United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA 22092

Mail Stop 908
September 11, 1981

Herbert Grossman, Esq.
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Grossman:

In response to your request, we are transmitting a review of pertinent reports and data regarding induced seismicity the review has been prepared by William Joyner and Jon P. Fletcher.

In order to expedite transmittal, the report has not been subjected to peer review nor USGS policy. In accordance with your conversation with James F. Devine we are also providing a copy of the review to Robert E. Jackson, Geoscience Branch, NRC.

I trust the review will be of assistance.

Sincerely,

Robert H. Morris

Robert H. Morris

Enclosure

Copy to Bob Jackson

September 9, 1981

Memorandum

To: Robert H. Morris

From: William B. Joyner
Jon B. Fletcher

Subject: Virgil C. Summer Nuclear Station

As you know, we believed at one time that we might be called to testify at hearings on the Virgil C. Summer Reactor. At Judge Grossman's request we reviewed hearings transcripts, a report entitled Supplemental Seismologic Investigation, portions of the Safety Evaluation Report, and Section 361 of the Final Safety Analysis Report. Since it now appears that we will not be called and that the NRC Staff will be making another presentation to the Board on September 15, we are communicating the conclusions from our review to you in this memo with the suggestion that you send it to the NRC Staff in the hope that it might be of help to them. We also suggest you send a copy to Judge Grossman. Our conclusions in this memo should not be considered as a comprehensive site review. We restricted our attention to two issues, (1) the maximum magnitude of the reservoir-induced earthquakes and (2) the ground motion to be expected from reservoir-induced earthquakes. Furthermore, we did not have sufficient time for a thorough review even of those two issues. In view of the time limitations on us, the material we present here should be considered as input for the NRC staff to use in developing their analysis and not as final answers.

Maximum Magnitude of the Reservoir Induced Earthquakes

One approach used to estimate the maximum magnitude is to estimate the stress drop and the maximum dimensions and from those compute a moment and from the moment a magnitude. We prefer to bypass computation of the stress drop and use the August 27, 1978 earthquake as a basis. We find the radius of the equivalent circular fault for the August 27 event from the corner frequency and then scale the moment magnitude up to the estimated maxium radius. This is the equivalent of assuming that the stress drop of the larger event will be the same as that for the August 27 event. Although our approach bypasses the computation of stress drop, we should note for the record that the stress drop we compute from rms acceleration for the August 27 event, 38 or 30 bars depending upon which horizontal component is used, is significantly larger than that obtained by the applicant. (These values are different from the values given earlier by Fletcher because the hypocentral coordinates have been revised.) We obtained our values using the rms acceleration as did the applicant, but the applicant used the formulas given in McGuire and Hanks (1980), which are based on the assumption that the corner frequency is negligibly small compared to the natural frequency is 8.9 Hz and the frequency of the instrument is 25 Hz. We avoid the assumption by carrying out a numerical integration of the squared spectrum. The stress drop calculated in this way is remarkably close to the 44 bars obtained for the 180^o component from a straightforward application of the Brune model.

To estimate the maximum magnitude in our approach, it is necessary to estimate a maximum fault dimension. The applicant invokes arguments involving the concept of "stress bariers" and arguments from the heterogeneity of the stress field and of material properties to limit the maximum dimension of the rupture to 1 km. We find these arguments unconvincing. It is reported that 98 percent of the hypocenters are shallower than 2 km. On that basis, one might choose a maximum dimension of 2 km for a vertical fault. This would correspond to a maximum radius of 1 km for a vertical circular fault and 1.4 km for a circular fault dipping at 45 degrees. The corner frequency, f_o, of the August 27 event was 8.9 Hz determined from the spectra of the horizontal components, and the moment, M_o, was 1.85 x 10^{20}, which gives a moment magnitude of 2.8. We determine the radius, r, from the corner frequency using the Brune (1970, 1971) model.

$$f_o = \frac{2.34}{2\pi r}\beta$$

Taking the shear velocity, β, to be 3 km/sec, gives 126 m for the radius. Scaling the moment upward for constant stress drop $\Delta\delta$ by

$$\Delta\delta = \frac{7M_o}{16r^3}$$

and converting from moment to moment magnitude we get a magnitude of 4.6 for a radius of 1 km and 4.9 for a radius of 1.4 km.

One might question the precision of source radius estimates by the Brune model, and it is worthwhile to look at other ways for estimating the maximum magnitude. In section 361.18 of the FSAR the applicant extrapolated the recurrence curve of reservoir-induced earthquakes at Monticello to get estimates of 4.0 and 4.5 for the magnitudes corresponding to return periods of 10 and 50 years, respectively. This is interesting and relevent information, but one should be careful not to put too much trust in it because reservoir-induced seismicity is not necessarily a steady-state phenomenon. In the case of the Denver earthquake sequence (Healy et al., 1968) the largest earthquakes occurred late in the cycle and could not have been predicted from recurrence curves based on the earlier seismicity. We realize that the circumstances of the Denver sequence were very different from those of the Monticello sequence, but the example illustrates the need for caution on this point.

A more promising approach is to consider all cases of reservoir-induced seismicity in the Piedmont province, as has been done by the applicant and the NRC staff. The largest event appears to be the m_b 4.3 earthquake at Clark Hill reservoir. We have not had time to review this line of evidence, but believe it to be an important consideration.

Mark Zoback believes from an analysis of the downhole stress measurements that the earthquakes are restricted to the upper few hundred meters. We consider this to be inconsistent with the earthquake location data, but it is possible that the events with the larger stress drops all have depths in that range. If that is true it suggests a maximum vertical dimension substantially less than 1 km and a maximum magnitude substantially less than [illegible].6. The magnitude-frequency plots of the reservoir induced earthquakes at Monticello, shown in Appendix IX of report Supplemental Seismologic Investigation, are consistent with this in that way seem to be leveling off at the high magnitude end. this line of reasoning is suggestive and scientifcally interesting, but we would hesitate to place major reliance on it.

<u>Ground Motion Estimates for the Maximum Reservoir-Induced Earthquake</u>

All our comments on ground-motion estimates will be made with respect to the site of the strong-motion record. We assume that the same earthquakes are possible near the reactor site as near the strong-motion site. We understand the applicant has done an analysis of the effect of site conditions at the strong-motion site and concluded that the equivalent "rock-site" acceleration appropriate for the reactor would be smaller than that measured at the instrument site. We consider this possible, but we can't endorse it without knowing how the calculations were performed or how the shear velocity values and soil damping values were measured.

Our approach to estimating ground-motion paramenters is somewhat different from used by the applicant, but this difference in approach is far less important than two other factors. The first is that for the strong-motion data at the site we use exclusively the results of digitization at 500 samples per second rather than the earlier digitzation at 100 samples per second. The peak acceleration is about twice as high with the more closely spaced digitization. We grant that the difference represents rather high frequency motion. Whether or not these high frequencies are significant to the structure is an engineering judgment, however, and we believe it should be kept separate from the seismological analysis.

Our second major difference with the applicant's analysis concerns the saturation of ground motion parameters with decreasing distance to the source. In section 361.17.4 of the FSAR, the applicant suggests that, at distances R less than 4 times the source radius r, the point source approximation is invalid. This seems a rather large distance to us. If one considers a circular source with an observation site at a distance of 4r along a perpendicular line through the center, there is only a 3 percent variation in distance from the observation site to any point within the source. We know of no rigorous basis for choosing a precise limit for the validity range of the point source approximation.

We consider one source radius to be at least as reasonable a choice as four source radii, and that choice would, of course, permit much larger ground motion values.

The applicant introduces distance saturation in a slightly different way in Appendix XI of the report "Supplemental Seismologic Investigations." There it is asserted that extrapolation of the point-source model to a source-to-site distance of one source diameter gives a reasonable approximation to the acceleration saturation level. In support of this concept they present some California strong-motion data. These same data, however, have been fit by California strong-motion data. These same data, however, have been fit by Joyner and Boore (1981) with a magnitude-independent attenuation curve. These data are consistent with the interpretation that the distance saturation is controlled not by the source size but by the depth of the energetic portion of the source. We know of no rigorous basis for determining the saturaiton level in the circumstances at Monticello, and we consider the point-source value calculated for one source radius to be as good an estimate as the value calculated at one source diameter. Actually, the assumption that the saturation level corresponds to the value computed at any fixed multiple of the source radius leads to the unpalitable conclusion that the saturation level decreases with magnitude. The source model used by the applicant implies that peak acceleration is inversely proportional to hypocentral distance within the distance range for which the point source approximation is valid. (This is not readily apparent from the equations given in section 361.17.r of the PSAR, but it becomes apparent if the limit of those equations is taken as Q approaches infinity, which is an appropriate approximation in this case.) The rms acceleration in the applicant's model is proportional to the square root of source radius and the peak acceleration approximatley to the 0.6 power of source radius. A little algebra shows that these assumptions lead to a saturation level of peak acceleration that is inversely proportional to the 0.4 power of source radius and thereby decreases with increasing magnitude.

Even if we were to accept the concept of a saturation level corresponding to the point-source value at a distance of one source diameter, however, we would, as will be shown below, obtain a peak acceleration value substantially higher than those given by the applicant.

Our approach for estimating peak horizontal acceleration and velocity at Monticello is not basically very different form the approach of the applicant.

In an attempt to make maximum use of the local strong motion data and to introduce the minimum in the way of additional assumptions, we take the August 27, 1978 event, keep the hypocentral distance the same, and scale up the peak horizontal acceleration and velocity with magnitude. We assume that peak acceleration scales as the 0.25 power of moment magnitude. That is the value obtained from empirical studies by Joyner and Boore (1981) and by Donovan (1973); it is somewhat less than the value of approximately 0.3 predicted by the model (Hanks and McGuire, 1981) used by the applicant. We assume that the peak velocity scales as the 0.5 power of moment magnitude which corresponds to a value of 0.5 implied by both the theoretical models of Boatwright (1980) and McGarr (1981). Magnitudes are estimated as described in the preceding section and the results are shown in Table 1. The last column gives the corner frequency calculated from the radius using the Brune (1970, 1971) formula and is included to illustrate the shift to lower frequency with increasing magnitude. The values given in Table 1 are essentially point-source approximations, and the next to the last column, which gives the ration of the source distance R to the source radius r, is an indication of the validity of the approximations. The second line of the table shows that even for events with the distance equal to one source diameter the peak horizontal acceleration is 0.44 g and the peak horizontal velocity is 6.6 cm per second. For the last two lines in the table, we can't prove the approximation valid, but neither do we see how anyone could prove that the values are too large. Given estimates of peak acceleration and peak velocity response spectra can be computed by the methods of Newmark and Hall (1969).

We should emphasize in closing that, while the peak acceleration values we cite are rather high, the frequencies are also high. Whether the motions represent a problem for the facility or not is an engineering judgment which is not ours to make.

Table 1

Source Radius r (km)	Moment Magnitude	Peak Acceleration (g)	Peak Velocity (cm/sec)	R/r	Corner Frequency
0.126	2.8	0.26	2.3	5.6	8.9
0.35	3.7	0.44	6.5	2.0	3.2
0.7	4.3	0.62	12.9	1.0	1.6
1.0	4.6	0.73	18.3	0.7	1.1

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