THE ASSESSMENT OF TORNADO MISSILE HAZARD TO NUCLEAR POWER PLANTS

J. Goodman and J. E. Koch

Bechtel Power Corporation,
12400 E. Imperial Hwy,
Norwalk, CA 90650, U.S.A.

ABSTRACT

Numerical methods and computer codes for assessing tornado missile hazards to nuclear power plants are developed. The method of calculation has been based on the theoretical model developed earlier by authors. Historical data for tornado characteristics are taken from computerized files of the National Severe Storms Forecast Center and potential missiles characteristics are adopted from an EPRI report [1].

Due to the uncertainty and randomness of tornado and tornado-generated missiles' characteristics, the damage probability of targets has highly spread distribution.

The propos d method is very useful for assessing the risk of not providing protection to some nonsafety-related targets whose failure can create a hazard to the safe operation of nuclear power plants.

1. INTRODUCTION

The ability of tornadoes to generate and propel missiles is a commonly recognized natural hazard to the safe operation of nuclear power plants.

A detailed EPRI study on tornado missile hazard has been presented by Twisdale et al. [1]. However, the results of this study are highly specific and cannot readily be applied to other tornado missile problems. Therefore, there is a need for an explicit analysis that is applicable to the broad spectrum of problems. This paper describes an analysis that fulfills that need.

The probability of damage by tornado missile to a target, P_T, can be expressed as the multiplication of three probabilities: 1) frequency of the tornado occurrence, P_o, at the nuclear power plant site per year; 2) conditional probability of hitting the target, P_H, given the tornado occurrence; and 3) conditional probability of damage, P_D, given a hit.

This paper considers numerical methods of calculating the above probabilities.

2. THEORETICAL MODEL

The main characteristics of tornadoes, which determine the probability of damage, are the tornado path area, a, and Fujita scale, F[2].

The tornado path area, a, is a product of the length, L, and width, W, of the tornado's devastative track on the earth's surface:

$$a = L \times W \tag{1}$$

The Fujita scale, F, is a characteristic of tornado intensity that depends on the damaging wind speed according to Table 1.

Let f(a, F) be a probability density that a striking tornado has path area a and Fujita scale F.

Table 1

Relationship Between Fujita Scale F and Damaging Wind Speed w

Fujita Scale F	Range for the Maximum Wind Speed (m/s)
F0	$18 < w \leq 32$
F1	$32 < w \leq 50$
F2	$50 < w \leq 70$
F3	$70 < w \leq 92$
F4	$92 < w \leq 116$
F5	$116 < w \leq 142$
F6	$142 < w \leq 170$

The probability, P_o, of tornado occurrence with given a and F at a nuclear power plant site per year according to Thom [3] can be defined as:

$$P_o = \frac{\nu a}{S} \tag{2}$$

where ν is the frequency of tornado occurrences in the specified area, S, having the same tornado occurrence characteristics as the plant site.

The conditional probability of hitting a target, P_H, given a tornado strike to the plant site was developed by Goodman and Koch [4, 5]. There, the tornado missile motion is shown to be a Markovian process satisfying the Fokker-Planck equation [6]. The solution of this equation for the Green function averaged over many tornado histories, yields the expression for P_H in the form:

$$P_H\ (a, F) = n_p A\ \eta(F)\ \psi\ (z,F) \tag{3}$$

where η_p is the surface density of distribution of potential missiles, A is the area of the target, $\eta(F)$ is the probability of missile injection, $\psi(z, F)$ is the height distribution of airborne tornado missiles, and z is the elevation of the target.

The conditional probability of damage given a missile hit is denoted as $P_D(F)$. The total probability of damage per year, P_T, given tornado characteristics a and F is:

$$P_T = \frac{\nu \cdot a}{S}\ n_p\ A\ \eta(F)\ \psi\ (z,F)\ P_D\ (F) \tag{4}$$

The probability density, f(a, F), can be presented in the form:

$$f(a, F) = f(a)\cdot\phi\,(F|a) \qquad (5)$$

where f(a) is the distribution of tornado path area a considered by Thom [3] and $\phi\,(F|a)$ is the conditional probability of Fujita scale, F, given a path area a.

In fact, the total probability, P_T, depends on some additional parameters because of uncertainty of ν, n_p, $\eta(F)$, $\psi\,(z, F)$ and $P_D(F)$. Denote the set of parameters which determine the distributions of ν, n_p, $\eta(F)$, $\psi\,(z,F)$ and $P_D\,(F)$ as $\vec{\xi}$ and their distributions as $g\,(\vec{\xi})$. Then a complete distribution function for the total probability is:

$$f(a,F,\vec{\xi}) = f(a)\cdot\phi(F|a)\cdot g(\vec{\xi}) \qquad (6)$$

The expectation $\bar{P}_T$ of the total probability $P_T(a, F, \vec{\xi})$ given by eq. (4) can be found by formula:

$$\bar{P}_T = \iint \frac{\nu\cdot a}{S}\, n_p\, A \left[\sum_{F=1}^{6} \phi\,(F|a)\ \eta\,(F)\ \psi\,(z,F)\ P_D\,(F)\right] f(a)g(\vec{\xi})da d\vec{\xi} \qquad (7)$$

However, the standard deviation of the probability, P_T, is so high that point estimate (7) becomes meaningless. Therefore, the distribution for P_T has to be developed.

Using the Monte Carlo method, parameters a, F and $\vec{\xi}$ are simulated according to the density function (6). For every trial set of parameters, $P_T\,(a, F, \xi)$ is calculated, and then, using the standard procedures, the distribution of the total probability of damage, P_T, is obtained.

3. FREQUENCY ν OF TORNADO OCCURRENCE AT SOME SPECIFIED AREA S.

A computer code using the historical data file of the National Severe Storms Forecast Center [7] has been developed. This code estimates the empirical distributions for frequency, ν, of tornado occurrence at some specified area s. For compatibility of results, area S = 10,000 sq. mi. is always used.

The input data contain the latitudes and longitudes bounded a square by 100 mi x 100 mi with the center at the plant site.

However, because the square 100 mi x 100 mi can include water or a less populated area with a low efficiency of tornado reporting, we have an option to calculate the frequency ν_r for a county, several counties, or even a state. In this case, the frequency ν_r is referred to the area S_r of the county or state. The frequency ν referred to the area S = 10,000 sq. mi. can be estimated by the formula:

$$\nu = \nu_r\cdot\ \frac{S}{S_r} \qquad (8)$$

In addition, the computer code provides the best analytical fit to the empirical distribution and reports median, upper, and lower limits; mean; and variance.

4. JOINT DISTRIBUTION OF TORNADO PATH AREA A AND FUJITA SCALE F

A computerized file at the National Severe Storms Forecast Center keeps information about tornado length L in tenths of miles, tornado width W in tens of feet, and Fujita Scale F.

The product of recorded numbers L and W gives the tornado path area a in miles-feet according to formula (1). A classification of tornadoes according to path area a is given in Table 2.

Table 2

Classification of Tornadoes According to Path Area a

Classification	Range of Tornado Path Area a (mi-ft.)
A1	$1 < a \le 10$
A2	$10 < a \le 10^2$
A3	$10^2 < a \le 10^3$
A4	$10^3 < a \le 10^4$
A5	$10^4 < a \le 10^5$
A6	$10^5 < a \le 10^6$
A7	$10^6 < a \le 10^7$

The computer code selects complete records containing L, W, and F, and belonging to some geographical area. Based on these data, it develops the correlation matrix between a and F scales.

The correlation matrix for the U.S.A. for 32 years, based on 14058 complete records, is given in Table 3.

A special computer code using least squares method fits the discrete joint distribution for a and F scales by a two-dimensional lognormal distribution f(a,w) of tornado path area a and wind speed w:

$$f(a,w) = \frac{1}{2\pi\sigma_a\sigma_w aw} \exp\left\{- \frac{1}{2(1-\rho^2)} \left[\left(\frac{\ln a-\mu_a}{\sigma_a}\right)^2 + \left(\frac{\ln w-\mu_w}{\sigma_w}\right)^2 - 2\rho \left(\frac{\ln a-\mu_w}{\sigma_a}\right) \left(\frac{\ln w-\mu_\delta}{\sigma_u}\right)\right]\right\} \qquad (9)$$

Table 3

Correlation Matrix Between a and F Scales
(U.S.A., 1950-1981)

	F0	F1	F2	F3	F4	F5	F6	Marginal Distribution For Path Area
A1	.0565	.0369	.0064	.0006	.0000	.0000	.0000	.1004
A2	.0744	.1122	.0396	.0040	.0004	.0001	.0000	.2307
A3	.0411	.1445	.0990	.0202	.0034	.0001	.0000	.3084
A4	.0108	.0730	.1097	.0506	.0170	.0017	.0000	.2628
A5	.0018	.0131	.0299	.0277	.0178	.0038	.0000	.0942
A6	.0000	.0001	.0011	.0014	.0008	.0001	.0000	.0036
A7	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
Marginal Distribution For Fujita Scale	.1847	.3799	.2857	.1046	.0393	.0058	.0000	

where μ_a, σ_a, μ_w, σ_w, and ρ are parameters of a lognormal distribution which are the expectations of the following expressions:

$$\mu_a = E\ (\ln a) \tag{10}$$

$$\mu_w = E\ (\ln w) \tag{11}$$

$$\sigma_a^2 = E\ \left[(\ln a - \mu a)^2\right] \tag{12}$$

$$\sigma_w^2 = E\ \left[(\ln w - \mu w)^2\right] \tag{13}$$

$$\rho = \frac{E\left[(\ln a - \mu a)(\ln w - \mu_w)\right]}{\sigma_a \sigma_w} \tag{14}$$

The relationship between F scale and tornado wind speed w is given in Table 1. The relationship between A-scale and tornado path area a is given in Table 2. For the correlation matrix given in Table 3, parameters (10)-(14) have numerical values:

$$\mu_a = -2.7001 \tag{15}$$

$$\mu_w = 4.6450 \tag{16}$$

$$\sigma_a = 1.2260 \quad (17)$$

$$\sigma_w = 0.4130 \quad (18)$$

$$\rho = 0.51418 \quad (19)$$

Our computer code allows evaluation of parameters (10)-(14) for every state in the U.S.A. and any larger geographical area.

5. SURFACE DENSITY OF POTENTIAL MISSILES n_p

In the EPRI study [1], the number of potential missiles in the missile origin zone (2.5×10^7 ft^2 including the plant site) is provided. For a two-unit plant with both units under operation, the possible range for the number, N_p, of potential missiles is:

$$5836 \leq N_p \leq 6196 \quad (20)$$

Dividing eq. (20) by the missile origin area, we find the range for the average density of potential missiles:

$$2.33 \times 10^{-4} \leq \bar{n}_p \leq 2.48 \times 10^{-4} \quad (21)$$

Assuming the lognormal distribution for average density $\bar{n}_p$ with a 90 percent confidence interval given by inequality (21) we can readily find the parameters of this distribution (see Table 4).

An analysis of zone distribution of potential missiles in the area of 2.5×10^7 ft^2 based on data given in [1] shows that the maximum deviation from the average density for a plant under operation is 2.55.

The local density of potential missiles n_p can be presented in the form:

$$n_p = K_n \bar{n}_p \quad (22)$$

where K_n is the nonuniformity coefficient.

Assuming for coefficient K_n a lognormal distribution with upper limit 2.55 and median equal to 1, we find the distribution for n_p as a product of two lognormal distributions for $\bar{n}_p$ and K_n. The parameters of the distribution for n_p are given in Table 4.

Table 4

Density of Potential Missiles

	Lower Limit (5th Percentile)	Median (50th Percentile)	Upper Limit (95th Percentile)
Average density ($\bar{n}_p$)	2.33×10^{-4}	2.40×10^{-4}	2.48×10^{-4}
Nonuniformity (K_n) coefficient	0.39	1.00	2.55
Local density (n_p)	9.42×10^{-5}	2.40×10^{-4}	6.13×10^{-4}

6. PROBABILITY OF INJECTION $\eta(F)$

The probability that a potential tornado missile could become airborne or the probability of injection was considered in [5]. This probability is different for potential missiles located on the surface and at some elevation. For the surface potential missiles, the probability of injection is lower because the minimum restraining force is gravity. For elevated potential missiles, the minimum restraining force is friction, which is less than gravity. For both cases, the maximum restraining force is assumed five times greater than gravity. This restraint can be overcome only by tornadoes F5 and F6.

For the surface potential missiles (so-called vertically injected missiles) the distribution of $\eta(F)$ is shown in Table 5.

Table 5

Probability of Injection $\eta(F)$ For Surface Potential Missiles

Fujita Scale	Lower Limit	Median	Upper Limit
F2	0.0001	0.0017	0.0305
F3	0.0006	0.0086	0.1230
F4	0.0143	0.0527	0.1943
F5	0.0450	0.1050	0.2449
F6	0.1089	0.1761	0.2847

This distribution is created by random orientation of potential missiles and random distribution of restraining coefficients. Tornadoes of Fujita scales F0 and F1 cannot lift the potential missiles specified in [8] from the surface.

For the elevated potential missiles (so-called horizontally injected missiles) the distribution of injection probability $\eta(F)$ is shown in Table 6.

Table 6

Probability of Injection $\eta(F)$ For Elevated Potential Missiles

Fujita Scale	Lower Limit	Median	Upper Limit
F0	0.0008	0.0119	0.1756
F1	0.0020	0.0292	0.4274
F2	0.0029	0.0435	0.6528
F3	0.0098	0.0866	0.7657
F4	0.0789	0.2546	0.8218
F5	0.2160	0.4310	0.8602
F6	0.3529	0.5593	0.8865

7. HEIGHT DISTRIBUTION OF AIRBORNE MISSILES ψ (z, F)

The height distribution of airborne missiles ψ (z, F) for a uniformly spread source of potential missiles is addressed by [5]:

$$\psi(z, F) = \begin{cases} \dfrac{B(z)}{B(0)}, & 0 \leq z \leq h_o \\ \dfrac{1}{B(0)} e^{\alpha_2 (F)\cdot(h_o - z) - \alpha_1 (F)\cdot z}, & z > h_o \end{cases} \tag{23}$$

where

$$B(z) = e^{-\alpha (F) z} + \left[\frac{\alpha_1 (F)}{\alpha_2 (F)} - 1\right] e^{-\alpha (F) h_o} \tag{24}$$

According to [5], parameters $\alpha_1(F)$ and $\alpha_2(F)$ can be found from the formula:

$$\alpha = - \lim_{\Delta\tau \to 0} \left[\frac{\overline{\Delta z}}{\frac{1}{2}\overline{(\Delta z^2)}}\right] \tag{25}$$

where $\overline{\Delta z}$ and $\overline{(\Delta z^2)}$ are average displacement and squared displacement in the vertical direction for time $\Delta\tau$.

The differential equation of tornado missile motion in the vertical direction is:

$$\ddot{z} = a_z - g \tag{26}$$

where g is the gravitational constant and

$$a_z = \frac{R_z}{m} \tag{27}$$

where m is the missile mass and R_z is the z-component of the random aerodynamic force.

For a small increment of time $\Delta\tau$:

$$z = z_o + v_{oz} \Delta\tau + (a_z - g) \frac{(\Delta\tau)^2}{2} \tag{28}$$

Because of zero averaged values

$$\overline{v_{oz}} = 0 \tag{29}$$

$$\overline{a_z} = 0 \tag{30}$$

due to random distribution of velocity and acceleration directions, the average increment in elevation is:

$$\overline{\Delta z} = \frac{g(\Delta\tau)^2}{2} \tag{31}$$

Similarly

$$\overline{(\Delta z^2)} = \overline{v_{oz}^{\ 2}} \cdot (\Delta\tau)^2 + \ldots \tag{32}$$

where higher degrees of $\Delta\tau$ are omitted.

Putting eq. (31) and eq. (32) into eq. (25) we obtain:

$$\alpha = \frac{g}{\overline{v_z^{\ 2}}} \tag{33}$$

where $v_{oz}^{\ 2}$ is replaced by $v_z^{\ 2}$ because the average $\overline{v_z^{\ 2}}$ does not depend on time.

In the region

$$0 \le z \le h_o \tag{34}$$

the number of horizontally injected missiles is dominant because the probability of horizontal injection is much higher.

For horizontally injected missiles, it can be assumed, at the moment of injection, the vertical velocity of the missile is equal to zero. Multiplying (26) by $v_z = \dot{z}$ and integrating from the moment of injection to the moment of striking the ground yields the following:

$$\frac{v_g^{\ 2}}{2} = \overline{a_z v_z} \cdot t + gz_o \tag{35}$$

where

z_o = initial elevation of missile,

t = flight time of missile,

v_g = vertical velocity at the ground

Because

$$\overline{a_z v_z} = 0 \tag{36}$$

due to eq. (29) and eq. (30) and independence of a_z and v_z:

$$v_g^{\ 2} = 2\ gz_o \tag{37}$$

It is clear that

$$\overline{v_z^2} = \frac{1}{2} v_g^2 \qquad (38)$$

where $\overline{v_z^2}$ is an average squared velocity in a vertical direction for a missile falling from elevation z_0.

Therefore,

$$\overline{v_z^2} = gz_o \qquad (39)$$

For uniform distribution of initial elevation z_o, from $z_o = 0$ to $z_o = h_o$ the average for all missiles is:

$$\overline{v_z^2} = \frac{1}{2} gh_o \qquad (40)$$

Putting (40) into (33) yields:

$$\alpha_1 = \frac{2}{h_o} \qquad (41)$$

In this approximation, the parameter $\alpha_1(F)$ does not depend on Fujita scale F.

Now, consider the region

$$z > h_o \qquad (42)$$

In this region there are only vertically injected missiles. Let w be the damaging wind speed. According to [7] and [8], the range for the maximum missile velocity is:

$$\frac{1}{4} w \leq v_{max} \leq \frac{1}{2} w \qquad (43)$$

Because

$$\overline{\vec{v}^2} = \frac{1}{2} v_{max}^2 \qquad (44)$$

and

$$\overline{v_z^2} = \frac{1}{3} \overline{\vec{v}^2} \qquad (45)$$

The following expression is obtained:

$$\overline{v_z^2} = \frac{1}{C} w^2 \tag{46}$$

Hence,

$$\alpha_2(F) = \frac{Cg}{w^2} \tag{47}$$

where coefficient C is in the range:

$$24 \leq C \leq 98 \tag{48}$$

Coefficient C is assumed to have lognormal distribution with a median value of 24 and an error factor of 2.

If we address to any Fujita scale, F, a corresponding middle value from the intervals given in Table 1, then this velocity w can be found as:

$$w = 6.30\ (F + 2.5)^{1.5} \tag{49}$$

putting eq. (49) into eq. (47) we obtain:

$$\alpha_2(F) = \frac{C_o}{(F+2.5)^3} \tag{50}$$

where

$$C_o = \frac{9.81 \cdot C}{6.30^2} \tag{51}$$

8. CONDITIONAL PROBABILITY OF DAMAGE P_D (F) GIVEN A MISSILE HIT

The conditional probability of damage, $P_D(F)$, given a missile hit, depends on the missile impact velocity, mass, shape, incidence angle and orientation. It also depends on the barrier reinforcement, material strengths, and loadings.

Let F_j be the minimum Fujita scale of a tornado which can cause target damage by the jth sort of missiles with given penetration characteristics. A simplistic and conservative expression for the probability $P_D(F)$ is given by the formula:

$$P_D(F) = \sum_{j=i}^{N} \lambda_j(F) \cdot \eta(F-F_j) \tag{52}$$

where $\lambda_j(F)$ is the fraction of damaging missiles of the jth sort and $\eta(F-F_j)$ is a step-function:

$$\eta(F-F_j) = \begin{cases} 0\ , & F<F_j \\ 1\ , & F\geq F_j \end{cases} \tag{53}$$

The fraction of damaging missiles λ_j (f) can be presented in the form:

$$\lambda_j(F) = \lambda_{oj} \cdot \mu_j\ (F) \tag{54}$$

where λ_{oj} is an initial fraction of the jth sort of missiles and $\mu_j(F)$ is a damaging ratio which shows the fraction of the jth sort of missiles having ability to damage a target for an F-scale tornado.

A more rigorous approach substitutes the discrete distribution function $\mu_j(F) \cdot \eta(F-F_j)$ by continuous cumulative function $D_j(w)$:

$$P_D(w) = \sum_{j=i}^{N} \lambda_{oj} \cdot D_j(w) \tag{55}$$

where D_j (w) is a fragility of target for the jth sort of missiles. Conditional probability of target damage, $P_{HD}(F)$, given a tornado strike is given by expression:

$$P_{HD}(a,F,\vec{\xi}) = P_H(a,F,\vec{\xi}) \cdot P_D(F) \tag{56}$$

where P_H is determined by eq. (3) and P_D by eq. (52) or eq. (55).

9. MULTIPLE TARGET STRIKE

In some cases, the probability of damaging several targets is of interest. For example, some systems consist of n redundant subsystems. Failure of any m subsystem constitutes the failure of the system. In this case, we are interested in the probability of damage to any m out of n subsystems of the system due to tornado missile impact.

Conditional probability of damage to any m out of n subsystem, $P_{m,n}$, given a tornado strike to the plant site and assuming that impacts of different targets are independent, is given by binominal distribution:

$$P_{m,n} = \frac{n!}{(n-m)!m!} \left(P_{HD}\right)^m \left(1-P_{HD}\right)^{n-m} \tag{57}$$

where P_{HD} is given by eq. (56).

The dependency between strikes of different targets can be taken into account by a special cluster correction factor $F_{m,n}$ considered in [4]:

$$F_{m,n} = 1 + \frac{S_1}{S_m} x^m \left(\frac{1-xP_H}{1-P_H}\right)^{n-m} \quad , \ n > 1 \tag{58}$$

where S_1 is the effective area of a local cluster of airborne missiles, S_m is the missile origin zone area ($s_m = 2.5 \times 10^7$ ft^2), x is the ratio of density of missiles in the cluster to the mean density of missiles, and P_H is given by eq. (3).

The total probability of damaging any m out of n targets per year is:

$$P_T = \frac{\nu a}{S} \cdot P_{m,n} \cdot F_{m,n} \tag{59}$$

In the case of one target (n = 1, m = 1) the formula (56) automatically reduces to the formula (4).

10. NUMERICAL EXAMPLE

Consider a nuclear plant with a spray pond as its ultimate heat sink. The spray pond is not protected against tornado missile impact. It is known that the loss of 10 percent of the spray arms is the maximum damage that the spray pond can sustain without losing the ability to reject sufficient heat from the plant systems.

Assume that the spray pond has 100 nozzle sets with an effective area of 230 ft^2 of each set for the spectrum of potential missiles specified in [1]. We adopt Thom's [3] distribution f(a) for tornado path area and nationwide distribution for conditional probability ϕ (F|a) and frequency ν. The result of Monte Carlo simulation is shown in Table 7. This result indicates that tornado-generated missiles are not a significant threat to the spray system and no physical barriers are required to protect the spray pond from tornado-generated missiles.

The spread of the damage probability distribution is very high because of high uncertainty and randomness of tornado and tornado-generated missile characteristics.

Table 7

Probability of Damage to m Nozzle Sets Per Year

Number of Nozzle Sets Damaged, m	Lower Limit	Median	Upper Limit
1	2.56×10^{-9}	3.65 x 10-7	7.30 x 10-4
2	1.33×10^{-12}	4.00×10^{-9}	5.33×10^{-6}
3	2.92×10^{-16}	2.43×10^{-11}	4.86×10^{-7}
4	5.32×10^{-20}	1.24×10^{-13}	5.35×10^{-8}
5	6.48×10^{-24}	5.83×10^{-16}	3.89×10^{-9}
6	7.09×10^{-28}	2.36×10^{-18}	2.36×10^{-10}
7	7.77×10^{-32}	1.73×10^{-20}	2.59×10^{-11}
8	9.45×10^{-36}	6.30×10^{-23}	2.21×10^{-12}
9	8.05×10^{-40}	2.30×10^{-25}	2.64×10^{-13}
10	8.39×10^{-44}	1.01×10^{-27}	2.52×10^{-14}

11. CONCLUSION

The numerical method of tornado missile hazard to nuclear power plants is developed. This method is very useful for assessing the risk of not protecting nonsafety-related targets whose failures will create a hazard to the safe operation of nuclear power plants.

REFERENCES

1. Twisdale, L. A., et al., "Tornado Missile Risk Analysis," EPRI-768, 769, May (1978)

2. Fujita, J. J., "Proposed Characterization of Tornadoes and Hurricanes by Area and Intensity," the University of Chicago, SMRP Research Paper No. 91, February (1971)

3. Thom, H.C.S., "Tornado Probabilities," Monthly Weather Review, Oct.-Dec., 730, (1963)

4. Goodman, J. and Koch, J. E., "Conditional Probability of the Tornado Missile Impact Given a Tornado Occurrence," Proceedings of International ANS/ENS Topical Meeting on Probabilistic Risk Assessment, Vol. I, pp 419-424, Port Chester, New York, September (1981)

5. Goodman, J. and Koch, J. E., "The Probability of a Tornado Missile Hitting a Target," Nuclear Engineering and Design, 74, (1983)

6. Ta-You Wu, "Kinetic Equations of Gases and Plasmas," Addison-Wesley Publishing Company, Palo Alto-London-Don Mille, Ontario

7. U. S. Tornado Breakdown by Counties 1950-1981, U.S. Department of Commerce National Oceanic and Atmospheric Administration, National Weather Service, National Severe Storms Forecast Center, Room 1728, Federal Building, 601 E. 12th Street, Kansas City, Missouri, 64106.

8. Standard Review Plan, U. S. Nuclear Regulatory Commission, NUREG-0800, Section 3.5.1.4, July (1981)