\ I_s$$

G13. McGuire (1977) (Eqs. 4-3 and 4-7)

$$\ln(a) = \begin{cases} -0.83 + 0.85\ I_s & \text{(medium sites)} \\ 0.27 + 0.6\ I_s & \text{(soft sites)} \end{cases}$$

G14. Trifunac and Brady (1975) (Eq. 4-5)

$$\ln(a) = 0.032 + 0.69\ I_s$$

G15. Murphy and O'Brien (1977) (Eq. 4-6)

$$\ln(a) = 0.58 + 0.58\ I_s$$

G16. Trifunac (1976) (Eq. 4-4)

$$\ln(a) = -0.19 + 0.67\ I_s + 0.33S$$

S = 0 (alluvium)
S = 1 (intermediate rock sites)
S = 2 (basement rock sites)

Subcategory I-2. Distance Weighting

G21. Bernreuter (1981a) (Eq. 4-13)

$$\ln(a) = 1.79 + 0.57\ I_s - 0.323 \ln R$$

G22. McGuire (1977) (Eqs. 4-11 and 4-12)

$$\ln(a) = \begin{cases} 1.45 + 0.68\ I_s - 0.359 \ln R & \text{(medium sites)} \\ 2.01 + 0.51\ I_s - 0.313 \ln R & \text{(soft sites)} \end{cases}$$

Subcategory I-3. Magnitude Weighting

G31. Bernreuter (1981a) (Eq. 4-15)

$$\ln(a) = 0.96 + 0.63\ I_s - 0.13\ M_L$$

Subcategory I-4. Magnitude and Distance Weighting

G41. Murphy and O'Brien (1978) (Eq. 4-16)

$$\ln(a) = 1.38 + 0.32\ I_s + 0.55\ M_L - 0.68 \ln R$$

Subcategory I-5. Semi-Empirical

G51. Battis (1981) (Eq. 4-29)

$$\ln(a) = 3.16 + 1.24\ m_b - 1.24 \ln (R + 25)$$

G52. Nuttli and Herrmann (1978) (Eq. 4-23)

$$\ln(a) = 1.47 + 1.2\, m_{bLg} - 1.02 \ln R; \; R > 15 \text{ km}$$

G53. Weston Geophysical Corp. (Eq. 4-31)

$$\ln(a) = 1.47 + 1.1\, m_b - 0.0017R - 0.88 \ln R$$

II. Direct Models

Subcategory II-1. γ Variable

D11. Campbell (1981b) (Eq. 4-41)

$$\ln(a) = 2.64 + 0.79M - (0.023 - 0.0048M + 0.00028\, M^2)R - 0.862 \ln [R + 0.0286 \exp(0.778M)]$$

where R = closest distance to fault rupture

D12. Campbell (1981b) (Eq. 4-42)

$$\ln(a) = 4.39 + 0.922M - 0.023R + 0.0048RM - 0.00028RM^2 - 1.27 \ln (R + 25.7)$$

where R is epicentral distance, and for both D11 and D12

$$M = \begin{cases} 1.02\, m_b + 0.30 & (m_b < 5.59) \\ 1.64\, m_b - 3.16 & (m_b \geq 5.59) \end{cases}$$

D13. Campbell (1982) (Eq. 4-48)

$$\ln(a) = -4.29 + 0.777M - 0.797 \ln[R + 0.012 \exp(0.898M)] - \gamma R$$

where R = closest distance to fault rupture and
γ = frequency-dependent absorption coefficient (e.g. Singh and Herrmann, 1983)

D14. Nuttli (1979) (Eq. 4-34)

$$\ln(a) = 1.481 + 1.15\, m_b - (0.0136 - 0.00172\, m_b)R - 0.833 \ln R$$

D15. SSMRP (Eq. 4-37)

$$\ln(a) = 3.99 + 0.59\, m_b - 0.003\, (R^2 + 28.09)^{1/2} - 0.833 \ln (R^2 + 28.09)^{1/2}$$

where R = closest distance to surface projection of fault rupture.

Subcategory II-2. γ and m_b Variable

D21. Nuttli (App. C-A)

$$\ln(a) = \begin{cases} 3.892 + 0.576\, m_b - 0.834 \ln [R^2 + \exp(-4.371 + 1.308\, m_b)]^{1/2} - 0.00281\, (R-1) & m_b \leq 4.4 \\ 1.313 + 1.15\, m_b - 0.833 \ln [R^2 + \exp(-7.968 + 2.100\, m_b)]^{1/2} - 0.00281\, (R-1) & 4.4 < m_b \leq 7.4 \end{cases}$$

7.3.2 Peak Ground Velocity

I. Intensity-attenuation models, A1 through A5 are the same as in Section 7.3.1.

Subcategory I-1. No Weighting

GV11. McGuire (1977)

$$\ln(v) = \begin{cases} -4.02 + 0.952\ I_s & \text{(medium sites)} \\ -1.51 + 0.543\ I_s & \text{(soft sites)} \end{cases}$$

GV12. Trifunac (1976)

$$\ln(v) = -2.25 + 0.67\ I_s + 0.032\ S$$

S = 0 (alluvium)

S = 1 (intermediate rock sites)

S = 2 (basement rock sites)

GV13. Trifunac and Brady (1975)

$$\ln\ (v) = -1.45 + 0.58\ I_s$$

Subcategory I-2. Distance Weighting

GV21. Bernreuter (1981a)

$$\ln\ (v) = -2.94 + 0.76\ I_s + 0.06\ \ln R$$

GV22. McGuire (1977)

$$\ln(v) = \begin{cases} -3.61 + 0.923\ I_s - 0.064\ \ln R & \text{(medium sites)} \\ -1.11 + 0.521\ I_s - 0.072\ \ln R & \text{(soft sites)} \end{cases}$$

Subcategory I-3. Magnitude Weighting

GV31. Bernreuter (1981a)

$$\ln(v) = -2.62 + 0.51\ I_s + 0.17\ M_L$$

bcategory I-4. Magnitude and Distance Weighting
(No models)

Subcategory I-5. Semi-Empirical

GV51. Nuttli - Herrmann (1978)
$\ln(v) = -6.72 + 2.3\ m_b - \ln R$

GV52. Western Geophysical Corporation

$$\ln(v) = -0.924 + .95\ m_b - .0023R - .765\ \ln R + .923E_1 + E_2$$

where E_1 and E_2 are random variables with mean zero and standard deviation σ_1 and σ_2. E_1 and E_2 represent the error terms in the fit of site intensity versus source intensity and distance, and the fit of site intensity as a function of magnitude and distance, respectively.

II. Direct Models

Subcategory II-1.

DV11. Nuttli (1979)
This model only appears in the form of a set of curves of velocity versus distance and magnitude. The reader is referred to the publication (Nuttli, 1979).

DV12. SSMRP(a)
$\ln(v) = -7.86 + 2.3\ m_b - C_v R - .835\ \ln R$
where $C_v = .0076 - .00099\ m_b$

DV13. SSMRP(b)
$\ln(v) = -\ .963 + 1.15\ m_b - C_v R - .833\ \ln R$

Subcategory II-2.

DV21. Nuttli (App. C-A)

$$\ln(v) = -3.11 + 1.15 m_b - 0.833\ \ln\ [R^2 + \exp(-4.371 + 1.308\ m_b)]^{1/2} - 0.00122(R-1) \qquad m_b \leq 4.4$$

$$\ln(v) = -8.29 + 2.3\ m_b - 0.833\ \ln\ [R^2 + \exp(-7.968 + 2.100\ m_b)]^{1/2} - 0.00122(R-1) \qquad 4.4 < cm_b < 7.4$$

7.3.3 Response Spectra

RS1 Modified Reg. Guide 1.60 (spectral shape anchored to PGA)
RS2 NBS, 1978 - ATC (spectral shape anchored to PGA)
RS3 Newmark and Hall (1982) (spectral shape anchored to PGA and PGV)
RS4 Bernreuter (1981a): Distance-weighted model

$\ln(SA) = C_1 + C_2 I_o + C_3 R + C_4 \ln R$
where SA = pseudo-absolute acceleration in cm/sec^2

Frequency (Hz)	C_1	C_2	C_3	C_4
25.0	2.35	0.55	-0.0025	-0.542
20.0	2.49	0.55	-0.0025	-0.565
12.5	2.84	0.56	-0.0026	-0.612
10.0	2.98	0.56	-0.0025	-0.605
5.0	2.87	0.56	-0.0026	-0.487
3.3	2.27	0.62	-0.0028	-0.433
2.5	1.60	0.65	-0.0030	-0.346
1.0	-1.21	0.816	-0.0038	-0.100
0.5	-3.19	0.886	-0.0041	0.061

RS5 Bernreuter (1981a) Magnitude-weighted model

$\ln(SA) = C_1 + C_2 I_o + C_3 R + C_4 \ln R$

Frequency (Hz)	C_1	C_2	C_3	C_4
25.0	2.67	0.59	-0.0007	-0.760
20.0	2.73	0.58	-0.0007	-0.761
12.5	3.04	0.57	-0.0007	-0.768
10.0	3.20	0.56	-0.0007	-0.775
5.0	3.84	0.52	-0.0007	-0.740
3.3	3.63	0.57	-0.0007	-0.762
2.5	3.34	0.57	-0.0007	-0.719
1.0	1.23	0.71	-0.0006	-0.637
0.5	-0.34	0.74	-0.0005	-0.536

7.4 QUESTIONS

Based on your opinion of the data and methods used to develop a model, the ability of a model to accurately reflect the attenuation and ground motion within a region, and any other information you deem appropriate to judge the models, please respond to the following questions using the included Questionnaire Reply Forms.

7.4.1 Peak Ground Acceleration

For each of the four regions and two magnitude scales,

Question 1. Among the peak ground acceleration models catalogued in Section 7.3.1, indicate the one model (or attenuation/ground motion pair) which you consider to be the most appropriate ground motion model, i.e., select the "best estimate" model for peak ground acceleration.

Question 2. For each of the seven subcategories (types) of peak ground acceleration models, I-1 through I-5, II-1, and II-2, select the one model within the subcategory which you consider to be most appropriate (Note: for subcategories I-1 through I-4, this should be a pair of models).

Question 3. For each of the seven subcategories, indicate a confidence level which you associate with that type of model.

Notes:
(1) See the discussion of confidence level in Section 7.2
(2) For each region, magnitude scale pair, if $C_1, C_2, \ldots, C_7$ denote the confidence levels for the seven subgroups
- o any C_i can be zero
- o the sum of the C_i's should equal 1.0

Question 4. Indicate any ground motion models for PGA which were not included in the catalogue in Section 7.3.1 and which you consider worthy of consideration by the panel at a future time.

7.4.2 Peak Ground Velocity

For each of the four regions and two magnitude scales,

Question 5 Among the peak ground velocity models catalogued in Section 7.3.2, indicate the one model (or attenuation/ground motion pair) which you consider to be the most appropriate ground motion model, i.e., select the "best estimate" model for peak ground velocity.

Question 6 For each of the seven subcatagories of peak ground velocity models I-1 through I-5, II-1, and II-2, select the one model within the subcatagory which you consider to be most appropriate (Note: for subcatagories I-1 through I-4, this should be a pair of models).

Question 7 For each of the seven subcatagories, indicate a confidence level which you associate with that type of model. (See the Note after Question 3)

Question 8 Indicate any ground motion models for PGV which were not included in the catalogue in Section 7.3.2 and which you consider worthy of consideration by the panel at a future time.

7.4.3 Spectra

Response for each of the four regions and two magnitude scales,

Question 9. Among the response spectra models catalogued in Section 7.3.3, indicate the spectral shape model (or attenuation/spectra pair) which you consider to be the most appropriate response spectra model.

Question 10 For each of the response spectra models in Section 7.33, indicate a confidence level which you associate with that type of model (see the notes after Question 3).

Question 11 Indicate any response spectra models which were not included in the catalogue in Section 7.3.3 and which you consider worthy of consideration by the panel at a future time.

7.4.4 Random Variation

As discussed in Section 7.1, the standard deviation of the error associated with a model includes both a measure of the random variation in the GMP about its expected or average value as well as a measure of the adequacy of the model. It is important in doing the hazard analysis that only the random variation component be used when making the probability calculations. Thus, we need to elicit your opinions about the magnitude of the random variation associated with each of the ground motion parameters.

Since the GMP is a function of earthquake magnitude and distance, we are interested in the random variation in GMP conditional on magnitude and distance. Our hazard analysis assumes that the GMP random variation is independent of magnitude and distance as well as the site, although we do allow for regional variation by asking you to provide your estimates on a regional basis.

Since we will be modeling the random variation in the GMP by a lognormal distribution, we would like you to provide your estimates of the random variation either in terms of

- o the standard deviation of the lnGMP, σ
- o the coefficient of variation of the GMP, COV

Using Table 7.1, included in this Questionaire, for each of the GMP's and each of the four regions, Question 12 Give your best estimate of the random variation (either σ or COV) in the GMP at a site.

Question 13 Give an interval which you believe, with a high degree of confidence, represents the possible range of σ or COV.

Question 14 Do you agree with our choice of the lognormal distribution to describe the random variation in the GMP's? If not, please indicate a distribution which is more appropriate.

7.5 Self-Rating

In our hazard analysis it will be necessary to combine the risks at a site based on the different ground motion models chosen by a panel member as well as combining over the the opinions provided by all panel members. Combining the risks estimate using the different models suggested by an individual member will be based on the confidence levels you provide. To combine over all the panel members we propose to use a weighted average procedure. Of course, this requires an appropriate set of weights.

Although there are several weighting schemes (e.g., equal weights, LLNL derived weights), the set of weights we propose to use is based on your appraisal, i.e., self- rating, of your expertise about the utility of ground motion models.

We recognize some of the weaknesses and difficulties in eliciting and using self-rating, however, most alternative weighting schemes are also subjective and involve some of the same problems as self-rating. Overall, we believe self-rating to be a viable means of developing weights for combining the results derived from your opinions about the ground motion models. Thus, we would like you to indicate your level of expertise with regard to assessing the utility of the ground motion models.

In appraising your level of expertise, we ask that you use a 1-10 scale where low values indicate a low level of expertise and high values a high level of expertise. An integer value is not necessary, although not more than one decimal place (e.g., 7.3) is appropriate.

Question 15. Please indicate your level of expertise with regard to assessing the utility of ground motion models.

Table 7.1
(Questions 12 and 13)

Parameter		Region Northeast	Southeast	North Central	South Central
PGA	Best Estimate:				
	Confidence Bounds:				
PGV	Best Estimate:				
	Confidence Bounds:				

Spectra

A. PEAK GROUND ACCELERATION

	REGION							
	Northeast		Southeast		Northcentral		Southcentral	
Question 1	MMI	m_b	MMI	m_b	MMI	m_b	MMI	m_b
"Best Estimate" Model								
Questions 2 and 3								
I. Intensity Based Models								
I-1. No Weighting								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	(,)
Confidence								
I-2. Distance Weighting								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	
Confidence								
I-3. Magnitude Weighting								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	
Confidence								
I-4. Magnitude + Distance Weighting								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	(,)
Confidence								
I-5. Semi-Empirical								
Model								
Confidence								
II. Direct Models								
II.1. γ Variable								
Model								
Confidence								
II.2 γ K(M) Variable								
Model								
Confidence								

(1) For categories I-1 thru I-4, a ground motion model consists of (a) an intensity-attenuation relation and (b) a PGA site intensity relation.

B. PEAK GROUND VELOCITY

	REGION							
	Northeast		Southeast		Northcentral		Southcentral	
Question 5	MMI	m_b	MMI	m_b	MMI	m_b	MMI	m_b
"Best Estimate" Model								
Questions 6 and 7								
I. Intensity Based Models								
I-1. No Weighting								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	(,)
Confidence								
I-2. Distance Weighting								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	
Confidence								
I-3. Magnitude Weighting								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	
Confidence								
I-4. Magnitude + Distance Weighting								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	(,)
Confidence								
I-5. Semi-Empirical								
Model								
Confidence								
II. Direct Models								
II.1. γ Variable								
Model								
Confidence								
II.2 γ K(M) Variable								
Model								
Confidence								

(1) For categories I-1 thru I-4, a ground motion model consists of (a) an intensity-attenuation relation and (b) a PGV-site intensity relation.

Question 4 Additional Peak Ground Acceleration Models

Question 8 Additional Peak Ground Velocity Models

C. RESPONSE SPECTRA

	REGION							
	Northeast		Southeast		Northcentral		Southcentral	
	MMI	m_b	MMI	m_b	MMI	m_b	MMI	m_b
Question 9								
"Best Estimate" Model								
Question 10								
RS1. Reg. Guide 1.60								
Confidence								
RS2. NBS, 1978 - ATC								
Confidence								
RS3. Newmark-Hall								
Confidence								
RS4. Distance-Weighting								
Confidence								
RS5. Magnitude-Weighting								
Confidence								
RS6 Westermo, et al.								
Confidence								

Question 11 Additional Response Spectra Models

D. RANDOM VARIATION

Questions 12 and 13

		REGION			
		Northeast	Southeast	Northcentral	Southcentral
1. Peak Ground Acceleration					
	Best Estimate				
	"Confidence" Bounds				
Peak Ground Velocity					
	Best Estimate				
	"Confidence" Bounds				
Response Spectra					
	Best Estimate				
	"Confidence" Bounds				

Question 14

Is lognormal distribution an adequate description of random variation?
If no, what is a more appropriate distribution?

E. SELF RATING

Question 15

Self-Rating:

References Cited

S. T. Algermissen, et al., (1976). "A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous U.S.," USGS Open File Rept. 76-416.

S. T. Algermissen, et al., (1982). "Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous U.S.," USGS Open-File Rept. 82-1033.

R. J. Apsel, D. M. Hadley, and R. S. Hart, (1982). "Effects of Earthquake Rupture Shallowness and Local Soil Conditions on Simulated Ground Motions," NUREG/CR-3102 (UCRL-15495).

J. Battis, (1981). "Regional Modification of Acceleration Attenuation Functions," Bull. Seismol. Soc Am., 71, 1309-1321.

D. L. Bernreuter, (1979). "Site Soil Column Considerations in Seismic Hazard Analysis," in Proc. 3rd ASCE Speciality Conf. on Structural Design of Nuclear Power Plants, (Boston, MA, April 3-5, 1979).

D. L. Bernreuter, (1981a). "Seismic Hazard Analysis: Application of Methodology, Results and Sensitivity Studies," NUREG/CR-1582 (UCRL-53030, Vol. 4.)

D. L. Bernreuter, (1981b). "Seismic Hazard Analysis: Review Panel, Ground Motion Panel, and Feedback Results," NUREG/CR-1582 (UCRL-53030, Vol. 5).

R. J. Brazee, (1976). "Analysis of Earthquake Intensities with Respect to Attenuation, Magnitude and Rate of Recurrence," NOAA Tech., Memo, EDS-NGSDC-2.

K. W. Campbell, (1981a). "Near-Source Attenuation of Peak Horizontal Acceleration," Bull. Seismol. Soc. Am., 71, 2039-2070.

K. W. Campbell, (1981b). "A Ground Motion Model for the Central U.S. Based on Near-source Acceleration Data," Proc. Conf. on Earthquakes and Earthquake Engineering: The Eastern U.S., Vol. 1, pp 213-232.

Campbell, K. W., (1982). "A Preliminary Methodology for the Regional Zonation of Peak Ground Acceleration", Proc. 3rd International Earthquake Microzonation Conference, Seattle, Washington, Vol. I, pp 365-376.

D. H. Chung and D. L. Bernreuter, (1981). "Regional Relationships Among Earthquake Magnitude Scales," Reviews of Geophysics and Space Physics, Vol. 19, 649-663. See also NUREG/CR-1457 (UCRL-52745).

I. N. Gupta and O. W. Nuttli, (1976). "Spatial Attenuation of Intensities for Central U. S., Bull. Seismol. Soc. Am., 66, 743-751.

D. M. Hadley and D. V. Helmberger, (1980). "Simulation of Strong Ground Motions," Bull. Seismol. Soc. Am., 70, 617-630.

W. J. Hall, B. Mohraz, and N. M. Newmark, (1976). "Statistical Studies of Vertical and Horizontal Earthquake Spectra," Nuclear Regulatory Commission Report, NUREG-0003.

S. Hayashi, Tsuchida and E. Kurata, (1971). "Average Response Spectra for Various Subsoil Conditions," Proc. 3rd Joint Meeting of U. S. - Japan Panel on Wind and Seismic Effects.

R. B. Herrmann and M. J. Goertz, (1981). "A Numerical Study of Peak Ground Ground Motion Scaling," Bull. Seismol. Soc. Am., 71, 1963-1979.

R. B. Herrmann and O. W. Nuttli, (1982). "Magnitude: The Relation of M_L to m_{blg}," Bull. Seismol. Soc. Am., 72, 389-397.

W. B. Joyner and D. M. Boore, (1981). "Peak Horizontal Acceleration and Velocity from Strong Motion Records dIncluding Records from the 1979 Imperial Valley, California," Bull Seismol. Soc. Am., 71, 2011-2038.

M. W. McCann, Jr. and D. M. Boore, (1983). "Variability in Ground Motions: Root Mean Square Acceleration and Peak Acceleration for the 1971 San Fernando, California, Earthquake," Bull. Seismol. Soc. Am., 73, 615-632.

R. K. McGuire, (1974). "Seismic Structural Responses Analysis Incorporating Peak Responses Regressions on Earthquake Magnitude and Distance," M.I.T., Department of Civil Engineering Research Report, R74-51, pp371.

R. K. McGuire, (1977). "The Use of Intensity Data in Seismic Hazard Analysis," Proc. 6th World Conf. on Earthquake Eng., New Delhi, India, 709-714.

J. R. Murphy and L. J. O'Brien, (1977). "The Correlation of Peak Ground Acceleration Amplitude with Seismic Intensity and other Physical Parameters,"Bull. Seismol. Soc. Am., 67, 877-915.

NBS, (1978). "Tentative Provisions for the Development of Seismic Regulations for Buildings," National Bureau of Standards Special Publication 510, Applied Technology Council Report ATC-3-06.

Newmark, N. M., J. A. Blume and K. K. Kapur, (1973a). "Seismic Design Spectra for Nuclear Power Plants," J. Power Division, Nuclear Regulatory Commission Report, ASCE, 99:287-303.

Newmark, N. M., W. J. Hall and B. Mohraz, (1973b). "A Study of Vertical and Horizontal Earthquake Spectra," U.S. Atomic Energy Commission Report, WASH-1255.

Newmark, N. M. and W. J. Hall, (1978). "Development of Criteria for Seismic Review of Selected Nuclear Power Plants," Nuclear Regulatory Commission Report, NUREG/CR-0098.

Newmark, N. M. and W. J. Hall, (1982), "Earthquake Spectra and Design," Earthquake Engineering Research Institute, Berkeley, California.

O. W. Nuttli and J. E. Zollweg, (1974). "The Relation Between Felt Area and Magnitude for Central United States Earthquakes," Bull. Seismol. Soc. Am., 64, 73-85.

O. W. Nuttli, (1979). "The Relation of Sustained Maximum Ground Acceleration and Velocity to Earthquake Intensity and Magnitude," State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 16, Misc. Paper S-73-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

O. W. Nuttli and R. B. Herrmann, (1978). "Credible Earthquakes in the Central United States," State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 12, Miscellaneous Paper S-73-1 Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

O. W. Nuttli and J. Dwyer, (1978). "Attenuation of High Frequency Seismic Waves in the Central Mississippi Valley," State-of-the-Art for Assessing Earthquake Hazards in the United States; Miscellaneous Paper S-73-1, Report 10, Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

O. W. Nuttli, (1983a). "Average Seismic Source Parameter Relations for Mid-plate Earthquakes," Bull. Seismol. Soc. Am., 73, 519-535.

O. W. Nuttli, (1983b). "Empirical Magnitude and Spectral Scaling Relations for Mid-plate and Plate-margin earthquakes, Tectonphysics 93 (in press).

J. B. Savy, (1978). "Determination of the Seismic Design Parameters: A Stochastic Approach," Ph.D. dissertation, Stanford University, Stanford, CA.

J. B. Savy, (1981). "A Geophysical Model of Strong Motion for Large Ensemble Generation," M.I.T., Department of Civil Engineering Research Report, R81-6.

P. B. Schnabel and H. B. Seed, (1973). "Accelerations in Rock for Earthquakes in the Western United States," Bull. Seism. Soc. Am., Vol. 53, 501-516.

H. B. Seed and I. M. Idriss, (1969). "Influence of Soil Conditions on Ground Motions During Earthquakes," Journal of Soil Mechanics and Foundations Division, ASCE, Vol. 95, No. SML, January, pp. 99-137.

H. B. Seed, C. Ugas, and J. Lysmer, (1976), "Site Dependent Spectra for Earthquake Resistant Design," Bull. Seism. Soc. Am., 66:221-244.

H. B. Seed, I. M. Idriss and F. W. Keifer, "Characteristics of Rock Motions During Earthquakes, J. Soil Mechanics and Foundation Division, ASCE, 95:1199-1218.

A. F. Shakal and D. L. Bernreuter, (1981). "Empirical Analyses of Near-source Ground Motion," NUREG/CR-2095 (UCRL-523028), Lawrence Livermore National Laboratory, Livermore, CA 65pp.

S. Singh and R. G. Herrmann, (1983), "Regionalization of Crustal Code Q in the Continental United States," J. Geophys. Res., 88:527-538.

M. D. Trifunac and A. G. Brady, (1975). "On the Correlation of Seismic Intensity Scales with the Peaks of Recorded Strong Ground Motion," Bull. Seism. Soc. Am., 65, 139-162.

M. D. Trifunac, (1976), "A Note on the Range of Peak Amplitudes of Recorded Accelerations, Velocities and Displacements with Respect to the Modified Mercalli Intensity," Earthquake Notes, Vol. 47, No. 1, 9-24.

USAEC (1973), "U.S. Atomic Energy Commission Regulatory Guide 1.60," Directorate of Regulatory Standards.

B. D. Westermo, J. G. Anderson, M. D. Trifunac, and M. Dravinski, (1980). "Seismic Risk Tables for Pseudo Relative Velocity Spectra in Regions with Shallow Seismicity," Dept. of Civil Engineering Report 80-01, University of Southern California.

Weston Geophysical Corporation, Inc., (981). "Seismic Response Spectra for the Yankee Nuclear Power Station, Rowe, Massachusetts," Report YAEC-1263, Yankee Automatic Electric Company, Farmingham, MA. 79pp.

A P P E N D I C E S

Appendix C-A: Nuttli's Letter
(January 24, 1983)

Appendix C-B: Trifunac's Letter
Regarding R
(January 18, 1983)

Appendix C-C: Campbell's Letter
Regarding R
(January 1, 1983)

A P P E N D I X C - A

OTTO W. NUTTLI
PROFESSOR OF GEOPHYSICS
P.O. BOX 8099. LACLEDE STA.
ST. LOUIS. MISSOURI 63156
(314) ~~???-????~~ 658-3124

January 24, 1983

FEB 4 REC'D

Dr. Dae H. Chung, L-95
Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94550

Dear Dan;

I am writing to offer my suggestions as to how to handle the attenuation problem in LLNL's sensitivity study of strong ground motion.

My recommendation is to use three different models, to determine the sensitivity of the site ground motion to different attenuation relations. Model 1 would be the one used two or three years earlier in the LLNL-TERA study for specific eastern nuclear power plant sites. There are two reasons for including this model: first, it will show the sensitivity to different source models in the two studies, as the attenuation relation will be the same for both; second, it is based on intensity data, which make up the bulk of eastern United States data, and thus is the most empirical (relies least on theoretical modeling) kind of attenuation relation. The problem is that we have to use data bases from other parts of the world, primarily the western United States, that relate M.M. intensity to ground acceleration, velocity and displacement, and we have good reason to suspect that these data are not directly applicable to the eastern United States.

Model 2 would be Ken Campbell's attenuation curves for strong ground motion for the central United States. These curves assume that the source excitation is the same for eastern and western earthquakes of a given magnitude, but that the anelastic attenuation is different for the two regions. The idea is similar to that employed by Algermissen and Perkins in constructing their hazard maps for the United States, and to that used by me in the 1979 report for the Waterways Experiment Station of the Corps of Engineers. One potential problem with Campbell's curves is the way he defines magnitude, i.e., M_L for M_L less than 6.5 and M_S for M_S greater than 6.5. The relations which I obtain for the eastern United States (spectral scaling paper to appear in April 1983 issue of BSSA) are:

$$M_S = 1.0\ m_b - 1.15 \qquad \text{for } m_b \leq 4.5$$

$$M_S = 2.0\ m_b - 5.65 \qquad \text{for } 4.5 \leq m_b \leq 7.0.$$

For the eastern United States Bob Herrmann and I showed that $M_L = m_b$. In the East you seldom will have to deal with earthquakes of M_L greater than 6.5. Therefore my suggestion is to use M_L (or m_b) values with Campbell's curves.

Model 3 is one which has evolved from studies of Bob Herrmann and myself. The most recent published version is my paper in the Proceedings of the June 1982 Earthquake Microzonation Conference. The method uses empirical studies of mid-plate magnitudes and moments to establish spectral scaling relations, from which a scaling law for peak ground acceleration, velocity and displacement is derived. Frequency-dependent anelastic attenuation relations are obtained from measurements of eastern earthquakes by observatory-type instruments. The level of the attenuation curves is determined by existing central United States strong-motion data, as present in the Microzonation paper. Thus Method 3 is semi-empirical, semi-theoretical. Although I am not impartial and unbiased, I believe it represents the best existing set of strong motion relations for the East.

I don't believe it is advisable to attempt to distinguish between differences of anelastic attenuation in the craton region of the central and eastern United States and the accreted coastal-plain regions to the east and south of the Appalachian and Ouachita-Wichita Mountains. By attempting to consider this effect you would be introducing a refinement that has smaller consequences than those resulting from more basic uncertainties in the attenuation relations.

In the paper for the Microzonation meeting I presented my attenuation relations only in the form of sets of curves. In the past week I put them in equation form. Also, based upon material contained in my spectral scaling paper, I have more carefully considered the problem of minimum focal depth, which affects the ground motion at small epicentral distances. Included is a figure showing how the ground acceleration at near-source distances changes with focal depth for an $m_b = 5.0$ earthquake. Because we cannot possibly estimate focal depth for all the historical earthquakes, I suggest that in all cases you use the attenuation curves for minimum focal depth, as in the three figures included with this letter (for maximum acceleration, velocity and displacement). This is most conservative, in the sense that it will give the largest possible ground motions.

Please don't hesitate to call me if you have any questions, criticisms, suggestions, or such.

With best regards,

Sincerely,

Otto

Otto W. Nuttli

Enclosures

P.S. The equations and curves are an average for various rock and soil types. Probably they are most representative of a stiff or competent soil.

STRONG GROUND MOTION ATTENUATION RELATIONS
FOR THE CENTRAL UNITED STATES

Minimum Focal Depth

$$\log_{10} h_{min} \text{ (km)} = -0.949 + 0.284\ m_b \quad \text{for } m_b \leq 4.4$$

$$\log_{10} h_{min} \text{ (km)} = -1.730 + 0.456\ m_b \quad \text{for } m_b > 4.4$$

Q_o (quality factor at 1 Hz) = 1000; $Q(f) = 1000f^{0.3}$ (f = frequency)

Max-Acc = arithmetic average of peaks on 2 horizontal components

assumed: a_{max} has a frequency of 5 Hz
v_{max} has a frequency of 1.5 Hz
d_{max} has a frequency of 0.5 Hz

$$\log_{10} a_{max} \text{ (cm/sec}^2) = 1.69 + 0.25\ m_b - 0.833 \log_{10}\ r^2+h^2 - 0.00122\ (r-1) \quad \text{for } m_b \leq 4.4$$

$$\log_{10} a_{max} = 0.57 + 0.50\ m_b - 0.833 \log_{10}\ r^2+h^2 - 0.00122\ (r-1) \quad \text{for } 4.4 < m_b \leq 7.4$$

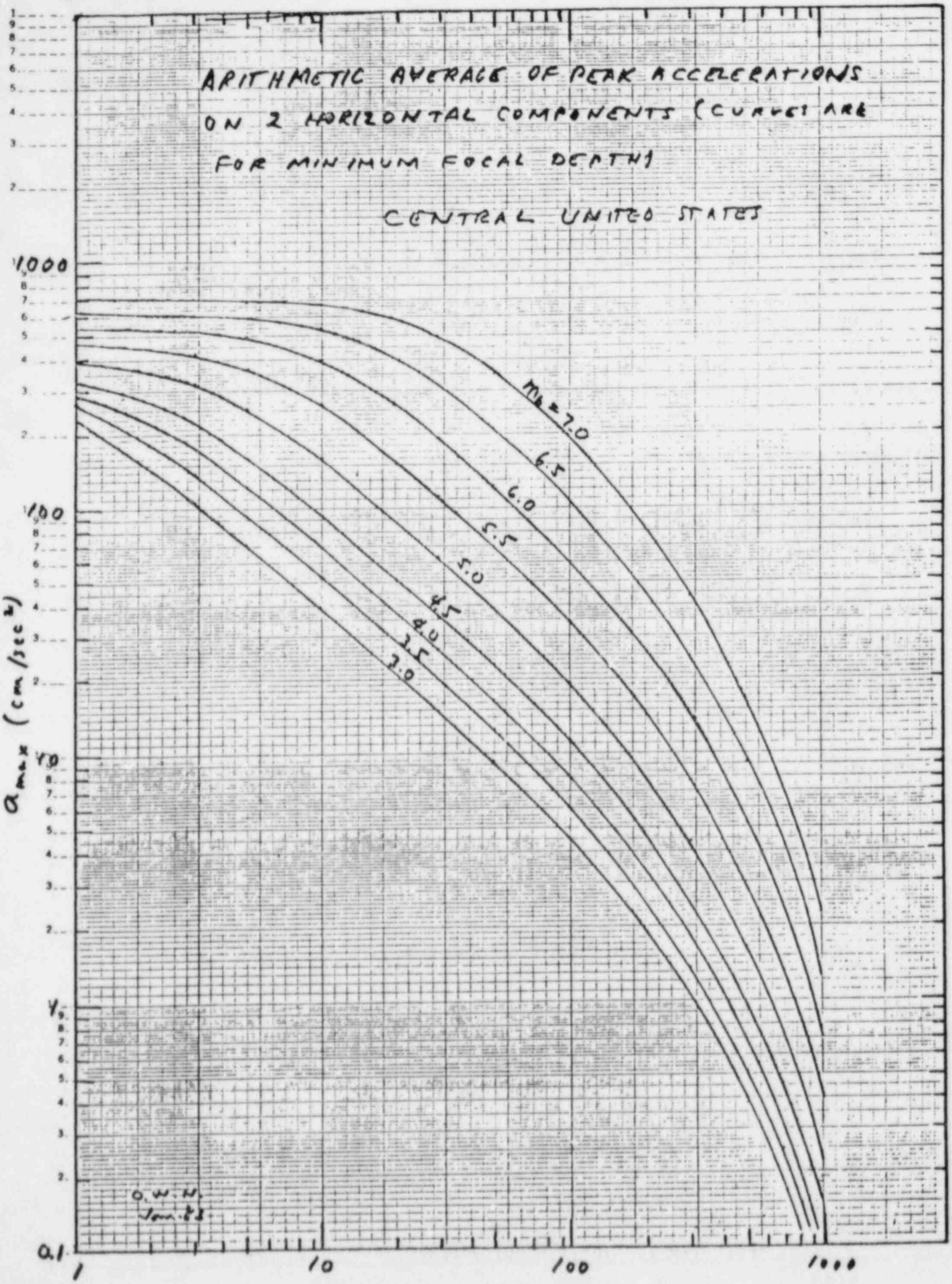
$$\log_{10} V_{max} \text{ (cm/sec)} = -1.35 + 0.50\ m_b - 0.833 \log_{10}\ r^2+h^2 - 0.000532\ (r-1) \quad \text{for } m_b \leq 4.4$$

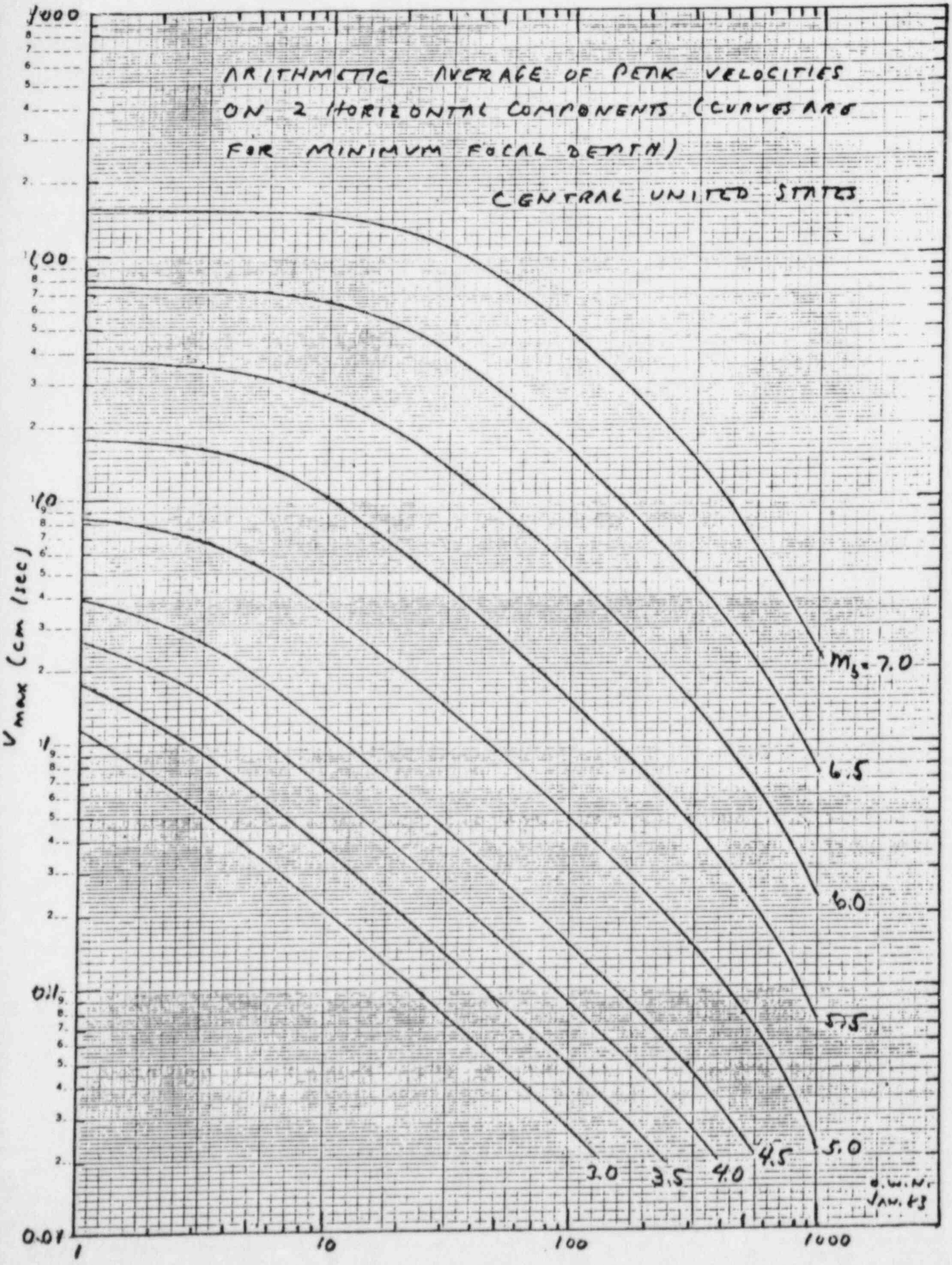
$$\log_{10} V_{max} = -3.60 + 1.00\ m_b - 0.833 \log_{10}\ r^2+h^2 - 0.000532\ (r-1) \quad \text{for } 4.4 < m_b \leq 7.4$$

$$\log_{10} d_{max} \text{ (cm)} = -3.43 + 0.75\ m_b - 0.833 \log_{10}\ r^2+h^2 - 0.000244\ (r-1) \quad \text{for } m_b \leq 4.4$$

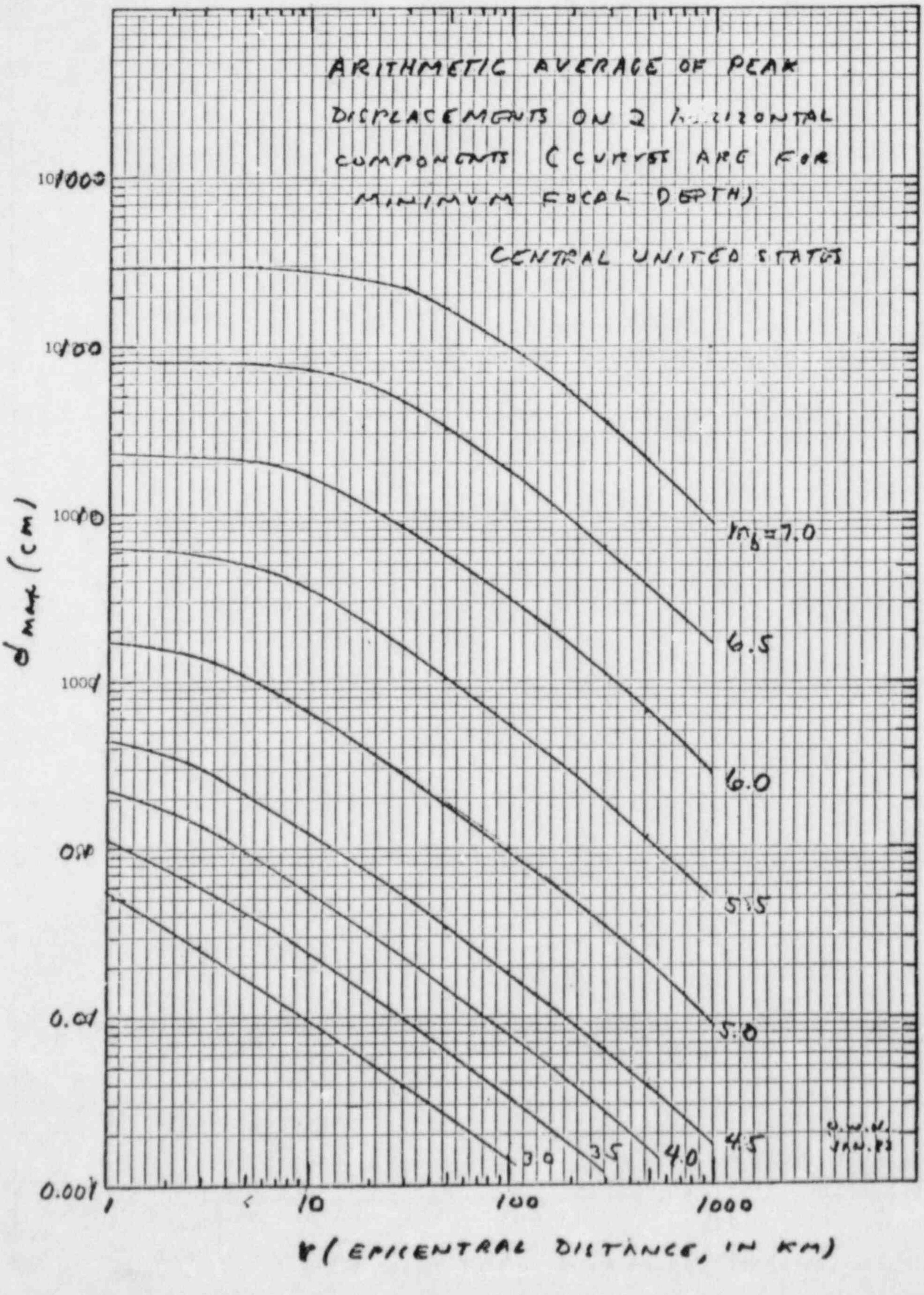
$$\log_{10} d_{max} = -6.81 + 1.50\ m_b - 0.833 \log_{10}\ r^2+h^2 - 0.000244\ (r-1) \quad \text{for } 4.4 < m_b \leq 7.4$$

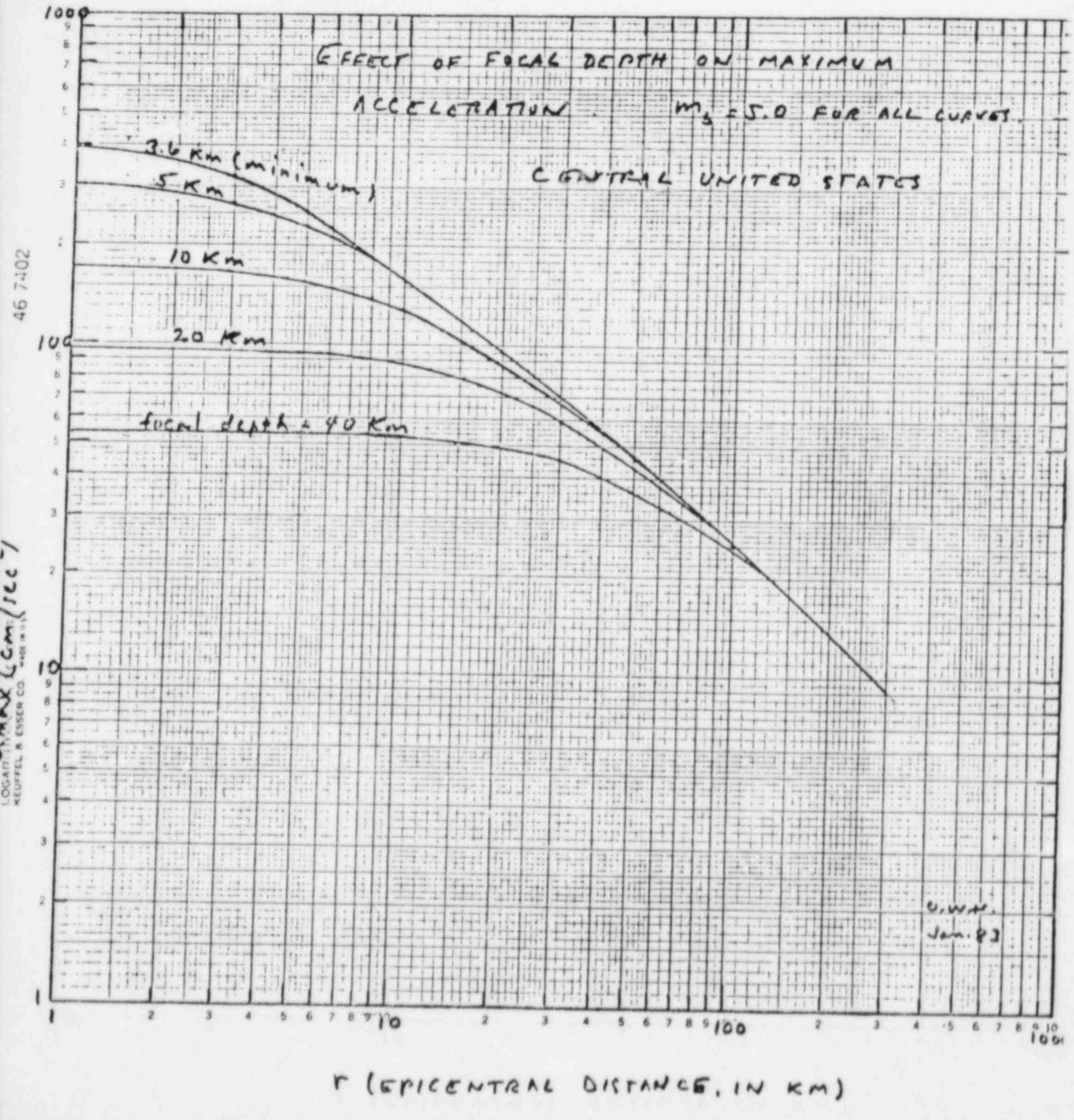
where h = focal depth (in km) and r = epicentral distance (in km).


ARITHMETIC AVERAGE OF PEAK ACCELERATIONS
ON 2 HORIZONTAL COMPONENTS (CURVES ARE
FOR MINIMUM FOCAL DEPTH)
CENTRAL UNITED STATES
1,000
100
10
1
0.1
1
10
100
1000
a_{max} (cm/sec²)
m_b = 7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
O.W.N.
Jan. 83


ARITHMETIC AVERAGE OF PEAK VELOCITIES ON 2 HORIZONTAL COMPONENTS (CURVES ARE FOR MINIMUM FOCAL DEPTH)
CENTRAL UNITED STATES
V_{MAX} (cm/sec)
1000
100
10
1
0.1
0.01
1
10
100
1000
M_S = 7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
d.w.n.
JAN. 83

MODEL DATE


ARITHMETIC AVERAGE OF PEAK
DISPLACEMENTS ON 2 HORIZONTAL
COMPONENTS (CURVES ARE FOR
MINIMUM FOCAL DEPTH)
CENTRAL UNITED STATES
m_b=7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
1000
100
10
1.0
0.1
0.01
0.001
1
10
100
1000
d_{max} (cm)
r (EPICENTRAL DISTANCE, IN KM)


EFFECT OF FOCAL DEPTH ON MAXIMUM ACCELERATION. m_b = 5.0 FOR ALL CURVES
CENTRAL UNITED STATES
3.6 Km (minimum)
5 Km
10 Km
20 Km
focal depth = 40 Km
U.W.N. Jan. 83
r (EPICENTRAL DISTANCE, IN KM)
46 7402
LOGARITHMIC
KEUFFEL & ESSER CO.

APPENDIX C-B

UNIVERSITY OF SOUTHERN CALIFORNIA

UNIVERSITY PARK • LOS ANGELES, CALIFORNIA 90007

SCHOOL OF ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING

FEB 4 REC'D

January 18, 1983

Dr. Dae H. Chung
Lawerence Livermore Laboratory
University of California
Livermore, California 94550

Dear Dae,

As you requested I am enclosing my brief comments on the use of 'distance' in the papers by Joiner and Boore (1981) and Campbell (1981). Those are:

1. Joiner and Boore (1981) employ a definition of distance which is equivalent to $(R_o{}^2+ h^{*2})^{1/2}$ in the enclosed Figure 1. In their work h* is a 'measure' of the source depth selected to minimize the sum of the squares of the residuals. This definition of distance would be appropriate if an argument could be made that the peak ground motion comes from the portion of the fault surface which is at 'depth' h* and beneath A in Figure 1.

2. Campbell (1981) uses distance R_2 (in Figure 1) and a magnitude dependent 'coefficient' C(M) which physically resembles h*. This is also fitted to the data to minimize the sum of the residuals squared.

Assume we have recorded three peak accelerations and we wish to plot those versus same distance R as in Figure 2. In a typical case (say Imperial Valley 1979 data) I interpret Campbell's work to plot these data points as crosses (+) in Figure 2. Joiner and Boore (1981) definition would lead to the peaks plotted as circles (o) in Figure 2 (assuming that somehow we know h*). Assuming on the other hand, that we wish to plot those peak accelerations versus distance R_1, which is a distance to a 'center' of the fault surface we would get the points shown by asterisks,(Figure 2). It is obvious from the geometry of Figure 2 that $R_o<R_1$, $R_2<R_1$ and $(R_o{}^2+ h^{*2})^{1/2}<R_1$. Since we do not know a priori which part of the fault will contribute most to the peak ground motions, unless $L>>R_1$ it would seem reasonable to use some definition (in the mean) close to R_1. This effect is of course significant only for small R_1 and as $R_1 \to \infty$ all definitions of distance become indistinguishable. Therefore I believe that Joiner and Boore (1981) as well as Campbell (1981) have a tendncy to underestimate peak amplitudes of ground motion for small R. This is seen from sketch in Figure 2.

I am taking the liberty of sending these comments to Boore and Campbell directly. I hope they can examine them and suggest wether I have erred in my interpretation of their results.

Please let me know if you feel that these comments are not clear and wether there are additional aspects of interest that I did not discuss.

Sincerely,

M. D. Trifunac

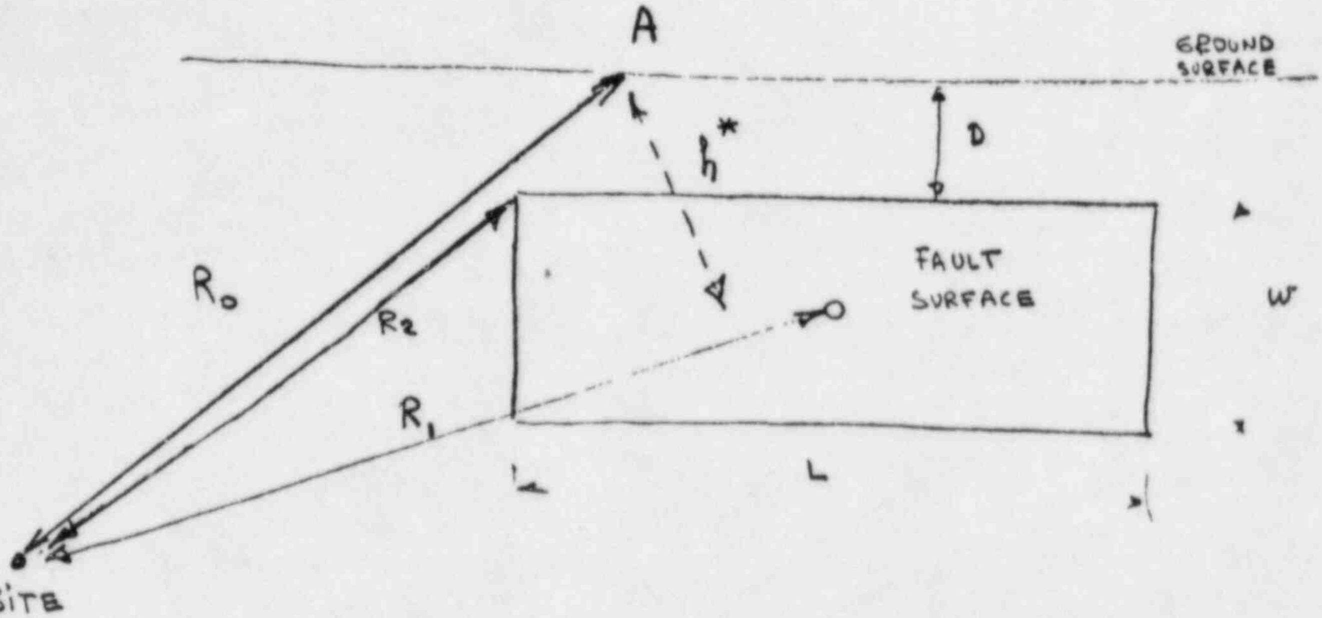
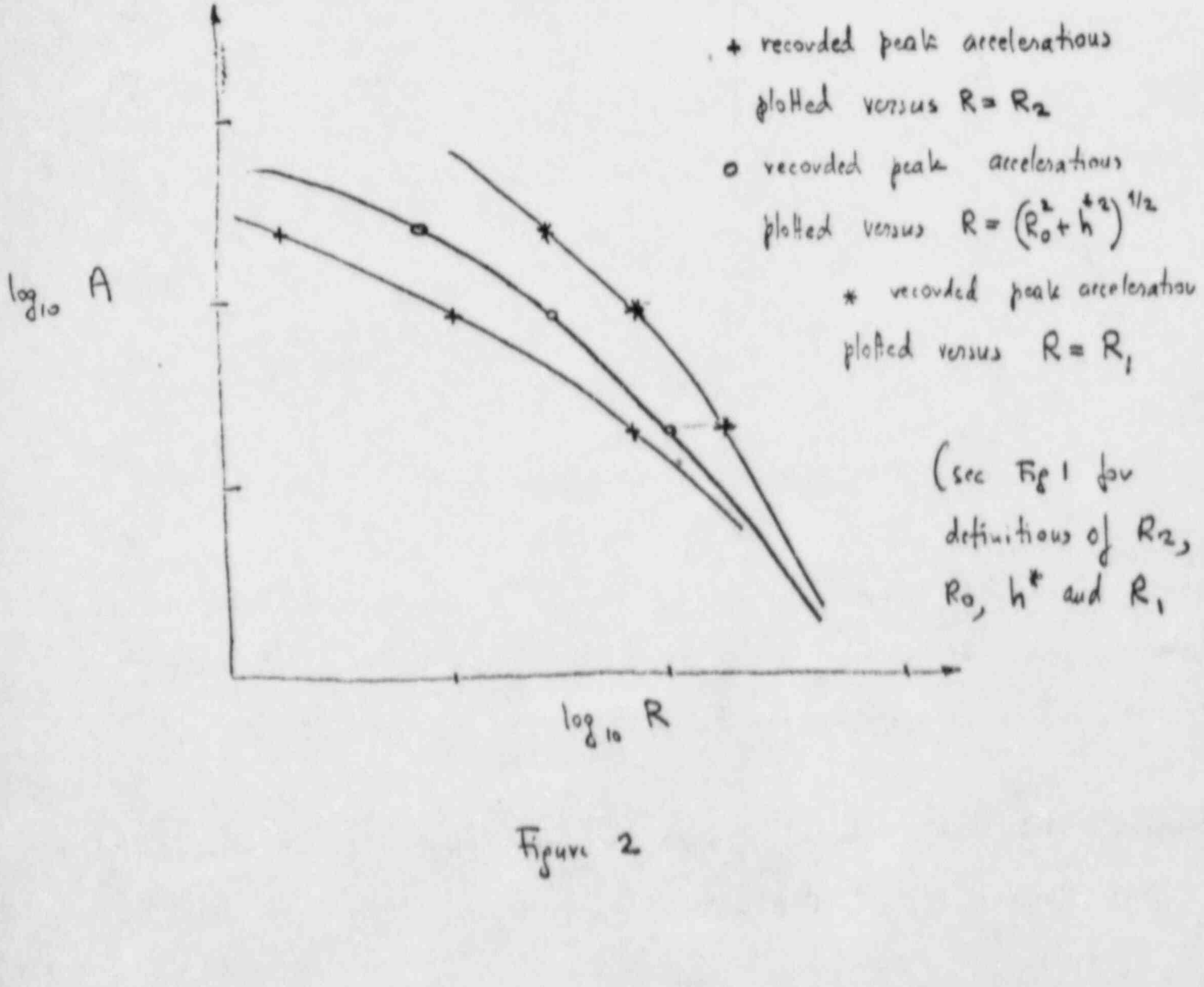


Figure 1

BOORE & JOINER (1981) use $r = (d^2 + h^2)^{1/2}$ where "d is the closest distance from the recording site to the surface projection of the fault rupture." This corresponds to R_0 in Figure 1

Campbell (1981) uses " shortest distance between the station and the fault rupture surface"... I interpret this to correspond to distance like R_2 in Figure 1



+ recorded peak accelerations plotted versus R = R2
o recorded peak accelerations plotted versus $R = (R_0^2 + h^{*2})^{1/2}$
* recorded peak acceleration plotted versus R = R1
(see Fig 1 for definitions of R2, R0, h* and R1
log10 A
log10 R

Figure 2

APPENDIX C-C

TERA

February 3, 1983

FEB 8 REC'D

Dr. Dae H. Chung, L-90
Lawrence Livermore National Laboratory
P. O. Box 808
Livermore, California 94550

Dear Danny:

I would like to take this opportunity to respond to Dr. Trifunac's letter of January 18 regarding the use of "distance" in strong-motion scaling relationships. He claims that the use of shortest distance between the recording site and the fault rupture surface (used by Campbell, 1981) has a tendency to underestimate peak amplitudes of strong ground motion for small distances. He infers from his Figure 2 that this could be avoided by defining distance as the distance from the recording site to the center of the fault surface. This latter definition is preferred by Dr. Trifunac, since it is not known in advance which part of the fault will contribute most to peak ground motions.

Although we may not know in advance where the peak motions will come from, there is considerable evidence to suggest that closest distance to the fault rupture (R_2) is a more appropriate measure than distance to the center of fault rupture (R_1) for characterizing and predicting the scaling properties of strong-motion parameters. In fact, scaling relationships based on R_1 as they are commonly used will lead to overestimation of peak parameters in some cases. Arguments in support of these statements are as follows:

(1) The use of closest distance to the fault rupture is consistent with the definition of distance in seismic design scenarios. For lack of more detailed information, design earthquakes are always hypothesized to rupture that portion of the causative fault closest to the site and distance is always measured from the closest point of this rupture. This is identical to the definition of distance used to develop the scaling relationship of Campbell (1981). The degree to which this distance is inappropriate in both past and future earthquakes is reflected adequately in the uncertainty associated with the prediction (the standard error of estimate) and may be properly accounted for by using a prediction based on a percentile greater than 50 percent (the median).

(2) With the realization that the portion of the fault responsible for the peak motion at a recording site is most likely closer than the center of rupture, taken with the way design earthquakes are hypothesized, the use of distance to the center of fault rupture will result in overestimation of strong-motion parameters in situations where the fault rupture is adjacent to the site. There are many fault rupture configurations where the fault can rupture adjacent to the site. For all but one of these configurations, the center of the fault rupture will not be associated with the

TERA CORPORATION
2150 SHATTUCK AVENUE BERKELEY, CALIFORNIA 94704 415-845-5200 TELEX: 338592

closest portion of the rupture. In fact, for very large events, the center of rupture could be tens of kilometers further away than the closest point. The inevitable assumption for design purposes that the closest approach of the fault zone represents the center of rupture characterizes only one extremely rare rupture configuration. Coupled with the realization that distances to the center of rupture used in the development of the scaling relationships would be based on a random selection of such rupture scenarios, this inevitably leads to the overestimation of predicted values for typical design scenarios. To properly account for this discrepancy, distance should more appropriately be taken as the average distance to the center of all possible rupture configurations that lead to rupture adjacent to the site.

(3) The analysis of peak acceleration has shown that distances measured to single fixed points on the fault rupture surface are statistically inferior to those measured to the closest point on the fault. In the case of the 1979 Imperial Valley earthquake, distance scaling relationships based on closest distance to the rupture were found to have substantially lower standard errors than those based on any single fixed point on the fault, including the center of rupture and the epicenter. Multiple regression analyses for the Campbell (1981) dataset have also demonstrated that substantially lower standard errors are obtained when closest distance is used rather than epicentral or hypocentral distance.

(4) Earthquake modeling studies of recent earthquakes indicate that there are multiple patches of rupture (i.e., asperities) on the fault that contribute to strong ground motion and that those patches nearest the recording station tend to dominate the motion at that station. This would tend to favor closest distance to the fault rupture over distance to the center of rupture as the appropriate distance measure to use for scaling purposes.

It must be emphasized that, in order for these arguments to hold, one must use the closest distance to the hypothesized fault rupture when using the relationship of Campbell (1981), or any other relationship based on closest distance, to predict ground motion for either deterministic or probabilistic analyses. The use of epicentral or hypocentral distance with such a relationship in probabilistic analyses will lead to the underestimation of peak amplitudes for a given return period. However, if the proper distance measure is used, then the use of such a relationship can appropriately lead to smaller probabilistic estimates because of the smaller standard error associated with the expression.

In conclusion, Dr. Trifunac's simple argument is not appropriate in light of the known characteristics of strong ground motion and the way in which seismic design scenarios are formulated. Closest distance to the fault rupture surface does represent a realistic and appropriate means of characterizing distance for the development of strong-motion scaling relationships. I hope this discussion clarifies the confusion that developed at the strong-motion panel meeting regarding the appropriate definition of distance. If there are any more questions, please feel free to give me a call.

Sincerely,

Kenneth W. Campbell

KWC:cas

cc: Dave Boore
Leon Reiter
M. D. Trifunac

APPENDIX D

Seismic Hazard Analysis Calculations

D.1 Introduction

Seismic hazard at a site is usually quantified through seismic hazard curves for the peak values of ground motion parameters, e.g. peak ground acceleration, at the site. The seismic hazard curve is a description of the probability during a given period of time, e.g., per year, that one or more earthquakes occur which result in the peak, over the duration of the earthquake, value of the ground motion parameter at the site exceeding the value a, given as a function of a. Figure D.1 illustrates a typical hazard curve for the peak ground acceleration (PGA) at a site shown on a logarithm scale, where the commonly used notation $A > a$ refers to the event that one or more earthquakes occur resulting in the PGA at the site exceeding a (cm/sec^2). It should be noted that the event $A > a$ is equivalent to the event that the maximum, over all earthquakes, PGA is greater than a.

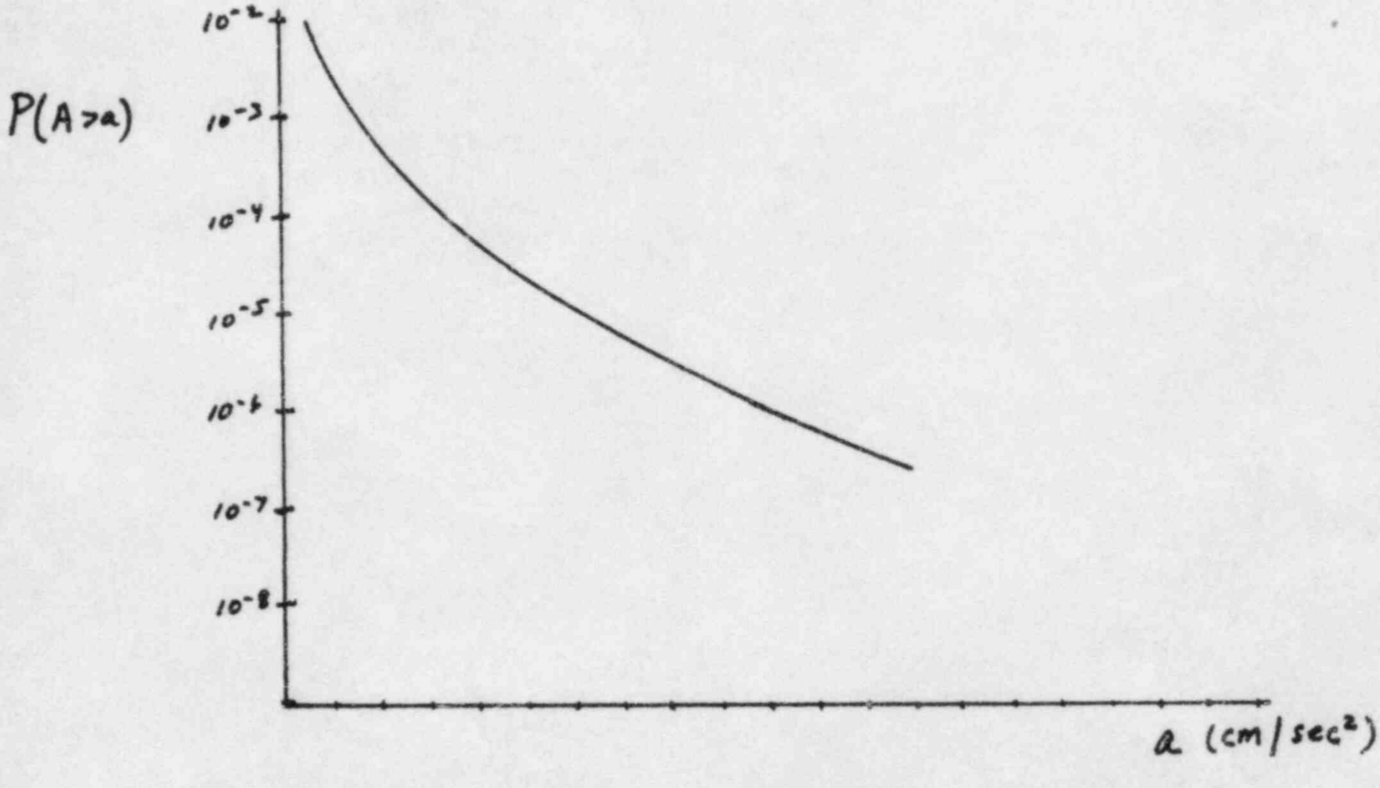


Figure D.1. Typical Seismic Hazard Curve

Evaluation of the seismic hazard curve at a site typically involves four steps:

- o Identification of seismic sources.
- o Specification of the seismicity for each source.
- o Specification of an attenuation/ground motion model.
- o Evaluation of the hazard curve or hazard spectrum.

For the Eastern United States (EUS) seismicity project steps 1 through 3 were implemented by the formation of two panels:

- o A panel of experts familiar with geological and seismological characteristics throughout the EUS.

- o A panel of experts familiar with the development of attenuation/ground motion models used to relate ground motion parameters at a site to characteristics of an earthquake at the source.

Opinions about the appropriate parameters and models were elicited from members of the two panels in the following form:

- o Seismic Sources

  Seismic sources were identified by eliciting maps which partition the EUS into zones (area, line or point sources) representing regions of uniform seismicity in terms of occurrence rate, and range and distribution of magnitude.

- o Seismicity

  For each zone, the following seismicity information was elicited from the experts;

  - o Occurrence rate of earthquakes with magnitude above a minimum level, $M_o = 3.75\ M_{bLg}$ or IV MMI.

  - o Upper magnitude cutoff, M_U, representing the largest magnitude expected to occur within a zone.

  - o Distribution of magnitudes represented by a magnitude-recurrence relation.

- o Attenuation/Ground Motion Model

  Weights, representing their confidence in the applicability of a model, for a catalogue of attenuation/ground motion models were elicited.

Discussions about the elicitation, compilation and interpretation of the experts' opinions are given in other sections of this report. This appendix will concentrate on the methodology used to evaluate the seismic hazard curve (and spectra) at a site.

D.2 Philosophy of the Evaluation Methodology

Evaluation of the seismic hazard curve at a site is based on a probabilistic approach using the experts' opinions about seismicity and ground motion to specify models for the random events influencing the seismic hazard at a site. The method assumes that events, such as the occurrence of earthquakes within a zone, affecting ground motion at a site are subject to inherent physical variation and hence are properly treated as random events. Thus, the maximum value of a ground motion parameter experienced at a site over a period of time is a random quantity or variable. The hazard curve, or probability of one or more earthquakes occurring resulting in the maximum value exceeding the value a, is assumed to represent the likelihood, based on the inherent variation in the physical world, that the physical conditions will exist that lead to the maximum value of the ground motion parameter exceeding a. That is, the occurrence of an earthquake is assumed to be a random event and, if an earthquake does occur, the magnitude of the event and attenuation of ground motion from source to site are all subject to inherent variability. Thus, the ground motion at a site is variable and any ground motion parameter is properly considered a random variable. The seismic hazard curve is assumed to be a description of the probability distribution of the maximum value of the ground motion parameter.

The probabilistic approach is based on modeling the physical variation by probability distributions and using these distributions to evaluate the probabilities of interest, i.e. the seismic hazard curve. However, characteristics of the distributions describing nature are unknown, thus the opinions of the experts are elicited to estimate these characteristics. Thus, the methodology produces an estimate of the seismic hazard curve which is based on the opinions provided by the experts on the two panels.

The evaluation method also recognizes that expert opinions about seismological properties and ground motion models are based on limited knowledge about the physical phenomena affecting these parameters, hence expert opinions are subject to uncertainty. The uncertainties associated with the experts' opinions do not contribute to the level of seismic hazard but do influence the effectiveness of the evaluation process in estimating the hazard. Another source of uncertainty associated with a probabilistic analysis is the choice of probabilistic models used to model physical phenomena. These mathematical models are only approximations to the real world. The choice of models is a matter of judgement by the analyst and, like experts' opinions about seismicity and ground motion, are based on limited knowledge of the physical world. Uncertainties associated with the choice of mathematical models is more difficult to assess because a comparison between different models can only be made if the evaluation of seismic hazard using competing models is actually done. This is not always possible.

The method for evaluating the seismic hazard curve at a site involves a two-stage estimation process:

- A single hazard curve, referred to as the 'best estimate' hazard curve, is evaluated using the experts' best estimate evaluations of seismic sources, seismicity and attenuation/ground motion models.

- The uncertainty in estimating the seismic hazard due to the uncertainties associated with the experts' opinions is quantified by evaluating bounds for the seismic hazard which reflect the experts' uncertainties. This analysis is called an 'uncertainty analysis'.

Because the elicitation process involves several experts, at times it will be necessary to combine the information derived from several experts to evaluate a hazard curve which reflects the combined opinions of the several experts. The method developed for combining over experts is based on a self evaluation by the experts of their level of expertise with regard to seismological issues and attenuation/ground motion modeling respectively. For the seismicity panelists the self-evaluation was done for four regions, NE, SE, NC, SC, in the EUS. These four self weights were combined into a single weight which was used when combining over seismicity experts. The method of combining over experts, essentially a weighted average, assumes that the self weights reflect not only the experts' level of overall knowledge about seismological issues (or attenuation/ground motion modeling) but also reflects the experts' abilities to translate this knowledge into responses about characteristics of probability distributions. Thus, the method assumes that the self weights are a quantification of the expected utility of an expert's opinions for estimating the seismic hazard. The weights for combining the self weights for the four regions are the probabilities that the largest value at the site of the ground motion parameter comes from each region. These probabilities, at the site, will vary for different sites.

Although self weights were used for the present analysis, the same methods could be used with weights derived from other sources such as weights from peers or weights developed by the analyst or any user of the methodology. The important criterium is that the weights should reflect some judgement of the utility of an experts' opinions for estimating the seismic hazard. That is, the weights should be a judgement of how well the estimated hazards, based on the experts' opinions, can be expected to describe the real seismic hazard.

D.3 Mathematical Background and Assumptions

D.3.1 Seismic Hazard Curve

Seismic hazard at a site is quantified by the values of a ground motion parameter, at the site, which is exceeded with a given probability in a specified number of years. The mathematical development of hazard relations will be based on peak ground acceleration (PGA) although identical relations hold for peak ground velocity (PGV) and spectral acceleration or velocity as well.

The parameter of interest is the probability that the PGA at the site will exceed a given value, a, at least once within the specified time period, t years. This probability, expressed as a function of a and denoted $P(A > a)$, is called the seismic hazard curve at the site. As noted earlier, the hazard curve is the tail of the complement of the cumulative distribution function for the random variable, the maximum, over all earthquakes, PGA at the site.

Typically, the region affecting ground motion at a site consists of a number of seismic source zones. The seismic hazard at the site is a combination of the hazard from all relevant sources. In addition, the value of the ground motion parameter, e.g. peak ground acceleration, will depend on both the distance of the source from the site as well as the magnitude of the earthquake at its source.

The following assumptions about the occurrence of earthquakes throughout the EUS form the basis for the probability calculations used to evaluate the hazard curve at a site:

- For each zone, it is assumed that earthquakes could occur uniformly at random within the zone.
- All earthquakes are assumed to be point sources, thus the fact that earthquakes are created by the rupture of tectonic faults of finite length is neglected.
- The occurrence of earthquakes is assumed to be independent between zones.
- The occurrence rate of earthquakes within a zone is considered to be constant; its value is based on the seismic and tectonic conditions that presently exist within the zone.

We further assume that:

- The expected number of earthquakes, $\Lambda(m)$, occurring within a zone of magnitude m or greater can be described by the magnitude-recurrence relation

  $$\log \Lambda(m) = H(m) \qquad M_o \le m \le M_U$$

  The functional form of H(m) is based on information elicited from the experts.
- Given the magnitude of an earthquake at its source and the distance of the site from the source, it is assumed that the physical variation in the PGA at the site is adequately described by a lognormal probability distribution.

Given that we are interested in earthquakes with magnitudes above the minimum magnitude M_o and given the assumption that earthquakes occur at random throughout a zone, the number $N_t(M_o)$ of earthquakes with magnitude greater than M_o occurring within a zone in a time period of length t, e.g. t years, is a Poisson random variable with parameter Λ_o, the expected number of events with magnitude greater than M_o (occurrence rate) per unit time.

Thus, the probability of exactly n earthquakes with magnitude greater than M_o in t years is given by

$$P(N_t(M_o) = n) = (\Lambda_o t)^n e^{-\Lambda_o t} / n! \qquad n=0,1, \ldots \qquad (D.1)$$

The parameter Λ_o can be written as $\lambda_o P(M > M_o)$ where λ_o is the expected number of earthquakes per unit time and $P(M > M_o)$ is the probability that the magnitude is greater than M_o given an earthquake occurs. Similarly, for any m such that $M_o \leq m \leq M_U$, if $N_t(m)$ is the number of earthquakes of magnitude greater than m in t years

$$P(N_t(m) = n) = (\Lambda_m t)^n e^{-\Lambda_m t} / n! \qquad n=0,1, \ldots \qquad (D.2)$$

where $\Lambda_m = \Lambda_o P(M > m)$ is the expected number of events $\Lambda(m)$ per year with magnitude greater than m.

Under the further assumptions that earthquakes are point sources which occur uniformly throughout a zone, if $N_t(r,m)$ is the number of earthquakes in t years of magnitude greater than m occurring at points in the zone which are r(km) to r+dr(km) from the site, then $N_t(r,m)$ is a Poisson random variable with parameter

$$\Lambda(m) f_R(r) dr$$

where $f_R(r)$ is the density function for the distribution of the distance from the site to the points within the zone. This distribution is the proportion of a given zone located within specific ranges of distance from the site.

Given an earthquake of magnitude greater than m at a distance (r,r+dr) from the site, we assume the PGA at the site is a lognormal random variable such that the mean of the logarithm of PGA is given by the attenuation/ground motion model which depends on m and r. We denote the conditional probability of PGA exceeding the value a by $P(A > a \mid m,r)$.

Let $N_t(a)$ denote the random variable, the number of earthquakes occurring in a zone in t years such that the PGA at the site is greater than a. The probability that one or more earthquakes occur in a zone in t years resulting in the PGA at the site exceeding a, denoted $P_q(A_t > a)$, where q indexes the zone, is given by

$$P_q(A_t > a) = P(N_t(a) \geq 1) \qquad (D.3)$$

This probability can be estimated by appealing to the Poisson distribution with parameter

$$\lambda_a = \int_{M_o}^{M_U} \int_{r>o} P(A > a \mid m,r)\, f_R(r)\, dr\, d\Lambda(m) \qquad (D.4)$$

In our analysis we approximated the integral numerically by subdividing both the distance and magnitude range into subintervals. Distances out to 1250 km were considered and subdivided into 18 subintervals. Details of the partition are given in Section 2.3. Let $\pi(r_k)$ denote the proportion of the zone at distances in the kth subinterval, i.e.

$$\pi(r_k) = \int_{\substack{r \text{ in} \\ \text{kth subinterval}}} f_R(r)dr \qquad (D.5)$$

Similarly, magnitudes were partitioned into subintervals of length 0.25 (M_{blg}) or 0.5 (MMI). Let m_j, the midpoint of the jth magnitude subinterval, be the representative value for the jth subinterval, and let

$$\lambda(m_j) = \int_{m_j-\Delta}^{m_j+\Delta} d\Lambda(m) \qquad (D.6)$$

= the expected number of earthquakes in t years with magnitudes in the jth subinterval ($m_j-\Delta$, $m_j+\Delta$)

Then

$$\lambda_a \doteq \sum_{j=1}^{J} \lambda(m_j) \sum_{k=1}^{K} \pi(r_k)P(A > a \mid m_j, r_k) \qquad (D.7)$$

Therefore, for source zone q,

$$P_q(A_t > a) = P_q(N_t(a) \geq 1)$$

$$\doteq 1 - \exp\left[-t \sum_{j=1}^{J} \lambda_q(m_j) \sum_{k=1}^{K} \pi_q(r_k) P(A > a \mid m_j, r_k)\right] \quad (D.8)$$

where $\lambda_q(\cdot)$ and $\pi_q(\cdot)$ are dependent on the zone.

Finally, under the assumption that events between zones are independent, the seismic hazard in t years at a site can be evaluated by

$$P(A_t > a) \doteq 1 - \prod_q \left[1 - P_q(A_t > a)\right]$$

$$= 1 - \prod_q \left\{\exp\left[-t \sum_{j=1}^{J} \lambda_q(m_j) \sum_{k=1}^{K} \pi_q(r_k) P(A > a \mid m_j, r_k)\right]\right\} \quad (D.9)$$

In the analysis the range of accelerations a is also discretized, thus the hazard is actually evaluated at a finite number (10) of accelerations, a_i, $i=1, \ldots I=10$.

D.3.2 Uniform Hazard Spectrum

The notion of a uniform hazard spectrum (UHS) is discussed in detail in ([1], Section 5.0). However, we summarize some of the mathematical aspects relevant to the evaluation methodology. A uniform hazard spectrum is developed such that for each frequency the spectral amplitude has the same probability of being exceeded in t years.

Based on the method outlined in the previous section, the hazard curve, i.e. the probability that the maximum PGA per year (in t years) exceeds the value a or the probability of exceedence, is assessed independently for each frequency. Assuming that the occurrence of earthquakes is a Poisson process, for each frequency, f (assuming t = 1 year).

$$P(A_f > a) = 1 - e^{-\lambda_a} \quad (D.10)$$

where λ_a is the expected number of events per year such that the peak spectral acceleration at the site exceeds a. Therefore, the time between events such that $A_f > a$, denoted $T(A_f > a)$, has expected value

$$RP_f(a) \equiv \varepsilon\left[T(A_f > a)\right] = \lambda_a^{-1} \tag{D.11}$$

which is the return period of events such that $A_f > a$ at the site. Therefore the relation between the return period and the probability of exceedence is

$$\begin{aligned} RP_f(a) &= \left\{-\ln\left[1-P(A_f > a)\right]\right\}^{-1} \\ &\doteq \left[P(A_f > a)\right]^{-1}, \text{ for long return periods} \end{aligned} \tag{D.12}$$

A typical plot of the return period, on the log scale, versus a is shown in Figure D.2 for two frequencies. For a return period of interest, e.g., 10,000 years, the spectral PGA's corresponding to the return period are used as the spectral amplitudes for the different frequencies f_1, f_2, . . .(9 frequencies were included in the analysis).

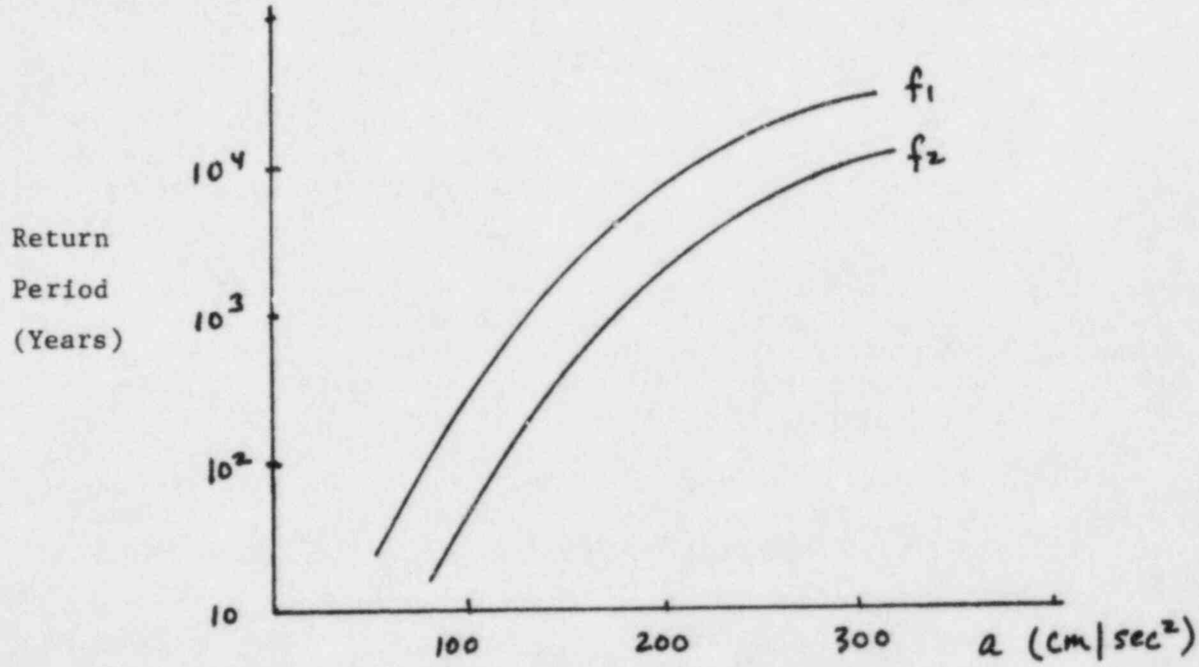


Figure D.2 Relationship Between Spectral Acceleration and Return Period

D.3.3 Weights for Seismicity Experts

Both seismicity and attenuation/ground motion model information were elicited from several experts. Thus, seismic hazard curves could be estimated using information from any pair of experts - a seismic expert and a ground motion model expert. In addition, it is necessary to combine the opinions of the experts. This could be done at two points in the evaluation process

- o A consensus could be reached on a single set (or a finite collection) of values for the seismicity parameters as well as agreement on the 'best' attenuation/ground motion model or set of models.

- o The opinions of the individual experts could be used to evaluate a seismic hazard curve and then the resulting hazard curves could be combined to form a combined hazard curve which represents, in some fashion, the opinions of all the experts.

We feel it is important to retain the diversity of opinions that might have existed between the experts, thus hazard curves were evaluated for every pair, i.e. seismicity-ground motion pair, of experts and these were subsequently combined to evaluate an 'average' hazard curve.

The method for combining the individual results is based on a weighted average of the individual hazard curves or uncertainty distributions. The weights for the attenuation model experts are the normalized values of the self-weights the experts provided. The weights for the seismicity experts are themselves a weighted average of the four regional self-weights provided by the experts.

Although the following development is not entirely consistent with the general philosophy of the overall evaluation process, it does provide a convenient basis for combining the regional self-weights for the seismicity experts into a single 'self-weight'.

Let s index the sth seismic expert, s=1, . . ., S and let w index the wth region, w = 1, 2, 3, 4. Also let W_{sw} denote the self-weight of expert s in the wth region. Let

$$A_w = \max_{\substack{q \text{ in wth} \\ \text{region}}} (A_q \; ; q=1 \; . \; . \; . \; N_w)$$

be the maximum PGA at the site due to earthquakes originating in the wth region. Based on the best estimate information from the sth expert, his assessment of the cumulative distribution function for A_w is

$$\Omega_{sw}(a) = \prod_{\substack{q \text{ in wth} \\ \text{region}}} [1-\hat{P}_{sw}(A_q > a)] \tag{D.13}$$

From a decision theoretic approach, if A_w is the unknown state of nature, $\Omega_{sw}(a)$ is considered the sth expert's decision regarding predicting the value of A_w. In this context W_{sw} can be considered to be the expected utility for $\Omega_{sw}(a)$ as a predictor of A_w.

Suppose the parameter of interest is $A = \max_w (A_w : w = 1, 2, 3, 4)$, the maximum PGA at the site. Let $\Omega_s(a)$ denote the sth expert's assessment of the cumulative distribution function of A based on the $\Omega_{sw}(a)$. That is,

$$\begin{aligned} \Omega_s(a) &= \prod_w \Omega_{sw}(a) \\ &= \prod_w \prod_{\substack{q \text{ in wth} \\ \text{region}}} \left[1 - \hat{P}_{sw}(A_q > a) \right] \end{aligned} \tag{D.14}$$

Then, the expected utility for $\Omega_s(a)$ as a predictor of A is

$$W_s = \sum_w W_{sw} P(A = A_w) \tag{D.15}$$

where $P(A = A_w)$ is the probability that the maximum PGA at the site results from an earthquake originating in the wth region. The normalized value of W_s is the weight assigned to the sth seismicity expert where $P(A = A_w)$ is estimated from the expert's best estimate $\hat{P}_{sw}(A_t > a)$ of the distribution of the maximum PGA at a site due to earthquakes originating in the wth region.

An appealing feature of these weights is that the weight for an expert will be relatively 'high' if his self-weights are highest in regions which have the highest probability of producing the maximum PGA at a site. Conversely, an experts' weight will be low if his highest self-weights are in regions with low probability of producing the maximum PGA at the site.

D.4 Summary of Elicitation Results - Inputs for the Evaluation Process

Detailed discussions of the elicitation, compilation and interpretation of the experts' opinions are presented in previous sections of the report. However, to provide continuity in the presentation of the probabilistic calculations it is necessary to summarize the elicited opinions as they are used as inputs into the estimation of the seismic hazard at a site.

D.4.1 Seismic Source Indentification

Each seismicity expert was asked to identify seismic sources throughout the EUS, expressed in terms of a complete zonation of the region. Identification of zones throughout the EUS was elicited in two forms:

- A 'best estimate' map, representing, in the expert's opinion, the most appropriate zonation of the EUS.
- Alternative zonations representing the expert's uncertainty about the zonation, produced by
  - expressing a 'level of confidence' or degree of belief that a zone should be identified as a source separate from the surrounding area
  - suggesting alternative configurations for individual zones or clusters of zones along with a measure of degree of belief for each configuration.

Using the program module COMAP the collection of all possible maps along with the degree of belief (probability) for each map could be produced. Actually, a maximum of 30 maps, with the highest probabilities, were inputs into the analysis.

D.4.2 Seismicity Parameters

For each zone identified on the maps for a seismicity expert estimates of the following seismicity parameters and models were elicited

- the upper magnitude cutoff, M_U - largest magnitude expected to occur under current geologic and tectonic conditions
- the occurrence rate λ_o of earthquakes with magnitude greater than a minimum M_o (3.75 m_{blg} or IV MMI) - λ_o is the expected number of events per year with magnitude greater than M_o
- the magnitude recurrence relation,

  $$\log \Lambda(m) = H(m)$$

  which relates the expected number of events per year with magnitudes greater than m, $\Lambda(m)$, to the level m.

Information elicited about these parameters, used as inputs in the analyses, were

- Upper magnitude cutoff M_U
  - Best estimate, $\hat{M}_U$
  - Bounds (M_{UL}, M_{UU}) which represent the expert's level of confidence in the resources he relied on to estimate M_U. The range M_{UL}, M_{UU} was treated as absolute bounds for M_U. Thus we assumed that M_U, in the opinion of the expert, will not exceed M_{UU}. Conversely, we assume it is the experts opinion that M_U will exceed M_{UL}.
- Occurrence rate, λ_o
  - Best estimate, $\hat{\lambda}_o$
  - Bounds (λ_{oL}, λ_{oU}) which represent his 'confidence' in the resources used to estimate λ_o. We treated λ_{oL} as the value of which the expert is 97.5% confident, based on the available resources, is the lowest value of λ_o. Conversely, λ_{oU} is the value which the expert is 97.5% confident is the largest value of λ_o.

Magnitude (intensity) recurrence relation

- A mathematical model for H(m) - all but one expert chose a linear model $H(m) = a + bm$; the only alternative was a piecewise linear model. The model represents Log_{10} [number of earthquakes with magnitude greater or equal to m].
- The range of magnitudes (M_{LB}, M_{UB}), $M_o \leq M_{LB} \leq M_{UB} \leq M_{UU}$, over which the model is applicable.
- Best estimates and bounds for each of the parameters in the model. The bounds for the coefficients were treated in the same way as the bounds for λ_o.

D.4.3 Attenuation/Ground Motion Models

Elicitation of opinions about attentuation/ground motion models was based on providing the experts with a catalogue of models for each of the ground motion parameters, PGA, peak ground velocity (PGV), and spectral acceleration and velocity. Seven classes of PGA and PGV models were identified, five of which were intensity based models and two classes which were empirically derived models relating the ground motion parameter directly to the source characteristics.

The experts were asked to express their opinions in the following form. For each of the four regions NE, SE, NC, SC and the two magnitude scales M_{bLg} and MMI,

- o The 'best estimate' model - the attenuation/ground motion model which, in their opinion, best models the expected ground motion at a site in terms of the source parameters, e.g. m, r.
- o The 'best' model from each of the seven classes of models along with their 'confidence' in each class of models.
- o The best estimate and bounds for the coefficient of variation (standard deviation of the logarithm of the ground motion parameter)

Analogous to the zonation maps, this information was summarized into a collection of models with corresponding confidences (probabilities).

D.5 Evaluation Methodology

D.5.1 Introduction

If the parameters of the probability models, e.g. expected values, $\lambda(m)$, and coefficients of the attenuation models, were all known, evaluation of the seismic hazard curve is straightforward and would follow the mathematical methods outlined in Section D.3. However, these parameters are not known so they must be estimated. Values of these parameters were elicited from experts, thus estimation of the hazard curve at a site is based on subjective judgements. Because opinions can only be based on limited knowledge of the physical factors affecting seismicity and attenuation of ground motion, there are uncertainties associated with these opinions. Therefore, the methods used to estimate a hazard curve should recognize the uncertainties associated with the values of the parameters based on expert opinions. The uncertainties associated with subjective assessments of physical phenomena are recognized in the procedure used to estimate the hazard at a site. The procedure involves a two-step estimation process:

- o Evaluation of a 'best estimate' hazard curve, i.e., evaluation of a hazard curve based on the experts' best estimates of the model parameters, e.g., $\hat{M}_U$, $\hat{\lambda}_o$.
- o Evaluation of a set of curves derived from the uncertainty in $P(A_t > a)$, for each a, attributable to the uncertainties in the estimates of the model parameters, i.e., quantification of the 'confidence', degree of belief or level of knowledge, about the model parameters, expressed by the experts.

The evalution process also recognizes that there is a potential difference in the level of expertise between the members of each of the panels. Thus, whenever estimates are combined over experts, the combined estimate is based on weighting the estimates of the individual experts.

A summary graphical description of the overall estimation process is given in Figure D.3. Although the description is given in terms of estimating a hazard curve, comparable calculations are performed for spectral velocities which in turn are used to estimate the uniform hazard spectrum.

D.5.2 Best Estimate Calculations

The method for evaluating the "best estimate" hazard curve is a straightforward application of the equations in Section D.3. The best estimates, as provided by each expert, are used as the parameters of the models and distributions needed to estimate the hazard curve at a site.

The flow chart of the seismic hazard calculations in Figure D.3 is followed in describing the best estimate analysis:

Inputs

- Per seismicity expert, s
  - Self weights for the four regions: W_{sw}: w = 1,2,3,4
  - Best estimate map consisting of
    - Zone index, q
    - δ_{wq} - Identifier of regional location of qth zone
    - $\{\pi_q(r_k);\ k = 1,\ldots K\}$ - distribution of distances from site of points in qth zone
    - Best estimate occurrence rate $\hat{\lambda}_{oq}$ for each zone
    - Best estimate of upper magnitude cutoff $\hat{M}_{Uq}$ for each zone
    - Best estimate model coefficient and range for magnitude-recurrence model, $(\hat{a}_q,\ \hat{b}_q;\ M_{LBq},\ M_{UBq})$
- Per attenuation expert, u
  - Self weights, W_{Au}
  - "Best Estimate" attenuation model, $\hat{G}_u(m, r)$
  - Best estimate of random variation for ground motion parameter, $\hat{\sigma}_{Ru}$

Calculation of Probability Parameters

- Conditional probability of PGA given magnitude m and range r, $P_u(A > a \mid m, r)$ - derived from a lognormal distribution with parameters

$$\mu_u\ (m,\ r) = \hat{G}_u\ (m,\ r)$$

$$s_u = \sigma_{Ru}$$

FIGURE D.3 Summary Flow Chart of the Seismic Hazard Calculations

START

IDENTIFY SEISMICITY EXPERT(s)

↓

CALL ALEAS

- o Read in inputs
- o Calculate necessary probability parameters
- o Evaluate best estimate (BE) hazard curve for each attenuation expert
- o Evaluate BE hazard curve combined over attenuation experts
- o Evaluate weight W_s for seismicity expert
- o Evaluate contribution γ_{sq} from qth zone
- o Do uncertainty analysis for each attenuation expert
- o Compute bounds for P(A > a) for all a for each attenuation expert
- o Compute bounds for P(A > a) combined over all attenuation experts

↓

OUTPUT RESULTS FOR sTH SEISMICITY EXPERT

↓

CREATE FILE OF RESULTS FOR COMB

↓

ITERATE OVER s = 1, . . . S

↓

CALL COMB

- o Read in inputs
- o Combine BE hazard curves over all experts
- o Compute bounds for P(A > a) for all a combined over all experts

↓

OUTPUTS

- o Combined BE hazard curves
- o 15th, 50th and 85th percentile curves

o Expected number of events with magnitude m_j ($j = 1, \ldots J$), $\lambda_{sq}(m_j)$

To assess $\lambda_{sq}(m_j)$ for all $j = 1, \ldots, J$ it is necessary to have the occurrence rate $\Lambda_{sq}(m)$ identified for all m in (M_o, $\hat{M}_{Uq}$) where $\hat{M}_{Uq}$ is the best estimate of the upper magnitude cutoff in the qth zone.

If $M_{LB} = M_o$, $M_{UB} \geq \hat{M}_{Uq}$, then

$$\hat{\Lambda}_{sq}(M_o) = \text{Ave.}\left\{\hat{\lambda}_{oq},\ 10^{H(M_o,\ \hat{a}_q,\ \hat{b}_q)}\right\}$$

$$\hat{\lambda}(m_J) = \hat{\Lambda}_{sq}(m_J - \Delta) \text{ if } 10^{H(\hat{M}_{Uq};\ \hat{a}_q,\ \hat{b}_q)} \neq 0$$

where Δ is one-half the width of a magnitude segment created in the discretization of the magnitude axis.

If $M_o < M_{LB}$ or $M_{UB} < \hat{M}_{Uq}$

for $M_o \leq m \leq M_{LB}$, $\hat{\Lambda}_{sq}(m)$ is based on a quadratic polynomial model subject to

o $\hat{\Lambda}_{sq}(M_o) = \hat{\lambda}_{oq}$

o $\hat{\Lambda}_{sq}(M_{LB}) = 10^{H(M_{LB};\ \hat{a}_q,\ \hat{b}_q)}$

o the derivative of $\hat{\Lambda}_{sq}(m)$ is continuous at $m = M_{LB}$

o for $M_{UB} \leq m \leq \hat{M}_{Uq}$, $\hat{\Lambda}_{sq}(m)$ is based on the model

$\Lambda_{sq}(m) = \alpha e^{\beta m}(m - \hat{M}_{Uq})^2$

subject to

o $\Lambda_{sq}(M_{UB}) = 10^{H(M_{UB}\ ;\ \hat{a}_q,\ \hat{b}_q)}$

o the derivation of $\hat{\Lambda}_{sq}(m)$ is continuous at $m = M_{UB}$

A graphical illustration of the adjusted occurrence rate $\hat{\Lambda}(m)$, assuming a linear magnitude recurrence relation

$$\log_{10} \Lambda(m) = a + bm$$

is given in Figure D.4

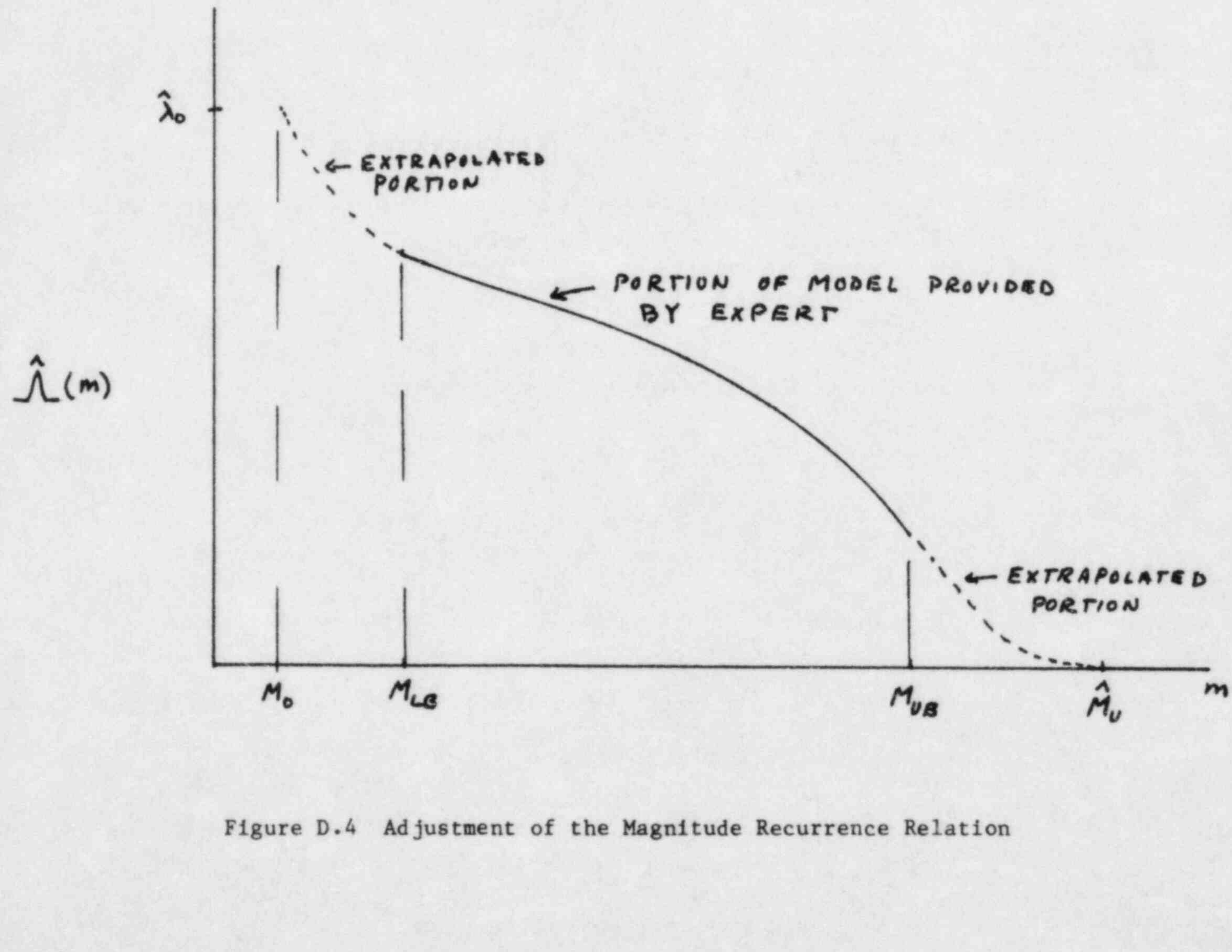


Figure D.4 Adjustment of the Magnitude Recurrence Relation

Given the adjusted occurrence rate function $\Lambda_{sq}(m)$, the expected number of earthquakes in the qth zone with magnitude in the jth segment $(m_j - \Delta, m_j + \Delta)$, based on the sth expert's seismicity parameters for the qth zone, is

$$\hat{\lambda}_{sq}(m_j) = \hat{\Lambda}_{sq}(m_j - \Delta) - \hat{\Lambda}_{sq}(m_j + \Delta)$$

<u>Best Estimate Hazard Calculations</u>

For each seismicity expert, s

- Best estimate hazard at the site due to events in the qth zone

$$\hat{P}_{suq}(A_t > a) = 1 - \exp\left\{- t \sum_{j=1}^{J} \hat{\lambda}_{sq}(m_j) \sum_{k=1}^{K} \pi_{sq}(r_k)\, \hat{P}_u(A > a \mid m_j, r_k)\right\}$$

for $a = a_1, a_2 \dots, a_I$

- Best estimate hazard at the site due to events over all zones in the best estimate map

$$\hat{P}_{su}(A_t > a) = 1 - \prod_q \exp\left\{-t \sum_{j=1}^{J} \lambda_{sq}(m_j) \sum_{k=1}^{K} \pi_{sq}(r_k)\, \hat{P}_u(A > a \mid m_j, r_k)\right\}$$

for $a = a_1, a_2 \dots, a_I$

- Best estimate hazard at the site due to events in the qth zone, combined over attenuation experts

$$\hat{P}_{sq}(A_t > a) = \left\{\sum_u W_{Au}\, \hat{P}_{suq}(A_t > a)\right\} \Big/ \sum_u W_{Au}$$

- Best estimate hazard at the site due to events over all zones in the best estimate map, combined over attenuation experts

$$P_s(A_t > a) = \left\{\sum_u W_{Au}\, \hat{P}_{su}(A_t > a)\right\} \Big/ \sum_u W_{Au}$$

We have used the terminology "best estimate" to identify these hazard curves. In reality these curves are the hazard curves at a site based on specific values, the expert's best estimates, for the inputs. Given the uncertainties associated with the inputs the best estimate hazard curve is unlikely to coincide with the best estimate of the hazard curve in the classical statistical sense.

Other Calculations

- Two other calculations, in addition to the best estimate hazard curves are:
  - Per cent of hazard at a site attributable to the qth zone

$$\gamma_{sq}(a) = \frac{\hat{P}_{sq}(A_t > a)}{\hat{P}_s(A_t > a)}$$

  - Weight for sth seismicity expert

    A discussion of the background for evaluating a single weight for each seismicity expert is given in Section D.3.3. The weight for the sth seismicity expert, W_s, is the weighted average of the self weights in the four regions, i.e.

$$W_s = \sum_{w=1}^{4} W_{sw} \hat{P}_s (A = A_w)$$

where $\hat{P}_s(A = A_w)$ is the estimate, based on the sth expert's best estimate inputs, of the probability that the maximum PGA at the site is due to an earthquake originating in a zone in the wth region, which is the normalized value of

$$\hat{P}_s(A = A_w) = \left\{ \sum_{a_i} \left[\prod_{w' \neq w} \hat{P}_s(A_{w'} \leq a_i) \right] \left[\hat{P}_s(A_w \leq a_{i+1}) - \hat{P}_s(A_w \leq a_i) \right] \right\} \Big/ \hat{P}_s(A > a_1)$$

where $\hat{P}_s(A_w \leq a_{I+1}) = 1.$ for all w, and

$$\hat{P}_s(A_w \leq a) = \prod_q [\hat{P}_{sq}(A \leq a)]^{\delta_{wq}}, \quad a = a_1, \ldots a_I$$
$$w = 1, \ldots 4$$

$$\delta_{wq} = \begin{cases} 1 \text{ if the qth zone is in the wth region} \\ 0 \text{ otherwise} \end{cases}$$

Note that $P_s(A_w \leq a)$ is the probability that maximum PGA at the site due to earthquakes from the wth region is no greater than a.

Although the best estimate calculations have been presented in terms of the PGA, analogous calculations are applicable for the PGV and spectral accelerations or velocities. If a uniform hazard spectrum is the desired output, a best estimate hazard or probability of exceedence curve is evaluated for several (9) frequencies or periods. Then the spectral amplitude for the uniform hazard spectrum is evaluated as follows:

- o For return period RP, let a_i be the acceleration such that for frequency f,

  $$\ln P(A_f > a_i) > \ln RP^{-1} > \ln P(A_f > a_{i+1})$$

  Based on a linear interpolation of the probability of exceedence curve, the spectral amplitude at f is

$$a_{RP}(f) = \exp\left\{\ln a_i - \frac{\ln\left(\frac{ai}{a_{i+1}}\right)}{\ln\left[\frac{P(A_f > a_i)}{P(A_f > a_{i+1})}\right]} \ln\left[\frac{P(A_f > a_i)}{(RP)^{-1}}\right]\right\}$$

  If $\ln RP^{-1} > \ln P(A_f > a_I)$, the spectral amplitude at f is evaluated by a quadratic extrapolation of $\ln P(A_f > a)$.

Finally, after the best estimate calculations are completed for all seismicity experts, the best estimate curves are combined over all seismicity experts to produce the combined best estimate hazard curve. Following the philosophy that the weights are a measure of the level of expertise of the experts, the combined best estimate hazard curve is

$$P(A_t > a) = \left\{\sum_s W_s \hat{P}_s(A_t > a)\right\} \Big/ \sum_s W_s$$

$$= \left\{\sum_s \sum_u W_s W_{Au} P_{su}(A_t > a)\right\} \Big/ \sum_s \sum_u W_s W_{Au}$$

D.5.3 Uncertainty Analysis

In addition to their best estimate of the parameters used to evaluate the seismic hazard at a site, the experts also provided a measure of their confidence in the data, available information and any other resources used to formulate their opinions. Quantification of confidence in the basis for the experts' opinions took several forms depending on the parameter:

- o Uncertainty in identifying seismic sources (zones)

  A collection of alternative maps with associated "confidence" or degree of belief reflecting

  - o Confidence that a zone is seismically distinct from the surrounding region.

  - o Confidence in alternative boundary shapes for a zone or cluster of zones.

  The collection of maps for each seismicity expert was treated as a finite population, the probability associated with each map being the confidence assigned it by the expert.

- o Uncertainty in seismicity parameters

  For occurrence rate λ_0 and coefficients in the magnitude recurrence model, the bounds were treated as the 2.5th and 97.5th percentiles of a lognormal distribution with mode equal to the best estimate of the parameter. For the upper magnitude cutoff the bounds were treated as the range of a triangular distribution with mode equal to the best estimate $\hat{M}_U$.

- o Uncertainty in attenuation models

  By having the experts select a model from each of the 7 classes of models and associating a confidence to each class, a finite collection (up to 7) of models was available for each region and the two magnitude scales. As with the maps, the collection of models was treated as a finite population with probabilities assigned to each model in the population.

- o Uncertainty in random variation in PGA

  The uncertainty in σ_R was treated the same as λ_o.

The purpose of the uncertainty analysis is to produce a set of curves which reflect the variability in estimates of hazard at a site due to the uncertainties associated with the experts' opinions. The curves so produced describe the possible range of hazard, i.e., the range of values of $P(A > a)$ for each a, at the site along with a measure of the expert's "confidence" in the values within the range. That is, for each pair of experts (seismicity-ground motion pair) it quantifies the variation in the estimates of hazard due to the uncertainties in the opinions of the individual experts. When combined over several experts, the variation in the hazard also reflects the variation in opinions about the input parameters between experts.

Propagation of the uncertainties in the inputs through the evaluation process is based on simulation methods. That is, each input parameter is treated as a random variable with the appropriate continuous or discrete probability distribution, e.g., λ_o is treated as a lognormal random variable and the maps and ground motion models have discrete distributions.

For each pair of experts (seismicity-ground motion pair) a random sample of each of the parameters, maps and ground motion models is selected from the appropriate distributions. Then,

- o Given a set of inputs, the hazard, $P_{su}(A_t > a \mid \text{inputs})$, $a = a_1, \ldots a_I$, is evaluated based on the inputs.

- o The sample $P_{sul}(A_t > a)$, $l = 1, \ldots L$ represents a sample from the "uncertainty" distribution for $P(A_t > a)$ for each $a = a_1, \ldots a_I$.

- o For each a_i, the empirical cumulative distribution function (CDF) is used to estimate the distribution for $P(A_t > a_i)$. This is illustrated in Figure D.5. An approximation to the continuous CDF is also included in the illustration. $Q_{su}(\cdot)$ is an estimate of the uncertainty CDF for $P(A > a_i)$ given the uncertainties expressed by the (s, u)th pair of experts.

- o Using the percentiles, e.g., 15th, 50th, 85th, from $Q_{su}(\cdot)$ for each a_i, $i = 1, \ldots I$, a series of curves, reflecting the variation in hazard due to the uncertainties expressed by the (s, u)th pair of experts, can be produced.

To combine the uncertainty results over several experts, we want to estimate the uncertainty CDF for $P(A > a)$ which reflects the uncertainties of individual experts as well as the variation in opinions between experts. $Q_{su}(\cdot)$ is an estimate of this CDF if there were only the two experts. Using the weights W_{Au}, W_s as a measure of the utility or level of expertise of the experts, the uncertainty CDF for $P(A > a)$ is estimated by taking a weighted average of the $Q_{su}(\cdot)$'s. That is, for each p

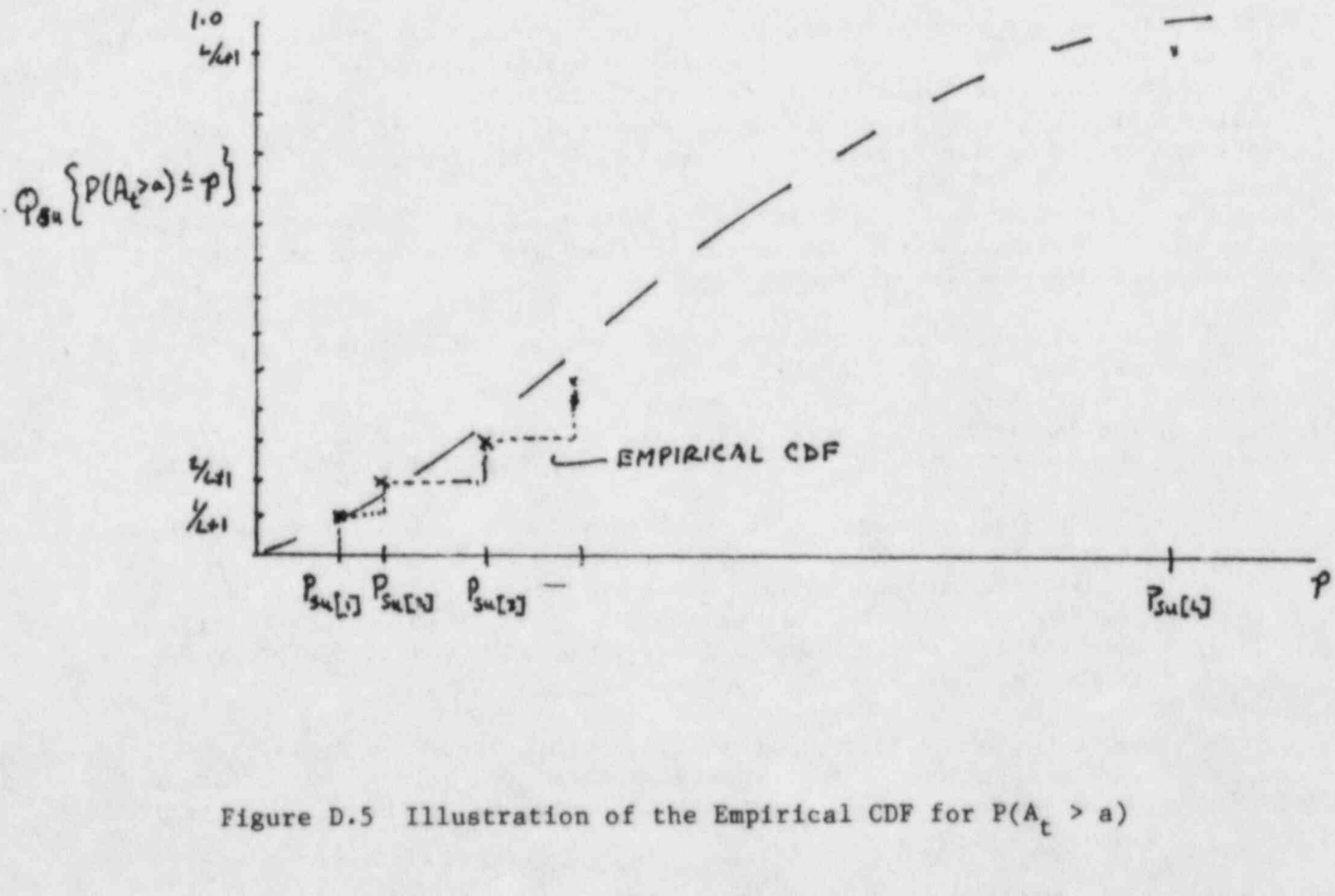


Figure D.5 Illustration of the Empirical CDF for $P(A_t > a)$

$$Q\left\{P(A > a) \leq p\right\} = \left[\sum_s \sum_u W_s \, W_{Au} \, Q_{su}\left\{P(A > a) \leq p\right\}\right] \Bigg/ \sum_s \sum_u W_s \, W_{Au}$$

This is illustrated in Figure D.6 for three pairs of experts.

For each a individually, each $Q_{su}(\cdot)$ is an estimate of the uncertainty associated with estimating $P(A > a)$. The combined CDF, $Q(\cdot)$ reflects a level of uncertainty consistent with the weights associated with the experts.

The combined CDF's for $P(A > a)$, for $a = a_1, \ldots, a_I$, are used to determine bounds for $P(A > a)$ for each a_i. For example, the 15th percentile $p_{.15}(a)$ is the value of p such that

$$Q\left\{P(A > a) \leq p\right\} = 0.15$$

Similarly for the 85th percentile.

To produce corresponding 15th and 85th curves, which reflect the potential variation in the hazard curve at a site, the points $p_{.15}(a_i)$, $i=1,\ldots I$, are combined to form the 15th percentile curve and, correspondingly, the points $p_{.85}(a_i)$ are combined to form the 85th percentile curve.

One must be careful in interpreting the bounds as hazard curves which correspond to a specific set of input parameters. The bounds are analogous to the bounds which are used to define Uniform Hazard Spectra (UHS). The UHS is the locus of points each corresponding to the same probability of exceedence and does not represent a distinct spectrum since the inherent physical correlation between the values at different frequencies has been lost in the calculations. However, it can be interpreted as an envelope of all possible spectra. Similarly the 85th and 15th percentile hazard curves do not represent the hazard curve corresponding to a specific set of input parameters. Rather they are the locus of probabilities such that the "Probability" (due to the uncertainty of the experts' in their inputs) in the probability $P(A > a)$ being greater than .15 (.85) respectively for each a. It can be interpreted as an envelope of all possible hazard curves. It is not correct to interpret the 85th percentile curve as a hazard curve which will not be exceeded by 85 percent of the hazard curves produced by the uncertain parameters. It is true, however, that for a fixed value a the value $P_{.85}(A > a)$, taken from the 85th percentile curve at a, is an estimate of the value of $P(A > a)$ which has "degree of belief" or "confidence" 0.85 that it will not be exceeded, where the "confidence" is a weighted average of the level of confidence of the individual experts.

D.6 References

[1.] Bernreuter, D. L. "Seismic Hazard Analysis, A Methodology for the Eastern United States," NUREG/CR-1582, Vol. 2, August 1980.

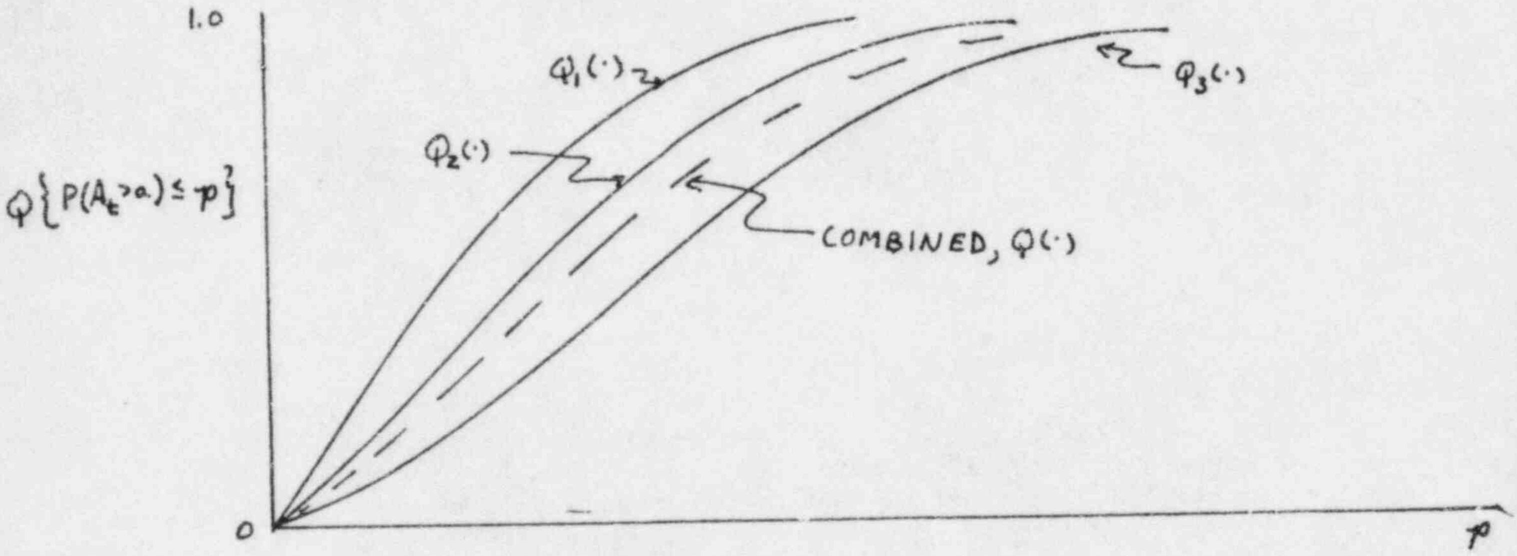


Figure D.6 Illustration of Uncertainty Distribution for P(A > a) for Fixed a

NRC FORM 335 (7-77)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)
NUREG/CR-3756
UCRL-53527

4. TITLE AND SUBTITLE (Add Volume No., if appropriate)
Seismic Hazard Characterization of the Eastern United States: Methodology and Interim Results for Ten Sites

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
D. L. Bernreuter, J. B. Savy, R. W. Mensing, D. H. Chung

5. DATE REPORT COMPLETED

MONTH	YEAR
April	1984

DATE REPORT ISSUED

MONTH	YEAR
April	1984

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Lawrence Livermore National Laboratory
P.O. Box 808, L-95
Livermore, California 94550

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Health, Siting and Waste Management
Office of Nuclear Regulatory Research
Division of Engineering
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.
FIN-A0390
FIN-A0428

13. TYPE OF REPORT
Technical

PERIOD COVERED (Inclusive dates)

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less)

The EUS Seismic Hazard Characterization Project (SHC) is the outgrowth of an earlier study performed as part of the U.S. Nuclear Regulatory Commission's (NRC) Systematic Evaluation Program (SEP). The objectives of the SHC are: 1) to develop a seismic hazard characterization methodology for the region east of the Rocky Mountains; and 2) the application of the methodology to ten sites to assist the NRC staff in their assessment of the implications in the clarification of the U.S. Geological Survey (USGS) position on the Charleston earthquake.

As in the SEP, the fundamental characteristics of the methodology used in SHC consists in using expert opinions for all the input data. The most important improvement over the methodology used in the SEP leads to an estimate of the distribution of the hazard rather than just point estimates. An important aspect of eliciting expert opinion consists in holding feedback meetings in order to fine tune the methodology and the input data. At this point, the feedback process has not been completed. Our methodology and preliminary input from the expert panels is presented. Estimates of the hazard (PGA and spectral velocity) at ten representative sites are discussed including a sensitivity analysis and a comparison with the SEP results at four sites.

17. KEY WORDS AND DOCUMENT ANALYSIS

Seismic Hazard Characterization Project
Methodology to ten sites

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS (This report)
UNCLASSIFIED

20. SECURITY CLASS (This page)
UNCLASSIFIED

21. NO. OF PAGES

22. PRICE
$

NRC FORM 335 (7-77)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984-421-297:3913

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

FOURTH CLASS MAIL
POSTAGE & FEES PAID
USNRC
WASH. D.C.
PERMIT No. G 67

120555078877 1 1AN1RA1RD1RM
US NRC
ADM-DIV OF TIDC
POLICY & PUB MGT BR-PDR NUREG
W-501
WASHINGTON DC 20555