SEISMIC DESIGN DECISION ANALYSIS

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NUCLEAR POWER PLANTS AND THE OPERATING BASIS EARTHQUAKE - PHASE I

by

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Nuclear power plants are affected by two earthquake levels in their design and operation: the safe shutdown earthquake (SSE) and the operating basis earthquake (OBE). This study is concerned solely with the OBE and the probability that a plant, two plants simultaneously, or generally that n plants simultaneously will have to shutdown for inspection during the next Y years. The study is not concerned with structural response, but solely with the question of whether shutdowns for inspection will be required. This report describes the first phase of this study which looked at an area comprised of three seismic source zones and nine nuclear power plants. The location of the plants were considered to be: Wiscasset, Maine; Seabrook, New Hampshire; Vernon, Vermont; Rowe, Massachusetts; Plymouth, Massachusetts; Charlestown, Rhode Island; Waterford, Connecticut; Haddam, Connecticut; and Shoreham, Long Island. The OBE was taken as a modified Mercalli intensity VI for each plant, even though this may not be the actual situation. Differences in plant capacity were ignored in this initial study. A computer program developed in Russia at the Institute of Geophysics for damage and loss studies was used to compute the effect of an earthquake on these sites. The assumptions used in the description of the seismicity of the region are described in this report. The results from this phase of the study are presented.

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THE PROBLEM

Nuclear power plants are affected by two earthquake levels in their design and operation:

(1) the safe shutdown earthquake (SSE), and

(2) the operating basis earthquake (OBE).

For earthquakes in regions where there are no identified active faults, the safe shutdown earthquake is the maximum earthquake intensity which has occurred in the seismotectonic province in which the plant is located. The OBE earthquake has been defined in several ways over the years; most recently it has been defined as an intensity with 1/2 the peak acceleration of the safe shutdown earthquake. The OBE is used in two ways:

(1) The plant and its equipment must be designed such that the stresses must stay within normal code-specified working stresses if an $a_g =$ OBE occurs at the site, and

(2) If an $a_g >$ OBE occurs at the site, then the plant must shut down and be inspected to determine if it is safe for continuous operation.

If an earthquake occurs which generates ground motion greater than the safe shutdown level, the plant must be designed so that it can safely shut down even though damage may have occurred.

This study is concerned solely with the OBE and the probability that a plant, two plants simultaneously, or generally that n plants simultaneously will have to shut down for inspection during the next Y years. We are not concerned with structural response, but solely with the question of whether shut-downs for inspection will be required.

This question arose from the fact that many utility companies would like to see the OBE lowered, since the OBE at present controls the design of certain portions of a typical plant. (That is, the OBE plus the requirement of staying within normal working stresses is, for some of a plant, a more stringent design requirement than safe shut-down following on SSE.) On the other hand, if the OBE is lowered, then the likelihood of it being exceeded is increased and the probability that more than one plant could be affected is increased. The decision to study these probabilities was made for two reasons:

(1) This could turn into a very interesting and worthwhile application of some of the work developed in the SDDA project;

(2) This would include an investigation of the feasibility of using a computer program developed in Russia at the Institute of Geophysics for damage and loss studies (see first four entries on reference list).

This report describes the first phase of this study. Later phases will look at plants in the entire northeast region (New England, New York, Pennsylvania, and New Jersey) and use the seismic source zones and occurrence data developed by Algermissen.

This initial phase of study looked at an area comprised of three seismic source zones and nine nuclear power plants. The power plants are located (or might in the future be located) at:

1. Wiscasset, Maine
2. Seabrook, New Hampshire
3. Vernon, Vermont
4. Rowe, Massachusetts
5. Plymouth, Massachusetts
6. Charlestown, Rhode Island
7. Waterford, Connecticut
8. Haddam, Connecticut
9. Shoreham, Long Island.

The OBE was taken as a modified Mercalli intensity VI for each plant, even though this may not be the actual situation. Differences in plant capacity were ignored in this initial study. The seismic source zones have the following frequency of occurrence and intensity range:

Zone A:	ν =15/250 per year;	$V \leq I_o \leq$ VIII.3
Zone B:	ν = 6/250 per year;	$V \leq I_o \leq$ VIII.3
Zone C:	ν =33/250 per year;	$V \leq I_o \leq$ VIII.7
Background:	$\nu = 8 \times 10^{-7}$/yr/mi^2,	$V \leq I_o \leq$ VI.3

where I_o is the maximum epicentral intensity for each source zone and ν is the annual rate of occurrence of earthquakes with $I_m \geq 5$ in each zone. These source zones were originally suggested by Richard Holt of Weston Geophysical, and the source zone parameters were developed by Professor Cornell from data supplied by Mr. Holt.

The area is shown in Figure 1. The plants are designated by a ☐ with the number inside corresponding to the number in the list above. The zones are labelled A, B, C except for the background zone. That zone consists of the triangular area bounded by the A, B, C zones.

As mentioned before, a Russian program (KKM program, for its authors: Keilis-Borok, Kronrod and Molchan) was used to compute the effect of an earthquake on these sites. The assumptions used in the description of the seismicity of the region are described in the next section of this report; the results from this phase of the study are given in the third section of this report.

ASSUMPTIONS

The following assumptions were made about the models and their parameters.

1. Magnitude-intensity relationship.

The relationship between magnitude and epicentral intensity was assumed to be

$$M = 1 + \frac{2}{3} I_o.$$

2. The frequency-of-occurrence law.

The model for frequency-of-occurrence of earthquakes used in the KKM program is

$$\log N(M) = \alpha_o - \gamma_1 (M-M_o) \qquad \text{for } M \leq MLR$$

$$\log N(M) = \alpha_o - \gamma_1 (MLR-M_o) - \gamma_2 M \qquad \text{for } M > MLR.$$

The slope of the magnitude-log of rate of occurrence curve was assumed constant; hence, there was no "point of bend" MLR or second slope γ_2. Thus our model was simply the first equation,

$$\log N(M) = \alpha_o - \gamma_1 (M-M_o)$$

where M_o is merely that magnitude for which α_o is computed, and with $M \leq MMAX_i$ $\quad i=1,4$

where $MMAX_i$ is the truncation point for the curve of magnitude vs. log of rate of occurrence curve for seismic zone i.

For purposes of the first phase of this study, it was desirable to use seismicity data which had already been used for seismic risk computations of sites in our area of interest. This would provide us with a check on the KKM program and on the interpretations of input specifications to this program. For this reason, rate-of-occurrence data was extrapolated from Figure 2 of SDDA Report No. 11.

It became obvious (after a while) that the M_o had to be chosen carefully in order to compute a slope γ_1 that gave a reasonable area (total rate of occurrence). This was due at least in part to having to "eyeball" the percentages for each level of intensity.

The parameters, then, were

	α_o	γ_1	Mo	MMAX
Zone A	-3.6904	.7028	5.0	6.53
Zone B	-4.0883	.7028	5.0	6.53
Zone C	-3.3479	.7028	5.0	6.8
Background	-4.8401	.9574	5.0	5.2

3. The model of isoseismals.

Shape and orientation:

Isoseismals, for the purposes of the first phase of this study, were assumed circular. Hence there was no variation in the orientation of the isoseismal - in essence, no orientation. Actually, the isoseismals were specified as ellipses with a major/minor axis ratio (elongation) of 1.0 and a fixed orientation with no corrections.

Areas:

The model for isoseismal area used in the KKM program is

$$\log Q_c\ (e|g) = \log \hat{Q}_c\ (e|g) + \Delta Q(g)$$

where $\log \hat{Q}_c$ is the mean value of the log of area $Q_c(e|g)$ and ΔQ is a random addition defined by a distribution function. The mean value $\hat{Q}_c$ and the magnitude M of an earthquake are related by

$$\log \hat{Q}_c\ (M|g) = a_c\ (g) + b_c\ (g)\ M$$

and the function for correction ΔQ is defined by σk where

$b_c M + \sigma k \geq \varepsilon$.

For this study, then, the following parameter values were used:

$b_c = 0.8$

$\sigma = 0.2$

$k = 2.5$

$a_c = -1.04, -1.62, -2.20, -2.76$ for intensities VI through IX respectively. These values for a_c were computed based upon the relationship

$I_{SITE} = 2.6 + I_o - 1.3 \ln (R)$ $\qquad R \geq 10$ mi

$I_{SITE} = I_o$ $\qquad R < 10$ mi.

The values for b_c and σ were obtained from SDDA Report No. 11.

Ground corrections:

The KKM program provides for corrections to the intensity of tremors at a point $\tilde{g}$ due to local soil conditions. For this study, no corrections for local soil conditions were introduced

Effect of earthquake:

A tremor at a site of intensity c causes an effect expressed by a relationship of the form:

effect (t, g, e) = DAM (g) · LAWD (g, c)

where LAWD is a relationhip between damage and intensity (a DPM) for a specific site g and DAM is a base factor for damage.

For the purposes of the first phase of this study, the base factor DAM was defined as the same for all 9 sites and the damage/intensity relationship was 1.0 for all intensities; i.e., the same damage would occur for intensity VI as for VII, VIII and IX. This makes sense when this relationship is interpreted as saying that a plant would have to shut down no matter what the intensity as long as the intensity was VI or greater.

FINDINGS

The results obtained from this phase of the study are:

1. The annual probability of 1 or more plants being hit by intensity VI or greater is 9.87×10^{-3}.
2. The annual probability of 2 or more plants being hit by intensity VI or greater is 6.87×10^{-4}.
3. The annual probability of 3 or more plants being hit by intensity VI or greater is 8.04×10^{-5}.
4. The annual probability of Seabrook being hit by intensity VI or greater is 4.28×10^{-3}. (This is of interest as a check, since this annual probability had been computed in earlier studies by Professor Cornell.)
5. The maximum number of plants which would be affected by a single earthquake is three. That is, with the assumed maximum magnitudes and attenuation law, it turns out that no more than 3 plants can experience an intensity VI or greater during a single earthquake.

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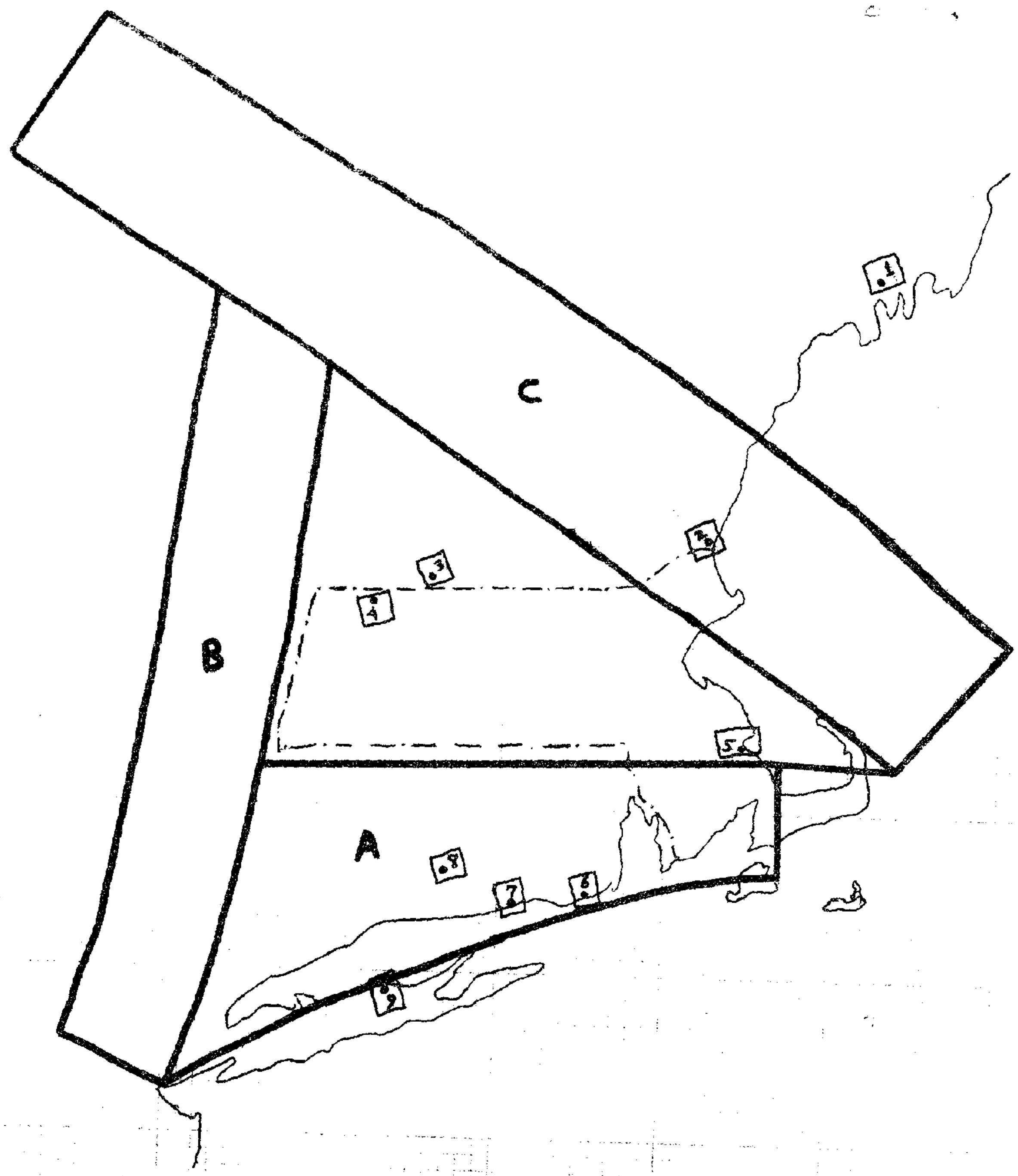

FIGURE 1.

AREA OF INTEREST FOR PHASE ONE