March 1985

Final Summary Report

TORNADO MISSILE RISK ANALYSIS OF MILLSTONE UNIT 3 EMERGENCY GENERATOR ENCLOSURE OPENINGS

Prepared for

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1.0 Introduction

A probabilistic analysis has been performed to estimate the risk of tornado-propelled missile entrance into any of four openings in the Emergency Generator Enclosure of the Millstone Nuclear Power Station, Unit No. 3. This work has been performed as part of Northeast Utilities response to Ref. 1. The analysis was made based upon a site-specific survey and characterization of potential missiles at the plant and TORMIS [2,3] computer simulations of tornado missile effects on the plant. The specific tasks of this investigation included:

(a) Tornado Wind Hazard. A site-specific tornado analysis was performed to develop tornado occurrence rates for the TORMIS analysis. Regional data [3,4] on tornado path length, width, and direction statistics were used with this windspeed frequency curve to define the tornado data set.

(b) Missile Characterization and Plant Survey. A general missile spectrum [2] was used to characterize the potential missiles at the Millstone site. This spectrum includes the NRC missiles [5] as a subset. A plant survey was conducted to characterize the potential missiles at the site. Based on the results of this survey, and previous surveys of other plants, a conservative characterization of the potential missiles was developed and documented.

(c) Plant Model. A model of the plant was developed to describe the main Unit 3 structures, with particular emphasis on the structures in the vicinity of the Emergency Generator Enclosure. Twenty two (22) targets were modeled in the plant model, including the four safety-related targets of interest.

(d) TORMIS Simulations and Analysis. Using the results of Tasks 1, 2, and 3, the TORMIS simulation methodology [3,6,7] was used to generate hit and damage probabilities for each of the modeled targets. Further calculations were made to account for target and missile size effects to estimate the probability of missile entrance into the small safety-related openings.

This summary report documents the tornado occurrence data, summarizes the TORMIS input data and presents the results of the missile analysis.

2.0 Tornado Wind Hazard Characteristics

The Millstone Station is located near the Connecticut coastline at latitude 41°20'N and longitude 72°50'W. The station is located in the far northeast quadrant of NRC Tornado Region I [8]. Consistent with the specified scope of

this effort, regional data coupled with site-specific occurrence rates were used in this study. The tornado path length, width, and direction data are taken from the Region C analysis of Twisdale and Dunn [3]. Table 1 summarizes the local-state F-scale tornado occurrence rates and windspeeds that were used in the TORMIS tornado missile risk calculations. F6 tornadoes (with windspeeds > 318 mph) were not simulated since they correspond to probabilities of exceedance of about $1x10^{-8}$ per year for this site. These data should provide a conservative characterization of tornadoes for Millstone since the station is located near the periphery of both NRC Region I and Region C.

3.0 Tornado Missile Risk Analysis Methodology

A methodology for estimating the probabilities of tornado missile related events has been developed for application to nuclear power plant risk analysis, as documented in Refs. 2, 3, and 6. This methodology was applied to assess the tornado missile risk to four openings in the Emergency Generator Enclosure (EGE) structure at Millstone Unit 3. For the specified targets at Millstone 3, the EGE vulnerability is related to the probability of missiles passing through relatively small openings. For these targets, missiles must not only pass through the initial opening but also work their way to the exhaust pipe and damage it in order to pose a threat to the safe operation of the plant. The TORMIS outputs were adjusted by two factors to estimate the probability of missile entrance into these small openings.

TABLE 1. ADJUSTED OCCURRENCE RATES AND WINDSPEED INTERVALS FOR TORMIS SIMULATIONS

Tornado Intensity	Occurrence Rate (per sq mi per yr)	F-Scale Windspeed
F1	$4.0x10^{-5}$	73-112
F2	$3.1x10^{-5}$	112-157
F3	$4.1x10^{-6}$	157-206
F4	$5.0x10^{-7}$	206-260
F5	$1.0x10^{-7}$	260-318

(a) Target Size Factor, K_a - To improve the accuracy of the simulations, the target planar areas of the openings are increased so that the modeled target openings in TORMIS are larger than those actually at the plant. For example, a 4 ft by 14 ft opening might be modeled as a 10 ft by 20 ft opening. The larger size will collect more hits for the same number of missile simulations and hence provide a better estimate of the missile flux in the immediate vicinity of the opening. If the increased size is properly selected so that deviations from uniform flux are minimal (especially in the vertical direction), then the larger target provides better scoring statistics in the simulations. An adjustment factor K_a for actual target size is given simply as

$$K_a = T/T_m \quad , \tag{1}$$

where T = actual opening target area and T_m is the TORMIS modeled target opening area.

(b) Missile Length Factor, K_m - The trajectories of the missiles in TORMIS are predicted by integrating the equations of motion. These equations of motion are referenced to the center of mass of the missile as is the impact position of those missiles that hit targets. For missiles in which one or more dimensions approach or exceed the smallest dimension of a target opening, the chance for missile ricochet or missile entanglement in the opening is significant. Hence, a K_m factor is used to estimate the frequency of missile entrance given missile hit within the area presented by the opening. These K_m factors were developed very conservatively, considering only missile length and neglecting missile angular velocity.

The final probability is then given by $P \cdot K_a \cdot K_m$.

4.0 Millstone 3 Missile and Target Data

On February 13, 1985, a site survey of the Millstone Nuclear Power Station, Unit 3, was carried out for the purposes of characterizing the targets and documenting the potential wind-borne missile sources. Figure 1, which is taken from the station plan for the Millstone site, illustrates the area immediately around Unit 3.

Consistent with the TORMIS methodology for specifying the site and missile origin zones, an inertial, Cartesian reference system was established, under the convention that the y-axis is parallel to plant north (15° counterclockwise from true north) and the x-axis points toward plant east. The plant site extending to the water and wooded areas or to approximately 1,000 ft from the nearest safety-related target was divided into 19 missile zones. Figure 2(a) is a

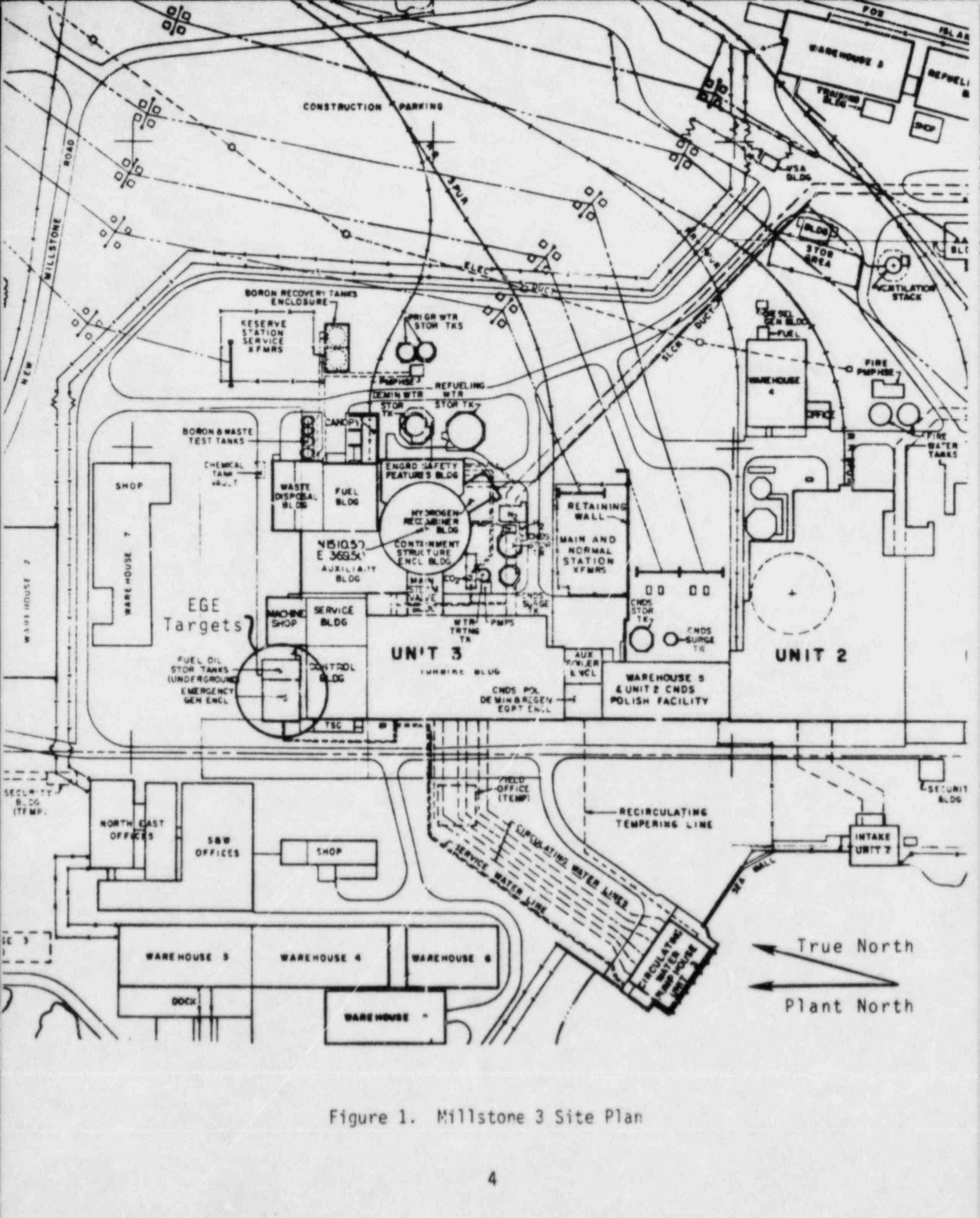
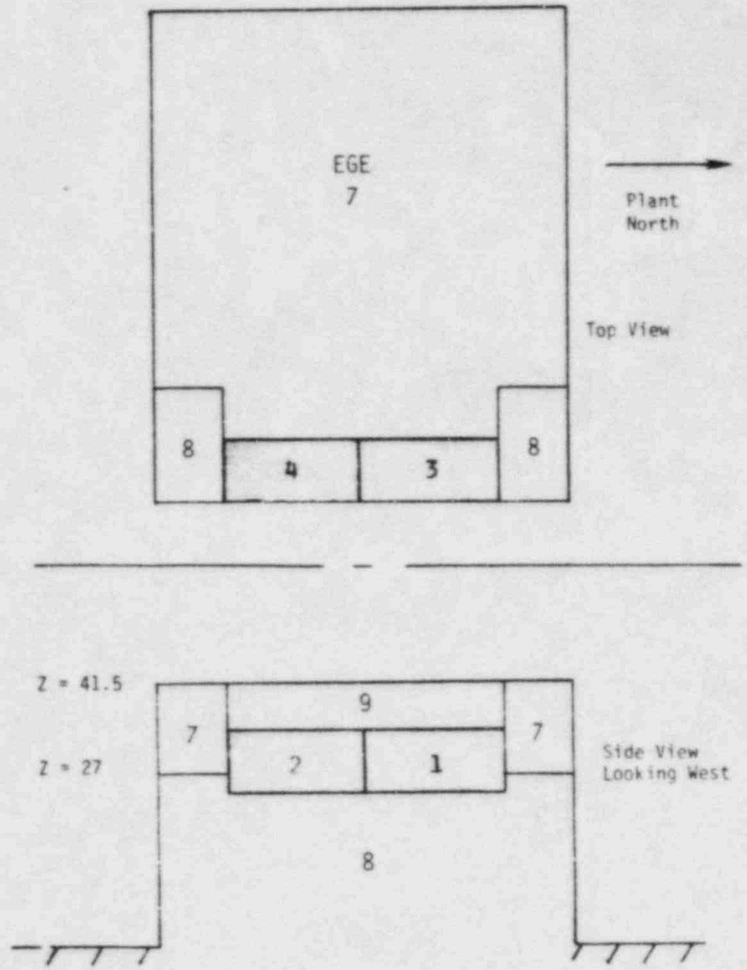


Figure 1. Millstone 3 Site Plan

(a) Photograph



(b) TORMIS Modeled Geometry

Figure 2. EGE Wall and Roof Openings

photograph of the 4 EGE openings and Fig. 2(b) shows how the wall penetrations and roof exhaust openings were modeled. All four safety-related targets are contained in the area just west of Zone 1, south of Zone 2 and east of Zone 5.

Detailed surveys of Zones 1, 2, 3, 4, 5, 6, 7, 8 and 11 were carried out to characterize potential missile sources that are typical near the EGE with Unit 3 under construction. A visual inspection of the EGE, Control, Service and Auxiliary Buildings, the Machine Shop and the operating floor of the Turbine Building was made. In addition, Ref. 9 and aerial and ground photographs were used to estimate potential missile populations in the remote zones. A total of 41,733 potential missiles were modeled in the analysis. It is noted that Unit 3 was still under construction on February 13, when the survey was conducted. The probabilities determined for the Unit 3 safety-related targets are thus assumed to provide very conservative upper bounds, since significantly less construction material is likely to be present on the Unit 3 site when Unit 3 is operating.

5.0 Simulation Results

TORMIS simulations were made for each F-scale given in Table 1. The results for missile impact on the EGE wall penetrations and exhaust openings are summarized in Table 2. These results are given in terms of whether or not one or both of the diesel generator exhaust trains was hit. Each train (A and B) has two openings, a wall penetration and a roof opening (see Fig. 2). Train A corresponds to Openings 1 and 3 and Train B corresponds to Openings 2 and 4. The mean probability that a tornado occurs and generates missiles that will enter any one of the four EGE openings is estimated as 1×10^{-6} per year. This is

TABLE 2. MISSILE HIT PROBABILITIES

Event	Mean Probability (per year)
Tornado Occurs and Missile Hits Exhaust Openings A or Hit Exhaust Openings B	1×10^{-6}
Tornado Occurs and Missile Hits Exhaust Openings A and Hit Exhaust Openings B	7×10^{-8}

the A ∪ B scoring event and is written as P[(1∪3)∪(2∪4)]. The probability that a tornado occurs and generates missiles that will enter one or more openings on both trains during the same tornado strike is estimated as 7×10^{-8} per year. This is the A ∩ B scoring event and is written as P[(1∪3)∩(2∪4)].

These probabilities are felt to be conservative mean estimates that meet the criteria outlined in Ref. 1.

6.0 Discussion and Conservatisms

Several final points regarding these results are emphasized. First, the mean probabilities in Table 2 represent the probabilities of a missile hitting an exhaust opening. A missile hit, however, does not necessarily represent damage to the exhaust pipes upstream of the access hatch. Hence, the actual probability of damage would need to be further reduced to reflect the appropriate conditional damage probabilities.

Second, the uncertainties in the Monte Carlo calculations represent a factor of about 2 to 3 in the mean probability estimates. These uncertainties are on the mean value and result from the finite number of simulation runs.

Third, there are additional conservatisms built into this analysis, including the following:

(a) The conditions under which the computer simulations were run reflected a modest construction effort at Unit 3, resulting in a conservative potential missile population at the plant. When Unit 3 is operational, the potential missile sources from construction materials would be expected to be substantially reduced, especially in Zones 1, 2, 3, 4 and 5 which are close to the EGE. Hence, the average per year threat may be several time less than the peak threat estimated herein.

(b) The missile characterization at the plant considers failure of non-tornado proof buildings at all F-scales; i.e., even at low windspeeds, and thus is judged to be conservative. Further, several engineered structures, e.g., the Service Building, the upper part of the Waste Processing Building, the Vent/Stack and the Machine Shop, were conservatively treated as failing like non-engineered structures. A total of 41,733 potential missiles were modeled in the analysis.

(c) Injection heights for each missile subset were conservatively specified as being uniformly distributed between the minimum and maximum storage heights for that subset. For some zones, most objects are stored within a few feet of the ground but a few objects (e.g., a non-engineered structure) may extend up to 12 or

15 feet; in these cases all missiles within the appropriate subsets would be injected up to the highest storage height. This was especially significant for the Machine Shop for which some missiles were stored on the roof (see Fig. IV-4(d)). As can be seen in Table IV-9 for Structure Origin 17, almost all injection heights extend beyond 25 ft, even though most of the potential missiles were stored inside the shop and thus at lower elevations.

(d) The K_m missile entrance adjustment accounted only for missile length and neglected angular velocity effects.

7.0 References

1. Youngblood, B. J., (NRC) letter to W. G. Counsil (Northeast Utilities), "SER Supplement for Millstone 3," Docket No. 50-423, December 10, 1984.

2. Twisdale, L. A., et al., "Tornado Missile Risk Analysis," NP-768 and NP-769, Electric Power Research Institute, Palo Alto, California, May 1978.

3. Twisdale, L. A., and Dunn, W. L., "Tornado Missile Simulation and Design Methodology," EPRI NP-2005, Electric Power Research Institute, Palo Alto, California, August 1981.

4. Twisdale, L. A., "Regional Tornado Data Base and Error Analysis," Preprint, AMS 12th Conf. on Severe Local Storms, San Antonio, Texas, January 1982.

5. U.S. Nuclear Regulatory Commission, Standard Review Plan, "Missiles Generated By Natural Phenomenon," Section 3.5.1.4, Washington, D.C., November 1975.

6. Twisdale, L. A., "Risk-Based Design Against Tornado Missiles," Preprint 3596, Civil Engineering and Nuclear Power, ASCE, Boston, Massachusetts, April 1979.

7. Twisdale, L. A., and Dunn, W. L., "Probabilistic Analysis of Tornado Wind Risks," Journal of Structural Engineering, Vol. 109, No. 2, February 1983.

8. Markee, E. H., Beckerley, J. G., and Sanders, K. E., "Technical Basis for Interim Regional Tornado Criteria," WASH-1300, 1974.

9. Millstone Unit 3 Final Safety Analysis Report, Northeast Utilities, Hartford, Connecticut.