July 1979

Final Report 44T-1844

TORNADO MISSILE RISK ANALYSIS OF THE NORTH ANNA NUCLEAR POWER STATION UNITS 1 & 2 SPENT FUEL POOL

Prepared for

Virginia Electric and Power Company
1 James River Plaza
7th and Cary Streets
Richmond, Virginia 23219

Under

Purchase Order No. 88881

Prepared By

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I. INTRODUCTION

This document is a report prepared by Research Triangle Institute (RTI) under Virginia Electric and Power Company (VEPCO) Purchase Order No. 88881, "Tornado Missile Analysis." The objective of this investigation was to estimate the probability of tornado missile impact to the spent fuel pool of Units 1 and 2 of the North Anna Nuclear Power Station. The scope of the study consisted of four basic tasks: (1) acquisition of the relevant data regarding the plant design and missile characteristics, (2) formalization of a plant model with the important features of the spent fuel pool region and the initial conditions of the postulated missiles, (3) computer simulation analyses of the tornado missile threat to the spent fuel pool region, and (4) compilation of the simulation results and the documentation of the findings of the study. The information required to define the plant, structures, and postulated missile input variables was obtained from VEPCO and/or Stone and Webster Engineering Corporation. Tornado inputs were obtained from a recent analysis of the pertinent tornado data record with an upperbound intensity given by the Nuclear Regulatory Commission (NRC) Region I design basis tornado. A simulation computer code (TORMIS), developed explicitly for tornado missile risk analysis, was used to estimate the missile impact probabilities. The results of over 60,000 individual missile simulation histories indicate that the probability that a single missile would impact the pool region is 4.15×10^{-11} per year. The risk from the entire postulated missile population is estimated as 7.65×10^{-7} per year. This report documents the input data used in the investigation and summarizes the methodology and results.

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II. METHODOLOGY

A. Introduction

In general, the quantitative assessment of tornado missile risk requires a mathematical model of the physical process, probability models of the identified random variables, specification of the probability sample space, and a means to assign probability measures to the points in the sample space. The models and methodology developed by Twisdale et al. [1] for tornado missile risk analysis of nuclear power plants have been used in this investigation to estimate missile impact probabilities to the spent fuel pool for Units 1 and 2. Figure 1 illustrates the modeling and data components that comprise the integrated risk analysis approach. Due to the complexity of the mathematical models that describe the general tornado missile event sequence and the relatively large number of random variables and requisite probability density functions, Monte Carlo simulation is used to estimate individual event probabilities. This section summarizes the components of the methodology; detailed description of the models and previous results are given in several reports and publications [1-6].

B. Models and Tornado Input Data

A sequence of events must occur for a safety-related component at a nuclear plant to be impacted and actually damaged by a tornado-generated missile. First of all, a tornado must occur and pass through the plant site area. Five years of the national tornado data record (4,582 tornadoes) were analyzed to provide input information to the risk analysis on tornado occurrence rates and strike characteristics [1, 4]. The investigation also included analyses of the potential for tornado classification error based upon storm damage interpretations and the lack of a damage medium (structures, vehicles, trees, etc.) in some regions. The research also addressed the

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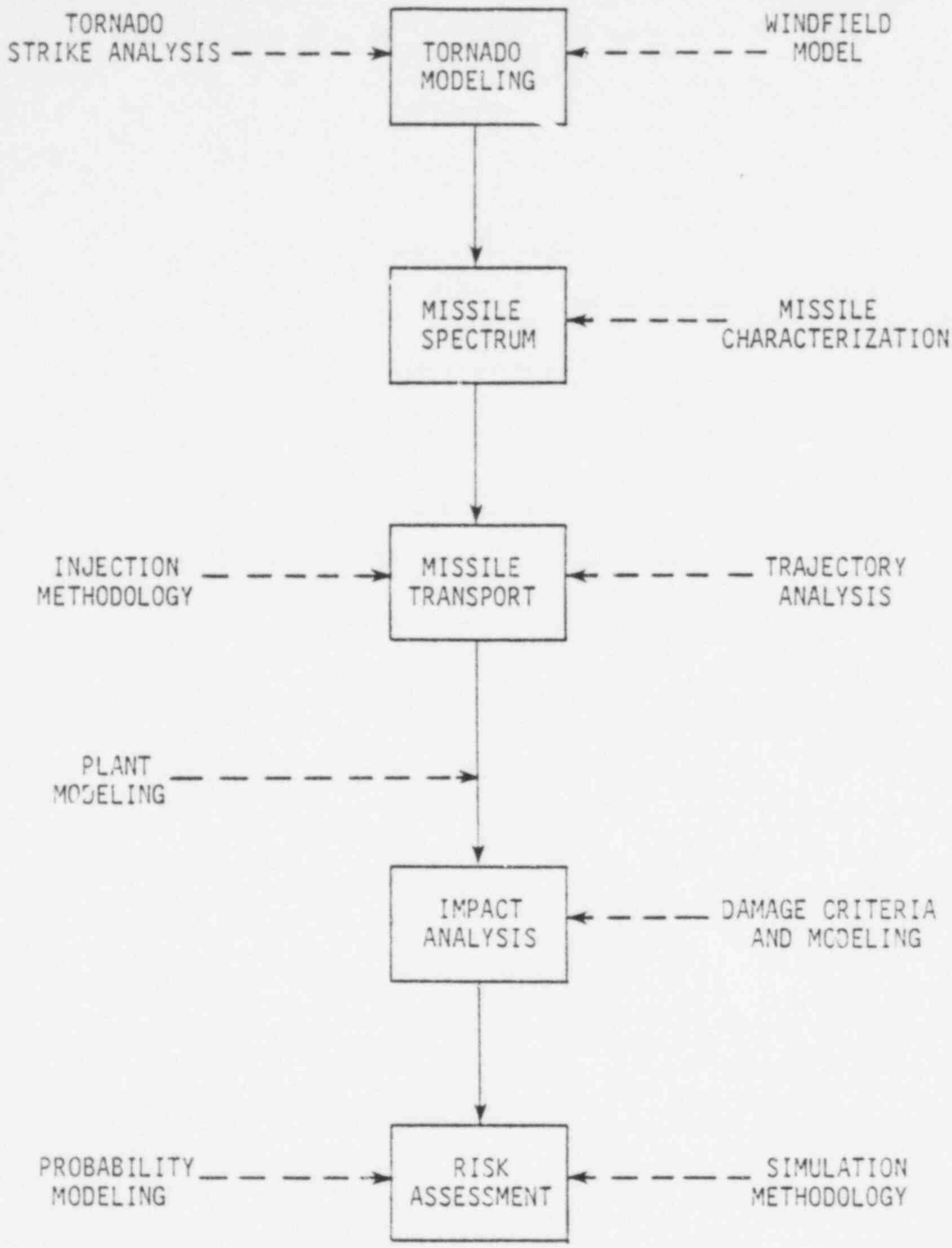

Figure 1. Components of the Tornado Missile Hazard Simulation Analysis

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uncertainty in windspeed ranges and the variation of storm intensity along the path length; a data set of 148 tornadoes was analyzed to provide quantitative input on intensity variation. Combination of these analyses resulted in a methodology to assess tornado strike probabilities and quantified input for each of the Nuclear Regulatory Commission (NRC) tornado regions [7] in the United States.

A tornado windfield model was also developed to be compatible with the entire range of observed windfield intensities and path widths. Tornado flow characteristics were identified that were potentially significant in terms of missile transport phenomena. In order to account for both modeling uncertainty and the natural variability observed among tornadoes, several random variables were specified in the model, including tornado intensity, path width, translational speed, radius to maximum tangential velocity, ratio of the radial to tangential wind speeds, vertical variation of core size, and boundary layer thickness. In view of the difficulty in establishing a priori conservative flow characteristics for missile transport, the windfield model was synthesized from theoretical, observational, and probabilistic considerations. A significant aspect of the model is that the parameters can be adjusted to make the intensity, size, and velocity variables consistent with the tornado path width boundary specifications.

Another component in the hazard must be the availability of objects in the plant vicinity before any missiles can be generated. These objects must be accelerated by the tornado winds to pose a potential threat to any of the plant's safety systems. A missile transport model was needed that would be efficient to permit simulation studies of thousands of trajectories and yet describe the expected variance of turbulent tornado transport. A random orientation transport model was developed and statistically verified through a

series of comparisons to both simplified three-degree-of-freedom and rigid body six-degree-of-freedom trajectory models. The missile injection methodology was developed to provide for missile release to the moving tornado when the restraint forces are exceeded by the tornado-induced aerodynamic forces. A simulation study was performed to determine the optimum specification of missile restraint forces to ensure conservatism in this component of the mechanistic analysis.

Finally, if the potential missile is transported by the tornado, it must hit a "target" or safety related system to pose an actual threat to the operation of the plant. An impact methodology was developed for a spectrum of missiles to provide a basis for predicting structual damage, given an impact. Recent impact test data [8] were used in a probabilistic approach to account for structural strength variations and random impact orientations. An analytical study of oblique missile impact was also performed [6].

These components of the tornado missile hazard were linked together to form an integrated model of the process as indicated in Figure 1. A total of 24 random variables were used to characterize the modeling uncertainty, natural variability of tornado events, and the site-specific characteristics at a particular plant. Specification of the probability models for these variables, identification of the output sample space, and the use of simulation techniques to assign probabilities to this sample space complete the risk assessment methodology.

C. <u>The Probabilistic Simulation Model</u>

The probability model that is adopted to simulate tornado missile events relies on the following hypotheses: (1) a finite and deterministic number (N) of potential missiles exist in the plant vicinity and thus completely define the sampling population; (2) each potential missile in the sampling population

has an equally likely chance to be transported by each tornado that strikes the plant; (3) a sequential event model for multiple missile generation is adopted: (4) the sample and/or event spaces for target impact are discrete; and (5) individual missile events, including ground interaction and termination, do not affect the governing sampling distributions of the process. These hypotheses form a basis for constructing event spaces and interpreting the resulting probability estimates from the simulations. The deterministic restriction on N in the first hypothesis results in considerable simplification in the event space specification as well as in the probability estimation and can be easily managed through conservative specification. The second hypothesis ensures that a random sampling scheme that uses the common missile input distributions is applicable. With respect to the first two hypothesis, it is noted that N is not the total number of objects in the plant vicinity but only those that have restraint forces that can be exceeded by the tornado-induced forces. The number of potential missiles available for transport during the actual time duration of a specific tornado is significantly less than the number of countable objects because of the structural and storage mode restraints that limit missile availability characteristics. The third hypothesis represents an approximation of the true stochastic nature of the problem by adopting a sequential model of multiple missile events rather that a "simultaneous" model with time history superpositions. Hypothesis four is simply a statement of the discrete nature of missile impact events. The final hypothesis specifies that a missile history will not affect the sampling distributions for subsequent histories in the same tornado event. Statistically, this suggests independence among the missile histories in the sense that the sampling distributions remain unchanged for a given tornado event.

D. Probability Assignment

The defined sampling experiment of tornado missile events specifies a sequence of individual missile trials to define the outcome of an individual tornado history. The developed methodology involves the assignment of multiple missile experimental outcomes from an analytical formulation that uses the single missile probability estimations. In the following paragraphs, the basic analytic model for risk evaluation is given, the applicability of the Bernoulli process and Poisson trials model is examined, and an analytical model for multiple missiles is presented.

The basic tornado arrival process model for tornado missile risk assessment is adopted from Wen and Chu's work [9] and can be expressed as

$$P(A) = 1 - \exp[-\nu\, E(A)T] \cong \nu\, E(A)T, \qquad (1)$$

where $P(A)$ = probability that event A occurs at least once during the time period (T), ν = tornado occurrence rate, and $E(A)$ = an expectation over the random variables defining event A for a single tornado. This expression is the exact analytical expression for tornadoes that are characterized by a Poisson arrival process and a union concept of success for event A. For rare events, the approximation in Equation 1 is accurate to within 0.5 percent for $\nu E(A)T \leq 0.01$. Consistent with the discrete nature of the tornado FPP (Fujita intensity, Pearson path length, Pearson path width) classification system [e.g., 10], E(A) is evaluated by its equivalent form

$$E(A) = \sum_{I=0}^{F_t} E(A|I)P(I), \qquad (2)$$

where I denotes the F-scale classification and F_t the upperbound tornado intensity.

For the assumed sequence of N missiles generated during a tornado strike, (I_j), the probability of target damage can be formulated analytically from the single trial probability, $P(A|I_j)$. The probability of the event that target A is damaged by at least one of the N missiles in the sampling population during the j[th] tornado F-scale intensity I is denoted as $P^N(A|I_j)$. A conservative union (U) concept of damage success being adopted, this probability is

$$P^N(A|I_j) = P[(A_1|I_j) \cup (A_2|I_j) \cup \ldots \cup (A_N|I_j)], \quad (3)$$

where A_i denotes the event that A is damaged by missile i. If mutual independence is assumed among the A_i, then Equation 3 can be stated equivalently as

$$P^N(A|I_j) = 1 - \prod_{i=1}^{N} P(\overline{A}_i|I_j) = 1 - \prod_{i=1}^{N} [1 - P(A_i|I_j)], \quad (4)$$

where $\overline{A}_i$ denotes the complement of event A_i. This assumption of mutual independence means that the missile trials are repeated under identical conditions for the assumed tornado; i.e., the i[th] trial alone determines whether or not A_i occurs. If the missiles are treated as being indistinguishable (nonordered) in the sampling experiement in terms of event A, then $P(A_i|I_j)$ is replaced by $P(A|I_j)$ and

$$P^N(A|I_j) = 1 - [1 - P(A|I_j)]^N. \quad (5)$$

This familiar expression provides a basis for assigning multiple missile event likelihoods during a specific tornado event (I_j) with an estimate of $P(A|I_j)$ from the sequential sampling experiment.

Examination of Equation 5 suggests that this expression is identical to the extensively studied Bernoulli process. It is noted that the expected number of successes during tornado i on a single target "A" is $N \cdot P(A|I_j)$, and

the variance is $N \cdot P(A|I_j)[1 - P(A|I_j)]$. Correspondingly, Equation 4 is the analogous statement for Bernoulli trials with variable probabilities, i.e., Poisson trials [11]. The significance of the assumption of indistinguishable missiles has been evaluated by comparing features of Poisson trials to Bernoulli trials. It can be shown [cf. 1] that the Bernoulli model provides a conservative estimate of the variance and an estimate of the expected value that is within a few percent of that obtained from the more general Poisson trials model. Thus, the simplification provided by Equation 5 is used to assign multiple missile probabilities.

E. Simulation Methodology

Probabilistic Monte Carlo simulation [e.g., 12, 13] is used to estimate the missile event probabilities--e.g., $P(A|I_j)$--because of the complex and multidimensional form of the random process. The TORMIS simulation code has been developed to produce numerical estimators of both single and multiple missile event probabilities. The output consists of statistically independent outcomes, each of which follows the same probability law. The expected value and variance are the population descriptors evaluated explicitly in the TORMIS code. For a mathematical statement of the tornado missile simulation, it is convenient to introduce the functions $g(\bar{x}|\bar{z})$ and $h(\bar{z})$ to represent the complete stochastic process. The random process for the tornado definition and occurrence is defined by $h(\bar{z})$, where $\bar{z}$ is a vector of tornado random variables. The function $g(\bar{x}|\bar{z})$ denotes the tornado missile random process in which $\bar{x}$ is a vector of missile random variables. Thus, the complete stochastic process is given by the product $g(\bar{x}|\bar{z})h(\bar{z})$; the notation for an outcome is $g(\bar{X}_i|\bar{Z}_j)h(\bar{Z}_j)$, where $\bar{X}_i$ denotes the i^{th} vector of tornado variables sampled from $f(\bar{x})$. For a single missile history, the outcome relative to some defined event A is a random variable "a." This outcome being denoted as

$g_A(\bar{X}_i|\bar{Z}_j)h_A(\bar{Z}_j)$, the characteristics of the probability law of "a" can be inferred from n independent observations. The expected value of "a" is estimated by

$$E(a|I) = \frac{1}{m} \sum_{j=1}^{m} h_A(\bar{Z}_j) \frac{1}{n} \sum_{i=1}^{n} g_A(\bar{X}_i|\bar{Z}_j), \qquad (6)$$

where n = m·n. For the Bernoulli trial model, the probability of success of A is given by this expectation, and hence $P(A) = E(a)$ and $\widehat{P}(A) = \widehat{E}(a)$. The estimate of $P(A|I_j)$ is given by the right summation in Equation 6. It is noted that for single missile events the estimation of $P(A|I)$ is not dependent upon the division of m and n for large n, provided that a reasonable number (m) of tornadoes is considered and n is sufficiently large. However, for multiple missile events, n must be large enough to provide an estimate of $P(A|I_j)$, which can be used in the analytical expressions derived previously. Thus, the estimation accuracy of $P(A|I_j)$ is useful; the sample variance, $\widehat{\sigma^2}(a|I_j$ and the variance of $P(A|I_j)$ follow the standard forms [1]. In the TORMIS code, confidence bounds are calculated assuming normality, which has been shown to give accurate results compared to a modified binomial sampling procedure [1].

III. PROBLEM DESCRIPTION AND SIMULATION INPUTS

A. Plant Definition

The spent fuel pool for Units 1 and 2 is located within the fuel building, which is directly between Containments 1 and 2 and south of the auxiliary, service, and turbine buildings. To simulate the tornado missile threat to the spent fuel storage area, the structures shown in Figure 2 were modeled as a cluster of 13 targets. The interior of the pool itself was modeled as two separate targets (Numbers 7 and 8). Target 7 represents the interior of the pool, from the top of the pool to a point 6 feet above the elevation of the top of the spent fuel assemblies. Target 8 covers the area from 6 feet above the location of the fuel assemblies to the bottom of the pool at elevation 249 feet 4 inches. This targeting arrangement was devised to provide the most information about potential impacts within the pool. Impacts to Target 7, which was modeled with no top or bottom surfaces, represent actual hits to the interior walls of the pool. Impacts to Target 8 represent hits to the fuel assemblies or to pool walls just above the fuel assemblies. The probability of missiles entering the top portion of the pool is thus the addition of the individual probabilities for Targets 7 and 8. The fluid within the pool was ignored in the trajectory analyses, and thus the predicted missile impact veloctities are higher than those that would actually occur because of the increased drag resistance provided by the water.

Targets 3, 4, 5, and 6 include the exterior pool walls and the remaining portion of the fuel building. The portion of the fuel building above the elevation of the top of the pool (elevation 291 feet 10 inches) was not considered to provide any significant missile protection to the pool and hence was not modeled in the analysis. The remaining targets include the containment structures, the auxiliary, service, and turbine buildings, and the

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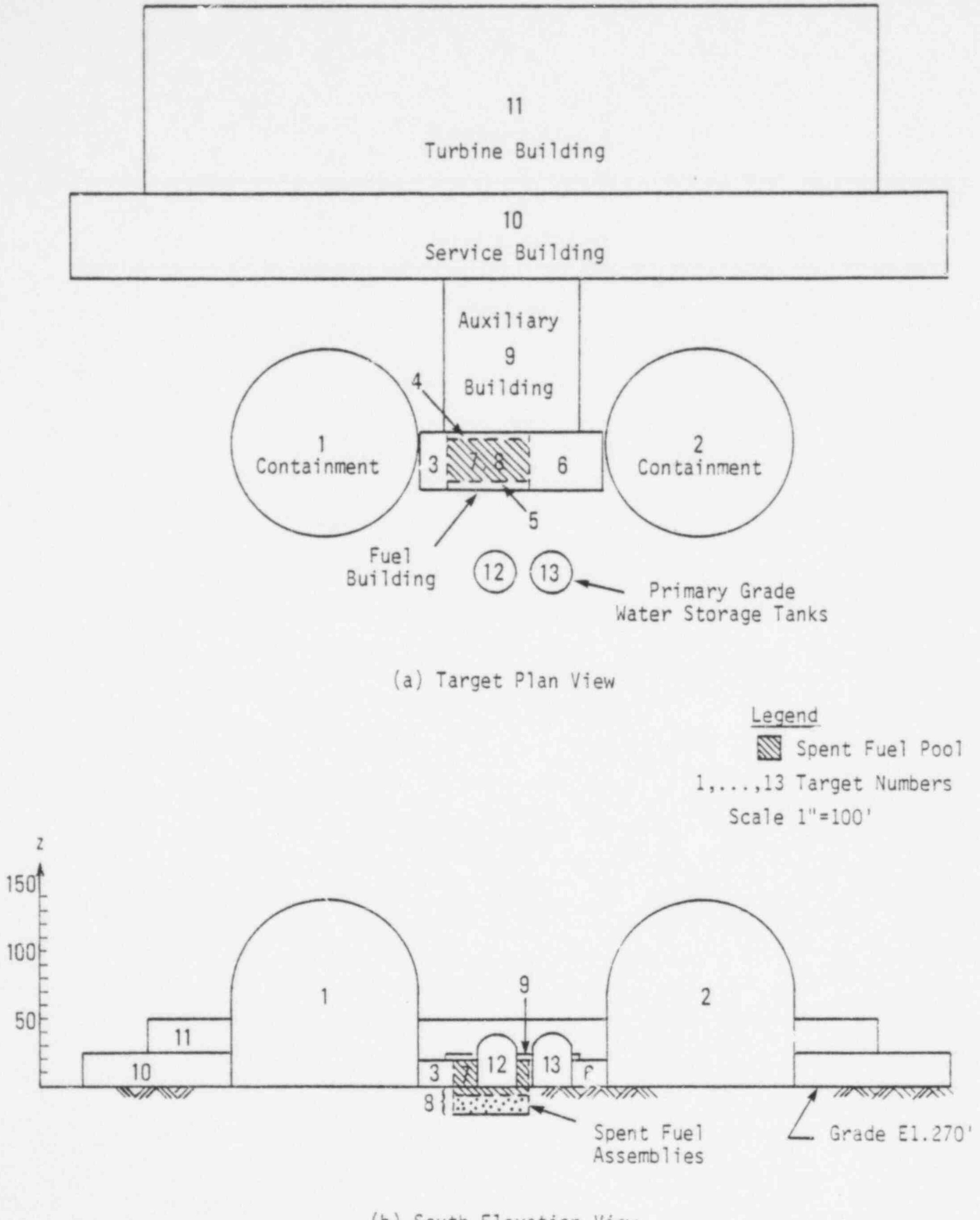

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Figure 2. Plan and Elevation Views of Plant Targets

primary grade water storage tanks. The auxiliary, service, and turbine buildings were modeled up to elevations that would continue to provide missile protection during the design basis tornado. Other structures, components, etc., in the region of the spent fuel pool were not explicitly modeled in this study. Hence, only the major "shadows" were modeled, and the shadowing effects of other structures, such as those of the waste disposal building, are conservatively ignored in the missile simulations.

B. Postulated Missile Threat

The missile threat that was postulated for the spent fuel pool included buildings, loose objects, construction materials, and other sources over the entire plant and construction site area. As noted in Figure 3, a total of 17 areas were used to identify different missile origin zones. The zones include storage and laydown areas, parking, Units 3 and 4 construction area, the switchyard, and wooded regions. These areas include the contiguous land region around the plant and thus all possible missile origins within 2,000 feet of the actual spent fuel pool target. A previous investigation indicated that missiles rarely travel more than 2,000 feet and hence do not contribute significantly to the impact risk for targets that are located more than 2,000 feet from the missile source. Simulation of missile trajectories and field observations suggest that the greatest hazard is from missiles that originate within several hundred feet of the target.

The numbers of each of the standard missile types [14] postulated by zone is summarized in Table I. A total of 19,995 potential missiles were specified to simulate the availability of missile sources during the period of on-site construction activities for Units 3 and 4. Upon completion of these units, the number of potential on-site missiles will diminish, and thus this time period is expected to represent the worst case in terms of the tornado missile

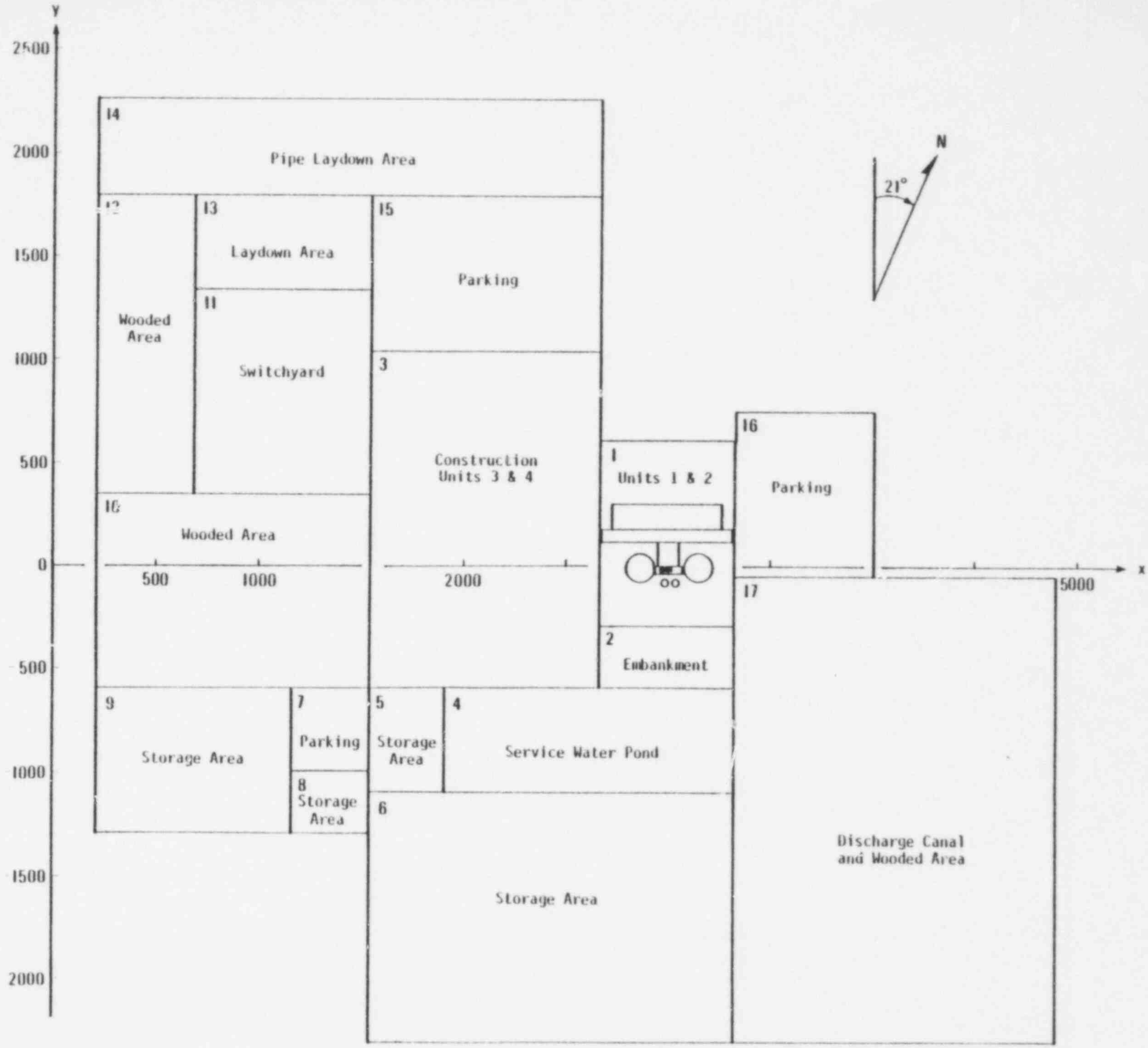

Figure 3. Missile Origin Zone Definition

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TABLE I. MISSILE SPECIFICATION BY ZONE

Plant Zone Number	Number of Missiles by Type: Wood Beam	6" Pipe	1" Rod	Utility Pole	12" Pipe	Automobile	Total Number Of Missiles
1	10	10	10	5	10	5	50
2	100	100	100	5	100	5	410
3	1,000	1,000	1,000	500	1,000	100	4,600
4	0	0	0	0	0	5	5
5	50	0	0	30	0	50	320
6	1,000	1,000	1,000	500	1,000	100	130
7	0	0	0	20	0	300	4,600
8	100	50	50	10	50	10	320
9	500	250	250	50	250	50	1,350
10	100	0	0	10	0	50	160
11	0	500	100	0	500	5	1,105
12	0	0	0	0	0	0	0
13	100	100	0	0	100	25	325
14	1,000	1,000	1,000	500	1,000	100	4,600
15	0	0	0	80	0	1,200	1,280
16	0	50	0	40	0	600	690
17	0	0	0	100	0	0	100
Total	3,960	4,060	3,510	1,850	4,010	2,605	19,995

*Zone 12 is a wooded area that is more than 2,000 feet from the spent fuel pool target.

threat. These missiles were specified to originate at heights that follow the land topography, building, and material laydown storage heights. The zone elevation and maximum injection heights are given in Table II. The minimum injection height was conservatively considered to be five feet above the zone grade elevation. The missiles were uniformly injected over the interval defined by these minimum and maximum heights, incorporating the differences in zone elevations. The automobile was injected at a constant height of five feet above grade for all zones.

C. Tornado Hazard

The input data for the tornado hazard definition was taken from an analysis of 4,582 tornado data entries reported in the 1971-1975 FPP data base [1]. Specifically, the data for NRC tornado Region I was used in the specification of tornado intensity, path width, path length, and tornado direction. The design basis tornado with a windspeed of 360 mph [7] was used as the maximum intensity event. Thus, as noted in Table III, the F'6 tornado intensities were specified to have a windspeed interval of from 277 to 366 mph and an occurrence rate of 2.152×10^{-7} per square mile per year. A review of the 1971-1975 data for the State of Virginia confirmed the conservatism of using Region I tornado statistics in the tornado hazard simulation. The angular difference of 21 degrees clockwise between plant north and true north was also accounted for in the directional tornado data input relative to the plant target model and missile zone geometry.

D. Simulation Inputs

Appendix A includes an actual computer printout of all of the input data for the simulation of a given tornado intensity interval. The input data were checked against the problem description defined in this chapter to insure the validity of the results.

TABLE II. MISSILE INJECTION HEIGHT BY ZONE

Plant Zone Number	Grade Elevation (ft)	Maximum Injection Height Above Grade (ft) by Missile Type					
		Wood Beam	6" Pipe	1" Rod	Utility Pole	12" Pipe	Automobile
1	270	30	30	30	5	30	5
2	270	20	20	20	20	20	5
3	270	50	50	50	20	50	5
4	320	-	-	-	-	-	5
5	320	2	-	-	20	-	5
6	320	3	30	30	30	30	5
7	320	-	-	-	5	-	5
8	320	2	20	20	20	20	5
9	320	2	20	20	20	20	5
10	300	2	-	-	20	-	5
11	270	-	40	40	-	40	5
12	270	-	-		-	-	-
13	270	5	5	-	-	5	5
14	270	5	5	5	5	5	5
15	270	-	-	-	5	-	5
16	270	-	20	-	20	-	5
17	270	-	-	-	20	-	-

TABLE III. TORNADO INTENSITY INTERVALS AND OCCURRENCE RATES

Tornado Intensity (F'-Scale)	Windspeed Interval (mph)	Occurrence Rate (/sq. mi. yr.)
F'0	40-73	2.206×10^{-4}
F'1	73-103	1.207×10^{-4}
F'2	103-135	6.413×10^{-5}
F'3	135-168	1.941×10^{-5}
F'4	168-209	4.390×10^{-6}
F'5	209-277	9.469×10^{-7}
F'6	277-360	2.152×10^{-7}
All	40-360	4.304×10^{-4}

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IV. RESULTS

Missile impact probabilities to the spent fuel pool targets were estimated with the methodology developed for the TORMIS computer code and the specified input data. Ten thousand missile time histories were simulated for tornado events within each tornado intensity interval. A total of 60,000 histories were recorded for F1 through F6 intensity tornadoes. The tornado charactistics of direction, path length, path width, translational windspeed component, etc., were sampled from the defined frequency distributions for each tornado event simulated. Missiles were selected from each of the types specified and positioned within the zones for possible injection and transport by the tornado. Missiles that impacted the structures were scored and the target impact probabilities generated. The predicted impact probabilities for the spent fuel targets (Numbers 7 and 8) are presented in Table IV for each tornado intensity. The 95 percent confidence bounds are also given to indicate the degree of statistical uncertainty in the simulation output, as indicated in the example computer printout in Appendix A.

The results summarized in Table IV indicate that the probability of a single tornado-generated missile, picked at random from the entire missile population, entering the spent fuel pool is estimated to be 4.15×10^{-11} per year. The majority (95 percent) of this risk is due to impacts to the upper portion of the interior wall the pool, as defined by Target 7. The model predicts that the likelihood of a direct hit to Target 8 (the spent fuel assemblies and the portion of the interior pool walls extending six feet above the top of the assemblies) is 2.37×10^{-12} per year.

Multiple missile probabilities, as defined mathematically in Section II.D, are also given in Table IV. Since there is more than one potential missile at the plant, these probabilities are simply the total risk from all

TABLE IV. PREDICTED IMPACT PROBABILITIES AND 95 PERCENT STATISTICAL CONFIDENCE BOUNDS

Tornado Intensity (F'-Scale)	Target Number (1)	Single Missile			Multiple Missile		
		Lower Limit (2)	Mean	Upper Limit (2)	Lower Limit (2)	Mean	Upper Limit (2)
1	7	0	1.12×10^{-13}	2.46×10^{-13}	0	1.73×10^{-9}	4.12×10^{-9}
	8	2.07×10^{-16}	5.79×10^{-15}	1.14×10^{-14}	0	3.65×10^{-11}	1.06×10^{-10}
	7 or 8	0	1.18×10^{-13}	2.51×10^{-13}	0	1.79×10^{-9}	4.17×10^{-9}
2	7	0	3.21×10^{-11}	9.11×10^{-11}	0	5.84×10^{-7}	1.66×10^{-6}
	8	0	2.59×10^{-13}	7.13×10^{-13}	0	3.74×10^{-9}	1.09×10^{-8}
	7 or 8	0	3.24×10^{-11}	9.14×10^{-11}	0	5.89×10^{-7}	1.66×10^{-6}
3	7	0	5.52×10^{-12}	1.28×10^{-11}	0	1.06×10^{-7}	2.46×10^{-7}
	8	0	7.05×10^{-13}	2.05×10^{-12}	0	1.28×10^{-8}	3.71×10^{-8}
	7 or 8	0	6.23×10^{-12}	1.36×10^{-11}	0	1.19×10^{-7}	2.65×10^{-7}
4	7	1.02×10^{-13}	9.76×10^{-13}	1.85×10^{-12}	1.44x10-9	1.85×10^{-8}	3.55×10^{-8}
	8	0	1.01×10^{-12}	2.93×10^{-12}	0	1.93×10^{-8}	5.61×10^{-8}
	7 or 8	0	1.99×10^{-12}	4.10×10^{-12}	0	3.78×10^{-8}	7.82×10^{-8}
5	7	2.48×10^{-14}	4.12×10^{-13}	7.99×10^{-13}	4.27×10^{-10}	7.9×10^{-9}	1.54×10^{-8}
	8	0	3.90×10^{-13}	9.28×10^{-13}	0	7.57×10^{-9}	1.80×10^{-8}
	7 or 8	1.39×10^{-13}	8.02×10^{-13}	1.47×10^{-12}	1.81×10^{-9}	1.55×10^{-8}	2.92×10^{-8}
6	7	0	7.41×10^{-14}	1.86×10^{-13}	0	1.37×10^{-9}	3.44×01^{-9}
	8		*(3)			*	
	7 or 8	0	7.41×10^{-14}	1.86×10^{-13}	0	1.37×10^{-9}	3.44×10^{-9}
All	7	1.48×10^{-11}	3.91×10^{-11}	6.34×10^{-11}	2.77×10^{-7}	7.20×10^{-7}	1.16×10^{-6}
	8	1.37×10^{-12}	2.37×10^{-12}	3.37×10^{-12}	2.47×10^{-8}	4.34×10^{-8}	6.21×10^{-8}
	7 or 8	1.72×10^{-11}	4.15×10^{-11}	6.58×10^{-11}	3.22×10^{-7}	7.65×10^{-7}	1.21×10^{-6}

Notes: (1) Target 7 = Spent fuel pool volume above fuel assemblies
Target 8 = Spent fuel pool volume containing fuel assemblies up to a point 6' above the top of spent fuel
7 or 8 = Impact to either region defined by target 7 or target 8
(2) Upper and lower limits of the 95% statistical confidence bounds
(3) * indicates that no hits were obtained to the target for the specified tornado intensity

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the potential missiles specified in the missile threat definition. The event is not based upon the assumption that only one missile is generated per tornado, but that the entire population of potential missiles may be generated for any tornato event. The term multiple missile is also interpreted to mean that all of the missiles have restraining forces that are specified within an optimum interval for transport and thus are potentially transported by any tornado that strikes the plant. Thus, the multiple missile risk provides a conservative estimate of tornado-generated missile impact probabilities. For multiple missile generation for each tornado event, the respective probability estimates are 7.65×10^{-7} per year for missiles entering the pool and 4.34×10^{-8} per year for missiles hitting near the fuel assemblies (as specified by Target 8). The 95 percent confidence bounds for these results are relatively close to the predicted mean values, indicating that a sufficient number of simulations were made to minimize the statistical uncertainty of the outcomes.

An examination of these results indicates that the simulation model predicted event likelihoods that closely follow expected missile occurrences. In the first place, the pool offers a very limited target as illustrated in Figure 1; it is shadowed, or partially shadowed, from practically every direction by adjacent structures. The missiles must avoid these targets and at the same time be lifted to a height of at least 20 feet above the plant grade elevation. If a missile, by chance, is transported into the region above the pool, its trajectory must fall quickly, or else it will be carried over the pool and into another target or a ground impact. Inspection of the simulation results indicates that these types of outcomes occured more frequently than the event of a missile trajectory intersecting the pool. For example, the single missile hit probability to the outside south wall of the

pool (Target 5) is more than 10 times likely than a hit to the pool itself (4.61×10^{-10} vs 4.15×10^{-11}). None of these predicted hits to the outside wall produced damage to the massive 6-foot-thick, reinforced concrete barrier.

Table IV also indicates the contribution by tornado intesity to the overall risk. The maximum intensity tornado events (F'6) produced no hits to Target 8, althouth it produced the most hits to the adjacent targets. For these high intensity tornadoes, all of the hits to the pool occurred to the interior walls within eight feet of the top of the pool. The speeds of the missiles were higher, and thus they did not drop sufficiently during the time interval they were over the pool to result in a direct hit to Target 8. The hit probability for both Targets 7 and 8 peaked at the strong intensity tornadoes (F'2 or F'3) as opposed to weak intensity tornadoes (F'0 or F'1) or violent storms (>F'4). F'0 intensity tornadoes were not simulated because of the noted reduction in risk contribution for the F'1 intensity.

In addition to the estimation of missile impact risk, the TORMIS code is also capable of estimating damage to a target given missile impact. To provide some indication of the likelihood of damage to the fuel assemblies under hypothetical conditions, Target 8 was assumed to have a one-quarter-inch steel plate element on its top surface. If oblique angles of entry and the presence of the fuel rack structures are considered, this case may provide a lower limit to the range of fuel assembly damage probability. The predicted damage (plate perforation) probabilities for missiles entering the pool and directly hitting Target 8 were 1.35×10^{-13} per year from a single missile and 2.58×10^{-9} per year for all the missiles combined. These probabilities are each more than an order of magnitude less than the predicted impact probabilities and, further, do not include the effect of the fluid drag

provided by the 24 feet of water above the assemblies. Tornadoes with intensities of F'3 or less did not contribute any to this actual damage risk.

An analysis of the impact risk contribution by missile type to Target 8 provides further information regarding this difference in impact risk and actual damage risk. The simulation outcomes for all the tornadoes indicate that 82 percent of the impact risk to Target 8 was from the wood beam missile (4 inches by 12 inches by 12 feet) with a total weight of only 115 lbs. The 6-inch steel pipe contributed 16 percent of the risk; the 1-inch steel rod contributed 1 percent; and the utility pole, 12-inch pipe, and vehicle contributed less than 1 percent combined. Thus, the order of magnitude reduction in the predicted impact risk versus the damage risk is partially due to the fact that many of the predicted impacts involve one of the lighter missiles that has a relatively weak damage potential.

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V. CONCLUSIONS

On the basis of this investigation, the following conclusions are made regarding the likelihoods of missile impact events in the spent fuel pool for Units 1 and 2:

(1) Missiles Entering the Pool - The mean probability of a tornado-generated missile entering the spent fuel pool for Units 1 and 2 is estimated as 4.15×10^{-11} per year. For the entire population of postulated missiles, the combined probability of at least one tornado-generated missile entering the spent fuel pool is estimated as 7.65×10^{-7} per year.

(2) Missiles Directly Hitting the Assemblies - The mean probability of a tornado-generated missile entering the spent fuel pool and directly hitting the spent fuel assemblies (or the interior pool wall just above the top of the assemblies) is estimated as 2.37×10^{-12} per year. For the entire population of postulated missiles, the combined probability of at least one tornado-generated missile directly hitting the assemblies is estimated as 4.34×10^{-8} per year.

(3) Missiles Damaging the Assemblies - A hypothetical lower-limit estimate of the probability of a tornado-generated missile entering the pool and damaging the spent fuel assemblies is estimated as 1.34×10^{-13} per year. For the entire population of postulated missiles, the combined probability of at least one tornado-generated missile damaging the assemblies is estimated as 2.58×10^{-9} per year.

The results indicate that the probability of tornado-generated missile damage is less than the 10^{-7} per year risk criterion specified in the Standard Review Plan [14] for missiles generated by natural phenomena. In addition, the conservatisms in the analysis, coupled with the tightness of the predicted statistical confidence bounds, suggest that the actual risk is likely to be less than the lower bound of the predicted risk.

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VI. REFERENCES

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APPENDIX A

TORMIS Input and Output Sample

The input and a portion of the output of the computer simulation is given in this appendix for the computer simulation of F'5 tornadoes. Table A-1 illustrates the data input requirements for the TORMIS code. In Table A-2 the output summary by target number and impact event is presented. The four impact events that the code analyzes are as follows:

(1) Missile impact or a hit to the target.

(2) Missile impact with velocity greater than a specified value.

(3) Damage evaluation for specified target properties.

(4) Damage evaluation for a second set of target properties.

The output summary also includes estimates of missile impact and damage to combinations of targets. The notation "7 8 UN" in Table A-2 represents the union of Targets 7 and 8 and hence the combined probabilities for each target. The notation "7 8 IN" represents the interesection of both targets and hence the probability that both targets are impacted in the same tornado event.

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TABLE A-1. INPUT DATA FOR F'5 SIMULATION

CONTROL DATA

KLMTOR,NSAME,KTINT,INTEN,NSSET	20	50C	5	5	6
KKIND,KNBC,NUMBC,KRIC,KT	0	1	1	0	1
KTDEF,MDEF,KRITE	0	0	3		
IX,IXL,IXM,IXK	45551123	87677753	88863387	44453873	
IMAX,JMAX,DOUT,RELERR,ABSERR	300	10	0.100000E 00	0.100000E 00	0.100000E 00
AIRDEN,G,TTS,TM,DEGLAT	0.251856E-02	0.320509E 02	0.196003E 01	0.100000E 01	0.0
IPTDIR	1				
IPTPOS,YTSTD	1	0.150000E-01			
IPSPOS	1				
XMIFA,XMIFB,XMIFC,YMIFA,YMIFB	0.100000E 03	0.0	0.0	0.400000E 00	0.0
XSIFA,XSIFB,XSIFC,YSIFA,YSISB	0.150000E 00	0.0	0.0	0.0	0.0
IBETA,BETA	1	0.500000E 00			
IPPSIN	1				
IPHIGH,ZIMR,FIMR	1	0.200000E 01	0.0		
IPMIS	0				
IIR,PKILL	1	0.900000E 00			

TORNADO STRIKE DATA

OCCUR(I)	0.120700E-03	0.641300E-04	0.194100E-04	0.439000E-05	0.946000E-06	0.215200E-06		
TRANSL(I)	0.900000E 00	0.310000E 01	0.590000E 01	0.310000E 02	0.990000E 02	0.315000E 03		
TRANSW(I)	0.510000E 02	0.165000E 03	0.525000E 03	0.166800E 04	0.475200E 04	0.163680E 05		
WINDC(I)	0.151100E 03	0.198050E 03	0.246060E 03	0.306600E 03	0.406360E 03	0.528100E 03		
TCFDIR(I)	0.224700E 00	0.764100E 00	0.843300E 00	0.864100E 00	0.869500E 00	0.878400E 00	0.892900E 00	0.100000E 01
FWC(I)	0.343000E 00	0.612000E 00	0.797000E 00	0.918000E 00				
FWC(I)	0.0	0.365000E 00	0.634000E 00	0.858000E 00				
FWC(I)	0.0	0.0	0.432000E 00	0.698000E 00				
FWC(I)	0.0	0.0	0.0	0.585000E 00				
PW(I)	0.200800E 00	0.701100E 00	0.907500E 00	0.989100E 00	0.999500E 00			
PW(I)	0.919000E-01	0.457400E 00	0.793300E 00	0.975700E 00	0.996100E 00			
PW(I)	0.420000E-01	0.240200E 00	0.546600E 00	0.907000E 00	0.982300E 00			
PW(I)	0.315000E-01	0.736000E-01	0.294600E 00	0.705200E 00	0.957900E 00			
PW(I)	0.0	0.0	0.300000E 00	0.700000E 00	0.900000E 00			
[illegible]	[illegible]	[illegible]	[illegible]	0.992000E 00	0.100000E 01			

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(Continued)

TABLE A-1. INPUT DATA FOR F'5 SIMULATION (Continued)

EI(I)	0.326600E 00	0.675900E 00	0.853600E 00	0.979700E 00	0.100000E 01
EI(I)	0.154400E 00	0.589500E 00	0.788000E 00	0.980400E 00	0.100000E 01
PI(I)	0.0	0.403800E 00	0.701900E 00	0.100000E 01	0.100000E 01
EI(I)	0.0	0.0	0.0	0.100000E 01	0.100000E 01
PI(I)	0.806300E 00	0.887900E 00	0.969500E 00	0.100000E 01	0.100000E 01
EI(I)	0.425700E 00	0.738400E 00	0.905100E 00	0.981900E 00	0.100000E 01
EI(I)	0.215100E 00	0.564300E 00	0.832500E 00	0.972300E 00	0.997300E 00
PI(I)	0.112700E 00	0.497500E 00	0.687500E 00	0.964400E 00	0.995100E 00
EI(I)	0.135900E 00	0.500000E 00	0.592200E 00	0.100000E 01	0.100000E 01
EI(I)	0.0	0.0	0.243200E 00	0.100000E 01	0.100000E 01
PI(I)	0.571400E 00	0.714300E 00	0.785700E 00	0.100000E 01	0.100000E 01
EI(I)	0.333500E 00	0.636700E 00	0.833500E 00	0.984900E 00	0.100000E 01
EI(I)	0.783000E-01	0.274500E 00	0.617500E 00	0.911900E 00	0.980400E 00
PI(I)	0.416000E-01	0.241700E 00	0.491700E 00	0.883200E 00	0.100000E 01
EI(I)	0.0	0.400000E-01	0.240000E 00	0.720000E 00	0.100000E 01
EI(I)	0.0	0.0	0.0	0.833300E 00	0.100000E 01
EI(I)	0.0	0.0	0.0	0.333300E 00	0.666700E 00
EI(I)	0.750600E 00	0.750600E 00	0.100000E 01	0.100000E 01	0.100000E 01
PI(I)	0.475000E-01	0.143000E 00	0.380500E 00	0.904500E 00	0.100000E 01
EI(I)	0.514000E-01	0.230900E 00	0.384800E 00	0.820500E 00	0.974400E 00
PI(I)	0.0	0.415000E-01	0.166600E 00	0.624900E 00	0.916500E 00
EI(I)	0.0	0.0	0.0	0.750600E 00	0.100000E 01
EI(I)	0.0	0.0	0.0	0.0	0.0
EI(I)	0.0	0.0	0.0	0.0	0.0
EI(I)	0.0	0.0	0.0	0.100000E 01	0.100000E 01
PI(I)	0.0	0.0	0.0	0.250000E 00	0.750000E 00
PI(I)	0.0	0.0	0.0	0.0	0.100000E 01
EI(I)	0.0	0.0	0.0	0.0	0.100000E 01

PLANT DATA

NZ,NZC,NZCP,NPPE	17	39	97	8				
XZC(I)	0.491000E 04	0.491000E 04	0.401000E 04	0.401000E 04	0.333000E 04	0.333000E 04	0.333000E 04	0.333000E 04
XZC(I)	0.333000E 04	0.333000E 04	0.333000E 04	0.267000E 04	0.267000E 04	0.267000E 04	0.267000E 04	0.267000E 04
XZC(I)	0.267000E 04	0.155000E 04	0.155000E 04	0.155000E 04	0.155000E 04	0.155000E 04	0.191000E 04	0.155000E 04
XZC(I)	0.155000E 04	0.[illegible]000E 04	0.155000E 04	0.155000E 04	0.117000E 04	0.117000E 04	0.117000E 04	0.690000E 03
XZC(I)	0.690000E 03	0.690000E 03	0.270000E 03	0.270000E 03	0.270000E 03	0.270000E 03	0.270000E 03	
YZC(I)	-0.230000E 04	-0.400000E 02	-0.400000E 02	0.760000E 03	0.760000E 03	0.620000E 03	-0.400000E 02	-0.280000E 03
YZC(I)	-0.580000E 03	-0.108000E 04	-0.230000E 04	-0.580000E 03	-0.280000E 03	0.620000E 03	0.104000E 04	0.180000E 04
YZC(I)	0.226000E 04	0.180000E 04	0.134000E 04	0.104000E 04	0.340000E 03	-0.580000E 03	-0.580000E 03	-0.980000E 03
YZC(I)	-0.108000E 04	-0.108000E 04	-0.128000E 04	-0.230000E 04	-0.128000E 04	-0.980000E 03	-0.580000E 03	0.340000E 03
YZC(I)	0.134000E 04	0.180000E 04	0.226000E 04	0.180000E 04	0.340000E 03	-0.580000E 03	-0.128000E 04	
LCONZ(1,J)	14	6	8	1[illegible]	14			
LCONZ(2,J)	13	8	9	12	13			
LCONZ(3,J)	22	20	15	12	22			
LCONZ(4,J)	23	9	10	26	23			
LCONZ(5,J)	22	23	26	25	22			

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(Continued)

TABLE A-1. INPUT DATA FOR F'5 SIMULATION (Continued)

LCONZ(8,J)	30	24	27	29	30			
LCONZ(9,J)	38	31	29	19	38			
LCONZ(10,J)	37	21	22	38	37			
LCONZ(11,J)	33	19	21	32	33			
LCONZ(12,J)	36	34	32	17	36			
LCONZ(13,J)	34	18	19	33	34			
LCONZ(14,J)	35	17	16	36	35			
LCONZ(15,J)	18	16	15	20	18			
LCONZ(16,J)	5	4	3	7	5			
LCONZ(17,J)	7	2	1	11	7			
XPE(I)	0.284000E 04	0.266000E 04	0.266000E 04	0.280000E 04	0.283000E 04	0.320000E 04	0.335000E 04	0.302000E 04
YPE(I)	0.600000E 03	0.190000E 03	0.110000E 03	-0.660000E 03	-0.680000E 03	-0.220000E 03	0.175000E 03	0.600000E 03
XCO,YCO,WIO,ZS,NORTH		0.300000E 04	0.0	0.430000E 03	0.0	0.590850E 01		
NUMTAB,NTAB,NTABB,NUMSAP,NTASA,NTASB,NTABSF,MAXSAP	13 66 0 13 7 8 0 0							
XTF,YTR,ZC(I),WX,WY,WZ		0.286350E 04	0.0	0.0	0.675000E 02	0.0	0.720000E 02	
XTF,YTR,ZC(I),WX,WY,WZ		0.313650E 04	0.0	0.0	0.675000E 02	0.0	0.720000E 02	
XTF,YTR,ZC(I),WX,WY,WZ		0.293200E 04	-0.337500E 02	0.0	0.210000E 02	0.410000E 02	0.218300E 02	
XTF,YTR,ZC(I),WX,WY,WZ		0.295300E 04	0.150000E 01	0.0	0.605000E 02	0.575000E 01	0.218300E 02	
XTF,YTR,ZC(I),WX,WY,WZ		0.2953[illegible]E 04	-0.337500E 02	0.0	0.605000E 02	0.600000E 01	0.218300E 02	
XTF,YTR,ZC(I),WX,WY,WZ		0.301350E 04	-0.337500E 02	0.0	0.545000E 02	0.410[illegible]E 02	0.218300E 02	
XTF,YTR,ZC(I),WX,WY,WZ		0.295300E 04	-0.277500E 02	0.100000E 01	0.605000E 02	0.29250[illegible] 02	0.208300E 02	
XTF,YTR,ZC(I),WX,WY,WZ		0.295300E 04	-0.277500E 02	-0.206700E 02	0.605000E 02	0.292500E 02	0.216700E 02	
XTF,YTR,ZC(I),WX,WY,WZ		0.295000E 04	0.725000E 01	0.0	0.130000E 03	0.116750E 03	0.218300E 02	

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POOR ORIGINAL

(Continued)

TABLE A-1. INPUT DATA FOR F'5 SIMULATION (Continued)

XTF,YTR,ZC(I),WX,WY,WZ	0.266600E 04	0.124000E 03	0.0	0.658500E 03	0.685000E 02	0.240000E 02
XTF,YTR,ZC(I),WX,WY,WZ	0.273000E 04	0.192500E 03	0.0	0.540000E 03	0.135000E 03	0.500000E 02
XTF,YTR,ZC(I),WX,WY,WZ	0.298800E 04	-0.937500E 02	0.0	0.150000E 02	0.0	0.390000E 02
XTF,YTR,ZC(I),WX,WY,WZ	0.302700E 04	-0.937500E 02	0.0	0.150000E 02	0.0	0.390000E 02

TAR	NUMSUF	RT	HT	XC	YC	ZC	TYPTAR	LAP	THETA
1	3	70.	140.	2864.	C.	0.	3	3	0.0
2	3	70.	140.	3137.	0.	0.	3	3	0.0
3	6	31.	22.	2943.	-13.	C.	1	8	0.0
4	6	36.	22.	2983.	4.	0.	1	8	0.0
5	6	36.	22.	2983.	-31.	C.	1	8	0.0
6	6	40.	22.	3041.	-13.	0.	1	8	0.0
7	6	39.	22.	2983.	-13.	1.	1	8	0.0
8	6	39.	1.	2983.	-13.	-21.	1	8	0.0
9	6	79.	22.	3000.	66.	C.	1	8	0.0
10	6	331.	24.	2995.	158.	0.	1	12	0.0
11	6	279.	50.	3000.	260.	C.	1	10	0.0
12	3	25.	39.	2988.	-94.	0.	4	2	0.0
13	3	25.	39.	3027.	-94.	C.	4	2	0.0

TAR	SURF	NWALL	TYPE	MTL	XL	XU	YL	YU	ZL	ZU	STRENGTH	WTL	WTH
1	1	1	4	0	68.	0.	0.	0.	0.	72.	4000.	72.	72.
1	2	2	5	0	68.	0.	0.	0.	72.	140.	4000.	72.	72.
1	3	3	0	-1	2796.	2931.	-68.	68.	0.	0.	4000.	0.	0.
2	1	4	4	0	68.	0.	0.	0.	0.	72.	4000.	72.	72.
2	2	5	5	0	68.	0.	0.	0.	72.	140.	4000.	72.	72.
2	3	6	0	-1	3069.	3204.	-68.	68.	0.	0.	4000.	0.	0.
3	1	7	1	0	2932.	2932.	-34.	7.	0.	22.	4000.	12.	12.
3	2	8	2	0	2932.	2953.	-34.	-34.	0.	22.	4000.	72.	72.
3	3	9	0	-1	2953.	2953.	-34.	7.	0.	22.	4000.	0.	0.
3	4	10	2	0	2932.	2953.	7.	7.	0.	22.	4000.	69.	69.
3	5	11	3	0	2932.	2953.	-34.	7.	22.	22.	4000.	10.	10.
3	6	12	0	-1	2932.	2953.	-34.	7.	0.	0.	4000.	0.	0
4	1	13	1	0	2953.	2953.	2.	7.	0.	22.	4000.	12.	12.
4	2	14	0	-1	2953.	3014.	2.	2.	0.	22.	4000.	0.	0.
4	3	15	1	0	3014.	3014.	2.	7.	0.	22.	4000.	12.	12.
4	4	16	2	0	2953.	3014.	7.	7.	0.	22.	4000.	69.	69.
4	5	17	3	0	2953.	3014.	2.	7.	22.	22.	4000.	10.	10.
4	6	18	0	-1	2953.	3014.	2.	7.	0.	0.	4000.	0.	0.
5	1	19	1	0	2953.	2953.	-34.	-28.	0.	22.	4000.	12.	12.
5	2	20	2	0	2953.	3014.	-34.	-34.	0.	22.	4000.	72.	72.
5	3	21	1	0	3014.	3014.	-34.	-28.	0.	22.	4000.	12.	12.
5	4	22	0	-1	2953.	3014.	-28.	-28.	0.	22.	4000.	0.	0.
5	5	23	3	0	2953.	3014.	-34.	-28.	22.	22.	4000.	10.	10.
5	6	24	0	-1	2953.	3014.	-34.	-28.	0.	0.	4000.	0.	0.
6	1	25	0	-1	3014.	3014.	-34.	7.	0.	22.	4000.	0.	0.
6	2	26	2	0	3014.	3068.	-34.	-34.	0.	22.	4000.	72.	72.
6	3	27	1	0	3068.	3068.	-34.	7.	0.	22.	4000.	12.	12.
6	4	28	2	0	3014.	3068.	7.	7.	0.	22.	4000.	69.	69.
6	5	29	3	0	3014.	3068.	-34.	7.	22.	22.	4000.	10.	10.
6	6	30	0	-1	3014.	3068.	-34.	7.	0.	0.	4000.	0.	0.
7	1	31	1	0	2953.	2953.	-28.	2.	1.	22.	4000.	42.	42.
7	2	32	2	0	2953.	3014.	-28.	-28.	1.	22.	4000.	72.	72.
7	3	33	1	0	3014.	3014.	-28.	2.	1.	22.	4000.	72.	72.
7	4	34	2	0	2953.	3014.	2.	2.	1.	22.	4000.	69.	69.

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(Continued)

TABLE A-1. INPUT DATA FOR F'5 SIMULATION (Continued)

```
 7   6   36   0   -12953.3014. -28.    2.    1.    1.     4000.   0.   0.
 8   1   37   1    12953.2953. -28.    2.  -21.    1.    36000.   0.   1.
 8   2   38   2    12953.3014. -28.  -28.  -21.    1.    36000.   0.   1.
 8   3   39   1    13014.3014. -28.    2.  -21.    1.    36000.   0.   1.
 8   4   40   2    12953.3014.   2.    2.  -21.    1.    36000.   0.   1.
 8   5   41   3    12953.3014. -28.    2.    1.    1.    36000.   0.   1.
 8   6   42   3    12953.3014. -28.    2.  -21.  -21.    36000.   0.   1.
 9   1   43   1    02950.2950.   7.  124.    0.   22.     4000.  12.  12.
 9   2   44   2    02950.3050.   7.    7.    0.   22.     4000.  12.  12.
 9   3   45   1    03050.3050.   7.  124.    0.   22.     4000.  12.  12.
 9   4   46   2    02950.3050. 124.  124.    0.   22.     4000.  12.  12.
 9   5   47   3    02950.3050.   7.  124.   22.   22.     4000.  12.  12.
 9   6   48   0   -12950.3050.   7.  124.    0.    0.     4000.   0.   0.
10   1   49   1    02666.2666. 124.  193.    0.   24.     4000.  12.  12.
10   2   50   2    02666.3324. 124.  124.    0.   24.     4000.  12.  12.
10   3   51   1    03324.3324. 124.  193.    0.   24.     4000.  12.  12.
10   4   52   2    02666.3324. 193.  193.    0.   24.     4000.  12.  12.
10   5   53   3    02666.3324. 124.  193.   24.   24.     4000.  12.  12.
10   6   54   0   -12666.3324. 124.  193.    0.    0.     4000.   0.   0.
11   1   55   1    02730.2730. 193.  328.    C.   50.     4000.  12.  12.
11   2   56   2    02730.3270. 193.  193.    0.   50.     4000.  12.  12.
11   3   57   1    03270.3270. 193.  328.    0.   50.     4000.  12.  12.
11   4   58   2    02730.3270. 328.  328.    0.   50.     4000.  12.  12.
11   5   59   3    02730.3270. 193.  328.   50.   50.     4000.  12.  12.
11   6   60   0   -12730.3270. 193.  328.    0.    0.     4000.   0.   0.
12   1   61   4    0   15.   0.   C.   0.    0.   39.     4000.  12.  12.
12   2   62   3    02973.3003.-109.  -79.   39.   39.     4000.  12.  12.
12   3   63   0   -12973.3003.-109.  -79.    0.    0.     4000.   0.   0.
13   1   64   4    0   15.   0.   0.   0.    0.   39.     4000.  12.  12.
13   2   65   3    03012.3042.-109.  -79.   39.   39.     4000.  12.  12.
13   3   66   0   -13012.3042.-109.  -79.    0.    0.     4000.   0.   0.

KE1,KBRL,BS,CUW,ER,WUW        0.163000E 03  0.100000E 01  0.970000E 00  0.150000E 03  0.100000E 01  0.400000E 02

NMZ(I)           0.500000E 02  0.410000E 03  0.460000E 04  0.500000E 01  0.130000E 03  0.460000E 04  0.320000E 03  0.270000E 03

KPZ(I)           0.135000E 04  0.160000E 03  0.110500E 04  0.100000E-01  0.325000E 03  0.460000E 04  0.128000E 04  0.690000E 03

KPZ(I)           0.100000E 03


        MISSILE DATA

NSET,LKEY                5             -1
   1   0.12000E 02   0.95500E 01   0.48000E 02   0.27260E 01   0.0          0.12000E 05   0.0          0.0         9   4
   2   0.66250E 01   0.18970E 02   0.55800E 01   0.17080E 03   0.0          0.27170E 02   0.0          0.0         3   3
   3   0.10000E 01   0.26700E 01   0.78500E 00   0.16750E 03   0.0          0.36000E 02   0.0          0.0         1   1
   4   0.13500E 02   0.32000E 02   0.14310E 03   0.18060E 03   0.0          0.31110E 02   0.0          0.0         2   2
   5   0.12750E 02   0.49600E 02   0.14600E 02   0.15430E 03   0.0          0.14120E 02   0.0          0.0         3   3
   6   0.79200E 02   0.24390E 03   0.40860E 04   0.19380E 03   0.0          0.28800E 01   0.0          0.0        25   5

CIFMZ( 1,K)      0.200000E 00  0.400000E 00  0.600000E 00  0.700000E 00  0.900000E 00

CIFMZ( 2,K)      0.244000E 00  0.488000E 00  0.732000E 00  0.744000E 00  0.988000E 00

CIFMZ( 3,K)      0.217000E 00  0.435000E 00  0.652000E 00  0.761000E 00  0.978000E 00

CIFMZ( 4,K)      0.0           0.0           0.0           0.0           0.0

CIFMZ( 5,K)      0.385000E 00  0.385000E 00  0.385000E 00  0.615000E 00  0.615000E 00

CIFMZ( 6,K)      0.217000E 00  0.435000E 00  0.652000E 00  0.761000E 00  0.978000E 00

CIFMZ( 7,K)      0.0           0.0           0.0           0.620000E-01  0.620000E-01
```

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(Continued)

TABLE A-1. INPUT DATA FOR F'5 SIMULATION (Continued)

CEFMZ(9,K)	0.370000E 00	0.556000E 00	0.741000E 00	0.778000E 00	0.963000E 00		
CEFMZ(10,K)	0.625000E 00	0.625000E 00	0.625000E 00	0.688000E 00	0.688000E 00		
CEFMZ(11,K)	0.0	0.452000E 00	0.543000E 00	0.543000E 00	0.996000E 00		
CEFMZ(12,K)	0.0	0.0	0.0	0.100000E 01	0.100000E 01		
CEFMZ(13,K)	0.307000E 00	0.615000E 00	0.615000E 00	0.615000E 00	0.923000E 00		
CEFMZ(14,K)	0.217000E 00	0.435000E 00	0.652000E 00	0.761000E 00	0.978000E 00		
CEFMZ(15,K)	0.0	0.0	0.0	0.620000E-01	0.620000E-01		
CEFMZ(16,K)	0.0	0.720000E-01	0.720000E-01	0.130000E 00	0.130000E 00		
CEFMZ(17,K)	0.0	0.0	0.0	0.100000E 01	0.100000E 01		
ZSMIN(1,K)	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02		
ZSMIN(2,K)	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02	0.590000E 02		
ZSMIN(3,K)	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02	0.590000E 02		
ZSMIN(4,K)	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03		
ZSMIN(5,K)	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03		
ZSMIN(6,K)	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03		
ZSMIN(7,K)	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03		
ZSMIN(8,K)	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03		
ZSMIN(9,K)	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03	0.660000E 03		
ZSMIN(10,K)	0.420000E 03	0.420000E 03	0.420000E 03	0.420000E 03	0.420000E 03		
ZSMIN(11,K)	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02	0.590000E 02		
ZSMIN(12,K)	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02	0.590000E 02		
ZSMIN(13,K)	0.590000E 02	0.590000E 02	0.590000E 02	0.590000E 02	0.590000E 02		
ZSMIN(14,K)	0.590000E 02	0.590000E 02	0.590000E 02	0.590000E 02	0.590000E 02		
ZSMIN(15,K)	0.590000E 02	0.590000E 02	0.590000E 02	0.590000E 02	0.590000E 02		
ZSMIN(16,K)	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02	0.590000E 02		
ZSMIN(17,K)	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02	0.590000E 02		
ZSMAX(1,K)	0.360000E 03	0.610000E 02	0.360000E 03	0.360000E 03	0.610000E 02		
ZSMAX(2,K)	0.240000E 03	0.240000E 03	0.240000E 03	0.240000E 03	0.600000E 02		
ZSMAX(3,K)	0.600000E 03	0.240000E 03	0.600000E 03	0.600000E 03	0.600000E 02		
ZSMAX(4,K)	0.840000E 03	0.840000E 03	0.840000E 03	0.840000E 03	0.661000E 03		
ZSMAX(5,K)	0.840000E 03	0.840000E 03	0.840000E 03	0.840000E 03	0.661000E 03		
ZSMAX(6,K)	0.960000E 03	0.960000E 03	0.960000E 03	0.960000E 03	0.661000E 03		
ZSMAX(7,K)	0.661000E 03	0.661000E 03	0.661000E 03	0.661000E 03	0.661000E 03		
ZSMAX(8,K)	0.840000E 03	0.840000E 03	0.840000E 03	0.840000E 03	0.661000E 03		
ZSMAX(9,K)	0.840000E 03	0.840000E 03	0.840000E 03	0.840000E 03	0.661000E 03		
ZSMAX(10,K)	0.600000E 03	0.600000E 03	0.600000E 03	0.600000E 03	0.421000E 03		
ZSMAX(11,K)	0.480000E 03	0.480000E 03	0.480000E 03	0.480000E 03	0.600000E 02		
ZSMAX(12,K)	0.240000E 03	0.240000E 03	0.240000E 03	0.240000E 03	0.600000E 02		
ZSMAX(13,K)	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02		
ZSMAX(14,K)	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02		
ZSMAX(15,K)	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02	0.600000E 02		
ZSMAX(16,K)	0.240000E 03	0.240000E 03	0.240000E 03	0.240000E 03	0.600000E 02		
ZSMAX(17,K)	0.240000E 03	0.240000E 03	0.240000E 03	0.240000E 03	0.600000E 02		
TOTAL NUMBER MISSILES	19995.						
A2ONE	0.594000E 06	0.198000E 06	0.181440E 07	0.710000E 06	0.180000E 06	0.217160E 07	0.152000E 06
	0.114000E 06	0.630000E 06	[illegible]	0.860000E 06	0.613200E 06	0.395600E 06	0.110400E 07
	0.851200E 06	0.544000E 06	0.357000E 07				

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***** TARGET DAMAGE ASSESSMENT FOR SPECIFIED TORNADO INTENSITY AND MISSILE SUBSETS *****

DAMAGE PARAMETERS FOR UPPERBOUND WINDSPEEDS OF TORNADO INTENSITY= F 5

WALL THICKNESS MISSILE SUBSET NUMBER

TABLE A-2. SIMULATION OUTPUT SUMMARY FOR F'5 TORNADOES

STATISTICAL SUMMARY FOR THIS SIMULATION RUN

		SINGLE MISSILE					MULTIPLE MISSILE			
TARGET	EVENT	P(A)	VAR(P)	VAR(P)-G	CONFIDENCE BOUNDS		P(A)**N	VAR(P**N)	CONFIDENCE BOUNDS	
1	1	0.48597E-09	0.13095E-18	0.46687E-19	-0.22329E-09	0.11952E-08	0.16431E-05	0.48228E-12	0.28192E-06	0.30042E-05
1	2	0.12298E-09	0.12212E-19	0.12943E-19	-0.93618E-10	0.33958E-09	0.83457E-06	0.45682E-12	-0.52016E-06	0.21293E-05
1	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1	0.71593E-10	0.38780E-21	0.20102E-21	0.32955E-10	0.11019E-09	0.95343E-06	0.82215E-13	0.39148E-06	0.15154E-05
2	2	0.74821E-11	0.21054E-22	0.21922E-22	-0.15113E-11	0.16476E-10	0.73513E-07	0.20223E-14	-0.14629E-07	0.16165E-06
2	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1	0.90834E-11	0.94825E-23	0.75117E-23	0.30478E-11	0.15119E-10	0.17016E-06	0.32895E-14	0.57743E-07	0.28257E-06
3	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	3	0.19398E-11	0.24441E-23	0.26270E-23	-0.11244E-11	0.50040E-11	0.37563E-07	0.92005E-15	-0.21888E-07	0.97014E-07
3	4	0.19398E-11	0.24441E-23	[illegible]	-0.11244E-11	0.50040E-11	0.37563E-07	0.92005E-15	-0.21888E-07	0.97014E-07
4	1	0.34716E-15	0.11450E-30	[illegible]	-0.31605E-15	0.10104E-14	0.0	0.0	0.0	0.0
4	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1	0.13627E-10	0.16445E-22	0.84401E-23	0.56784E-11	0.21575E-10	0.24589E-06	0.50553E-14	0.10653E-06	0.38524E-06
5	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	3	0.23797E-14	0.53798E-29	0.56517E-29	-0.21664E-14	0.69258E-14	0.39306E-10	0.14677E-20	-0.35783E-10	0.11440E-09
5	4	0.23797E-14	0.53798E-29	0.56517E-29	-0.21664E-14	0.69258E-14	0.39306E-10	0.14677E-20	-0.35783E-10	0.11440E-09
6	1	0.13421E-10	0.23777E-22	0.90025E-23	0.38637E-11	0.22978E-10	0.23428E-06	0.70491E-14	0.69723E-07	0.39884E-06
6	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1	0.41178E-12	0.38985E-25	0.47298E-25	0.23763E-11	0.79877E-12	0.79330E-08	0.14535E-16	0.42662E-09	0.15373E-07

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TABLE A-2. SIMULATION OUTPUT SUMMARY FOR F'5 TORNADOES (Continued)

7	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	1	0.39018E-12	0.75308E-25	0.82834E-25	-0.14758E-12	0.92833E-12	0.75675E-08	0.28271E-16	-0.28539E-08	0.17589E-07
8	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	3	0.13237E-12	0.16645E-25	0.17486E-25	-0.120[illegible]E-12	0.38524E-12	0.25866E-08	0.63559E-17	-0.23547E-08	0.75279E-08
8	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	1	0.27124E-10	0.77769E-22	0.70922E-22	0.98350E-11	0.44408E-10	0.42070E-06	0.15431E-13	0.17723E-06	0.66417E-06
9	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	3	0.11399E-10	0.43475E-22	0.49346E-22	-0.15242E-11	0.24323E-10	0.15930E-06	0.59466E-14	0.81581E-08	0.31045E-06
9	4	0.11399E-10	0.43475E-22	0.49346E-22	-0.15242E-11	0.24323E-10	0.15930E-06	0.59466E-14	0.81581E-08	0.31045E-06
10	1	0.75782E-09	0.97876E-19	0.43977E-19	0.14463E-09	0.13719E-08	0.18422E-05	0.48860E-12	0.47223E-06	0.32123E-05
10	2	0.11514E-10	0.12595E-21	0.13232E-21	-0.13482E-10	0.33511E-10	0.75517E-07	0.54177E-14	-0.68748E-07	0.21978E-06
10	3	0.21393E-09	0.65067E-20	0.63591E-20	0.55624E-10	0.37203E-09	0.12964E-05	0.28506E-12	0.24952E-06	0.23429E-05
10	4	0.21393E-09	0.65067E-20	0.63591E-20	0.55624E-10	0.37203E-09	0.12964E-05	0.28506E-12	0.24992E-06	0.23429E-05
11	1	0.53618E-09	0.14770E-18	0.88254E-19	-0.24708E-09	0.12594E-08	0.13439E-05	0.26678E-12	0.33156E-06	0.23563E-05
11	2	0.77995E-11	0.57779E-22	0.60659E-22	-0.70950E-11	0.22698E-10	0.10196E-06	0.98743E-14	-0.92799E-07	0.29673E-06
11	3	0.29995E-09	0.69811E-19	0.73873E-19	-0.21751E-09	0.81782E-09	0.44212E-06	0.32764E-13	0.87343E-07	0.79689E-06
11	4	0.29995E-09	0.69811E-19	0.73873E-19	-0.21751E-09	0.81782E-09	0.44212E-06	0.32764E-13	0.87343E-07	0.79689E-06
12	1	0.19399E-10	0.83372E-22	0.36633E-22	0.15026E-11	0.37295E-10	0.34810E-06	0.25708E-13	0.33843E-07	0.66236E-06
12	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	3	0.68765E-11	0.23366E-22	0.25426E-22	-0.25978E-11	0.16351E 10	0.12882E-06	0.81232E-14	-0.47836E-07	0.30547E-06
12	4	0.68765E-11	0.23366E-22	0.25426E-22	-0.25978E-11	0.16351E-10	0.12882E-06	0.81232E-14	-0.47836E-07	0.30547E-06
13	1	0.79292E-11	0.35068E-23	0.39372E-23	0.42568E-11	0.11600E-10	0.14880E-06	0.12110E-14	0.80595E-07	0.21701E-06
13	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	3	0.19899E-11	0.11943E-23	0.13648E-23	-0.15213E-12	0.41319E-11	0.38115E-07	0.43351E-15	-0.26934E-08	0.78924E-07
13	4	0.19899E-11	0.11943E-23	0.13648E-23	-0.15213E-12	0.41319E-11	0.38115E-07	0.43351E-15	-0.26934E-08	0.78924E-07
ALL	1	0.19129E-08	0.69394E-18	0.17840E-18	0.28020E-09	0.35457E-08	0.23162E-05	0.49545E-12	0.93655E-06	0.36959E-05
ALL	2	0.14978E-09	0.12392E-19	0.13157E-19	-0.68410E-10	0.36796E-09	0.97192E-06	0.45936E-12	-0.35649E-06	0.23003E-05
ALL	3	0.53622E-09	0.97596E-19	0.80253E-19	-0.76052E-10	0.11485E-08	0.15576E-05	0.32827E-12	0.43466E-06	0.26806E-05
ALL	4	0.53609E-09	0.97518E-19	0.80253E-19	-0.75980E-10	0.11482E-08	0.15576E-05	0.32827E-12	0.43466E-06	0.26806E-05
7 8 UN	1						0.15512E-07	0.48904E-16	0.18050E-08	0.29218E-07
7 8 UN	2						0.0	0.0	0.0	0.0
7 8 UN	3						0.25866E-08	0.63558E-17	-0.23547E-08	0.75279E-08
7 8 UN	4						0.0	0.0	0.0	0.0
7 8 IN	1						-0.44037E-10	0.13029E-20	-0.11475E-05	0.26739E-10
7 8 IN	2						0.0	0.0	0.0	0.0
7 8 IN	3						0.0	0.0	0.0	0.0
7 8 IN	4						0.0	0.0	0.0	0.0

NHITS,NHITV,NDAM,NDAM2,AVHWT,AVHWTS 1552 12 169 168 0.4616584E-01 0.4629[illegible]31E-02

FOR A STATICALLY INDEPENDENT SUBSEQUENT RUN,INPUT A NEW VALUE FOR IX
AND THESE VALUES FOR THE RANDOM INTEGER SEEDS:
IXL,IXM,IXN -1497647509 +57962139 -510699179

POOR ORIGINAL

798 294