Enclosure B

INTERIM SEISMIC DESIGN BASIS

FOR

YANKEE NUCLEAR POWER STATION

ROWE, MASSACHUSETTS

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By

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1.0 INTRODUCTION AND SUMMARY

Topic II-4 of the NRC's Systematic Evaluation Program is a review of the geology and seismology of the Yankee Rowe Site. The NRC, in its letter of January 15, 1979 to Yankee Atomic Electric Company, stated the necessity for Yankee to assess the seismic design criteria for the Yankee Rowe Site. The NRC noted that, "Evaluation of various site-specific response spectra methodologies may demonstrate a more realistic approach in determining seismic input". Yankee has undertaken an extensive program to determine the Site-Dependent Response Spectra for the Rowe Site.

This paper summarizes the results of Yankee's program to develop Site-Specific Seismic Response Spectra leading to selection of a conservative Interim Seismic Design basis for the Yankee plant.

The following conclusions and summary statements apply to Yankee's seismic response spectra:

1. The Interim Seismic Design Basis Spectrum (see Figure 1) was developed in accordance with the methodology of Appendix A, 10CFR100.

2. The Interim Design Basis Spectrum has a median exceedance probability of less than 10^{-3} per year.

3. The proposed Interim Design Basis is considered adequately conservative for an interim evaluation of the Rowe plant because:

   a. The historical seismicity in the Rowe region is characterized by very infrequent earthquakes of low intensity.

b. The proposed Interim Seismic Design Basis Spectrum falls above the mean of the real site-specific data set for all periods and is above the 84th percentile of the real data set for periods above 0.9 seconds (see Figure 3).

c. The proposed spectrum (developed from real data) has been scaled up to a peak ground acceleration of .1g and has been modified for conservatism to maintain a constant peak velocity for periods of 0.4 seconds and above (see Figure 1).

d. The peak ground acceleration (Figure 4) of .1g is more than three times greater than the calculated historical maximum peak acceleration for over 250 years of record in the Rowe area.

e. The proposed spectrum adequately incorporates site amplification.

f. The proposed Yankee response spectrum has a return period on the order of 1,000 years. Over the two year interim period, the chance of not observing this event is 99.8%. Conversely, the chance of observing the 1,000 year event over the next two years is 0.2%, which is less than that implicitly accepted by the NRC in recent licensing decisions.

2.0 BACKGROUND

The Yankee Rowe facility is located in the town of Rowe, Franklin County, Massachusetts, on the east side of the Deerfield River, three-quarters of a mile south of the Vermont-Massachusetts border. Most of the land in the immediate vicinity of the site is heavily forested, including parts of state and national forests. The only community with a population of more than 2,500 within 16 km is North Adams, Massachusetts, located about 14 km to the west-southwest; Pittsfield, Massachusetts, which lies 34 km to the southwest, is the closest city or town with a population of greater than 25,000.

Geologically, the site is located in the Green Mountain Section of the New England Physiographic Province (Reference 1). Tecton. ally, the site is located on the east flank of the Berkshire - Green Mountain anticlinorium in the central axial zone of the Western New England Foldbelt (Reference 1). The historical seismicity in this tectonic province is of very low frequency and intensity. Figure 2 shows Yankee Rowe in relation to historical earthquake epicenters demonstrating the low historical seismicity of the Yankee Rowe site region. For the province, the largest earthquake not associated with geologic structure is an intensity V. The largest earthquake in the province is an intensity VI, m_b=4.8 event, which occurred in Woburn, Quebec, approximately 338 km north-northeast of Rowe. It is believed that this earthquake is associated with the mafic intrusive-fault complex near M.gantic, Quebec.

Peak horizontal ground motion at the Rowe site, based upon historic seismic activity (more than 250 years), has been determined using the conservative relationship of Nuttli and Herrmann (1978). Figure 4 is a plot of the calculated horizontal ground accelerations that would have been felt at the Rowe Site. As shown, the maximum historical acceleration was calculated to be .029g. The earthquake that generated this computed maximum acceleration is the 1755 Cape Ann event located 214 km from the Rowe site.

3.0 SITE SPECIFIC RESPONSE SPECTRUM

This section describes the development and characteristics of the Site-Specific Seismic Response Spectrum for the Yankee Nuclear Power Plant. It is emphasized that the Interim Design Basis Spectrum is more severe than this Site-Specific Spectrum.

The Site-Specific Response Spectrum for the Yankee Site was developed using actual recorded accelerogram data from earthquakes which approximate the magnitude, hypocentral distance, and the site foundation conditions of the controlling earthquake. This approach, which is in accordance with 10CFR100, Appendix A, is "site-specific" and avoids many of the problems inherent with determining ground motion by scaling event size or epicentral distance. From recent seismological studies, it is known that the shape of the response spectrum is dependent on earthquake size, recording distance and the associated frequency-dependent attenuation effects. The proper selection of accelerograms which are used to construct the response spectra avoids the errors resulting from scaling.

3.1 Geology and Seismology

The seismic evaluation for Yankee Rowe prepared by Weston Geophysical was submitted to the NRC on February 23, 1979(1). This report entitled, "Geology and Seismology, Yankee Rowe Nuclear Power Plant", considered the seismicity within the site tectonic province, as well as adjacent tectonic provinces and structures to reach the conclusion, "that an Intensity VI(MM) is an appropriately conservative estimate of the Safe Shutdown Earthquake". The Safe Shutdown Earthquake is best characterized by a magnitude of 4.5 in the report entitled "Eastern United States Tectonic Structures and Provinces

Significant to the Selection of a Safe Shutdown Earthquake" prepared by Weston Geophysical for the SEP Owner's Group and submitted to the NRC on October 16, 1979[2].

The occurrence of larger earthquakes at greater epicentral distances was also considered in the seismicity evaluation of the Rowe site. The magnitude of maximum historical activity located in the adjacent provinces (Ossipee, 1940; Cape Ann, 1755) are estimated to be near 5.5.

On the basis of the historical activity, the ground motion potential is conservatively estimated to be 4.8 in the site province and 5.7 in the White Mountain series. This is a conservative representation of the maximum historical events migrated throughout their respective provinces and is consistent with 10CFR100 Appendix A.

3.2 Site-Dependent Response Spectra

The report, "Site-Dependent Response Spectra - Yankee Rowe" prepared by Weston Geophysical and Dr. Erik Vanmarcke,[3] was transmitted to the NRC on February 29, 1980. That report describes the methods and results of a program to develop site dependent response spectra.

The following are the ranges of magnitudes and distances for the two categories of events that were conservatively defined to represent the ground motion potential.

Province	Magnitude Range (m_b)	Epicentral Distance Range (km)
Site	4.5-5.4	2-33
Distant	5.4-6.0	50-85

Geological investigations of the site locale show that the Yankee plant is situated on glacial sediments in the lower elevation of a broad bedrock valley with the bedrock surface beneath the site dipping at 30° to 50° to the southeast. Seismic refraction surveys and test borings have identified the glacial deposits as very dense till. In situ velocity measurements,[4] transmitted to the NRC on April 5, 1979, have determined that the 70 to 140 feet of glacial till beneath the site has a compressional wave velocity of 6,700 to 7,000 ft/sec and a shear wave velocity of 1,700 to 2,200 ft/sec (equivalent to many sedimentary bedrock types).

Using the seismicity and site conditions defined above, the worldwide strong motion data base was searched for accelerograms produced by earthquakes within the appropriate magnitude and epicentral distance ranges and recorded at sites whose geologic setting and/or foundation conditions (based on shear wave velocity data, if available) resemble those at Rowe. The selected accelerograms were corrected for instrument response in accordance with state-of-the-art procedures Response spectra were then computed for each available component.

The data selected to represent the earthquake in the site province included 62 horizontal components (17 earthquakes). The earthquake magnitudes ranged from 4.5 to 5.4 (mean magnitude 4.8), and the epicentral distances ranged from 1.7 to 33.2 kilometers (mean epicentral distance 15.0 km). The selected accelerogram data set included 22 recordings from California (12 from 1975 Oroville earthquake sequence) and 40 recordings from the 1976 Friuli, Italy earthquake sequence.

For the distant earthquake eight (8) components (three earthquakes) met the seismicity-distance criteria. These accelerograms, all from California earthquakes, have a magnitude range of 5.4 to 6.0 (mean magnitude 5.7) and an epicentral distance range of 53 to 85 km (mean epicentral distance 69 km). The shorter epicentral distances in the selected data set account for the slower attenuation for eastern United States earthquakes.

The seismic design response spectrum recommended for the Rowe site, was obtained by enveloping the mean spectra derived for the site province and for distance sources. The spectrum developed for a seismic event within the site province, governs at periods less than .5 seconds while the spectrum developed for a distant seismic event outside the site province governs at periods greater than .5 seconds. The mean and 84th percentile envelope of these spectra are shown in Figure 3.

3.3 Conclusion and Proposed Spectrum

The aforementioned studies indicate that a site-dependent response spectrum with peak ground acceleration of 0.06g to 0.07g is conservative for the Rowe site. This peak ground acceleration is twice as large as the maximum calculated historical value based on more than 250 years of record.

To arrive at an Interim Design Basis Spectrum, the Site-Specific Response Spectrum has been scaled up to a peak ground acceleration of 0.1g and its shape has been modified to maintain a constant peak velocity above a period of 0.4 seconds. This is consistent with Appendix A of 10CFR100 which assumes a peak ground acceleration of 0.1g. Figure 1 shows Yankee's Interim Design Basis Response Spectrum.

It should be noted, that the Interim Design Basis Spectrum has a peak ground acceleration (0.1g) more than three times higher than the maximum calculated historical value based on over 250 years of record. Furthermore, the proposed spectrum is well above the mean of representative real data at all points and exceeds the median plus one standard deviation (84th percentile) of representative real data at periods above 0.9 seconds.

4.0 PROBABILISTIC ANALYSIS OF SEISMIC HAZARD

Yankee has performed a probabilistic analysis to estimate the peak ground acceleration and uniform hazard spectra for different return periods at the Yankee Rowe site.

The probabilistic approach utilized is basically that developed by Cornell[5], and further developed by McGuire[6]. This method allows for the utilization of geologic, seismologic, geophysical and historic information. It also accounts for uncertainty in the attenuation models.

Input parameters to the Cornell/McGuire program are:

1. Source area geometry (provinces)
2. Seismicity of each source area
3. Upper magnitude cutoff (upper bound) for each source area
4. Attenuation model
5. Measure of uncertainty (σ).

The source area geometries (tectonic provinces and structures), Figure 2, were determined by Weston Geophysical Corporation in their August 1979 report[2]. Figure 5 is the actual source area geometry used in this analysis. These areas were defined by:

1. Geologic interpretation

2. Regional and local geophysical data; i.e., gravity, aeromagnetic, seismic

3. Historical and recent seismic activity.

For the purpose of this analysis, the seismicity and upper magnitude cutoff for each source area were determined by Weston Geophysical. Mean annual recurrence rates were computed by Weston, using only segments of the earthquake catalog assumed to be complete on the basis of known population distribution in time. Table 1 presents the input seismicity parameters including recurrence rates and upper bounds for all 13 source areas.

TABLE 1

SOURCE AREA SEISMICITY

Province or Source Area	Lower Bound	Upper Bound	Beta	Rate/yr.
1	3.50	6.00	2.35	.741
2	3.50	5.30	2.60	.121
3	3.50	5.30	2.53	.156
4	3.50	5.50	2.56	.610
5	3.50	5.30	2.30	.377
6	3.50	5.50	2.30	.291
7	3.50	6.50	2.12	.724
8	3.50	7.50	1.50	.624
9	3.50	6.00	1.80	.098
10	3.50	5.30	2.30	.131
11	3.50	6.50	1.98	.460
12	3.50	7.50	2.19	1.758
13	3.50	6.50	2.07	1.062

The attenuation model used in the analysis was developed by Weston Geophysical, and is appropriate for the area, since it is based on the observed intensity attenuation for 4 well documented Northeastern U.S. earthquakes. Peak ground acceleration and velocities were associated to the predicted site intensities using the equation of McGuire, 1977. The uncertainty in the attenuation model is defined by $\ln a_g$ or $\ln v_g = 0.70$. This is approximately equal to a factor of 2. The distribution associated with the uncertainty is truncated at three standard deviations.

The Cornell/McGuire program output is an estimate of the peak ground acceleration (PGA) and velocity (PGV) at various probabilities. To determine the uniform hazard spectra, this output is used as input to NUREG/CR-0098. For this analysis, the median uniform hazard spectra are presented for the 10^{-3} and 10^{-4} PGA/PGV at 5% damping.

Figure 6 is a plot of the 10^{-3} and 10^{-4} uniform hazard spectra and the proposed Yankee Interim Design Basis Spectrum.

The results of this analysis indicated that the Yankee spectrum is between the 10^{-3} and 10^{-4} annual exceedance probability.

These results are comparable to the 1,000-10,000 year return periods which have been implicitly accepted by the NRC in recent licensing decisions. In particular, this return period must be viewed with reference to the relationship between it and the "risk" of its occurrence during the operating life of the facility. "Risk" is defined as the chance of some undesirable event. For new facilities, the operating life is usually about 40 years.

The following equations will show the relationship between return periods and "risk".

The return period T is defined by

$$T = 1/p,$$

where p is the annual probability of some value x being equalled or exceeded. Using the fundamental rules for the calculation of probabilities, one can derive expressions for the probability of various combinations of events

1. The probability that x will occur next year is, by definition

$$P = 1/T \qquad (1)$$

2. The probability that x will not occur next year is

$$q = 1 - p = 1 - 1/T \qquad (2)$$

3. The probability that x will occur at least once in the next j years is the sum of the probabilities of its occurrence in the 1st, 2nd, . to jth years.

$$P_j = p + pq + pq^2 + \ldots + pq^{j-1}$$
$$= 1 - q^j = 1 - (1 - \frac{1}{T})^j \qquad (3)$$

Equation (3) is commonly referred to as the risk equation and is written

$$R = 1 - (1 - \frac{1}{T})^j \qquad (4)$$

where R is the risk of seeing the event associated with the return period T over the timeframe j.

For comparison purposes, it is more meaningful to specify some risk that must not be exceeded during the design life and then calculate the required return period of the design event. Table 2 gives gives the values of the appropriate return period T corresponding to a number of values of the risk R and design period j.

TABLE 2

Risk Associated with Return Period and Operating Life

RISK (R) = %	Operating Life (j) 2	5	10	20	30	40
	RETURN PERIODS T					
4	50	127	250	500	7[illegible]0	1000
2	100	250	500	1000	1500	2000
.4	500	1250	2500	5000	7500	10000
.2	1000	2500	5000	10000	15000	20000

To illustrate the use of this Table, suppose a nuclear facility is being seismically designed with a projected operating life of 40 years, and that a 10^{-3} seismic response spectrum is specified. This equates to a 4% chance of experiencing the design event during the 40 year period. The table illustrates that a plant with an operating life of 10 years, requires only a 250 year return period response spectrum to maintain an equal risk of 4%. Likewise, over a 2 year interim period, a 50 year return period response spectrum would have an equivalent risk of 4%.

Based upon this, it is apparent that event return period by itself is not a reliable measure of the hazard, and can be misleading if it is not viewed in the context of the risk associated with its occurrence during the operating life of the facility.

With respect to Yankee Rowe, the proposed response spectrum has a return period on the order of 1,000 years. Over the next 2 years, the chance of not observing this event is 99.8%. Conversely, the chance of observing the event is only 0.2% which is less than the risk implicitly accepted by the NRC in recent licensing decisions.

5.0 SITE AMPLIFICATION

The issue of site seismic amplification has been addressed in two ways. First, site amplification was incorporated directly into the development of the site-specific spectrum because this spectrum was developed from real earthquake data which was recorded at sites with geologic/geophysical characteristics similar to those at Yankee Rowe.

Second, a theoretical study of the potential amplification of ground motion from local bedrock topography and basin effects was undertaken by Drs. Vanmarcke, Kausel, Aki and Bouchon, using the Aki-Larner-Bouchon method. A variety of wave types, P, SH, SV, and varying angles of incidence, were input to a two-dimensional model of the alluvial basin of the Deerfield River geometry at the plant site for the frequency range of 0 to 8 Hz, and amplifications of sinusoidal inputs have been evaluated.

Results indicate the absence of any large amplification of ground motion in the range of 0 - 2 Hz. Amplification factors are restricted to values below 1.25 in this range.

This model does predict higher amplification above 2 Hz. However, material damping in the soil column was neglected in this basin-effect study. When a realistic amount of soil column damping is incorporated, basin-effects will decrease and amplification at higher frequencies is greatly reduced.

Based on these two studies, it is concluded that:

- Site amplification is adequately incorporated into the development of the Yankee spectra.

- There is no significant site amplification at the longer periods of the spectrum.

6.0 REFERENCES

1) Weston Geophysical Corporation, "Geology and Seismology, Yankee Rowe Nuclear Power Plant", January 1979.

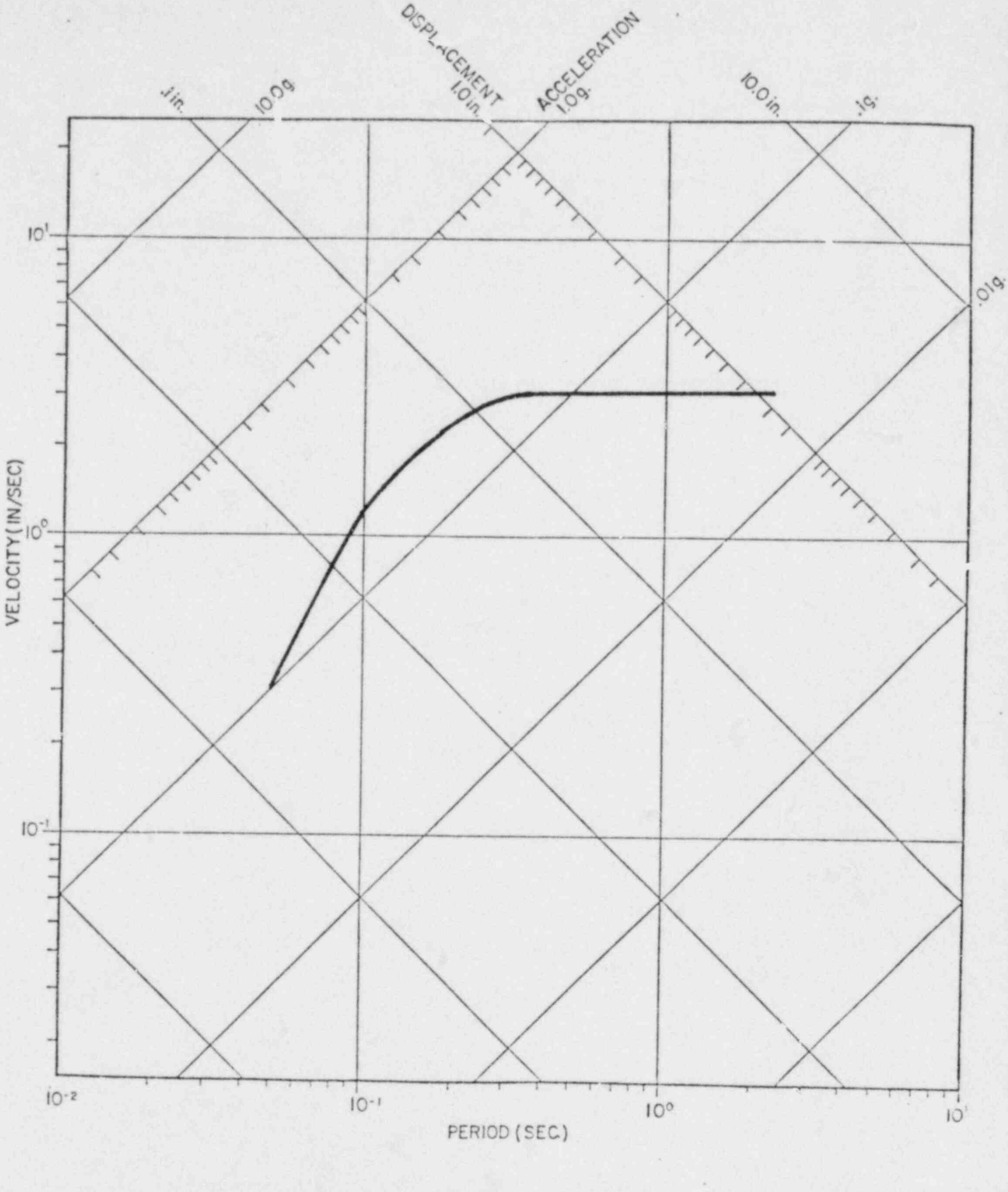
2) Weston Geophysical Corporation, "Eastern United States Tectonic Structures and Provinces Significant to the Selection of a Safe Shutdown Earthquake", August 1979.

3) Weston Geophysical Corporation, 1980, "Site-Dependent Response Spectra, - Yankee Rowe", February 1980.

4) Weston Geophysical Corporation, "In-Situ Velocity Measurements Yankee Nuclear Power Station - Rowe, Massachusetts", March 30, 1979.

5) Cornell, C.A., "Engineering Seismic Risk Analysis", Bulletin of the Seismological Society of America, Vol. 58, No. 5, October 1968, pp. 1583-1606.

6) McGuire, R.K., "Fortran Computer Program for Seismic Risk Analysis", United States Department of the Interior Geological Survey, 1976.



INTLRIM SEISMIC DESIGN BASIS SPECTRUM
(5% DAMPING)

Figure 1

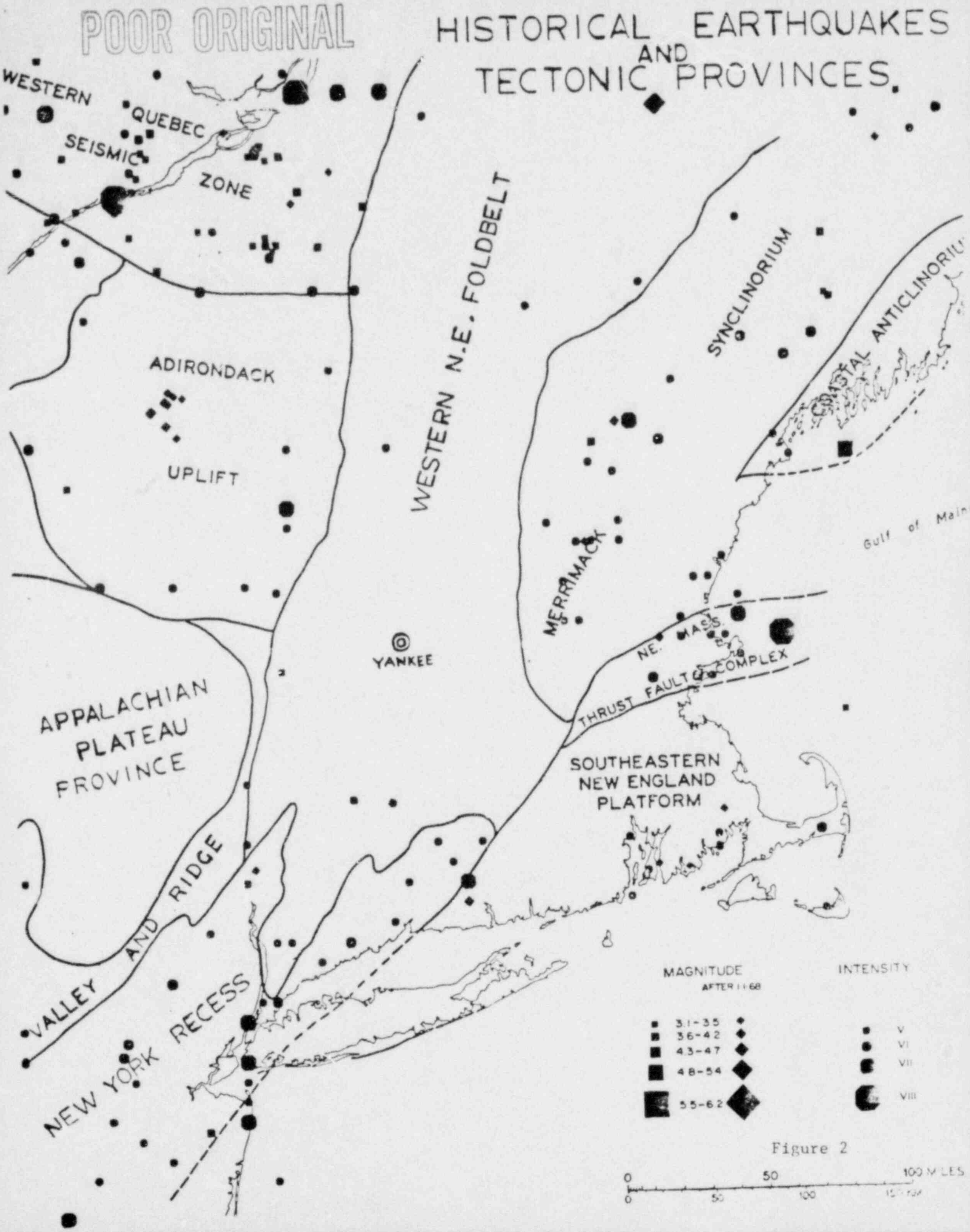
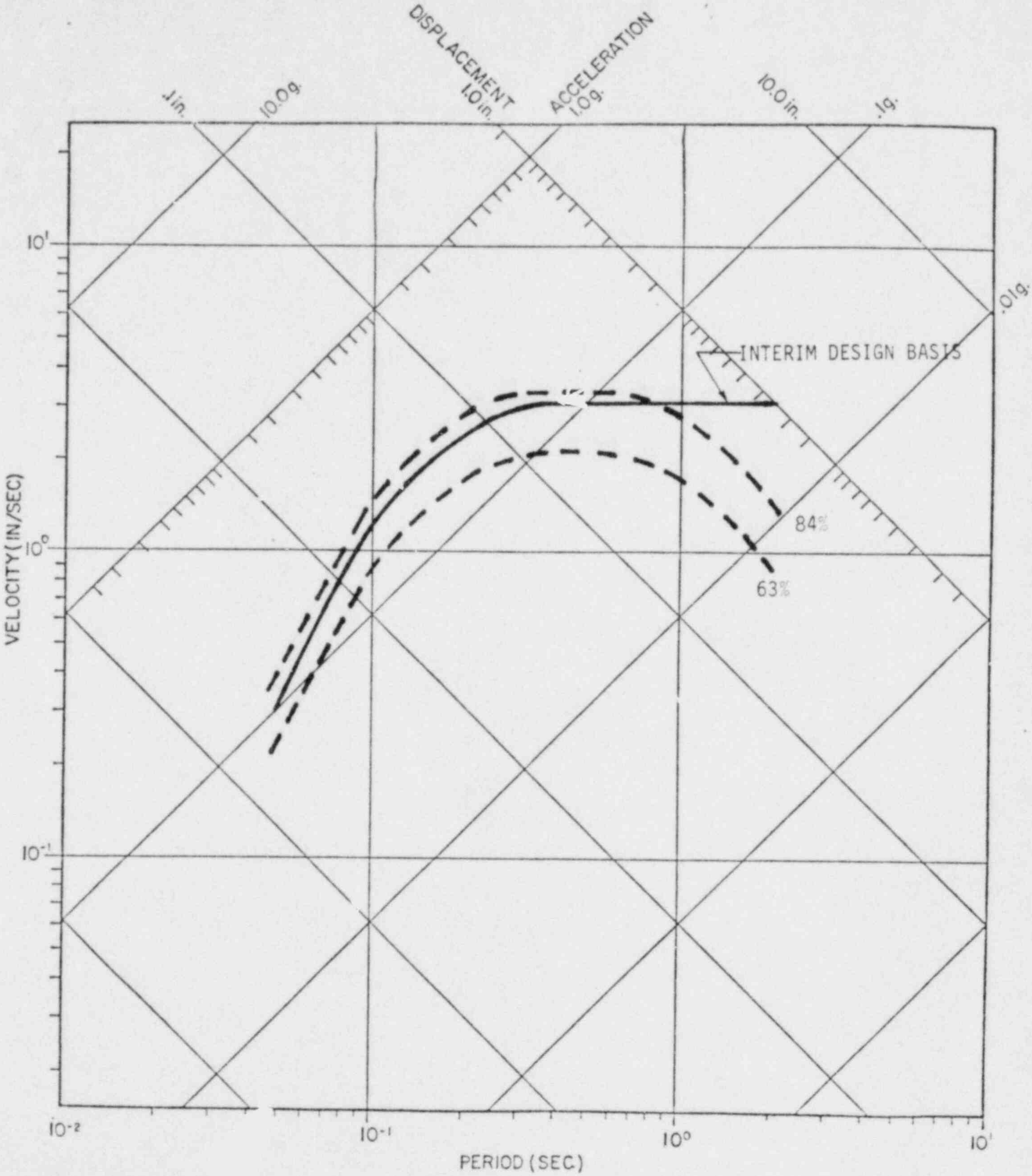

HISTORICAL EARTHQUAKES AND TECTONIC PROVINCES
WESTERN QUEBEC SEISMIC ZONE
ADIRONDACK UPLIFT
WESTERN N.E. FOLDBELT
MERRIMACK SYNCLINORIUM
COASTAL ANTICLINORIUM
Gulf of Maine
NE. MASS. THRUST FAULT COMPLEX
YANKEE
APPALACHIAN PLATEAU PROVINCE
VALLEY AND RIDGE
NEW YORK RECESS
SOUTHEASTERN NEW ENGLAND PLATFORM
MAGNITUDE
AFTER 1-1-68
3.1-3.5
3.6-4.2
4.3-4.7
4.8-5.4
5.5-6.2
INTENSITY
V
VI
VII
VIII
0
50
100 MILES
0
50
100

Figure 2



SITE SPECIFIC SPECTRA

(5% DAMPING)

Figure 3

CALCULATED PEAK HISTORICAL GROUND MOTION

FELT AT YANKEE ROWE (NUTTLI-HERRMANN ATTN)

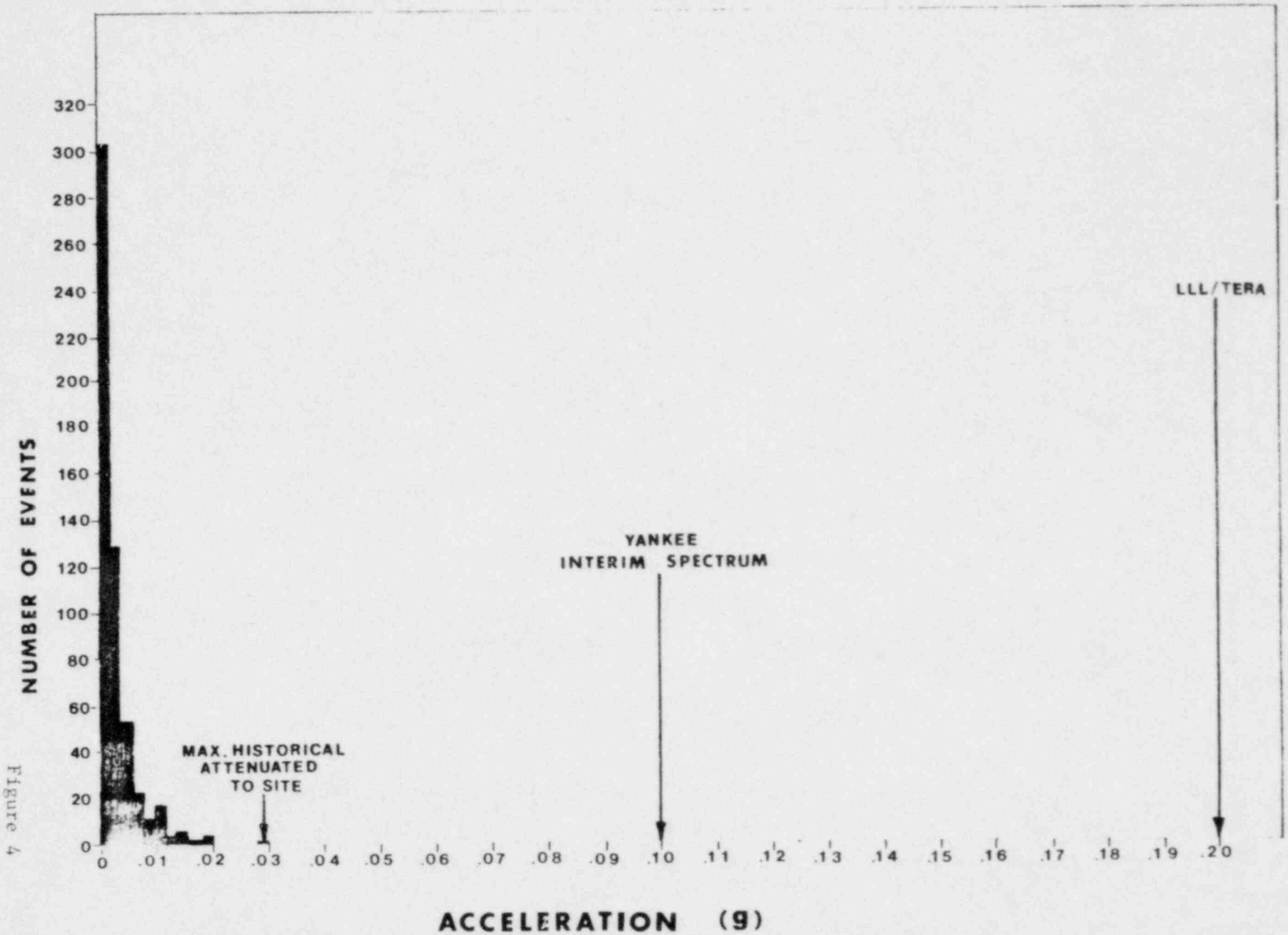


Figure 4

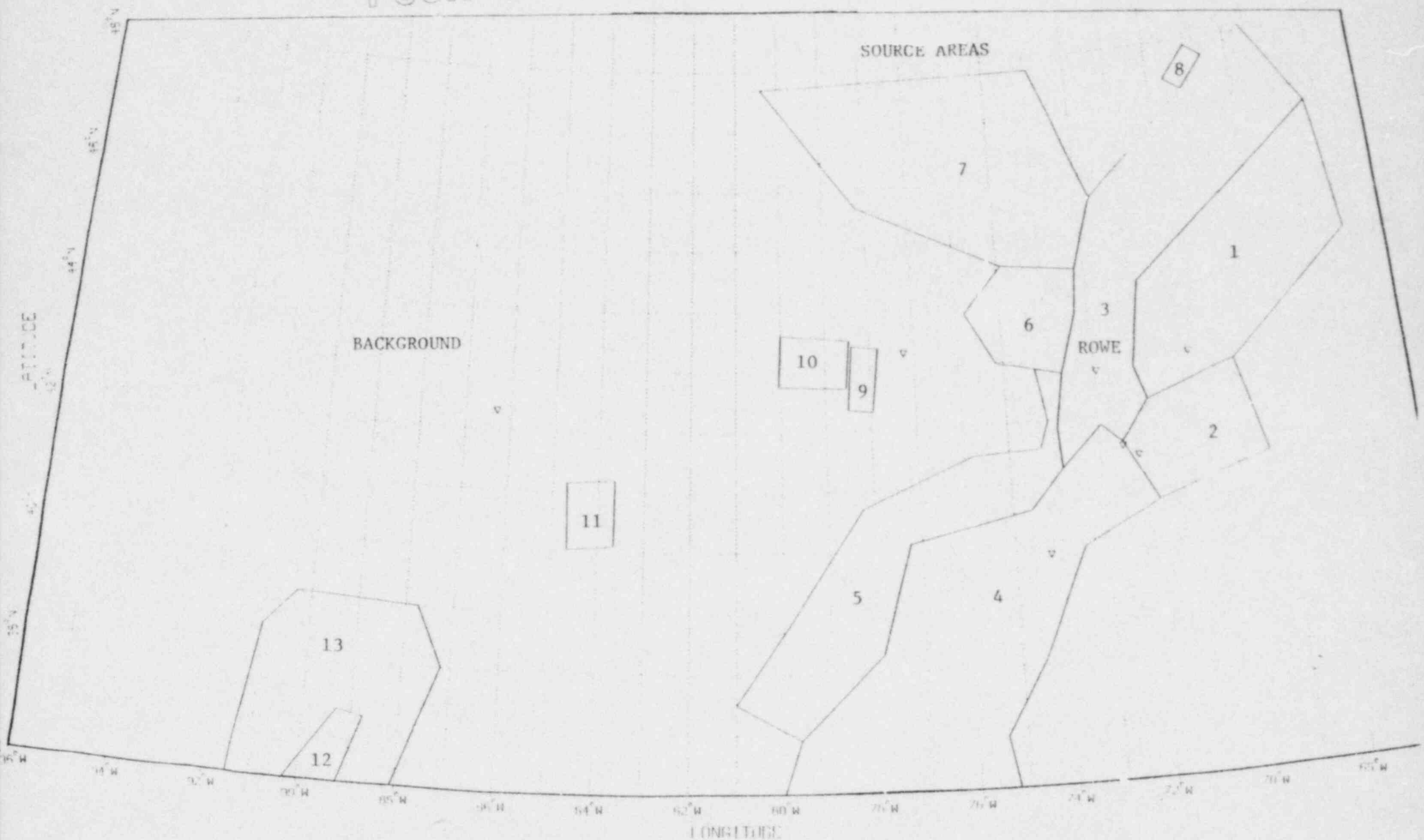
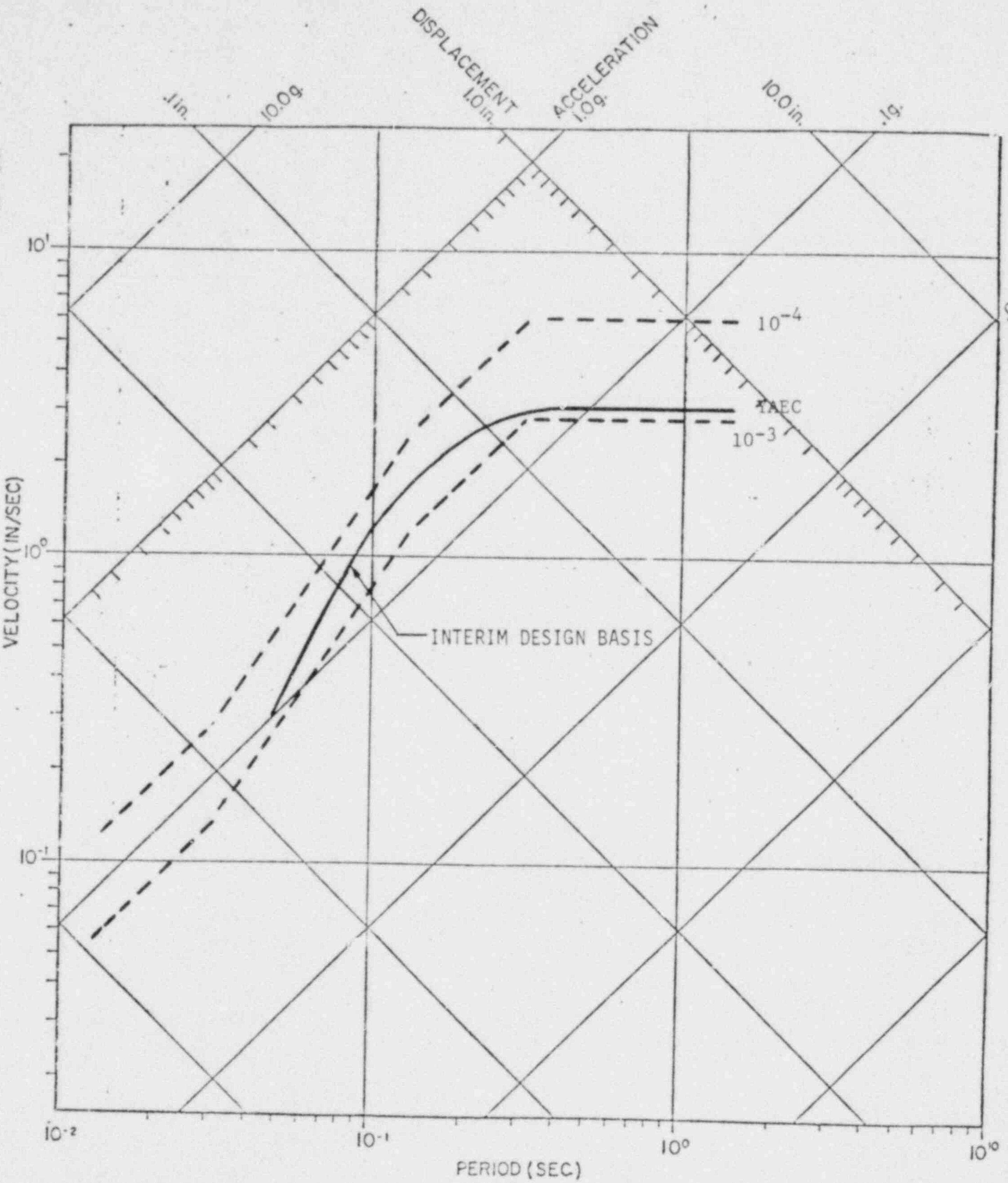


Figure 5



INTERIM DESIGN BASIS SPECTRUM AND
NUREG/CR 0098 MEDIAN UNIFORM HAZARD CURVES

(5% DAMPING)

Figure 6