APPLICANT EVALUATION

TRIFUNAC REPOR

VIRGIL C. SUMMER NUCLEAR STATION
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APPLICANT EVALUATION OF TRIFUNAC REPORT ON
VIRGIL C. SUMMER NUCLEAR STATION
SEISMICITY STUDIES

INTRODUCTION

Professor M.D. Trifunac has written comments on seismic studies performed in connection with the Virgil C. Summer Nuclear Station, dated September, 1981. Trifunac's comments are based, in large part, on studies that are not applicable to the site, or on a misunderstanding of the bases for the seismic studies submitted by the Applicant. In order to clarify these issues, the Applicant addresses the points that Trifunac raises.

INSTRUMENTAL VERSUS DESIGN ACCELERATION

Trifunac's comments imply that design or effective acceleration (the acceleration at zero period in a spectral response diagram; i.e., the acceleration used to "anchor" the design spectrum) can be compared directly with the peak instrumental acceleration. For example, in his Figure 1, which is referred to repeatedly, the OBE and SSE vertical lines at 0.10g and 0.15g, respectively, are compared, or mingled with, a_o, the peak "instrumental" acceleration. Because strong motion accelerographs may record high frequency acceleration pulses that have no effect on structures, particularly for ground motions close to the causative fault, the two are not equivalent. The Diablo Canyon plant, as a recent example, uses 1.15g instrumental acceleration and 0.75g effective or design acceleration, which value was upheld after years of hearings. The Diablo Canyon ratio is 0.75/1.15 or 0.65. Trifunac generally has agreed with such concepts as can be inferred from statements in his scientific papers, e.g.: " ... serious damage to structures comes predominantly from long shaking and not from one or two high-frequency, high-acceleration pulses which, because of their short duration, may represent only small, impulsive excitation." (from Trifunac, 1972). Also: "Finally, it should be pointed out here that from the practical earthquake engineering point of view, high acceleration amplitudes should not

necessarily be associated with a proportionally higher destructive potential. An extended duration of strong ground motion and high acceleration amplitudes characterize destructive earthquake shaking, while one or several high-frequency high-accleration peaks may, in fact, constitute only minor excitation because of the short duration involved and may lead to only moderate or small impulses when applied to structural system." (from Trifunac, 1976). 1/

ESTIMATES OF PEAK ACCELERATION

Trifunac's commentary rests very largely on regression analyses performed by himself, either individually or with associates. Work by other authors on regression analysis of strong motion data is ignored. On the second page of the section entitled "General Considerations," Trifunac begins the first full paragraph with the following statement: "The body of the strong motion data which is now available is not adequate to find the form of the distribution functions of the amplitudes of peak recorded ground accelerations." Concerning this statement, there are two pertinent comments. First, in making this statement, Trifunac renders his commentary unexaminable. Second, the statement is not correct. For example, the distribution of peak ground accelerations, for given levels of MM intensity, was studied by Murphy and O'Brien (1977). Attached is Figure 1 from Murphy and O'Brien, showing distributions of a set of 67 pairs (two horizontal components) of peak ground acclerations corresponding to MM intensity VI. These data are from a study by Trifunac and Brady (1975). Two distributions are shown: one about the arithmetic mean (82.46 cm/sec^2) and the other about the geometric mean (51.98 cm/sec^2). The distribution about the geometric mean matches the normal distribution quite well, i.e., peak ground accelerations are approximately lognormally distributed. This refutes Trifunac's claim that the data now available are not adequate to find the form of the distribution function.

Note that the arithmetic mean exceeds the geometric mean by a substantial margin. This largely accounts for the difference between the Trifunac and Brady (1975) and Murphy and O'Brien (1977) intensity-acceleration correlations. Trifunac and Brady computed arithmetic means

1/ i.e., Trifunac (1976 b).

of peak accelerations for each intensity level (their Table 3) and then fitted these means with a linear equation relating the logarithm of peak acceleration with intensity (their equation 1). Because Trifunac and Brady assumed normal rather than lognormal distribution of peak accelerations, the results of their regression analysis are seriously biased, as shown by Murphy and O'Brien (1977).

In subsequent work, both with intensity and magnitude data, Trifunac (1976a, b) performed regressions using the logarithms of peak ground accelerations, but adopted an unorthodox regression scheme, the statistical meaning of which cannot be ascertained. In his work on intensity, Trifunac (1976a) used the same data set as did Trifunac and Brady (1975). Comparison of the results of these studies shows that Trifunac (1976a) obtained practically the same mean values as Trifunac and Brady (1975), indicating that he again used arithmetic rather than geometric averaging. The results are not directly comparable because Trifunac (1976a) includes site geology as a regression parameter. In doing so, he reduces the population of his data cells considerably.

Tables 1, 2, and 3 compare various estimates of peak horizontal ground acceleration for Modified Mercalli intensities VI, VII, and VIII. Estimates are given according to Murphy and O'Brien (1977; equation 9), Trifunac and Brady (1975; equation 1 and Table 3), and Trifunac (1976a; Table III). The means given in Figure 1 of the Trifunac report correspond to Trifunac (1976a) for s = 2 (rock sites). These exceed the expectations given by Murphy and O'Brien (1977) by factors of about 2. The acceleration given by Trifunac for intensity VII (177.8 cm/sec^2) equals the expectation of Murphy and O'Brien (1977) for intensity VIII.

The results of regression analysis similarly performed by Trifunac (1976b) using magnitude data are likewise marred by erroneous statistical treatment.[1/] Such work should not be used in appraising peak ground accelerations for the Virgil C. Summer Nuclear Station.

As noted above, a further difficulty in applying Figure 1 of Trifunac in assessing design accelerations is that the difference between

1/ i.e., Inapplicable distribution function.

peak instrumental acceleration and design acceleration is overlooked. If adjusted for statistical error and for the difference between design and free-field instrument acceleration, Trifunac's Figure 1 would indicate that the SSE design acceleration is appropriate for ground shaking of MM intensity VII, or ground motion due to an earthquake of magnitude 5 to 5.5 occurring in the immediate vicinity of the site.

In summary, the methodology used by Trifunac in estimating peak accelerations for given intensities and magnitudes leads to overestimation of acceleration. Thus conclusions regarding the inadequacy of the SSE are inappropriate.

VERTICAL ACCELERATIONS

Trifunac suggests that the ratio of peak vertical accelerations to peak horizontal accelerations should be close to 1, and cites a "number of recent recordings" to substantiate this view. These recordings are apparently from magnitudes greater than 6. For smaller magnitudes in the range 4 to 6, the vertical-to-horizontal acceleration ratio is closer to 0.5.[1/] This was documented by the Applicant in section 361 of the FSAR, Figures 361.17.4-20 through 361.17.4-23. The data from the Monticello accelerograph support this: The ratio for the 27 August 1978 earthquake, computed as the vertical peak divided by the average of the two horizontal peaks, is 0.34.

SOIL AMPLIFICATION

Trifunac questions the Applicant's and NRC staff's conclusion that the August 27, 1978, earthquake recording on a soil site represents an amplification of wave motion through the soil. To support his argument he cites Trifunac and Brady (1975) to assert that "average of peak accelerations recorded on rock is higher than the average of acceleration recorded on soil and alluvium.[2/]" More recent studies, by Campbell (1981) and Joyner and Boore (1981), which include consideration of near-field records, conclude that level of accelerations recorded on soil and rock are similar.[3/] The accelerations discussed above refer to free-field accelerations. The potential that the SMA recording represents on amplified response of a natural hill-like structure is discussed below.

1/ We note that Dr. Luco reports observations consistent with those of Applicant on this mat

2/ i.e., For a given intensity level.

3/ i.e., For the same magnitude and distance.

The SMA instrument is located on the abutment between Monticello Dams B and C. An examination of the topography of this region indicates that the instrument site is located almost at the top of a hillock that is partly man-made and partly natural. The surrounding region slopes down rapidly around the area formed by the dam crests and the abutment area with the surface elevation of 300' in the region of epicenter. Thus, the SMA recording, in all liklihood, does represent an amplification of the hillock responding to the free field acceleration. Nonetheless, the Applicant has conservatively assumed that no such amplification has occurred in its use of the SMA recording of the August 27, 1978, earthquake to evaluate earthquake source parameters.

EARTHQUAKE STRESS DROPS

Trifunac states that stress drop estimates in California are highly variable; this is certainly true when these estimates are made in the frequency domain from long period level and corner frequency observations. However, when stress drop estimates are made from time domain data (specifically, observations of a_{rms}), they are quite stable and invariant for California earthquakes (Hanks and McGuire, 1981). The latter is the methodology used in deriving an appropriate stress drop value to characterize reservoir-induced earthquakes at Monticello.

The comparisons of peak-acceleration-to-stress-drop ratio by Trifunac is invalid. The stress drops used by the Applicant are derived from a_{rms}; those cited in Trifunac's references are determined by spectral methods, which are often one-tenth the value determined by a_{rms} for the same earthquake (Hanks and McGuire, 1981). Thus the discrepancy found by Trifunac is easily explained by the factor of ten difference in stress drop estimates by various methods, and does not imply that the Applicant's peak acceleration estimates are low.

PROBABILITY STUDIES

Trifunac finds, in his Tables 1 and 2, return periods for the SSE that are substantially different from those presented by the Applicant in Tables 361.19-1 and 361.19-2. The Applicant's analysis was based

on several sets of seismogenic zones: the zones used for the FSAR are available in that document and are shown in Figure 2, and the zones proposed by Algermissen and Perkins (1976) are reproduced in Figure 3. Both allow tectonic events to occur at the site.

There are several reasons why Trifunac finds larger probabilities than those of the Applicant. First, he uses the recurrence curve of Chinnery (1979) for the southeastern United States. This is a combination of Bollinger's (1973) South Carolina-Georgia seismic zone and Southern Appalachian seismic zone Since the latter has more historical seismicity than the former (see Figure 4), combining the two increases the perceived hazard for any site within the former zone (such as the Virgil C. Summer Nucl Plant). No investigator, to the Applicant's knowledge, has proposed combining these zones for the purposes of determining seismic hazard; Chinnery's (1979) investigation had the purpose of comparing general seismicity characteristics in different parts of the eastern United States, not calculating seismic hazard at sites.

The second difference is in the attenuation curves that are used to estimate ground motion characteristics. The Applicant has used, for Modified Mercalli (MM) intensity, an equation based on MM intensity observed during the 1886 Charleston earthquake, which is the most extensive data base available for the southeastern United States. For acceleration an equation developed by Nuttli for the central United States was used. These attenuation functions are described in section 361.19-4 of the FSAR, and are the most site-specific, least interpretive attenuation equations available. Those used by Trifunac are described in NUREG/CR-689 and estimate spectral velocities as a function of earthquake intensity and distance. While this is a novel approach,1/ there are no eastern U.S. earthquake data with which to judge its appropriateness, nor has this methodology received substantial peer review. Thus the use of this equation to make probability calculations and statements results in highly tenuous conclusions that should be viewed with caution.

STRUCTURAL DAMPING

The primary reason for using 7 percent, instead of 2 percent, damping is due to the fact that 7 percent is more realistic than 2

1/ Applicant chose the more conventional and widely accepted approach, similar to that method used by Algermissen and Perkins.

percent during a 0.22g near-field earthquake for structures originally designed for a 0.15g far-field earthquake, and not solely because it is permitted by the Regulatory Guide. The 7 percent damping was verified by test data that were discussed extensively in the Diablo Canyon ALAB hearings. The decision of the same ALAB hearings acknowledged that 7 percent damping is appropriate.

The effect of structural damping used in the analysis is to control the amplified motion from the input to the top of the building such that the amplification factor matches the recorded data in general. In the reevaluation of the Virgil C. Summer Station design, the resulting amplification factor based on 7 percent damping was 3.0, which is generally higher than recorded amplifications. In the original design with 2 percent damping, an amplification of 4.75 was obtained. This large amplification factor is totally unrealistic. The value of 7 percent was used to provide calculation of realistic, but still conservative, structural response. 1/

EFFECTIVE ACCELERATION 2/

Trifunac disputes the SER statement that "the finite size of large structures would attenuate high frequencies" claiming that it has not been demonstrated so far, and that it does not reduce the high frequency input motions significantly and systematically to warrant its use in design calculations. The reference cited for this claim (Feng, et al., 1982) is unavailable to the Applicant. However, in a recent study, Campbell (1981) reports comparisons between small building/free-field recordings (115 components) at ground level, and recordings obtained in the lowest basement of large buildings (40 components). Campbell found that peak acceleration recorded in the basement of large buildings was on the 24 3/ percent lower than that recorded at ground level. 4/ This result was found to be significant at the 90 percent confidence level.

1/ The damping values of 5% and 7% conform to R.G. 1.61.

2/ A more accurate title for this section is: ATTENUATION EFFECTS OF LARGE FOUNDATIONS.

3/ i.e., The average 24 percent.

4/ i.e., In small buildings or in the free-field.

REFERENCES

Algermissen, S.T., and D.M. Perkins (1976), "A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous United States," USGS Open-File Report 76-416, 45 pp.

Bollinger, G.A. (1973), "Seismicity and Crustal Uplift in the Southeastern United States," American Journal of Science, Cooper vol. 273-A, pp. 390-408.

Campbell, Kenneth W. (1981), "Near-Source Attenuation of Peak Horizontal Acceleration," submitted to the Bulletin of the Seismological Society of America.

_____ (1981), "Near-source Attenuation of Peak Horizontal Acceleration, submitted to the Bulletin of the Seismological Society of America.

Chinnery, M.A. (1979), "A Comparison of Seismicity of Three Regions of the Eastern United States," Bulletin of the Seismological Society of America, vol. 69, pp. 757-772.

Hanks, T.C., and R.K. McGuire (1981), "The Character of High Frequency Strong Ground Motion," Bulletin of the Seismological Society of America, vol. 71, Dec. (in press).

Joyner, William B., and David M. Boore (1981), "Peak Horizontal Acceleration and Velocity from Strong Motion Records, including Records from the 1979 Imperial Valley, California, Earthquake," submitted to the Bulletin of the Seismological Society of America.

Murphy, J.R., and O'Brien, L.J. (1977), "The Correlation of Peak Ground Acceleration with Seismic Intensity and Other Physical Parameters." Bulletin of the Seismological Society of America, vol. 67, pp. 877-915.

Trifunac, M.D. (1972), "Stress Estimates for the San Fernando, California, Earthquake of February 9, 1971: Main Event and Thirteen Aftershocks," Bulletin of the Seismological Society of America, vol. 62, pp. 721-750.

_____ (1976a), "A Note on the Range of Peak Amplitudes of Recorded Accelerations, Velocities and Displacements with respect to the Modified Mercalli Intensity, Earthquake Notes, vol. 47, no. 2, pp. 9-24.

_____ (1976b), "Preliminary Analysis of the Peaks of Strong Earthquake Ground Motion - Dependence of Peaks on Earthquake Magnitude, Epicentral Distance and the Recording Site Conditions," Bulletin of the Seismological Society of America, vol. 66, pp. 189-219.

Trifunac, M.D., and A.G. Brady (1975), "On the Correlation of Seismic Intensity Scales with the Peaks of Recorded Strong Ground Motion," Bulletin of the Seismological Society of America, v. 65, pp. 139-162.

TABLE 1

PEAK HORIZONTAL GROUND ACCELERATION ESTIMATES FOR MM INTENSITY VI 1/

Author	Assumed distribution function	Expected acceleration (cm/sec^2)	Accelerations for -/+ 1 standard deviation (cm/sec^2)
Murphy & O'Brien (1977): Eq. (9)	Lognormal	56.23	24.55/128.78
Trifunac & Brady (1975): Eq. (1)	Normal	65.16	
Table 3		82.46	4.79/160.13
Trifunac (1976a)			
S=0 (alluvium)	?	46.77	
S=1 (intermediate)		66.07	
S=2 (rock)		91.02	

1/ Although the calculations give results to 2 decimal places as reflected here, accuracy is not implied beyond the decimal point.

TABLE 2

PEAK HORIZONTAL GROUND ACCELERATION
ESTIMATES FOR MM INTENSITY VII [1/]

Author	Assumed distribution function	Expected acceleration (cm/sec^2)	Accelerations for -/+ 1 standard deviation (cm/sec^2)
Murphy & O'Brien (1977): Eq. (9)	Lognormal	100.00	43.67/229.09
Trifunac & Brady (1975): Eq. (1)	Normal	130.02	
Table 3		131.29	69.99/192.59
Trifunac (1976a)			
S=0 (alluvium)	?	93.33	
S=1 (intermediate)		128.82	
S=2 (rock)		177.83	

1/ Although the calculations give results to 2 decimal places as reflected here, accuracy is not implied beyond the decimal point.

TABLE 3

PEAK HORIZONTAL GROUND ACCELERATION ESTIMATES FOR MM INTENSITY VIII 1/

Author	Assumed distribution function	Expected acceleration (cm/sec^2)	Accelerations for -/+ 1 standard deviation (cm/sec^2)
Murphy & O'Brien (1977): Eq. (9)	Lognormal	177.83	77.65/407.23
Trifunac & Brady (1975): Eq. (1)	Normal	259.42	
Table 3		166.67	82.61/250.73
Trifunac (1976a)			
S=0 (alluvium)	?	181.97	
S=1 (intermediate)		251.19	
S=2 (rock)		346.74	

1/ Although the calculations give results to 2 decimal places as reflected here, accuracy is not implied beyond the decimal point.

FIGURE 1

(Taken from Murphy and O'Brien, 1977)

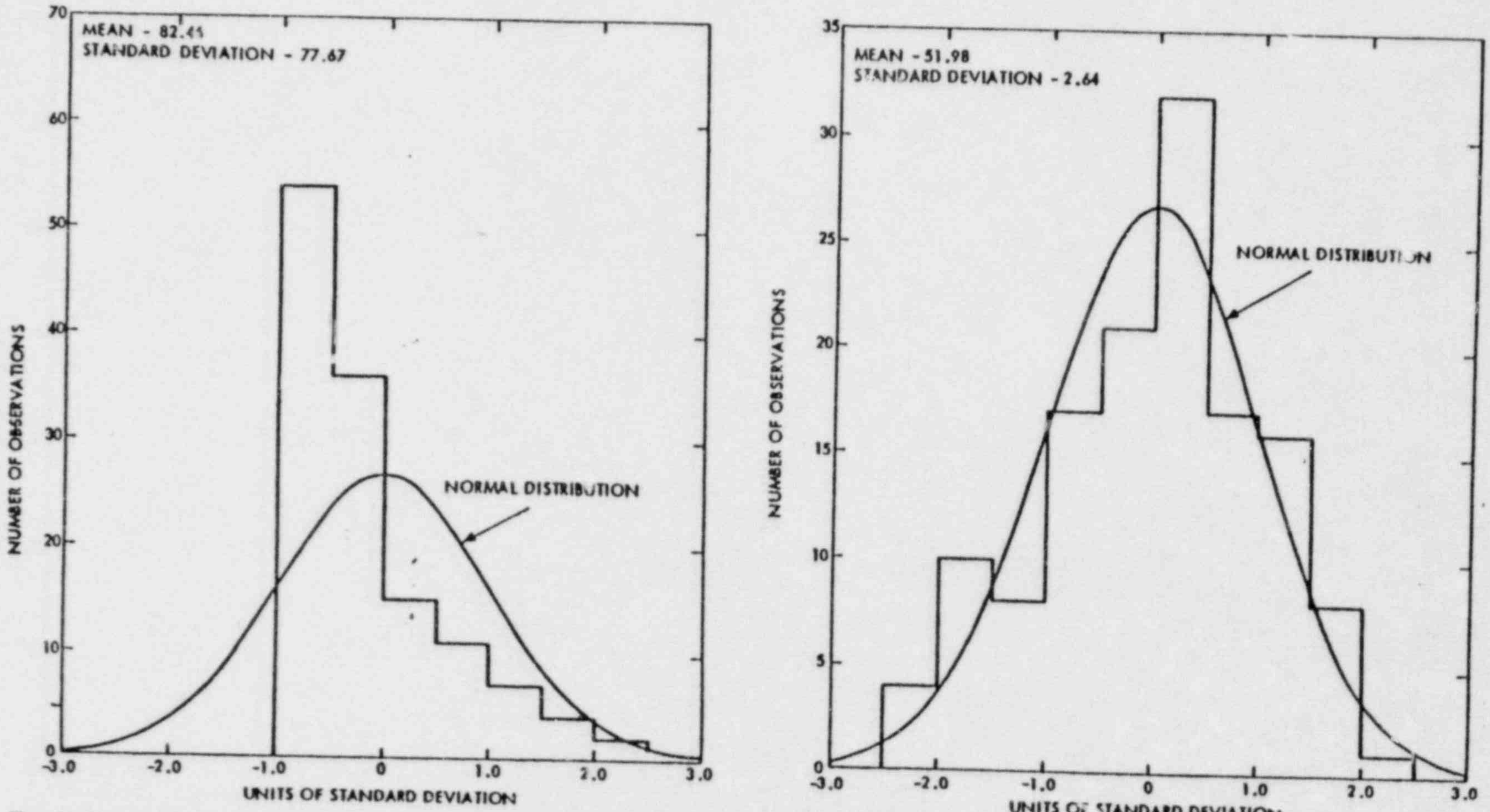

FIG. 7. Comparison of the distribution of the Trifunac and Brady (1975) sample with respect to the arithmetic (*left*) and logarithmic (*right*) means, Modified Mercalli Intensity VI.

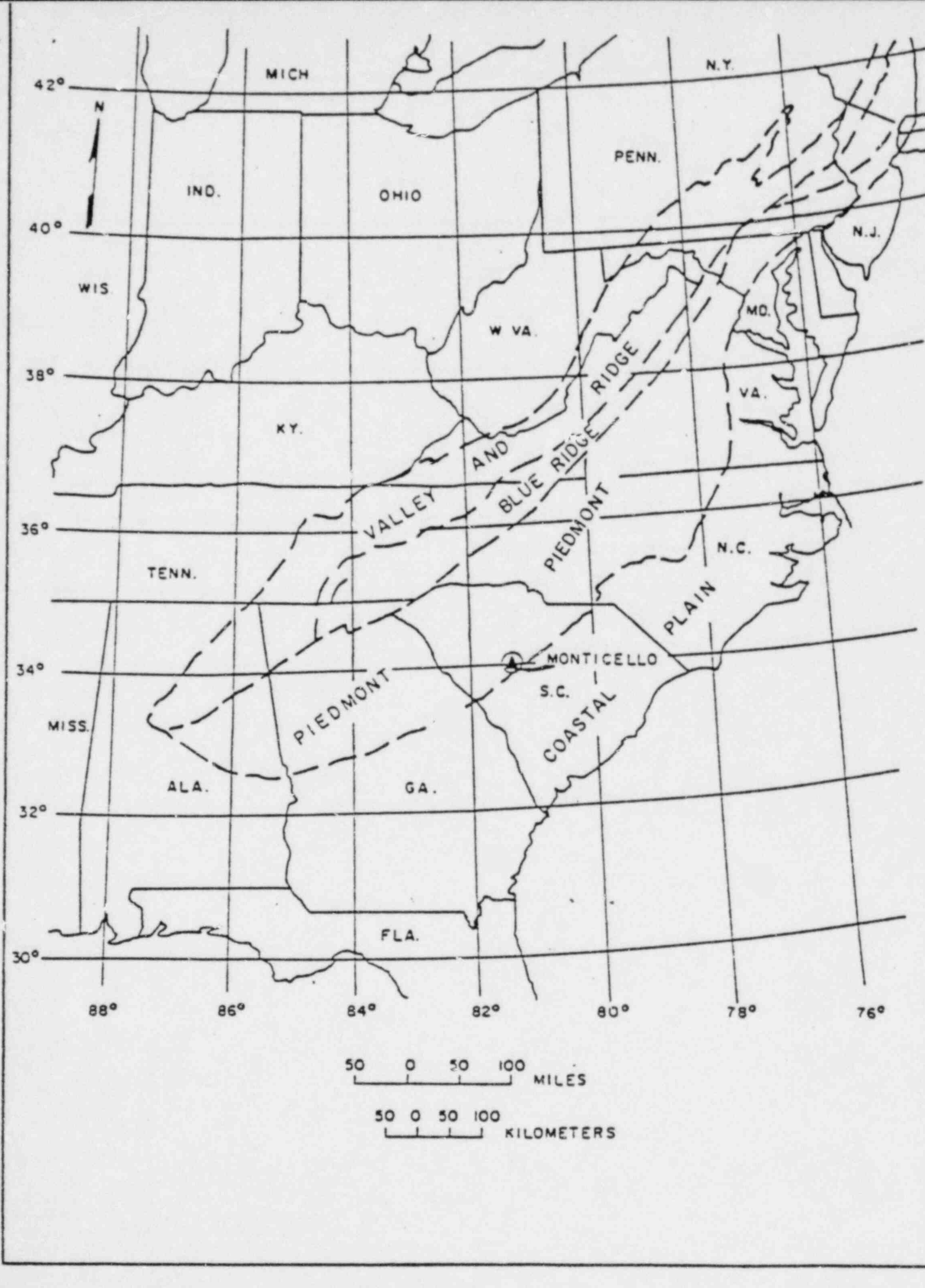

Figure B/ 2
SEISMOGENIC ZONES USED IN FSAR

Correction

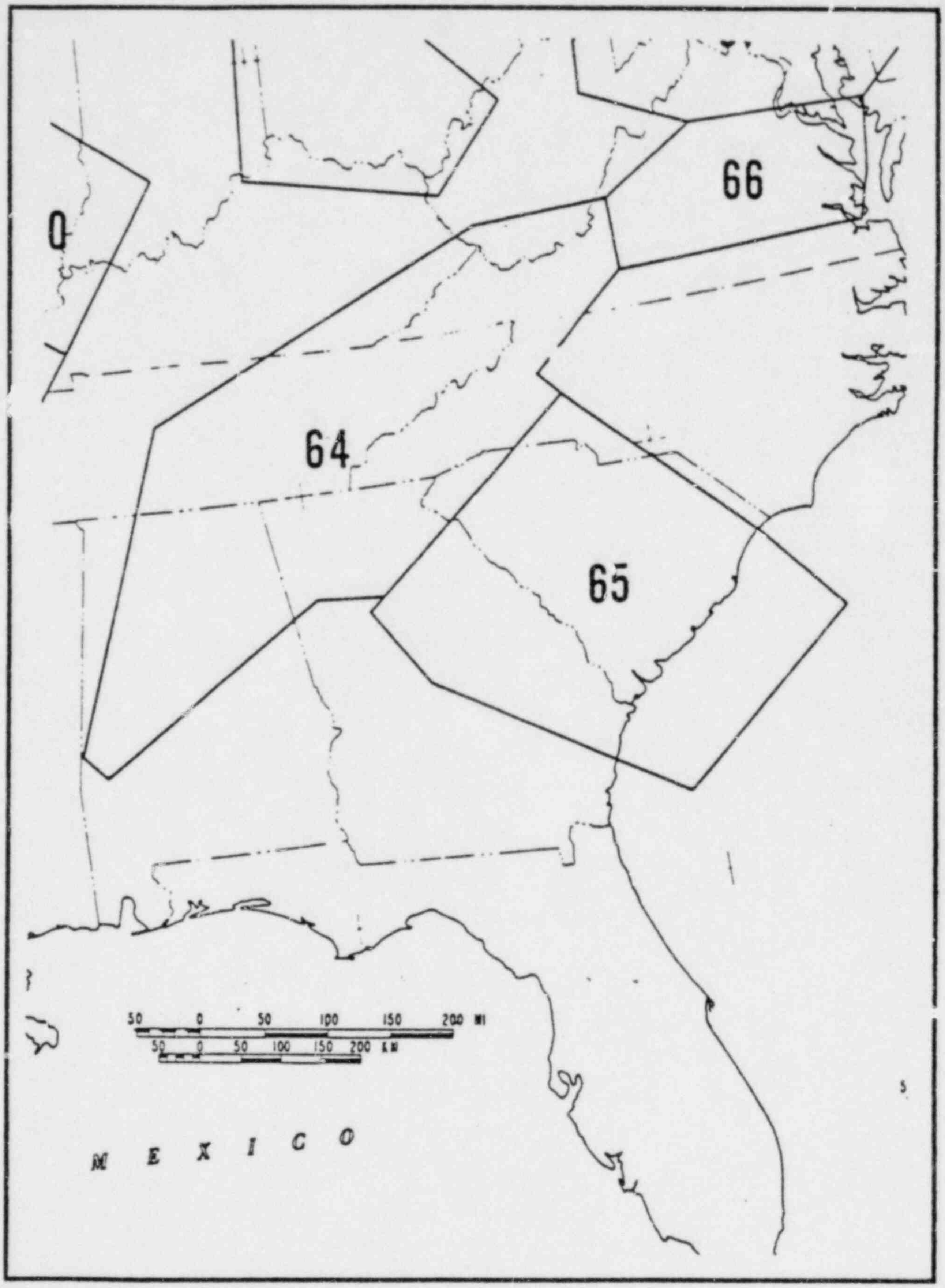

Figure 4 3 1/

SEISMOCENIC ZONES IN SOUTHEAST U.S.
USED BY ALGERMISSEN AND PERKINS (1976)

1/ Correction of Figure No.

FIGURE ~~2~~ 4 1/

(Taken from Bollinger, 1973)

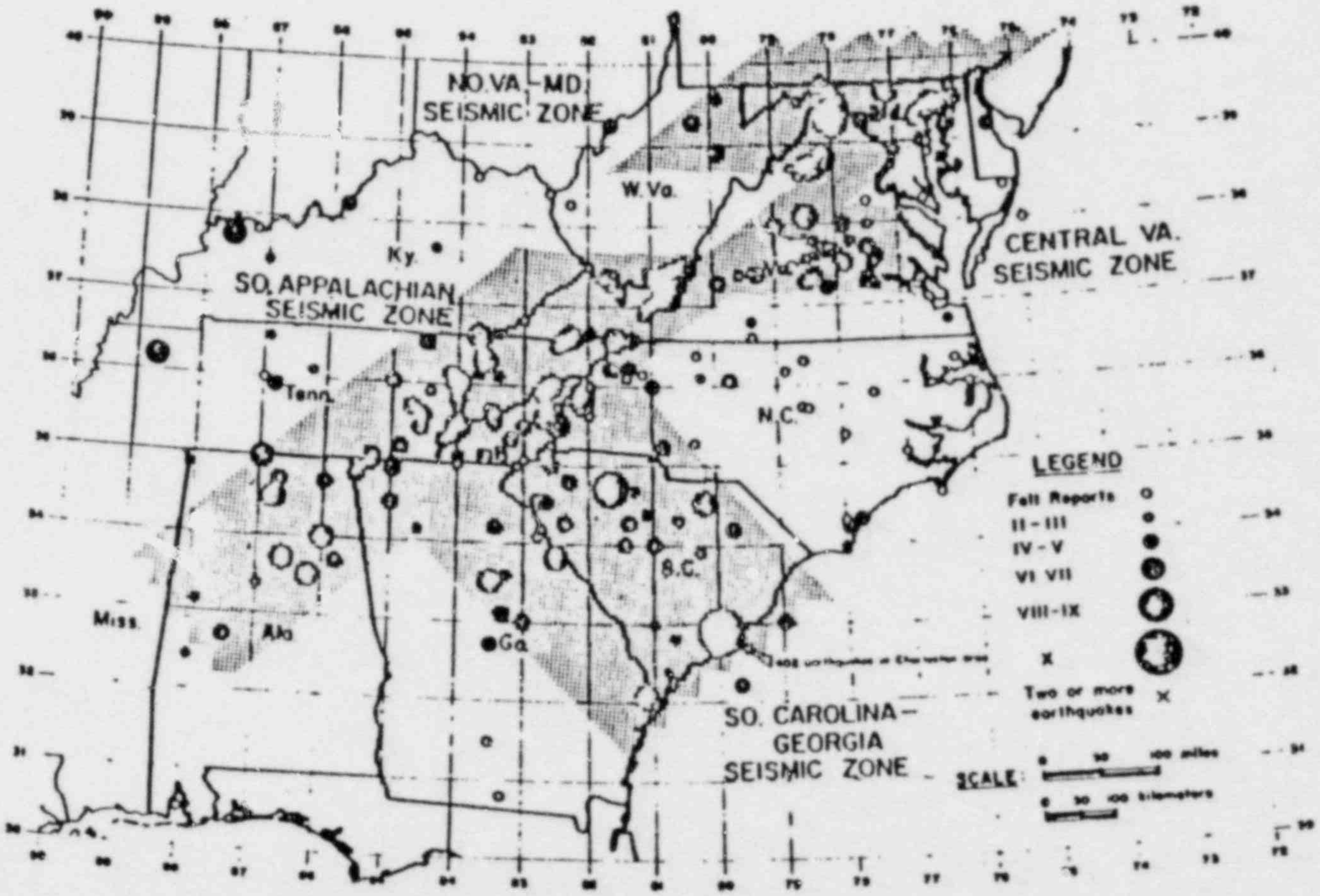

Fig. 3. Seismic zones in the southeastern United States.

1/ Correction of Figure No.