5.11 Maine Yankee

5.11.1 Zonation Effects

Maine Yankee is a rock site (Category I) located in the northeastern part of the Northeast region of the EUS. None of the seismicity experts' CZ contain this site. For all except Expert 10, the host zone is the dominant zone at both low and high PGA values. For Expert 10, a nearby zone is dominant at low PGA values. The zonal dominance in the BEHC at low and high PGA values is summarized in Table 5.11.1.

5.11.2 PGA Hazard Curves

The BEHC combined over all experts is presented in Fig. 5.11.1. The BEHC per seismicity expert is shown in Fig. 5.11.2. No significant outliers are present in Fig. 5.11.2, although it is noted that the curves of Experts 5, 12, and 13 do lie below the main group of curves due to a combination of low seismicity and/or low upper magnitude cutoffs. No curve has a significantly different shape. The spread of the curves is a factor of 3 to 4 at low PGA and a factor of 15 to 20 at high PGA values. The CPHC is shown in Fig. 5.11.3. The results of the CPHC are consistent with the BEHC with an increase in dispersion at high PGA. The BEHC is a factor of 1 to 2 higher than the 50th percentile hazard curve at low PGA values; the BEHC is a factor of about 5 higher at high PGA values.

5.11.3 Uniform Hazard Spectra

The BEUHS combined over all experts for the return periods selected is presented in Fig. 5.11.4. The curves exhibit a shape very close to a Newmark-Hall spectrum shape. The BEUHS per seismicity expert for a 500 year return period and a 1,000 year return period are shown in Figs. 5.11.5 and 5.11.6 respectively. The dispersion in the experts' curves is smaller than average. A factor of 2 to 3 from lowest to highest at both low and high periods. No outliers are present. The curves of Experts 3, 4, and 5 turn downward at long periods. This is due to the interplay of the dominant host zone and nearby significant zones. Overall, there is a uniformity of opinion and symmetry to the distribution of the seismicity parameters. The CPUHS for a 500 year return period, 1,000 year return period, and 10,000 year return period are presented in Figs. 5.11.7, 5.11.8, and 5.11.9 respectively. These figures show a lower than average dispersion in the spectral hazard estimates. The uncertainty increases at periods longer than.3 secs. due to the uncertainty in the method of site correction described in Section 4.4. The BEUHS and the 50th percentile curves are practically the same.

TABLE 5.11.1

Zonal Dominance In The
BEHC At Low and High PGA

SITE: Maine Yankee
SITE CLASSIFICATION: Rock
REGIONAL LOCATION: Northeast

Seismicity Expert	Expert's Host Zone		Contribution to the Hazard									
			Low PGA (.05g)						High PGA (1.0g)			
1	22	Zone	22	21	20				22	21		
		Contribution	.91	.05	.04				.98	.02		
2	31	Zone	31	32	CZ				31	32		
		Contribution	.84	.16	.01				.94	.06		
3	7	Zone	7	6	3	1	4		7	1	6	3
		Contribution	.78	.14	.04	.03	.01		.95	.03	.02	.01
4	20	Zone	20	18	19	16			20	18		
		Contribution	.69	.27	.03	.02			.99	.01		
5	1	Zone	1	6	3				1			
		Contribution	.93	.04	.02				1.00			
6	4	Zone	4	3	2	5			4	3		
		Contribution	.91	.06	.02	.01			.99	.01		
7	24	Zone	24	19	20	26	CZ		24	26		
		Contribution	.81	.06	.05	.04	.02		.99	.01		
10	1	Zone	23	1	21	8	22	25	1	23		
		Contribution	.46	.31	.12	.04	.03	.02	.63	.37		
11	1	Zone	1	3	CZ	2			1	3	CZ	
		Contribution	.81	.16	.02	.01			.95	.04	.01	
12	3	Zone	3	18	16	17			3	18	16	
		Contribution	.74	.13	.10	.03			.96	.03	.01	
13	10	Zone	10	CZ	12	11			10	CZ	12	
		Contribution	.79	.10	.09	.02			.61	.38	.01	

NOTE: Contributions may not add up to 1.00.

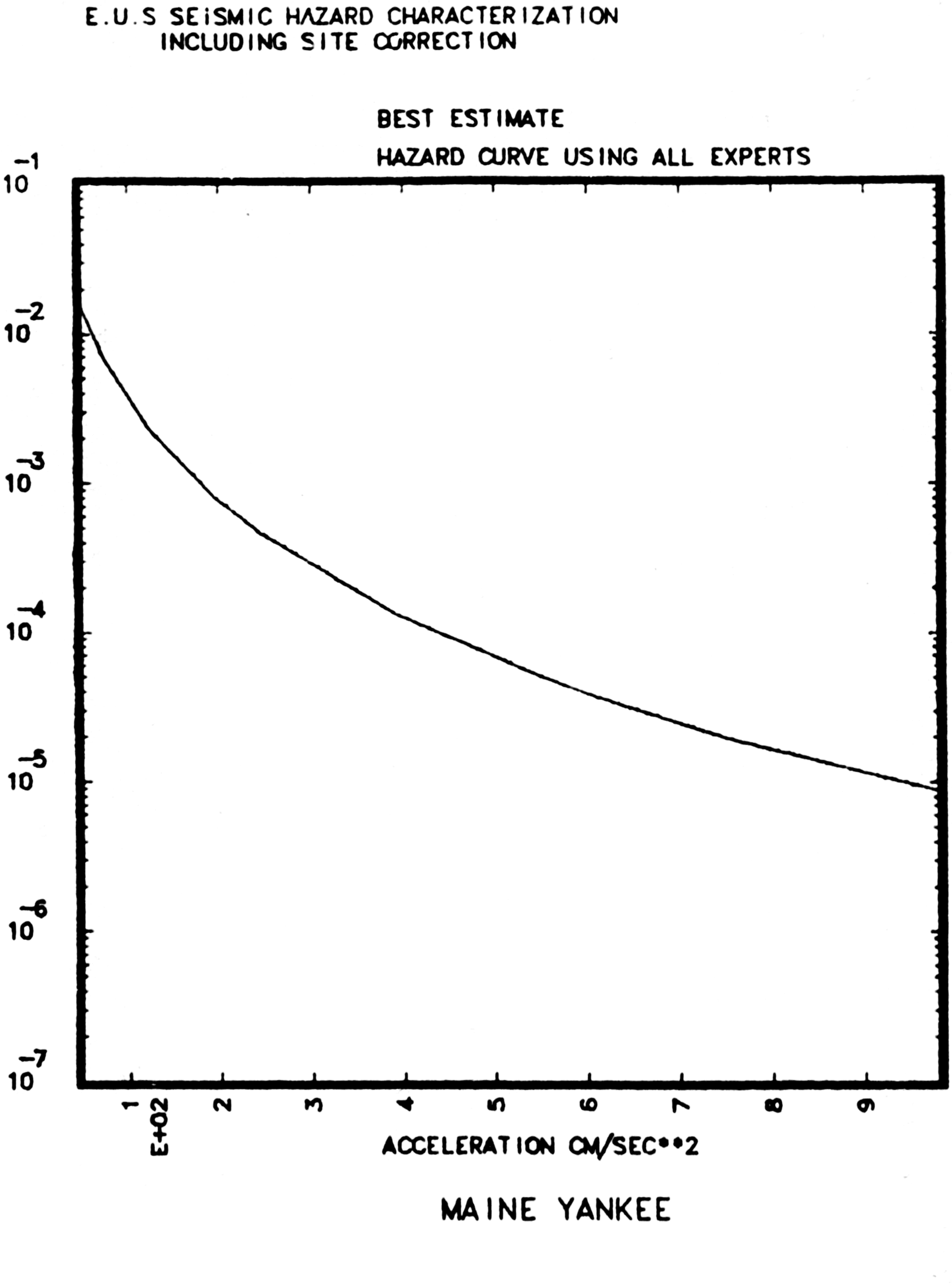


Figure 5.11.1 BEHC Combined Over All Experts

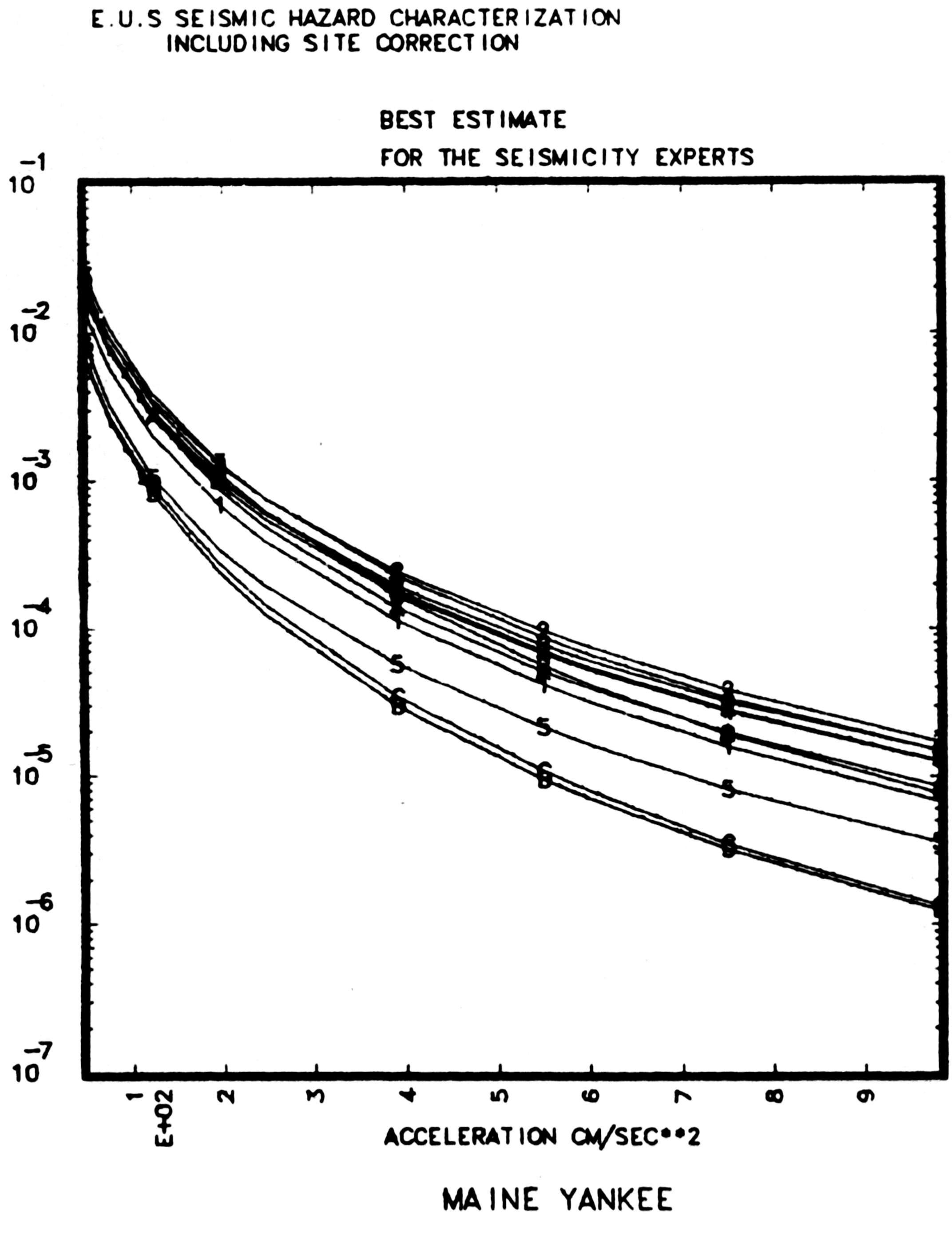


Figure 5.11.2 BEHC per Seismicity Expert Combined Over All Ground Motion Experts

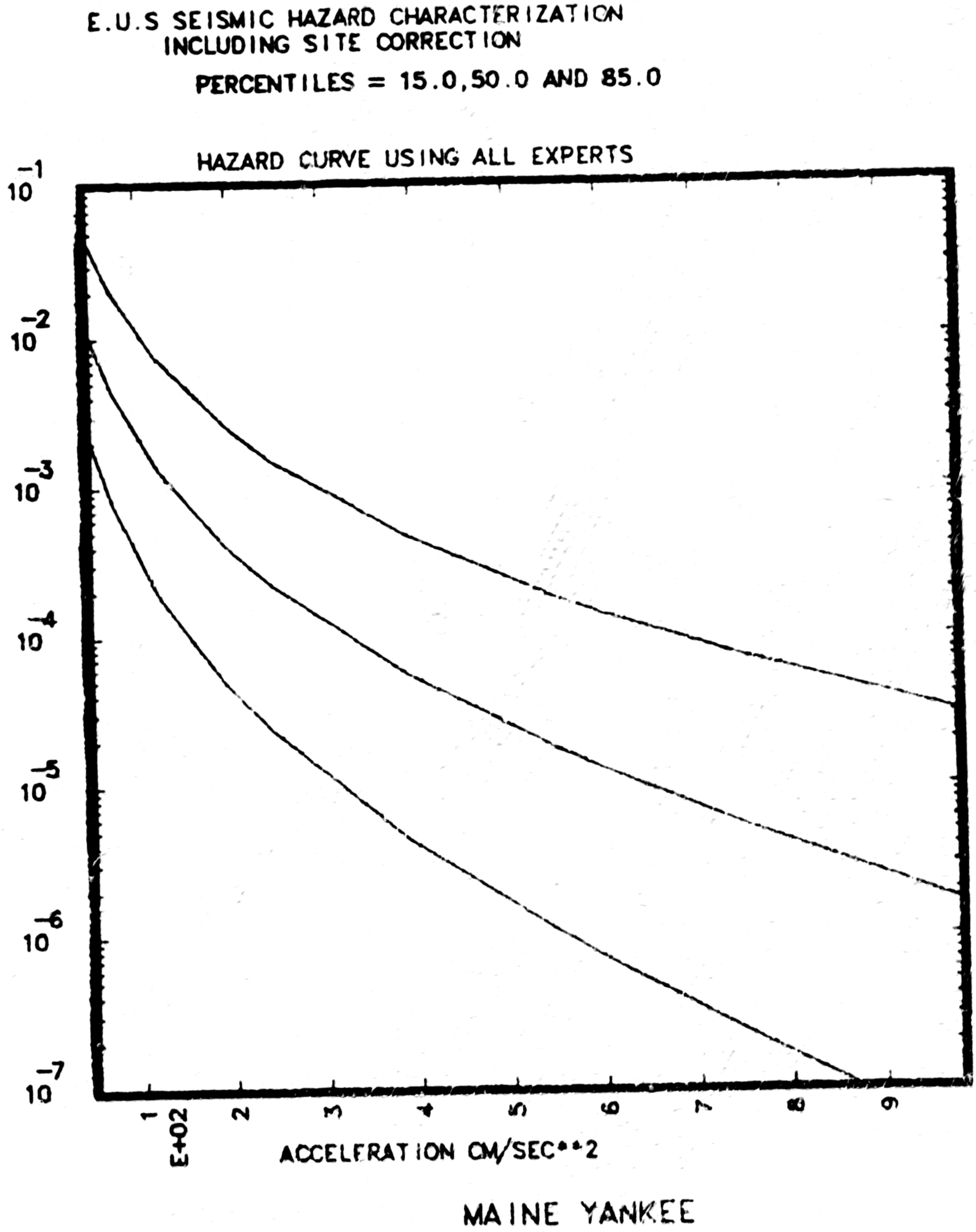


Figure 5.11.3 Constant Percentile Hazard Curves (CPHC) Over All Experts

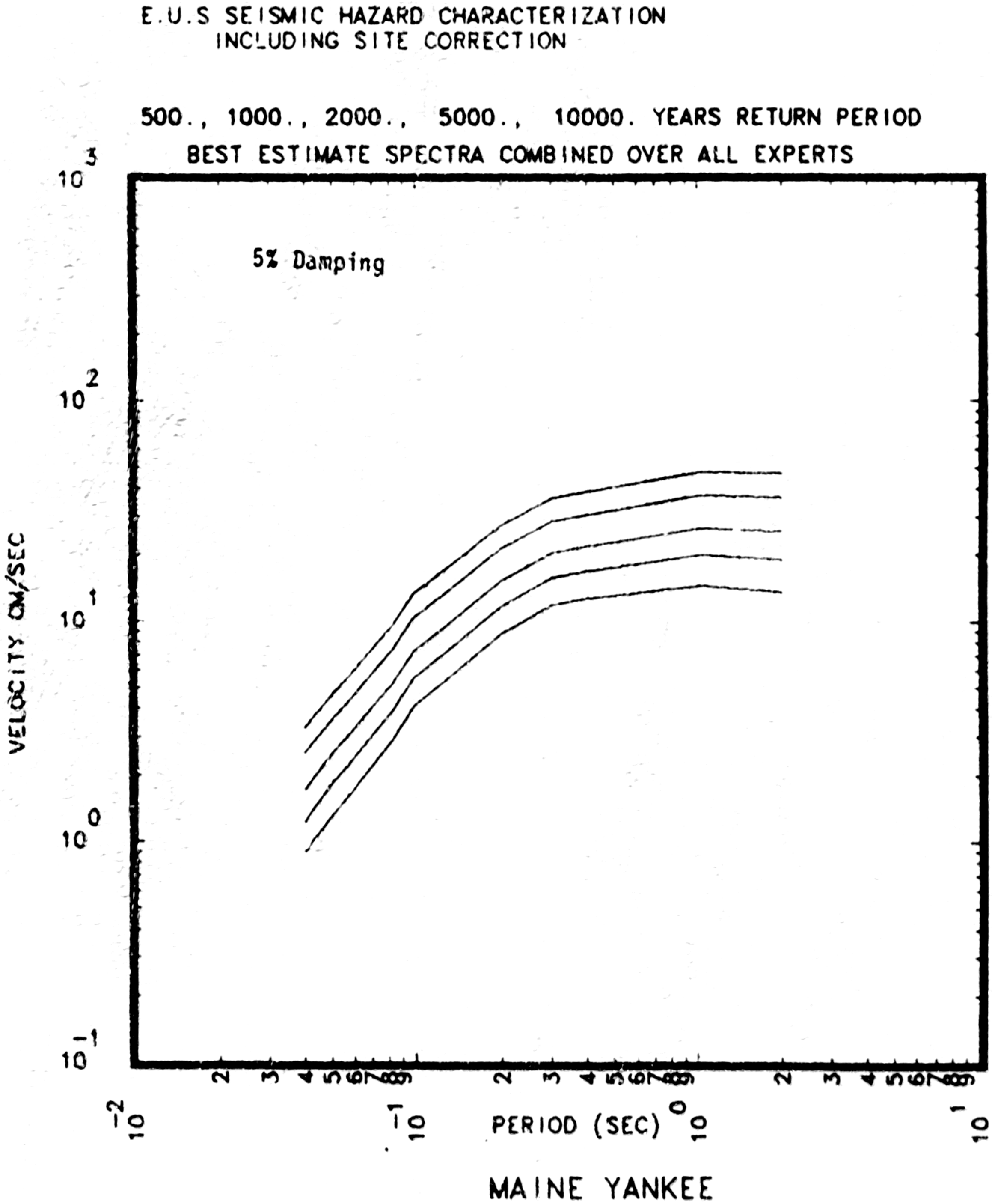


Figure 5.11.4 Best Estimate Uniform Hazard Spectra (BEUHS) Curves Over All Experts

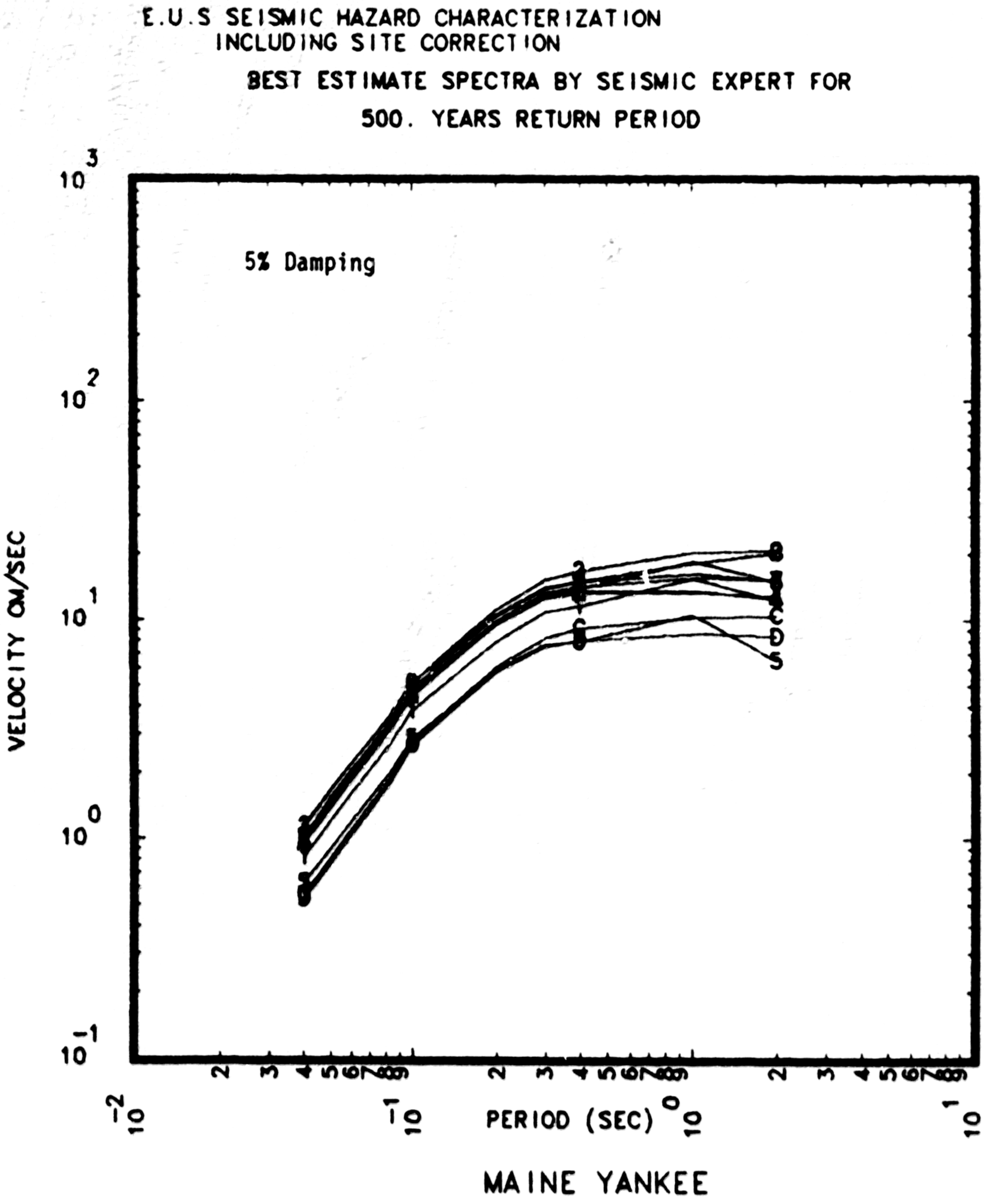


Figure 5.11.5 500 Year Return Period BEUHS per Seismicity Expert Combined Over All Ground Motion Experts

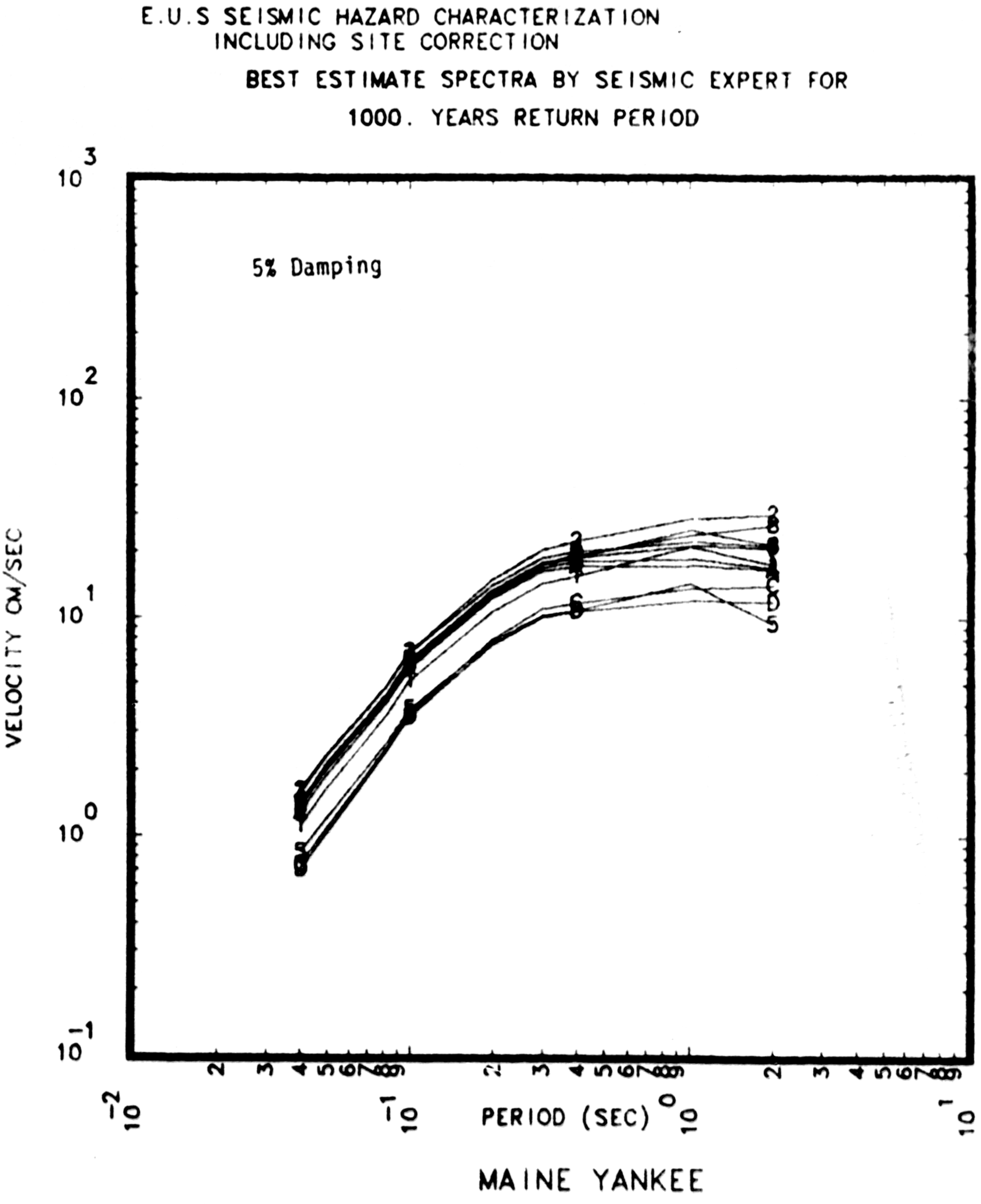


Figure 5.11.6 1,000 Year Return Period BEUHS per Seismicity Expert Combined Over All Ground Motion Experts

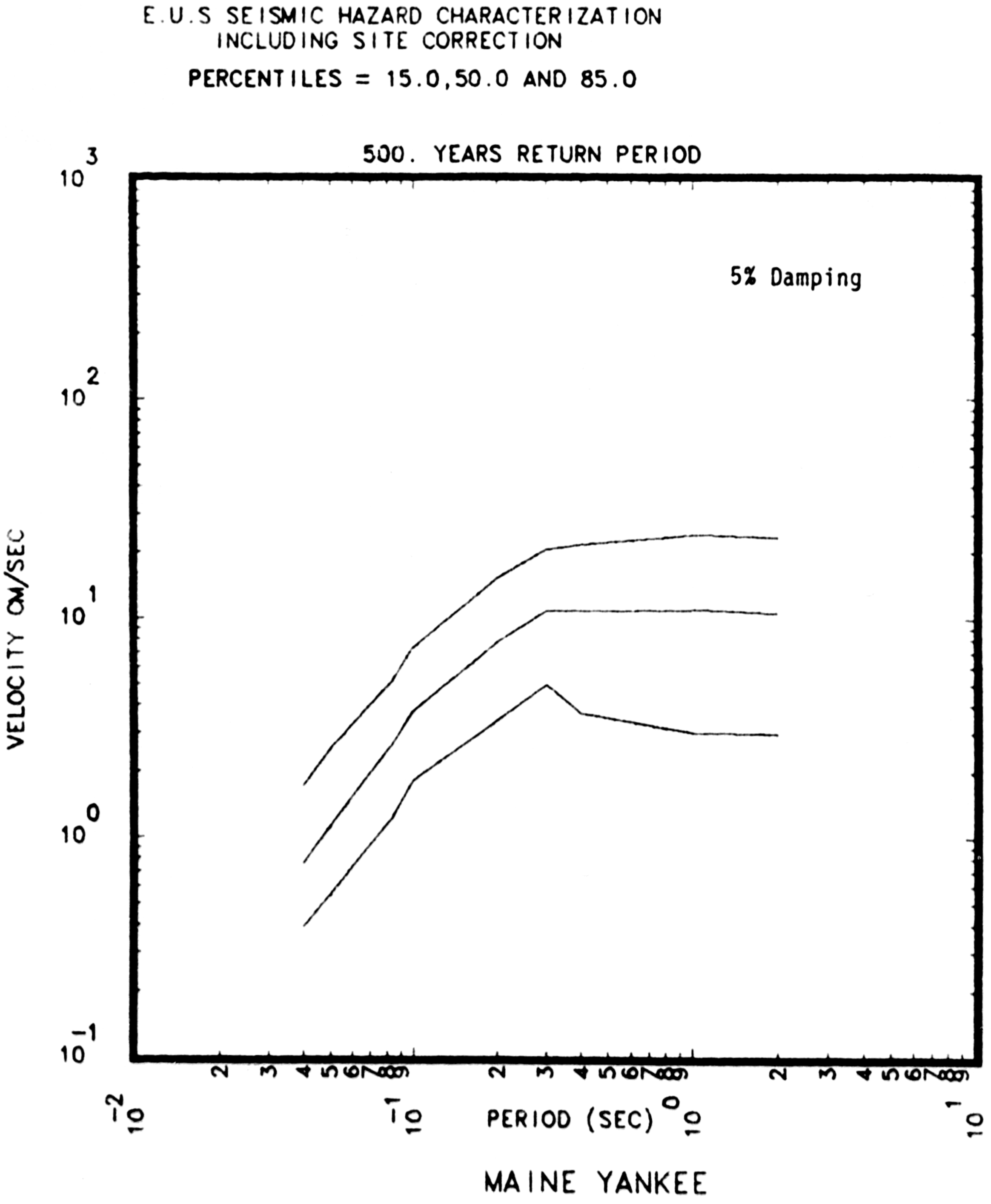


Figure 5.11.7 500 Year Return Period CPUHS Over All Experts

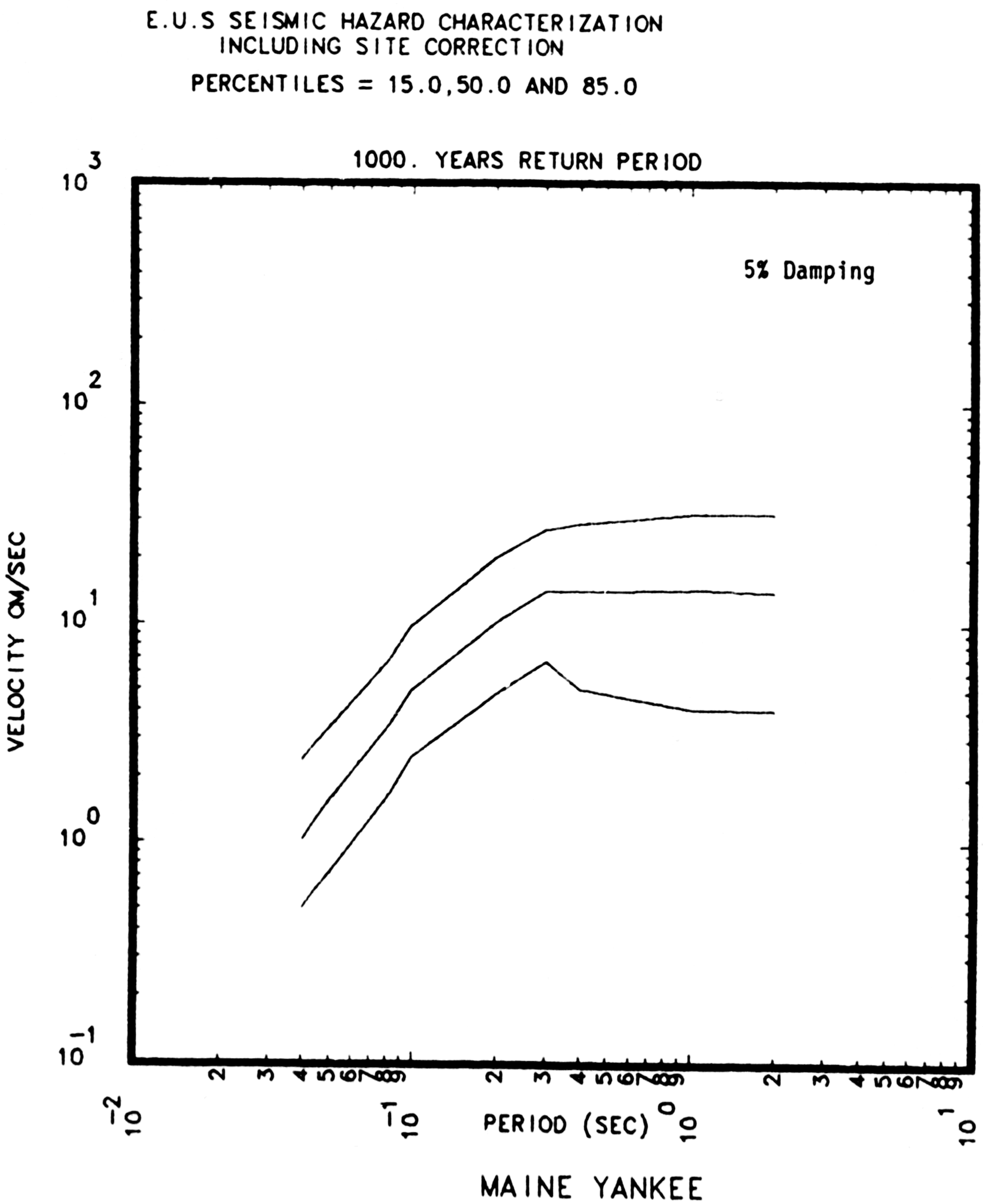


Figure 5.11.8 1,000 Year Return Period CPUHS Over All Experts

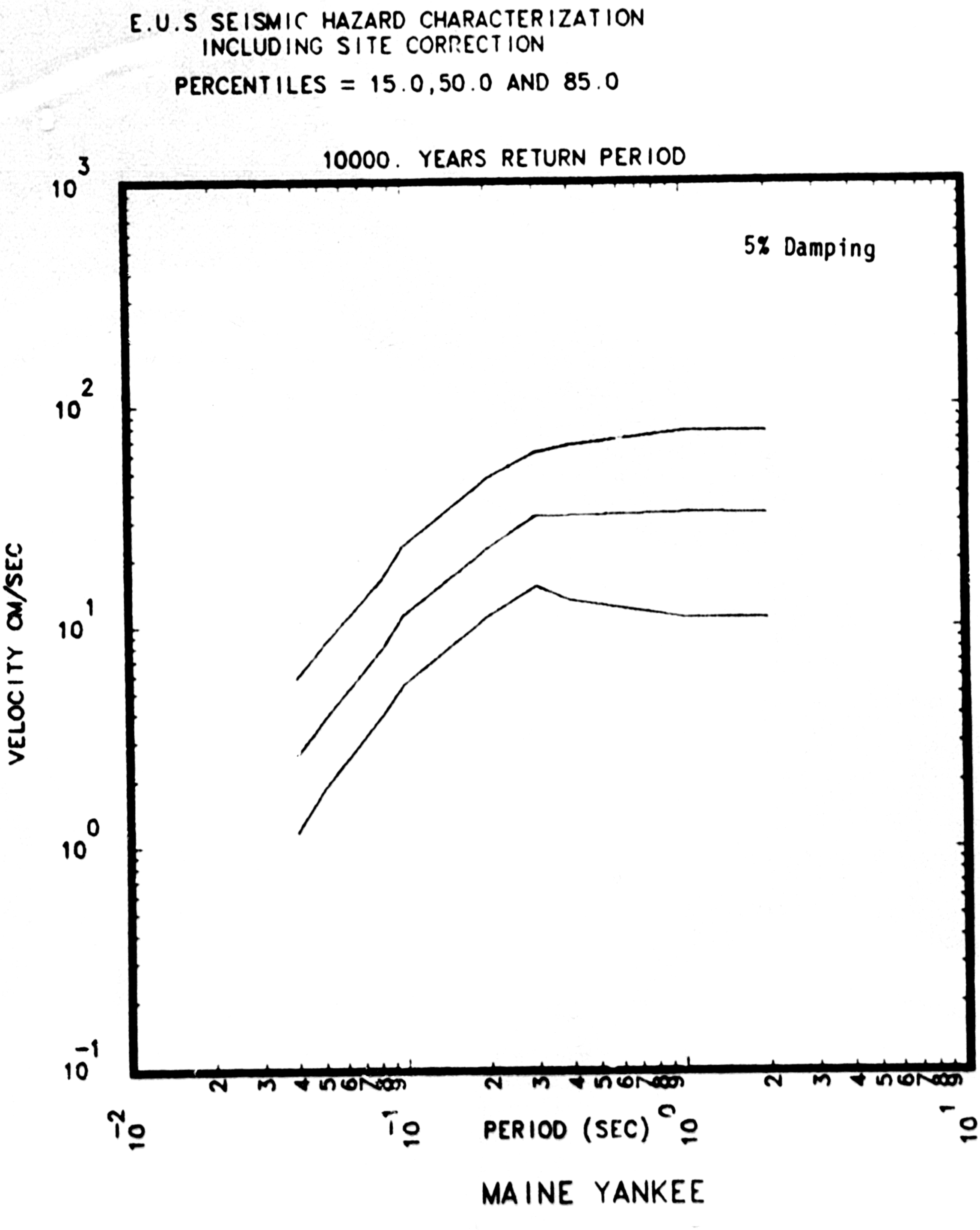


Figure 5.11.9 10,000 Year Return Period CPUHS Over All Experts

5.12 Summary of Sites By Region

As indicated in Sec. 2.5.4, four regions are identified for the EUS. These regions are shown in Fig. 2.4. The BEHC and the BEUHS for 1000 year return period of the Ten Test Sites are displayed in Figure 5.12.1a and b in summary of the results of Section 5.2 through 5.11.

Overall, the sites in the northeast and southeast regions have higher BE hazards than those associated with the north central and south central regions. The BEUHS are relatively comparable between regions with no sites within a region producing perceptibly higher or lower spectra.

5.12.1 Northeast Region

Two sites fall within the northeast (NE) region: Millstone (Sec. 5.5), located in the southeast portion, and Maine Yankee (Sec. 5.11), located in the middle of the region. Both are classified as rock sites. Both BEHC (combined over all experts) give a similar hazard. Maine Yankee is a uniform factor of 1.1 to 1.2 higher in hazard (See figure 5.12.2a). The BEHC per seismicity expert for the two sites are similar in shape and spread, with the opinion of the various experts relatively consistent but a slightly higher curve for Maine Yankee. Nine of eleven experts place the two sites in the same host zone. The two experts who did not (Experts 4 and 10) are the two with the greatest change in hazard curves between the two sites (Fig. 5.12.2.b). The CPHC for the two sites have similar shapes with the Maine Yankee slightly higher; this is consistent with the BEHC findings. The same consistency of opinion is also present in the comparison of UHS for the two sites. (Fig. 5.12.2b) As with the hazard curves, the greatest difference between the two sites are the result of the differences between curves for Expert 4 and 10 who have differing host zones.

5.12.2 North Central Region

Two sites fall within the north central (NC) region: Braidwood (Sec. 5.2), located in the central southeast portion of the region, and La Crosse (Sec. 5.7), located in the central northeast portion of the region. Braidwood is classified as a rock site; La Crosse, a shallow soil site. A comparison of the BEHC combined over all experts shows that a higher hazard is found for Braidwood (See Fig. 5.12.3a). The Braidwood BE hazard is a factor of about 2 higher at low PGA and a factor of about 7 higher at high PGA. A comparison of BEHC per seismicity experts for the two sites shows that the spread between the experts' opinions for La Crosse is lower than for Braidwood. For both sites, Expert 11 is an outlier on the high side (See Figs. 5.2.2 and 5.7.2). Four of the experts (Experts 3, 4, 5, and 13) place both sites in the same host zone. These experts have some consistency of hazard due to their placement of the two sites on the same zone. The CPHC for the two sites are almost the same (See Figs. 5.2.3 and 5.7.3). This is interesting considering the spread of the curves for the Braidwood site. The shape of the BEUHS combined over all experts compares well between the two sites. As with the hazard curves, the spread between the experts' opinions on the UHS is lower for La Crosse than for Braidwood (See Fig. 5.12.3.b). The relative position of each expert's curve in the cluster is consistent between the sites. The CPUHS for the specified return periods have almost the same 15th and 85th percentile curves, with the 50th percentile curve for Braidwood slightly higher than that for La Crosse.

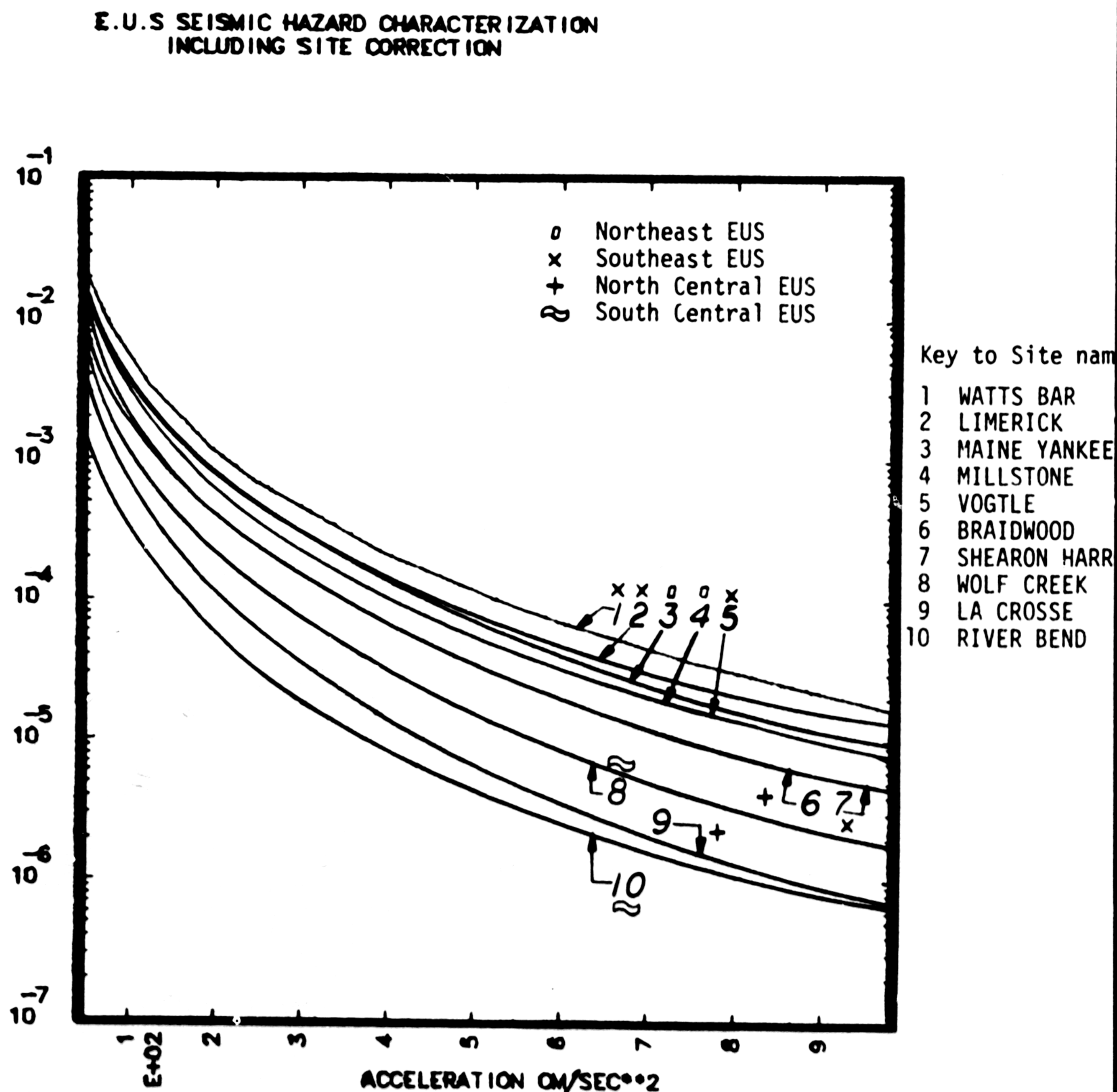


Figure 5.12.1a Summary of the BEHC for the ten test sites

E.U.S SEISMIC HAZARD CHARACTERIZATION
INCLUDING SITE CORRECTION

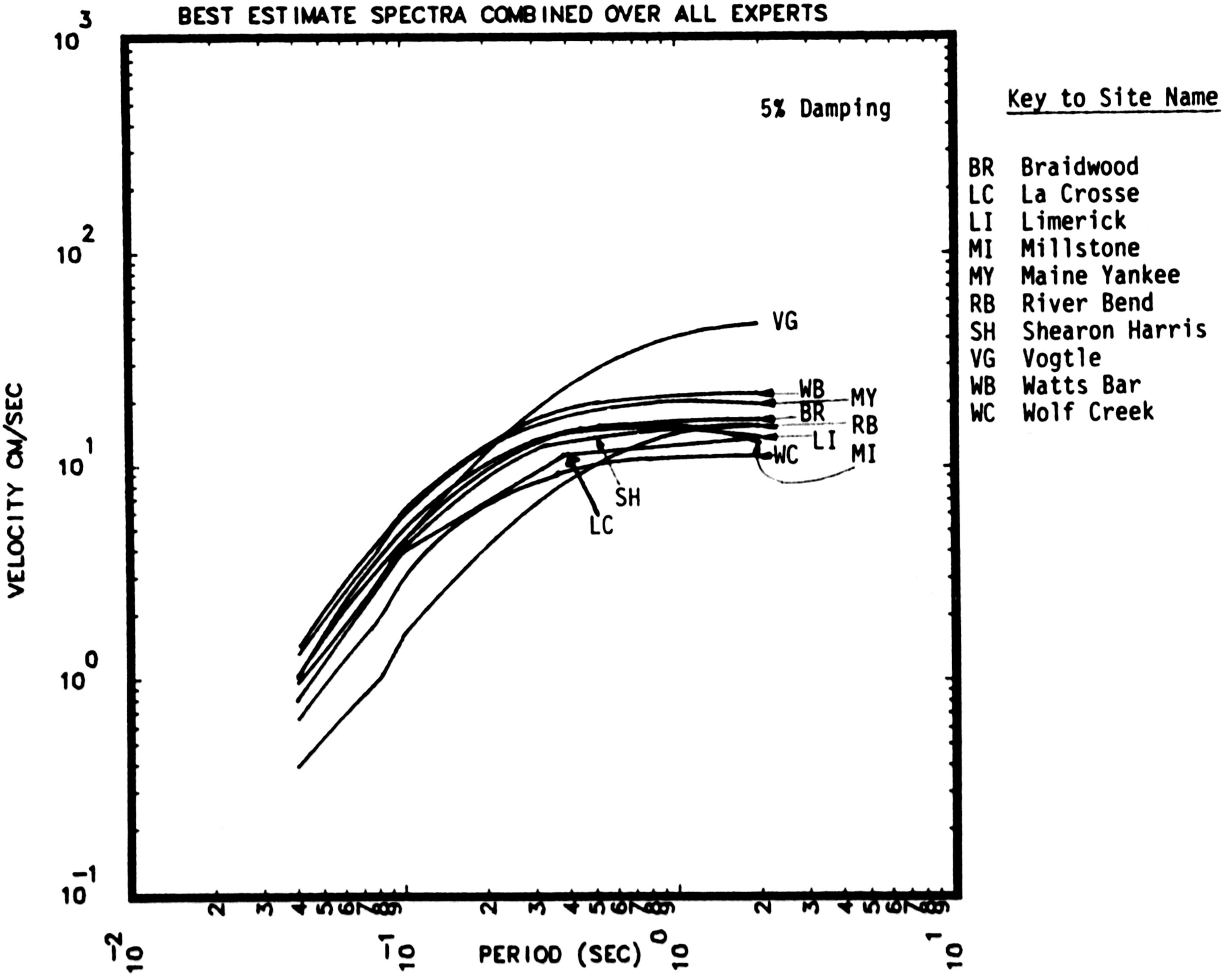


Fig. 5.12.1b 1000 year Return Period BEUHS for the Ten Test Sites in the EUS

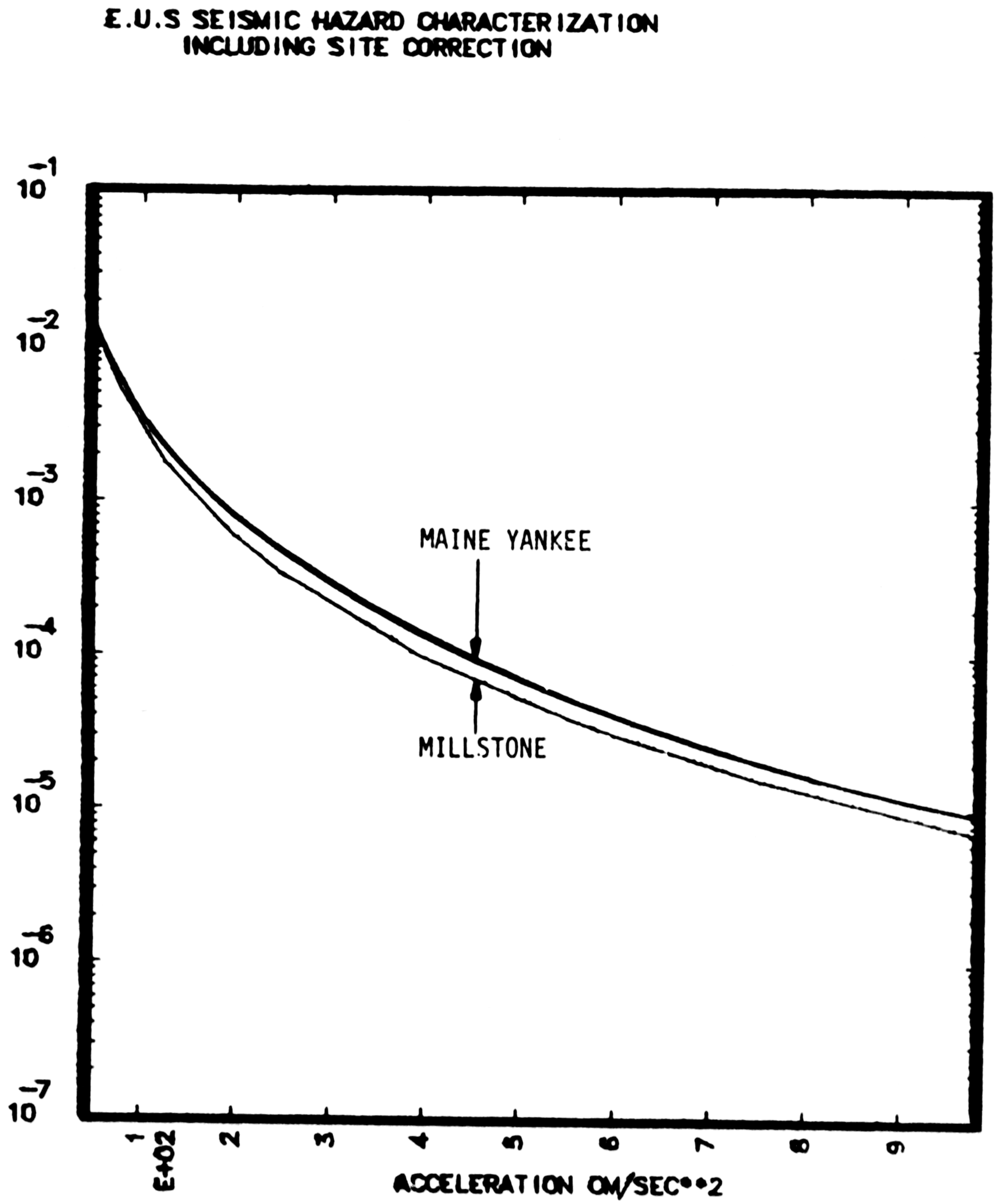


Figure 5.12.2a Summary of the BEHC for the Northeast of the EUS

E.U.S SEISMIC HAZARD CHARACTERIZATION
INCLUDING SITE CORRECTION

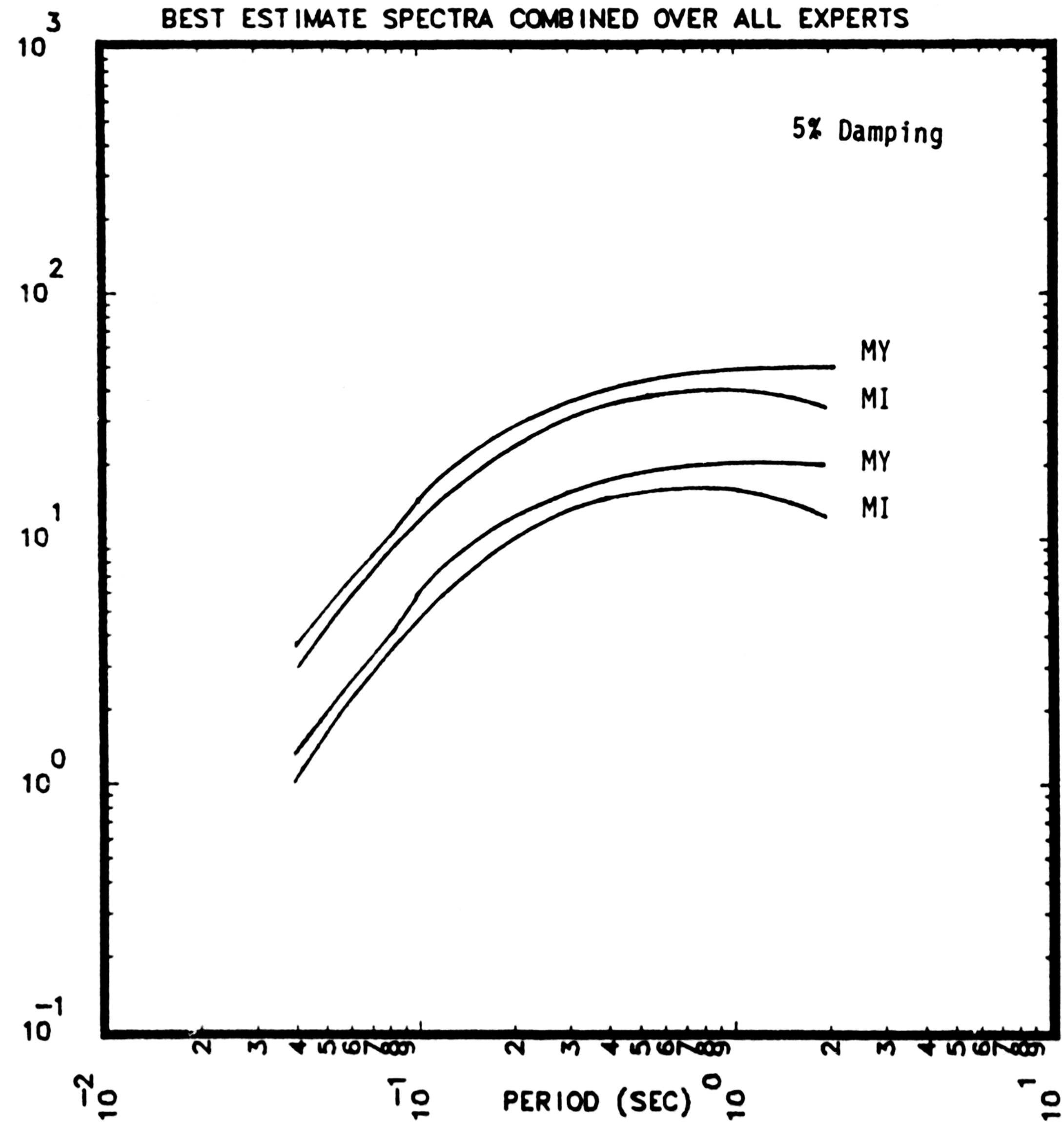


Fig. 5.12.2.b 1,000 Year and 10,000 Year Return Period BEUHS for Millstone (MI) and Maine Yankee (MY) in the Northeastern Region of the EUS.

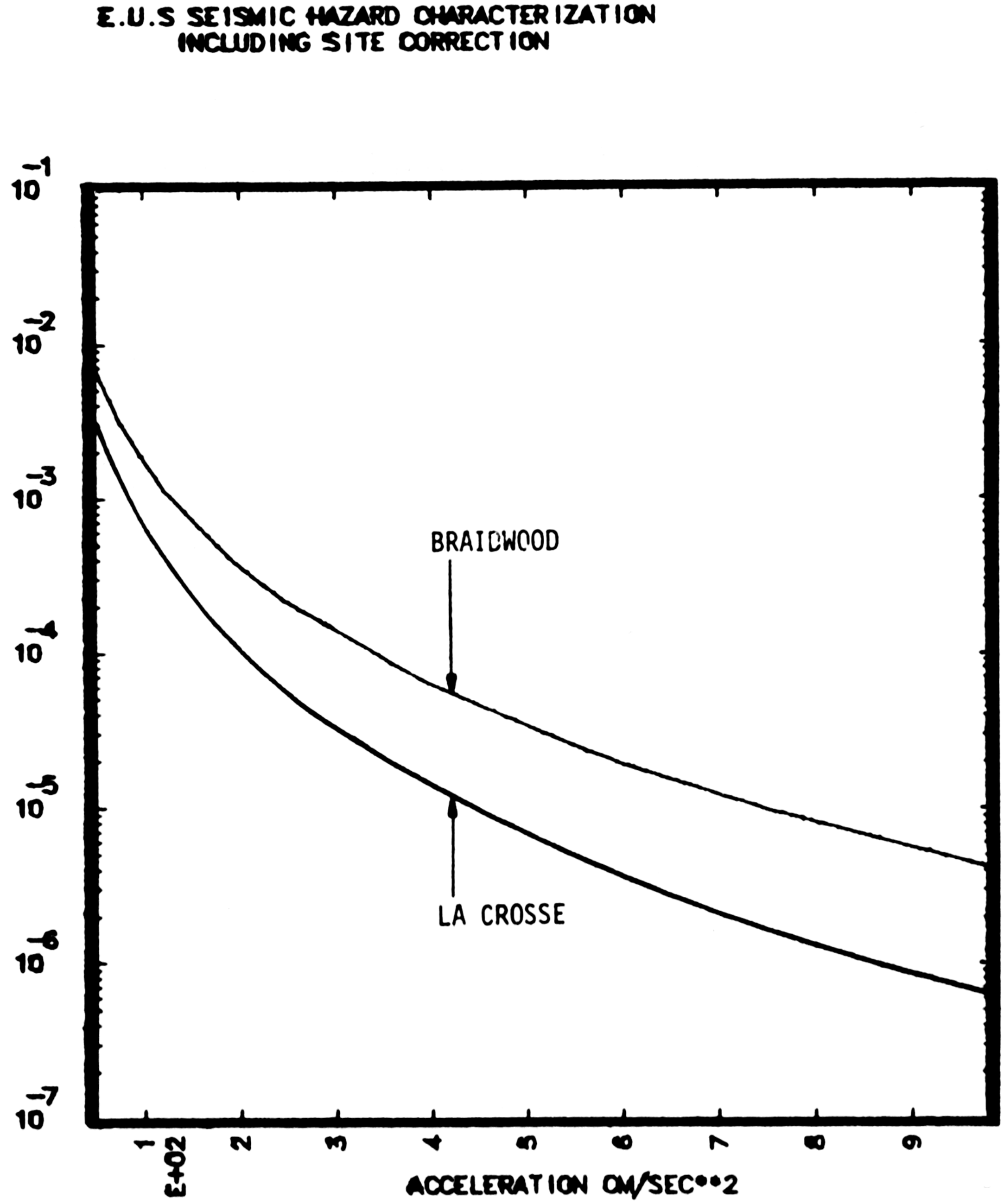


Figure 5.12.3a Summary of the BEHC for the North Central part of the EUS

E.U.S SEISMIC HAZARD CHARACTERIZATION
INCLUDING SITE CORRECTION

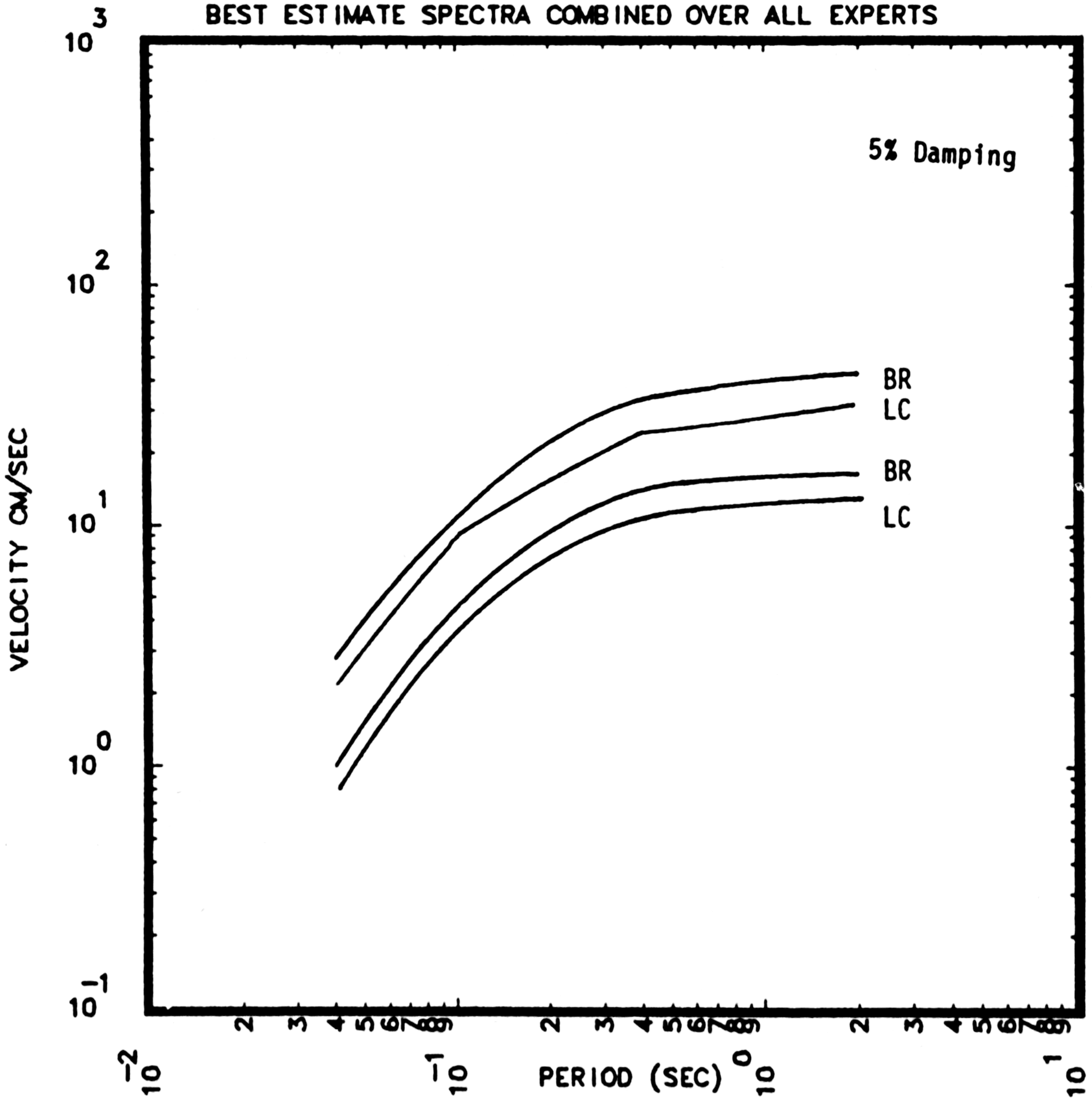


Fig. 5.12.3b 1,000 Year and 10,000 Year Return Period BEUHS for Braidwood (BR) and La Crosse (LC) in the North Central Region of the EUS.

5.12.3 Southeast Region

Four sites fall within the southeast (SE) region: Shearon Harris (Sec. 5.3), located on the northwest portion; Limerick (Sec. 5.6), located in the northern boundary area; Watts Bar (Sec. 5.9), located on the western boundary area; and, Vogtle (Sec. 5.10), located on the south central portion of the region. All but Vogtle are classified as rock sites. Vogtle is classified as a deep soil site. A comparison of BEHC combined over all experts (Figure 5.12.4a) shows that similar hazard curves exist for all four sites. The lowest hazard is found for the Shearon Harris site; the highest, for the Watts Bar site. A factor of 2.5 separates the high and low hazard curve at low PGA, a factor of 4 separates them at high PGA. The BEHC per seismicity expert for each site is similar in curve shape. The spread between experts' opinions is lower for Shearon Harris and Watts Bar. The largest spread between experts is found for Limerick. The general relative position of each expert's curve is consistent between sites (i.e., Expert 2 is consistently on the high side of the curve spread while Expert 12 is consistently on the low side of the spread). Expert 1 places both Limerick and Watts Bar in the same host zone; Experts 4 and 12 place Shearon Harris and Limerick in the same host zone; Expert 5 places Shearon Harris and Vogtle in the same host zone; and, Experts 10 and 13 place Shearon Harris, Limerick, and Vogtle in the same host zone. For each of the above, the consistency of hazard curves between sites located in the same zone is very good. The same trend found on the BEHC combined over all experts is present on the CPHC combined over all experts. Watts Bar has the highest 50th percentile hazard curve and Shearon Harris has the lowest. A factor of 3 separates them at low PGA and a factor of 6 separates them at high PGA. Vogtle (the deep soil site) has the lowest spread between the 15th and 85th percentile (about 10 at low PGA and about 250 at high PGA). The other sites have spreads similar to one another, with a factor of between 25 and 30 at low PGA and between 300 and 600 at high PGA. The BEUHS combined over all experts is similar for the rock sites (see Fig. 5.12.4b); Vogtle, the deep soil site, has a much flatter spectra. The BEUHS per seismicity expert, when compared for all sites, indicates that Expert 2 is consistently on the high side of the spread. At long periods, this expert can be considered an outlier at all sites except Limerick. Expert 12 is consistently on the low side of the spread. This expert can also be considered an outlier at high periods for all sites except Limerick. The same consistency of opinion present in the comparison of the UHS is present in the hazard curves. As with the CPHC, the CPUHS for specified return periods have the least spread between 15th and 85th percentile for the Vogtle site. For all sites, the spread between the 15th and 85th percentiles is greater at long periods than at short periods. It is noted that the influence of the New Madrid zone on the Watts Bar site is greater than the Charleston zone on the Shearon Harris site or Vogtle site.

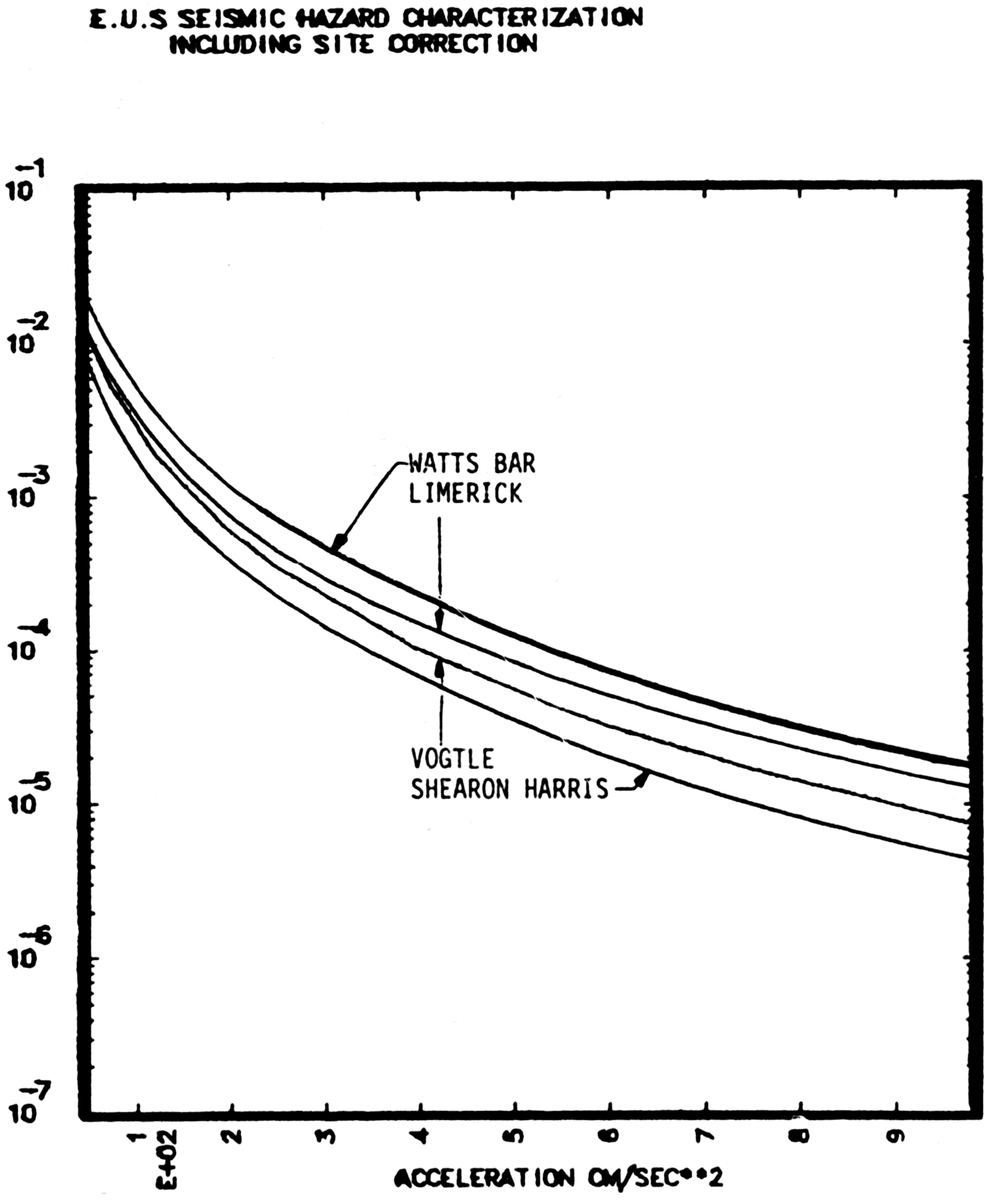


Figure 5.12.4 a Summary of the BEHC for the Southeast of the EUS

E.U.S SEISMIC HAZARD CHARACTERIZATION
INCLUDING SITE CORRECTION

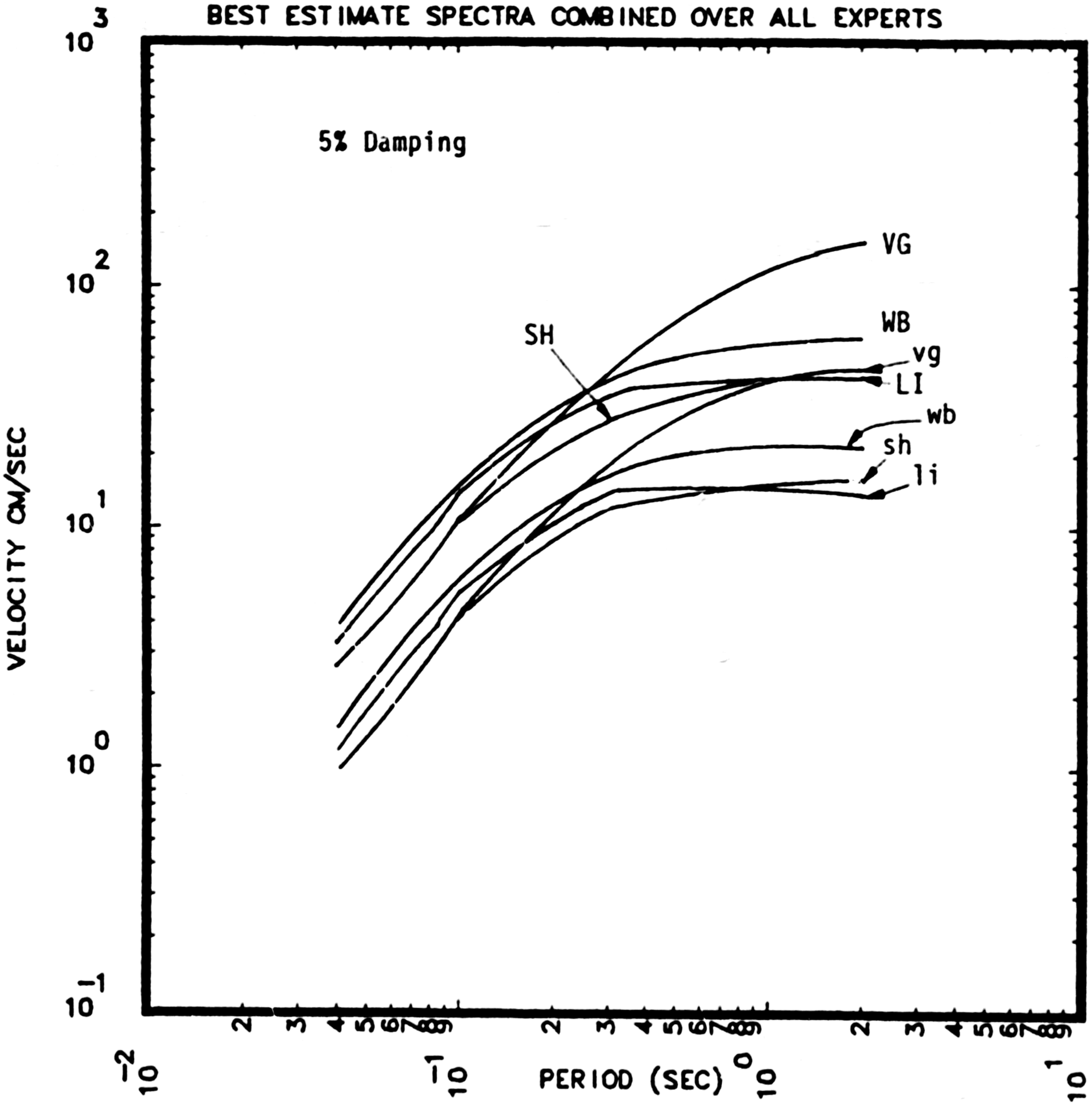


Fig. 5.12.4.b 1,000 Year and 10,000 Year Return Period BEUHS for Limerick (LI), Shearon Harris (SH), Vogtle (VG) and Watts Bar (WB) in the Southeastern Region of the EUS (The upper case symbols are for 10,000 year and lower case symbols are for 1,000 year return periods).

5.12.4 South Central Region

Two sites fall within the south central (SC) region: River Bend (Sec. 5.4), located in the boundary between the southeast and south central regions, and Wolf Creek (Sec. 5.8.1), located in the northern portion of the region. River Bend is classified as a deep soil site; Wolf Creek, a rock site. The BEHC combined over all experts, when compared for the two sites, (Fig. 5.12.5a) gives a higher hazard for the Wolf Creek site. The BE hazard is higher for Wolf Creek by a factor of about 2 at low PGA and a factor of about 3 at high PGA. The BEHC per seismicity experts for the two sites are similar in shape with more spread of expert opinion found for the River Bend site (See Figs. 5.4.2 and 5.8.2). Six of the eleven experts place the two sites in the same host zone. For these experts, the host zone is the CZ. A consistency of hazard between the two sites can be seen for these six experts. This consistency is not present for the other five experts. Expert 2 is an outlier on the high side for the Wolf Creek site. This expert is not an outlier for the River Bend site. The CPHC for the two sites have similar shapes with Wolf Creek slightly higher. This is consistent with the BEHC findings. The comparison of the BEUHS combined over all experts shows a flatter spectrum for River Bend (the deep soil site) than for Wolf Creek (see Fig.5.1.2.5b). This is consistent with the findings for Vogtle (a deep soil site in the SE region). On the BEUHS per seismicity expert, Expert 2 is again an outlier on the high side for the Wolf Creek site. A comparison of the CPUHS shows higher velocities for the River Bend site. The spread between the 15th and 85th percentiles is also lower for this site. This is partly due to the fact that no site correction is applied to the River Bend site since its soil is a generic soil (Base case), therefore no additional uncertainty is introduced.

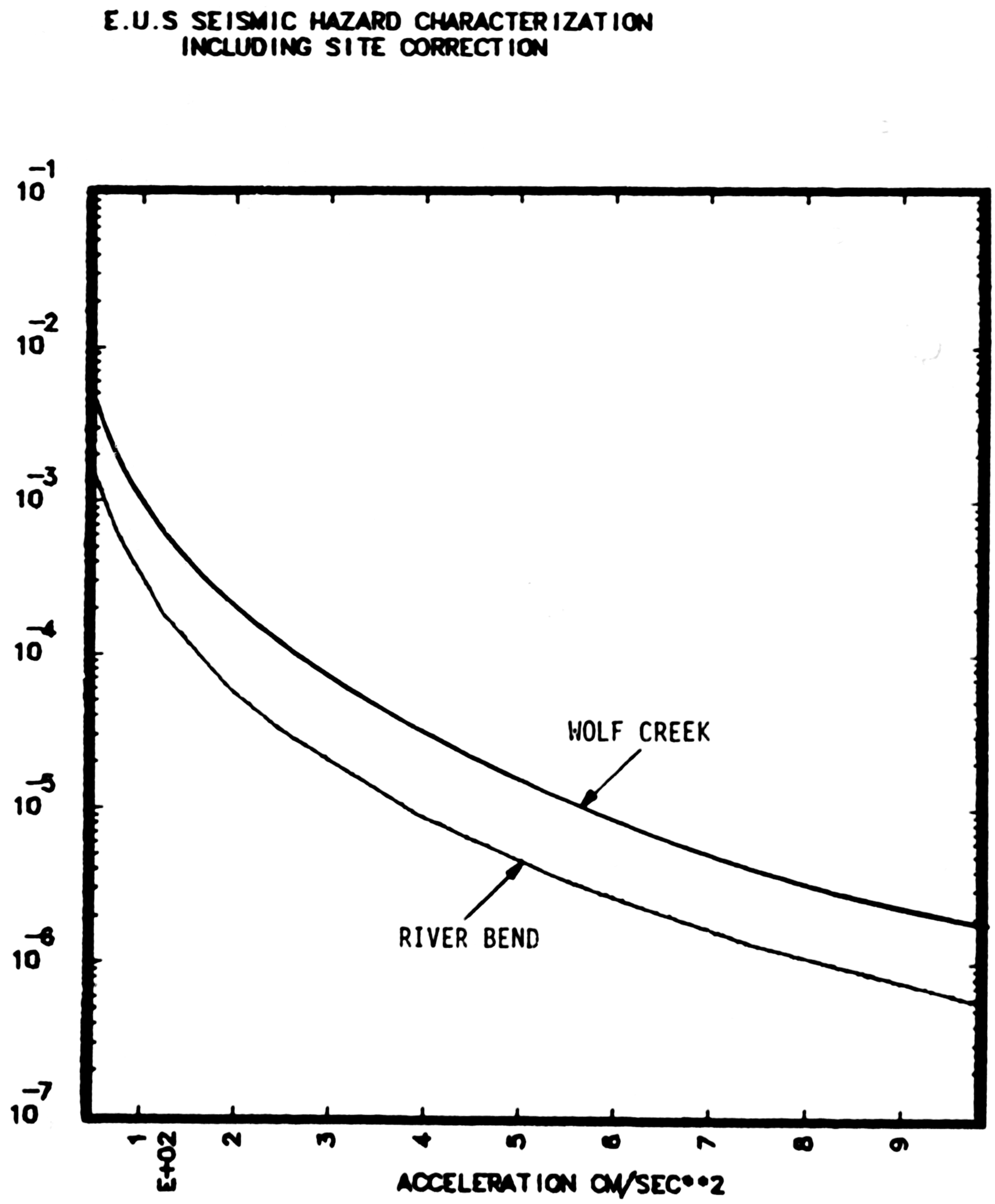


Figure 5.12.5a Summary of the BEHC for the South Central part of the EUS

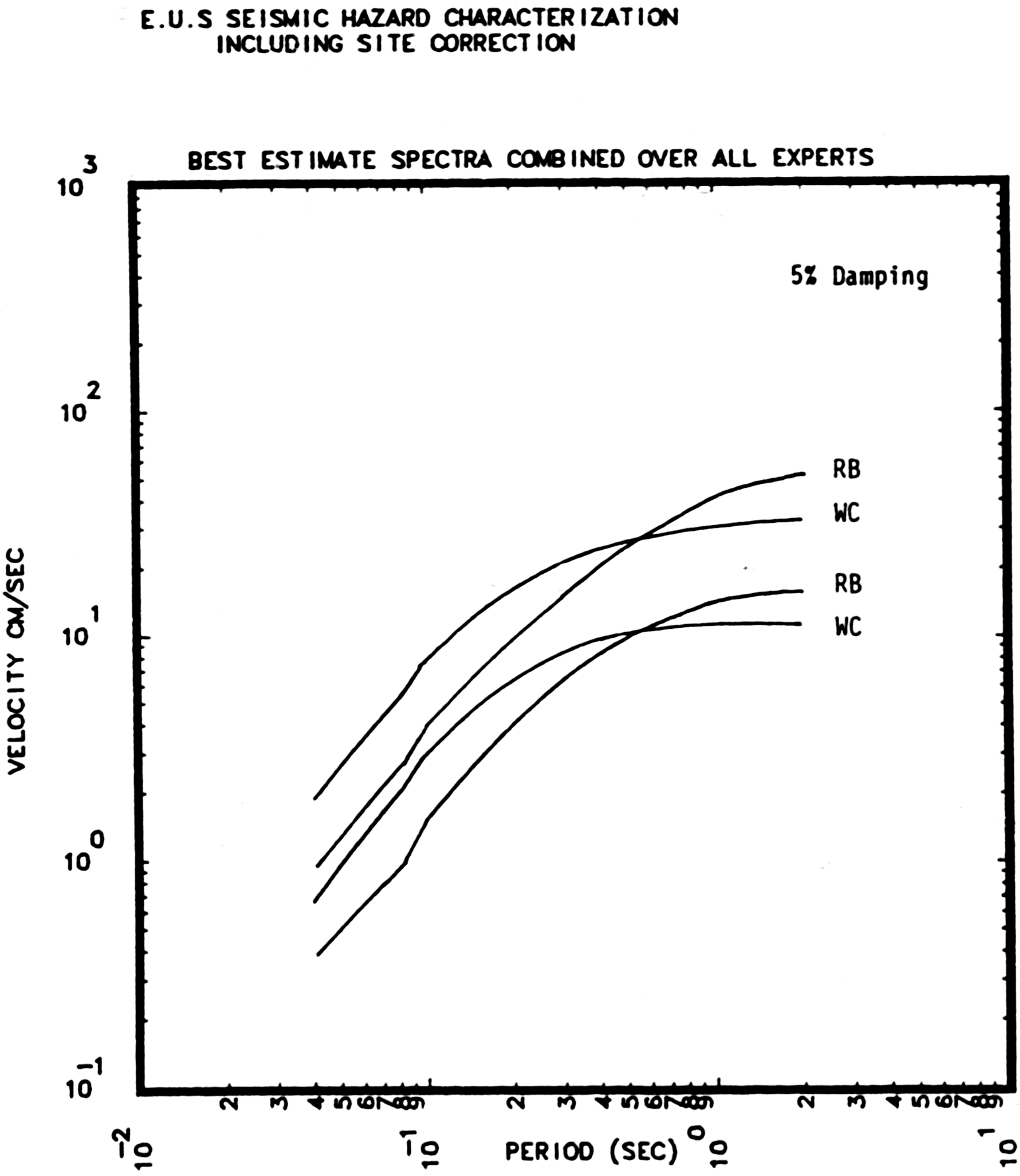


Fig. 5.12.5b 1,000 Year and 10,000 Year Return Period BEUHS for River Bend (RB) and Wolf Creek (WC) in the South Central Region of the EUS.

SECTION 6: COMPARISONS TO OTHER METHODS

6.1 Introduction

Verification of the estimates derived from typical seismic hazard studies is impractical for several reasons. First, it is not possible to produce data for experimental verification and secondly, because of the low level of seismic activity, hundreds of years are required before sufficent data would be available to assess the accuracy of the hazard estimates. However, some use can be made of the historical record. In general, verification is generally reduced to the validation of one's computer codes and comparison to other studies.

This study is based primarily on experts' opinion about the seismicity, the EUS and their uncertainty about their estimates. Therefore, it could be argued that the only verification required is to demonstrate that the computer programs correctly perform the analysis and that we have adequately sampled expert opinion. However, as our approach was structured so that the experts were expected to assimilate available data and appropriate physical models in forming their opinions, it is our expectation that the results of this study provide reasonable estimates of the seismic hazard in the EUS. Thus, it could be expected that results from other studies should agree reasonably well with the estimates derived from the opinions of one or more of our experts.

When comparing results with other studies, there are several types of comparisons that can be made. One level is simply to compare hazard curves. However, because of the sensitivity of the estimates to the ground motion models and site correction, such comparisons may not be very useful and major differences may result because of systematic differences introduced by the ground motion model. To validate the "reasonableness" of the seismicity input it would be necessary to compare results using the <u>same</u> ground motion models and site correction factors.

6.2 Comparison Using the USGS Zonation and Seismicity Models.

The USGS sponsored study reported on in Algermissen et al. (1982) is an interesting contrast to our study. In our study each expert's input was kept intact and a separate analysis performed. The final BEHC and CPHC were developed by a weighted aggregation of all hazard curves. By contrast the USGS held a number of regional workshops to develop data and zonations. These were aggregated in some manner <u>by the investigators</u> at the input level. Only a BE zonation and single BE values of the seismicity parameters were developed and used in their analysis.

One problem in making direct comparisons between the results given in Algermissen et al. and our results is that the ground motion model used in Algermissen et al. is significantly different than any of the ground motion models selected by our Ground Motion Panel. In addition it is very difficult to make comparisons because Algermissen et al.'s results are smoothed contours on a small map whereas our results are for specific sites. However, to make direct comparisons we reproduced Algermissen's et al.'s zonations and seismicity models in a form compatiable with our computer programs and developed BEHC at the ten test sites consistent with the BEHC discussed in Section 5. Figures 6.2.1 - 6.2.10 compare the BEHC for each of our seismicity experts with the BEHC we obtained using the Algermissen et.al zonation and seismic data on a site-by-site basis. Because of overlapping curves we have not used plot symbols for our experts on Figures 6.2.1-6.2.10. The BEHC obtained using the Algermissen et al.'s seismicity model are denoted by the plot symbol X.

There is generally good agreement between the BEHC obtained using the Algermissen et al. model and our experts, except at the Limerick and Millstone sites.

It is interesting to examine the differences between the seismicity models used in this study and Algermissen et al.'s model which contribute to the large differences in the BEHC at the Millstone and Limerick sites. But, before making such comparisions several issues must be discussed. First, it should be noted that the recurrence model used by Algermissen et al. is expressed in terms of modified Mercalli intensity. This introduces a problem because, except for the model chosen by Expert 5 of the Ground Motion Panel, the BE ground motion models for these two sites are in terms of magnitude. The problem occurs when the ground motion model is expressed in one scale, e.g. magnitude, and the recurrence model is expressed in a second scale, e.g. intensity. Since the hazard analysis is based on a single scale, the conversion between scales is made when the expected value of the ground motion is computed using a conversion specified by the seismicity expert. In this case the hazard results depend on the specific relation between magnitude and intensity used in the analysis.

If a conversion relation different from that specified by the seismicity expert is introduced, one might expect the recurrence model to change. However,it is not possible to assess what impact the choice of using a different relation between intensity and magnitude might have on the recurrence models for the various seismicity experts. We can, however, assess the impact that different conversions would have on the hazard curve assuming that no change in the recurrence model is required. Generally for our study, the overall effect is small because most experts (both Seismicity and Ground Motion Panel members) worked with magnitude as the primary variable and therefore no conversion was required. Only Seismicity Expert 5 and for some zones, particularly New England, Expert 1 chose intensity as the variable for the recurrence model.

Three intensity-magnitude relations were specified by our panel members:

- Expert 1: $I_o = 2.17M - 4.41$
- Expert 10: $I_o = 1.49M - .66$
- All Others: $I_o = 2M - 3.5$

In all cases the relation is between epicentral intensity and m_b. Algermissen et al. use a relation developed by Gutenberg and Richter (1942)

$$I_o = 1.67M - 2.167$$

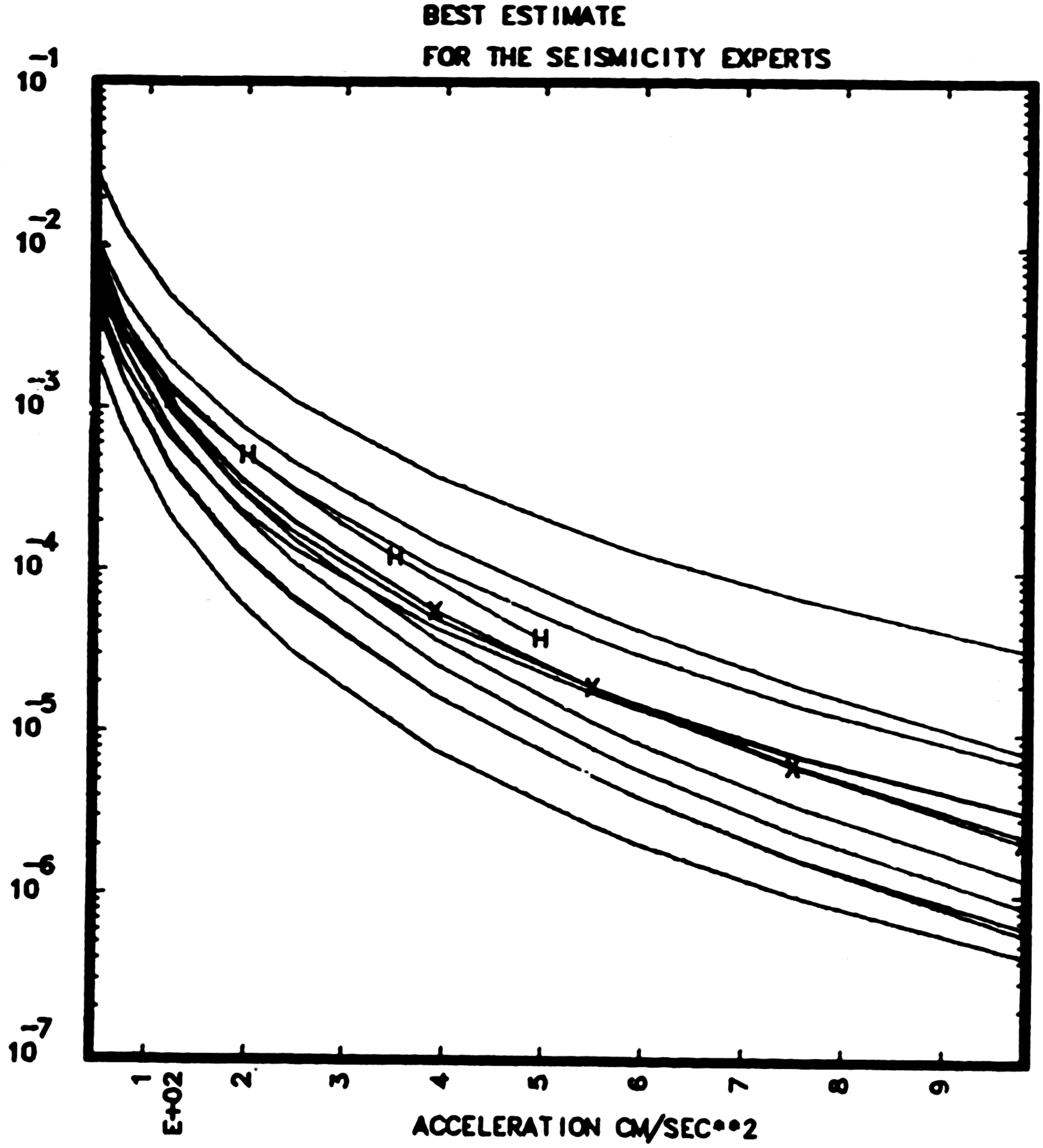
The magnitude M in the Gutenberg-Richter relation is M_L for earthquakes of 7 less and M_s for larger events. However, our ground motion models require the magnitude to be expressed in terms of m_b. It is not clear how Algermissen et al. interpreted the relationship between M_L and m_b for the EUS. We followed the interpretation of Herrmann and Nuttli (1982) and assumed that the M_L scale of the west is equivalent to the m_b scale of the EUS.

Figure 6.2.11a shows the sensitivity of the BEHC combined over all Ground Motion Experts, to the three different intensity-magnitude conversions used by our seismicity panel members for Seismicity Expert 1's zonation and sieismicity parameters. It is seen that the resultant BEHC is not very sensitivity to the Io-M conversions used by various panel members. As noted above, the sensitivity for most experts is much less because their recurrence models were expressed in magnitude. Figure 6.2.11b shows that the Gutenberg-Richter conversion has a slightly more significant effect on the BEHC than the other conversions. It should be noted that the comparisons shown on Figures 6.2.11 a ard b are slightly misleading because they are the average of five ground motion models and one of the ground motion models is not influenced by the conversion used. The effect on any individual model is larger, particularly for the Gutenberg-Richter conversion.

Comparison of Figure 6.2.11a to Figure 6.2.11b, indicates that the BEHC based on Algermissen et al.'s seismicity model is about a factor of 10 higher than the BEHC based on, Expert 1's seismicity model. The hazard for the Millstone site for the Algermissen et al.'s model comes primarily from their zones 103 and 107. For Expert 1, it comes primarily from zone 22 (Table 5.5.1). The normalized recurrence models are compared in Table 6.2.1. We see from Table 6.2.1 that the rate of earthquake recurrence around the Millstone site is about a factor of 10 higher in Algermissen et al's model than it is for Expert 1's model. The difference between Expert 1's BEHC and Algermissen et al.'s BEHC is greater at the high PGA end than at the low PGA end. This is due to the difference in b value and upper magnitude cutoffs used.

Figure 6.2.1

COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 180 YRS.) H



BRAIDWOOD

Figure 6.2.2

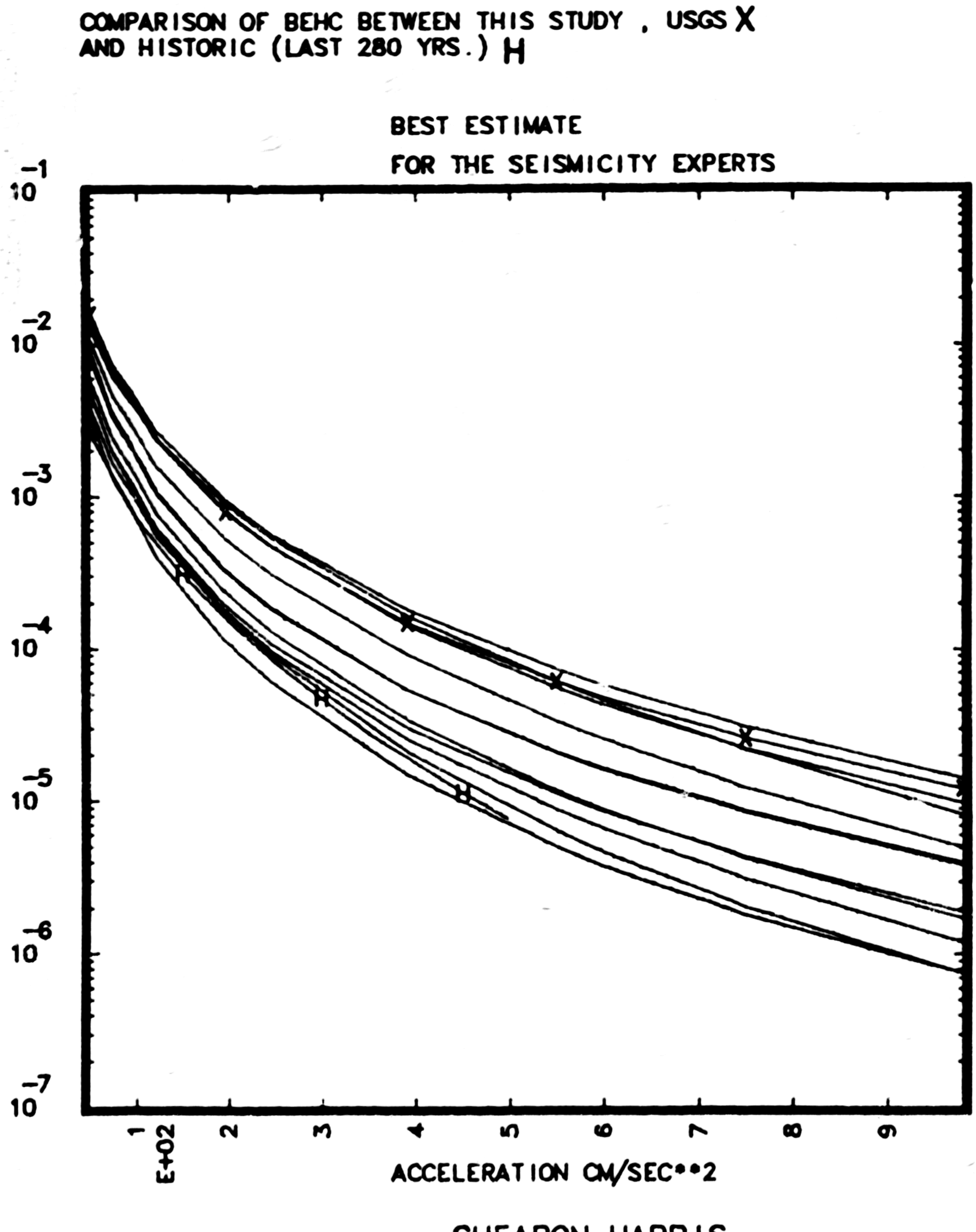
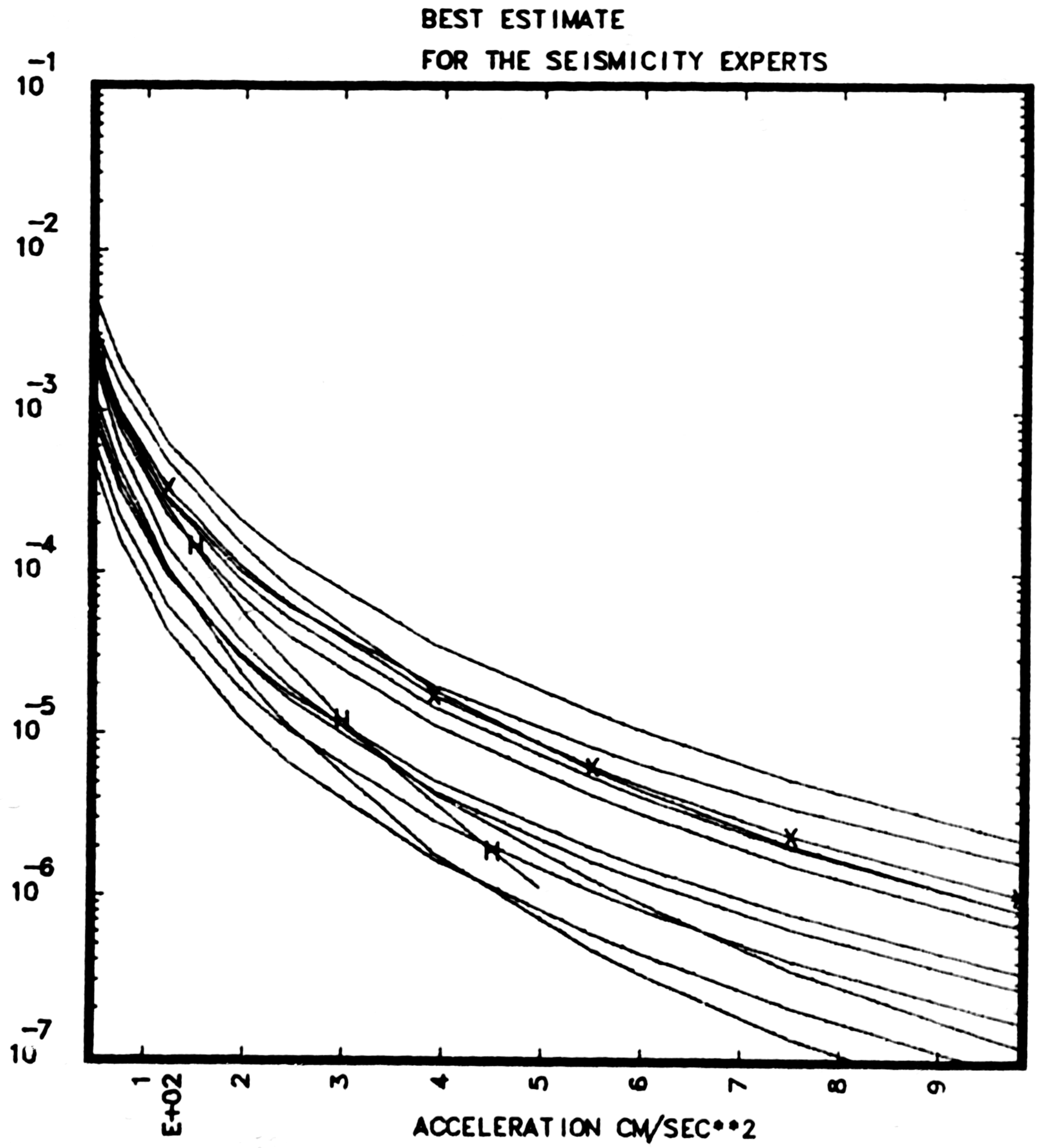

COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 280 YRS.) H
BEST ESTIMATE
FOR THE SEISMICITY EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
SHEARON HARRIS

Figure 6.2.3

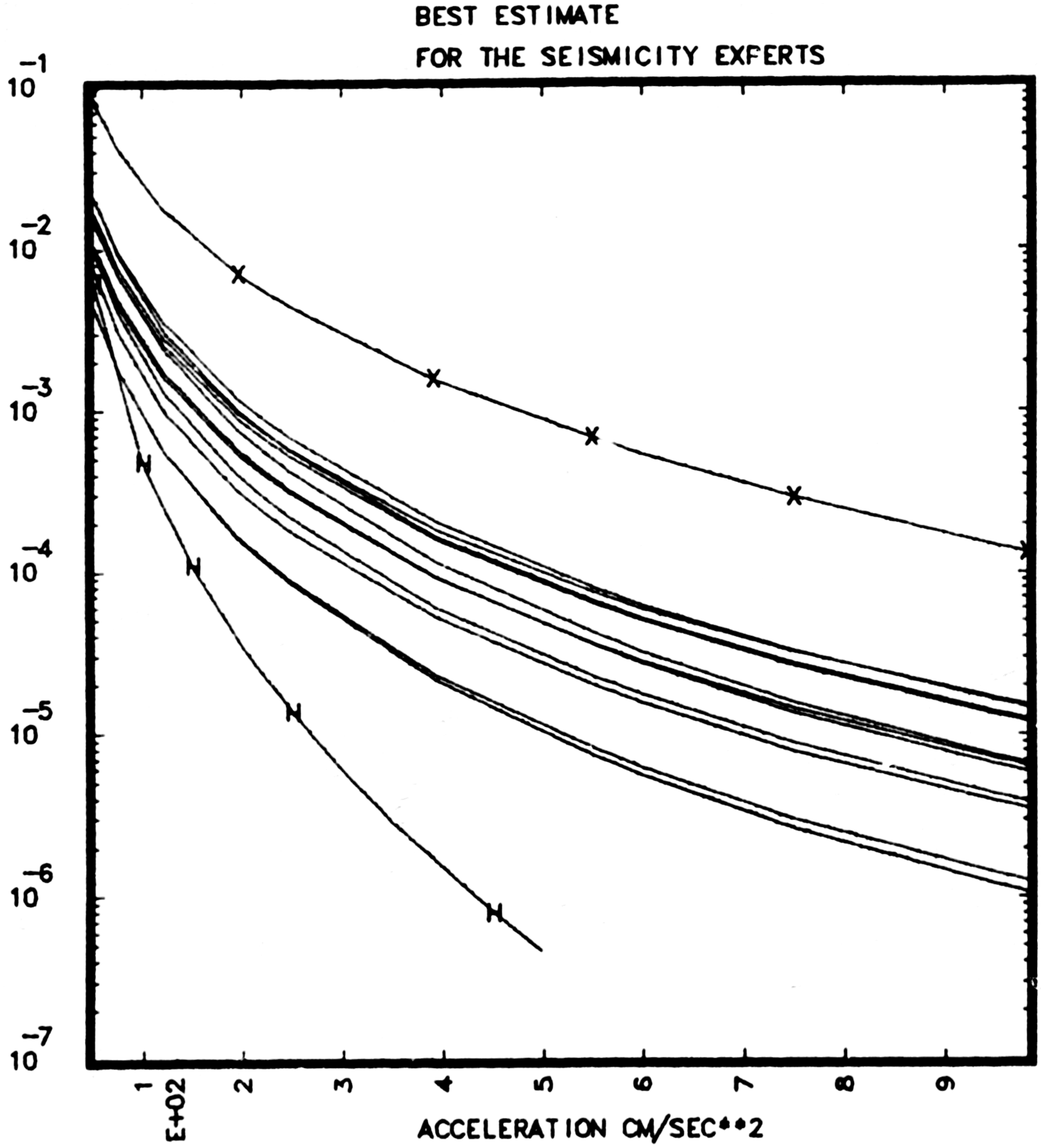
COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 180 YRS.) H



RIVER BEND

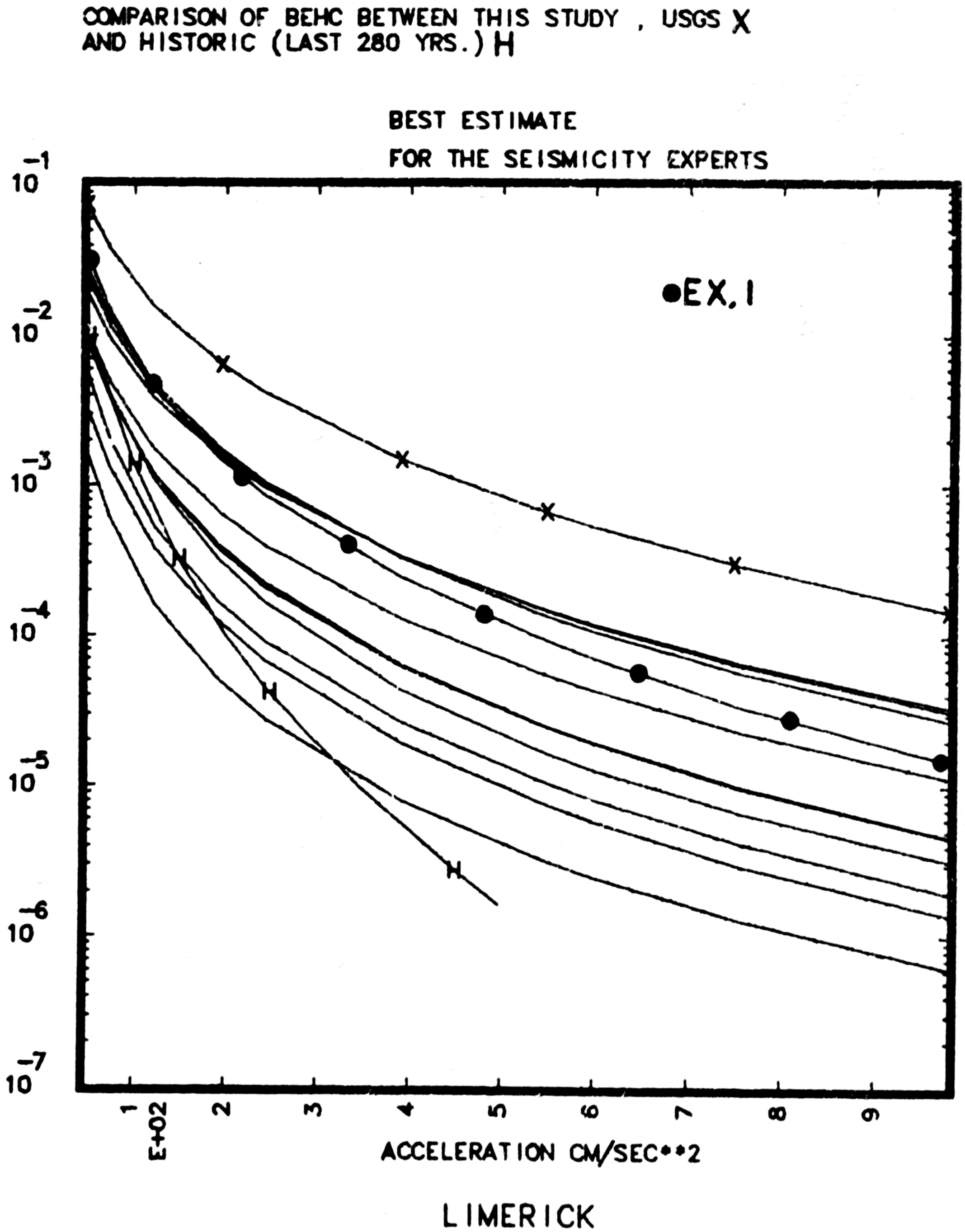
Figure 6.2.4

COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 280 YRS.) H



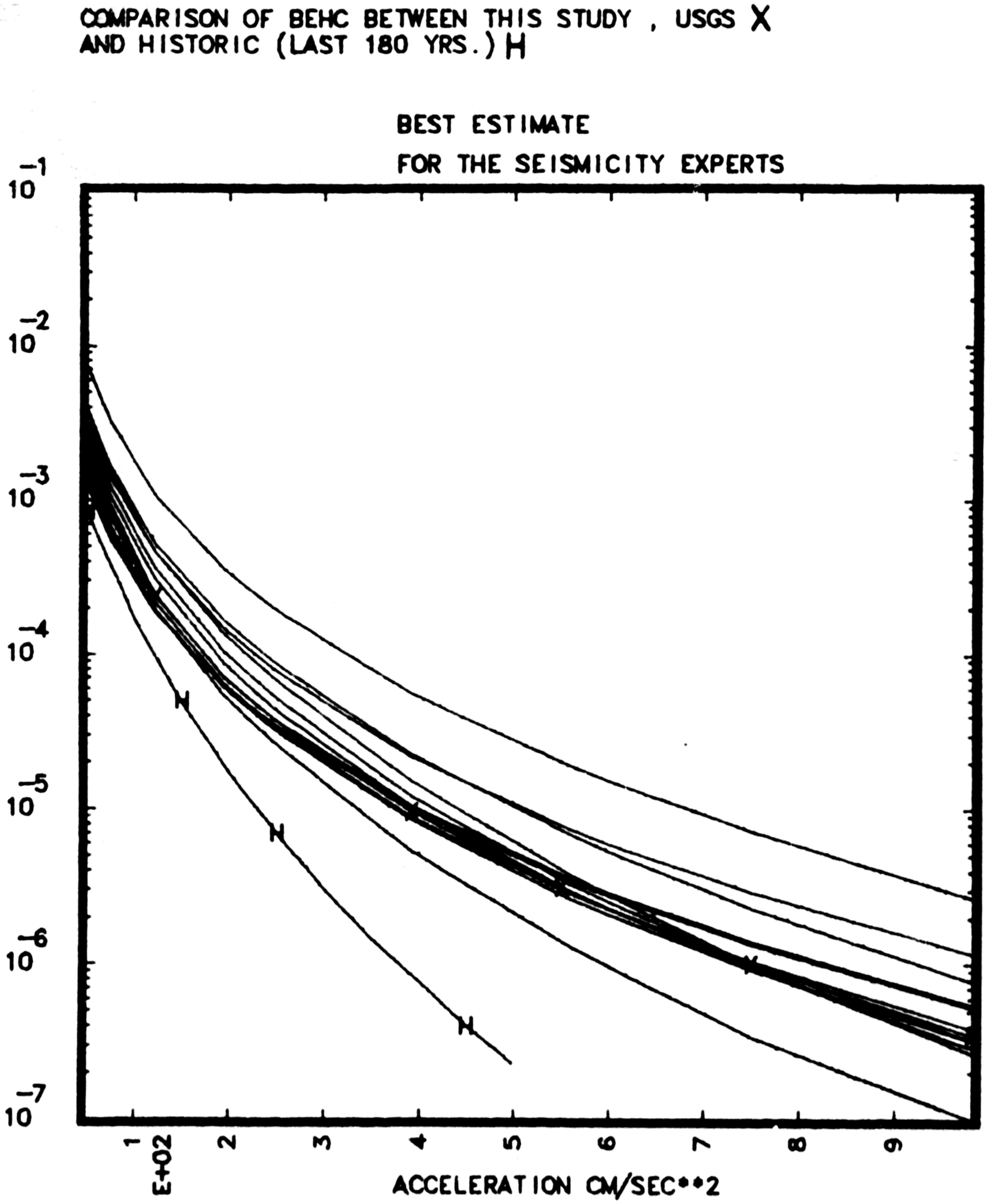
MILLSTONE

Figure 6.2.5



COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 280 YRS.) H
BEST ESTIMATE
FOR THE SEISMICITY EXPERTS
●EX.1
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
LIMERICK

Figure 6.2.6



LA CROSSE

Figure 6.2.7

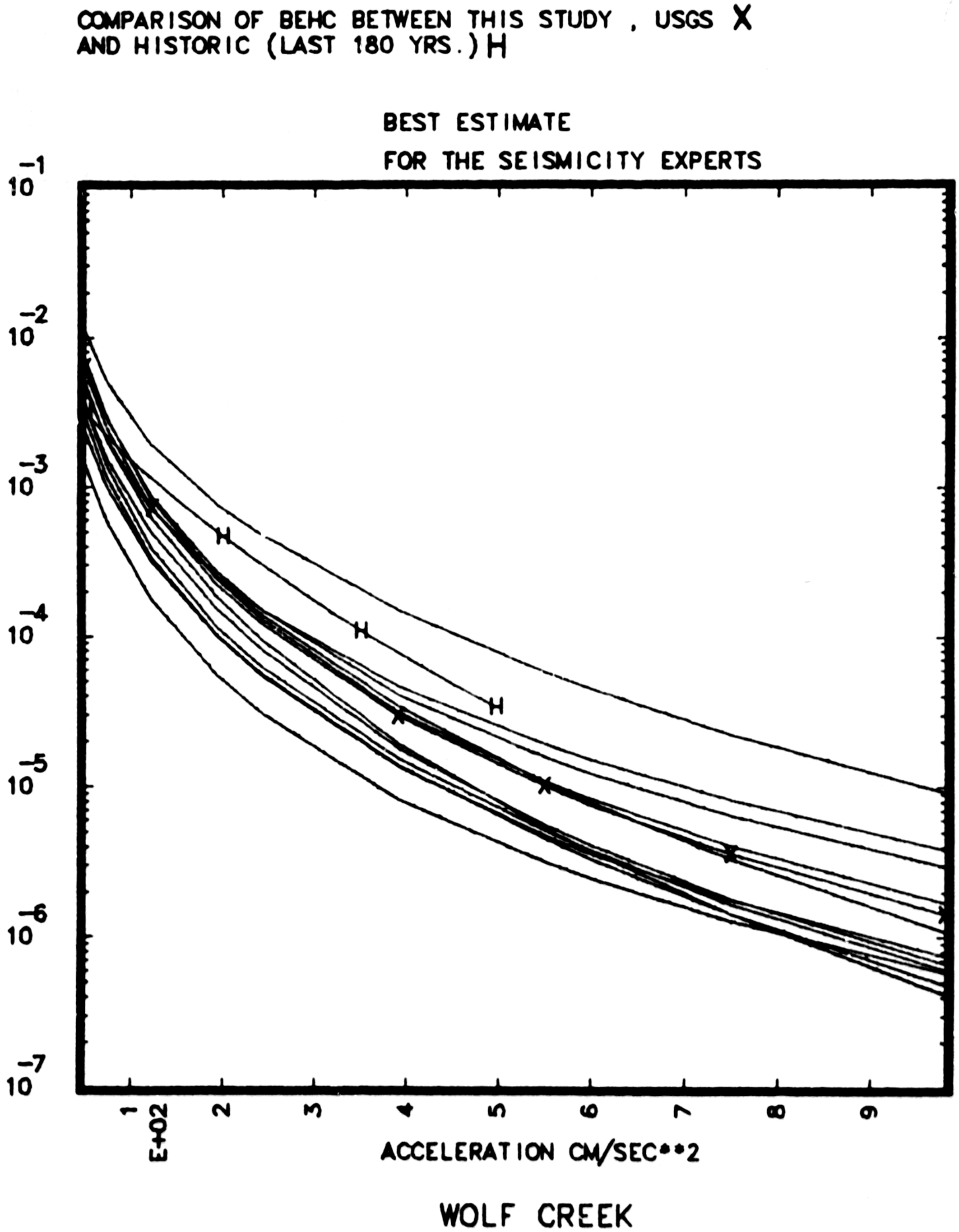
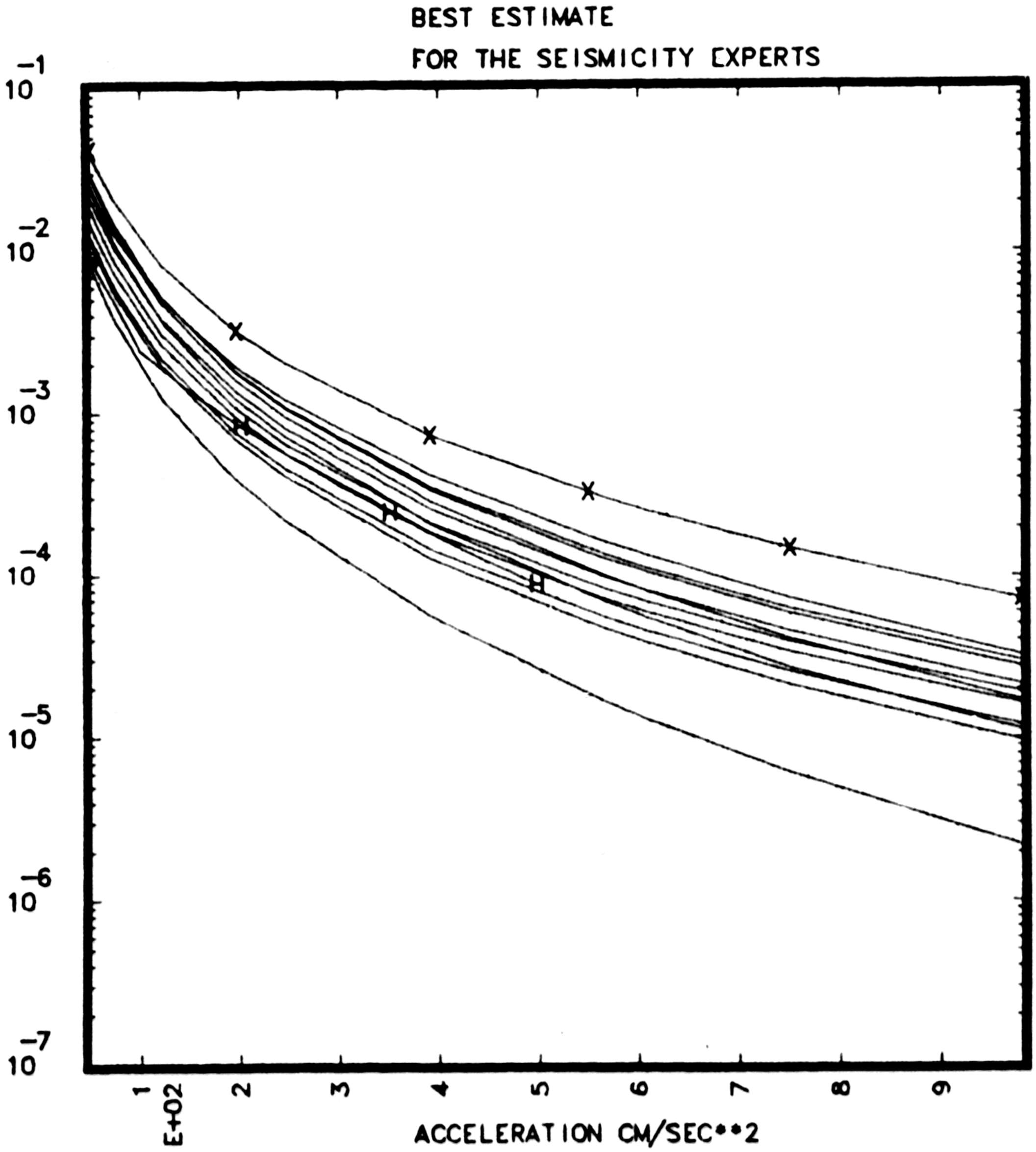

COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 180 YRS.) H
BEST ESTIMATE
FOR THE SEISMICITY EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
2
3
4
5
6
7
8
9
E+02
ACCELERATION CM/SEC**2
WOLF CREEK

Figure 6.2.8

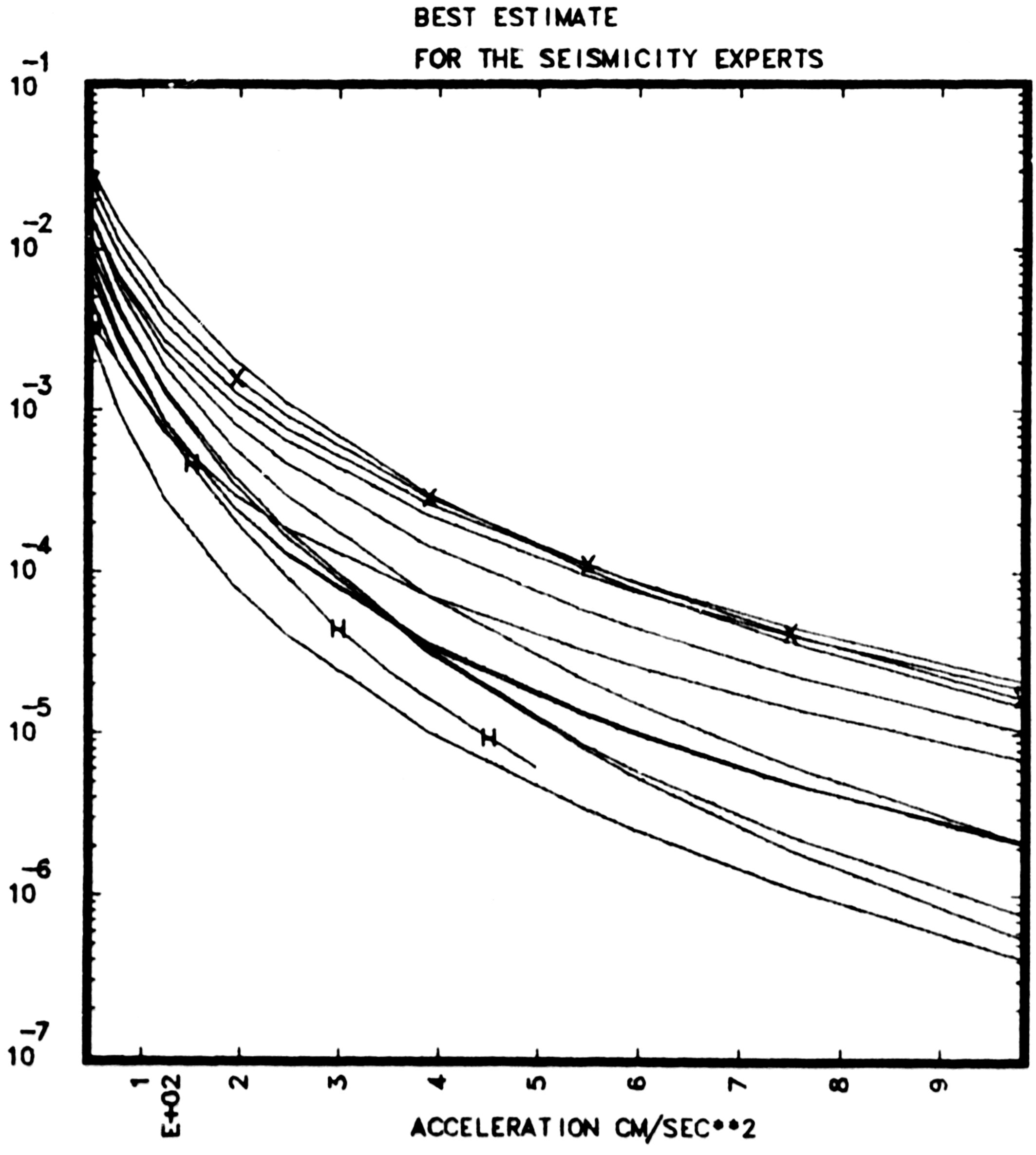
COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 180 YRS.) H



WATTS BAR

Figure 6.2.9

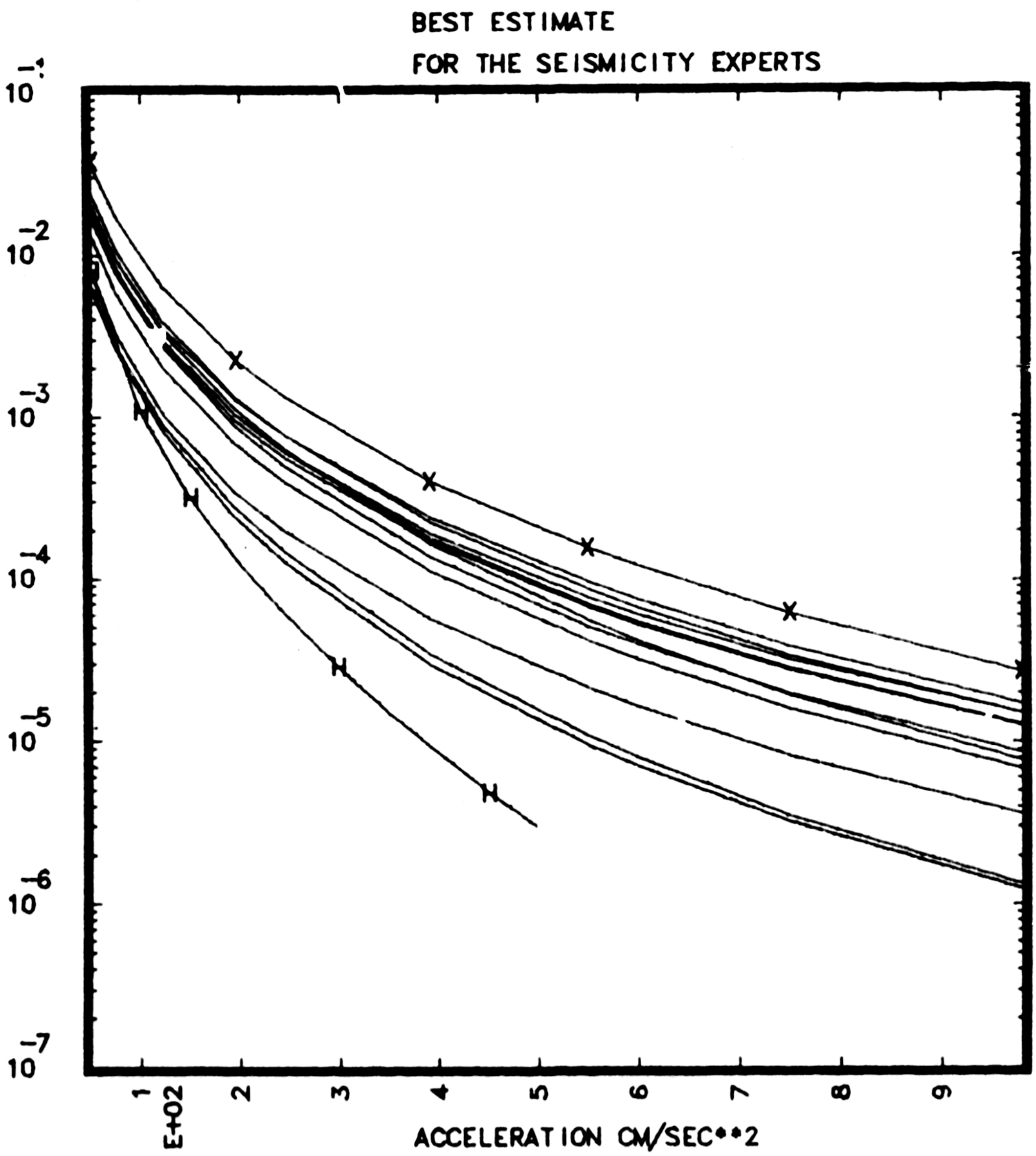
COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 280 YRS.) H



VOGTLE

Figure 6.2.10

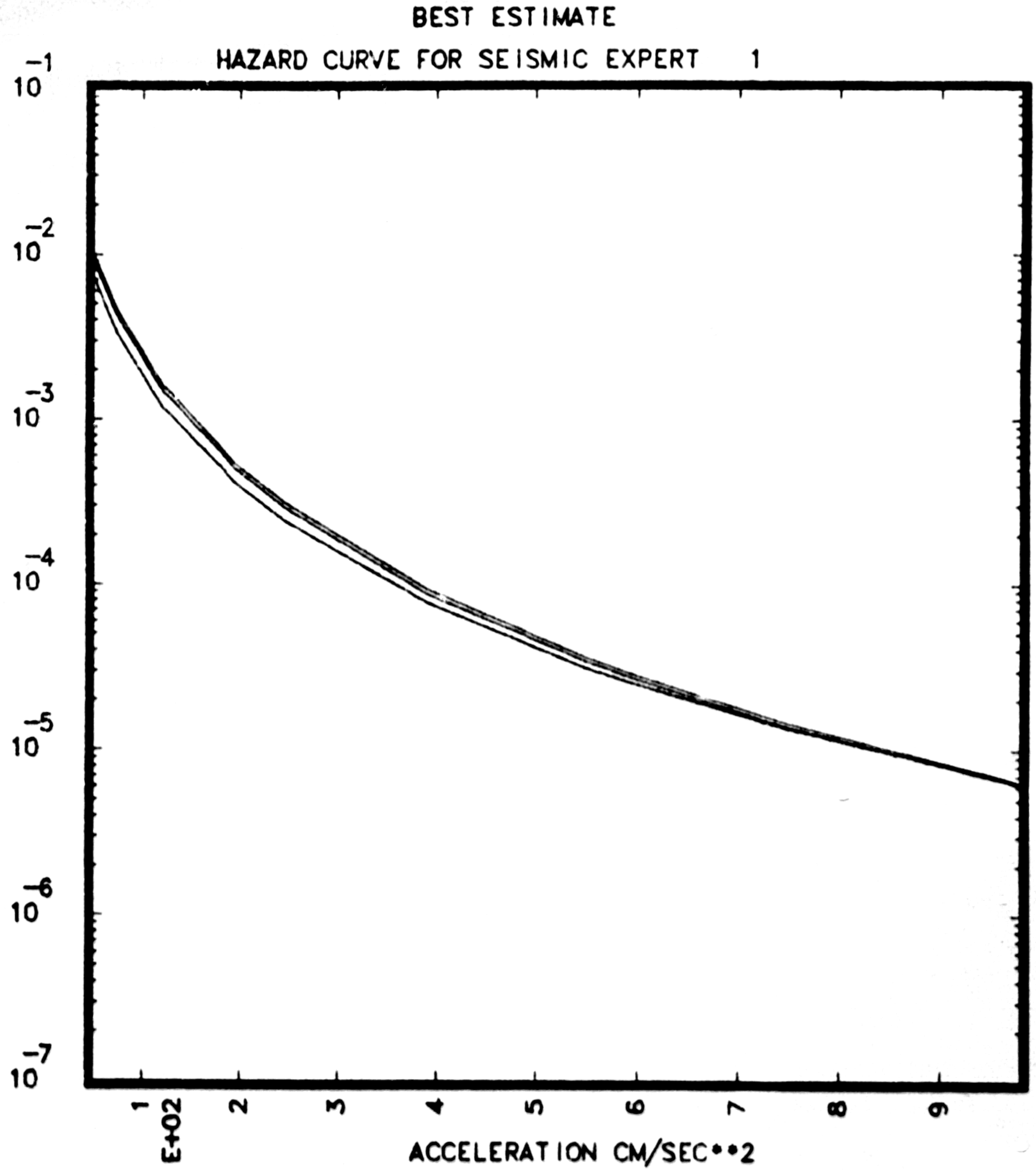
COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 280 YRS) H



MAINE YANKEE

Figure 6.2.11a

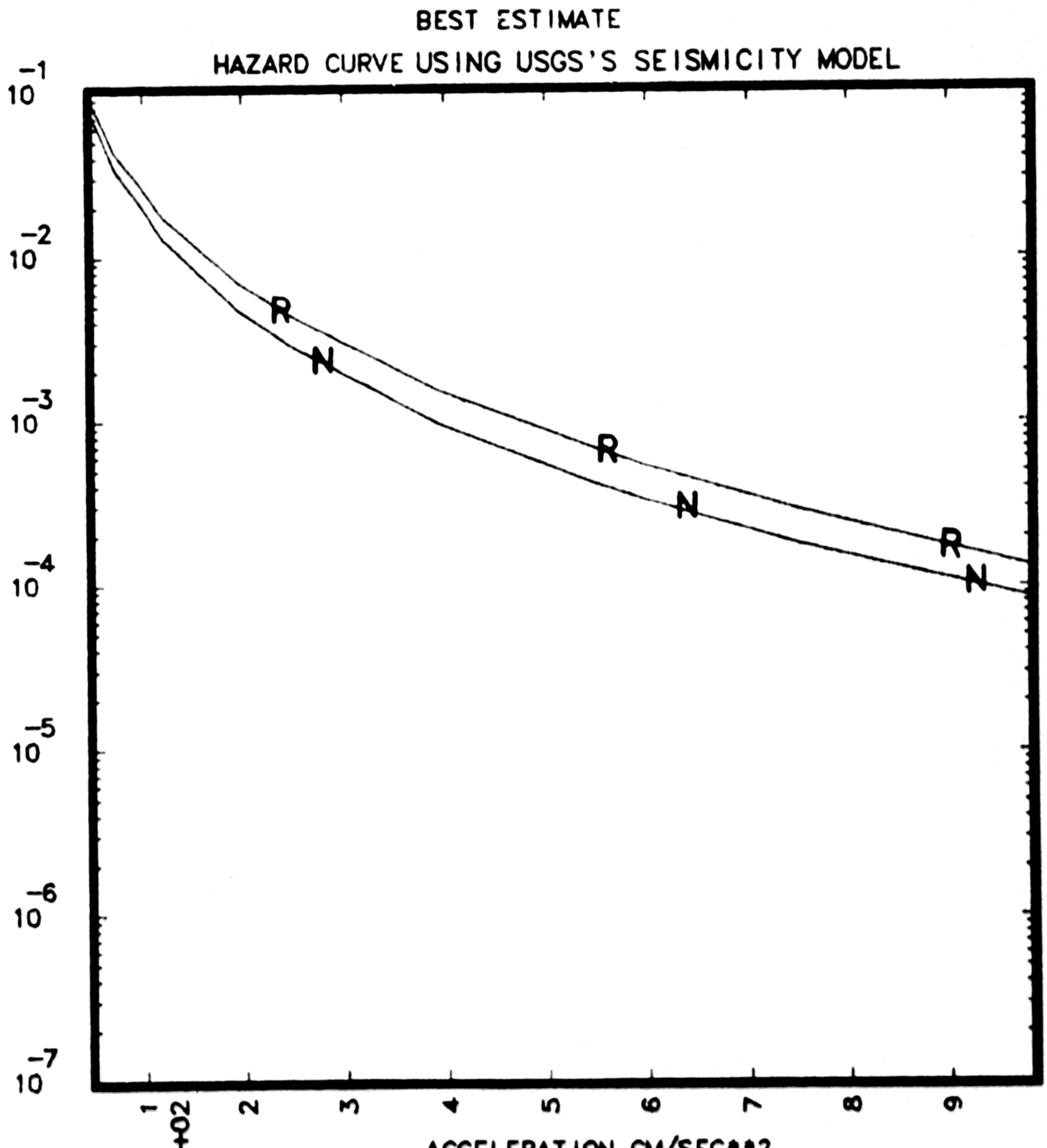
SENSITIVITY TO THE MAGNITUDE-INTENSITY RELATION
COMPARISON OF THE BEHC OBTAINED USING THE 3 MODELS
PROPOSED BY OUR SEISMICITY PANEL MEMBERS



MILLSTONE

Figure 6.2.11b

SENSITIVITY TO THE MAGNITUDE-INTENSITY RELATION
COMPARISON OF THE BEHC USING NUTTLI &RICHTERS CONVERSIONS



MILLSTONE

Table 6.2.1

Comparison of normalized seismicity parameters for the zones most influncing the hazard at Millstone and Limerick based on Expert 1's and Algermissen et al.'s (Zones 103 and 107) seismicity models.

Zone No.	(1) Area	(1) a	b	(2) N≥5	I Max
22	5.4	2.10	-0.61	11	9.5
103	0.6	2.38	-0.5	75	10
107	0.2	2.59	-0.5	123	10
4	4.0	3.27	-0.75	33	9.1

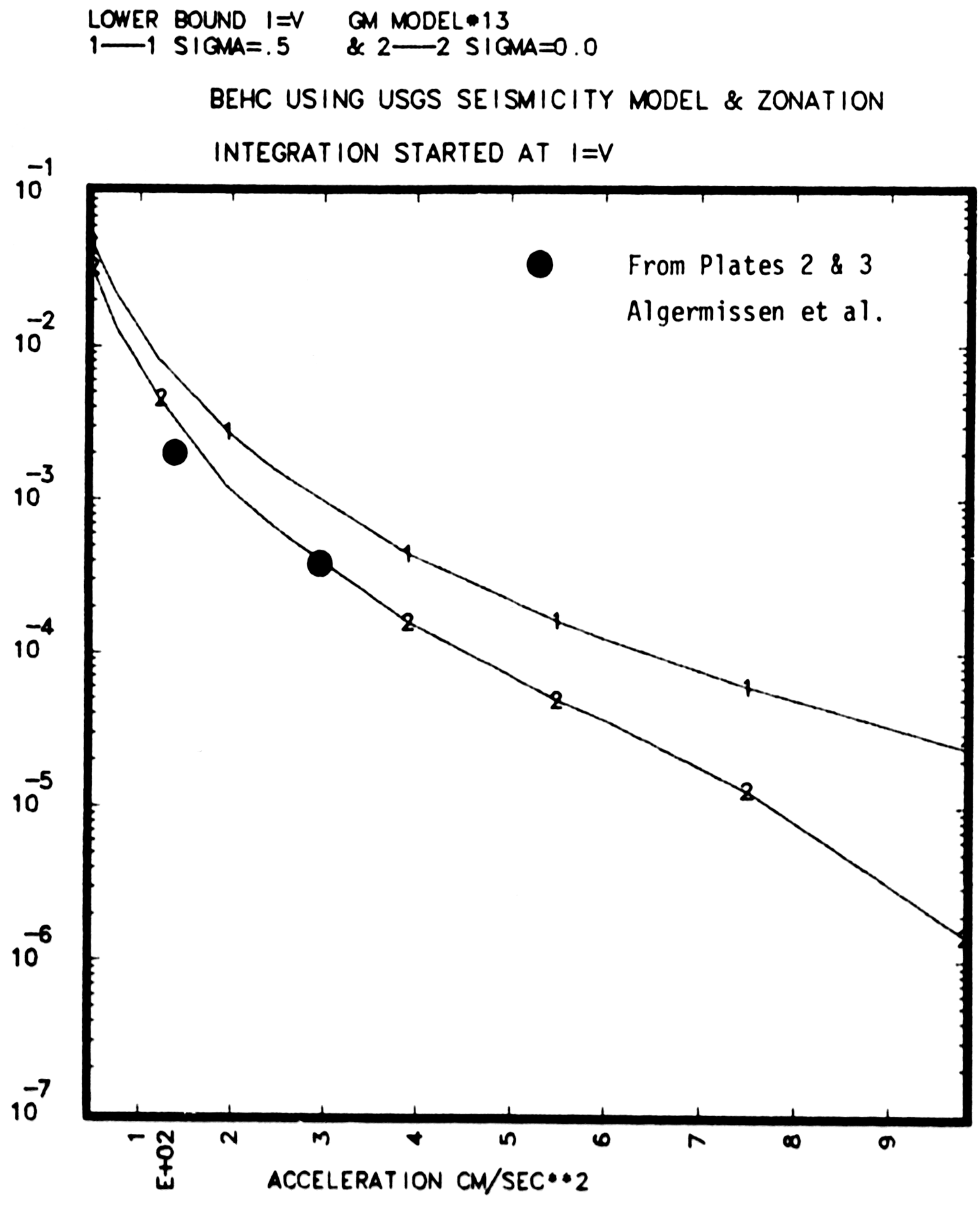
(1) Per 100,000 square km

(2) Per 100 years

The effect of different b values and upper magnitude cutoff is even more evident for the Limerick site. Expert 1's BEHC on Figure 6.2.5 is plotted with the symbol 0. At the low PGA end, Algermissen et al.'s BEHC is about a factor of 2-3 higher than Expert 1's BEHC but at the high PGA end it is about a factor of 10 higher. The hazard for the Limerick site comes primarily from zone 4 for Expert 1's model and zone 103 for Algermissen et al's model. Table 6.2.1 give the normalized recurrence models for these two zones. We see that the rate of earthquakes greater than intensity 5 are more than a factor of 2 higher for the Algermissen et al's model than for Expert 1's model. We also see that the absolute value of b is much larger for Expert 1's model resulting in fewer larger earthquakes than for the Algermissen et al.'s model. The net result, as illustrated in Section 4.3, is a difference between the two BEHC of about a factor of 10. In addition the upper magnitude cutoff is larger for the Algermissen et al.'s model than for Expert 1's model. This also increases the spread between the two curves (see Figure 4.3.3).

The BEHC for the Algermissen et al.'s seismicity model produced in this analyses are much higher than the results given in Algermissen et al. (1982). For example, if the Millstone site is located on Plate of the Algermissen et al. report, it lies within the 0.30g contour with approximately $4X10^{-4}$ annual probability of being exceeded. This is significantly less than the BEHC for the Algermissen et al.'s model plotted on Figure 6.2.4. The main reason for this difference lies in the ground motion mode's used. Several major differences exist between the two studies. First, Alermissen et al. only use one ground motion model which has the same scaling with magnitude in both the EUS and WUS. In our study we use a number of different models (5 for these comparisons). Most of our models have a different scaling with magnitude between the EUS and WUS. Secondly, Algermissen et al. assumed that there is no random uncertainty associated with their ground motion model. Thirdly, the model used by Algermissen et al is only evaluated in one-intensity unit increments. Finally, we started our integration of the hazard curve at intensity IV, whereas Algermissen et al. started at intensity V. Because no analytic equation is given for the ground motion model used by Algermissen et al., it was not possible to reproduce their results. However, we did select one of our models (#13) with a scaling similar to the Algermissen et al's model and computed the hazard curve for the case when the random uncertainty is zero and the integration was started at intensity V. The resultant hazard curve in shown on Figure 6.2.12. The hazard curve is sensitive to the random variation associated with the ground motion. This is illustrated in Figure 6.2.12 where we also show the hazard curve for the case where the parameter for random variation, sigma, has a value of 0.5. We also note that the hazard curve for the case of no random variation and using model #13 is in reasonable agreement with the results given in Algermissen et al. (1982).

Figure 6.2.12



MILLSTONE

6.3 Historical Analysis

The methodology developed as part of this study can be characterized as the seismic-source approach to the calculation of the seismic hazard. It is based on utilizing statistical and geological evidence to define geographical regions (seismogenetic zones) with homogeneous Poisson activity uniformly throughout the zone. This activity is described by a recurrence relationship. Calculation of the seismic hazard from the source geometry and seismic activity then depends on specification of a ground motion model, which expresses the decay with distance of the median value of a ground motion parameter, e.g. PGA for different magnitudes.

The seismic-source approach is based on a set of models which are assumed to describe the regional seismicity. The choice of models implies some prior knowledge about the characteristics of seismic activity throughout the region. For example, the seismic-source approach assumes that a set of homogenous sources exists and the locations of these sources can be physically identified. Further, it relies on knowledge about the recurrence rate and magnitude distribution, given in terms of the magnitude-recurrence relationship, as well as knowledge about the maximum magnitude for each source. Whenever such prior knowledge exists (e.g. seismic activity can be associated with well-defined active faults for which the maximum magnitude can be reasonably estimated from physical principles), seismic-source methods are most appropriate. When the hazard analysis relies on such a state of knowledge, as it does in this study, it is appropriate to validate this assumptions as well as possible.

One method for validating the basic models inherent to the seismic-source approach is to compare the estimates with historical data for which no or minimal modeling is assumed. Such a nonparametric method was used in previous studies, Bernreuter (1981a) and Bernreuter et al.(1983), to partially validate the models developed in those studies. In the nonparametric method, each historical earthquake in a catalog is attenuated to the site and the average rate at which a given site intensity is exceeded is calculated. The exceedance rate for a given intensity includes attenuation variation (variability in the intensity experienced at the site during each historical earthquake) and also can include a correction for catalog incompleteness. Some issues that have been identified with regard to this method are:

1. It produces hazard estimates without quantifying estimation uncertainty.

2. In the range of acceleration of general interest, the hazard estimates are found to be sensitive to the maximum historical event in the catalogue affecting the site.

3. In the same range of site intensities, the historical method is biased in the sense that most of the times it produces hazard estimates which are low.

4. The correction for incompleteness is a function of the numbers of events and does not account for spacial incompleteness.

Veneziano et al. (1984) have developed a parametric method based on the historical data to overcome some of the difficulties noted above.

The hazard curve, based on the historical data, of course, is only an estimate of the true historic hazard curve as no ground motion measurements were taken at any of the sites. The estimated hazard depends on the ground motion model and the model for the random variation in the ground motion parameter used to transform the source to the site.

In our application of the historic method we chose not to apply a correction for incompleteness of the catalog because this would require an additional assumed model. The philosophy of the historic analysis is to make as few assumptions as possible. On the other hand, it is reasonable to view the seismic-source approach as introducing such corrections for incompleteness in both space, time and distribution of events in a reasonably physical way. The parameters of the models are generally estimated using the historical catalog. What we hope to gain by comparing the historical hazard curve to the BEHC is some measure of the impact that the adjustments introduced by the <u>models</u> have on the computed seismic hazard. Except for the necessary ground motion model, the only "correction" that we have introduced into our historical analysis is to select different time periods for the four regions defined by Figure 2.4. That is, for the sites located in regions 1 and 2, we used the last 280 years, i.e. all earthquakes from 1700-1980, and for regions 3 and 4 we used only the last 180 years. The resultant historical hazard curves for the in Figures 6.2.1-6.2.10 are denoted by the symbol H. These curves were obtained by combining the historical hazard curves obtained for each of the BE ground motion models.

The agreement between the historical hazard curves and the BEHC is reasonably good at the low PGA end. At high values of PGA (lower annual recurrence rates) incompletness, and the shortness of the historical record affect the estimate based on the historical data.

To show the sensitivity of the historic hazard to the time frame used we compare on Figures 6.3.1-6.3.10, the BEHC for each of our experts shown in Figures 6.2.1-6.2.10 to the historic hazard curve computed using only the last 100 years of data. As before the historic curve is plotted with the symbol H. Comparisons between Figures 6.2.1-10 and 6.3.1-10 show that at many sites the historic hazard remains relatively constant. For sites in regions of very low seismic activity, e.g. La Crosse, the historic hazard is low compared to the BEHC resulting from the seismicity models of our experts. This is as expected as one of the purposes of seismic-source approach is to adjust for potential completeness in space of the historical data. For most sites, as already noted, there is good agreement at low PGA values between the historic method and the results of this study. At the higher PGA values, the historic method generally results in much lower hazard estimates. The difference between the two is related to the corrections for incompleteness in both time, space and distribution of magnitudes included in the seismic-source approach. It is seen that in general such corrections are significant.

These comparisons cannot be considered an independent check because the parameters of the recurrence model in the seismic-source approach are based, subject to correction, on the historic data. The comparisons do provide some assurance that the assumed models have not led to seismic hazard estimates grossly inconsistent with the historical record.

Figure 6.3.1

COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 100 YRS.) H

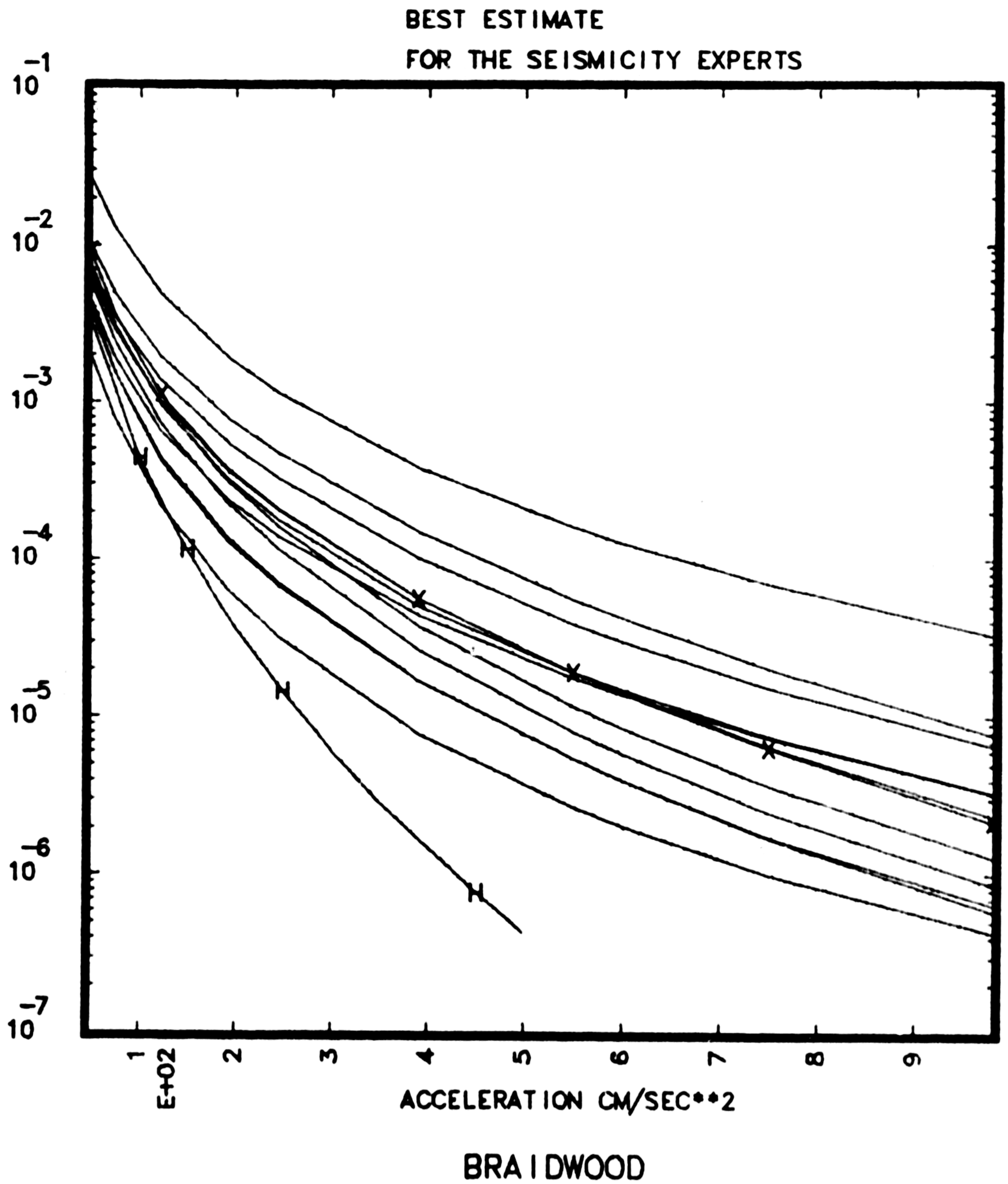
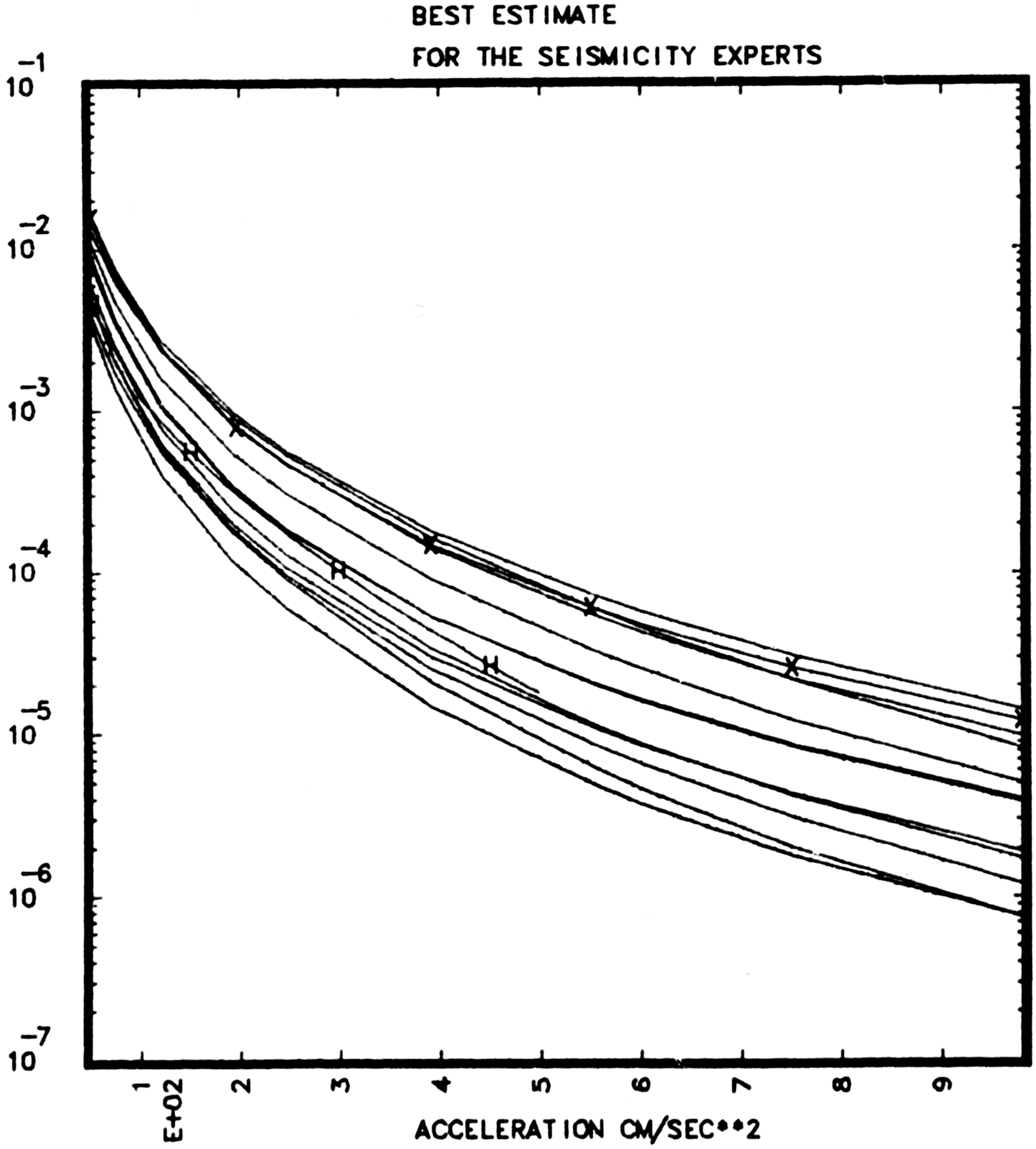


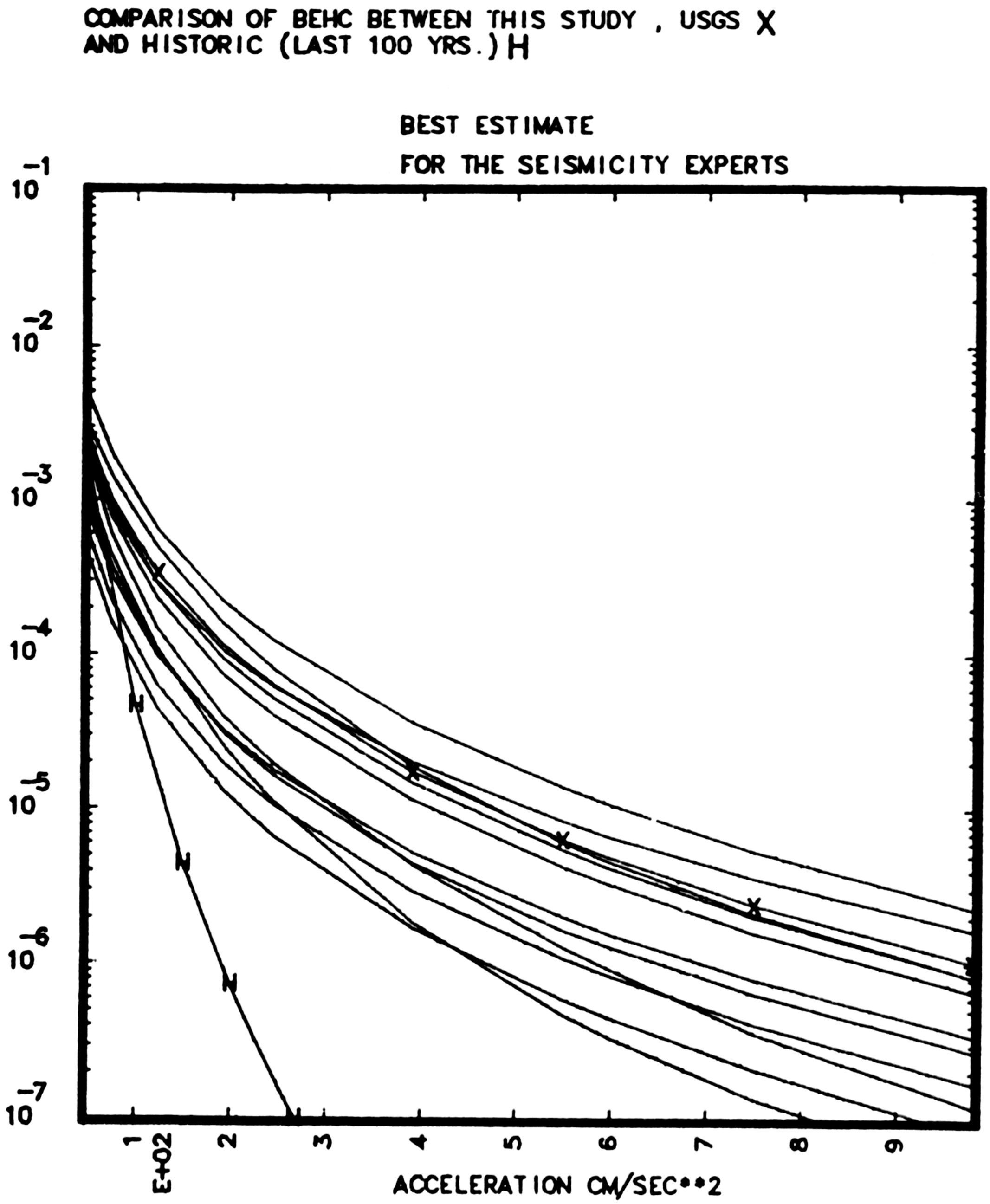
Figure 6.3.2

COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 100 YRS.) H



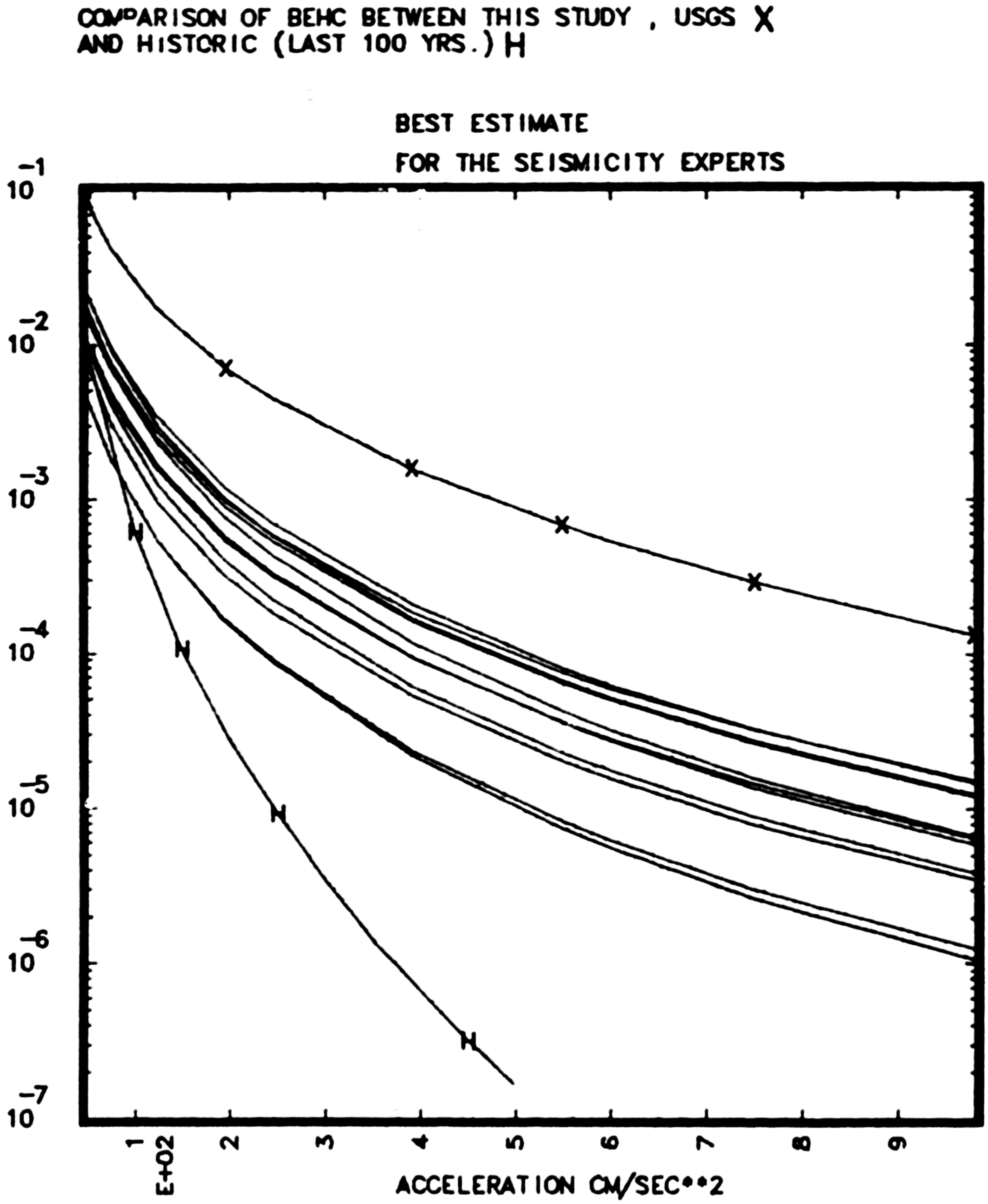
SHEARON HARRIS

Figure 6.3.3



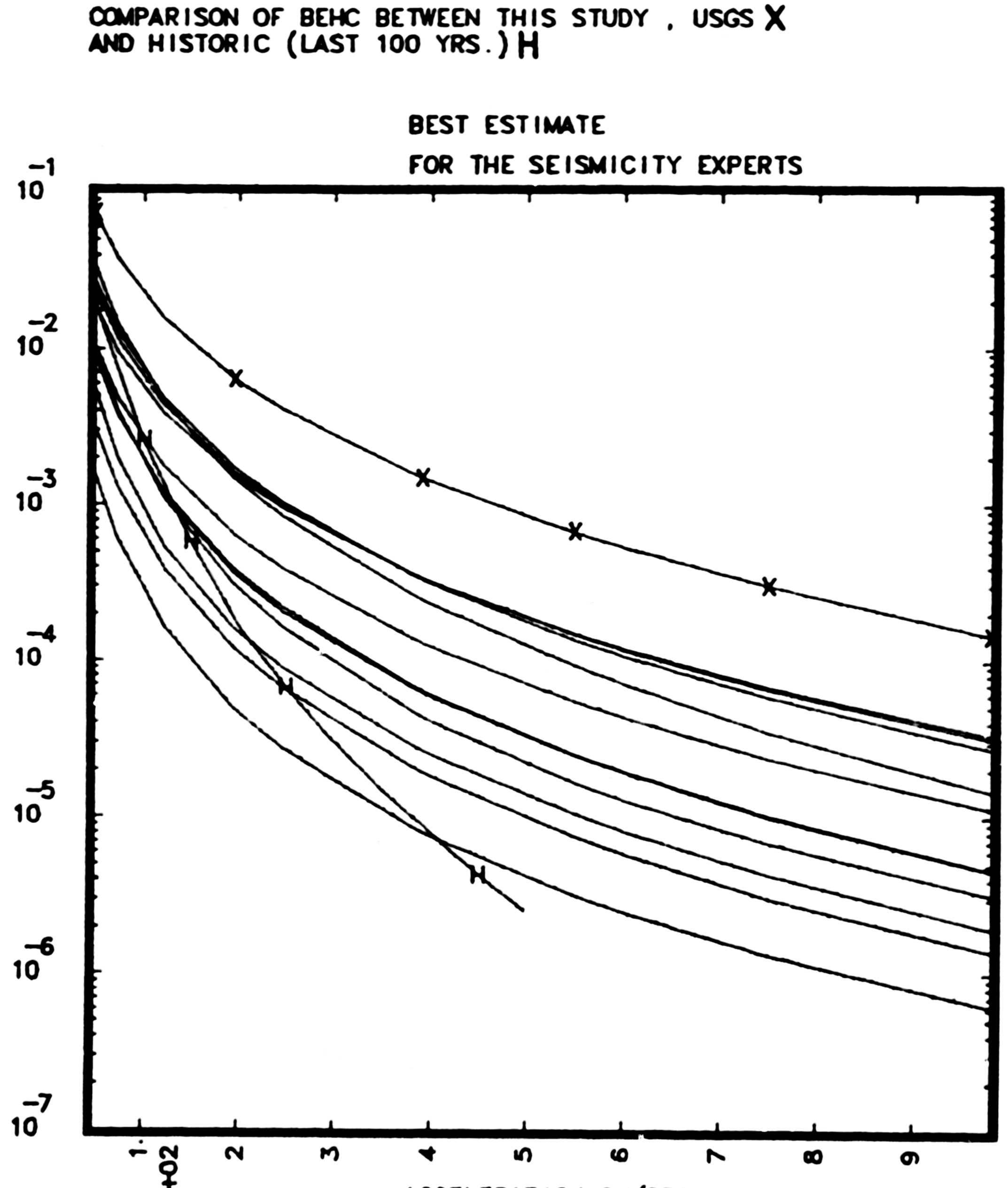
RIVER BEND

Figure 6.3.4



MILLSTONE

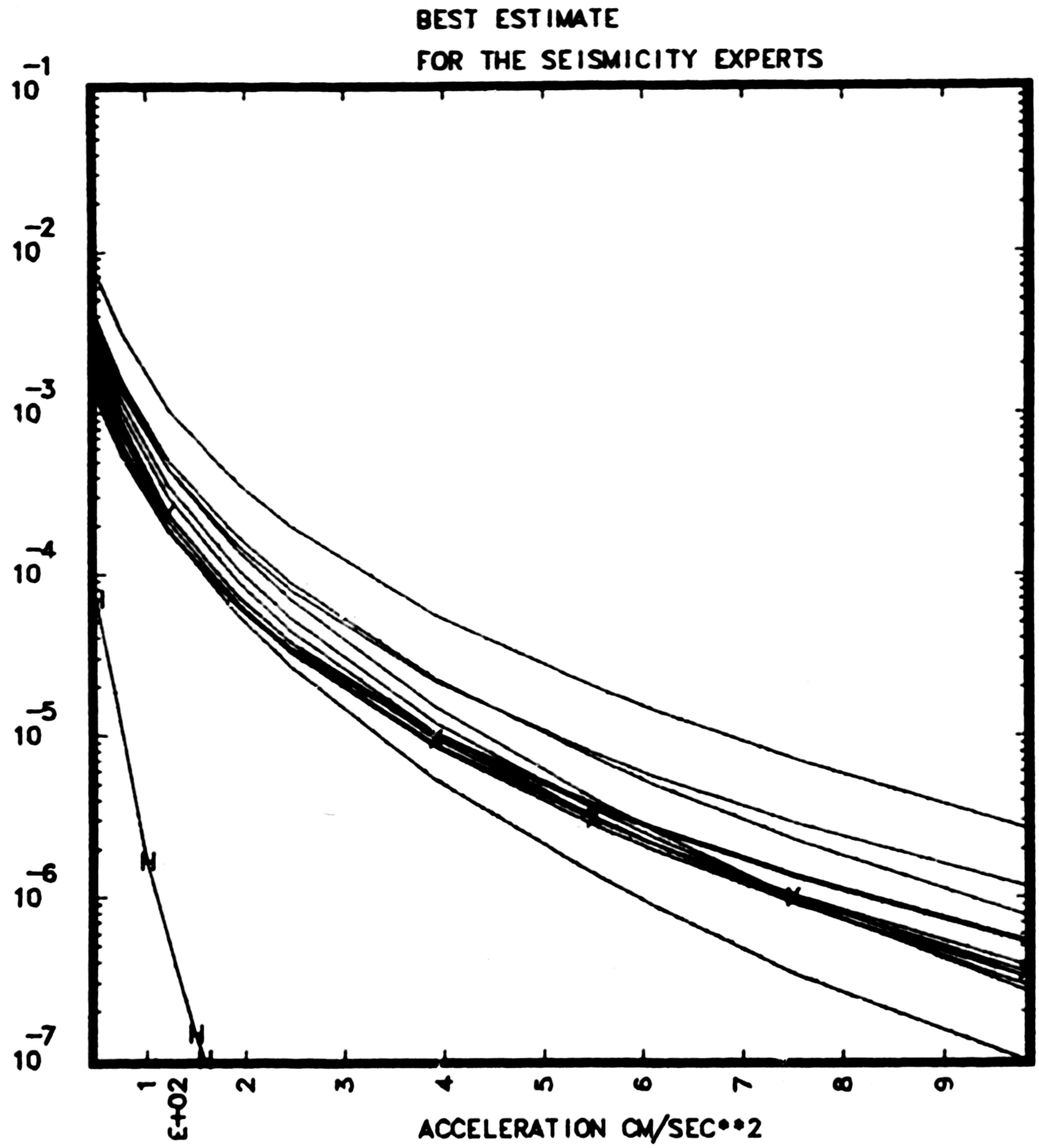
Figure 6.3.5



LIMERICK

Figure 6.3.6

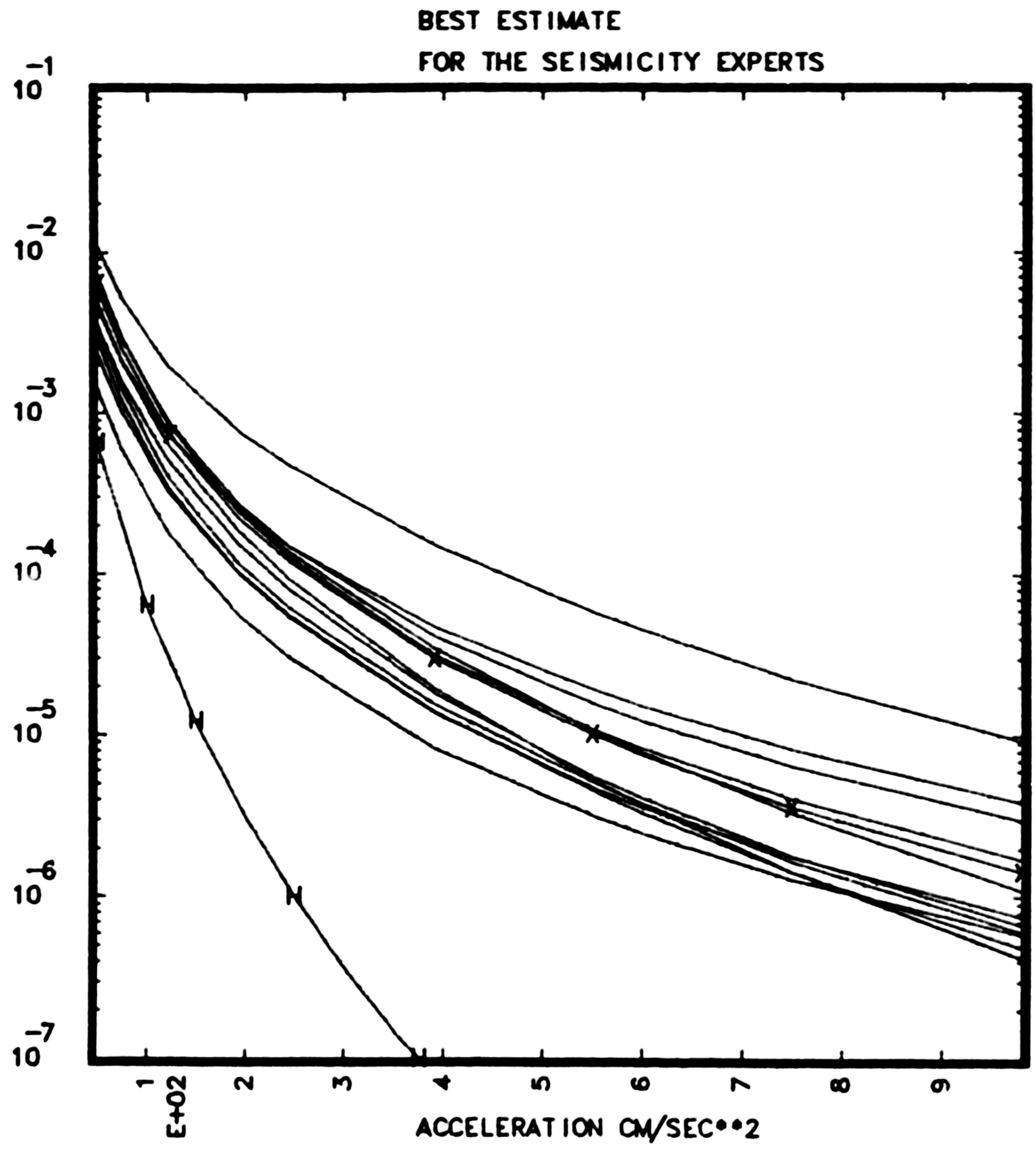
COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 100 YRS.) H



LA CROSSE

Figure 6.3.7

COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 100 YRS.) H



WOLF CREEK

Figure 6.3.8

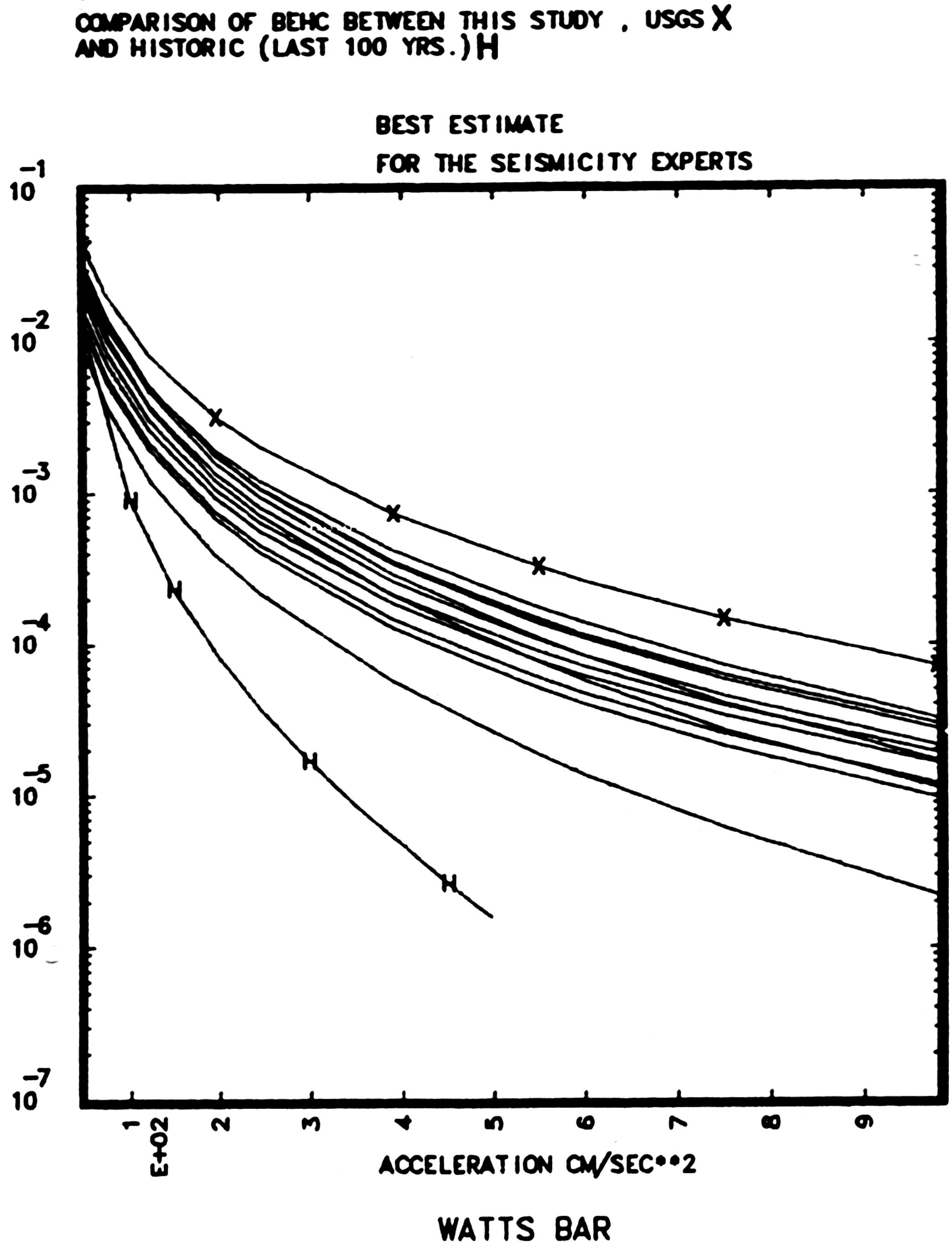
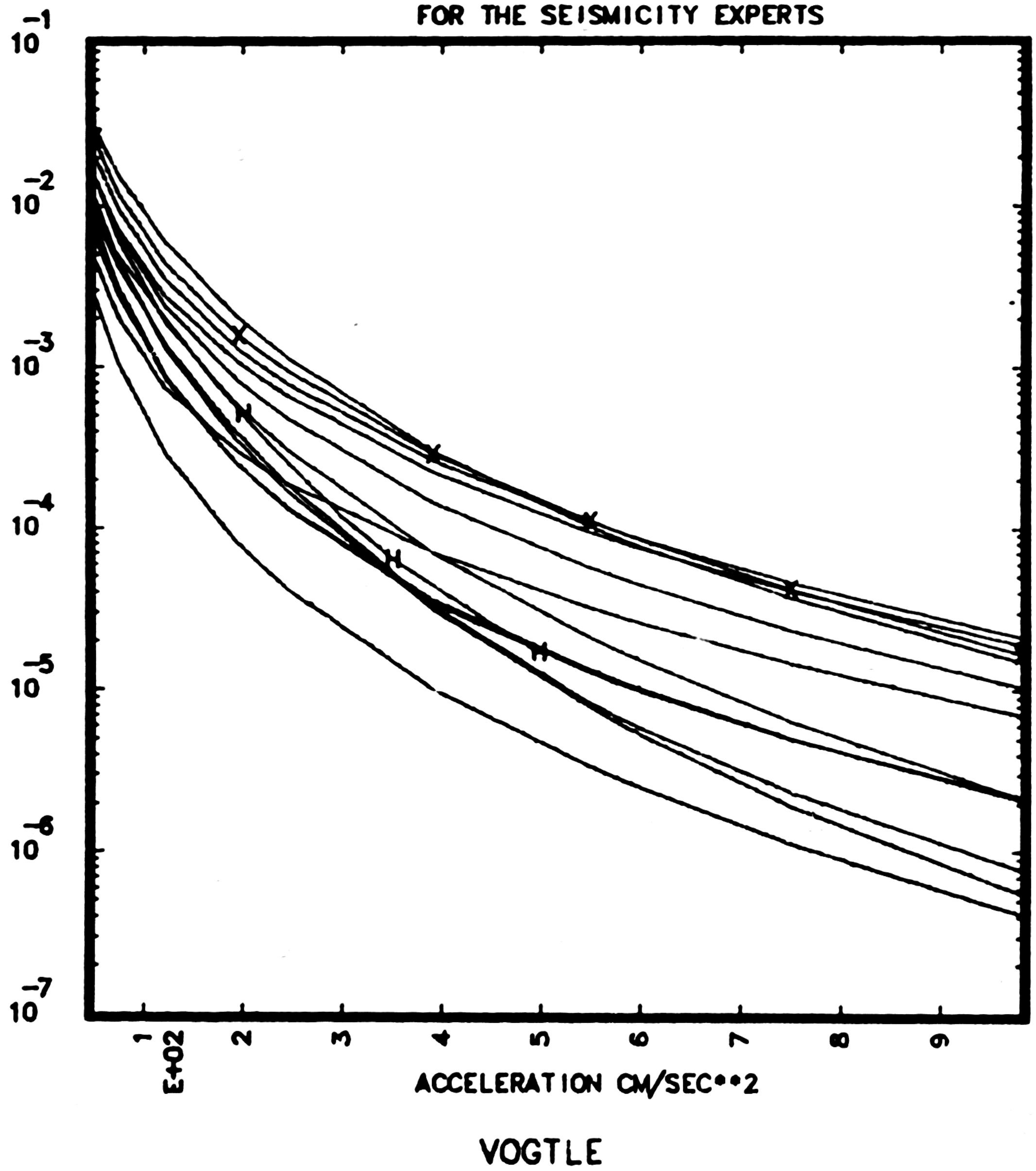

COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 100 YRS.) H
BEST ESTIMATE
FOR THE SEISMICITY EXPERTS
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
2
3
4
5
6
7
8
9
E+02
ACCELERATION CM/SEC**2
WATTS BAR

Figure 6.3.9

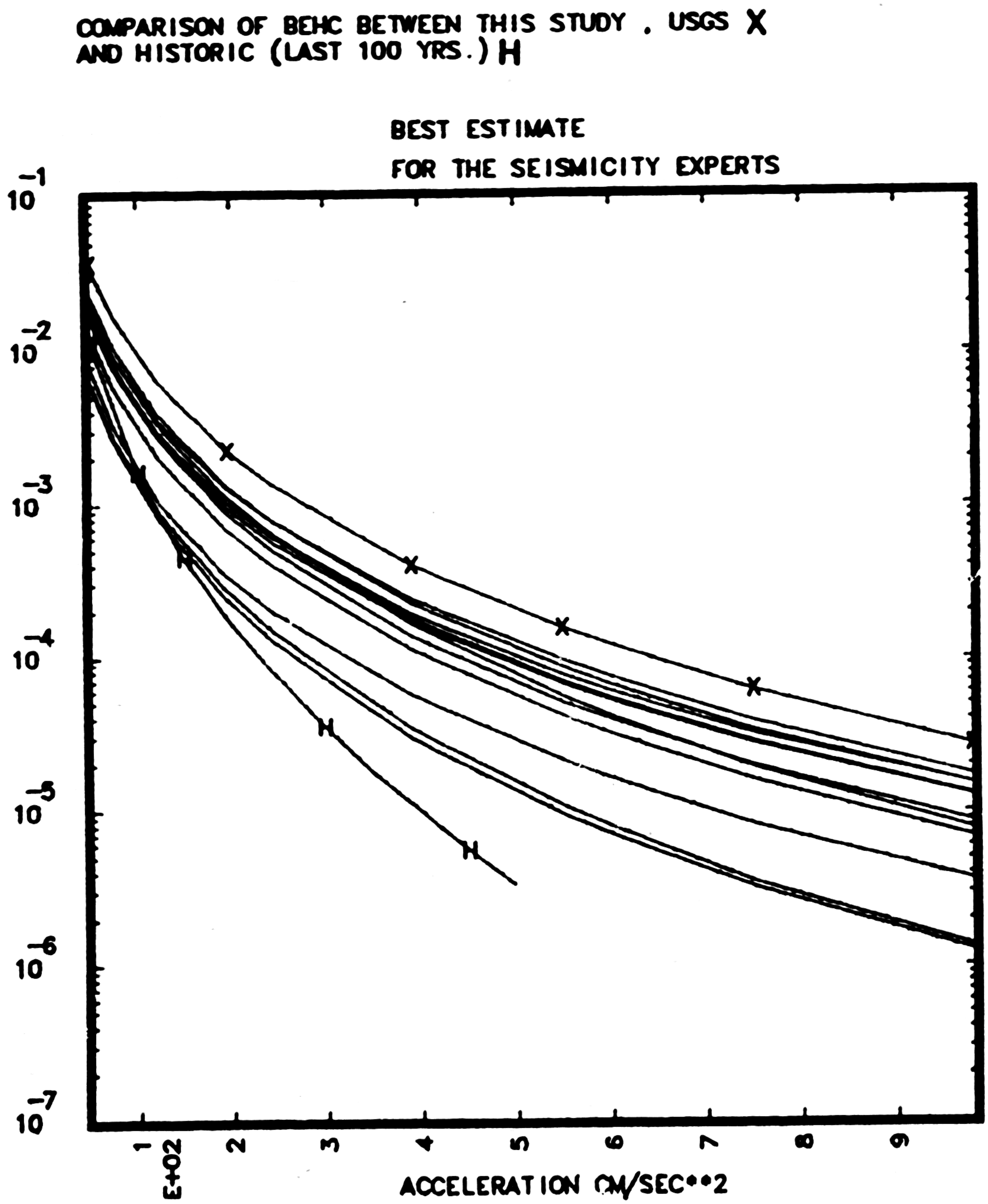
COMPARISON OF BEHC BETWEEN THIS STUDY , USGS X
AND HISTORIC (LAST 100 YRS.) H

BEST ESTIMATE
FOR THE SEISMICITY EXPERTS



VOGTLE

Figure 6.3.10



MAINE YANKEE

6.4 Comparisons to the SEP Study

In Section 1, we noted that this project, The Seismic Hazard Characterization of the Eastern United Stated identified hereafter as simply the SHC, had its roots in an earlier study (Bernreuter and Minichino, 1983) performed as part of NRC's SEP. 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 memebers:

- 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.

- EPRI has instituded a major Seismic Hazards Research Program using a number of our Seismicity Panel members.

As six out of eleven Seismicity Experts participating in this study also participated in the SEP study (see Table 6.4.1), we have 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?

These two questions were examined in detail in Bernreuter et al. (1984) based on the input provided by our two Panels at the end of the first round of our elicitation process. The conclusion was reached that overall the process is reasonably stable and the addition of different experts did not seem to significantly alter the resulting combined hazard curve for various sites. In this section, we briefly reexamine these questions using the final updated responses of our panel members.

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. First, different ground motion models were used for the two studies. This problem is addressed by making a set of comparisons for the case where the hazard curves are based on the same ground motion model, as well as, comparisons between the final results of the two studies. Secondly, in the SEP, the Experts were asked to provide seismicity information for two pre-zoned maps, as well as, allowed to provided their own zonation. A number of the panel members used only the zones on the two pre-zoned maps. In addition many of the panel members did not provide a values for the recurrence models. These were developed in a uniform manner. In contrast for the study, no prezoned maps were used and each panel member independently developed both the a and b values for the recurrence model. In addition, as noted in Section 1, in this study we have performed a complete uncertainty analysis as compared to the limited uncertainty analysis performed in the SEP. This problem is addressed by comparison of BEHCs for the two studies. Finally, as only two sites are common between the two studies, Millstone and La Crosse, 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. 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.

Figures 6.4.1-6.4.4 show a comparison between the BEHC obtained using BE maps and seismicity parameters provided by the SHC Seismicity Panel members (curves denoted by small symbols) and the PGA hazard curves obtained using the zonations and seismicity parameters provided by the SEP Seismicity Panel members (curves denoted by the large symbols). All hazard curves were developed using PGA Model No.8 with a sigma of 0.6. The Experts who only participated in the SEP are identified by the large symbos B,C,D,E on the figures. The SHC Experts 11, 12 and 13, are identified by the small symbols B,C, and D. For simplicity, the SEP expert numbers have been changed to agree with the Expert numbering for this study. Overall there is reasonable agreement between the results of this study and those from the SEP study.

TABLE 6.4.1

EXPERTS WHO PARTICIPATED IN THE SHC AND SEP

Professor G.A. Bollinger

Mr. R.J. Holt

Professor O.W. Nuttli

Dr. P.W. Pomeroy

Professor R.L. Street

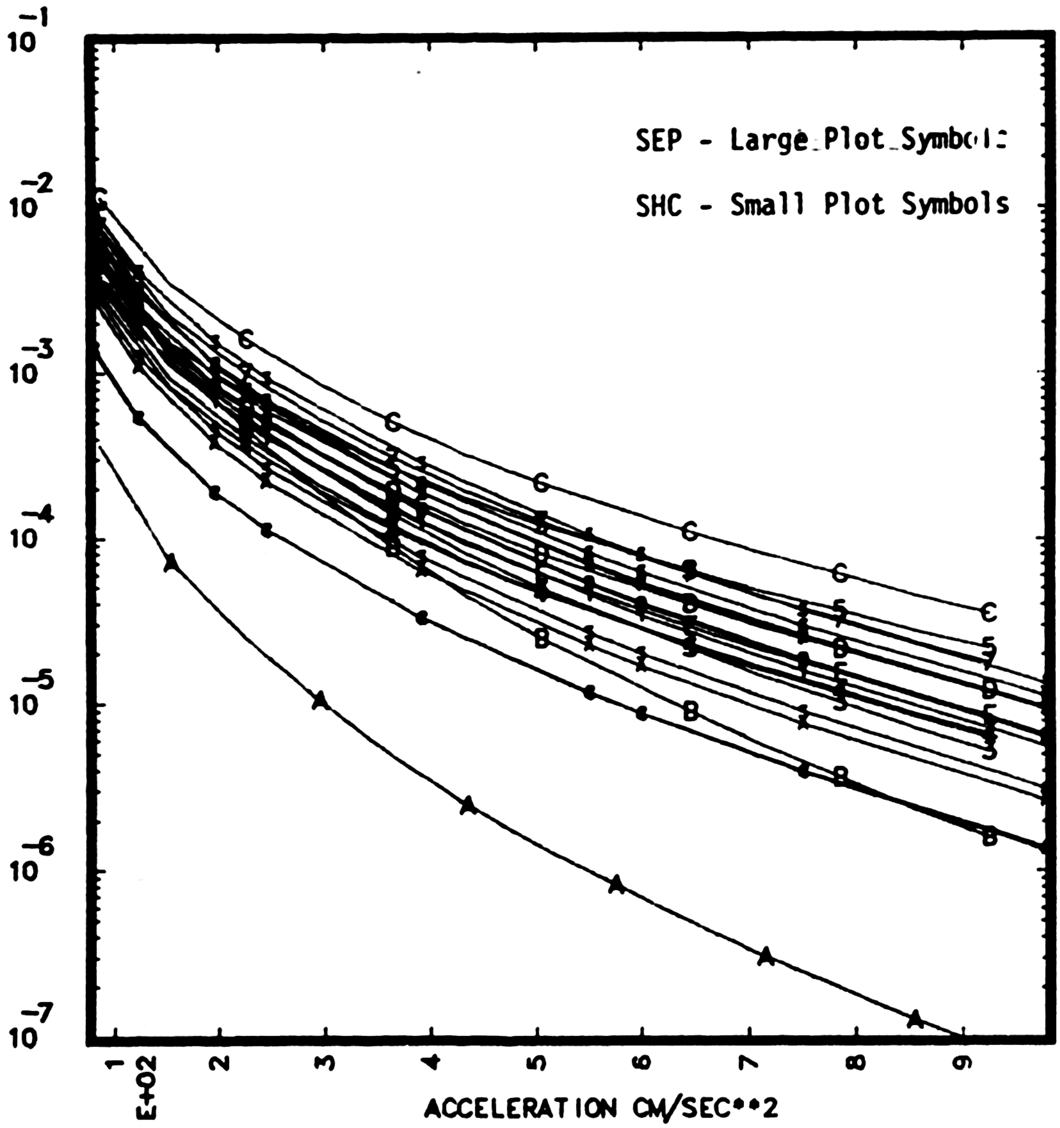
Professor M.N. Toksöz

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

Figure 6.4.1

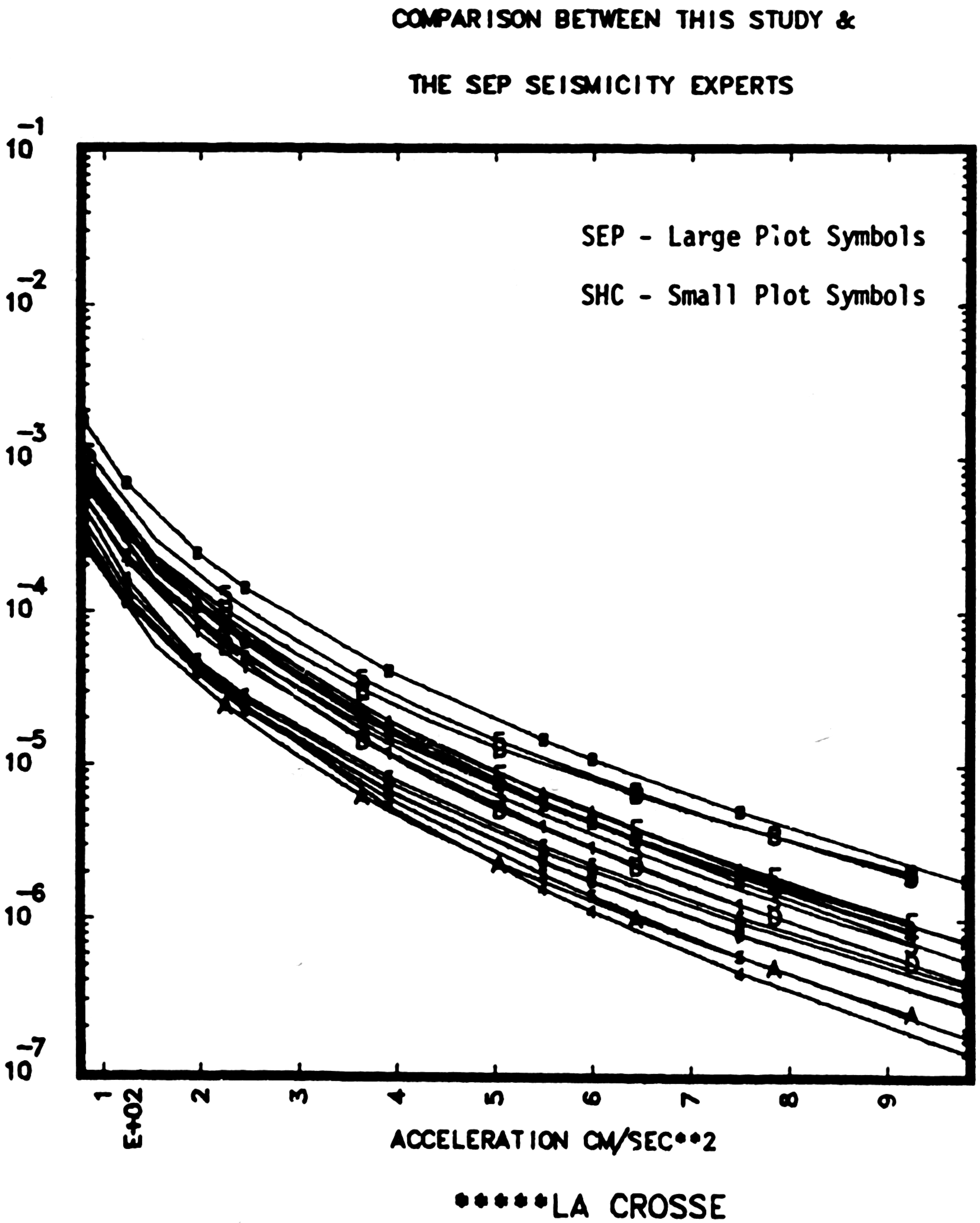
COMPARISON BETWEEN THIS STUDY &

THE SEP SEISMICITY EXPERTS



*MILLSTONE

Figure 6.4.2



COMPARISON BETWEEN THIS STUDY &
THE SEP SEISMICITY EXPERTS
SEP - Large Plot Symbols
SHC - Small Plot Symbols
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 6.4.3

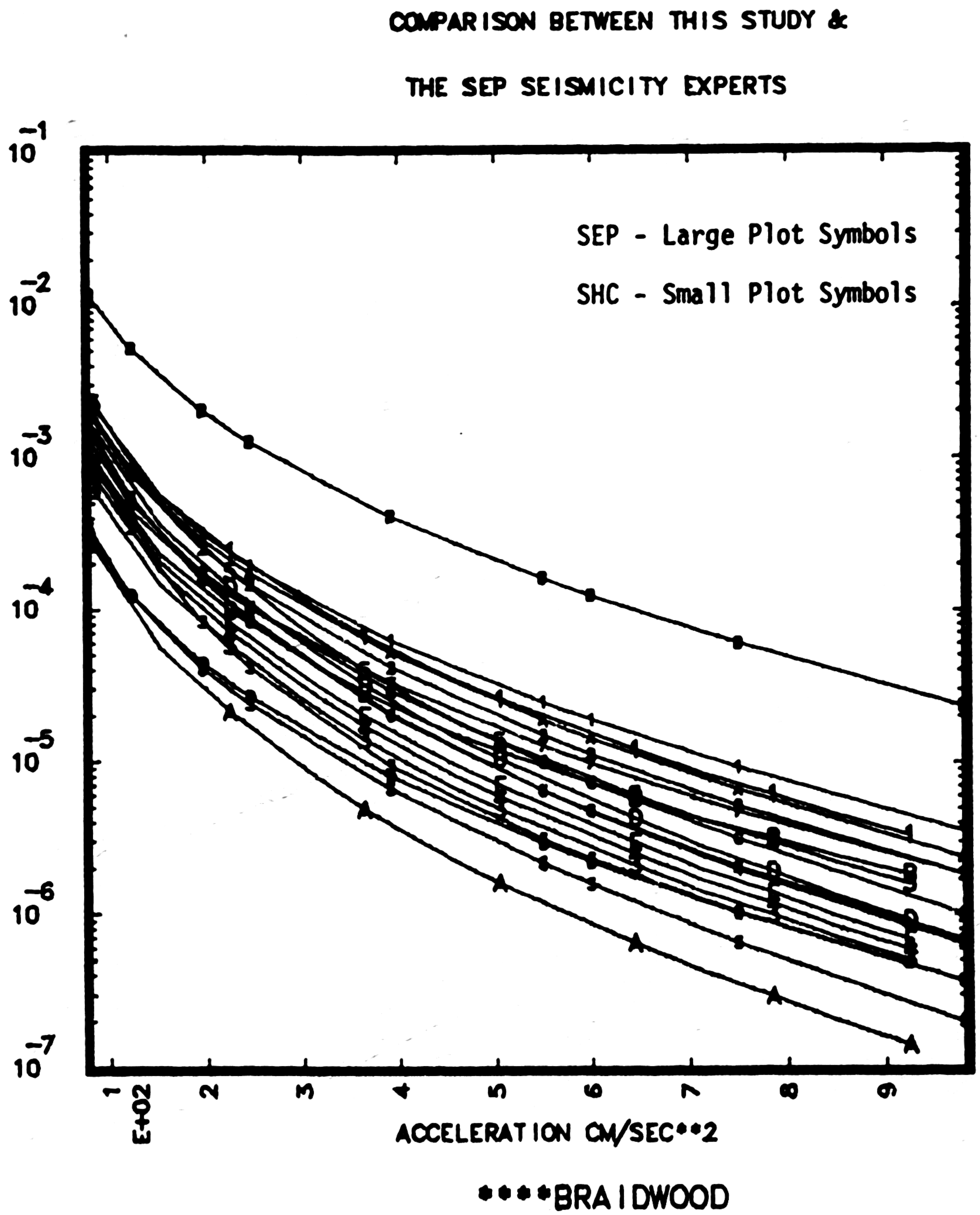
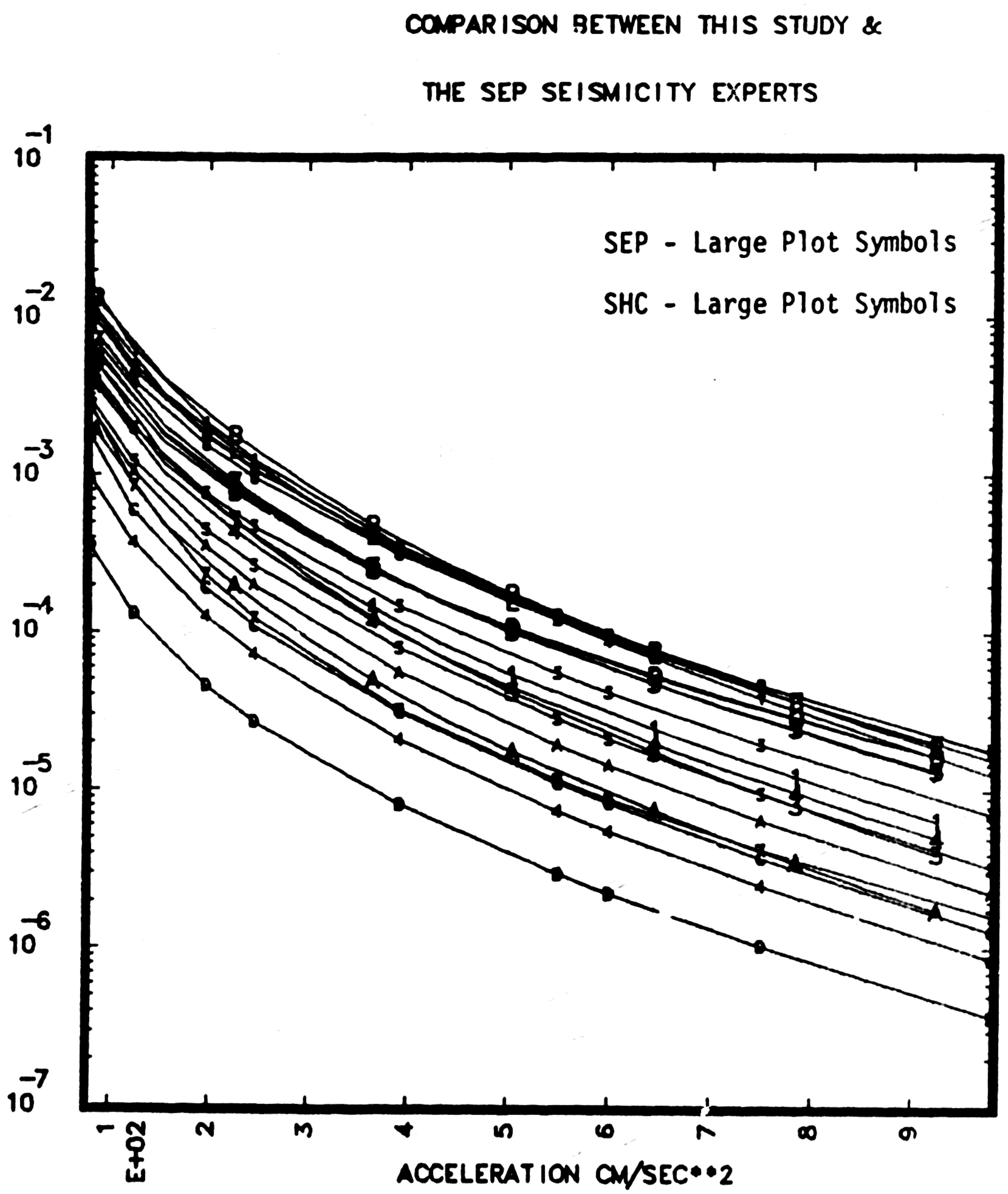

COMPARISON BETWEEN THIS STUDY &
THE SEP SEISMICITY EXPERTS
SEP - Large Plot Symbols
SHC - Small Plot Symbols
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
****BRAIDWOOD

Figure 6.4.4



*LIMERICK

However, the hazard curve for a few panel members have shifted considerably between the two studies. The important changes are identified and discussed in Bernreuter et al. (1984). Only very minor changes to the sesimicity data were introduced by the feedback round so the results and discussion in Bernreuter et al. (1984) are still valid and will only be summarized here. Tables 6.4.2-6.4.4 summarize the significant differences between the two sets of input for each panel member that lead to differences in the hazard curves between this study and the SEP.

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.

The comparison between the two studies discussed above were restricted to the difference in the seismicity modeling between the two studies. However, there was a major difference in how the uncertainty in the ground motion modeling was incorporated into the two studies. 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 La Crosse 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.

TABLE 6.4.2

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 form MMI II to m_b= 6.5. 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 (MMI 9.5).
5	Lower	Lower M_U and a larger absolute value for b in Zone 8. In the SEP, a 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

TABLE 6:4.3

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 La Crosse site is located in the CZ of most Experts.

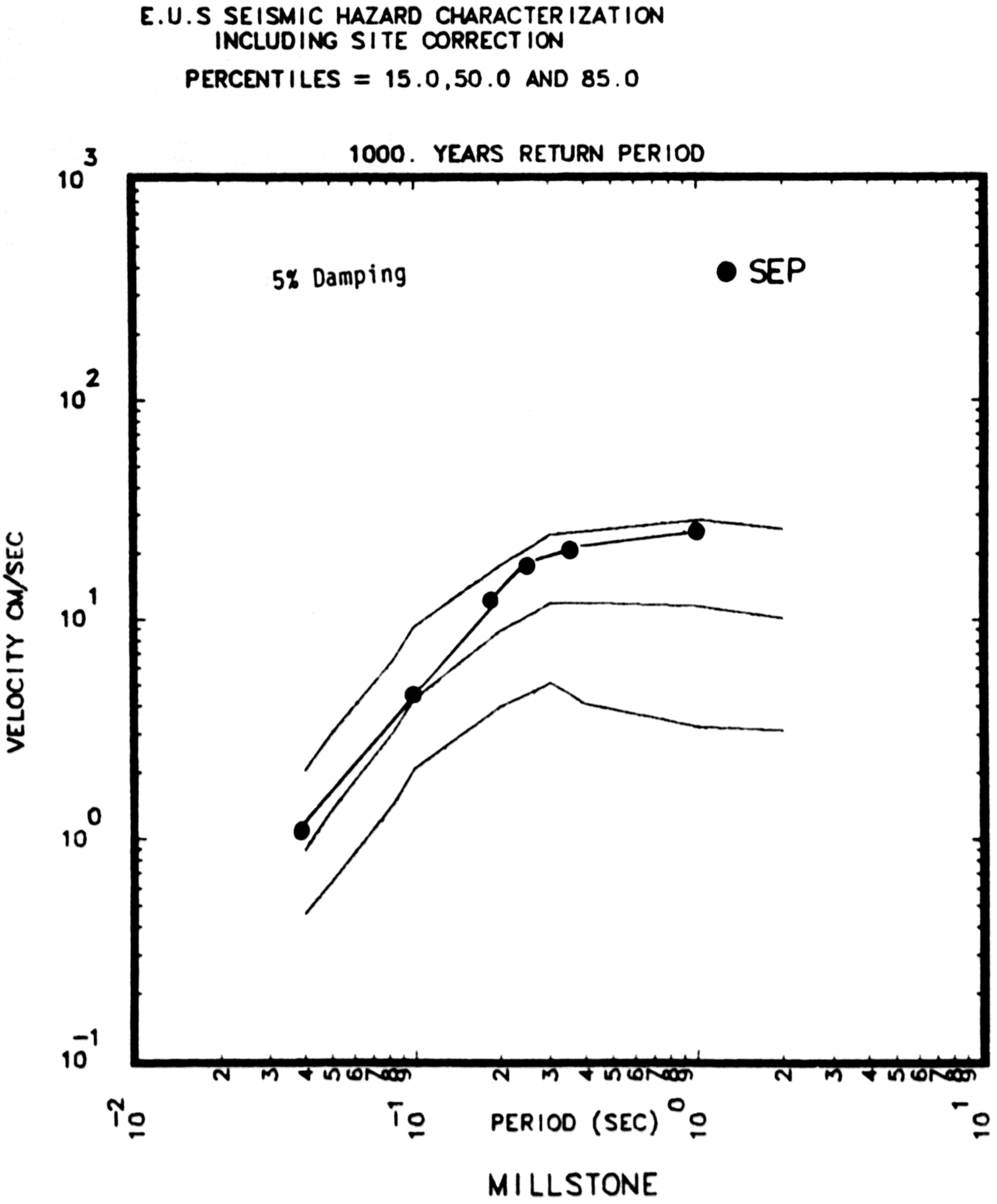
(2) Only Experts 10 and 1 provided rate of earthquakes occurrence for the CUS for the SEP.

TABLE 6.4.4

Summary of Differences in the Seismic Hazard Curves Between SEP and the SHC For the Braidwood Site

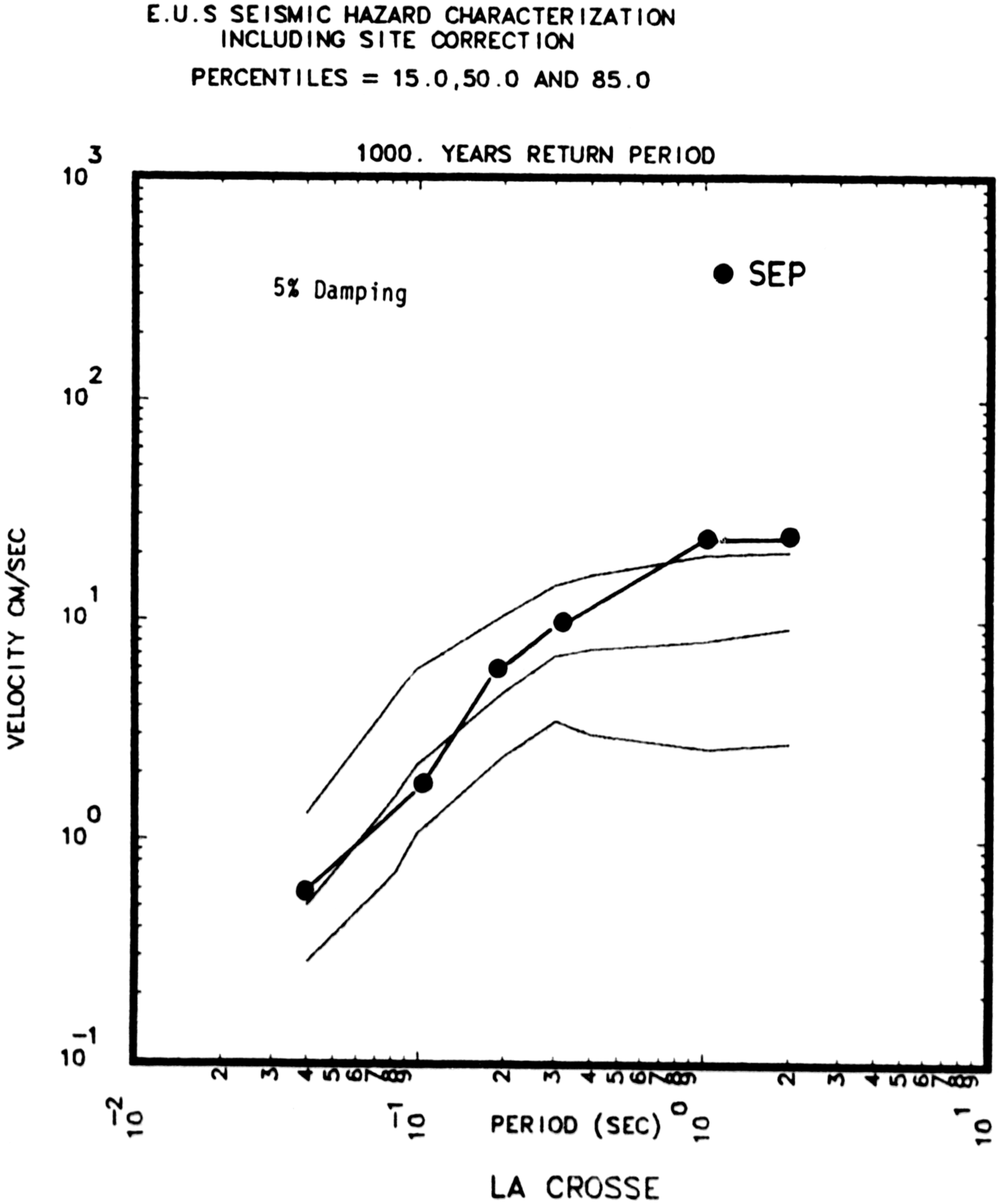
SHC Number	SHC Change From SEP	Differences in Input
3	Higher at Lower Range of PGA Levels	Zone 14 influences hazard in lower range of PGA Values. Higher rate than for the SEP.
10	Much Higher	Change in zonation with much higher M_U and rate of activity. No zone in SEP.
1	About the Same	Zonation slightly 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	For the SHC added Zone 6 with higher rate and larger M_U.
7	N/A	Did not provide seismicity parameters for CUS for SEP.

Figure 6.4.5



E.U.S SEISMIC HAZARD CHARACTERIZATION
INCLUDING SITE CORRECTION
PERCENTILES = 15.0,50.0 AND 85.0
1000. YEARS RETURN PERIOD
5% Damping
SEP
VELOCITY CM/SEC
PERIOD (SEC)
MILLSTONE

Figure 6.4.6



E.U.S SEISMIC HAZARD CHARACTERIZATION
INCLUDING SITE CORRECTION
PERCENTILES = 15.0,50.0 AND 85.0
1000. YEARS RETURN PERIOD
5% Damping
● SEP
VELOCITY CM/SEC
PERIOD (SEC)
LA CROSSE

By contrast for the SHC, as noted earlier, the uncertainty in the ground mation models 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 should also be noted that the Ground Motion Panel introduced a number of significant changes as a result of the feedback process.

Figures 6.4.5 and 6.4.6 show a comparison of the recommeded UHS for Millstone and La Crosse sites from Reiter and Jackson (1983) to the 1000 year return period CPUHS for these two sites developed as part of this project. At short periods there is reasonable agreement between the SEP UHS and the 50th percentile CPUHS. At longer periods the SEP UHS are higher than the 50th percentile CPUHS. One reason for this is site correction factors used in this study reduces the longer period amplitudes (see Figures 3.4.1 and 3.4.2). Another reason why the SEP results are more conservative at low frequencies is because they are based only on one ground motion model (The Gupta-Nuttli model) which (see Volume 2, Appendix C or Bernreuter, 1981a) has low attenuation. Therefore, long period motion is influenced by distant source zones such as the New Madrid Zone. For this study, Newmark-Hall type spectral models were about equally weighted with SEP spectral models. It can be seen from the comparisons of the different spectral models given in Section 3 and Appendix B, that the Newmark Hall models have less long period spectral content than the SEP spectral models.

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

6.5 Comparisons to Other Studies

Seismic hazard analyses have been developed for the Maine Yankee site, Yankee Atomic Electric Company (1983), The Limerick site, ERTEC (1982), and The Millstone site, Dames and Moore (1983) and (1984). The ERTEC and the Dames and Moore studies were performed to provide seismic hazard estimates for Probabilistic Risk Assessment (PRA) studies for the Millstone and Limerick nuclear power plants. The Yankee Atomic study is the most complete and a full uncertainty analysis was performed and CPHC were developed. Thus, it is possible to directly compare Yankee Atomic's results to our results. Only a limited uncertainty analysis was performed for the other studies. Yankee Atomic's CPHC for the Maine Yankee site and our CPHC (Figure 5.11.3) are compared in Figure 6.5.1. It is observed that the two median hazard curves are in resonable agreement although our bounds are much wider than Yankee Atomic's bounds.

There are several reasons why our median curve is higher than Yankee Atomic's median. First, our median CPHC is higher than Yankee Atomic's median because we included a greater diversity of ground motion models in our study than Yankee Atomic used in their study. In particular for the Maine Yankee site Ground Motion Panel Expert 5's choice of ground motion model produced much higher estimates at the Maine Yankee site than the other models, primarily because of the site correction factor used. This behavior was noted in

Section 4 and illustrated on Figure 4.4.4a. In addition, the lower limit of integration for the Yankee Atomic Study was taken at m_b= 4.0 as compared to m_b=3.875 for this study. Although the change in the lower bound of integration is small, it can have an important effect on the hazard curve. To assess the impact of these two factors, we re-ran our analysis for the Yankee Atomic site eliminating Ground Motion Expert 5's model and taking m_b=4 as the starting point for the integration of the hazard. The modified CPHC are compared to Yankee Atomic's CPHC in Figure 6.5.2. It is observed that the two median hazard curves are in excellent agreement. However, our uncertainty bounds are much wider than Yankee Atomic's uncertainty bounds.

ERTEC (1982) developed an estimate of the seismic hazard at the Limerick site for use in a severe accident risk assessment study of the Limerick Generating Station, NUS (1983). Six weighted hazard curves were developed. It is difficult to directly compare our results to ERTEC's results for several reasons:

1. ERTEC used a lower bound of m_b= 4.5 as compared to 3.875 for our study
2. ERTEC truncated the PGA at 0.3g for its most heavily weighted model and other models at 0.5g, 0.6g, 0.8g and 1.0g
3. only one ground motion model was used

The above factors all significantly reduce the seismic hazard estimates. Figure 6.5.3 shows a comparison of the mean ERTEC hazard curve compared to our results for the Limerick site. The agreement between the two studies is good, however, if we had used the same lower bound of integration and trucation of the PGA distribution as ERTEC, our hazard curves would be significantly lower than ERTEC's curve.

Dames and Moore (1983) developed an estimate of the seismic hazard at the Millstone site for use a PRA performed for Millstone Unit 3. Figure 6.5.4 shows a comparison of the composite hazard curve given in Table 4 of the Dames and Moore (1983) reports corrected from peak sustained to peak instrumental to the our CPHC (Figure 5.5.3) for the Millstone site. It is not clear from the Dames and Moore report what lower limit of integration was used for their analysis. Figure 6.5.4 shows that Dames and Moore's results are in good agreement with our results.

Dames and Moore (1984) performed a new seismic hazard analysis for the Millstone site. As little reference is made to the earlier Dames and Moore (1983) study, it is not possible for us to state in detail how the two studies differ. Four major differences between the two Dames and Moore studies are:

1. The 1984 study uses two different relations to convert from epicentral intensity to magnitude. One of the relation used is the same as used in YAEC (1984) and the other is the same as used in Dames and Moore (1983).

Figure 6.5.1

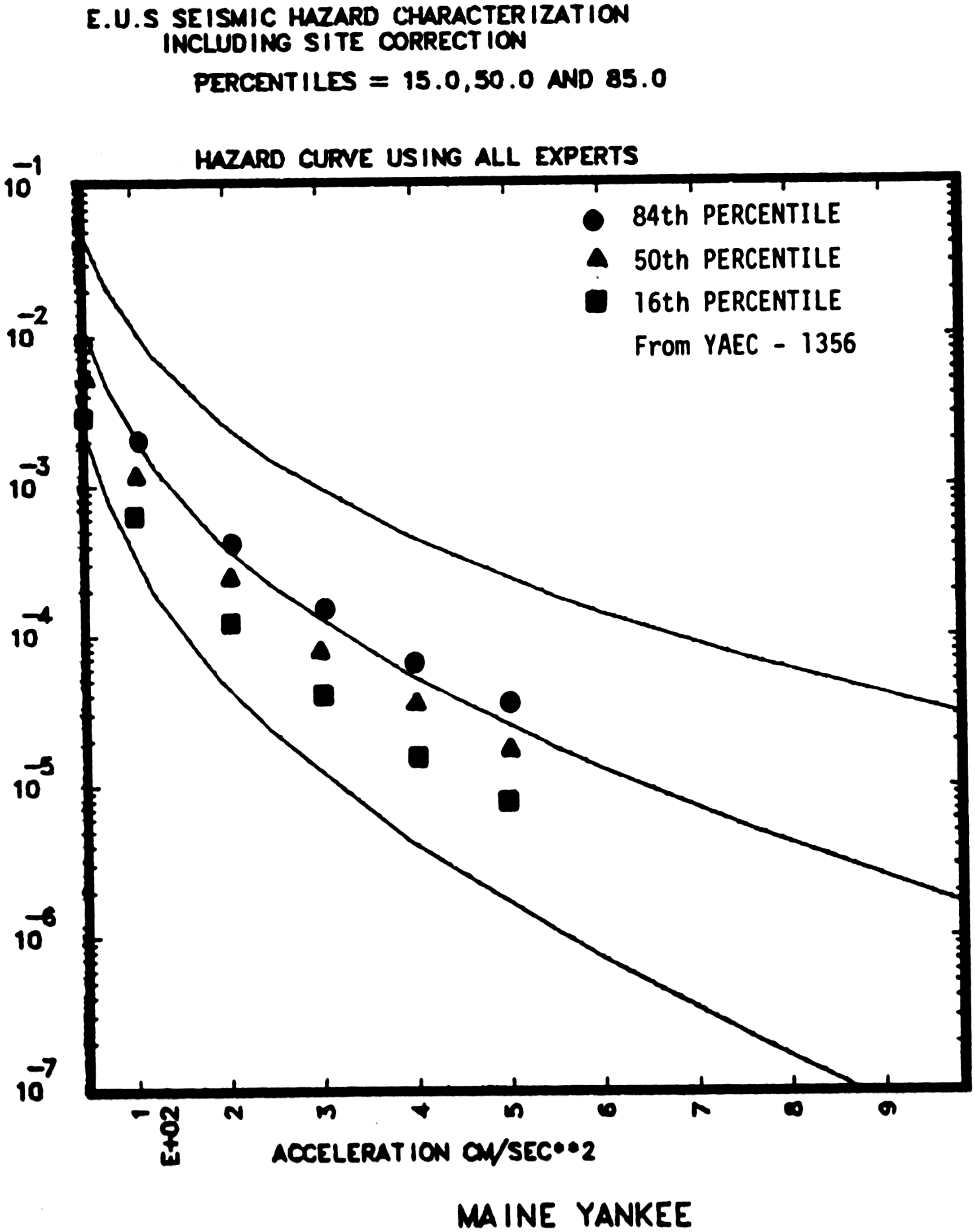
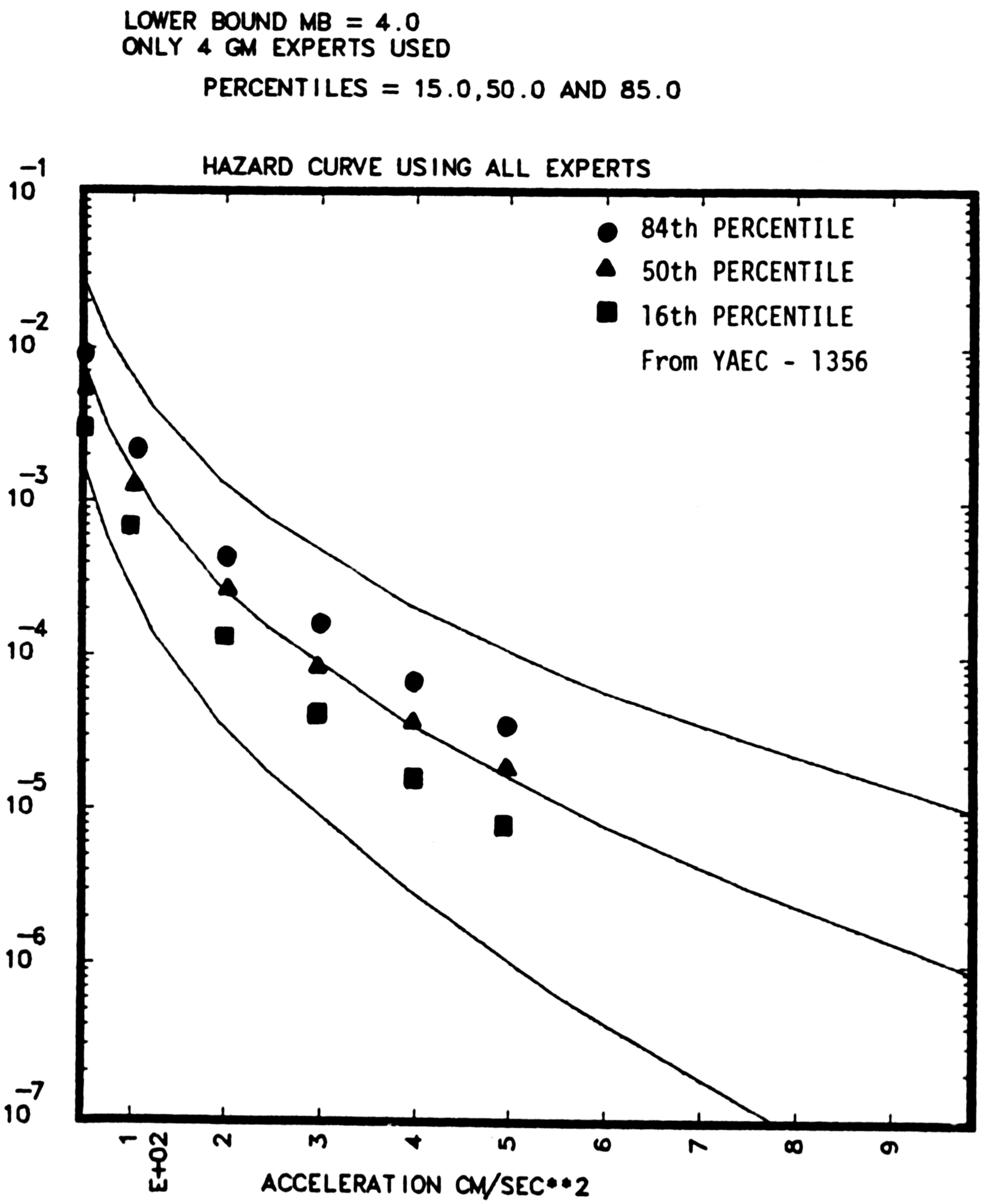
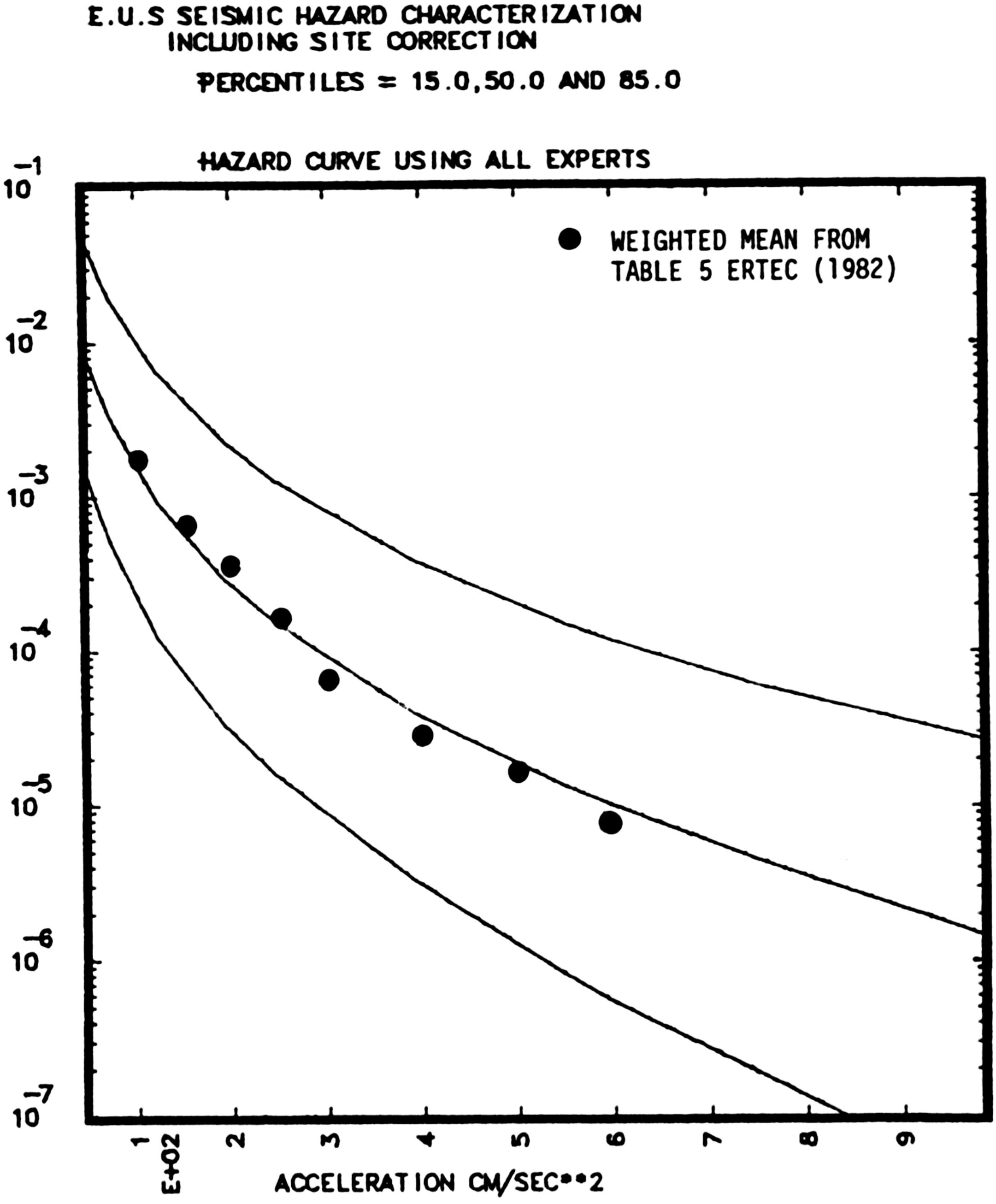

E.U.S SEISMIC HAZARD CHARACTERIZATION
INCLUDING SITE CORRECTION
PERCENTILES = 15.0,50.0 AND 85.0
HAZARD CURVE USING ALL EXPERTS
84th PERCENTILE
50th PERCENTILE
16th PERCENTILE
From YAEC - 1356
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
E+02
2
3
4
5
6
7
8
9
ACCELERATION CM/SEC**2
MAINE YANKEE

Figure 6.5.2



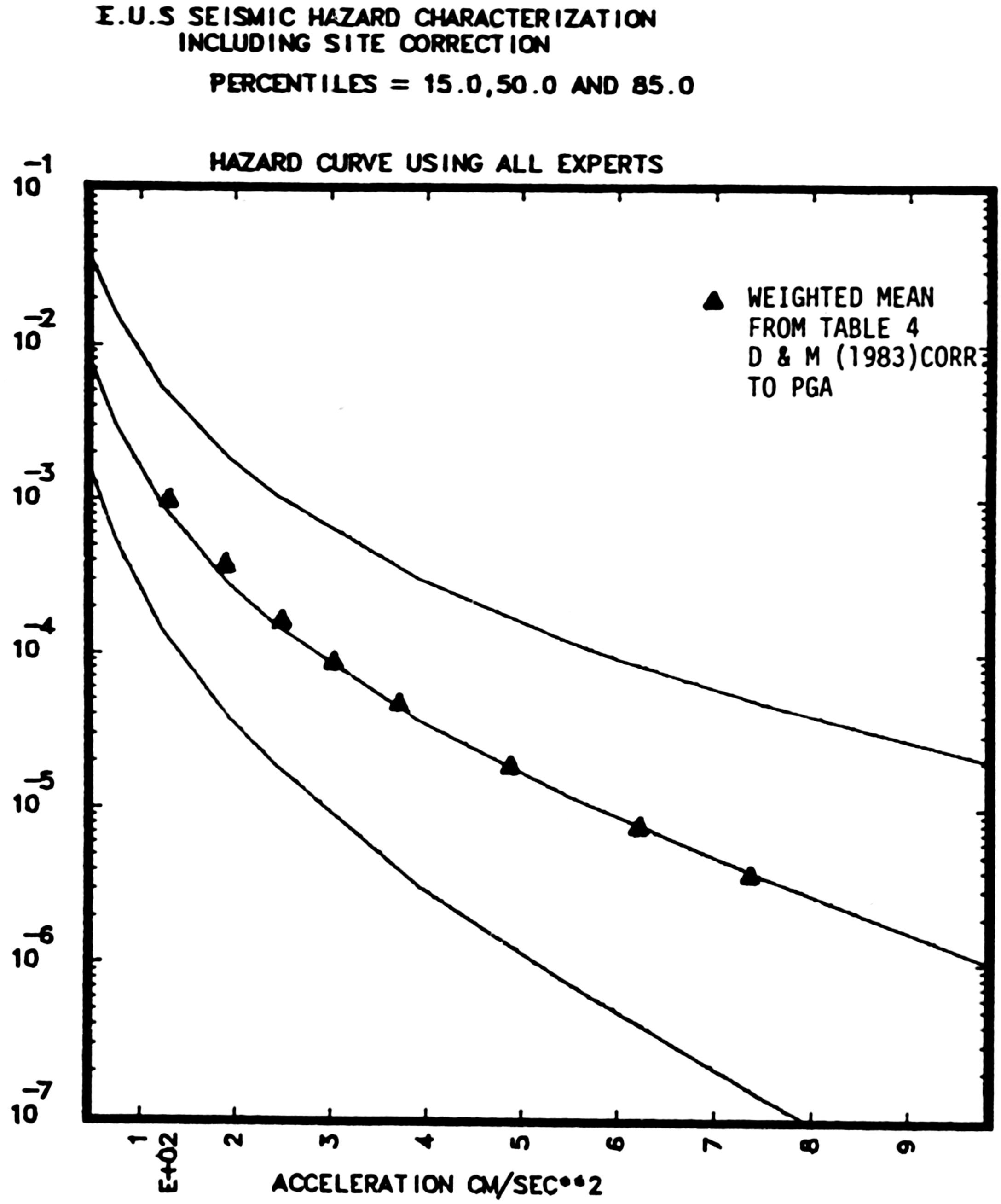
MAINE YANKEE

Figure 6.5.3



LIMERICK

Figure 6.5.4



MILLSTONE

2. Two new intensity based ground motion models are introduced in the 1984 study.

3. The maximum possible acceleration is truncated in the 1984 study as a function of magnitude.

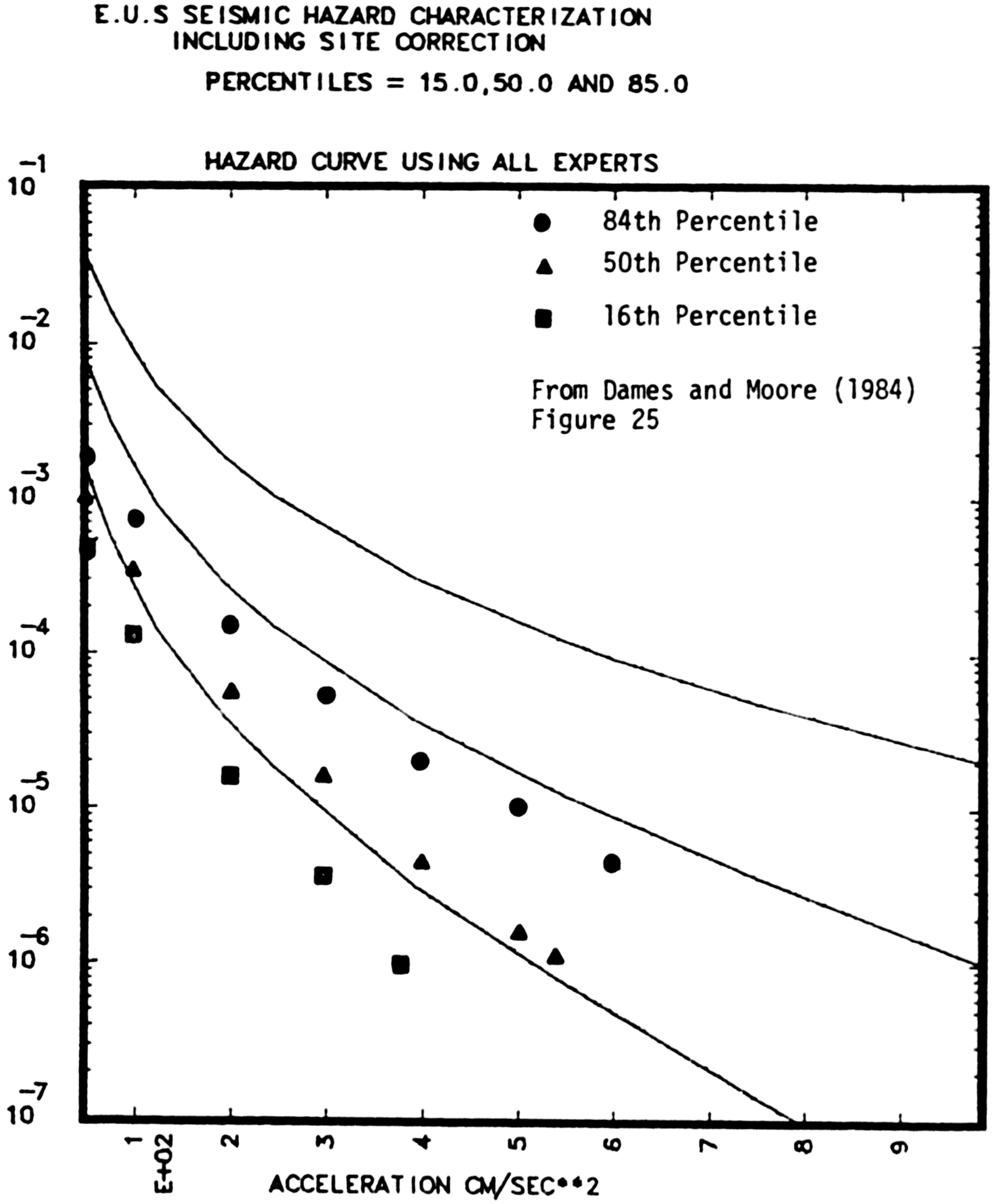
4. The lower limit of integration is taken as $m_b = 4.5$.

On Figure 6.5.5a, we compare the CPHC from the Dames and Moore (1984) study to the results of our study (Figure 5.5.3). It is seen that our CPHCs are much higher than Dames and Moore's (1984) CPHCs. This is to be expected because several important systematic differences exist between the Dames and Moore (1984) study and our study.

To put the Dames and Moore (1984) and our results on the same footing, we performed a limited uncertainty analysis (220 runs) where we restricted the ground motion models to four models that were similar to the ones used in the 1984 Dames and Moore study. We also introduced the same truncation of PGA as a function of magnitude as used by Dames and Moore (1984), and we took the lower limit of integration as $m_b = 4.5$. In figure 6.5.5b, the CPHCs resulting from this limited analysis are compared to the CPHCs given in Dames and Moore (1984). It is now observed that the results are in much better agreement. However, as was the case for Maine Yankee, our uncertainty bounds are wider than Dames and Moore's uncertainty bounds.

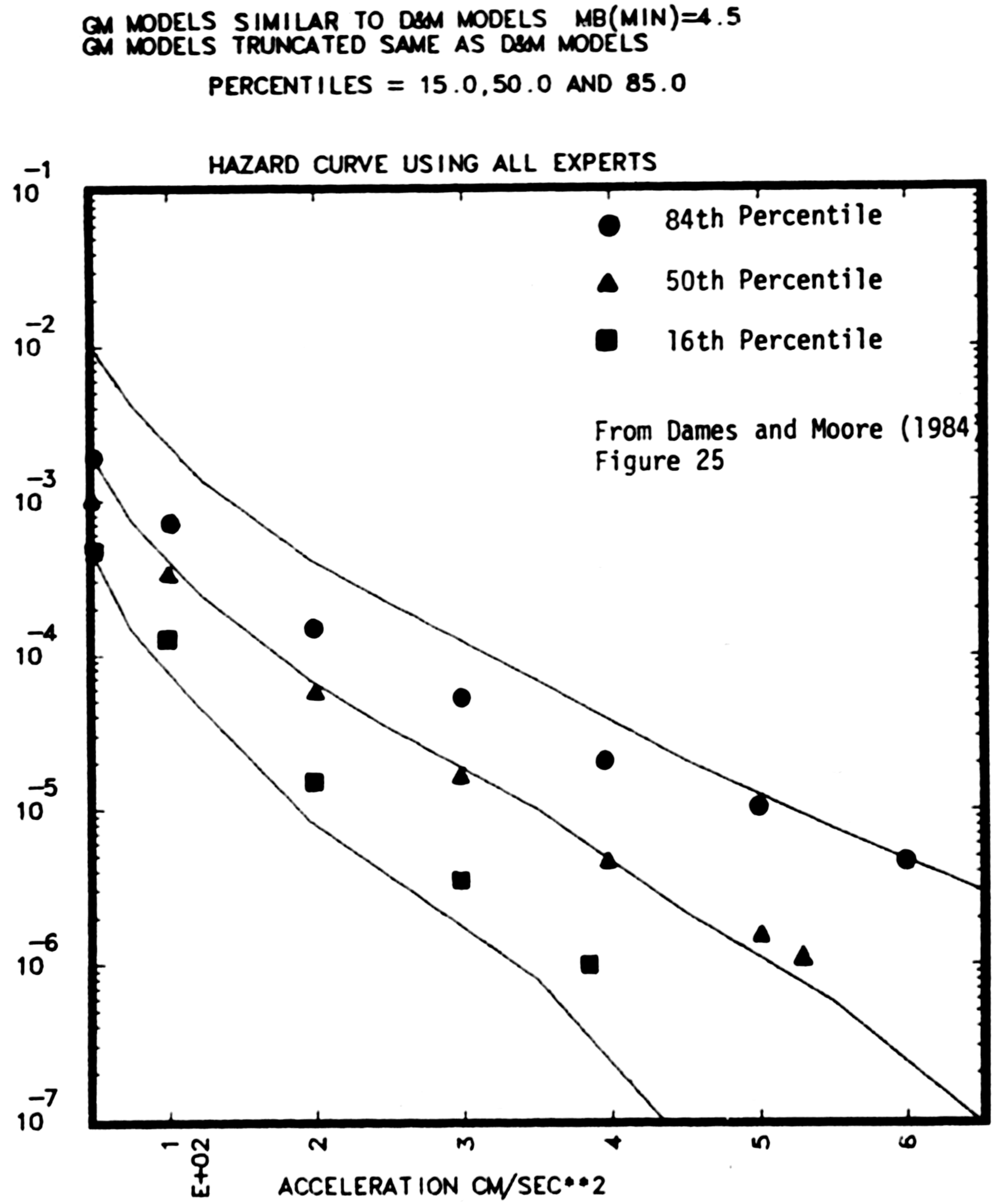
No explanation is given in Dames and Moore (1984) as to why the 1984 study hazard curves are so much lower than their 1983 results. We suspect that much of the difference comes from the differences between the ground motion models used in the two studies, the fact that the PGA distribution was truncated in the 1984 study and the lower limit of integration.

Figure 6.5.5a



MILLSTONE

Figure 6.5.5b



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SECTION 7 PEER REVIEW EVALUATION

7.1 Background

This study, the Seismic Hazard Characterization of the EUS (SHC) project, involved the elicitation of experts' opinions as well as the development of seismic hazard analysis methodology. These function were similar in format to the SEP which formed the foundation for the SHC study. An important element in the SEP was the Peer Review Panel. This panel, consisting of both seismologists and statisticians, provided comments identifying the weak and the strong points of the SEP study. A complete description of these comments, is given in Bernreuter (1981b)

Similarly, a peer review panel was formed as part of the SHC project. However, the peer review was formed at an earlier stage in the SHC project, so that appropriate adjustments could be made in the methodology and in the input data prior to finalizing the results. A flow chart of the functions of and interactions between seismicity experts, ground motion experts, peer reviewers, and LLNL was presented in Table 2-3.

As a result of this approach, we are confident that the weaknesses in the SEP study have been removed for the SHC methodology. Furthermore, the new elements appearing in the SHC have been extensively scrutinized by peers. In some cases this led to modifications in our methodology. It also spurred an extensive quality control analysis of the data provided by the members of the Seismicity Panel. We have attempted to remove from the SHC project the concepts and methods which have been identified by the peer reviewers as being weak or erronerous. Furthermore, the quality control anlysis provides confidence in the quality of the seismicity data. There are, however, some fundamental differences of opinions between LLNL and the peer reviewers. These points of disagreements, are discussed in this section.

The Peer Review Panel for this study included four experts, spanning the fields of seismology, geophysics, soil mechanics, structural engineering, and engineering statistics. A list of these experts is given in Table 7.1. The Peer Review Panel was formed after the interim results were obtained (see flow chart in Table 2-3). The reviewers were provided with a copy of our interim report, Bernreuter et al. (1984), and all the documents which were given to the seismicity experts and to the ground motion experts, as well as, their answers to the feedback questionnaires.

The members of the peer review panel had a minimum of two months to review all the relevant material prior to the Peer Review Meeting which took place in Cambridge, Mass. on August 15, 1984. A list of the participants at that meeting is given in Table 7.2. The reviewers presented their comments and the floor was opened for dissussion, explanations and clarifications. Each reviewer then finalized his comments and provided LLNL with a report, Appendix D.1 through D.4.

TABLE 7.1

List of Experts of the Peer Review Panel

Professor G.B. Baecher, Massachusetts Institute of Technology

Professor J.E. Ebel, Weston Observatory, Boston College

Professor L.T. Long, Georgia Institute of Technology

Professor D. Veneziano, Massachusetts Institute of Technology

TABLE 7.2

LIST OF THE PARTICIPANTS AT THE PEER REVIEW PANEL MEETING
IN CAMBRIDGE, MASSACHUSETTS, AUGUST 15, 1984

G.B. Baecher- Peer Reviewer

J.E. Ebel- Peer Reviewer

L.T. Long- Peer Reviewer

D. Veneziano- Peer Reviewer

A. Murphy- NRC

L. Reiter- NRC

D. Bernreuter- LLNL

R. Mensing- LLNL

J. Savy- LLNL

In addition to the comments generated by the Peer Review Panel, LLNL has been provided with comments from:

- The Atomic Industrial Forum, Inc.) (AIF) (letter from AIF to Mr. Richard Vollmer, August 13, 1984) see Appendix D.5

- Maine Yankee Atomic Power Company (letter from G.D. Whittier to Mr. R. Miller, May 31, 1984 and memo from J. Kimball to L. Reiter, June 18, 1984) see Appendix D.6.

- Yankee Atomic Electric Company (YAEC), Report YAEC 1455, 1984, "Review and Comment on NUREG/CR-3756"

- Dames and Moore, draft report, June 4, 1984, "Sensitivity of Seismic Hazard Results at Millstone to LLNL Study Assumptions on Attenuation and Seismicty." Draft report to Northeast Utilities. (This document in draft form has not been released in final form to LLNL at the present time)

These comments, as well as those of the Peer Review Panel, have been carefully considered. The most important of these comments are summarized and analyzed in the following sections.

7.2 Summary of Comments

The general concensus of the Peer Review panelists was that the methodology developed in the SHC project is a sound one. Its strengths are recognized in its efficiency, its ability to handle multiple seismicity and ground motion models, and it ability to reflect accurately the diversity of expert opinions.

At the time that the peer review was performed, the quality of the inputs from the seismicity experts was judged to be potentially the weakest element of the study. Several suggestions were made to improve the quality of the inputs. In particular, Professor Veneziano suggested an array of tasks to perform which, in his opinion, would substantially improve the quality and credibility of the LLNL results. These suggestions were carefully considered. However, due to budget and time limitations it was decided to perform only an extensive quality control of the seismicity data using simple methods rather than the more complete, but more complex methods, suggested. The important comments of each reviewer are presented and discussed, when appropri[illegible] in the following subsections.

7.3 Analysis of the Most Important Comments from the Reviewers

7.3.1 Professor Baecher:

Professor Baecher commented, "Overall, the study is carefully planned and well executed. While one may differ with particular items in the study, both the methodology and execution conform to the current state-of-the-art. In my view, this makes the results credible and as good as present scientific

understanding of eastern U.S. (EUS) seismicity probably allows. This is not to say that other competent workers would perform the study precisely as this one was performed, or that the results of similarly conducted studies would be exactly the same as the results obtained here. However, within reasonable confidence limits and for the present, the results appear to accurately reflect a consensus of expert opinion"...
"In their general behavior and absolute values the results must be considered to enjoy a reasonable level of confidence"....
"The estimates of the experts have been obtained through a well constructed and detailed questionnaire"...

The areas of improvement suggested by Professor Baecher are mentioned in his conclusion:

1. Better justification of experts' estimates,
2. Comparison of interim and final results with available statistical data, and
3. Integration of historical data with expert opinion.

Points 1 and 2 are the most important since they reflect a fundamental difference in the views between LLNL and the reviewer about the purpose of the study. From our perspective, the SHC study was intended to characterize the seismicity of the EUS as viewed by individuals familiar with the geotectonic and geophysical features of that region. To achieve this, a sample of experts was selected so that the views represented by those chosen could be expected to span the range of views within the professional community. In this way we felt we could derive a range of estimates of seismicity which would include the actual seismicity.

To insure that the opinions expressed were free of any biases that we might introduce and truly reflected the positions of the experts; the elicitation process was designed to encourage free expression of opionions, no matter how non-conventional they might be. Thus, we

- Did not attempt to have the experts come to a consensus.
- Elicited opinions anonymously.
- Did not require the experts to justify their opinions.
- Attempted to elicit opinions in a way which minimized potentially biasing the opinions.
- Did not expect the opinions to adhere strictly to the historical data, although the experts were encouraged to use any available data in formulating their opinions.

The SHC study was designed, in some sense, to purposely exclude the activities recommended in points 1 and 2.

However, we did introduce some safeguards into the elicitation and analysis process to detect any potential errors and inconsistencies that might occur. For example, prior to the interim report calculations, we devoted a substantial amount of time to checking the consistency of the responses of experts, mainly to make sure that the questionnaires had been understood correctly and that we had interpreted the responses correctly. At the same time, each expert was informally interviewed to identify the type of methods he used to account for incompleteness of the data bases and aftershocks and to calculate the parameters "a" and"b" of the recurrence relationships. In addition, a complete quality control of the seismicity data was performed following the suggestions of the Peer Review Panel. This quality control, described in Section 3.3, was based on checking the experts' input versus historic seismicity data. As a result of this operation, the experts were asked to reconsider their estimates of the a and b- values and upper magnitude (intensity) cutoff for the zones where we detected a possible error. Nine out of the eleven experts were asked to reconsider their seismicity data for a few zones. Three out of the nine experts did not make any changes, defending their input to us with valid arguments, and the other six made minor changes, due mainly to calculation or transcription errors.

With respect to point 3, the experts were expected to use the available historical data, either their own or a catalogue provided by LLNL, some data had already been used in formulating their opinions. Therefore, it would be difficult to develop formal procedures for integrating historical data with opinion which adjusts for the fact that some of the data formed a basis for the opinions. Elsewhere in this report, the results of the LLNL study are compared with results based on a "Historical Method". The complete comments of Professor Baecher are given in Appendix D1 (Section 6.3).

7.3.2 Professor J. Ebel:

Professor Ebel's comments included, "The members (of the Zonation and Seismicity Panel) represent a very qualified cross-section of the seismological society..."
"...thus the range of hazard values reported at each site probably fairly represents the range expected from the present diverse opinion of informed scientific experts."

The complete comments of Professor Ebel are given in Appendix D2. Professor Ebel points out some of the limitations in this study, which are common to all current seismic hazard analyses, such as the difficulty to develop accurate ground motion models for the eastern United States given the limited account of strong ground motion data in that region. Some other points, such as the sensitivity of the results to the choice of a soil condition correction, are discussed in other sections of this report (Volume 2, Appendix E)

Some of the points already noted by Professor Baecher are also mentioned by Professor Ebel. Finally Professor Ebel stresses the scale effect of the study. In his opinion some of the EUS should be defined with a better resolution than was done by most experts. This problem was carefully studied by LLNL and it was concluded that the uncertainty in the zonation and seismicity data did not actually warrant making micro zonations. This is also illustrated by comparing the SEP and the SHC studies. In the SEP, the experts were asked to provide zonations for use in hazard analyses for specific sites. Therefore the experts were aware of the site locations and were careful to devise zonation maps applicable to those sites.

In the SHC study, the experts were asked to provide seismic zonation maps for the entire eastern United States, east of longitude 104^{o}, without consideration of applicability to any specific site in the EUS. Yet, a comparison of the zonation maps in SEP and SHC, in particular a comparison of the maps for the experts who participated in both studies, shows that the scale or degree of resolution of the two studies are essentially the same. In addition, the scale of the zonations used by the Utility sponsored studies discussed in Section 6.5 for specific sites are very similar to the scale of the zones provided by our Seismicity Panel. This fact does not necessarily demonstrate that the resolution of the maps generated in the various studies is the best one, but it shows that it is probably the best that the experts can provide at the present time.

7.3.3 Professor L.T. Long

Briefly, Professor Long stated, "The uniqueness of this study is in the complete reliance on expert opinion to characterize seismic hazard and differences of opinion to characterize uncertainty. The de facto consensus is achieved through a probabilistic combination of expert opinions, whereas in most other studies, such as the EPRI study, the seismic hazard is computed from a predefined hypothesis or probabilistic combination of hypotheses and their estimated uncertainties. Hence, disagreements with the results of the computation in the study under review will essentially be disagreements with the experts and the experts understanding of the seismicity at the time of the study. One advantage of expert opinion over deterministic techniques is that the details of the logic need not be documented, and the intuition that precedes discovery and proof in scientific investigation can be factored into the analysis through the cognitive processes of the experts."

This last statement shows that a consensus does not exist between the Peer Reviewers on the necessity of documenting in detail the work of the experts. The complete comments of Professor Long are given in Appendix D2. Commenting on the quality of the input data and the relevance of non-conventional opinions, Professor Long stated:

"The degree of diversity observed was not expected by this reviewer (also an expert on the Seismicity Panel). Unfortunately, the understanding of seismicity is such that some of the radical opinions could prove correct for the rare large events. The rare large events are important events in seismic hazard characterization at low risk levels, and for them at this time, expert opinion may not be sufficiently knowledgable to define the risk."

In analyzing the model of ground motion attenuation, Professor Long questioned the choice of a log-normal distribution for acceleration. This was discussed at the feedback meeting on ground motion, where the members of the ground motion panel recommended some alternatives to the log-normal distribution and suggested they be given the opportunity to choose the type of distribution and/or a type of truncation method for the ground motion. "In summary, the SHC project and the use of expert opinion represent a potentially useful and significant element of seismic hazard evaluation. The technique is correct in its formulation, but a critical review and revision of the experts opinions should be performed before the results of this study are adopted for general use." Overall, Professor Long assessed the methodology to be correct, but recommended that an extensive quality control of the experts' input be performed, such as described in Section 3.3.

7.3.4 Professor Veneziano

The comments of Professor Veneziano (see Appendix D4 for the complete comments) were very extensive and dealt with almost every aspect of the study. We reviewed all of them, but discuss only in detail the most important ones. These were summarized in the conclusion of Professor Veneziano.

"My overall evaluation of the LLNL study is as follows:

a. The approach is sound except for elicitation and quality control of expert opinion. This and the elimination of biased ground motion models are the main areas of needed improvement.

b. Uncertainties are adequately represented in the results. However, better control of the input would reduce the scatter of hazard estimates due to judgemental or procedural errors by the experts and the elimination of biased attenuation models would lower calculated hazard at most sites.

c. There are components of input and modeling assumptions that affect the spatial variation of hazard and to which both absolute and relative hazards are sensitive. Examples are zonation and the ground motion model (e.g., compare curves "5" in Figs. 3.2 and 3.3 of the Q6 document). Of course, whether or not earthquake attenuation varies geographically is also very influential on relative hazard. One should consider these items most carefully if one wants to make comparative use of the results; see previous comments at points 3 and 5.

d. There is a general need for documentation of methods and criteria used by the experts in answering the questionnaires."

Points a,b and d have been addressed previously in the discussion of the comments of other reviewers. The concern with regard to biased ground motion models, expressed in points a and c was specifically included in the Ground Motion Panel feedback. In the response to the ground motion feedback questionnaire, which was available only after Professor Veneziano wrote his comments, Expert 5 modified his ground motion model, recognizing that its proper use was different from the one made in the interim calculations. Furthermore, the experts reconsidered all their choices of models and three out of the five experts decided to discard intensity-based models other than those of the magnitude-and-distance-weighted type, as recommended by Professor Veneziano.

A point of disagreement between LLNL and Professor Veneziano is that our views differ on what the sample of opinions is intended to represent. Professor Veneziano's view, we believe, is that the elicited opinions are intended to represent a sample of estimates of the "true" seismicity. Thus, one "expects" the ranges which reflect The Experts' uncertainty to include the "true" seismicity. It follows from this view that if two experts' uncertainty intervals do not overlap, then there is an inconsistency and at least one expert should "correct" his estimate or be eliminated. On the other hand, our view is that we have elicited the informed opinions which, because of the very limited amount of histroical data and overall information about the seismicity of the EUS, may not necessarily be "unbiased". However, by eliciting a range of opinions we believe the resultant range of seismicity estimates would include the actual or "true" seismicity. As a result we do not consider as necessarily inconsistent some of the large differences between seismicity models of the same region for two different experts. The fact that the lower bound seismicity for one expert lies above the upper bound of another expert for the same zone is not considered inconsistent, although Professor Veneziano considers this to be an inconsistency which "proves" that at least one of the two experts is in error.

7.4 Other Comments

As noted in Section 7.1, we have received and reviewed a number of comments on our interim report, Bernreuter et al. (1984). The most detailed set of comments are contained in the report by Yankee Atomic Electric Company (YAEC-1455). This report, YAEC-1455, covers all of the important points made in the report to Northeast Utilties by Dames and Moore and by G.D. Whittier in his letter to Mr. Miller. The review comments from The Atomic Industrial Forum (AIF) MYEC, YAEC and Dames and Moore dealt only with the work performed by LLNL up to the time of publication of Bernreuter et al. (1984), without consideration of the feedback performed on the zonations, the seismicity models and the ground motion inputs. Since the publication of Bernreuter et al. (1984), a number of elements in the methodology, as well as in the input data, have been adjusted to account for the information provided during the feedback and by the Peer Review Panel. This includes adjustment of the seismicity and zonation models, adjustment of the ground motion models and a comparison of the SHC results with results based on different methodologies and input data such as a historical analysis, use of the USGS zonation and seismicity models , a comparison with the SEP results and comparison with other studies discussed in Section 6.

The main comment in the AIF review is related to traceability. As has been explained previously in this section, one aspect of the LLNL study was to avoid biasing the experts and to allow them complete freedom of choice of alternatives compatible with their scientific understanding. It was judged that this goal could only be achieved by providing anonymity to the experts and by relying on their competence and experience for the reliability of their input. This does not mean, however, that the experts' inputs were taken ad verbum. As described earlier in this section, a substantial quality control was performed on the seismicity data, subsequent to the Peer Review Panel, as recommended by the Peer Review Members.

The report YAEC-1455, the report by Dames and Moore to Northeast Utilities and the letter of G.D. Whittier all identify four general "problem" areas with Bernreuter et al. (1984):

- o Methodology
- o Attenuation
- o Seismicity parameters
- o Lower bound magnitude

The problem with our methodology identified in YAEC-1455 is with the LLNL recurrence model. The purpose of the LLNL model, as discussed in Section 4, was not to attempt to represent a characteristic earthquake model, but to overcome the departure of the truncated exponential model from the linear relation

$$\log N = a - bM \tag{7.1}$$

in the range of validity of the model. The advantages and disadvantages of the LLNL model and the truncated exponential model were discussed at the feedback meeting and in our questionnaire Q5 sent to the Seismicity Panel members. The experts then individually selected the model which in their judgment was most appropriate. Six out of eleven experts chose the LLNL model. Our sensitivity results presented in Section 4 show that, compared to the other uncertainties, the differences between the LLNL model and the truncated exponential model are not significant.

The problem identified with attenuation in YAEC-1455 and the Dames and Moore report was with the use of the ground motion chosen by Ground Motion Expert 5 (model #14). The points rasied in YAEC-1455 were similar to the points that we made in Bernreuter et al. (1984). There are four reasons why Ground Motion Expert 5's model resulted in a high (as compared to other BE ground motion models) hazard at some sites: (1) low attenuation, (2) the scaling of PGA with magnitude was larger than other BE models so that zones with very large upper magnitude cutoff were more important than for other BE models, (3) the unmodified form of the Gupta-Nuttli attenuation relation was used (see the discussion provied as part of questionnaire Q4 to the Ground Motion Panel Section 4.1), and (4) the correction used for rock sites. These points were discussed at length with both our Seismicity and Ground Motion Panels. Some adjustments were made to the upper magnitude cutoffs (some were lowered). Ground Motion Expert 5 agreed that the modified form of the Gupta-Nuttli relation should be used. However, Ground Motion Expert 5 still was of the opinion that the approach used to develop model #14, was the best approach to use and that the site correction factor used for model #14 was the most appropriate. It should be noted that the site correction factor is the element, at rock sites, which makes the hazard computed using model #14 higher than for the other ground motion models. If the same simple correction factor of 1.0 is used for model #14 as for the other models, then there a much less difference between the BEHC for the other BE ground motion models as compared to model #14 for any Seismicity Expert.

The problem with our seismicity parameters identified in YAEC-1455 and the Dames and Moore report was in the choice of the relation used to convert from epicentral intensity to bodywave magnitude. Both YAEC and Dames and Moore indicated that, in their opinion, the relation that should have been used in the Northeast was

$$m_b = 0.44 - 0.67 I_o \qquad (7.2)$$

Only one of our Seismicty Panel members, Expert 10, explicity indicated that he used this relation. However, our Seismicity Panel members indicated that they used a number of different relations and historical catalogues to arrive at their estimates of the a and b values, not necessarily the default relation we suggested, nor our catalogue. In addition, the results shown in Figure 6.2.11a indicates that once the a and b values are set, the choice of the relation between epicentral intensity and magnitude is not very significant.

We also note, as shown in Figure 6.5.2, there is very little difference between our results and the results obtained by YAEC for The Main Yankee Site. In their study, YAEC used the relation (6.2) to derive their seismicity parameters. Finally, we note that the resultant BEHC for Expert 10, the one expert that definitely used relation (6.2), fall within the middle of the BEHC for both The Maine Yankee and Millstone sites. (See Figures 5.5.2 and 5.11.2)

The final point raised by YAEC, MYAEC, Dames and Moore and AIF is the choice of the lower bound magnitude for integration. This is not a seismological issue, but a fragility issue. The appropriate choice of the lower bound depends upon a number of issues such as; the structure or components of interest, the method of analyses used and failure modes.

The issues raised by YAEC, MYAEC, AIF and Dames and Moore are significant issues. These issues have also been considered by our Panel Members. There is considerable uncertainty associated with these issues and it is our opinion that our study has adequately modeled this uncertainty.

SECTION 8 VALIDATION AND DESCRIPTION OF COMPUTER PROGRAMS

8.1 INTRODUCTION

The validation of a computer program is generally performed in several steps.

Step 1:
This step consists of verifving that the operations performed by the computer are correct in the sense that they actually correspond to the theoretical derivations defined by a set of equations. This step is by far the most important, time consuming, and in some cases it is the only means of validation.

Step 2:
To strengthen our confidence in a computer program, it is necessary to perform a set of test calculations for which the results can be found independently either by developing an analytical solution to the problem or by comparing the results with those obtained with another validated program, for selected test cases. In this project, all means of validation were used whenever possible.

- Every module or section of module was checked with the analytical closed form solution whenever possible by verifying the results obtained for a selected set of test cases.

- The results obtained with our codes were compared with results obtained with other codes for several complex test cases. We performed the same test calculations with the previous codes developed in the SEP, and with Dr. McGuire's code and compared with our new results.

- We performed an extensive validation of the type described above as Step 1.

- A peer review opened our methodology and results to a critical analysis. Although this does not constitute a formal step of a validation, it is reasonable to assume that such a critical review of the results for as many as ten sites would have most likely revealed existing fundamental flaws in the computer codes.

In this section, we limit ourselves to presenting the Step 1 validation. Other aspects of the validation are presented either in Section 7, in the peer review evaluation or in Section 6, (comparison with other methods). Note, however, that the comparison with the USGS study and with the historical method are not direct comparisons since they do not attempt to solve the same equations. Nevertheless, they allow us to verify that our results are reasonable.

The complexity and size of the operations to be performed by the computer, lead to a modular concept of the software. One important benefit is the flexibility and versatility of the this array of computer programs. For example the output of any module can be modified at will either manually or using other computer programs, for the purpose of performing sensitivity analyses.

There are four main modules developed in the SHC Project. A number of ot er modules, more specific to the LLNL computer systems were also used but would not be available to other users. For instance, the input to the first module (PRD) consists of a set of files of zonation descriptions. These files were developed by using the digitization and plotting facilities available at LLNL.

The four modules mentioned above perform the following operations; also schematically represented in Figure 8.1.

1. Given a set of zones discribed by the longitude and latitude of the nodes following their contour, the module named PRD, generates the discrete probability density function of the distances to a given site. At this point the zones can be any type of zones and in particular, they do not necessarily represent a specific seismic zonation map, but they can constitute a portion, or a combination of maps.

2. The module named COMAP uses the output of PRD and the information on the probability of existence of the zones considered in PRD, their probability of having alternative shapes and the identity of the replacing zones, to generate a set of seismic zonation maps, with their respective weights.

3. The module named ALEAS calculates the hazard resulting from the choice of a given seismicity expert but for all ground motion experts. The input to ALEAS consists of the set of maps with their weights given by COMAP, the set of ground motion attenuation models with their weights given by the ground motion experts, and the seismicity parameters associated with each of the seismic zones.

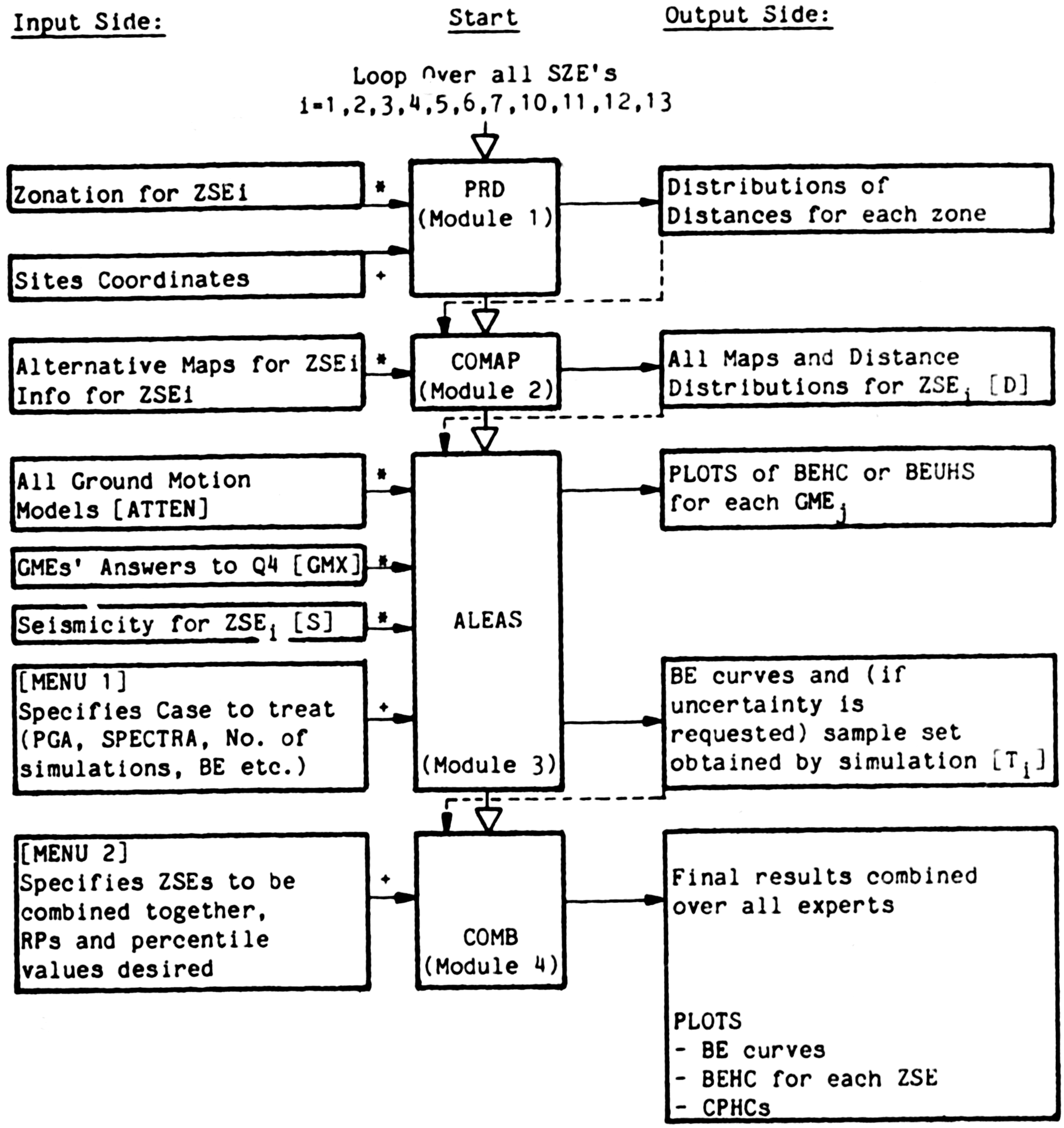
4. The last module called COMB, performs the combination of the hazard results over several seismicity experts. For each seismicity expert, COMB uses the set of weights calculated by ALEAS, as described in Appendix C. The combinations are performed on the Best Estimates and on the constant percentile curves , if desired.

8.2 VALIDATION

8.2.1 GENERAL

The program ALEAS is by far the most complex of the four modules. It is the heart of the hazard calculations. It could be used alone to perform a seismic hazard analysis using the methodology developed in the SHC project. The input to ALEAS could very well be manually developed for simple cases. As a result, this section emphasizes the validation of ALEAS.

Figure 8.1 Chain of Calculations for Computing the hazard at a given site, using the four basic modules.



KEY to Fig. 8.1:

+ = Non Permanent File, Created only For a Specific Run
* = Permanent File of Data, is an integer part of the SHC analysis tool.
BE = Best Estimate
BEHC = Best Estimate Hazard Curve
BEUHS = Best Estimate Uniform Hazard Spectrum
CPHC = Constant Percentile Hazard Curve
GMEj = Ground Motion Expert j
RP = Return Period
ZSE_i = Zonation/Seismicity Expert i
[ ] = File Name

8.2.2 PROGRAM PRD

The validity of this program lies in its ability to calculate properly,

- the distance between two points on the earth

- the area of a zone inside a contour determined by an array of nodal points, at the surface of the earth,and to combine properly set of subzones into a larger zone.

A number of calculations were performed for a variety of seismic zones ranging from simple single zones to more complex cases of zones including subzones and to cases including several zones.

The results for distance and area calculations were checked against results obtained with other independent programs which provide the areas and the distances, and also checked manually for the simple cases. The algorithm of combination of subzones into bigger zones was checked manually.

8.2.3 PROGRAM COMAP

This program generates all the possible combinations of zones and calculates the probability associated with each combination. It is schematically represented by an event tree, in Figure 8.1 in which a branch would represent any of the following event:

- Zone i exists, with probability p_i

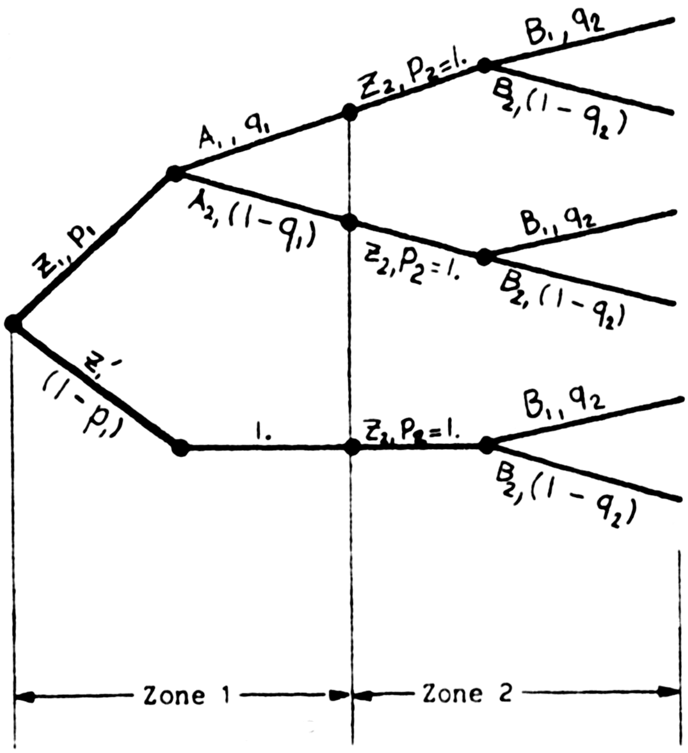
- Zone i does not exist, with probability $(1-p_i)$, in which case it becomes part of zone j.

- The shape of zone i is, say shape A_i, with probability q_i, or

- The shape of zone i is replaced by, shape B_i, with probability $(1 - q_i)$.

This enumeration scheme is performed automatically by the program COMAP. The weight of each combination is calculated and used to sort them in order of decreasing weight. Only the combinations with weight greater or equal to one-hundredth of the highest weight are retained, up to a maximum number of 30 combinations.

The validity of this program was checked manually by comparing with hand calculated solutions of simple cases and of several actual cases in this project.



All Possible Maps	Weights
(A1, B1)	$p_1 q_1 q_2$
(A1, B2)	$p_1 q_1 (1-q_2)$
(A2, B1)	$p_1 (1-q_1) q_2$
(A2. B2)	$p_1 (1-q_1)\ (1-q_2)$
(B1)	$(1-p_1) q_2$
(B2)	$(1-p_1)\ (1-q_2)$

Figure 8.1

Schematic representation of the process of generating all the possible maps, from the input of one zonation/seismicity expert. In this example shown , zone 1 (Z1) exists with probability p_1. When it exists, its shape is either shape A1 with probability, or shape A2 with probability (q_1). Zone 2 (Z2) always exists $(P_2=1)$ and its shape is either B1 or B2 with probability q_2 or $(1-q_2)$. If we assume in this example that p, q and q_2 are greater that .5, then the BEM is made of the zones with shape A1 and B1. Similarly, the other possible maps are (A1,B2)-(A2,B1)-(A2,B2)- (B1) and (B2).

8.2.4 Program ALEAS

8.2.4.1 GENERAL

The program ALEAS performs the seismic hazard analysis calculations described in Appendix C of this report. For a given S-expert, the hazard is calculated for each G-expert. Results for each pair of S-G, of experts are written to a file and the files are combined by the program COMB to produce the final hazard calculations for a single site. In addition, ALEAS combines the results over the G-experts.

This paragraph describes our efforts to verify the correspondence between the mathematics of Appendix C and the calculations performed by the modules ALEAS and COMB.

The general procedure in the validation of a calculation, such as the best estimate hazard curve consisted of four steps:

- o An input "case" of seismicity and attenuation data was created to test a logic path in the code.
- o Intermediate results from the logic path were printed during execution.
- o Intermediate results were hand checked (in the case of operation on a vector usually the first and last elements were verified if elements were logically undistinguishable).
- o Upon finding equality or near equality when roundoff error was present, output from the module or logic path was considered correct in cases logically identical to the verified case.

Many redundant checks were made during the validation process. A collection of 25 cases was run on the CDC 7600 under FTN/LTSS. A description of each case is given below with the specification that conditions unchanged from the immediately prior case are not restated. Inputs and results for each case are summarized in Table 8.1.

8.2.4.2 DESCRIPTION OF CASES RUN FOR THE VALIDATION

1. We began by running a best estimate only case with acceleration the variable of analysis. The best estimate map contained one zone and a single expert provided attenuation input. Numerous intermediate results were verified along with the final calculations of 1) best estimate hazard, 2) percent contribution of zone to hazard, 3) hazard by attenuation expert and 4) seismic weight. Specific intermediate results hand checked included:

   a) Building of various "utility" vectors in the subroutine MISC. (See Section 8.2.4.3) These include magnitude bin endpoints by scale, magnitude bin midpoints by scale, distance bin midpoints and log accelerations.

b) Correspondence of magnitude scale values derived from seismicity expert input as read in the subroutine SEISM. (See Section 8.2.4.3)

c) Correspondence of zone specific seismicity parameters and those used in the hazard calculation. Replacement of seismicity file magnitude values such as those defining the domain of the recurrence relation and upper magnitude cutoff with the index of nearest magnitude bin boundary. This operation is performed by the subroutine GETMAGI. (See Section 8.2.4.3)

d) Correct reading of attenuation expert information.

e) Calculation of the number of occurrences by magnitude when the recurrence relation specified by the seismicity expert has a domain which includes values less than the minimum allowable magnitude and greater than the upper magnitude cutoff specified. This calculation is performed by the subroutine LAMDA. (See Section 8.2.4.3)

f) Value of second sum of expression (C.7) page (C.8) when the attenuation equation is is chosen from the 1st class of models. Calculations are performed by the subroutine SIA. (See section 8.2.4.3)

g) Calculation of complementary hazard, regional complementary hazard for a single zone. Calculations are performed by the subroutine HAZARD. (See Section 8.2.4.3)

2. The seismicity data of case 1 was modified by restricting the domain of the recurrence relation to (4.6 8.24) MMI. This allowed validation of the subroutine SEISM for the example of an occurrence rate less than the value of the magnitude recurrence relation at its lowest magnitude (occurrence rate is assigned value of recurrence relation at that value). Since the upper bound on the recurrence relation was 8.0 and the upper magnitude cutoff was 9.45, we were able to validate the subroutine LAMDA when the recurrence relation must be connected to the upper magnitude cutoff by the LLNL method. Calculations from SIA were validated for an element of the 2nd class of attenuation models. (See Volume II, Appexdix C for discription of classes)

3. The subroutine SEISM was validated for the normal case of an occurrence rate larger than the value of the magnitude recurrence relation at its maximum. The subroutine LAMDA was validated for the case of the magnitude recurrence relation connected to the upper magnitude cutoff by a truncated exponential. Calculations from SIA were validated for an element of the 3rd class of attenuation models. (See Volume II, Appendix C for description of classes)

4. The subroutine LAMDA was validated when the occurrence rate must be connected to the magnitude recurrence relation (in arithmetic space) with a quadratic polynomial. Evaluations from SIA were validated for an element of the 4th class of attenuation models. (See Volume II, Appendix C for description of classes)

5. The subroutine LAMDA was validated for the conditions of case 4 except that the quadratic is forced to be increasing at the occurrence rate magnitude. The routine replaces the quadratic with a straight line. evaluations from SIA were validated for an element of the 5th class of attenuation models. (See Volume II, Appendix C for description of classes)

6. The subroutine SEISM was validated for the case in which a seismicity expert inputs an occurrence rate at a magnitude below that specified in the questionnaire. A quadratic is fit from the point to the beginning of the recurrence relation, yielding a value associated with the specified magnitude.

7. The input of case 6 is modified so that the occurrence rate is given at a magnitude above that specified in the questionnaire but below the domain of validity of the recurrence relation.

8. Case 8 begins a series of three tests of the logic paths executed when a seismicity expert specifies a two piece magnitude recurrence relation for a zone. Here, we validate the subroutine SEISM for coefficient adjustments associated with 2 segments. The subroutine LAMDA is checked for the case where the upper magnitude cutoff falls within the domain of the 2nd segment and the seismicity expert has chosen the LLNL method of connecting the recurrence relation and upper magnitude cutoff.

9. Validated the subroutine LAMDA for a zone with a 2 segment magnitude recurrence relation when the upper magnitude cutoff is beyond the domain of the recurrence relation and seismicity expert has chosen the truncated exponential as the connecting method.

10. The subroutine LAMDA was validated for the case of the upper magnitude cutoff within the domain of the 1st segment of a 2 piece magnitude recurrence relation. With this case we have completed the validation of the best estimate hazard calculation for the variable acceleration, when the best estimate map contains a single zone.

11. For the case of a map containing multiple zones, we verified the correspondence of seismic zone numbers with site dependent zone numbers in the subroutines RDDIS and SORTZ. The condition of duplicate seismic zone numbers within a map was processed correctly. Verified the calculation of hazard (expression C.9 in Appendix C) when the map contains multiple zones. Verified the calculation of complementary hazard (i.e. [1-hazard]) by region in the subroutine HAZARD. Checked calculation of percent contribution of hazard at site attributable to a zone in the subroutine WEIGHT.

12. Validation of the best estimate hazard calculations for the variable acceleration was concluded with the case of 2 ground motion experts and a best estimate map with 4 zones, 2 in region 3, 1 each in regions 1 and 4 and no zones in region 2. Hazard, hazard by ground motion expert, percent contribution by zone and complementary hazard (i.e. [1-hazard]) by region were checked. Calculation of weight for the seismicity expert in the subroutine SEIST was validated.

13. Since the logic paths and basic calculations are nearly independent of the variable of analysis, validation of the best estimate velocity spectra necessitated verification of only a few additional modules. These included:

    a) Building of certain vectors associated with frequency, such as acceleration as a function of frequency.

    b) Insuring the correspondence of the attenuation models selected by the subroutine RDATTN and those chosen by the attenuation expert.

    c) Calculation of the uniform hazard spectra by linear interpolation in the subroutine SPEC.

    d) Calculation of the spectra by least squares when required, performed by the subroutines SPEC and OLSQ.

14. With case 14 we begin validation of the routines associated exclusively with the simulation of the hazard curve. Those modules which do not distingish between the best estimate and simulated parameter cases need not be reverified here.

    Validation of the uncertainty calculations was begun with the case of acceleration the variable of analysis, a single map with positive probability and a single zone in the map. Specific checks include:

    a) Verification of the reading of map indicies and constituent zones by the subroutine RDDIS; normalization map weights by the subroutine SCALE.

    b) Validation of the subroutine TRIMS which receives the mode, 2.5 and 97.5 percentiles of a triangular distribution and returns the lower and upper bounds of that distribution. TRIMS was called with the correct arguments by the subroutine SEISM to obtain values for the distributions of upper magnitude cutoff, occurrence rate and magnitude recurrence parameters. The subroutine RDATEX called TRIMS with proper arguments to obtain distributions on the random variation parameter for the ground motion equations.

    c) Verified calculation of factors associated with the recurrence relation, in the subroutine SEISM, when the seismic expert chose the option of non perfect negative correlation between constant a and slope parameter b. Checked the calculation of the mode of the slope parameter during simulation under this option. This is performed by the subroutine RNSEISM.

d) Validated the subroutine TRIANG which generates a triangular random variate given a uniform (0,1) realization and the endpoints and mode of the triangular distribution.

e) Showed that in the hazard calculation best estimate values were replaced by simulated values for map index, attenuation model index, attenuation model random variation, occurrence rate, magnitude recurrence parameters and upper magnitude cutoff.

15. Validated algorithm to obtain the simulated occurrence rate when expert has chosen nonperfect negative correlation between constant a and slope parameters b of the recurrence relation. Verified final choice of occurrence rate as the maximum of the above and the value of the recurrence relation at its maximum. These calculations are performed in the subroutine LAMDA.

16. Validated algorithms to obtain the simulated occurrence rate and the distribution of the slope parameter when seismicity expert has specified independence between the parameters of the recurrence relation. validated calculation of confidence bounds when there are 2 ground motion experts with unequal weights. Checked calculation of bounds by ground motion expert as performed in subroutine CONFID.

    Showed that the best estimate and simulated accelerations developed in this run of the program ALEAS were written correctly by the subroutine WRTAP to a file, for later use by the program COMB. Verified the distribution on possible maps.

17. Validated algorithms to obtain the simulated occurrence rate and the slope parameter of the recurrence relation when the seismicity expert has selected perfect negative correlation between parameters of the recurrence relation.

18. Verified the simulation of recurrence parameters when the seismicity expert has chosen a two piece relationship for a zone. Calculations are performed in the subroutine RNSEISM.

19. Verified the simulation of recurrence parameters when the seismic expert has chosen a two piece relationship but the realized upper magnitude cutoff lies within the first segment. Checked calculation of the spectra when the specified probability lies <u>above</u> the hazard curve and must be estimated by least squares.

20. Validated calculation of the probability of exceedance from the attenuation equations, when the ground motion expert has chosen the "no truncation" option. (i.e. when a full log normal distribution of the ground motion around its median curve is assumed.)

21. Validated calculation of the probability of exceedance from the attenuation equations, when the ground motion expert has chosen the option of an absolute bound on the ground motion value (i.e. 1g or 2g or .5g ect.). Calculations are performed by subroutines RDATEX and SIA. Verified the effect of the analyst user choosing a magnitude above the minimum for final computation of the hazard curve.

22. Validated calculation of the probability of exceedance from the attenuation equations, when the ground motion expert has chosen the option of a bound by standard deviations. (i.e. when the upper bound of the strong motion value is a certain number of standard deviations above the mean in log-space)

23. Validated calculation of the probability of exceedance from the attenuation equations, when the ground motion expert has chosen the option of the minimum of the absolute bound and bound by standard deviations.

24. Verified calculation of the arithmetic and geometric mean hazard during the uncertainty analysis. Computations are done in the subroutine CONFID.

25. Verified calculation of the arithmetic and geometric mean hazard by frequency and arithmetic and geometric mean hazard by attenuation expert.

8.2.4.3 Description of Subroutines Called by ALEAS

SUBROUTINE	MAJOR TASKS PERFORMED (see Fig. 8.1)
RDIN	Read contents of file MENU 1. Information includes run-dependent quantities such as variable to be analyzed, whether or not simulations are to be performed and certain domain specifications. These include return periods, frequencies, accelerations and uncertainty bounds. Checks on the range of input values are performed and the run is terminated if errors are found.
RDATTN	Read from file ATTEN, the coefficients and model type of attenuation equations associated with the variable to be analayzed.
RDDIS	Read from file D, the number of zones associated with the site being analyzed and the distribution of distances for each zone. Read the correspondence of zone identification number in D to zone identification number in the seismicity file and sort to identify those seismic zones that may be needed for this run. Read number of maps for this site, weight and zone 1 composition of each map. Normalize map weights to insure they sum to 1.
MISC	Calculate miscellaneous quantities for later use by various subroutines. Examples are vectors of magnitude bin end points by Magnitude and Intensity scale, vector of distance bin mid points and vector of the logarithm of accelerations. Initialize various arrays.
SEISM	Read from file S the seismicity data. This includes expert dependent quantities such as regional self weights, relation between m_b and MMI scales, method of recurrence curve adjustment, and method of correlating parameters of recurrence relation during simulation. Read data for those seismic zones needed for the current site. For each zone adjust the occurrence rate if necessary, move magnitude specifications to nearest bin boundary, and adjust recurrence relation parameters if expert has specified a two piece function. If simulations are to be performed, solve for bounds of parameters and calculate certain adjustment factors for later use.
OPATEX	Read from file GMX the number of ground motion experts and the weight assigned to each. Normalize the weights to sum to one.
RDATEX	For the current ground motion expert, read from GMX the best estimate and bounds for random variation of the attenuation equations, as a function of region and magnitude scale. Read index of best estimate attenuation model by region and magnitude scale. If simulations are required read indicies of attenuation models and associated weights, normalize weights for each

region-magnitude scale. Solve for bounds of distributions of random variation parameters. Initialize some arrays. Read index of method of truncation of probability of exceedance.

RNMAPS	Randomly select maps from distribution provided in subroutine RDDIS. If doing the best estimate, select best estimate map.
SORTZ	Order zones in a map by seismic zone number from file S, carrying along index of zone from file D.
ATTPROB	If doing best estimate obtain appropriate random variations and attenuation models. If a simulation, randomly draw from the distributions provided in the subroutine RDATEX. Initialize an array.
RNSEISM	If doing best estimate, obtain appropriate recurrence relation parameters and upper magnitude cutoff. If a simulation, randomly draw upper magnitude cutoff and the intercept(s) of the recurrence relation(s) (if two pieces for considered zone). Obtain slope(s) as specified by seismicity expert. Either 1) randomly draw from the original distribution or 2) modify mode of distribution as a function of realized intercept value, recalculate range of distribution and randomly draw from the new distribution or 3) calculate slopes as a deterministic function of realized intercept. If a simulation and a two piece recurrence relation specified for current zone, modify intercepts and slopes.
LAMDA	Calculate recurrence curve. If necessary connect right most end of recurrence relation to upper magnitude cutoff using method specified by seismicity expert. If a simulation and the recurrence relation does not begin at the minimum magnitude, calculate occurrence rate from simulated recurrence relation and factors generated in subroutine SEISM.
SIA	Calculate the probability of exceeding a specified acceleration (velocity) given an attenuation model, random variation for that attenuation model, distance and a specified earthquake magnitude. Weigh the probability by the distribution of distances and sum over distances; perform the calculations for an array in magnitude across acceleration. If required, truncate probability of exceedance.
HAZARD	Calculate the complementary hazard for the current zone,(i.e. [1.-hazard]) update complementary hazard for current map. If doing best estimate, update complementary hazard by region and store complementary hazard by zone.
WEIGHT	Update ground motion expert weighted 1) contribution of zone to best estimate hazard, 2) complementary best estimate hazard by region and 3) best estimate hazard. Store complementary hazard by ground motion expert.

STOR	Store simulated hazard.
CONFID	Order simulations along with associated ground motion expert weights, then calculate uncertainty bounds on the hazard. Calculate uncertainty bounds by ground motion expert. Calculate arithmetic and geometric means.
SEISWT	Calculate seismic weight(s). Obtain hazard by ground motion expert from complementary hazard.
SPEC	Calculate spectral amplitudes from the best estimate spectra. If simulations have been done obtain arithmetic, geometric means and bounds on the amplitudes from spectral bounds. In general, results are obtained by interpolation, however, when the desired probability is not contained in the interval of generated hazards, least squares estimates are used for extrapolation.
PRIN	Print seismic weight(s), best estimates, percent contribution by zone and best estimates by ground motion expert. If simulations were done, print bounds.
PLOTTER	Plot results.
WRTAP	Write results of current run to a file (T_i file for seismicity expert i) for later use in the routine COMB.

Auxiliary Routine Used By ALEAS

OLSQ	Calculates estimates of the intercept and slope coefficent from an ordinary least squares fit.
GETMAGI	Given a magnitude value, returns the index of the nearest magnitude bin boundary.
SCALE	Normalizes a vector with non-negative elements and at least one positive member to sum to one.
TRIANG	Returns a realization from a triangular distribution given a uniform (0,1) variate and the end points and mode of the triangle.
TRIMS	Solves for the end points of a triangular distribution given the mode and the 2.5 th and 97.5 th percentiles.
AMEAN	Obtains arithmetic mean of elements of a vector.
GMEAN	Obtain geometric mean of elements of a vector.

Routines Used From The IMSL Library Are:

GGDA	Discrete random variate generator
GGNML	Normal distribution function.
GGUBS	Uniform (0,1) pseudo-random number generator.
LEQTIF	Linear equation solver.
MDNOR	Normal distribution function.
VSRTA	Sorting of arrays by algebraic value.
VSRTR	Sorting of arrays by algebraic value-permutations returned.

Definition of variables used in Table 8.1. If appropriate, name of variable or array in program ALEAS is given in parenthesis.

SUBSCRIPTS:

1. s: seismicity expert index
2. q: zone index
3. w: region index
4. u: ground motion expert index
5. k: distance bin index
6. m: magnitude scale index, 1= mb, 2= MMI
7. S: site index
8. v: variable of analysis index, 1= acceleration 2= velocity, 3= velocity spectra
9. l: acceleration or velocity index
10. f: frequency index

VARIABLES NAMED IN APPENDIX C	VARIABLE NAMED IN PROGRAMS
0 INDS: simulation indicator a) best estimate and bounds = 0 b) best estimate only = 1	
1. V: variable of analysis a) acceleration = -1 b) velocity spectra = 1 c) velocity = 0	(IYVAR)
2. IS_s : recurrence curve adjustment indicator a) LLNL method = 0 b) truncated exponential = 1	(INDC)

3. INC_s: index of correlation of magnitude recurrence relation parameters (INDCOR)

a) zero correlation = 0
b) some negative correlation = 1
c) perfect negative correlation = 2

4. W_{sw}: Seismicity expert s' self weight for the w th region (WTREG)

5. MA_s, MB_s: parameters relating the m_b and MMI magnitude scale. The relationship for the s th seismicity expert is given by MMI = MA_s = $MB_s + MB_s \times m_b$

6. $\hat{\lambda o}_{sq}$, $\lambda o_{sq}^{2.5}$, $\lambda o_{sq}^{97.5}$:best estimate, 2.5 and 97.5 percent bounds of occurrence rate. (BLAM)

7. $M_{o_{sq}}$: magnitude at which occurrence rate is given by seismicity expert.

8. IM_{sq}: indicator of magnitude scale in which seismic input is given. (KEYMS)

a) m_b = 1

b) MMI = 2

9. δ_{sq}: regional identifier (KEYREG)

10. $\hat{M}_{rsq}$, $Mu_{sq}^{2.5}$, $Mu_{sq}^{97.5}$: best estimate, 2.5 and 97.5 bounds of upper magnitude cutoff (PROBU)

11. $\hat{a}_{sqi}$, $a_{sqi}^{2.5}$, $a_{sqi}^{97.5}$: best estimate, 2.5 and 97.5 bounds of constant for i th segment of magnitude recurrence relation (B,BL,BU)

12. $\hat{b}_{sqi}$, $b^{2.5}_{sqi}$, $b^{97.5}_{sqi}$: best estimate, 2.5 and 97.5 upper bounds of slope coefficient for segment of magnitude recurrence relation. (B,BL,BU)

13. M_{sqiLB} M_{sqiUB}: magnitude domain of segments of magnitude recurrence relation.
If zone has two segments, then $M_{sq1UB} = M_{sq_{2LB}}$.

14. ICATEG2: Indicator of soil type for site correction method 2.

15. ICATEG3: Indicator of soil type for site correction method 3.

16. IR_s: regional identifier for sites. (IREGSIT)
= 1, 2, 3, or 4

17. $RA_{S_{sq}}$: ratio of area of original to updated zones. (RA)

18. Π_{Ssqk}: distance distribution of zone from site. (PIE)

19. $M_{S_{so}}$, $M_{S_{s1}}$, $M_{S_{s2}}$, $\cdots$, $M_{S_{s29}}$: best estimate and all other possible maps. Each map collection of zones. (MPBYZON)

20. $WT_{S_{s1}}$: probability weight on i th map i = 0,...,29 (WTMAP)

21. W_u: weight assigned to ground motion expert (WTATEX)

22. METBEST Index of the best estimate method of site correction.

23. WMETHOD Array of weights assigned by the ground motion expert to the methods of site correction.

24. MT_{uv}: method of truncation of attenuation equation (METTRC)

a) no truncation = 1
b) absolute bound = 2
c) bound by standard deviations = 3
d) minimum of (b,c) = 4

25. AB_{uv}: absolute bounds when MT_{vu} = 2 (ABBD)
(log AB replacing ABBD)

26. F_{uv}: multiple of standard deviation when MT_{vu} = 3 (FSIG)

27. IG_{uvwmo}: index of best estimate and possible ground motion models. (INDA)

28. $WTAM_{uvwm_1}, \ldots\ldots, WTAM_{uvwm_n}$: probability weight associated with possible ground motion models (ATEXWT)

29. $\hat{\sigma}_{uvw}, \sigma^{2.5}_{uvw}, \sigma^{97.5}_{uvw}$: best estimate, 2.5 and 97.5 bounds of ground motion equation random variation. (ATEXPAR)

30. $\hat{P}_{sl}, P^{.15}_{sl}, P^{.85}_{sl}$: best estimate, 15th and 85th percentile hazard as a function of ground motion parameter. (WPROD)

31. $\hat{P}_{sfl}, P^{.15}_{sfl}, P^{.85}_{sfl}$: best estimate hazard as a function of ground motion parameter. (WPROD)

32. a_l: acceleration array (ACCA)

33. a_{e_f}: spectral velocity arrays as a function of frequency (ACCA)

34. d_i: distance bin midpoints (ADIS)

35. m_{1i}: magnitude bin start points, m_b scale (AMAG)

36. m_{2i}: magnitude bin start point, MMI scale (AMAG)

37. m_{p1i}: midpoints magnitude bins, m_b scale (AMAGPH)

38. m_{p2i}: midpoints magnitude bins, MMI scale (AMAGPH)

39. $\hat{P}_{sul}$, $P^{.15}_{sul}$, $P^{.85}_{sul}$: best estimate, 15 th and 85th percentile hazard as a function of attenuation expert (PROD & SAVBD)

40. W_s: seismic weight when variable of analysis is acceleration or velocity. (WTSEISM)

41. W_{sf}: seismic weight when variable of analysis is velocity spectra (WTSEISM)

42. γ_{slq} : percent contribution to hazard by zone for first acceleration (weighted WGW)

43. STM_1: lowest magnitude in m_b scale included in final calculation of hazard (STMAG)

44. STM_2: lowest magnitude in MMI scale included in final calculation of hazard (STMAG)

45. $\hat{P}_{suql}$: best estimate hazard by seismic expert, by ground motion expert, by zone, for 1st acceleration (PROD)

46. λ^L_{osq}, λ^U_{osq}: domain of distribution of λ_{osq}

47. M^L_{Usq}, M^U_{Usq}: domain of distribution of M_{Usq}

48. a^L_{sqi}, a^U_{sqi}: domain of distribution of a_{sqi}

49. b^L_{sqi}, b^U_{sqi} : domain of distribution of b_{sqi}

50. σ^L_{uvw}, σ^U_{uvw} : domain of distribution of σ_{uvw}

51. P^{AM}_{sl} : arithmetic mean hazard (WPROD)

P^{AM}_{sfl} : arithmetic mean hazard by frequency (WPROD)

52. P^{GM}_{sl} : geometric mean hazard (WPROD)

P^{GM}_{sfl} : geometric mean hazard by frequency (WPROD)

8.2.5 Program COMB

A set of three cases were run on the CDC/600 under FTN/LTSS. COMB is a very short code, much of which duplicates routines in ALEAS.

8.2.5.1 Description of Case Run To Validate COMB

1. With velocity spectra the variable of analysis, a case with two seismicity experts, three ground motion experts per seismicity expert and one simulation per ground motion expert was run.

   Checks performed include:

   a. Verifed that input from files written by ALEAS were read correctly by the subroutine RDSEIS.

   b. Validated calculation of best estimate hazard in subroutine RDSEIS.

   c. Validated calculation of bounds on hazard in the subroutine CONFID.

   d. Verified calculation of the uniform hazard spectra by means of interpolation and by least squares when required value is above the hazard curve. Calculations were performed by subroutines SPEC and OLSQ.

2. Validated calculation of uniform hazard curve, by hand calculations.

3. Verified calculation of the arithmetic and geometric mean velocity spectra, by hand calculations.

8.2.5.2 Description of Subroutines Called By COMB

SUBROUTINE	MAJOR TASK PERFORMED
RDIN	Read contents of input files. Information includes run-dependent quantities such as number of seismicity experts, return periods, uncertainty bounds and the indicies of seismicity experts.
INITIAL	Initialize some values.
RDSEIS	Read from files written by ALEAS for each seismicity experts results for this site. Normalizes seismic weights, renormalizes attenuation weights (weights may not sum to 1, because of roundoff error). Calculate best estimate, arithmetic mean and geometric mean hazard.
CONFID	Order simulations from all seismicity ground motion expert combinations using the subroutine VSRTR. Calculate uncertainty bounds.

SPEC	Calculate spectral amplitudes from the best estimate spectra. If doing uncertainty analysis, obtain arithmetic and geometric means and bounds on the amplitudes from spectral bounds. In general, results are obtained by interpolation, however, when the desired probability is not contained in the interval of generated hazards, least squares estimates are used for extrapolation.
PRIN	Print results.
PLOTTER	Plot results

Auxiliary Routines Used By COMB

OLSQ	Calculate estimates of the intercept and slope coefficient from an ordinary least squares fit.
SCALE	Normalizes vector with nonnegative elements and at least one positive member to sum to one.
VSRTR	Sorts arrays by algebraic value-permutations returned (IMSL).

TABLE 8.1

Summary of Test Cases run in the validation of routine ALEAS.

Blanks indiciate variable is not referenced in the current cases or not relevant to logic tested. For maps with multiple zones, zone hazard rather than individual seismicity parameters are reported.

VARIABLE/CASE	1	2	3	4	5	6	7	8
INDS	1	1	1	1	1	1	1	1
V	-1	-1	-1	-1	-1-	-1	-1	-1
IS_s	0	0	1	1	1	1	1	0
INC_s								
W_{sw}	1	1	1	1	1	1	1	5
MA_s, MB_s	-4,2	-4,2	-4,2	-4,2	-4,2	-4,2	-4,2	-3.5,2
$\dot{\lambda}_{osq}$	1.9	9.5	9.6	9.6	9.6	9.6	9.6	9.4
$\lambda^{2.5}_{osq}, \lambda^{97.5}_{osq}$								
M_{osq}	4.0	4.0	4.0	4.0	4.0	3.25	4.95	3.75
IM_{sq}	2	2	2	2	2	2	2	1
δ_{sq}	1	1	1	1	1	1	1	3
$\dot{M}_{usq}$	9.45	9.45	9.45	9.45	9.45	9.45	9.45	6.0
$M^{2.5}_{usq}, M^{97.5}_{usq}$								
$\dot{a}_{sq1}$	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.1447
$a^{2.5}_{sq1}, a^{97.5}_{sq1}$								
$\dot{a}_{sq2}$								5.4647
$a^{2.5}_{sq2}, a^{97.5}_{sq2}$								
$\dot{b}_{sq1}$	-.6	-.6	-.6	-.6	-.6	-.6	-.6	-.85
$b^{2.5}_{sq1}, b^{97.5}_{sq1}$								
$\dot{b}_{sq2}$								-1.31
$b^{2.5}_{sq2}, b^{97.5}_{sq2}$								
M_{sq1LB}, M_{sq2uB}	3.0,9.65	4.6,8.24	4.6,8.24	5.6,8.24	5.6,8.24	5.6,8.24	5.6,8.24	3.5,5.04
M_{sq2LB}, M_{sq2uB}								5.04,6.5
ICATEG2	1	1	1	1	1	1	1	1
ICATEG3	1	1	1	1	1	1	1	1

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is not reference in the current case.

VARIABLE/CASE	9	10	11	12	13	14	
INDS	1	1	1	1	1	0	
V	-1	-1	-1	-1	1	-1	
IS_s	1	1	1	1	1	1	
INC_s						1	
W_{sw}	5.	5.	1.,4.,6.9.	1.,4.,6.,9.		1.	
MA_s, MB_s	-3.5,2.	-3.5,3.	-3.5,2.	-3.5,2.		-3.5,2	
$\hat{\lambda}_{osq}$	9.4	9.4				.5	
$\lambda_{osq}^{2.5}, \lambda_{osq}^{97.5}$						.417,.625	
M_{osq}	3.75	3.75				3.75	
IM_{sq}	1	1				1	
δ_{sq}	3	3	4,3,1,3,2,2	4,3,1,3		2	
$\hat{Mu}_{sq}$	6.95	4.25				6.25	
$Mu_{sq}^{2.5}, Mu_{sq}^{97.5}$						6.00,6.50	
$\hat{a}_{sq1}$	3.1447	3.1447				3.22861	
$a_{sq1}^{2.5}, a_{sq1}^{97.5}$						2.98861,3.47861	
$\hat{a}_{sq2}$	5.4647	5.4647					
$a_{sq2}^{2.5}, a_{sq2}^{97.5}$							
$\hat{b}_{sq1}$	-.85	-.85				-.911	
$b_{sq1}^{2.5}, b_{sq1}^{97.5}$						-.929,-.892	
$\hat{b}_{sq2}$	-1.31	-1.31					
$b_{sq2}^{2.5}, b_{sq2}^{97.5}$							
M_{sq1LB}, M_{sq2uB}	3.5, 5.04		3.5, 5.04				4.0,5.5
M_{sq2LB}, M_{sq2uB}	5.04, 6.5		5.04, 6.5				
ICATEG2	1	1	1	1	1	1	
ICATEG3	1	1	1	1	1	1	

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is not reference in the current case.

VARIABLE/CASE	15	16	17	18	19
INDS	0	0	0	0	0
V	-1	-1	-1	-1	1
IS_s	1	0	0	1	
INC_s	1	0	2	1	
W_{sw}					
MA_s, MB_s	-3.5, 2.	-3.5, 2.	-3.5, 2.		
$\hat{\lambda}_{osq}$	.5	Multiple Zones	2.5		
$\lambda^{2.5}_{osq}$, $\lambda^{97.5}_{osq}$	.417, .625		1.818, 2.857		
M_{osq}	3.75		3.75		
IM_{sq}	1		1	1	1
δ_{sq}	2		2	2	1
$\hat{Mu}_{sq}$	6.25		6.5		
$Mu^{2.5}_{sq}$, $Mu^{97.5}_{sq}$	6.00, 6.50		6.0, 7.0		
$\hat{a}_{sq1}$	3.22861		4.1669	3.08	
$a^{2.5}_{sq1}$, $a^{97.5}_{sq1}$	2.98861, 3.47861		2.9469, 5.3869	1.826, 4.402	
$\hat{a}_{sq2}$				5.747	
$a^{2.5}_{sq2}$, $a^{97.5}_{sq2}$					
$\hat{b}_{sq1}$	-.911		-1.06		
$b^{2.5}_{sq1}$, $b^{97.5}_{sq1}$	-.929, -.892		-1.226, -.901		
$\hat{b}_{sq2}$					
$b^{2.5}_{sq2}$, $b^{97.5}_{sq2}$					
M_{sq1LB}, M_{sq2uB}	4.0, 5.5		4.0, 6.0	3.5, 4.79	3.5, 5.04
M_{sq2LB}, M_{sq2uB}				4.79, 6.0	5.04, 6.5
ICATEG2	1		1		

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routi.e ALEAS.

Blanks indicate variable is <u>not</u> referehce in the current case.

VARIABLE/CASE	20	21	22	23	24		25
INDS	1	1	1	1	1	0	
V	-1	-1	-1	-1	-1		1
IS_s	1						
INC_s							
W_{sw}							
MA_s, MB_s							
$\hat{\lambda}_{osq}$							
$\lambda_{osq}^{2.5}$, $\lambda_{osq}^{97.5}$							
M_{osq}							
IM_{sq}							
δ_{sq}							
$\hat{Mu}_{sq}$							
$Mu_{sq}^{2.5}$, $Mu_{sq}^{97.5}$							
$\hat{a}_{sq1}$							
$a_{sq1}^{2.5}$, $a_{sq1}^{97.5}$							
$\hat{a}_{sq2}$							
$a_{sq2}^{2.5}$, $a_{sq2}^{97.5}$							
$\hat{b}_{sq1}$							
$b_{sq1}^{2.5}$, $b_{sq1}^{97.5}$							
$\hat{b}_{sq2}$							
$b_{sq2}^{2.5}$, $b_{sq2}^{97.5}$							
M_{sq1LB}, M_{sq2uB}							
M_{sq2LB}, M_{sq2uB}							
ICATEG2							
ICATEG3							

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is <u>not</u> reference in the current case.

VARIABLE/CASE	1	2	3	4	5	6	7	8	9	10	11	12	13
IR_s	*	*	*	*	*	*	*	*	*	*	*	*	*
RA_{ssq}	1	1	1	1	1	1	1	1	1	1	1	1	
Π_{ssq17}	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5			.5
Π_{ssq18}	.4	.4	.4	.4	.4	.4	.4	.4	.4	.4			.4
M_{sso}	1	1	1	1	1	1	1	1	1	1	20,23,32 33,33,34	20,23 32,33	2
WT_{ss1}													
WT_{ss2}													
Wu	1	1	1	1	1	1	1	1	1	1	1	.8,.2	.8,.2
METBEST	*	*	*	*	*	*	*	*	*	*	*	*	*
WMETHOD	*	*	*	*	*	*	*	*	*	*	*	*	*
MT_{uv}	*	*	*	*	*	*	*	*	*	*	*	*	*
AB_{uv}	*	*	*	*	*	*	*	*	*	*	*	*	*
F_{uv}	*	*	*	*	*	*	*	*	*	*	*	*	*
IG_{uvmo}	1	2	3	4	5	5	5	5	5	5			
STM1, STM2	*	*	*	*	*	*	*	*	*	*	*	*	

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is <u>not</u> reference in the current case.

VARIABLE/CASE	14	15	16	17	18	19	20	21	22
IR_s	*	*	*	*	*	*	*	*	*
RA_{ssq}	1	1	1	1	1	1	1	1	1
Π_{ssq17}	Multiple Non Zero Entries	Multiple Non Zero Entries		Multiple Non Zero Entries					
Π_{ssq18}									
M_{sso}	28	28		27	9	2			
WT_{ss1}	0.0	0.0							
WT_{ss2}	1.0	1.0							
Wu	1.0	1.0							
METBEST	*	*					1	2	3
WMETHOD	*	*							
MT_{uv}	*	*					1	2	3
AB_{uv}	*	*						90.0	
F_{uv}	*	*							1.3
IG_{uvmo}	6 (type 4)	6 (type 4)							
STm, STm2	*	*				3.75 4.0	4.0 4.5		

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is <u>not</u> reference in the current case.

VARIABLE/CASE	23	24	25
IR_s	*	*	*
RA_{ssq}	1	1	1
Π_{ssq17}			
Π_{ssq18}			
M_{sso}			
WT_{ss1}			
WT_{ss2}			
Wu		.571429 .428571	.571429 .428571
METBEST	4		
WMETHOD			
MT_{uv}	4		
AB_{uv}	90.		
F_{uv}	2.3		
IG_{uvmo}			

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is <u>not</u> reference in the current case.

VARIABLE/CASE	1	2	3	4	5	6	7	8
$WTAM_{uvml}$								
$\hat{\sigma}_{uvw}$	.5	.5	.5	.5	.5	.5	.5 .7	
$\sigma^{2.5}_{uvw}, \sigma^{97.5}_{uvw}$								
$\hat{P}_{s1}$	.5614E-05	.1247E-10	.1350E-12	.7448E-10	.7440E-06	.7440E-06	.7440E-06	.3798E-06
$\hat{P}_{s2}$	.4577E-08			.7105E-14	.3729E-09	.3729E-09	.3729E-09	.1579E-08
$\hat{P}_{s11}$	.5614E-05	.1247E-10	.1350E-12	.7448E-10	.7440E-06	.7440E-06	.7440E-06	.3798E-06
W_s	1.	1.	1.	1.	1.	1.	1. 5.	
γ_{s1q}	1.	1.	1.	1.	1.	1.	1. 1.	
$\hat{P}_{s1q1}$	.5614E-05	.1247E-10	.1350E-12	.7448E-10	.7440E-06	.7440E-06	.7440E-06	.3798E-06
$\hat{P}_{s2q1}$								

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is not reference in the current case.

VARIABLE/CASE	9	10	11	12
$WTAM_{uvml}$				
$\hat{\sigma}_{uvw}$	$^{-7}$	$^{-7}$		
$\sigma_{uvw}^{2.5}, \sigma_{uvw}^{97.5}$				
$\hat{P}_{s1}$	.2439E-05	.7840E-10	.4083E-03	.1938E-03
$\hat{P}_{s2}$	.4280E-07	.3553E-13	.5955E-04	.2095E-04
$\hat{P}_{s11}$	.2439E-05	.7840E-10	.4083E-03	.2377E-03
W_s	5.	5.	2.449	1.336
γ_{s1q}	1	1	.1659E-06, .4238E-05 .5430E-00, .3902E-01 .3085E-01, .3872E-00	.2496E-06, .5826E-05 .9305E-00, .6951E-01
$\hat{P}_{s1q1}$	.2439E-05	.7840E-10	.0677E-10, .1721E-08 .2217E-03, .1593E-04	.6774E-10, .1730E-08 .2217E-03, .15932E-04
$\hat{P}_{s2q1}$			.1260E-04, .1581E-03	.2010E-11, .1066E-12 .1713E-04, .1477E-05

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is <u>not</u> reference in the current case.

VARIABLE/CASE	13	14	15	16	17	18	19	20	21	22	23	24	25
$WTAM_{uvml}$		0,0,0,0	0,0,0,0										
$-WTAM_{uvwm7}$		.25,0.0,0.0	1.25,0.0,0.0										
$\hat{\sigma}_{uvw}$		.6	.6										
$\sigma^{2.5}_{uvw}, \sigma^{97.5}_{uvw}$		.45,.75	.45,.75										
$\hat{P}_{s1}$													
$\hat{P}_{s2}$													
$\hat{P}_{s11}$													
W_s													
γ_{s1q}													
$\hat{P}_{s1q1}$													
$\hat{P}_{s2q1}$													

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is <u>not</u> reference in the current case.

VARIABLE/CASE	1-13	14	15	16	17
λ^L_{osq}, λ^U_{osq}		.3899, .6575	.3899, .6575		
M^L_{Usq}, M^U_{Usq}		5.928, 6.572	5.928, 6.572		
a^L_{sq1}, a^U_{sq1}		2.919, 3.550	.2919, 3.550		2.596, 5.738
a^L_{sq2}, a^U_{sq2}					
b^L_{sq1}, b^U_{sq1}		-.9290, -.8920	-.9290, -8920		-1.269, -.8507
b^L_{sq2}, b^U_{sq2}					
σ^L_{uvw}, σ^U_{uvw}		.4068, .7932	.4068, .7938		

BELOW ARE SIMULATED PARAMETERS	SIMULATION NUMBER 1	2	1	2	1
λ	.4329	.5187	.7025	.4447	2.518
M_U	6.25	6.25	6.5	6.5	
a_1	3.075	3.293	3.460	3.109	4.357
a_2					
b_1	-.9095	-.9148	-.9034	-.9297	-1.0854
b2					
σ	.5229	.5982	.5684	.6257	
IAM	6(4)	6(4)	6(4)	6(4)	
P at 1st accel.	.3640E-02	.6434E-02	.4469E-02	.1074E-01	
P .15	.1092E-02		NA (Not Available)		
P .50	.3640E-02		NA		
P. 85	.5596E-02		NA		

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is not reference in the current case.

VARIABLE/CASE	18	19
$\lambda^L_{osq}, \lambda^u_{osq}$		
M^L_{Usq}, M^U_{Usq}		
a^L_{sq1}, a^U_{sq1}	1.826, 4.402	
a^L_{sq2}, a^U_{sq2}	4.503, 7.079	
b^L_{sq1}, b^U_{sq1}		
b^L_{sq2}, b^U_{sq2}		
$\sigma^L_{uvw}, \sigma^U_{uvw}$		

SIMULATION

	Before Adjustment	After Adjustment	
λ			
M_U			4.75
a1	3.2909	3.2453	
a_2	5.5734	5.5151	
b1	-.902755	-.8906	
b_2	-1.3781	-1.3684	
σ			
IAM			
P at 1st accel.			
P.15			
P.50			
P.85			

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is <u>not</u> reference in the current case.

Variable/Case	20	21	22	23	24	25	
λ^L_{osq}, λ^U_{osq}							
M^L_{Usq}, M^U_{Usq}							
a^L_{sq1}, a^U_{sq1}							
a^L_{sq2}, a^U_{sq2}							
b^L_{sq1}, b^U_{sq1}							
b^L_{sq2} b^U_{sq2}							
σ^L_{uvw}, σ^U_{uvw}							
λ							
M_U							
$a1$							
a_2							
$b1$							
b_2							
σ			2 simulations for 2 attentuation experts			2 simulations for 2 attentuation experts last frequences	
IAM							
P at 1st accel.			.286013E-06 (Exp.1) .746299E-05 (Exp.1)			.334310E-10 .107253E-05	
P.15			.157888E-02 (Exp.2) .24849E-02 (Exp.2)			.710543E-14 .190689E-08	
P.50							
P.85							
P.AM			.8730E-03				
P.GM			.3214E-04				
$P_{9,10}{}^{AM}$							.3069E-06
$P_{9,10}{}^{GM}$							.2518E-09

TABLE 8.1 (Cont.)

Summary Of Test Cases Run In The Validation Of Routine ALEAS.

Blanks indicate variable is <u>not</u> reference in the current case.

VARIABLE INDEX	d_i	m_{1i}	M_{2i}	m_{p1i}	m_{p2i}	a_i
1	2.55	3.75	4.0	3.875	4.25	80
2	7.5	4.00	4.5	4.125	4.75	180
3	12.5	4.25	5.0	4.375	5.25	280
4	20.0	4.50	5.5	4.625	5.75	380
5	30.0	4.75	6.0	4.875	6.25	480
6	42.5	5.00	6.5	5.125	6.75	580
7	62.5	5.25	7.0	5.375	7.25	680
8	87.5	5.50	7.5	5.625	7.75	780
9	112.5	5.75	8.0	5.875	8.25	880
10	137.5	6.00	8.5	6.125	8.75	980
11	175.0	6.25	9.0	6.375	9.25	
12	225.0	6.50	9.5	6.625	9.75	
13	350.0	6.75	10.0	6.875	10.25	
14	450.0	7.00	10.5	7.125	10.75	
15	600.0	7.25	11.0	7.375	11.25	
16	800.0	7.50	11.5	7.625	11.75	
17	1075.0	7.75	12.0	7.875	12.25	
18	1425.0	8.00	12.5	8.125	12.75	
19		8.25		8.375		
20		8.50		8.625		
21		8.75		8.875		
22		9.00		9.125		
23		9.25		9.375		

TABLE 8.2

Attenuation Models Used in the Validation of ALEAS

Note, the variable $smp_{s2\delta}$ is the value of mb given $mp_{2\delta}$ and the coefficients MA_s , MB_s. The variable $smp_{s1\delta}$ is the values of MMI given $mp_{1\delta}$ and the same coefficients. These are models hand checked. Models may vary over the magnitude range due to switching.

ACCELERATION MODELS

1. $\text{Log } a_e = 2.43 + .58\ mp_{2\delta} - .00064 d_i - .68 \log d_i$

2. $\text{Log } a_e = 1.47 + 1.1\ smp_{2\delta} - .0017 d_i - .88 \log d_i$

3. $\text{Log } a_e = 1.34 + 1.5\ smp_{2\delta} - .00281\ d_i$

   $- .417 \log \left(d_i^2 + e^{(2.1\ smp2\delta\ -7.96)} \right)$

4. $\text{Log } a_e = 2.839 + .7925\ smp_{2\delta} - .002\ d_i$

   $-.797 \log \left(d_i + .012\ e^{(.916\ smp2\delta\ +.2696)}\right)$

5. $\text{Log } a_e = 1.47 + 1.2\ smp_{2\delta} - 1.02 \log d_i$