COMPARING THE RADIATION AND NON-RADIATION SEISMIC RISKS TO PEOPLE NEAR A NUCLEAR POWER PLANT

T. K. Hasselman (I)
Ronald T. Eguchi (II)
<u>Presenting Author</u>: T. K. Hasselman

SUMMARY

The seismic risk to people living in a community is considered, for comparison with the additional seismic risk (due to accidental release of radiation) which might be incurred if a nuclear power plant were located in that community. Risk is evaluated in terms of the average number of fatalities per year. A large portion of the non-radiation seismic risk is attributed to fatalities which occur as the result of earthquake damage to buildings, in which people spend a great majority of their time. Alternative methods for evaluating the non-radiation risk are discussed, along with illustrative examples.

INTRODUCTION

Seismic risk studies have been performed to assess the radiation risk to communities adjacent to nuclear power plants, in the unlikely event that fission products are released into the atmosphere as the result of an earthquake-initiated failure of the containment boundary. The radiation risk can be presented as an annualized fatality rate. This risk is better understood when compared with the non-radiation seismic risk, in this case, an annualized fatality rate attributable to earthquake-initiated events other than a radiation release.

There are many kinds of earthquake-initiated events which claim lives. Tsunami, landslide, damage to man-made structures and fire are among the most common. Some of these events, like tsunami and landslide, are of course major threats but depend on locale. On the other hand, damage to buildings is a universal threat, because buildings are found wherever there are people. It has been estimated that people spend 90% of their time indoors. It follows that a large portion (if not a major portion) of non-radiation earthquake fatalities result from damage to buildings. The fatality risk associated with building damage is therefore a good basis for comparison of the radiation risk associated with damage to a nuclear power plant.

TECHNICAL APPROACH

Reference 1 presents guidelines for assessing the risk to human life from the accidental release of radiation from a nuclear power plant. Recent

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(I) President, Engineering Mechanics Associates, Inc., Palos Verdes, California, USA

(II) Principal Engineer, Agbabian Associates, El Segundo, California, USA

studies have accentuated the contribution of seismic events to the plant risk (Ref. 2,3,4). The seismic portion of the radiation risk depends on the following:

- The earthquake hazard at the plant site,
- The corresponding earthquake loads which act upon plant structures and systems,
- The capacity of these structures and systems to withstand the loads,
- The accident sequences which proceed from the failure of structures and systems, and the ultimate consequences in terms of the size of a radiation release, if any, and finally,
- The atmospheric conditions which affect the transport of radioactive materials from the plant to the surrounding community.

It is important to note that the seismic portion of the radiation risk depends on the earthquake hazard at a point -- the plant site.

The non-radiation seismic risk attributable to building damage depends on the following:

- The earthquake hazard in the <u>region</u> surrounding the plant,
- The corresponding earthquake loads which act upon buildings,
- The capacity of those buildings to withstand the loads,
- The correlation of building damage with occupant fatalities, and,
- The distribution of the population among various kinds of buildings (e.g. commercial, industrial, residential) by time of day.

In contrast to the radiation risk which depends on the earthquake hazard at a single site, the non-radiation risk depends on the earthquake hazard over a broad area. The non-radiation risk is less sensitive to strong motion attenuation uncertainty than the radiation risk, because it is aggregated over this broad area. Summing minimizes the increase in risk due to attenuation uncertainty.

Community at Risk

One of the more difficult questions arising from efforts to evaluate the non-radiation seismic risk to a community is that of defining the community. The community could be defined by political boundaries (city, county, etc.), by an area within a given radius of the plant, or by an area downwind of the plant most likely to be affected by a radiation release. In any case, the choice of such a boundary is arbitrary. Depending on which boundary is chosen, the risk might vary by orders of magnitude. An objective assessment of comparative risk may be impossible to make.

As a means of circumventing this problem, an alternative approach has been proposed. It is suggested by the following question: "Given an earthquake of such a magnitute and location that it could threaten the plant, what is the risk to people from the non-radiation effects of the same earthquake?" Answering this question leads to a scenario type of risk analysis, as opposed to a regional analysis. In the scenario analysis, risk is limited to the area affected by the earthquake, or by several earthquakes of specified magnitude and location. This automatically defines the community subjected to the non-radiation risk.

The problem with the scenario approach, however, is that the choice of earthquake magnitude and location is arbitrary. This choice also can affect the non-radiation risk by orders of magnitude. For example, a Magnitude 4.0 earthquake directly beneath a plant might cause a radiation release with numerous fatalities. The corresponding non-radiation fatalities would be few, if any, since the Magnitude 4.0 earthquake affects only a small area around the plant. A larger, more distant earthquake might result in the same level of ground motion at the plant as the smaller close-in earthquake, and consequently, the same likelihood of a radiation release, but could devastate the surrounding community. In general, the scenario approach does not offer an objective measure for assessing comparative risk, either.

Fortunately, a combination of the two approaches does permit an objective evaluation of the non-radiation risk. The regional analysis has the benefit of including all seismic activity, but the region is unbounded. The scenario analysis has the benefit of establishing natural boundaries, but does not include all seismic activity. A third approach would be to define a conditional hazard distribution, based on a limited seismic activity. The limited seismic activity would include all possible earthquakes in the region surrounding the plant, "which could threaten the plant". If this latter condition is quantified such that any earthquake included in the limited seismic activity must be capable of producing, say, at least 0.1 g peak acceleration at the plant site, or alternatively a Modified Mercalli Intensity of VII, then the limitation of seismic activity is defined, and a conditional hazard distribution can be computed for the region surrounding the plant.

Risk Evaluation

Fatality risk can be presented in a number of ways. One way is to develop a probability distribution for the number of fatalities per year. From this distribution, one may calculate the average or expected fatality rate, the median fatality rate (50% probability or nonexceedence) or a probable maximum fatality rate (typically defined as having a 90% probability of nonexceedence).

Alternatively, the average fatality rate can be estimated directly, without first determining the probability distribution. In evaluating the non-radiation risk, the following basic procedure has been applied (Ref. 5).

$$L = \sum_{J}\sum_{I} N(I,J)\ D(I)\ E(J) \tag{1}$$

where

L = The average fatality rate (fatalities per year),

$N(I,J)$ = The number of earthquakes per year producing an intensity, I, in an area, J,

$D(I)$ = The average number of fatalities per person at risk, corresponding to an earthquake of intensity, I,

$E(J)$ = The number of people at risk in area, J.

This basic computational procedure may be refined by considering other variables such as type of building (commercial, residential, etc.), time of day, and the distribution of the total population by building type and time of day.

In applying the foregoing procedure, one must be careful to choose the mesh size, i.e. the size of each Jth area, so that the fatality rate is not overestimated by the implicit assumption that the higher intensities apply to the entire Jth area. For example, a Richter Magnitude 5.0 earthquake may result in an intensity of MMI = X over an area of only a few square kilometers. If county-sized areas are used in computing the average fatality rate, the contribution from Intensity X will be grossly exagerated. Since Magnitude 5.0 earthquakes occur more frequently than larger magnitude events, the average fatality rate may be affected significantly.

An alternative computational procedure, applicable under certain conditions, helps to clarify this point.

$$L = \sum_{M} \sum_{I} N(M)\ A(M,I)\ D(I)\ E \qquad (2)$$

where

L = The average fatality rate (fatalities per year).

$N(M)$ = The number of earthquakes per year having magnitude, M, which originate in a particular source zone,

$A(M,I)$ = The area covered by intensity, I, which is generated by an earthquake of magnitude, M,

$D(I)$ = The same as previously defined,

E = The number of people at risk per unit area, assumed to be constant over the region of interest.

In the simple form presented, the above procedure applies to a region dominated by a single source zone, in which the population is uniformly distributed.

A key relationship in this procedure is A(M,I), the intensity area given as a function of earthquake magnitude. Such a relationship may be empirically derived, or may be derived analytically from indirect empirical relationships.

As an example of the latter, the curves shown in Figure 1 were derived from three empirical relationships: (1) peak ground acceleration as a function of earthquake magnitude and distance from fault (Ref. 6); (2) earthquake magnitude as a function of fault length (Ref. 7); and, (3) peak ground acceleration as a function of Modified Mercalli Intensity (Ref. 8).

The relationship D(I) which appears in both equations may be derived from Tables 9.II and 9.III of Ref. 9, in the case of commercial/industrial buildings. Different relationships are required for residential structures.

The relationships N(I,J) and N(M) are obtained from the earthquake hazard model, which is governed by equations of the form

$$\int_{M}^{\infty} N(m)\, dm = 10^{(a - bM)} \tag{3}$$

where a and b are empirical constants.

EXAMPLES

Some simple examples help to illustrate the foregoing discussion. Figure 2 illustrates the regional earthquake hazard for a single line source, in this case a fault 125 kilometers long. The hazard is depicted by contours which separate areas of different intensity. These particular contours correspond to a return period of 1000 years.

Two sites, labeled A and B in Figure 2, are shown to illustrate the conditional and unconditional earthquake hazards previously discussed. Suppose that a nuclear power plant were located at Site A (a purely hypothetical example). The unconditional earthquake hazard at that site is represented by the straight solid line shown in the frequency vs. intensity plot of Figure 3. The conditional hazard at the same site is represented by the long-dashed line, which coincides with the solid line for $\mathrm{MMI} \geq \mathrm{VII}$. In this example the limiting condition on seismic activity excludes all earthquake events which result in intensities lower than MMI = VII at the plant. The conditional frequency curve for Site B is represented by the short-dashed line. Here, the frequency of occurrence is seen to be lower than either of the other two frequency curves. The further a site is from the plant, the lower the frequency curve.

Table 1 shows how the average fatality rate is computed for a region surrounding the 125 kilometer fault shown in Figure 2. Through this example, one gains appreciation for the relative contributions made by earthquakes of different magnitudes, all of which may occur on the fault, and the extent of ground shaking produced by each one.

The values in Table 1 represent non-radiation seismic risk based on the unconditional earthquake hazard. Although the calculations were made using Equation (2), the same results should be obtained using Equation (1), provided that a sufficiently small mesh size is used. Use of the conditional earthquake hazard would reduce the computed non-radiation risk significantly, since the smaller magnitude earthquakes are eliminated for building sites distant from the plant.

The computed fatality rate of 340 fatalities per year does not seem unreasonable considering that a total area exceeding 5000 square kilometers is affected. For the assumed population density of 200 people per square kilometer, more than a million people are at risk. In this example, Magnitude 7.0 earthquakes occur on the average of once every 100 years.

CONCLUSIONS

Several ways of evaluating the non-radiation seismic risk to people near a nuclear power plant have been discussed. In this paper, the non-radiation seismic risk is treated as a bench mark for comparing the additional risk posed by the possibility of an earthquake-caused radiation release from the plant. The concept of a conditional earthquake hazard has been introduced. It is not necessarily recommended for seismic risk computations over the unconditional hazard; each has its place depending on the nature of he comparison between radiation and non-radiation seismic risks. The basis for comparison, as well as the computational procedure, should be carefully selected in any practical application.

REFERENCES

1. ANS-IEEE-NRC, PRA Procedures Guide: A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants, NUREG/CR-2300, January 1983.

2. Kennedy, R. P., and Ravindra, M. K., Seismic Fragilities for Nuclear Power Plant Risk Studies, presented at Second CSNI Specialist Meeting on Probabilistic Methods in Seismic Risk Assessment for Nuclear Power Plants, Livermore, California, May 16-19, 1983.

3. Commonwealth Edison Company, Zion Probabilistic Safety Study, 1981.

4. Consolidated Edison Company of New York and Port Authority of State of New York, Indian Point Probabilistic Safety Study, 1982.

5. Eguchi, R. T., and J. H. Wiggins, (1979), "A Bayesian Seismic Risk Study of California, with Loss Estimates", Technical Report No. 79-1328-1, Prepared for U.S. Geological Survey, J. H. Wiggins Company, Redondo Beach, California.

6. "Near-Source Attenuation of Peak Horizontal Acceleration", Bull. Seism. Soc. Am., Vol. 71, No. 6, Dec. 1981.

7. Slemmons, David B., "Faults and Earthquake Magnitude", State-of-the-Art for Assessing Earthquake Hazards in the U.S. Report 6, U.S. Army Engineer WES, Misc. P, S-73-1, May 1977.

8. O'Brien, L. S., Murphy, J. R., LaHoud, J. A., "The Correlation of Peak Ground Acceleration Amplitude with Seismic Intensity and Other Physical Parameters", Computer Sciences Corp. for U.S. Nuclear Reg. Comm., NUREG-0143, March 1977.

9. Lomnitz, C. and E. Rosenblueth, ed., Seismic Risk and Engineering Decisions, Elsevier Scientific Publishing Co., New York, 1976.

Table 1. Average Fatality Rate Computation

M	I	N(M)	A(M,I)	D(I)	N × A × D
E.Q. Magn.	MMI	Events/Year	km^2/Event	Fatalities/Person	Fatalities/yr./Person/km^2
4	VIII	5.205	16.20	.000625	.0527
	IX		3.72	.0136	.2635
	X		0.25	.048	.0620
5	VIII	0.655	90.39	.000625	.0370
	IX		24.63	.0136	.2194
	X		3.56	.048	.1121
6	VIII	0.0825	544.53	.000625	.0281
	IX		180.17	.0136	.2022
	X		46.59	.048	.1845
7	VIII	0.0104	3761.42	.000625	.0245
	IX		1525.01	.0136	.2157
	X		606.00	.048	.3025
					1.7042

Assuming a population density, E, of 200 people per square kilometer (representative of a major metropolitan area),

$$L = 1.70 \times 200 = 340 \text{ fatalities per year.}$$

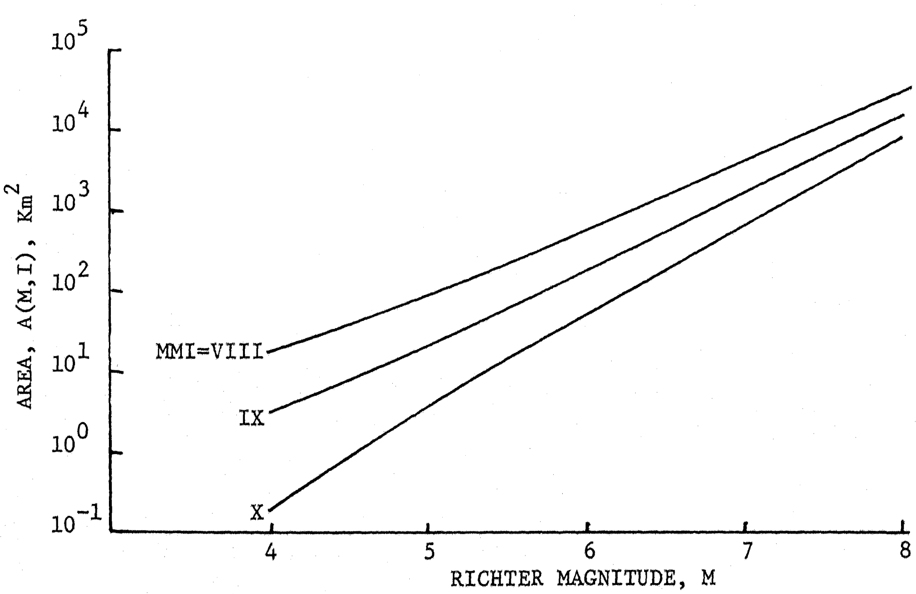

Figure 1. Intensity Area vs. Magnitude

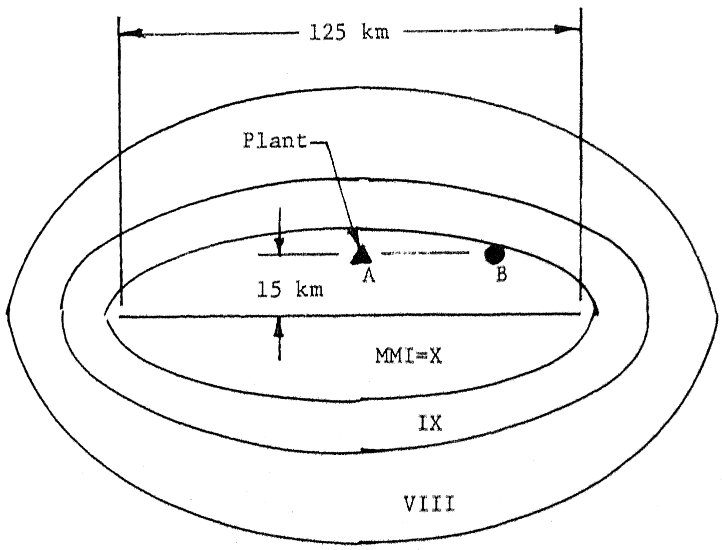

Figure 2. Unconditional Earthquake Hazard Contours for a 1000 Year Return Period

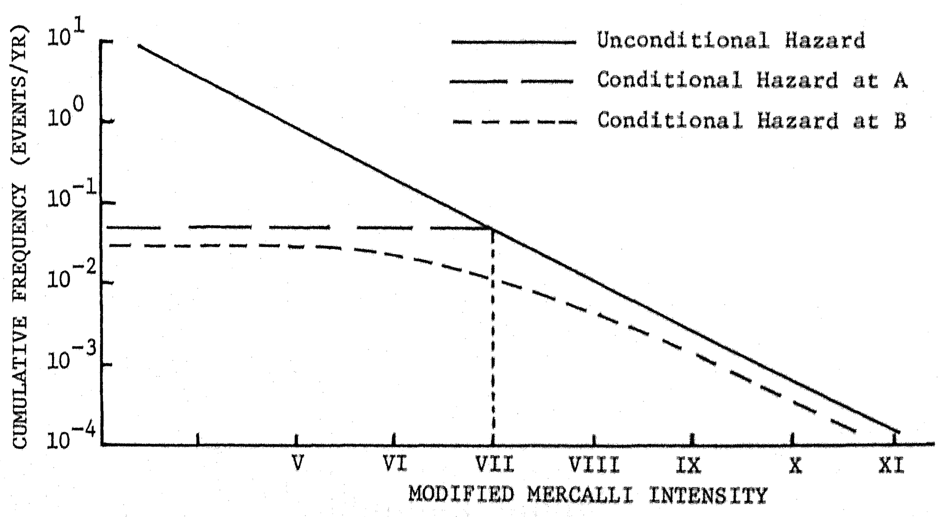

Figure 3. Occurrence Frequencies for Conditional and Unconditional Earthquake Hazards.