ATTACHMENT 1

Probabilistic Analysis of Tornado Missile Hazard For Dresden Nuclear Power Station

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I. INTRODUCTION

Loads generated during tornado strike have been categorized as extreme environmental loads which must be considered for the design of nuclear power plants. Some objects during tornado translation through the plant site get air-borne and become missiles. These postulated missiles may become hazardous to the plant by virtue of their impactive loading characteristics. As with other extreme loads, the objectives of the tornado missile hazard assessment are to determine the probabilities of the loads, load characteristics, and structural response effects and to provide specific design provisions, if necessary, for reducing to acceptable levels the probability of damage occuring to essential structures.

In this report the probability of tornado generated missiles striking the safety-related areas at Dresden Station is investigated. These safety-related areas (targets) are listed as follows:

1. The exterior intake and exhaust pipes and silencers of the standby (swing) diesel generator for Units 2 and 3 located on the roof (elevation 526'-6") of Unit 2/3 diesel generator building (target 1).

2. The Unit 2 exterior intake and exhaust pipes and silencers located on the roof (elevation 561'-6") of Unit 2 turbine building (target 2).

3. Cribhouse containing water pumps and piping systems for cooling purposes (target 3).

These areas are not currently protected against the strike of tornado missiles. It is necessary to point out that the Dresden plant is otherwise designed for the extreme environmental loads. The probabilities of tornado missile damage to the above targets described above are conservatively estimated, it is therefore concluded that the event of tornado generated missiles striking these particular safety-related targets is extremely unlikely and specific design provisions are not necessary to further reduce these probabilities.

The probability of striking the cribhouse (target 3) is estimated to be 2.96×10^{-6} per year. However, this by no means implies that the pumps and piping systems installed inside the cribhouse will result in having such a probability of being damaged by tornado missiles. In fact, the shielding strength of the exterior concrete block walls was not taken into consideration in modeling the cribhouse. This factor would reduce the probability even further.

The methodology used in estimating these probabilities is developed by the Research Triangle Institute (RTI) of North Carolina for the Electric Power Research Institute (EPRI) of California and is documented in Reference 1 through 5. The listing of TORMIS computer code which was used in estimating the conditional probabilities is given in Reference 1. A brief description of TORMIS is presented in the Appendix.

The tornado characteristics used in the analysis are given in Section II. Section III describes the plant geometry and missile zones. This section also identifies the targets under investigation. In Section IV, the results of the study are presented and discussed. Section V contains the summary and conclusions.

II. TORNADO CHARACTERISTICS

The tornado parameters which are pertinent to this study are the following:

1. The probability of a tornado strike.
2. The maximum tornado windspeed. (A sum of rotational and translational components).

Table 2-1 shows the probabilities of tornado strike for six F-scale tornado intensities for the Dresden site. These probabilities are calculated from the cumulative tornado strike probability curve given in Reference 5 considering the tornado wind speed intervals shown in Table 2-1. These tornado wind speed intervals are taken from Reference 1 and are built-in features of TORMIS Code.

According to the Regulatory Guide 1.76, Reference 7, the safety-related structures must be designed to withstand a maximum tornado windspeed interval of 295 to 360 mph. The maximum tornado windspeed interval used for this study is 277-300 mph. This windspeed interval corresponds to F-scale tornado intensity 6 (Table 2-1) and is the highest listed in TORMIS. It will be shown in Section IV that tornados with windspeeds exceeding 300 mph contribute insignificantly to the total probability of strike on a target.

III. PLANT MODEL

In this section, a description of the plant structures, the barrier thicknesses and their material properties, missile characteristics, and the concentration of missiles in the plant vicinity, are presented. Figure 3-1 shows the layout of eleven structures considered in the simulation model of the plant. Each structure is modeled as a paralellopiped having sides representing the concrete walls, the upper plane representing the roof, and the bottom plane representing the ground surface. Intermediate floors are omitted for simplicity. The safety-related intake and exhaust pipes, and silencers located on the Unit 2/3 diesel generating building roof and turbine building roof are referred to as targets 1 and 2, respectively. It is noted that structure 2 is a dummy structure modeled to represent intake and exhaust pipe, and silencer of the Unit 2/3 diesel generating building. The wall number 50 of structure 9 represents the exterior intake and exhaust pipes and silencers of the turbine building (see Figures 3-1 and 3-2). To simplify the modeling, Dresden Unit 1 is not considered. The elimination of the Dresden Unit 1, which partly protects Unit 2, from the model will yield conservative estimate of strike probability.

Unit 2, from the model will yield conservative estimate of strike probability.

The plant barriers are identified in Figure 3-2. There are 66 barriers in the model, 6 barriers representing each plant structure. Details of these structures are given in Table 3-1. It is noted from this table that the basemat elevation of the plant structures, except the dummy structure, is considered the same as the ground level which is 517'-6".

TORMIS code does not specifically use the actual barrier thickness. Instead, it estimates the probabilities of perforation through a range of barrier thicknesses. For Dresden model, four such thicknesses were used, i.e., 6", 9", 12", and 15". All barriers are assumed concrete barriers with crushing strengths of 4000 psi for reactor buildings and 3500 psi for the rest of the buildings. It is important to point out that neither wall thicknesses nor concrete strengths enter in the calculation of tornado missile strike probabilities. Therefore, the concrete thicknesses and strengths listed above are used merely for TORMIS input requirement and are not needed otherwise.

TORMIS code has a capability which can be used to specify site-dependent missile types and their characteristics. For Dresden study, six different missile types are used which are consistent with NRC tornado missile spectrum. These missile types and their characteristics are built-in in TORMIS as default parameters. The missile parameters such as weights, areas, etc., stored in TORMIS for these missiles, are consistent with those given by NRC in spectrum 2 of Reference 6. It should be noted that spectrum 2 does not identify 3" diameter pipe as tornado missile. In this study this missile was considered instead of wooden plank which is known to have insignificant damage potential.

Next step in the plant model is the specification of various missile zones, missile types in each zone, and the corresponding missile density in each zone.

The division of plant vicinity into various missile zones is established by considering the main features of the plant site such as the laydown areas, switch yards, parking lots etc. From this consideration, the Dresden plant site was divided into twelve distinct missile zones as shown in Figure 3-3. Including the main plant complex, these zones cover approximately 0.57 square miles of plant site. A radius of 2000 ft. is considered in establishing the outer boundary of the outer zones. It is assumed that the tornado strike beyond a distance of 2000 ft. will have negligible probability of damaging the structures (Reference 1). The specification of the tornado missile types and the number of missiles of each type in each missile zone requires site-specific investigation and collection of data for realistic assessment of the strike probability. For the purpose of this report, the information presented in Table Vl-2 of Reference 1 is used. This information is based on the analysis of a number of field surveys. Specifically, the missile densities from Reference 1 were used to obtain the number of missiles in each zone as given in Table 3-2. It is seen in Table 3-2 that a total of 6030 missiles is postulated over an area of about 0.57 square miles giving approximately one missile for every 2600 square ft. of area. The breakdown of these total missiles into various missile types is based on Table Vl-2 of Reference 1. The distribution of missile types thus obtained for each zone is shown in Table 3-3.

The missile injection heights for each missile type and zone are taken from Table IV-3 of Reference 1 and are reproduced here in Table 3-4. The distribution within the limits shown is considered to be uniform for each type. The injection height is the vertical distance above ground level through which the initial elevation of the missile is sampled.

IV. PRESENTATION AND DISCUSSION OF RESULTS

In this section a brief description of the methodology used in estimating the probability of tornado generated missiles striking the targets 1 and 2 is presented, along with the details of the simulation process involved. From the results of these simulations and the probability of tornado strike, as discussed in Section II, the strike probabilities are calculated. Based on these probabilities, the possibility of the design provision necessary to protect these targets in question is determined.

The probability of tornado generated missiles striking a target is calculated by the use of following formula:

$$P\ (A_j) = \sum_{i=1}^{n} P\ (A_j | F_i) \cdot P\ (F_i) \tag{4.1}$$

where:

A_j is the event of tornado generated missiles striking target j.

$P\ (A_j)$ is the probability of occurrence of event A_j per year.

$P\ (F_i)$ is the probability of occurrence of tornado of intensity F_i per year.

$P(A_j|F_i)$ is the conditional probability of tornado generated missiles striking target A_j given that the tornado of intensity F_i has occured.

n is the number of tornado intensities, as discussed in Section II. In this study n = 6 (tornado intensities F-1 through F-6).

The values of $P(F_i)$ for Dresden site are shown in Table 2-1. The values of conditional probabilities are estimated by Monte Carlo Simulation using the TORMIS Code. Ten thousand (10,000) missile histories were simulated for each tornado intensity involving one hundred tornados of intensity F_i and one hundred missile histories in each tornado. Each missile trajectory of a tornado is traced to determine the possibility of the missile striking any of the target structures. Of all the missiles, those striking a target are recorded and the single missile probability of a target strike is then determined by the total number of hits divided by the total number of simulations (100).

From the single missile probability, the multiple missile probability is calculated using the following relationship:

$$P^M(A_j|F_i) = 1 - (1 - P^S(A_j|F_i))^N \quad (4.2)$$

where:

$P^S(A_j|F_i)$ is the conditional single missile probability that event A_j occurs during a tornado strike with tornado intensity F_i.

$P^M(A_j|F_i)$ is the conditional single missile probability that event A_j occurs during a tornado strike with tornado intensity F_i.

N is the number of missiles sampled by that tornado.

By varying the tornado parameters such as tornado path width, direction, etc., 100 tornados are sampled for each F-scale tornado intensity. The final conditional probability, $P(A_j|F_i)$, for tornado F-scale intensity F_i is calculated by taking the average of individual multiple missiles probability values.

This process is repeated for all the tornado intensities and the conditional probabilities are calculated.

Table 4-1 shows the conditional probabilities of the strike on targets 1, 2 and 3 for six tornado intensities, F-1 through F-6, respectively.

Using Equation 4-1, the final probability of strike is calculated for each target and is summarized in Table 4-2. The last column of this table shows percent contribution of six F-scale tornado intensities to each target hit probability. In these calcualtions, conditional probabilities marked with an asterisk in Table 4-1 were treated as zero.

From Table 4-2, it is seen that the probabilities of tornado missile damage to targets 1 and 2 are 1.65×10^{7} and 2.25×10^{7} respectively. The cribhouse (target 3) has a probability of 2.96×10^{-6}/ year of being hit by tornado missiles. It is concluded from these results that no protection of any kind is needed for these three targets.

It is worth mentioning here that tornado windspeed interval, 277-300 mph, for tornado intensity 6 as shown in Table 2-1, is different from the corresponding interval of 295-360 mph as specified in Regulatory Guide 1.76 (Reference 7). It is seen from Table 2-1 that windspeeds with values in excess of 300 mph must be associated with a probability of occurrence less than 4.35×10^{-7} for the Dresden site. Therefore, the difference of windspeed interval noted above cannot significantly affect the probability of strike on all three targets are not of significance for the purpose of this report.

V. SUMMARY AND CONCLUSIONS

A tornado missile damage probability analysis has been performed for Dresden Units 2 and 3 using TORMIS code. Because safety-related structures at Dresden plant are protected against tornado missiles except the three target areas addressed in the preceding sections, the aim of the study is to evaluate the risk to this specific window of vulnerability. By employing the most severe tornado occurrence and strike data obtained through analysis of 29 years of tornado missiles spectrum, the probabilities of tornado generated missiles striking these specific targets are conservatively estimated. The probabilities of striking the exterior intake and exhaust pipes and silencers (target 1) located on Unit 2/3 diesel generator building and the exterior intake and exhaust pipes and silencers (target 2) located on turbine building of Unit 2 are estimated to be 1.65×10^{-7} per year and 2.25×10^{-7} per year, respectively. The probability of striking the cribhouse (target 3) is estimated to be 2.96×10^{-6} per year.

VI. REFERENCES

1. Twisdale, L. A. and Dunn, W. L., "Tornado Missile Simulation and Design Methodology, Vol. 1 Simulation Methodology, Design Applications, and TORMIS Computer Code," NP-2005, Electric Power Research Institute, Palo Alto, California, August 1981.

2. Twisdale, L. A. and Dunn, W. L., "Tornado Missile Simulation and Design Methodology, Vol. 2, Model Verification and Data Base Updates," NP-2005, Electric Power Research Institute, Palo Alto, California, August 1981.

3. Twisdale, L. A. et. al., "Tornado Missile Risk Analysis," NP-768, Electric Power Research Institute, Palo Alto, California, May 1978.

4. Twisdale, L. A. et. al., "Tornado Missile Risk Analysis - Appendixes," NP-769, Electric Power Research Institute, Palo Alto, California, May 1978.

5. McDonald, J. R., "Tornado and Straight Wind Hazard Probability for Dresden Nuclear Power Reactor Site, Illinois." Prepared by Institute for Disaster Research, Texas Tech. University, Lubbock, Texas, May 1980.

6. U. S. Nuclear Regulatory Commission, Standard Review Plan, "Missiles Generated by Natural Phenomenon," Section 3.5.1.4, Washington D. C., Rev. 2, July 1981.

7. U. S. Nuclear Regulatory Commission, Regulatory Guide 1.76, "Design Basis Tornado for Nuclear Power Plants," Washington D. C., April 1974.

TABLE 2-1 PROBABILITY OF TORNADO STRIKE AND ASSOCIATED WINDSPEED INTERVAL FOR SIX TORNADO F-SCALE INTENSITIES AT DRESDEN SITE

Tornado Intensity	Probability, P (F_i) (per year)	Windspeed Interval (mph)
F-1	1.05×10^{-4}	73-103
F-2	0.61×10^{-4}	103-135
F-3	3.50×10^{-5}	135-168
F-4	1.65×10^{-5}	168-209
F-5	6.80×10^{-6}	209-277
F-6	4.35×10^{-7}	277-300

TABLE 3-1 DESCRIPTION OF PLANT STRUCTURES

Building No.	Building	Approximate Plan Size	Height	Base Elevation	Remarks
1	2/3 Diesel Generator	55'-0" x 45'-0"	9'-0"	517'-6"	
2	2/3 Diesel Generator	55'-0" x 45'-0"	12'-0"	526'-6"	A dummy structure to simulate intake & exhaust pipes and silencers
3	Reactor Unit-3	150'-0" x 120'-0"	140'-6"	517'-6"	
4	Reactor Unit 2	150'-0" x 120'-0"	140'-6"	517'-6"	
5	Radwaste	125'-0" x 110'-0"	12'-0"	517'-6"	
6	Radwaste	75'-0" x 110'-0"	33'-6"	517'-6"	
7	Cribhouse	175'-0" x 75'-0"	25'-0"	517'-6"	
8	Turbine Unit-3	285'-0" x 130'-0"	104'-6"	517'-6"	
9	Turbine Unit-2	310'-0" x 130'-0"	104'-6"	517'-6"	
10	Turbine Unit-3	200'-0" x 50'-0"	49'-6"	517'-6"	
11	Turbine Unit-2	200'-0" x 50'-0"	49'-6"	517'-6"	

TABLE 3-2 DISTRIBUTION OF TOTAL TORNADO MISSILES IN THE PLANT VICINITY

Zone	Description	Area Sq. ft. 10^{-3}	No. of Missiles/ Sq. ft. x 10^{3}	Total Missiles
1	Main Complex	1020.0	0.487	500
2	138kv Switch Yard	850.0	0.347	300
3	Storage Area	850.0	0.648	550
4	Discharge Canal	1920.0	0.039	75
5	345kv Switch Yard	2750.0	0.347	955
6	Storage Area	2250.0	0.648	1460
7	Parking	700.0	0.946	665
8	Storage Area	1680.0	0.648	1090
9	Railroad Tracks	360.0	0.487	175
10	Parking	150.0	0.946	145
11	Natural Area	1470.0	0.022	35
12	Intake Canal	1995.0	0.039	80
		16.0×10^{6} Sq. ft.		6030

TABLE 3-3 DISTRIBUTION OF MISSILE TYPES IN EACH MISSILE ZONE

TORNADO MISSILES

Zone	Rod	Pole	3" pipe	6" pipe	12" pipe	Plank*	Auto	Total
1	115	0	115	115	115	0	40	500
2	57	57	57	57	57	0	15	300
3	108	108	108	108	108	0	10	550
4	14	14	14	14	14	0	5	75
5	184	184	184	184	184	0	35	955
6	288	288	288	288	288	0	20	1460
7	0	15	0	0	0	0	650	665
8	215	215	215	215	215	0	15	1090
9	40	0	40	40	40	0	15	175
10	0	3	0	0	0	0	142	145
11	0	30	0	0	0	0	5	35
12	15	15	15	15	15	0	5	80
							Σ	6030

***Note:** In this study, the 3 inch diameter pipe was considered instead of a wooden plank which is of insignificant damage potential.

TABLE 3-4 MISSILE INJECTION HEIGHT FOR VARIOUS ZONES, FT.

Zone	Rod	Pole	All Pipes	Plank	Auto
1	5 - 15	15 - 25	5 - 15	*	5 - 10
2	5 - 25	15 - 25	5 - 25	*	5 - 10
3	5 - 25	15 - 25	5 - 25	*	5 - 10
4	5 - 25	15 - 25	5 - 25	*	5 - 10
5	5 - 25	15 - 25	5 - 25	*	5 - 10
6	5 - 25	15 - 25	5 - 25	*	5 - 10
7	5 - 15	15 - 25	5 - 15	*	5 - 10
8	5 - 25	15 - 25	5 - 25	*	5 - 10
9	5 - 15	15 - 25	5 - 15	*	5 - 10
10	5 - 15	15 - 25	5 - 15	*	5 - 10
11	5 - 15	15 - 25	5 - 15	*	5 - 10
12	5 - 25	15 - 25	5 - 25	*	5 - 10

*Planks are not considered in this analysis because of their insignificant damage potential

TABLE 4-1 CONDITIONAL PROBABILITIES, PER YEAR, OF STRIKE ON TARGETS FROM A TORNADO WITH INTENSITIES F-1 THROUGH F-6, $P(A_j|F_i)$

	F-Scale Intensities					
Target	F-1	F-2	F-3	F-4	F-5	F-6
1	*	*	*	1.0×10^{-2}	*	*
2	*	*	*	0.90×10^{-2}	1.0×10^{-2}	2.0×10^{-2}
3	*	1.96×10^{-2}	3.44×10^{-2}	0.84×10^{-2}	6.00×10^{-2}	2.99×10^{-2}

*In the simulation process no hit was observed for these intensities.

TABLE 4-2 PROBABILITIES OF TORNADO MISSILE STRIKING TARGETS 1, 2 and 3

$$P(A_j) = \sum_{i=1}^{6} [(A_j | F_i) P(F_i)$$

Targets	Probabilities	Percent Contribution of Various F-Scale Tornado Intensities
1	1.65×10^{-7}	0,0,0,100,0,0,
2	2.25×10^{-7}	0,0,0,66,30,4
3	2.96×10^{-7}	0,40,41,5,14,0

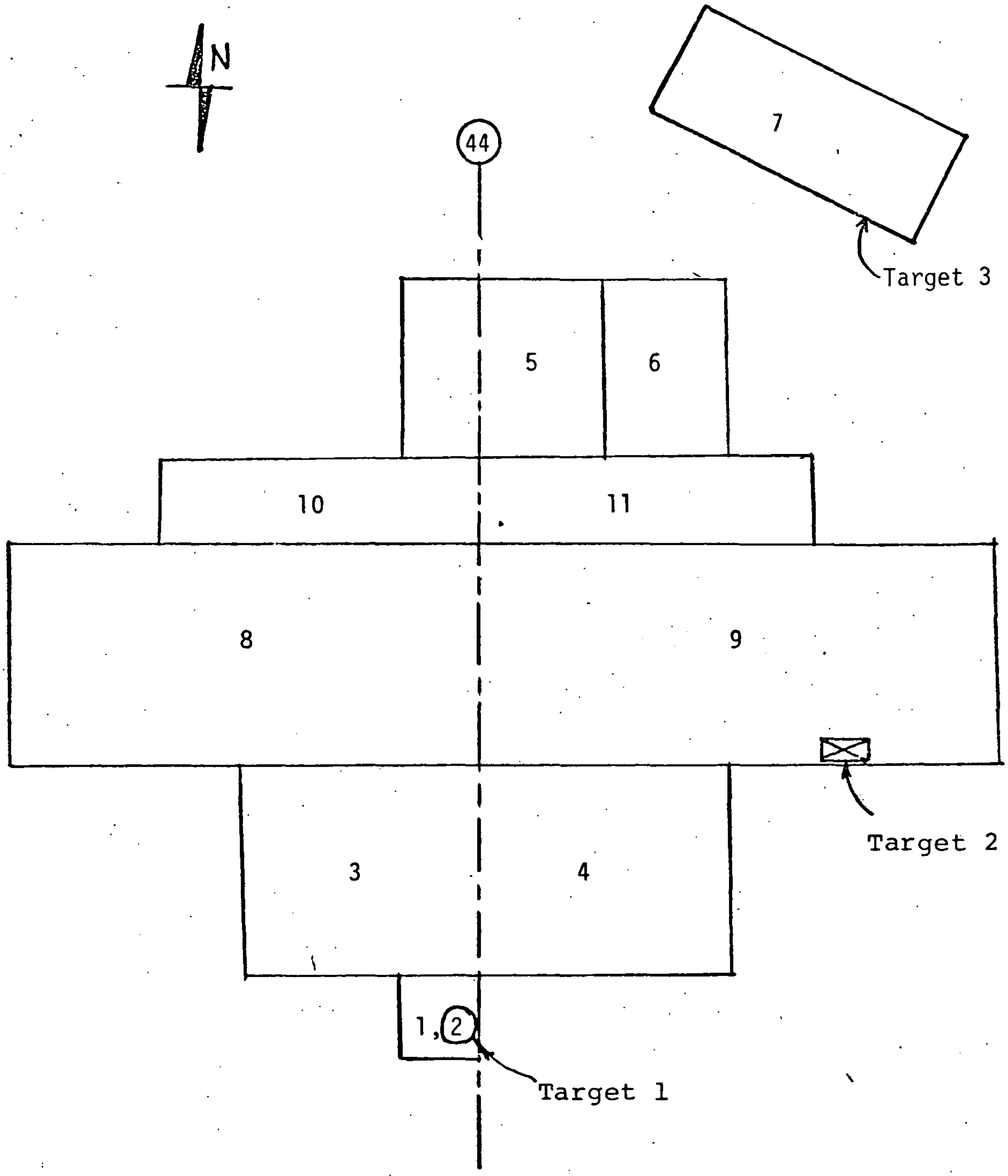

Figure 3-1
Plant Structures and Targets
See Table 3-1 for Details

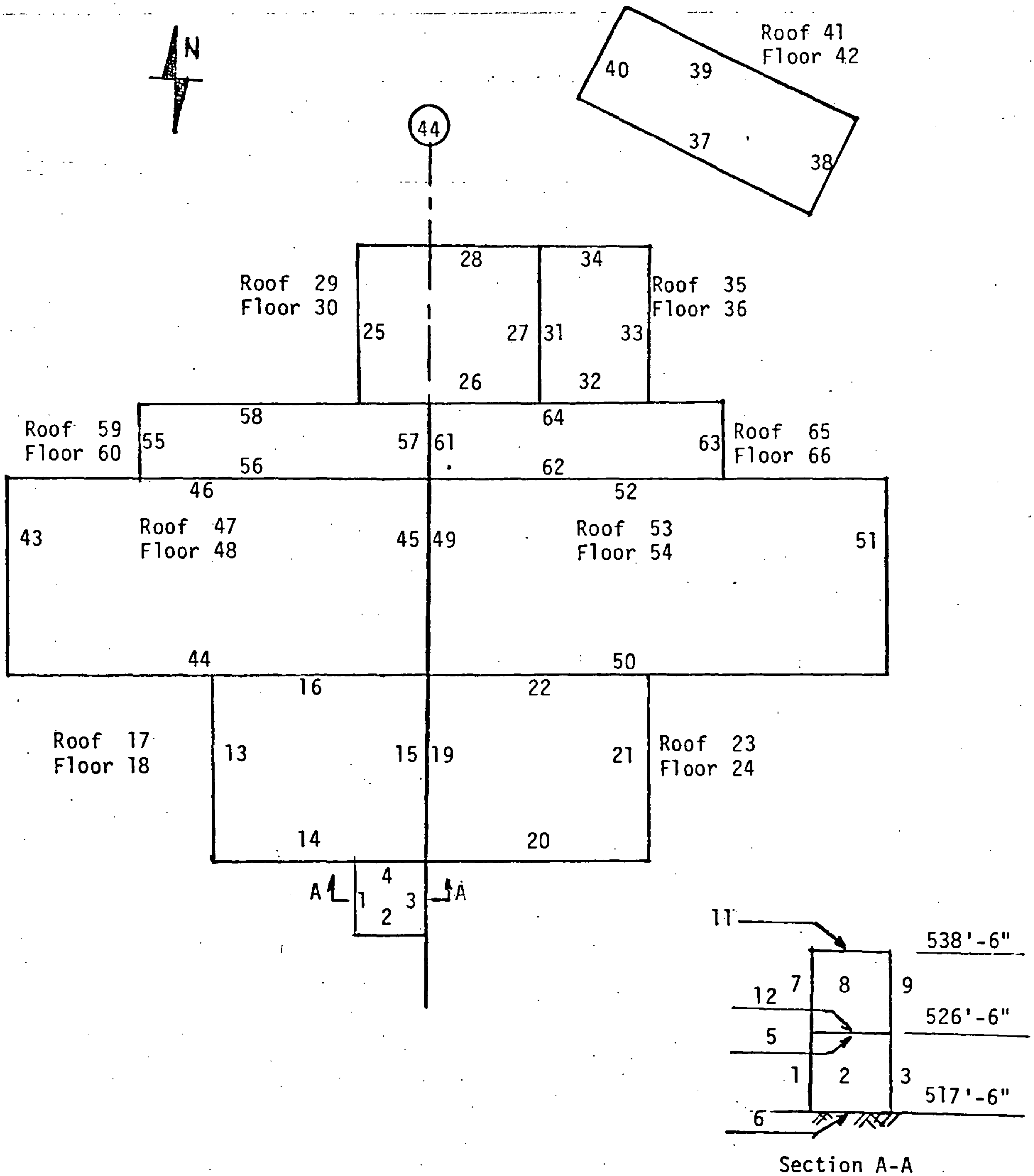

Figure 3-2

Plant Barriers

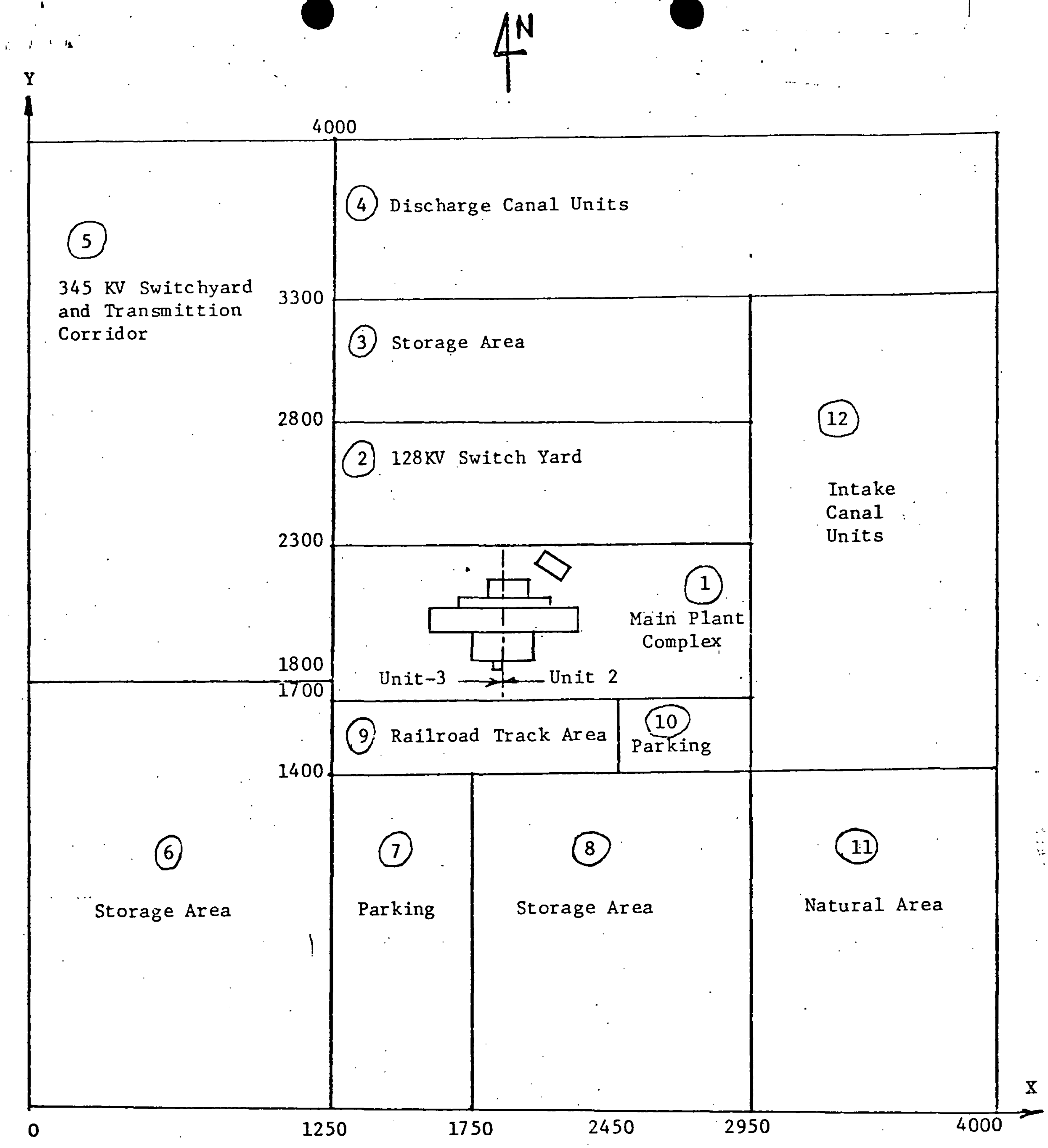

Figure 3-3

Tornado Missile Zones

APPENDIX

The TORMIS computer code is developed by the Research Triangle Institute of North Carolina for the Electric Power Research Institute of California. The listing of the code and the technical information on which the code is based may be found in References 1 through 5.

In this appendix a brief description of the TORMIS computer code is given. In TORMIS a probabilistic methodology has been developed to predict the probabilities of tornado-propelled missiles impacting and damaging nuclear power plant structures. The methodology relies on detailed mathematical models of tornado occurrence: near-ground wind field; missile aerodynamics, injection, and transport; and structural impact events to provide the mechanistic elements necessary for the total hazard assessment. The methodology uses random variables to model the inherent variations in tornado incidence, wind field characteristics, missile position and orientation, missile transport, and the distribution of the potential missile population. As illustrated in Figure A-1, time-history simulations are performed which predict the response of the postulated missiles to the tornado as it translates through the plant vicinity. TORMIS then simulates a large number of tornados and missile responses. These simulations are used to predict the probabilities of the impact and damage.

The probabilistic outcome sample space which result from such simulations is identified in terms of single and multiple missile events for each specified target. This outcome can also be used in calculating the probabilistics of union and intersection events of multiple targets.

The methodology developed in TORMIS has capability of predicting the estimates of the following:

1. The probability that a single missile, selected at random from the postulated missile population, impacts and damages each of the specified targets.

2. The total impact and damage probability to each target from all the postulated missiles.

3. The probability that a combination of targets (e.g., redundant components), will be damaged during a tornado strike.

4. The impact and damage probabilitics for the entire plant.

5. The barrier thickness corresponding to specified levels of impact and damage risks.

6. The variances of the predicted probabilities.

Various random variables and the form of their probability density functions used in the assessment of tornado missile hazard are summarized in Table A-1. The data used in generating probability density functions are given in references 2 and 4. For the code execution, the necessary input information can be lumped into four basic groups: The tornado data, the missile data, the plant data and the variance reduction data. For ease in code use, certain tornado, missile and damage assessment data are programmed into the code as default parameters.

The values of these default parameters are given in Table A-4 of Reference 5.

A brief description of each of these groups follows:

In tornado data the user has an option of either supplying the region-dependent tornado parameters or using the default values of these parameters built-in the TORMIS. In the latter case the region classification must be specified i.e. region A, B, C or D, or NRC Classification I, II, or III. In either case the tornado occurrence rates for F-scale tornado intensities must be provided.

In missile data once again the user has an option of either providing site dependent missiles and their characteristics or using missile and characteristics specified by NRC in Standard Review Plan (SRP) 3.5.1.4.

The plant data include specification of missile zones, the missile types and densities, the geometry of various target structures, the type of barriers, the range of barrier thicknesses, and barrier materials. TORMIS uses the modified NDRC formula for perforation through concrete barriers and the BRL formula for perforation through steel barriers.

The input information about the fourth data group is necessary only if the improved efficiency in the simulation process is attempted. In other words by using the variance reduction technique one can relatively reduce the number of simulations for a given risk level. This input is, therefore, not mandatory. TORMIS uses various variance reduction techniques such as sequential sampling, correlated sampling, stratified sampling, systematic sampling, importance sampling etc., depending upon the nature of the random variable. Table A-2 lists variables and associated techniques of variance reduction.

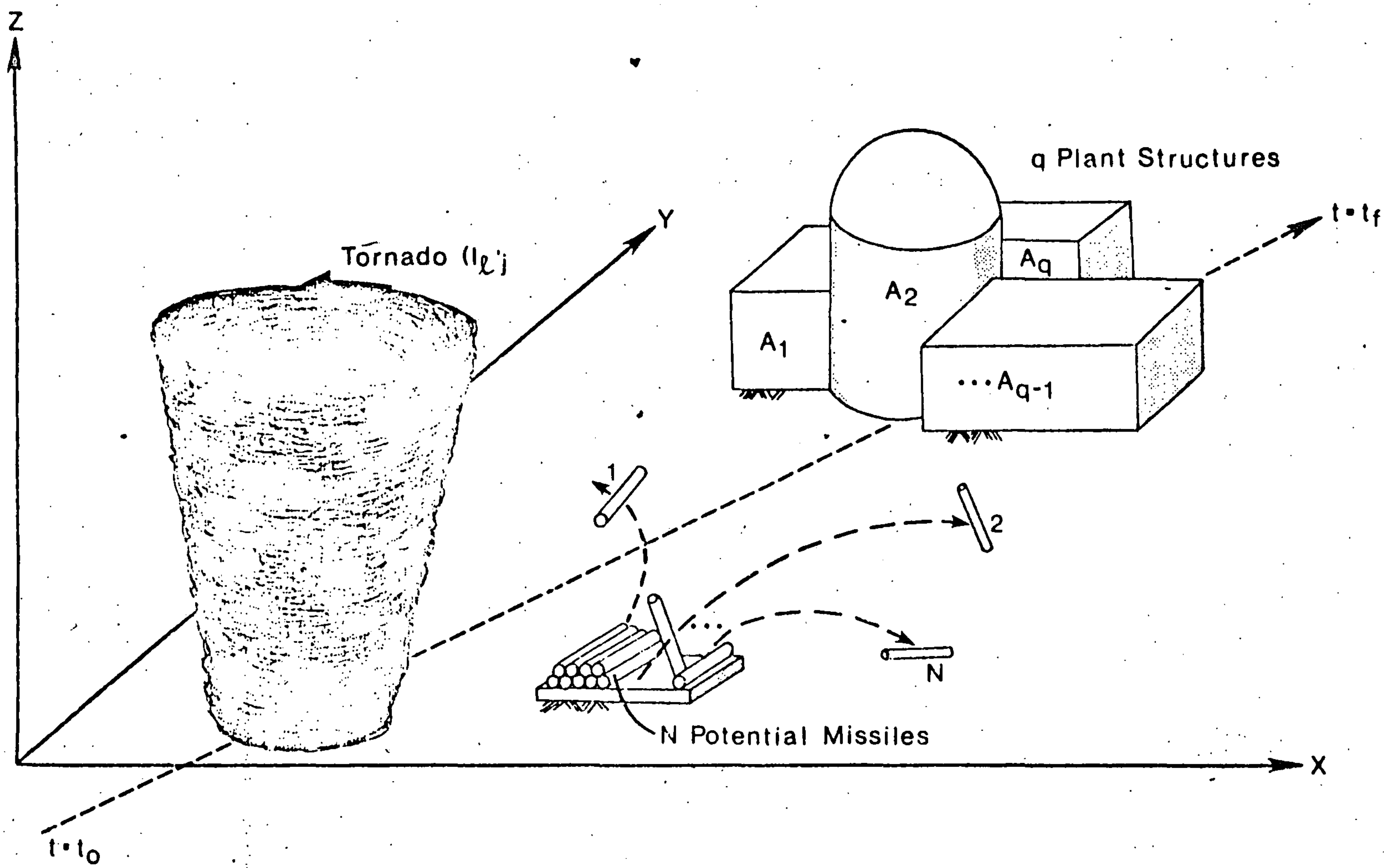

Figure A-1. Tornado Missile Time-History Simulation

TABLE A-1. SUMMARY OF RANDOM VARIABLES IN TORNADO MISSILE HAZARD ASSESSMENT

Prior Uncertainty Analysis	Random Variable	Form	Probability Density Function
Tornado Occurrence			
Unrated Events Annual Reporting Trend Nonreported Events (Z factor)	Adjusted Occurance Rate (ν)	$\nu \mid R,\ f_{\nu \mid R}(\nu \mid R)$	Gamma
Regional Frequencies $f(I_j \mid R)$ Direct Classification Error $P(I_i^{*} \mid I_j)$ Random Encounter Errors $P(I_k \mid I_i)$ Path Length Intensity Var $P(I_\ell^{*} \mid I_i)$	Local Intensity State (I_i^{*})	$P(I_i^{*} \mid R)$	Discrete
Path Area $E(A_i''' \mid R)$ Local Intensity State $P(I_j''')$ Random Encounter $P(I_i^{*} \mid I_j''')$	Characteristic Tornado Intensity (I_j''')	$P(I_j''' \mid I_i^{*}, R)$	Discrete
	Path Length Scale (P_L)	$f_{P_L \mid I,R}(P_L \mid I,R)$	Discrete
	Path Length (L_t)	$f_{L_t \mid P_L}(L_t \mid P_L)$	Truncated Normal
	Path Width Scale (P_W)	$f_{P_W \mid P_L,I}(P_W \mid P_L,I)$	Discrete
	Path Width (W_t)	$f_{W_t \mid P_W}(W_t \mid P_W)$	Truncated Normal
	Path Direction Octant (ϕ_t)	$f_{\phi_t \mid R}(\phi_t \mid R)$	Discrete
	Path Direction (ψ_t)	$f_{\psi_t \mid \phi_t}(\psi_t \mid \phi_t)$	Uniform
	Offset from Plant (O_t)	$f_{O_t}(O_t)$	Uniform
Tornado Windfield			
Updated F-Scale Calibration [1] Local Intensity State $P(I_i^{*} \mid R)$	Intra-F-Scale Windspeed (U_{max})	$f_{U_{max} \mid I_i^{*}}(U_{max} \mid I_i^{*})$	Trapezoidal, Exponential
	Translational Speed (U_T)	$f_{U_T \mid I_i}(U_T \mid I_i)$	Truncated Normal
	Radial Inflow (γ)	$f_\gamma(\gamma)$	Truncated Normal
Tornado Width, L_t Windspeed, U_{max} Translational Speed, U_T	Core Radius (ρ_m)	$f_{\rho_m \mid I_i}(\rho_m \mid I_i)$	Truncated Normal
	Slope of Core S	$f_S(S)$	Uniform
	Reference Boundary Layer (δ_0)	$f_{\delta_0}(\delta_0)$	Uniform
Missile Injection and Transport	Initial Missile Position (X_i, Y_i, Z_i)	$f_{X_i,Y_i,Z_i \mid O_Z}(X_i,Y_i,Z_i \mid O_Z)$	Uniform
	Restraining Forces (R_h, R_v)	$f_{R_h}(R_h)$, $f_{R_v}(R_v)$	Uniform
	Missile Axis Zenith Angle (θ)	$f_\theta(\theta)$	Uniform Solid Angle
	Missile Axis Azimuthal Angle (ϕ)	$f_\phi(\phi)$	Uniform
	Missile Axis Roll Angle (δ)	$f_\delta(\delta)$	Uniform
Missile Impact	Target Impact Position (X,Y,Z)	$f_{X,Y,Z}(X,Y,Z)$	Code Predicted
	Impact Velocity Vector ($\underline{V}_i$)	$f_{V_i,\theta,\theta',\phi-\phi'}(V_i,\theta,\theta',\phi-\phi')$	Code Predicted
	Ricochet Angle (α)	$f_\alpha(\alpha)$	Uniform Solid Angle

TABLE A-2. VARIANCE REDUCTION METHODS

Application Mode	Technique	Variable Sets
Prior Analysis	Sequential Sampling	Tornado Offset Postion Missile Initial Position Missile Type
	Correlated Sampling	Missile Initial Orientation
Risk Calculation	Stratified Sampling	Tornado Intensity F-Scale
Optional TORMIS Parameters	Systematic Sampling[1]	Missile Origin Zone
	Importance Sampling	Tornado Windspeed (Intra F-Scale) Tornado Direction Tornado Offset Position Missile Type Missile Initial Orientation Injection Restraining Force[2]
	Splitting	Trajectories that impact a target
	Russian Roulette	Trajectories falling away from target
	Expected Values	Tornado Strike Probability Impact Damage Assessment

[1] For single missile probability estimation, this becomes importance sampling on missile position.

[2] Applicable only to N'' missile population.

End of Appendix