COMBINED PARAMETER PROBABILITY ANALYSIS
GENERAL ELECTRIC TEST REACTOR

Prepared for

General Electric Company
San Jose, California

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TABLE OF CONTENTS

	Page
1. COMBINED PARAMETER PROBABILITY ANALYSIS	1-1
2. APPROPRIATE CANTILEVER LENGTH	2-1
3. SUMMARY	3-1
REFERENCES	R-1

1. COMBINED PARAMETER PROBABILITY ANALYSIS

A probabilistic analysis was conducted to determine combined parameter values for surface rupture offset and vibratory ground motion (Ref. 1). Since it is unrealistic to use the most extreme value for each parameter in a combined load analysis, a probabilistic methodology was developed to obtain combined values which have a uniform likelihood of occurrence equal to a specified criterion. The final result of this analysis is shown in Figure 1-1 which gives the interaction curve for the two potential earthquake effects. Instead of plotting offset displacement as the variable representing surface rupture offset, reactor building cantilever length is used, since this parameter is related to the structural response of the reactor building. The vibratory ground motion variable shown in Figure 1-1 is effective ground acceleration, which is the parameter to which the ground response spectrum is anchored.

As shown in Figure 1-2, a cantilever configuration is caused for certain locations of a shear under the reactor building. Since a new shear is equally likely to occur at any point beneath the foundation, assuming that it occurs beneath the reactor building, non-cantilever cases are more likely to occur. However, for these non-cantilever cases, the additional stresses in the concrete safety-related structures are not significant; hence for conservatism, the analysis focuses on only those offsets which lead to a cantilever configuration. It is important to note that the occurrence of a cantilever case is dependent on where the offset occurs, not on the size of the offset displacement. Thus, whether the offset displacement is one foot, two feet, or some other value, the resulting cantilever case is the same.

Figure 1-3 shows the relationship between an offset, soil pressure diagram, and reactor building cantilever length. The configuration shown is highly conservative since in reality the soil pressure diagram and cantilever length will vary as ground vibration occurs. The cantilever length, l_c, is defined as the length between the edge of the conservative soil pressure diagram and the outside surface of the reactor building wall. In this analysis, l_c is measured at the time of zero acceleration in the reactor building. This provides a reference value that can be included with the specified vibratory ground motion in the structural analysis.

The derivation of the probabilistic formulation for combined earthquake parameters is given in Reference 1. It can be easily demonstrated that the points (i.e., a and l_c) on the interaction curve shown in Figure 1-1 satisfy the following equation:

$$Q\left[\frac{\ln(a/0.3g)}{\ln\sqrt{2}}\right] \cdot \frac{24-l_c}{76} = \frac{P_{cr}}{P} \qquad (1\text{-}1)$$

where:

- a = effective ground acceleration (g-units)
- $Q[\cdot]$ = Complementary cumulated standardized normal distribution
- P_{cr} = Criterion probability value
- P = Probability of the occurrence of a future surface rupture offset at <u>any</u> point beneath the reactor building.

This interaction equation is valid for effective ground acceleration values greater than zero and for cantilever lengths greater than zero and less than 20 feet, where the latter value is the maximum length which can occur at zero acceleration. The points given by the interaction equation form a curve which separates values of cantilever length and surface rupture offset that exceed the criterion probability value (i.e., above curve) from values that are less than the criterion (i.e., below curve).

By expressing the interaction equation in terms of the probability P, the combined parameter analysis is related to the previous probability analysis for potential surface rupture offset of any size beneath the reactor building (Ref. 2). In this prior analysis the probability of a future offset was assumed to depend on unknown, undiscovered shears in the region and on offsets occurring on the existing shears. It was shown in the previous analysis that the best estimate annual probability value for surface rupture offset of any size at any point beneath the reactor building is 10^{-6}, with a conservative range based on parametric studies between 10^{-6} and 10^{-5}.

Equation 1-1 expresses the interaction between parameters in terms of P/P_{cr}. Thus the ratio between the calculated probability for an offset beneath the reactor building and the criterion probability value is significant. The curve shown in Figure 1-4 (which is repeated from Figure 1-1) is based on P/P_{cr} equal to 10, which is conservative since it has been shown that a more realistic value is close to unity (Ref. 2). The interaction curve is applicable for the combination of P and P_{cr} annual probability values which are also shown in Figure 1-4, where these values correspond to a P/P_{cr} ratio of 10. Note that if P is equal to P_{cr}, the interaction curve vanishes and no offset case beneath the reactor building should be considered.

The surface rupture offset acceptance criterion is selected to be in the range of 10^{-5} to 10^{-4} annual probability. This criterion is based on the results of recent probability analyses performed for existing nuclear power plants and on other criteria stated below. Based on analyses performed by the USNRC Probabilistic Analysis Staff (PAS) and others, it was learned that the average probability of core damage for seven existing nuclear power plants is about 10^{-4}. This value is well known and represents an average of median level probability values calculated for the existing plants analyzed. Recent analyses performed by the USNRC PAS show that the probability of large release categories (i.e., 60 to 70 percent of the core iodine and 25 percent curies of biosignificant isotopes) for existing plants is about 10^{-5}. This is consistent with the values found in the Reactor Safety Study (Ref. 3).

Another benchmark criterion value is the probability level implicitly selected for the safe shutdown earthquake (SSE). It is widely known that the SSE effective ground acceleration corresponds to a 10^{-4} to 10^{-3} probability range (Refs. 4 and 5).

To be consistent with the selection of SSE accelerations and in light of calculated probability values for degradation of core and large category release for existing nuclear power plants, a conservative criterion range for combined surface rupture offset and vibratory ground motion is 10^{-5} to 10^{-4}. Since the calculated value at the conservative end of the range (i.e., 10^{-5}) is equal to the low criterion value (which is also conservative), no combined case should be considered, since the P/P_{cr} ratio would be equal to unity. However, if a combined set of parameters must be considered, the interaction curve shown in Figure 1-4 is very conservative since it represents cases where the calculated probability of an offset beneath the reactor building is 10 times the criterion value.

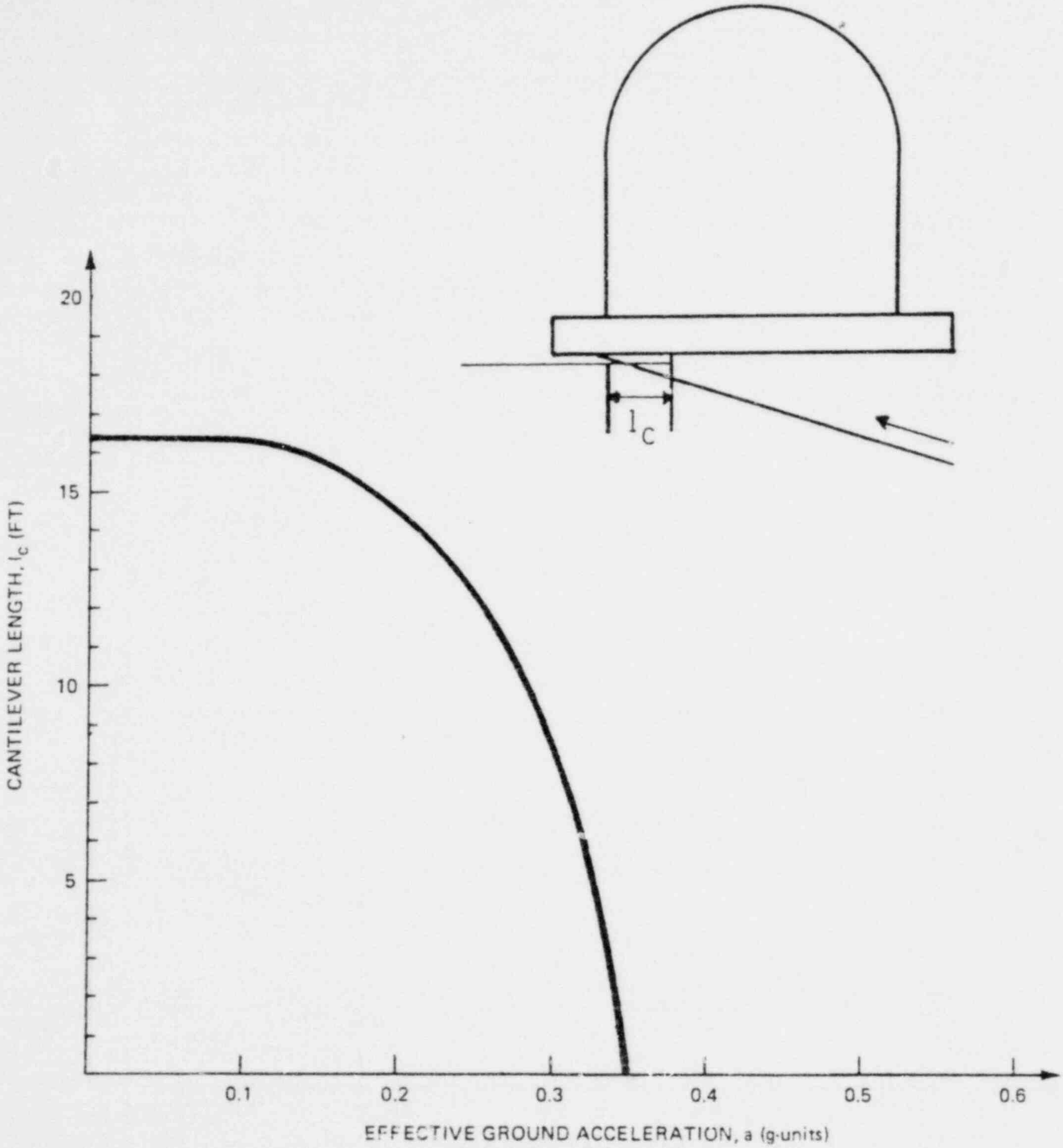

FIGURE 1-1 COMBINED PARAMETER INTERACTION CURVE

$l_c < l_{c\ max}$

$l_c = l_{c\ max}$

$l_c > l_{c\ max}$

(cantilever case
not possible)

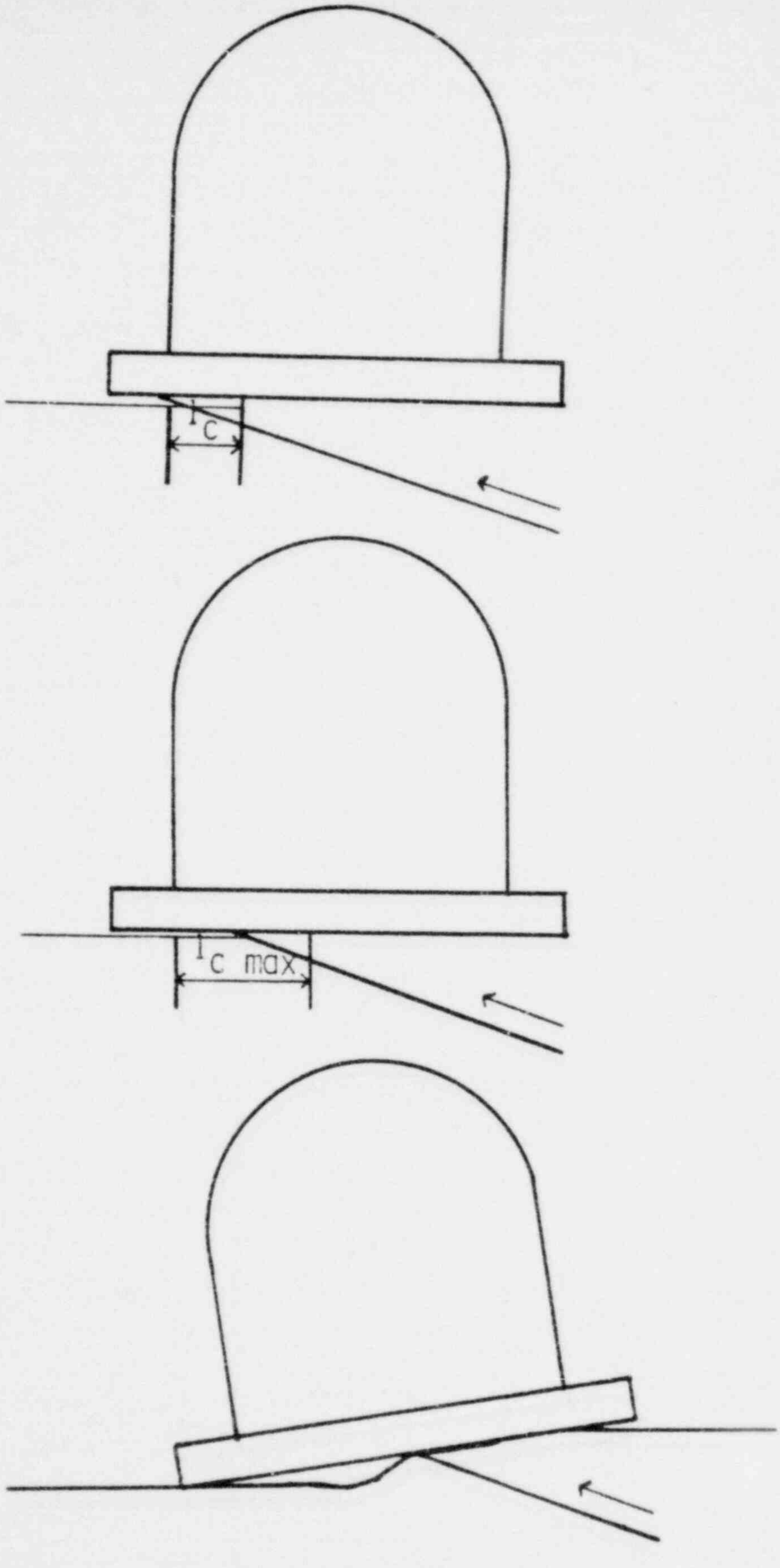

FIGURE 1-2 EFFECTS OF OFFSET

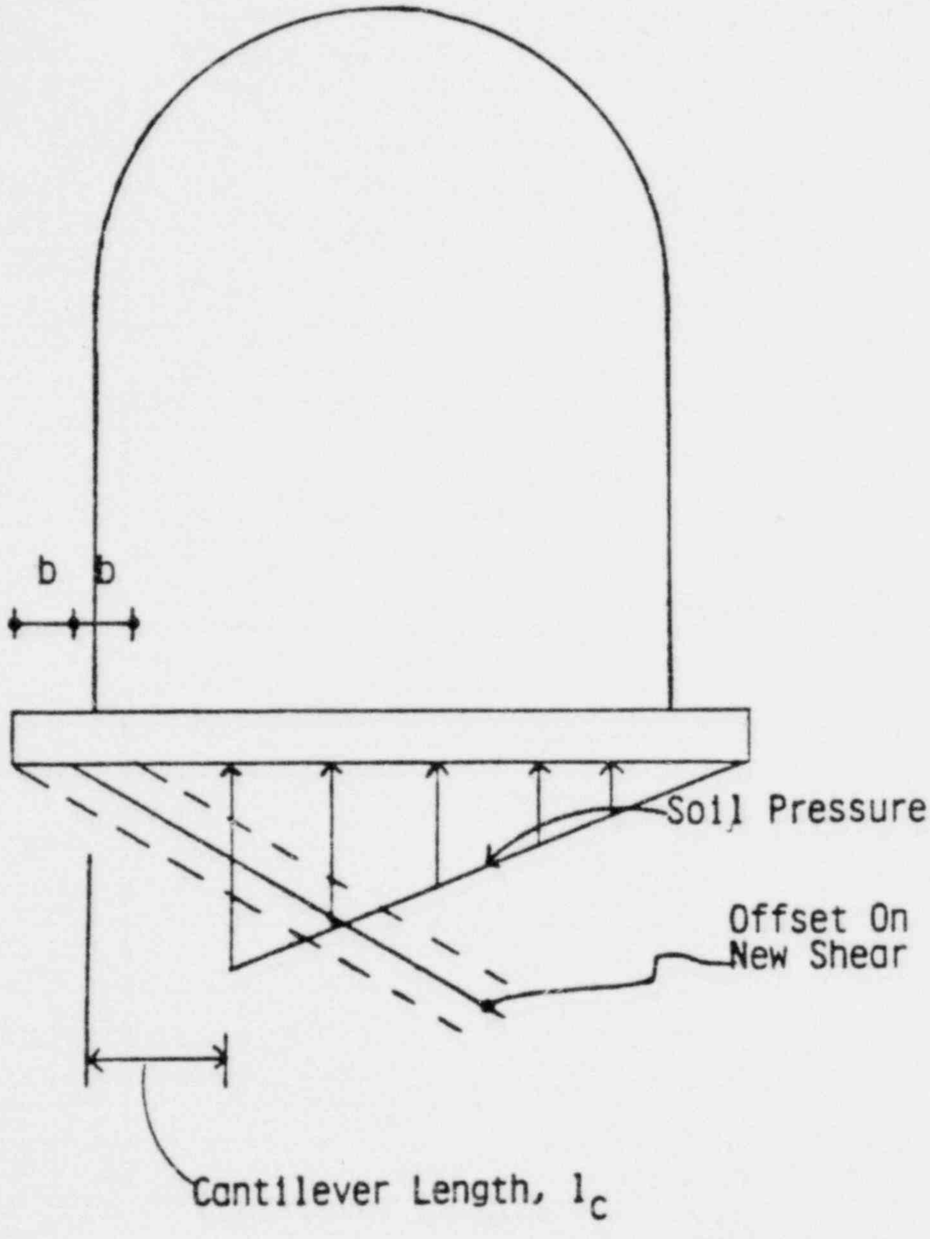

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FIGURE 1-3 RELATIONSHIP BETWEEN OFFSET, SOIL PRESSURE DIAGRAM, AND CANTILEVER LENGTH

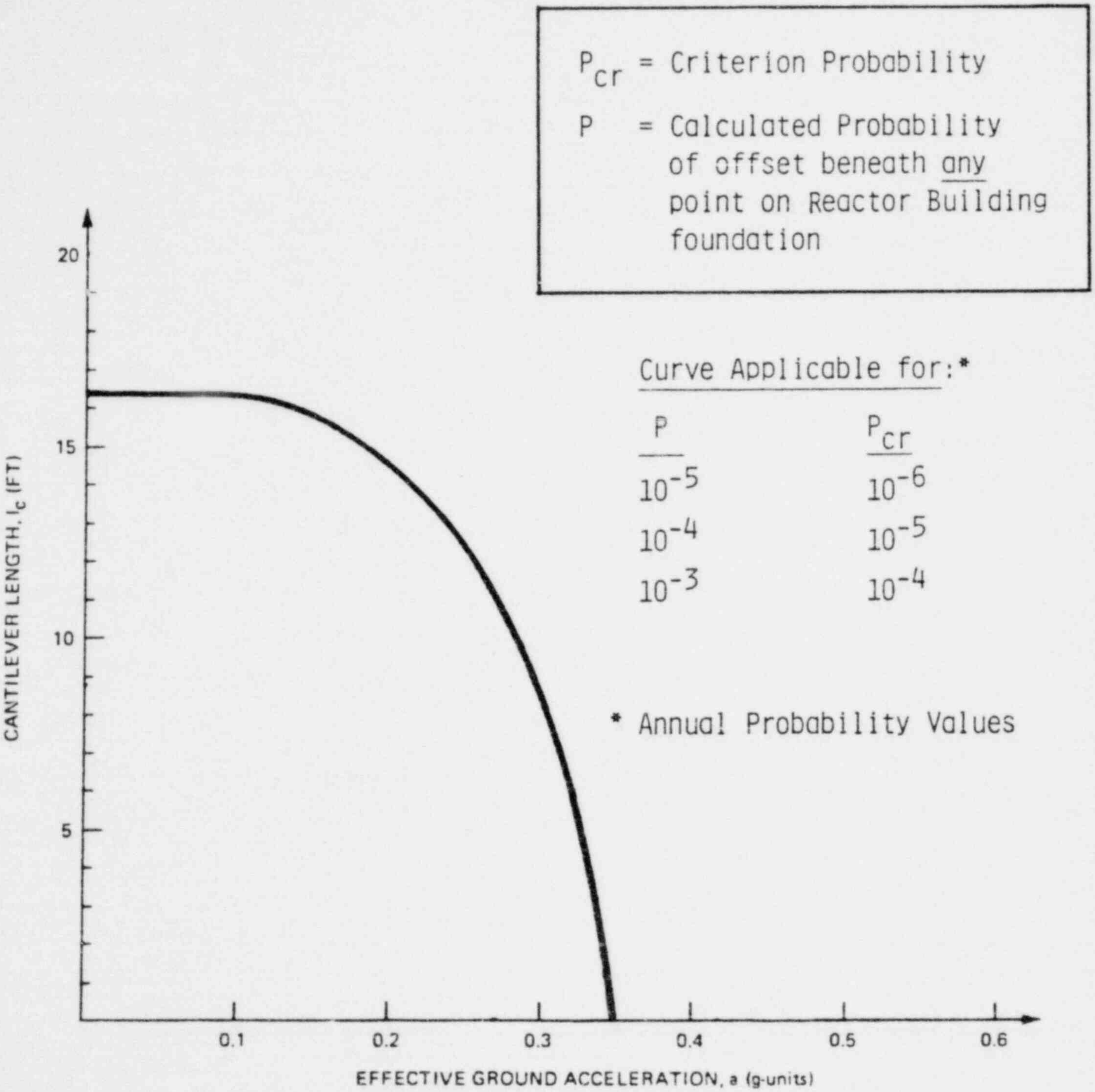

FIGURE 1-4 COMBINED PARAMETER INTERACTION CURVE

2. APPROPRIATE CANTILEVER LENGTH

An alternate approach was developed for determining the cantilever length to be used in a combined parameter analysis, where the maximum acceleration is used. Since it is highly unlikely that: (1) a surface rupture offset will occur, (2) a surface rupture offset will occur off the existing shears, (3) a surface rupture offset will occur beneath the reactor building, and (4) a cantilever case will be caused, it is reasonable to use an average cantilever length assuming that a future offset occurs beneath the reactor building. As shown below, the average cantilever length is 3 feet. This result reflects the fact that it is unlikely that a cantilever case will occur even if a future offset intersects the reactor building foundation. It is more likely that simple beam support or wall loading cases, which impose low stresses in the safety-related concrete, occur. The average 3-ft cantilever length is an appropriate value to be used with the maximum value of ground acceleration in a combined effects analysis.

In obtaining the average cantilever length, it is assumed that a surface rupture offset occurs beneath the reactor building and that it is equally likely to occur anywhere along the 72-foot wide foundation mat. Based on this assumption, an average cantilever length, $\overline{l}_c$, is calculated by the following equation.

$$\overline{l}_c(x) = \int_0^{72} l_c(x) \cdot p(x)\, dx \qquad (2\text{-}1)$$

where:

$$l_c(x) = \begin{cases} 0 & 0 \le x \le 4 \\ x-4 & \text{for: } 4 \le x \le 24 \\ 0 & 24 \le x \le 72 \end{cases}$$

$$
P(x) = \begin{cases} \dfrac{x/4}{68} & 0 \leq x \leq 4 \\ 1/68 & \text{for: } 4 \leq x \leq 68 \\ \dfrac{(72-x)/4}{68} & 68 \leq x \leq 72 \end{cases}
$$

Figure 2-1 shows the reactor building foundation dimensions and probability density function, p(x), which gives the probability for locations of offset given that one occurs beneath the reactor building. Note that the finite width of the offset causes the probability density function to taper to zero at both sides of the foundation.

Performing the calculation for Equation 2-1, the average cantilever length is 2.94 feet which is rounded to 3 feet. This calculation demonstrates that even if an offset occurs beneath the reactor building, it is improbable that a large cantilever configuration will be created.

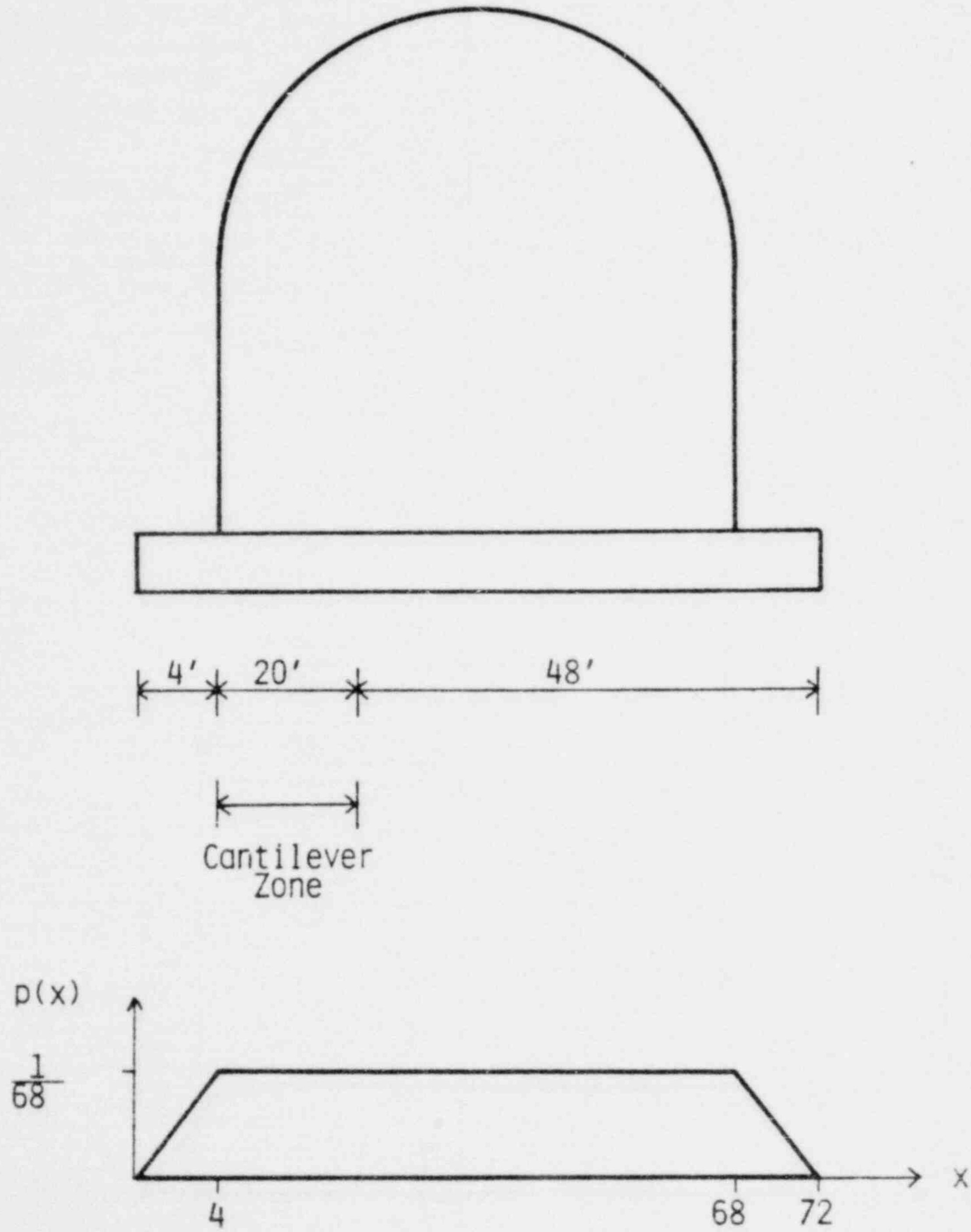

FIGURE 2-1 AVERAGE CANTILEVER LENGTH CALCULATION PARAMETERS

3. SUMMARY

In summary, Figure 1-4 provides an interaction curve of surface rupture offset and vibratory ground motion values which represent cases where the calculated probability of an offset beneath the reactor building is 10 times the criterion value. Although General Electric Company believes that surface rupture offset of any size should not be considered as a design basis event beneath the reactor building, the curve in Figure 1-4 represents a rational and conservative basis for selecting combined earthquake parameters, if surface rupture offset must be considered. Using the alternate probabilistic approach it was shown that the average cantilever length is 3 feet, assuming an offset occurs beneath the reactor building. This is an appropriate value, which was determined independently of ground acceleration, to be used in a combined effects analysis where the acceleration parameter is selected to be a maximum value.

REFERENCES

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5. Lawrence Livermore Laboratory, "Recommended Revisions to Nuclear Regulatory Commission Seismic Design Criteria," prepared for USNRC, NUREG/CR-1161RD, May 1980.

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