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10 CFR 50.90

September 19, 2018
Serial: RA-18-0106

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Shearon Harris Nuclear Power Plant, Unit 1
Docket No. 50-400 / Renewed License No. NPF-63

Subject: License Amendment Request to Incorporate Tornado Missile Risk Evaluator into Licensing Basis – Supplement and Request for Additional Information Response (EPID L-2017-LLA-0355)

Ladies and Gentlemen:

By letter dated October 19, 2017, as supplemented by letter dated January 11, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML17292B648 and ML18011A911, respectively), Duke Energy Progress LLC (Duke Energy) submitted a license amendment request (LAR) regarding Shearon Harris Nuclear Power Plant, Unit 1 (HNP). The submittal incorporated by reference Nuclear Energy Institute (NEI) technical report NEI 17-02, Revision 1, "Tornado Missile Risk Evaluator (TMRE) Industry Guidance Document," September 2017, which contains the TMRE methodology (ADAMS Accession No. ML17268A023). The proposed amendment would modify the licensing bases as described in the Updated Final Safety Analysis Report to include a new methodology for determining whether physical protection from tornado-generated missiles is warranted. The methodology can only be applied to discovered conditions where tornado missile protection is not currently provided, and cannot be used to revise the design basis to avoid providing tornado missile protection in the plant modification process.

By letter dated June 18, 2018, (ADAMS Accession No. ML18145A181), U.S. Nuclear Regulatory Commission (NRC) staff informed Duke Energy that additional information is needed to support the staff review. Many of the request for additional information (RAI) questions are either identical or similar to questions asked of Southern Nuclear Operating Company (SNC) regarding Vogtle Electric Generating Plant, responses to which were submitted by SNC in a letter dated July 26, 2018 (ADAMS Accession No. ML18207A876, Reference 1). Following receipt of the SNC response, NRC staff provided comments in a public meeting on August 2, some of which were discussed in a letter from the NRC to SNC dated August 30 (ADAMS Accession No. ML18236A445). NRC staff perspectives shared in those public forums have informed the Harris response, and the expansion of the TMRE methodology made by SNC that was discussed in the August 30 letter has been removed in the enclosed NEI 17-02, Rev. 1B.

Enclosure 1 provides the Duke Energy response to the RAI. Some of the Duke Energy responses reference docketed SNC correspondence, including SNC-proposed changes to the TMRE methodology, to avoid redundancy. For clarity and continuity with the SNC pilot efforts, Enclosure 2 contains the changes to the TMRE methodology from the SNC version of the TMRE submitted in Reference 1. Enclosure 3 contains a retyped copy of the TMRE methodology, revision 1B, incorporating the changes identified in Enclosure 2.

In addition to the RAI responses and revisions to the TMRE methodology described above, Duke Energy identified additional conditions that are not in conformance with the HNP design and licensing bases for tornado missile protection for which treatment under TMRE is requested. The TMRE evaluation of the additional components is described in Enclosure 4 to this letter.

The conclusions of the original No Significant Hazards Consideration and Environmental Considerations in the original LAR are unaffected by this supplement and RAI response.

This letter contains no regulatory commitments.

In accordance with 10 CFR 50.91, Duke Energy is notifying the State of North Carolina of this LAR supplement by transmitting a copy of this letter to the designated State Official.

If there are any questions or if additional information is needed, please contact Arthur Zaremba at (980) 373-2062.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on September 19, 2018.

Sincerely,

Bentley K. Jones

Bentley K. Jones

Enclosures:

1. Response to Request for Additional Information
2. Redline/strikeout changes to NEI 17-02, Rev 1A
3. Clean copy of NEI 17-02, Rev. 1B
4. Supplement to Address Additional Non-Conforming Conditions

cc: Mr. J. Zeiler, NRC Sr. Resident Inspector, HNP
Mr. W. L. Cox, III, Section Chief, N.C. DHSR
Ms. M. Barillas, NRC Project Manager, HNP
Ms. E. Brown, NRC TMRE Project Manager, DORL
Mr. G. E. Miller, NRC TMRE HNP Project Manager, DORL
Ms. C. Haney, NRC Regional Administrator, Region II

Enclosure 2 contains the changes to the TMRE methodology from the SNC version of the TMRE submitted in Reference 1. Enclosure 3 contains a retyped copy of the TMRE methodology, revision 1B, incorporating the changes identified in Enclosure 2.

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License Amendment Request to Incorporate Tornado Missile Risk Evaluator
into Licensing Basis – Supplement and Request for Additional Information Response
(EPID L-2017-LLA-0355)

Enclosure 1

Response to Request for Additional Information

Background

By letter dated October 19, 2017, as supplemented by letter dated January 11, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML17292B648 and ML18011A911, respectively), Duke Energy Progress LLC (Duke Energy) submitted a license amendment request (LAR) regarding Shearon Harris Nuclear Power Plant, Unit 1 (HNP). The submittal incorporated by reference Nuclear Energy Institute (NEI) technical report NEI 17-02, Revision 1, “Tornado Missile Risk Evaluator (TMRE) Industry Guidance Document,” September 2017, which contains the TMRE methodology (ADAMS Accession No. ML17268A023). The proposed amendment would modify the licensing bases as described in the Updated Final Safety Analysis Report to include a new methodology for determining whether physical protection from tornado-generated missiles is warranted. The methodology can only be applied to discovered conditions where tornado missile protection is not currently provided, and cannot be used to revise the design basis to avoid providing tornado missile protection in the plant modification process.

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NRC Question 1

(DRA/DSS) Section B.2.3, “Selection of Target Missile Hit Probabilities (P) for Developing MIP” of NEI 17-02, Revision 1, states, in part:

> choosing the most conservative target MIP [missile impact parameter] from NP-768 (Target 4) would lead to overly conservative results for many targets at a NPP [nuclear power plant]. Therefore, the normalized tornado missile impact probability from “All Targets” in NP-768 (from Table 3-15) is proposed for use in the TMRE. This results in a MIP that is based on the combined hits on all modeled surfaces in NP-768, Plant A.

The derivation of the MIP includes the containment building (Target 1). As stated in Section B.2.3, in part:

> [t]he containment building is surrounded by other buildings… so only the upper part of the containment is exposed to tornado missiles.

Additionally, the elevation of the exposed upper part of the containment is different from the elevation of other targets included in the calculation of near-ground missiles.

Due to the overall height and the large surface area of containment building, many missiles may be unable to reach upper portions of the containment building, which reduces the overall density of missile strikes and could become unrepresentative of other shorter plant buildings.

Section 3.2.3.2, "Missile Impact and Damage Probability Estimates," of the Electric Power Research Institute (EPRI) technical report EPRI NP-768, "Tornado Missile Risk Analysis," May 1978, states, in part:

> [t]he individual target contributions to the total hit probability is generally greater for the larger targets but least for the containment structure (7.65×10^{-10}, Table 3-8) which is shielded from impact for the first 60 feet (ft) above ground elevation.

Justify including Target 1 (containment building) of Plant A in EPRI NP-768 in computation of the average MIP for targets less than 30 ft. above grade, given that the containment building is shielded by other buildings and is not impacted by near-ground missiles. Discuss how inclusion of Plant A containment building in computation of the average MIP for targets less than 30 ft. above grade impacts this application.

Duke Energy Response 1

NEI 17-02, Rev. 1A was revised to remove the containment building from the near ground MIP calculation, resulting in the following changes:

- Section A.5, Tables A-3, A-6, and A-7
- Table 5-1
- Section 5.5 Examples
- Section B.3.1 and B.3.3 discussion related to target selection
- Section B.3.4 sensitivity study
- Section B.4 MIP derivation

CDF and LERF benchmark studies were not revised as the updated results are conservative relative to the original data.

In addition, as discussed in NRC Question 7, Duke Energy withdrew the proposed treatment of de minimis penetrations in a supplement to the LAR, but did not fully describe the effects on the TMRE calculation results. Duke Energy utilized the reformulated guidance for the near ground MIP and explicitly treated the non-conforming conditions previously treated as de minimis in a new calculation.

The calculation supporting the original LAR used robust missile fractions more conservative than supported by NEI 17-02, Rev. 1. When recalculating the MIPs to address the concerns discussed above, Duke Energy also aligned the MIP calculations with the robust missile fractions in NEI 17-02, Rev. 1. Note that Duke Energy did not use the three categories of robust missiles added in Rev. 1A then subsequently removed in Rev. 1B. The increase in near ground MIPs was significantly offset by the alignment of robust fractions to those in Rev. 1B, resulting in minimal effect on the numerical results and negligible impact on the conclusion that the non-conforming conditions are of very low safety significance.

The results of the revised calculation are provided below.

	Original LAR (per year)	Revised Calculation (per year)	RG 1.174 Guidance (per year)
Compliant Case CDF	5.22E-7	5.23E-7	Not Applicable
Degraded Case CDF	5.44E-7	5.46E-7	
Compliant Case LERF	5.55E-8	5.55E-8	
Degraded Case LERF	5.77E-8	5.78E-8	
ΔCDF	2.2E-8	2.3E-8	1E-6
ΔLERF	2.2E-9	2.3E-9	1E-7

NRC Question 2

(DRA/DSS) Section B.4, “MIP Values for Use in the TMRE,” of NEI 17-02, Revision 1, provides two sets of MIP values – one for elevated targets and one for near-ground targets. The demarcation between near-ground and elevated targets is 30 ft above the primary missile source for that target. For targets near the ground, the MIP appears to be derived using the target areas listed in Table B-2 of NEI 17-02, Revision 1, which generally excludes the area of the roof (with an exception for Target 6, which includes the area of the roof). For the elevated MIP value, the area used to derive the MIP includes all the areas listed in Table B-1 of NEI 17-02, Revision 1, which includes roof areas.

NRC Question 2a

EPRI NP-768 Plant A targets vary in height from 20 to 230 ft. With the exception of Target 1 (the containment building), the buildings range in height from 20 to 80 ft. The weighted average (weighted by the wall area) height of all targets is 94 ft. The weighted average (weighted by the wall area) height of the targets is 56 ft. if Target 1 is excluded.

Provide the basis for the 30 feet demarcation between near-ground and elevated targets, given that EPRI NP-768 Plant A buildings range in height from 20 to 230 ft.

Duke Energy Response 2a

Duke Energy is aligned with the SNC response (Reference 1) to SNC question 2a and hereby provides that documentation as the Duke Energy response to this question.

NRC Question 2b

The MIPs calculated for elevated targets in Section B.4 are about 54 percent of the MIPs calculated for near-ground targets. This percentage seems to reflect the assumptions with respect to areas included in calculation of MIPs for elevated and near-ground targets. The difference in area appears to be the only factor that determined the difference between MIPs for elevated and near-ground targets. One of the sensitivity analyses in Appendix E of NEI 17-02, Revision 1, examines the impact of target elevation on targets hit probabilities. Revision 1 of NEI 17-02 states that the results of this sensitivity analysis show that in general as target elevation increases, hit probability decreases.

Describe the relationship between the numerical results shown in Appendix E and address whether the Appendix E results are generally consistent with the ratio of elevated to near-ground MIPs calculated in Appendix B, “Bases for MIP and Missile Inventories.” If Appendix E numerical results are not consistent with the ratio calculated in Appendix B, provide a justification.

Duke Energy Response 2b

Duke Energy is aligned with the SNC response (Reference 1) to SNC question 2b and hereby provides that documentation as the Duke Energy response to this question.

NRC Question 3

(DRA/DSS) Section 5, “Evaluate Target and Missile Characteristics,” of NEI 17-02, Revision 1, states, in part, that:

> [t]he <30 ft MIP value can be used in cases where it is difficult to determine if the target is >30 ft above all missile sources.

Table 5-1 in NEI 17-02, Revision 1, refers to targets that are 30 ft above or below “grade,” and Note 2 to the table explains:

> [t]he term grade here is meant to refer to the elevation at which a majority of the missiles that can affect the target is located. Typically, this is plant grade, although for some targets it may be different.

The above discussions in Sections 5 and 5.1 of NEI 17-02, Revision 1, seem to provide different guidance regarding how to determine elevated targets (for which the MIP values are different). The NRC staff notes that missiles may exist at elevations above some nominal plant grade or that targets exist at elevations that are above and below the nominal plant grade.

NRC Question 3a

Describe the process that Duke Energy has used for determining near-ground and elevated targets considering various elevations of targets and missiles. The description should include how this process ensures proper consideration of missile source applicability for each target relative to the demarcation height.

Duke Energy Response 3a

NEI 17-02 was revised as follows:

- Rev. 1A
    - The term “reference elevation” was added as a defined term
    - Section 5.1 was revised to provide the details for determining the reference elevation.
- Rev. 1B
    - Sections 2.3 and 5.1 were revised to require documenting the reference elevation and justification for choosing its value.

The reference elevation for the HNP site was established as 260.5 ft. The missile walkdowns within the 2500 ft. radius noted some lower elevation areas, but only minimal increases in elevation above 260.5 ft. All structures and large missile populations were identified at 260.5 ft. elevation. All targets below 290.5 ft. elevation were considered near ground targets. Some of targets above 290.5 were treated as elevated, and some of the targets above 290.5 ft. elevation were conservatively assumed to be near ground targets.

NRC Question 3b

The hit frequency in EPRI NP-768 is a function of the insertion height of the missiles. In EPRI NP-768, the missiles were assumed inserted from heights ranging from 5 to 50 ft, except for cars, which were assumed inserted from 5 to 10 ft. Justify that the range of insertion heights would not underestimate hit probabilities.

Duke Energy Response 3b

Duke Energy is aligned with the SNC response (Reference 1) to SNC question 3b and hereby provides that documentation as the Duke Energy response to this question.

NRC Question 4

(DRA) Section 3.3.1, “High Winds Equipment List (HWEL)” of the enclosure to the LAR dated October 19, 2017, states, in part, that “the TMRE model uses the loss of offsite power (LOSP) sequences with no offsite power recovery, therefore PRA logic and components that do not support mitigating a LOSP can be screened.” Section 6.1, “Event Tree/Fault Tree Selection,” of NEI 17-02, Revision 1, states that, in addition to loss of offsite power (LOOP) event trees, other internal initiating events should also be reviewed to ensure that either (1) a tornado event cannot cause another initiating event or (2) the impact of the initiating event can be represented in the logic selected to represent the tornado-initiating event. It is not clear whether the review discussed in Section 6.1 of NEI 17-02 was performed by the licensee to support this submittal. For example, nuclear service cooling water tower fans do not appear to have been reviewed as initiators or as support system losses that need to be included in the sequences. The walkdowns also appear to have been performed with a focus on the LOOP mitigation and other initiators or support system failures do not appear to have been considered during the walkdowns.

NEI 17-02, Revision 1, appears to include limited guidance on consideration of secondary effects. These effects include consideration for fluid-filled tanks and pipes and combustion motor intake effects (loss of oxygen from inert gas tank rupture or exhaust re-direction scenarios) as well as other potential secondary effects to SSC function.

NRC Question 4a

Clarify whether a review was performed to ensure that a tornado event cannot cause another initiating event or the impact of the initiating event can be represented in the logic selected to represent the tornado event. Provide the results of this review including a discussion of any impact on or from walkdowns.

Duke Energy Response 4a

The HNP general transient tree addresses events such as steam loss in the turbine building, loss of service water, loss of primary makeup, loss of offsite power, and transient induced loss of coolant accidents such as seal failure or primary relief valve failure. The transients sequence applied to the LOSP initiating events address the tornado damage states expected based on a review of the vulnerable equipment and the LOSP. The tornado initiating events for TMRE were added to the model at the LOSP initiating event location in the CAFTA fault tree. The equipment vulnerable to tornado missiles were added to the model using exposed equipment failure probability events identified.

NRC Question 4b

Describe how secondary effects, including but not limited to the examples identified above, were considered in the implementation of NEI 17-02, Revision 1, for the identification of the initiating events and failure modes in the licensee's TMRE development.

Duke Energy Response 4b

Section 3.2.3 of NEI 17-02 was updated in Rev. 1A to describe secondary effects that should be noted during the walkdown. Section 6.1 was revised and Section 6.5.2 was added to NEI 17-02 in Rev. 1Bto require evaluation of these secondary effects of tornado missile impacts on non-conforming SSCs.

Secondary effects from tornado missile strikes on non-conforming conditions were considered during walkdowns, including, but not limited to, the possibility of flooding from non-conforming tanks and pipes and potential combustion motor intake effects like loss of oxygen due to non-conforming gas tank rupture or exhaust re-direction.

HNP target walkdowns considered proximity of non-Category I structures to exposed target SSCs that may collapse or tip-over and cause damage to an SSC, and vent paths for tanks that could be exposed to atmospheric pressure changes. No conditions were identified where secondary failure of SSCs as a result of a tornado missile strike to a non-conforming SSC were likely.

NRC Question 5

(DRA) Section 3.4.3, "Temporary Missiles," of NEI 17-02, Revision 1, states, in part, that:

The expected missile inventory for the post-construction site should be estimated, using walkdown results for the non-construction areas, information in Sections 3.4.2 and 3.4.4, along with design and construction information. The basis and assumptions used for the estimated number of post-construction missiles will shall be documented.

Section 3.4.3 of NEI 17-02, Revision 1, states, in part, that "the total missile count for the sensitivity analysis should include the non-construction-related missile inventory determined in accordance with Sections 3.4.2 and 3.4.4, and a conservative estimate of the number of all construction-related missiles." The NEI guidance further states that the basis and assumptions used to determine the conservative construction missile estimate should be documented. The guidance does not appear to describe the criteria for considering missiles as temporary.

NRC Question 5a

Describe the approach that will be used in future implementation of the HNP TMRE methodology to classify the construction-related missiles as temporary missiles.

Duke Energy Response 5a

NEI 17-02 was revised as follows:

- Rev. 1A
  - Section 3.4.3 revised to clarify treatment of both permanent and non-permanent construction missiles
- Rev. 1B
  - Section 3.4.3 further revised to clarify evaluation of the impact of non-permanent construction missiles
  - Section 7.4 added to address margin assessment and construction missiles

If a proposed construction activity would cause the site missile inventory to increase above the missile count used in the TMRE analysis, an assessment is needed to verify the higher missile count still meets the risk metric thresholds in Section 7.3 or prior NRC approval would be required.

NRC Question 5b

Section 3.4.3 of NEI 17-02, Revision 1, states that it is not necessary to explicitly account for the additional outage-related missiles in the TMRE missile inventory. The guidance further states that outages are of relatively short duration compared to the operational time at a nuclear power plant. The NRC staff notes that duration of outages or other temporary activities that involve bringing additional equipment to the sites may be not be relatively short, specifically for multi-unit site. It is not clear whether HNP has adequately considered additional equipment in estimating the number of missiles.

Clarify whether HNP outage-related missiles were considered in total number of missiles used in HNP TMRE implementation. Provide a justification if those missiles are not considered in estimating the total number of missiles at the site.

Duke Energy Response 5b

NEI 17-02, Rev. 1, Section 3.4.3, was revised. Sites that develop a missile count less than 240,000 (like the Harris missile count of approximately 140,000) have built in margin that can account for potential increases in missile counts during outage preparation and staging.

In the development of the original LAR, Duke Energy followed the guidance of NEI 17-02, Rev. 1 and did not estimate the impact of outages on the missile inventory. In the future, the missile inventory will be monitored as necessary to ensure missile inventory, including changes due to outages, will be managed in accordance with NEI 17-02, Rev. 1B, consistent with any terms and conditions established in the NRC safety evaluation.

NRC Question 5c

Section 3.4 of NEI 17-02, Revision 1, provides guidance for verifying the number of missiles resulting from the deconstruction of various types of buildings through the TMRE walkdown.

The guidance does not appear to involve walkdowns to count the potential missiles a non-Category I building contents inside the structure or to count missiles that would be generated by the deconstruction of the structure itself. Address how the approach described in the guidance ensures that the missile inventories from building deconstruction are not underpredicted for a specific plant.

NRC Question 5c(i)

For each type of building addressed in NEI 17-02, Revision 1, explain how HNP missile count considers building contents (i.e., materials that are not part of the building itself but available to become missiles if the building is hit).

Duke Energy Response 5c(i)

Missiles inside warehouses were surveyed and inventoried. For the inventory, both counts from the actual missile inventories and the number developed from the NEI 17-02, Rev. 1 methodology were conservatively summed for the site missile count.

NRC Question 5c(ii)

For those types of buildings where the NEI 17-02, Revision 1, methodology was applied, verify that the overall estimate of non-structural missiles within buildings is representative or bounding.

Duke Energy Response 5c(ii)

As discussed in the response to question 5c(1), Duke Energy performed a missile inventory and developed a number of missiles from building contents consistent with NEI 17-02, Rev. 1. Because the two numbers were added, the overall estimate is clearly bounding. NEI 17-02, Rev.

1, Section C.4 was revised to describe the technical basis for evaluating debris from damaged buildings, including stored contents. Future building construction TMRE evaluations will be developed in accordance with NEI 17-02, Rev. 1B, consistent with any terms and conditions established in the NRC safety evaluation.

NRC Question 6

(DRA) Table 3.3.5 in Attachment 1 to the LAR indicates that robustness of targets with respect to certain missile types is considered in HNP TMRE development and quantification. The LAR indicates that this methodology is intended to be applied to future discoveries of as-built non-conforming conditions but does not describe how this provision will be applied.

Sections 5.2, "Missile Inventories," and 5.2.1, "Missile Inventory Example," of NEI 17-02, Revision 1, explain that a bounding inventory of missiles was developed from a survey of five plants along with a generic distribution of missile types. These sections explain that the missile types and target robustness categories are used to determine if a target fails. Section 5.2 explains that in using the TMRE approach the missiles at a specific plant should be counted to ensure that the missile inventory at the plant is bounded by the inventory used in the TMRE method based on the survey. Finally, Section B.6, "Missiles Affecting Robust Targets," of NEI 17-01, Revision 1, states that the number of missiles used in the Exposed Equipment Failure Probability (EEFP) calculation can be adjusted to account for the population of missiles that can damage an SSC and provides the percentage of the total missile inventory for each type of robust target. These percentages appear to depend on specific missile type counts taken from two plant missile inventories as shown in Tables B-15, B-16, and B-17 of NEI 17-01, Revision 1.

The sections of NEI 17-02, Revision 1, cited above do not appear to provide guidance for adjusting the relative contribution of each missile type based on plant-specific information. A skewed distribution of missile types at a specific plant site could have an impact on the risk results of the TMRE PRA, because certain missiles (from certain missile robustness categories) can fail a greater number of SSCs than missiles from lesser robustness categories.

Describe how the HNP any future use of the TMRE guidance for adjusting the number of missiles for robust targets at HNP will be performed to ensure the evaluation will ensure that the contribution of each missile type to the overall missile population in NEI 17-02, Revision 1, is representative of the contribution of each missile type to the overall missile population in HNP.

Duke Energy Response 6

The SNC response (Reference 1) to RAI 6 provided additional justification regarding the technical adequacy of the NEI 17-02 methodology. Any future use of the TMRE guidance for adjusting the number of missiles for robust targets at HNP will be performed in accordance with NEI 17-02, Rev. 1B, consistent with any terms and conditions established in the NRC safety evaluation. This will provide reasonable assurance that the contribution of each missile type to the overall missile population is adequate for the risk evaluation.

NRC Question 7

(DRA) In a January 11, 2018, supplement to the LAR, Duke Energy withdrew those aspects of the request related to de minimis screening of vulnerabilities. A markup of the TMRE Industry Guidance Document was provided, showing those aspects of the current revision that would no longer be applied at HNP. It is unclear how the supplement affects the Enclosure and the Attachments to the LAR, that refer to this aspect of the guidance, for example, in Enclosure Sections 3.3.6, “Model Development,” and 3.3.9, “Sensitivities,” and Attachment Table 3.3.7-2, “PRA Results for Non-Conformance.”

Clarify how the supplement to the LAR affects the assessments in the original LAR related to de minimis screening (e.g., PRA modeling notes in Table 3.3.7-2).

Duke Energy Response 7

As discussed in Duke Energy Response 1, the non-conforming conditions originally treated as de minimis in the original LAR were treated explicitly as vulnerabilities in the revised analysis, along with the reformulated MIP.

NRC Question 8

(DRA/DSS) Section 5.3, “Target Exposed Area” of NEI 17-02, Revision 1, provides the method for calculating the Target Exposed Area. It is the area of an SSC that is exposed to being struck by a tornado missile that can result in the failure of the SSC. This section provides details on various types of SSCs and how their Target Exposed Area should be calculated for the EEFP. When calculating surface area, some components (e.g., tanks, ultimate heat sink fans, etc.) are susceptible to potential missiles in the vertical direction that could result in additional exposed area. As specified in RG 1.76, “Design-Basis Tornado, and Tornado Missiles for Nuclear Power Plants,” March 2007 (ADAMS Accession No. ML070360253), the NRC considers the missiles capable of striking in all directions with horizontal velocities and vertical velocities. HNP licensing basis defines parameters for missile velocities in all directions in HNP UFSAR, Table 3.5.1-3, “Characteristics of Tornado-Generated Missile Spectrum.”

Section 3.3.2, “Target Walkdowns,” of the enclosure to the LAR provides the scope of TMRE walkdowns. Item 3 of in that section of the LAR includes identifications of “directions from which tornado missiles could strike the target” in the scope of walkdowns. It does not appear to differentiate between horizontal and vertical missiles consistent with the HNP licensing basis.

Considering that tornado missiles could strike in all directions, describe how Item 3 in Section 3.3.2 of the enclosure to the submittal was performed and how directional aspects are included in the HNP TMRE.

Duke Energy Response 8

Target walkdowns evaluated the possible directions from which a missile could strike a particular target. Shielding that could physically prevent missiles from hitting a target in some directions was documented, and the effective area was adjusted to reflect that condition.

An example of the application of shielding to the HNP TMRE analysis is the exposed turbine driven auxiliary feed pump exhaust pipe, which protrudes through a wall in a Category 1 structure. The total area of the target was reduced by 25% because the pipe runs along a wall that shields the target from a missile from that side, as a missile could not come out of the wall.

NRC Question 9

(DRA) One of the key principles in RG 1.174, Revision 2, states that the proposed change meets the current regulations unless it is explicitly related to a requested exemption.

Section 2.2 of the enclosure to the submittal states that HNP was designed to meet General Design Criteria (GDC) 2, “Design bases for protection against natural phenomena,” and GDC 4, “Environmental and dynamic effects design bases,” in Appendix A to Part 50, “General Design Criteria for Nuclear Power Plants,” of Title 10 of the *Code of Federal Regulations* (10 CFR), are applicable to HNP. GDC 2 states that SSCs important to safety be designed to withstand the effects of natural phenomena such as tornadoes without loss of capability to perform their safety functions. GDC 4 states that SSCs important to safety be designed to accommodate the effects of missiles that may result from events and conditions outside the nuclear power unit, which includes tornadoes.

Section 4.1, “Applicable Regulatory Requirements/Criteria,” of the enclosure to the LAR states that Section 3.5.1.4, “Missiles Generated by Tornadoes and Extreme Winds,” of NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants” (SRP) allows for a probabilistic basis for “relaxation of deterministic criteria” for tornado missile protection of SSCs. The submittal further states “RG 1.174 establishes criteria…to quantify the ‘sufficiently small’ frequency of damage” discussed in the SRP. However, the cited SRP sections discuss the probability of occurrence of events and not the change in core damage frequency (CDF) and large early release frequency (LERF). The probabilistic criteria in SRP 3.5.1.4 (i.e., the probability of damage to unprotected safety-related features) are not directly comparable to RG 1.174 acceptance guidelines.

Address how the proposed methodology will continue to provide reasonable assurance that the SSCs important to safety will continue to withstand the effects of missiles from tornados or other external events without loss of capability to perform their safety function.

Duke Energy Response 9

Use of the proposed methodology will continue to provide reasonable assurance of the protection of public health and safety and the environment as described in the Updated Final Safety Analysis Report (UFSAR) without loss of the tornado safe shutdown capability.

Use of the proposed methodology will not result in an increase in the likelihood of a tornado. The design basis tornado frequency is driven by external factors and is not affected by use of this methodology. Further, use of this methodology does not increase the consequences of a tornado. Use of the methodology does not alter any input assumptions or the results of the accident analysis. Use of the methodology results in more realistic assessment of the very low likelihood of unacceptable consequences from a tornado event. Use of the methodology results in no physical changes to the facility so no new types of malfunctions or accidents are created.

The types of accidents, accident precursors, failure mechanisms and accident initiators already evaluated in the UFSAR remain unaltered. Finally use of the methodology does not reduce the margin of safety in the UFSAR. Use of the methodology does not exceed or alter any controlling numerical value for a parameter established in the UFSAR Chapter 6 and 15 safety analyses, and those analyses remain valid. Use of the methodology does not reduce redundancy or diversity of safety systems, nor does it reduce defense in depth as described in the UFSAR.

NRC Question 10

(DRA) Regulatory Position 2.1.2 in RG 1.174, Revision 2, discusses safety margin as one of the key principles of risk-informed integrated decision-making. This Regulatory Position states, in part, that with sufficient safety margin, the safety analysis acceptance criteria in the licensing basis (e.g., final safety analysis report, supporting analyses) are met or proposed revisions provide sufficient margin to account for analysis and data uncertainty.

Section 7.5, “Defense-in-Depth and Safety Margin,” of NEI 17-02, Revision 1, calls for a discussion of defense-in-depth reflecting the actual design, construction, and operational practices of the plant. It explains that engineering evaluation should be performed to assess whether the proposed licensing basis change maintains safety margin and identify conservatisms in the risk assessment to show that safety margin is maintained.

Section 3.2, “Traditional Engineering Considerations, “of the enclosure to the LAR discusses defense in depth and safety margin and states “safety analysis acceptance criteria in the licensing basis are unaffected by the proposed change” but provides no basis for that statement.

Section 2.3, “Evaluate Target and Missile Characteristics,” of NEI 17-02, Revision 1, states that tornado missile failures do not need to be considered for SSCs protected by 18-inch reinforced concrete walls, 12-inch reinforced concrete roofs, and/or 1-inch steel plate. The guidance requires no analysis for evaluating the risk of non-conforming conditions that are protected as described in Section 2.3 of NEI 17-02, Revision 1, and implies that no protection against the tornado-generated missiles is needed for those SSCs. Revision 1 of NEI 17-02 provides similar guidance in Sections 5 and 6.5 as well.

NRC Question 10a

Describe the basis for the conclusion that the safety analysis acceptance criteria in the licensee’s safety analysis are unaffected by the proposed change.

Duke Energy Response 10a

The safety analysis acceptance criteria in the Harris UFSAR described in chapters 6 and 15 are not affected by the change, as those events do not assume a tornado coincident with a design basis accident, except to the extent that the tornado has the potential to initiate any of the design basis accidents. The objective for protection from tornado as an external event is to bring the reactor to a safe and stable shutdown condition during or following a tornado. Special considerations such as single failure criteria are not required. The LAR documents that only a very small fraction of available SSCs that could be used to accomplish the objective are not protected from the effects of tornado missiles, and the remaining unaffected components provide reasonable assurance the objective would be achieved. In the event exposed components of one train of safety related equipment is affected by a tornado missile, there is reasonable assurance that opposite train equipment would be available to provide the safety function. In addition to the equipment credited in the safety analysis described in the UFSAR, on-site and near-site FLEX equipment is also available, which provides further assurance that the objective would be achieved. These factors provide reasonable assurance that the safety analysis acceptance criteria in the licensee's safety analysis are not impacted by the proposed change.

NRC Question 10b

Discuss any non-conforming conditions that were (or if identified in the future, will be) screened from HNP TMRE analysis using the criteria in Section 2.3 of NEI 17-02, Revision 1. For those non-conforming conditions, demonstrate that the safety analysis acceptance criteria in the licensing basis are met or that proposed revisions provide sufficient margin to account for analysis and data uncertainty.

Duke Energy Response 10b

Duke Energy did not use criteria in NEI 17-02, Rev. 1, Section 2.3 to screen non-conforming conditions from further analysis. However, NEI 17-02, Rev. 1, section B.6.3 was revised to add justification for screening. Any future application of NEI 17-02, Rev. 1B, will be consistent with any terms and conditions established in the NRC safety evaluation.

NRC Question 11

(DRA) Regulatory Position 2.4 in RG 1.174, Revision 2, discusses the risk acceptance guidelines. Section 7.3, "Comparison of Risk Metric Thresholds," of NEI 17-02, Revision 1, indicates that the delta risk between the compliant case and the degraded case PRA results should be evaluated against the "very small" change-in-risk acceptance guidelines given in RG 1.174, Revision 2 (change in CDF of smaller than 10^{-6} per year and change in LERF of smaller than 10^{-7} per year), and states:

> [it] is possible that some licensees will exceed these thresholds, in which case, additional discussion on defense-in-depth and safety margins may be warranted in the LAR.

Section 2.5 of NEI 17-02, Revision 1, states:

> [if] ΔCDF or ΔLERF are close to or exceed the thresholds of RG 1.174, refinements to the Compliant and/or Degraded Case PRAs may be appropriate,

And

> [if] further reductions to ΔCDF and ΔLERF are not possible [by refining the analysis], the licensee will need to decide whether physical modifications should be made and to which SSCs.

Section 7.3 of NEI 17-02, Revision 1, appears to allow providing more information about defense-in-depth if the change-in-risk thresholds of RG 1.174 are exceeded, whereas Section 2.5 appears to allow analysis refinement and plant modification if the thresholds are exceeded.

Describe HNP's approach if performance-monitoring programs indicate that the risk acceptance guidelines for "very small" change-in-risk in RG 1.174, Revision 2, are exceeded. Clarify whether any additional refinements beyond the guidance in NEI 17-02, Revision 1, will be made if acceptance guidelines are exceeded.

Duke Energy Response 11

NEI 17-02 was revised as follows:

- Rev. 1A
    - Sections 8 and 8.1 were significantly re-written to provide clarity of guidance for future performance monitoring.
- Rev. 1B
    - Section 8.1 was slightly revised for consistency with changes made resulting from other RAI responses.

If performance monitoring programs indicate the risk acceptance guidelines for "very small" change in risk in RG 1.174, Revision 2, are exceeded, the subsequent Duke Energy evaluations will be performed in accordance with the guidance of NEI 17-02, Rev. 1B, consistent with any terms and conditions established in the NRC safety evaluation.

NRC Question 12

(DRA) Regulatory Position 3 in RG 1.174, Revision 2, states that careful consideration should be given to implementation of the proposed change and the associated performance-monitoring strategies. Section 8.1, "Plant Configuration Changes," of NEI 17-02, Revision 1, states that design control programs meeting 10 CFR Part 50 Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," will ensure subsequent plant configuration changes are evaluated for their impact on of non-conforming SSC risk using TMRE. Section 8.1 also states, in part, that:

> [l]icensees should ensure that they have sufficient mechanisms to assure that any significant changes to site missile sources, such as a new building, warehouse, or laydown area are evaluated for impact to the TMRE basis, even if not in the purview of the site Design Control program.

Section 4.1, "Applicable Regulatory Requirements/Criteria," of the enclosure to the LAR states that "changes, whether permanent or temporary due to construction, that increase the site missile burden within the 2500' missile radius above the 240,000 missiles assumed in the methodology will be evaluated for impact on the TMRE analysis."

NRC Question 12a

Describe the mechanism(s) and approach(es) that will be followed by the HNP to determine whether a particular change to the facility is "significant" for evaluation of the impact to the TMRE basis.

Duke Energy Response 12a

NEI 17-02 was revised as follows:

- Rev. 1A
  - Section 8, 8.1, 8.2, and 8.3 were rewritten
- Rev. 1B
  - Section 8.1 was further clarified

Changes that have the potential to increase the missile count above that considered in the current TMRE analysis are considered significant and would be managed in accordance with NEI 17-02, Rev. 1B, consistent with any terms and conditions established in the NRC safety evaluation.

NRC Question 12b

Describe the mechanisms that assure temporary and permanent changes to site missile sources will be evaluated.

Duke Energy Response 12b

Duke Energy procedures AD-EG-ALL-1132, "PREPARATION AND CONTROL OF DESIGN CHANGE ENGINEERING CHANGES," and AD-EG-ALL-1133, "PREPARATION AND CONTROL OF DESIGN EQUIVALENT CHANGE ENGINEERING CHANGES," contain screening criteria to notify PRA organization to review for potentially impacts to the PRA Models if the proposed change has the potential to impact any tornado-generated missile protection feature credited in the plant analyses, or introduce the possibility of a new source of tornado-generated missiles that are not bounded by the existing analyses. Upon notification of a change that may introduce the possibility of a new source of tornado-generated missiles that are not bounded by the existing analyses, the PRA organization will be manage the change in accordance with NEI 17-02, Rev. 1B, consistent with any terms and conditions established in the NRC safety evaluation.

NRC Question 12c

Describe the processes that ensure changes that could affect HNP TMRE results (e.g., plant design changes, changes made to the licensee's base internal events PRA model and new information about the tornado hazard at the plant) are considered in future implementation of the licensee's TMRE.

Duke Energy Response 12c

The Duke Energy calculation HNP-FPSA-0106 contains the HNP TMRE evaluation. As indicated in the response to question 12b, the PRA staff would be notified of a change that could affect the TMRE calculation. The PRA staff would disposition the change by assessing the impact on the TMRE calculation. Any future implementation of the HNP TMRE would be reviewed for impact on that calculation which documents that future revisions will be managed in accordance with NEI 17-02, Rev. 1B, consistent with any terms and conditions established in the NRC safety evaluation.

NRC Question 12d

Describe, with justification, the treatment of the currently identified non-conforming conditions in future uses of the HNP TMRE PRA model.

Duke Energy Response 12d

Duke Energy is aligned with the SNC response (Reference 1) to SNC question 13d and hereby provides that documentation as the Duke Energy response to this question.

NRC Question 12e

Describe, with justification, how the cumulative risk associated with unprotected SSCs evaluated under TMRE will be considered future decision making (e.g., 10 CFR 50.59 criteria as well as in future risk-informed submittals).

Duke Energy Response 12e

NEI 17-02, Section 8.3 was revised to include: “In future risk-informed decision-making activities licensees may need to consider, as appropriate, the risk associated with previous nonconforming conditions that remain unprotected against tornado missile impacts.” In the future, the TMRE analysis will be managed in accordance with NEI 17-02, Rev. 1B, consistent with any terms and conditions established in the NRC safety evaluation.

NRC Question 13

(DRA) Regulatory Position 2.3.2 in RG 1.174, Revision 2, states that the level of detail required of the PRA is that which is sufficient to model the impact of the proposed change. This regulatory position further states that the characterization of the problem should include establishing a cause-effect relationship to identify portions of the PRA affected by the issue being evaluated.

Section 6.5, “Target Impact Probability Basic Events,” of NEI 17-02, Revision 1, states in part, that “SSC failures from tornado missiles may need to be considered for failure modes not previously included in the internal events system models.”

Section 6.5 then provides four relevant examples (i.e., flow diversion and/or leaks, tank vent failures, valve position transfer - spurious actuations, and ventilation damper failures). The section does not appear to provide guidance about when and to what extent such failure modes should be considered.

Describe how the potential failure modes stated in Section 6.5 of NEI 17-02, Revision 1, were considered by the licensee during the TMRE walkdown, identified, and included in the licensee's TMRE PRA model used to support this application.

Duke Energy Response 13

NEI 17-02 Rev. 1, was revised as discussed in the SNC response (Reference 1) to question 14. The TMRE process was followed as described in NEI 17-02, Rev. 1. New basic events and flags were added to address all the failure modes of the safety related and non-safety related system targets exposed to tornado missiles in accordance with the TMRE process.

NRC Question 14

(DRA) Section 3.3, "Ex-Control Room Action Feasibility," of NEI 17-02, Revision 1, states that no credit for operator action should be taken for actions performed within 1 hour of a tornado event outside a Category I structure (in a location for which the operator must travel outside a Category I structure), but can be considered after the 1 hour. Guidance in this section states that operator actions after 1 hour could be impacted by such environmental conditions as debris that blocks access paths and should be considered by taking into account whether equipment will be accessible and whether the time required to perform the action will be impacted.

Discuss, with justification, the assessments performed to ensure that environmental conditions will not affect operator actions that are credited after 1 hour in the HNP TMRE PRA model used to support this application.

Duke Energy Response 14

Operator actions were assessed based on NEI 17-02 guidance. Operator actions generally need to be performed in tornado-protected structures or performed more than one hour after the initial tornado strike to be considered not failed. An individual with HNP Auxiliary Operator experience was provided the list of credited and not credited operator action to verify challenging exposed operator actions were not being credited in the PRA.

Only one operator action performed outside Category I structures after one hour was credited. OPER-73, OPERATOR FAILS TO OPEN SWITCHGEAR OUTSIDE DOORS, has an estimate of 17 hours to complete. The doors open to the turbine building. If there is a challenge to open the doors, there is sufficient time to clear the doorways.

NRC Question 15

(DRA/DSS) Section 4.6, "Calculate Exceedance Probabilities," of NEI 17-02, Revision 1, states that exceedance probabilities should be generated for "the upper ranges for each F' category," F'2 through F'6, using the trendline equation. The figure provided in Section 4.6 suggests that the largest exceedance probability for each F' category, which corresponds to the lowest tornado speed for each F' category, is used. In LAR Section 3.3.4, "Tornado Hazard Frequency," the tornado hazard curve is developed from data in NUREG/CR-4461.

Describe how the exceedance probabilities influence on the initiating event frequencies in Table 3.3.4 of Enclosure 1 were determined using the guidance in Section 4.6 of NEI 17-02, Revision 1 in the TMRE methodology.

Duke Energy Response 15

Duke Energy is aligned with the SNC response (Reference 1) to SNC question 16 and hereby provides that documentation as the Duke Energy response to this question.

NRC Question 16

(DRA) Regulatory Position 2 in RG 1.174, Revision 2, states that the licensee should appropriately consider uncertainty in the analysis and interpretation of findings. Regulatory Position 3 states that decisions concerning the implementation of licensing basis changes should be made after considering the uncertainty associated with the results of the traditional and probabilistic engineering evaluations.

Regulatory Position 3 in RG 1.174, Revision 2, states that careful consideration should be given to implementation of the proposed change and the associated performance-monitoring strategies. This regulatory position further states that an implementation and monitoring plan should be developed to ensure that the engineering evaluation conducted to examine the impact of the proposed changes continues to reflect the actual reliability and availability of SSCs that have been evaluated. This will ensure that the conclusions that have been drawn from the evaluation remain valid.

Section 7.2, “Sensitivity Analysis,” of NEI 17-02, Revision 1, addresses the steps that should be taken if the change in CDF and LERF from the sensitivity analyses exceed 10^{-6} per year and 10^{-7} per year, respectively.

NRC Question 16a

Describe the HNP process if change-in-risk estimates from sensitivity analyses exceed the RG 1.174 acceptance guidelines for “very small” change in risk in response to other parts of this request or in future implementation of TMRE methodology.

Duke Energy Response 16a

NEI 17-02, Rev. 1A, Section 7.3 was revised to document that if the results of a sensitivity study exceed the acceptance guidelines, NRC approval is required.

NRC Question 16b

For future applications of the methodology, address how construction-related missiles would be considered in the analyses in Section 3.3.9, “Sensitivities.”

Duke Energy Response 16b

NEI 17-02, Section 7.4 was added in Rev. 1B to document that if a proposed construction activity would cause the site missile inventory to increase above the missile count used in the TMRE analysis, an assessment is needed to verify the higher missile count still meets the risk metric thresholds in Section 7.3 or prior NRC approval would be required.

NRC Question 16c

For any TMRE sensitivity analyses used to address the representation of construction-related missiles, describe how the importance measures are determined from the TMRE PRA model in the context of the 'binning' approach for the tornado categories employed in the model. Describe whether and how the same basic events, which were discretized by binning during the development of the TMRE PRA model, are combined to develop representative importance measures. For the same basic events that are not combined, provide a justification that includes discussion of any impact on the results.

Duke Energy Response 16c

Duke Energy is aligned with the SNC response (Reference 1) to SNC question 19c, as supplemented by SNC letter to the NRC NL-18-1179, SNC Supplemental Response to NRC Request for Additional Information dated September 14, 2018, and hereby provides that documentation as the Duke Energy response to this question.

NRC Question 16d

Identify the non-conforming conditions and vulnerabilities that met all the characteristics of a "highly exposed" SSC per Section 7.2.1 of NEI 17-02, Revision 1.

Duke Energy Response 16d

The term "highly exposed" is relevant to TMRE methodology Section 7.2.1, TMRE MISSILE DISTRIBUTION SENSITIVITY, which is to be performed if the ΔCDF or ΔLERF between the compliant and the degraded case exceed 10-7/yr or 10-8/yr, respectively. The HNP TMRE results did not exceed the thresholds, so SSCs were not evaluated to determine which were highly exposed.

NRC Question 16e

The discussions in Section 7.2 of NEI 17-02, Revision 1, do not appear to address whether sensitivity analyses will be aggregated in future implementations of the TMRE methodology. For example, it is not clear whether the licensee will combine the sensitivity analyses related to any future open PRA Facts and Observations (F&Os), sensitivities that address compliant case conservatism, and TMRE sensitivity analyses.

Describe, with justification, whether sensitivity analyses in Section 7.2 of NEI 17-02, Revision 1, will be aggregated in future implementation of the TMRE methodology.

Duke Energy Response 16e

Duke Energy is aligned with the SNC response (Reference 1) to SNC question 19e and hereby provides that documentation as the Duke Energy response to this question.

NRC Question 16f

Discussion in Section 7.2.3, "Compliant Case Conservatisms," and Section A.2.1.3, "Non-Category I Structures and Exposed Non-Safety Related SSCs," of NEI 17-02, Revision 1, recognizes that the TMRE PRA could produce non-conservative change-in-risk results if conservatively assumed failures in the Compliant Case mask change-in-risk. Accordingly, Section 7.2.3 of NEI 17-02, Revision 1, states, in part, that:

> [the] licensee should review cutsets in the top 90% of the TMRE compliant case to identify conservatisms related to equipment failure (opposed to offsite power recovery or operator actions) that could impact results.

Section 7.2.3 of NEI 17-02, Revision 1, explains that the licensee should perform sensitivity studies associated with these conservatisms as directed in Appendix D of the TMRE guideline for PRA standard supporting requirements (SRs) AS-A10, LE-C3, and SY-B7 to address equipment failures in the compliant case that may be masking change in risk but does not provide guidance on how such a sensitivity can be performed.

Section 3.3.9.1, "Conservative Risk Treatments Masking Sensitivity," of the enclosure to the LAR describes a sensitivity assessment performed to ensure conservative modeling treatments in the compliant case do not affect the risk assessment conclusions.

Describe any future sensitivity analysis that will be performed to assess the impact of conservatisms associated with modeling the equipment failures in the compliant case of the TMRE PRA model.

Duke Energy Response 16f

Duke Energy is aligned with the SNC response (Reference 1) to SNC question 19f and hereby provides that documentation as the Duke Energy response to this question. In the future, the HNP TMRE analysis will be managed in accordance with NEI 17-02, Rev. 1B, consistent with any terms and conditions established in the NRC safety evaluation.

NRC Question 16g

Modeling operator actions could contribute to underestimating the change-in-risk calculation associated with non-conforming SSCs. For example, if manual actuation of a non-conforming SSC is an important risk reduction action and the corresponding human error probability (HEP) is conservatively determined (for example conservatively set to a failure probability of 1.0), then this can mask the full risk associated with the SSC's non-conformance. Appendix D does address whether the concern described above could also apply to conservative human reliability analysis modeling (e.g., SR HR-G3 and HR-G7).

Describe how HNP will address the potential impact of TMRE assumptions related to certain HEPs within 1 hour after the accident on the compliant case.

Duke Energy Response 16g

Duke Energy is aligned with the SNC response (Reference 1) to SNC question 19g and hereby provides that documentation as the Duke Energy response to this question.

NRC Question 17

(DRA) Regulatory Position 2 in RG 1.174, Revision 2, states that the licensee should appropriately consider uncertainty in the analysis and interpretation of findings. Regulatory Position 3 states that decisions concerning the implementation of licensing basis changes should be made after considering the uncertainty associated with the results of the traditional and probabilistic engineering evaluations.

The discussion in Section A.7, "Zonal vs. Uniform (Z vs U) Sensitivity," of Appendix A to NEI 17-02, Revision 1, recognizes differences between zonal and uniform missile distributions without justification. Targets were categorized in Appendix A to separate intuitive from non-intuitive trends and an adjustment factor is proposed to account for zonal distribution of missiles.

Describe, with justification, how uncertainties associated with the impact of the missile distribution on the licensee's target hit probability are handled in the HNP TMRE methodology.

Duke Energy Response 17

NEI 17-02, Section 7.2.1 was revised in Rev. 1A and further revised in Rev. 1B. The current HNP TMRE analysis results did not exceed the thresholds, so the sensitivity described in Section 7.2.1 was not performed. In the future, the uncertainties associated with the missile distribution will be managed in accordance with NEI 17-02, Rev. 1B, consistent with any terms and conditions established in the NRC safety evaluation.

Serial: RA-18-0106

Shearon Harris Nuclear Power Plant, Unit 1
Docket No. 50-400 / Renewed License No. NPF-63

License Amendment Request to Incorporate Tornado Missile Risk Evaluator into Licensing Basis – Supplement and Request for Additional Information Response (EPID L-2017-LLA-0355)

Enclosure 2

Redline/strikeout Changes to NEI 17-02, Rev 1A

TORNADO MISSILE RISK EVALUATOR (TMRE) INDUSTRY GUIDANCE DOCUMENT

Prepared by the Nuclear Energy Institute
~~July~~ September 2018

Executive Summary

This Nuclear Energy Institute (NEI) guidance document establishes an acceptable risk-informed methodology for identifying and evaluating the safety significance associated with structures, systems and components (SSCs) that are exposed to potential tornado-generated missiles. The methodology, called the Tornado Missile Risk Evaluator (TMRE) was developed to provide NEI membership with a simple, cost-effective tool to address questions concerning vulnerability to tornado missiles. This document provides guidance on the identification of these vulnerabilities at a nuclear power plant site, the development and application of a TMRE model for the site, and a process for resolving discrepancies against licensing basis requirements. Overall the methodology provides a path forward to resolve low safety significant nonconforming conditions associated with tornado missile protection requirements of the licensing basis.

The Nuclear Energy Institute is the nuclear energy industry’s policy organization.
This document and additional about nuclear energy are available at nei.org
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Use and Applicability of this Guidance Document

The purpose of this document is to provide references, summations, examples and rationales in enough detail to enable the user to develop a TMRE model for their power plant with minimum effort and without the necessity for reliance on contractors or consultants. NEI estimates that the TMRE can be implemented and adopted with an expenditure of approximately 400-700 person-hours. Wherever possible, the TMRE methods and parameters have been simplified with the development of generic, bounding inputs that can be used by all plants. In some cases, plant-specific inputs must be used, and these are identified for the user with guidance on where/how to obtain the input. The use of this guideline, or the information it contains, is not mandatory.

Revision Table

Revision	Description of Changes	Date Modified	Responsible Person
0	Initial Issuance	June 2017	S. Vaughn
1	Editorial changes, fixed several errors in Appendices A, B and C, and removed Sections 2, 4, and 10 and Appendix F because they were considered not within scope of the TMRE methodology	September 2017	S. Vaughn
1A	Incorporated changes based on pilot LAR responses to requests for additional information, feedback from public meetings in 2017 and 2018, and other editorial and calculation corrections.	July 2018	S. Vaughn
1B	Incorporated changes based on staff feedback from Revision 1A review	September 2018	S. Vaughn

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TABLE OF CONTENTS

1. INTRODUCTION

The Tornado Missile Risk Evaluator (TMRE) is designed to provide operators of commercial nuclear power plants a cost-effective method to conservatively assess the risks posed by tornado-generated missiles. The TMRE is a hybrid methodology comprised of two key elements: (1) a deterministic element to establish the likelihood that a specific structure, system, or component (SSC) (or "target") will be struck and damaged by tornado-generated missile; and (2) a probabilistic element to assess the impact of the missile damage on the core damage and large early release frequencies.

The output of the deterministic element is a calculated Exposed Equipment Failure Probability (EEFP) that is based largely on a simplified generic relationship between tornado strength and the population of materials at a typical nuclear power plant that may become airborne during a tornado. Site-specific inputs to the EEFP include the likelihood of a tornado striking the site and the size and location of the target SSC being evaluated.

The probabilistic element uses the existing plant-specific peer-reviewed internal events probabilistic risk assessment (PRA) model to evaluate the impact of the loss of a target SSC. The risk assessment methods and acceptance criteria of the Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.174 are used to determine whether risks posed by potential tornado missiles at a site warrant protective measures.

Use of the TMRE is a new methodology as defined in Title 10 of the Code of Federal Regulations (10 CFR) 50.59, requiring NRC review and approval. This guidance document describes how to develop and apply the TMRE and how to adopt the TMRE in the plant-specific licensing basis.

1.1 BACKGROUND

The need for the TMRE originated with NRC's issuance of Regulatory Issue Summary (RIS) 2015-06, which reminded licensees of the need to comply with the plant-specific licensing basis for protection against tornado missiles. The RIS cited several examples where NRC issued violations for licensees failing to provide protection for SSCs that were exposed to potential tornado missiles. Examples of exposed SSCs included safety-related vent pipes for emergency diesel generator exhausts, diesel fuel oil storage tanks, and exhaust pipes for auxiliary feedwater and reactor core isolation cooling systems. The NRC typically cited 10 CFR 50, Appendix A, General Design Criterion 2, along with general statements in the station Updated Final Safety Analysis Report (UFSAR) regarding protection against the effects of tornadoes, as the basis for the violation.

The problem posed by RIS 2015-06 for many licensees is that in many cases, the licensing basis is stated in general terms without sufficient detail to provide clarity and predictability on how protection from tornado missiles was deemed adequate by NRC during the plant licensing phase. This allows questions to be raised whether safety-related components that are exposed to the elements met NRC regulatory requirements. This situation is exacerbated by the fact that NRC requirements for tornado missile protection evolved substantially over the years, and the level of detail in which the issue was described in plant UFSARs grew from almost no description at all to detailed descriptions of tornado missile characteristics and the design standards adopted for protection from them.

NRC explored the safety significance of the variations in protection from tornado missiles during the Systematic Evaluation Program (SEP) in the 1980s. Specifically, the NRC evaluated selected plants that were licensed prior to the issuance of the NRC Standard Review Plan (SRP) to determine whether plants of this vintage should be required to take additional measures to upgrade their level of protection. The conclusion reached by the SEP was that tornado missiles did not pose a significant risk to public health and safety to warrant generic regulatory action.

With the advent of Fukushima, additional interest was focused on protection from external events of all types. New methods to assess the risks of beyond design basis seismic, flooding, and high wind events were developed and updated.

The requirements for protection against external events described in the licensing basis are deterministic and must be met to maintain safety margins and defense-in-depth. On the other hand, the NRC recognizes the merits of alternative methodologies to determine the need for physical protection from tornado missiles, such as TORMIS, developed by EPRI during the 1980s and approved for use at several plants. Subsequent to the issuance of RIS 2015-06, NRC expressed willingness to consider risk-informed approaches to address this issue.

1.2 Purpose

The purpose of the TMRE is to present NRC with a RG 1.174 risk-informed option to assess the risk posed by tornado missiles at any site to determine whether additional physical protection is warranted. Because it is risk-informed, the TMRE can be applied regardless of the vintage of the plant or the content of the plant's licensing basis.

The impetus and foundation for the TMRE is the NRC-approved methodology developed for use at Calvert Cliffs in 1995. The Calvert Cliffs approach used a simplified method to calculate the likelihood that a SSC would be rendered unavailable by a missile strike during the passage of a tornado and then used the plant internal events PRA to evaluate a core damage frequency contribution from the event. This was then related to a threshold for exceeding 10 CFR Part 100 doses offsite.

1.3 Overview and Comments

This guidance document is a compilation of the structure of the TMRE methodology (Section 2), and a step-by-step explanation of how to develop and deploy the TMRE at a site (Sections 3 through 8). Several appendices are provided to amplify elements of the guidance where warranted.

1.4 Abbreviations

AOV – air operated valve
BE – basic event
CAP – corrective action program
CDF – core damage frequency
CLB – current licensing basis
DB – design basis
EEFP - exposed equipment failure probability
EGM – enforcement guidance memorandum
EPRI – Electric Power Research Institute
FSAR – final safety analysis report
HEP – human error probability
HW – high winds

HWEL – high winds equipment list
IA – instrument air
LAR – license amendment request
LERF – large early release frequency
LOOP – loss of off-site power
LOS – line of sight
MCC – motor control center
MFW – main feed water
MIP – missile impact parameter
MOV – motor operated valve
NEI – Nuclear Energy Institute
NPP – nuclear power plant
NRC – Nuclear Regulatory Commission
NUREG - U.S. Nuclear Regulatory Commission technical report designation
PRA – probabilistic risk assessment
PSAR – preliminary safety analysis report
RG – regulatory guide
RIS – regulatory issue summary
RWST – reactor water storage tank
SEP – safety evaluation program
SSC – system, structure, component
SSEL – safe shutdown equipment list
SR – supporting requirement
SW – service water
TMRE – tornado missile risk evaluator
UFSAR – updated final safety analysis report

1.5 Definitions

Correlation - The relationship between two or more SSCs that infers that by nature of their proximity to each other they could be damaged by a single tornado missile.

Exposed Equipment Failure Probability (EEFP) - The conditional probability that an exposed SSC is hit and failed by a tornado missile, given a tornado of a certain magnitude.

High Winds Equipment List (HWEL) - List of potential vulnerabilities, vulnerabilities, and nonconforming SSCs identified during the walkdown that can be evaluated using the TMRE to determine the risk of leaving them unprotected.

Missile Impact Parameter (MIP) - The probability of a tornado missile hit on a target, per target unit surface area, per missile, per tornado.

Reference Elevation - The elevation used to determine the 30 foot demarcation for elevated targets.

TMRE PRA - An adaption of the plant internal events PRA suitable for use in the TMRE.

TMRE Walkdown - A plant walkdown focused on collecting physical information to characterize exposed SSCs and the plant missile population for use in developing the TMRE model for the plant.

Vertical Missile - Any missile that has a non-horizontal velocity component.

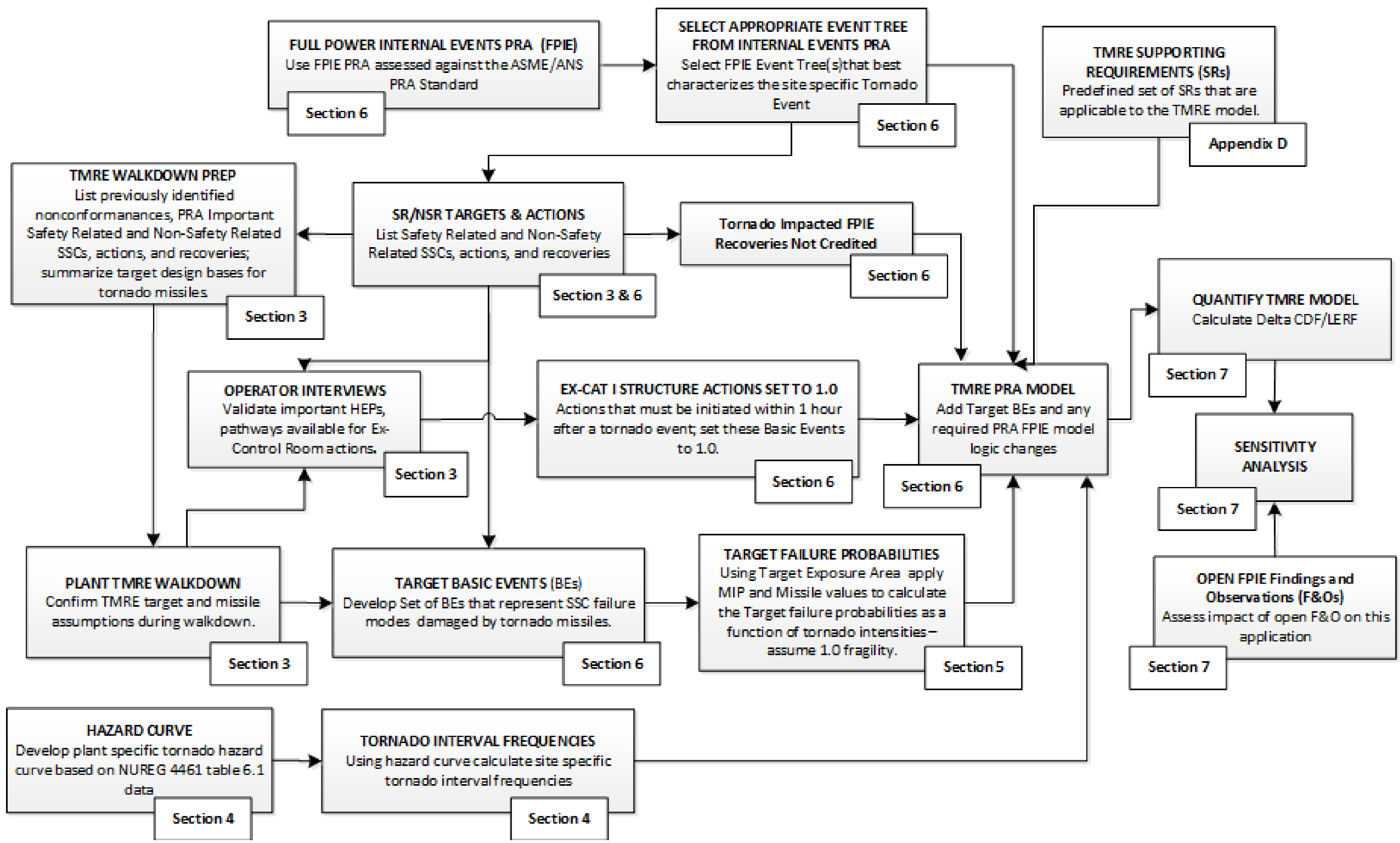
2 OVERVIEW OF TORNADO MISSILE RISK EVALUATOR METHODOLOGY

The Tornado Missile Risk Evaluator (TMRE) will be used to estimate the quantitative risk associated with tornado-generated missiles at U.S. nuclear power plants (NPP). It makes use of the licensee's internal events Probabilistic Risk Assessment (PRA) model, which is modified to reflect the anticipated effects of the passage of a tornado over the site. The TMRE involves three major steps:

- Site walkdowns are performed to gather relevant information regarding the SSCs that are not protected against tornado-generated missiles and missile characteristics.
- Failure probabilities for exposed SSCs important to safe shutdown are calculated using the Exposed Equipment Failure Probability (EEFP). This calculation takes into account the number of missiles that are damaging to the SSC, the exposed area of the SSC, and the Missile Impact Parameter (MIP), a parameter that relates the likelihood of a missile striking a target, based on the tornado intensity. If a damaging missile strikes an exposed SSC, it is assumed to fail.
- The increases in core damage frequency (ΔCDF) and large early release frequency (ΔLERF) are calculated using the "TMRE PRA" and compared to acceptance criteria in RG 1.174 [Ref. 2.4].

Figure 2-1 provides an overview of the process, which is described in detail in Sections 3 through 7.

Figure 2-1: TMRE Flowchart



2.1 Perform TMRE Walkdown

The TMRE Walkdown is used to gather physical data associated with vulnerable and nonconforming SSCs, and to identify any other SSCs that are modeled in the PRA but are not protected from tornado winds or missiles. Additionally, the walkdown is used to validate the missile inventories, used in the EEFP calculations, as bounding for the site. The TMRE walkdown process includes pre-walkdown activities, a "Vulnerable SSC Walkdown," and a "Missile Walkdown."

2.1.1 Pre-walkdown activities

Prior to sending personnel out on a walkdown, several activities are recommended to ensure that a complete walkdown is performed in an efficient manner. Preparations are needed primarily for the walkdown activities associated with identifying and characterizing vulnerable SSCs; less effort is needed to prepare for the missile count verification part of the walkdown.

The Vulnerable SSC Walkdown includes reviewing any previously identified potential vulnerabilities and nonconforming SSCs, to collect any data needed for the TMRE model. The Vulnerable SSC Walkdown will also search for and evaluate any SSCs credited in the TMRE PRA model that are not protected from tornado winds or missiles. Although these SSCs may not be required to be protected by the plant's licensing basis, their ability to function during a tornado event needs to be evaluated to ensure they are properly modeled in the TMRE PRA.

This guideline recommends the development of an HWEL, which provides the walkdown team with a list of SSCs to review during the walkdown. The initial HWEL will contain the list of previously identified potential vulnerable and nonconforming SSCs and a list of potentially unprotected PRA SSCs. During the TMRE walkdown, additional SSCs may be identified that will be added to the HWEL (e.g., PRA SSCs that were initially considered to be protected, but evidence from the walkdown indicated otherwise).

The HWEL development is detailed in Section 3, which is based primarily on the EPRI HW Walkdown Guidance (EPRI 3002008092, "Process for High Winds Walkdown and Vulnerability Assessments at Nuclear Power Plants" [Ref. 2.1]). It includes identifying potentially unprotected SSCs in the PRA and determining their location. This is done prior to walkdowns using plant documentation.

2.1.2 Vulnerable SSC Walkdown

The Vulnerable SSC Walkdown is performed to gather information on HWEL SSCs that are exposed to tornado missiles. The walkdown will determine which SSCs are vulnerable to tornado missiles and will be used to collect data, such as the exposed SSC "target" location, elevation, surface area, and construction details, and the type and location of any local structures that may provide a shielding effect. The data collected is needed for the TMRE model, specifically to determine the EEFP. It can also aid in development of modeling approaches for specific configurations, such as when SSCs are physically correlated. The EEFP is used to calculate the probabilities for SSC failure that are used in the TMRE PRA model; the EEFP is briefly discussed in Section 2.4, and described in detail in Section 5.

2.1.3 MISSILE WALKDOWN

The second major goal of the TMRE Walkdown is to perform a missile count. Objects within approximately 2500 feet of a common reference point (e.g., the center of containment) that can become airborne during a tornado event at the site are identified and counted. Twenty-three different missiles types are identified, each with a different capability to damage an exposed SSC. In addition to loose objects outside of structures (e.g., construction material), missiles can also be created by structures (e.g., warehouses, Butler buildings) and their contents, when those structures are not capable of withstanding tornado wind pressure effects and disassemble during a tornado. This walkdown is typically separate from the Vulnerable SSC Walkdown. Section 3.4 provides details on how the missile counts are performed.

2.2 DETERMINE SITE TORNADO HAZARD FREQUENCY

The initiating events for the TMRE PRA model are tornadoes at the site. Each licensee should develop site-specific tornado frequencies for applicable tornadoes. The tornadoes of interest are those tornadoes with a wind speed of approximately 100 mph or greater. For the purposes of the TMRE, the F'-scale (Fujita prime) will be used to classify tornadoes; this scale is somewhat different from the original Fujita Scale (F-Scale) and the Enhanced Fujita Scale (EF-Scale). The differences between these scales and the rationale for choosing the F'-scale are discussed further in Sections 4 and 5.

NUREG/CR-4461, Revision 2 [Ref. 2.2] is the recommended source of tornado data for developing the site-specific tornado frequencies to be used in the TMRE PRA. Each U.S. NPP site is provided with tornado wind speeds associated with 10^{-5}, 10^{-6}, and 10^{-7} probabilities per year of a tornado missile strike. Additionally, the total tornado strike frequency (i.e., the frequency of any tornado with wind speed greater than 65 mph) is provided for all locations in the continental United States. Using this data, a site-specific tornado frequency curve (hazard curve) can be developed, and the frequency of all tornadoes considered in the TMRE (F'2 through F'6) can be calculated. Details on the process of determining tornado frequencies for use in the TMRE are provided in Section 4.

2.3 EVALUATE TARGET AND MISSILE CHARACTERISTICS

Failures of SSCs that can be struck and damaged by a tornado missile will be added as new basic events to the TMRE PRA model. Tornado missile failures do not need to be considered for SSCs protected by 18" reinforced concrete walls, 12" reinforced concrete roofs, and/or 1" steel plate. The failure probability of these SSCs is calculated using the Exposed Equipment Failure Probability (EEFP). The EEFP is the conditional probability that an exposed SSC is hit and failed by a tornado missile, given a tornado of a certain magnitude. A single SSC will have five EEFP values calculated, one for each tornado category, F'2 through F'6.

The EEFP is defined as:

$$EEFP = (MIP)\ x\ (\#\ of\ Missiles)\ x\ (Target\ Exposed\ Area)\ x\ Fragility$$

Where:

The *Missile Impact Parameter (MIP)* is the probability of a damaging tornado missile hit on a target, per target unit surface area, per missile, per tornado. Generic MIP values are provided as part of the

TMRE methodology and are described in more detail in Section 5.1 and Appendix B. The MIP varies by the tornado category (i.e., F'2 through F'6) and the elevation of the target.

# of Missiles is the number of damaging missiles within approximately 2500 feet of a common reference point, such as the center of containment. Generic values for the total number of missiles are provided as part of the TMRE methodology and will be verified as bounding through the TMRE walkdown activity. More robust targets (e.g., steel pipes and tanks) will not use the entire missile inventory that can damage less robust SSCs (e.g., electrical panels, instrumentation), since only certain types of missiles can damage robust targets. Robust targets are subdivided into categories based on their characteristics (basically the thickness of the SSC's steel or concrete). Depending on the target's category of robustness, a certain fraction of the total missile inventory will be used in the EEFP calculations for that target. Missile inventories also vary by F'-scale, which takes into account the number of missiles produced by building deconstruction for each tornado category. The missile inventories to use for each type of target and each F'-scale tornado are described in Section 5.2. Further details are provided in Appendices B and C.

Target Exposed Area is determined for each SSC, based on plant documentation and information collected during the Vulnerable SSC Walkdown. More information on target areas is provided in Section 5.

Fragility is the conditional probability of the SSC failing to perform its function given that it is hit by a damaging tornado missile. For the purposes of the TMRE, it is assumed to be 1.0 (i.e., always failed if hit by a damaging tornado missile).

Plant-specific data used as input to the EEFP calculations (e.g., size of the SSC and its elevation) will be based on plant documents and drawings, plus information gathered during the TMRE Walkdowns. Details and examples of SSC exposed area calculations and EEFP calculations are provided in Section 5. Target Exposed Area is a direct input to the EEFP calculation and can typically be determined using drawings and other plant documents. Additional measurements may be made during the walkdowns. Shielding near or around an SSC may have the effect of reducing the amount of the target area actually exposed to missiles.

Target elevation affects the MIP value used in the EEFP for a given SSC. For targets that are less than or equal to 30 feet above the reference elevation, the 'Near Ground' MIP value is used. Targets greater than 30 feet above the reference elevation are considered 'Elevated' targets and may use the Elevated MIP values. Elevated MIP values are less than the Near Ground MIP values. The basis for the MIP values and the dependence on elevation are described in detail in Appendix B. The reference elevation and justification for choosing the value shall be documented. The target elevation can be determined from plant documents, but should also be confirmed by walkdown.

2.4 Develop TMRE PRA Model

The plant's at-power internal events PRA model of record is typically used as the basis for the TMRE model. Since F'2 tornadoes (i.e., tornadoes with wind speeds greater than or equal to 103 mph) are very likely to result in a Loss of Offsite Power (LOOP) to the plant, the LOOP event tree is typically chosen as the portion of the internal events PRA used for the TMRE PRA. This is similar to how at-power High Winds (HW) PRA models are developed. The analyst must ensure that the correct event tree(s) is chosen for the TMRE PRA, based on knowledge of the site-specific PRA model. The details for the PRA model changes needed to develop the TMRE PRA are provided in Section 6.

As described in Section 2.3, tornado events are used as initiating events in the TMRE PRA model. Each tornado from F'2 to F'6 will be represented as an initiating event, having a specific frequency. This is necessary, because the MIP values (and hence the EEFPs) are based on the tornado category. Since the missile strike failures are conditional on the tornado category, the tornado initiating event category must match the EEFP for that category, for each SSC.

Two PRA model cases are developed for the TMRE, the Compliant Case and the Degraded Case. Both of the cases are based on the same LOOP event tree, with certain typical modifications. For example:

- No offsite power recovery is credited in either the Compliant Case or the Degraded Case models.
- Operator actions that require transit or action outside Seismic Category I structures within the first hour of the event are assumed to fail (i.e., failure probability set to 1.0).
- Basic events are added for certain SSCs that are not protected against tornado missiles and/or winds (these are in addition to those nonconforming SSCs).

The main difference between the two models/cases is as follows:

- The Compliant Case represents the plant as if it met the current licensing basis with respect to tornado missile protection. Therefore, any nonconforming SSCs would be assumed protected against tornado missiles, and thus would not have additional tornado missile-induced failure modes in the Compliant Case.
- The Degraded Case represents the plant as it currently exists (the as-built, as-operated plant). Therefore, each of the nonconforming SSCs will need to have additional basic events added to represent the failure likelihood of the SSC due to tornado missiles. The basic events values are from the EEFP calculations, described in Section 2.4.

The specific changes to the PRA models and the differences between the Compliant Case and Degraded Case are provided in Section 6.

As part of the TMRE PRA model development, certain PRA Standard [Ref. 2.3] Supporting Requirements (SR) will need to be addressed, specifically for the TMRE PRA. These SRs are provided in tables in Section 6.

2.5 Quantify Risk, Perform Sensitivity Analyses, and Compare to Thresholds

The TMRE results are based on quantifying the Compliant and Degraded Case PRA models for CDF and LERF. The risk increase (ΔCDF and ΔLERF) is determined by subtracting the Compliant Case value from the Degraded Case value. ΔCDF and ΔLERF are compared to the acceptance criteria of RG 1.174 [Ref. 2.4].

If ΔCDF or ΔLERF are close to or exceed the thresholds of RG 1.174, refinements to the Compliant and/or Degraded Case PRAs may be appropriate. An example may be to refine the EEFP for certain SSCs by accounting for partial shielding of SSCs.

Quantification continues until the risk thresholds are met or no additional PRA/TMRE work can be done to provide an effective reduction in ΔCDF and/or ΔLERF. If further reductions to ΔCDF and ΔLERF are not possible, the licensee will need to decide whether physical modifications should be made and to which SSCs. The preliminary TMRE results may be used to guide the modification effort.

Sensitivity studies may be needed to determine the impact of certain TMRE or site-specific PRA model assumptions. TMRE-related sensitivity studies are recommended in Section 7. Key assumptions and open issues associated with the internal events PRA and applicable to the TMRE application may require sensitivity studies. This will be a plant-specific issue, based on the status of the underlying internal events PRA (e.g., open peer review findings).

2.6 PERFORMANCE MONITORING

Application of TMRE does not provide a basis for modifications to remove existing tornado missile protection or to omit protection for new configurations that otherwise require tornado missile protection according to the plant licensing basis. Design Control programs that meet 10 CFR 50 Appendix B will ensure that subsequent configuration changes are evaluated for their impact on the TMRE risk basis for accepting the identified nonconforming conditions. The TMRE risk basis must continue to be met (i.e. “very small” risk change per RG 1.174.)

2.7 REFERENCES

2.1 EPRI 3002008092, *Process for High Winds Walkdown and Vulnerability Assessments at Nuclear Power Plants*

2.2 NUREG/CR-4461, *Tornado Climatology of the Contiguous United States,* Rev. 2, US Nuclear Regulatory Commission, February 2007.

2.3 American Society of Mechanical Engineers/American Nuclear Society, *Standard for Level 1 / Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications,* ASME/ANS RA-Sb-2009, 2013.

2.4 U.S. Nuclear Regulatory Commission, *An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant Specific Changes To the Licensing Basis,* Regulatory Guide 1.174, Revision 3, January 2018.

3 PERFORM PLANT TMRE WALKDOWN

The TMRE Walkdown is performed after the list of nonconforming SSCs has been identified. The purpose of the TMRE Walkdown is to gather physical data associated with the nonconforming SSCs and any other SSCs that are modeled in the PRA but are not protected from tornado winds or missiles, and to validate the number of missiles to use in EEFP calculations. A significant portion of the walkdown task is performed prior to going out in the field for the actual walkdown; the preparation for the walkdown, which includes the development of a HWEL, is also described in this section.

TMRE Walkdown is broken into two phases: the Vulnerable SSC Walkdown and the Tornado Missile Walkdown. These two phases can be performed in parallel and generally do not affect each other. As such, separate personnel can be assigned to the two teams and they can proceed more or less independently. Additionally, the Tornado Missile Walkdown team does not require the same experience level as the Vulnerable SSC Walkdown. Sections 3.1 through 3.2 describe the preparations and walkdown for vulnerable SSCs. Section 3.3 describes the walkdown activities performed to help determine ex-control room operator action feasibility, which is typically performed as part of the Vulnerable SSC walkdown. Section 3.4 describes the Tornado Missile Walkdown preparation and execution.

Much of the information provided in this section can also be found in EPRI 3002008092, *Process for High Winds Walkdown and Vulnerability Assessments at Nuclear Power Plants* [Ref. 3.1].

3.1 VULNERABLE SSC WALKDOWN PREPARATION

Prior to sending personnel out on a walkdown, several activities are recommended to ensure that the walkdown is performed completely and in an efficient manner. The Vulnerable SSC Walkdown will review previously identified nonconforming SSCs to collect and verify any data needed for the TMRE model. The Vulnerable SSC Walkdown will also be used to locate and evaluate unprotected SSCs that are credited in the TMRE PRA model. Although all SSCs may not be required to be protected by the plant's licensing basis, SSCs that are credited in the TMRE PRA must be evaluated to ensure that they can function during a tornado event.

Development of a HWEL is recommended; the HWEL will provide the walkdown team with an initial list of SSCs to review during the walkdown. The HWEL is generally developed by PRA analysts familiar with the internal events PRA model, with support from design personnel. The initial HWEL should contain the list of vulnerable SSCs to include previously identified nonconforming SSCs and those that are not explicitly modeled in the PRA. It will also include a list of potentially unprotected SSCs that are in the TMRE PRA. Additional TMRE PRA SSCs may be identified during the walkdown that that will need to be added to the HWEL. For example, some SSCs may initially be thought to be protected, but determined to be unprotected during the walkdown. The final HWEL will be based on the work done prior to the walkdown and any additional information (e.g., other unprotected SSCs) collected during the walkdown.

An example HWEL is shown in Table 3-1. It includes the following information:

- **Equipment ID:** This is the equipment identifier for the SSC. This is typically taken from the plant equipment identification system, but other IDs can be used.

- **Equipment Description:** This is a text description of the SSC.

- **Basic Event:** This is the PRA basic event ID that the failure of the SSC will be assigned.
- **BE Description:** This is the text description of the basic event.
- **Building:** This is the building that houses the SSC.
- **Elevation:** This is the floor elevation designator for the location of the SSC.
- **Location:** This provides more details on the location of the SSC. It may be a room number, fire or flood zone number, row and column intersection, or grid position.
- **Normal Position:** This column identifies the normal state (normally closed, normally open, normally running, etc.) of the SSC during at-power operations.
- **PRA Desired Position:** This column identifies the desired state (open, closed, etc.) of the SSC for successful function in the TMRE PRA.
- **MOV/AOV Failed Position:** This identifies the valve failed state due to loss of power and/or air. This applies to MOVs, AOVs and similar valves (e.g., with solenoid or hydraulic operators). It is important to include this information in the HWEL for the walkdown team.
- **Correlated SSCs:** Notes of possible SSC correlations identified during the HWEL creation should be entered here, and any correlation information obtained during the walkdown should be added.

Table 3-1: Example of HWEL Entries

Equipment ID	Equipment Description	Basic Event (BE)	BE Description	Building	Elevation	Location	Normal Position	PRA Desired Position	MOV/ AOV Failed Position	Correlated SSCs
IA-001	IA Compressor Outlet Valve	IA001XC	Valve IA-001 Transfers Closed	Turbine	240’	TH/12	Open	Open	N/A	N/A
SW-P01A	Service Water Pump A	SWP1AFR	Service Water Pump A Fails to Run	Intake	200’	IA/14	On	On	N/A	N/A
MFW-P01B	Main Feedwater Pump B	FWP1BFR	Main Feedwater Pump B Fails to Run	Turbine	219’	TC/8	On	On	N/A	N/A
RWST	Reactor Water Storage Tank	RWSTCF	RWST Catastrophic Failure	Yard	219’	Near Aux Building	Available	Available	N/A	N/A
1A1-3	MCC 1A1-3	MCC1A13	MCC 1A1-3 Fails	Turbine	240’	TA/20	Energized	Energized	N/A	N/A
SW-10A	Service Water Discharge Valve A	SW10AFO	Valve SW-10A Fails to Open	Yard	205’	SW Pit	Open	Open	As-Is	In the SW Pit 3’ from SW-10B
SW-10B	Service Water Discharge Valve B	SW10BFO	Valve SW-10B Fails to Open	Yard (SW Pit)	205’	(SW Pit)	Open	Open	As-Is	In the SW Pit 3’ from SW-10A

As noted, the HWEL will include potentially vulnerable SSCs from the TMRE PRA. This will require initial work to create the TMRE PRA, at least to the degree that is needed to support HWEL development. Section 6.1 describes the initial step of selecting the event trees from the internal events PRA model that will be used to form the TMRE PRA model. After completing the step described in Section 6.1, the analyst will be able to determine what SSCs will be included in the TMRE PRA. The SSCs considered in the TMRE PRA and the previously identified nonconforming SSCs form the initial list of SSCs to consider for the HWEL. The following steps are taken to refine the HWEL:

a. Screen out SSCs that are not included in the selected accident sequences (if not already done in the Section 6.1 steps) and non-equipment basic events.
b. Screen out SSCs that are located inside Category I structures and that are located away from vulnerable openings or features (e.g., ventilation louvers, roll-up doors).
c. Screen SSCs that are dependent on offsite power, since the TMRE assumes there will be a non-recoverable loss of offsite power.
d. Determine SSC location, normal position, desired position (from the TMRE PRA), and failed position (for MOVs and AOVs).

Following these steps, an initial HWEL will be developed; it will then be used to support the Vulnerable SSC Walkdown.

Prior to the walkdown, any ex-control room human failure events (HFE) should be identified. These actions will need to be reviewed with an operator and the operator locations, transit pathways and operation locations will need to be evaluated as part of the walkdown. The following information should be reviewed with an operator prior to the walkdown:

a. Operator action task (e.g., switch CST suction for AFW pumps)
b. Operator action location, where the action takes place
c. Normal location of the operator(s) at the time of the event. If the site procedures have specific locations for operators to take shelter during a tornado, those should be the starting location for the operators. Otherwise, potential operator locations will need to be considered.
d. Potential pathways for the operator to transit from their initial location to the action location.

3.2 Vulnerable SSC Walkdown

The purpose of the Vulnerable SSC Walkdown is to locate and document all potentially vulnerable and previously identified nonconforming SSCs and any TMRE PRA SSCs that are not protected from tornado missiles. Additionally, actions performed outside of the control room (ex-control room actions) will be reviewed to verify that station personnel can safely get from their initial location to the action location after a tornado has struck the plant.

3.2.1 Personnel for Vulnerable SSC Walkdown

The Vulnerable SSC Walkdown should be performed by a team consisting of personnel familiar with the plant systems, personnel responsible for the TMRE PRA, and a civil or structural engineer familiar with the plant. Structural personnel provide expertise to identify screening characteristics applicable to SSCs. Risk assessment personnel participate in the walkdowns to provide insights on the failure modes of the equipment in the TMRE PRA, as well as to have hands-on experience with the SSCs that will be modeled. If the walkdown will be conducted primarily by vendors/contractors, it is recommended that the plant PRA personnel be actively involved in the process.

As stated previously, the Vulnerable SSC Walkdown can be performed independently from the Tornado Missile Walkdown. The personnel recommendations for the Tornado Missile Walkdown are discussed in Section 3.4.1.

3.2.2 Vulnerable SSC Identification and Data Collection

The initial HWEL, developed in accordance with Section 3.1, is the roadmap for the Vulnerable SSC Walkdown. It should list all the SSCs that need to be identified and reviewed during the walkdown, both previously identified potentially nonconforming SSCs and additional TMRE PRA SSCs that may be exposed to tornado missiles. The HWEL should not be considered static; any additional SSCs in the TMRE PRA that are exposed to tornado missiles and not on the HWEL should be added. Any incorrect or missing information can also be noted while in the field, for updates to the HWEL.

3.2.3 SSC Failure Modes

In addition to SSCs being vulnerable to tornado missile strikes, other failure modes and configurations of interest should be noted during the walkdown:

- Active (e.g., pumps, compressors) or passive (e.g., tanks, piping) components that are outside or in areas where they are exposed directly to tornado wind forces.
- Components inside non-Category I structures; these SSCs will be damaged when the structure collapses, or exposed to tornado wind pressures from walls or siding failure.
- SSCs adjacent to non-Category I SSCs, that may be impacted when the non-Category I SSC collapses.
- SSCs that could be affected by flooding or combustion motor intake effects, due to tornado missile failure of non-conforming fluid-filled tanks or pipes (i.e., secondary effects.)

These situations should be noted and documented during the walkdown. The treatment of SSC failures in the TMRE model is described in Sections 6.5 and 6.6. The selection of the representative initiating event(s) and event tree(s) should also take these failures into account.

3.2.4 Walkdown Activities and Documentation

Each of the SSCs on the HWEL should be located, and information on the SSC should be collected, to support the incorporation of the SSC EEFP in the TMRE PRA model. The information to be collected is described below. Both field notes and photographs should be taken while performing the walkdowns. In order to limit the need for additional walkdowns or document reviews later, quality notes supplemented with numerous photographs should be taken to provide necessary documentation from the walkdown. Notes and dispositions regarding specific SSCs can be added to the HWEL. Documentation from the walkdown will also serve as useful information in the future, if plant modifications are performed which could alter the conclusions derived from the TMRE.

The walkdown activities should consist of the following:

a. Locate and identify the SSC; verify that the SSC is located where it is documented to be. Note any support systems or subcomponents, such as electrical cabling, instrument air lines, and controllers.

b. Photograph the SSC, including its surroundings. Ensure that any subcomponents or support systems identified are photographed. Example photographs are provided in Section 4 of the EPRI walkdown guidance, EPRI 3002008092 [Ref.3.1].

c. Document and describe barriers that could prevent or limit exposure of the SSC to tornado missiles; Photograph any barriers that could prevent tornado missiles from impacting the SSC. This may include barriers or shielding designed to protect an SSC from tornado missiles, as well as other SSCs that may preclude or limit the exposure of the target SSC to missiles (e.g., buildings, large sturdy components).

d. Identify directions from which tornado missiles could come from to strike the target. This may best be done with sketches and notes, in addition to photographs of the area surrounding the SSC. For SSCs inside Category I structures, note whether there is a line of sight from an opening to the SSC.

e. Determine and/or verify the dimensions of the target SSCs, including any subcomponents or support systems. It is helpful to have the dimensions from drawings or other documents prior to the walkdown, so that the walkdown can be used for confirmation. Determine the dimensions of any openings that allow the SSC to be exposed to a tornado missile.

f. Determine the proximity and potential correlation to other target SSCs. For the purpose of the TMRE, correlated targets are SSCs that can be struck by the same tornado missile.[1] Photographs of SSCs that are close together (correlated or not) are useful for documenting the decision made regarding correlation.[1]

g. Note any nearby large inventories of potential tornado missiles. Relocation of large groups of potential missiles in close proximity to exposed risk significant SSCs may be considered to improve defense in depth. The intent of this is not to count missiles, since that is done in a separate walkdown.

h. Proximity of non-Category I structures to exposed target SSCs should be documented. A non-Category I structure may collapse or tip-over and cause damage to an SSC.

i. Identify vent paths for tanks that may be exposed to atmospheric pressure changes (APC). These should be noted during the documentation and drawing review, but verified and documented as part of the walkdown.

j. Look for additional issues affecting credited equipment or other potential vulnerabilities that may not have been previously identified.

General information on walkdowns can also be found in EPRI 3002008092, *Process for High Winds Walkdown and Vulnerability Assessments at Nuclear Power Plants* [Ref. 3.1].

[1] If targets are correlated, the entire area of the correlated targets should be determined, and one EEFP will be calculated for the correlated targets, to be used to fail all correlated SSCs.

3.3 EX-CONTROL ROOM ACTION FEASIBILITY

Ex-control room HFEs should have been identified during the development of the HWEL (see Section 3.1). Operator actions performed outside of Category I structures or requiring the operator to transit outside Category I structures should be evaluated for the TMRE. These types of operator actions that need to be performed within 1 hour of the tornado event are assumed to be failed. However, actions requiring transit or operation outside Category I buildings after 1 hour may also be affected by the tornado, especially for higher category tornadoes. For example, access paths may be blocked or debris may prevent easy access to some equipment. Primary and alternate paths for operator transit should be identified and verified with operations staff. Paths should be verified during the walkdown and any relevant notes should be taken. Examples of items to note are the number of pathways available for the operator (taking into account where operators typically shelter during a tornado event), whether the equipment will be accessible, and whether timing is expected to be affected. Ex-control room operator actions that are performed inside Category I buildings and do not require transit outside of Category I buildings are considered to be unaffected.

The results of the operator interviews and the walkdown notes should be reviewed by a Human Reliability Analyst. It is not expected that longer term action (greater than 1 hour) human error probabilities will be noticeably impacted by the tornado event. Section A.2.1.2 provides considerations for not changing the Human Error Probabilities (HEP) of such actions. The results of the ex-control room action feasibility evaluation should be documented to justify the treatment of such actions in the TMRE model.

3.4 TORNADO MISSILE IDENTIFICATION AND CLASSIFICATION

One of the key inputs to the EEFP is the number of missiles capable of damaging exposed SSCs. In order to simplify the calculations, Section 5.1 provides generic values for the number of missiles to include in the EEFP calculation. The Tornado Missile Walkdown is performed to verify that the number of missiles recommended in Table 5-1 is bounding for the site being evaluated. This walkdown is recommended to be performed separately from the Vulnerable SSC Walkdown; it can be performed in parallel with the Vulnerable SSC Walkdown or at a different time.

3.4.1 TORNADO MISSILE WALKDOWN PERSONNEL

Personnel performing the Tornado Missile Walkdown do not require PRA expertise or knowledge, and structural engineering experience is not required. The personnel only need to be trained on the methods for identifying and counting potential missiles. This section and Section 4.3 of EPRI 3002008092 provide adequate information to support training Tornado Missile Walkdown personnel.

3.4.2 NON-STRUCTURAL MISSILE INVENTORY

The Tornado Missile Walkdown should cover the entire plant area, out to a distance of 2500 feet from a common reference point, such as the center of the containment. If there are target SSCs more than 1500 feet from the reference point, additional verification of missile populations near those SSCs may be required. Recommendations for this situation are discussed at the end of this section.[2]

[2] The bases for the areas and distances considered for the TMRE missile inventory are provided in Appendix B.

The survey area may be divided into zones to simplify record keeping and allow multiple teams (if desired) to perform the walkdown. Zones should be defined by geographic or well-recognized landmarks, to minimize the potential for double-counting or overlooking missiles. A plant layout drawing and/or satellite image of the plant can be marked up to indicate the zones. The number of zones can vary from a few (5 - 7) to about 30.

Although High Winds PRAs generally require the type and number of missiles to be counted, only the total number of missiles are required to be counted for the TMRE PRA. However, it may be beneficial to count the types of missiles, for record-keeping purposes and for potential use in the future. The types of missiles are listed in Table 3-2, including examples of which objects would be binned as a certain missile type. Not every potential missile is listed in this table, so other objects that can become missiles should be binned with the closest missile type. A similar list of missile types is provided as Table 4-2 in EPRI 3002008092 and an example missile inventory table (including nominal dimensions for the missiles) is provided in Table 4-3 of the same EPRI report.[3]

In the case of targets greater than 1500 feet from the plant area reference point, a qualitative evaluation of the missile inventory within 2500 feet of the outlying target(s) should be done. The intent of this evaluation is to determine whether the missile inventory used for the TMRE is applicable to all the targets. If the missile inventory/density surrounding an outlying target is judged to be comparable to (or bounded by) the missile inventory determined from the missile survey out to 2500 feet from the reference point, then no further action is required. Otherwise, a missile inventory should be determined for the area out to 2500 feet from any outlying target.

[3] Missile Type 10 in Table 3-2 is not included in EPRI 3002008092. The Dumpster/Storage Container missile type in EPRI 3002008092 is not included here; they can be binned as vehicles (Missile Type 22).

Table 3-2: Potential Tornado Missile Type

Type	Missile Description and Nominal Dimensions	Nominal Weight (lbs)	Example Missiles
1	Rebar: Steel, 1” dia x 3’ long	8	Rebar
2	Gas Cylinder: Steel, 10” dia x 5’ tall	290	Gas Cylinder
3	Drum, tank: Steel 20” dia x 5’ tall	500	55-gallon drum
4	Utility Pole: Wood, 13.5” dia x 35’ long	1500	Wooden light pole or ‘telephone pole’
5	Cable Reel: Wood, 42” dia x 1.8’ wide	253	Cable Reel
6	3” Pipe: Steel, 3.5” dia x 10’ long	76	Fence posts, conduit, sprinkler piping
7	6” Pipe: Steel, 6.63” dia x 15’ long	284	Larger pipes
8	12” Pipe: Steel, 12.75” dia x 15’ long	744	Steel light poles or utility poles
9	Storage bin: Steel 3.5’ x 3’ x 6’	675	Small metal containers, ‘gang boxes’, filing cabinets
10	Concrete Paver	88	Concrete Roof Pavers
11	Concrete Block: 8” x 8” x 16”	36	Cinder blocks
12	Wood Beam: 4” x 12” x 12’	200	Thick wood beams, wood posts
13	Wood Plank: 1” x 12” x 10’	27	Thinner wood planks, 2 x 4s
14	Metal Siding	125	Building siding, steel plates
15	Plywood Sheet: 7/8” x 4’ x 8” -	84	Plywood sheets
16	Wide Flange: Steel, 14” WF x 15’	390	Angle iron, larger I-beams
17	Channel Section: Steel, 6” C x 15’	195	C-beams
18	Small Equipment: 2.5’ x 2.5’ x 3’	388	Small portable generators, small pumps
19	Large Equipment: 4 ‘x 3’ x 6’	1350	Lathe, small concrete mixers, larger generators and pumps
20	Frame/Grating: Steel, 2’ x 1” x 12’	74	Ladders, scaffolding, floor grating
21	Large Steel Frame: 10’ x 4’ x 16’	1040	Warehouse shelving, pallet racks
22	Vehicle: Examples – 5.5’ x 5.5’ x 16’	4000	Cars, trucks, sea van containers, trash dumpsters
23	Trees 8” dia x 20’ tall	700	Trees[4]

[4] For forested areas or large stands of trees, counts are typically estimated by determining the area of interest (e.g., via satellite image) and assuming a certain tree density.

Note that the dimensions provided in Table 3-2 are nominal dimensions, used to help classify objects that do not fit the exact description of the missile. For example, a steel light pole that is 10” in diameter and 20’ high could be classified as a Type 8 (12” pipe) missile.
The following (and similar) items are either lightweight, sufficiently massive, or fixed; thus, they pose no significant threat to NPP SSCs; they should not be counted as missiles:

- Soft materials, such as insulation, foam, cardboard, etc.
- Small and light objects, such as plastic fittings, light gauge metal fasteners, ventilation louvers, etc.
- Small plants and trees, bushes, etc.
- Very heavy equipment (main transformer, turbine generator, etc.)
- Cement or concrete pads or building foundations

3.4.3 Non-Permanent Missiles

Outages

Prior to and during NPP outages, additional equipment is brought onsite, staged in laydown areas, and left outdoors (e.g., scaffolding, construction material, construction trailers). Although this additional equipment may lead to a higher total missile inventory than was surveyed as part of the TMRE walkdown, it is not necessary to explicitly account for the additional outage-related missiles in the TMRE missile inventory. Moreover, many outage related missiles, if not staged during the time that walkdowns are performed, would be counted as part of laydown areas or included in warehouse inventory. In many cases, equipment used during outages is stored elsewhere on site during non-outage times to prevent having to purchase new outage support equipment before each outage.

Sites that develop a missile count of less than 240,000 missiles still use 240,000 missiles in their TMRE analysis and have built in margin that can account for potential increases in missiles during outage preparation and staging. Additionally, outages are of relatively short duration compared to the operational time at a NPP. Sites have procedures that require securing equipment and potential missile sources in the event of forecasted severe weather. Additionally, the increased manpower onsite during outage periods provides for more available personnel to help secure potential missile sources. Based on these factors, the impact to the tornado missile risk posed by additional outage-related missiles is minimal.

Construction

The TMRE risk estimates will be used in a risk-informed change the permanent licensing basis for the plant, for nonconforming SSCs. Although construction at a site may temporarily add to the missile inventory used in TMRE, the new licensing basis should reflect the state of the as-built and as-operated plant configuration, and not have to change as short-term configurations or activities occur at the plant site.

Construction is typically a short-term condition relative to the operating life of the plant. Additional non-permanent missiles do not need to be included in the missile inventory for the TMRE CDF and LERF calculations (i.e., those calculations performed in Section 7.1). A similar consideration is discussed above for outages. However, the expected final site configuration (i.e., after construction is completed) should be evaluated to ensure that the missile count used in the TMRE continues to be bounding or if the missile count input should be updated. For example, if non-Category I structures are being built, the missile count from the final structures within the required range needs to be determined and included in the site-specific missile inventory. These are called "permanent post-construction missiles."

The guidance for periods of construction is:

- The expected missile inventory for the post-construction site should be *estimated*, using walkdown results for the non-construction areas, information in Sections 3.4.2 and 3.4.4, along with design and construction information. The basis and assumptions used for the estimated number of permanent post-construction missiles shall be documented. Bounding and conservative estimates are recommended, to account for uncertainty.
    - If the inventory of current missiles (those counted outside the construction area) plus the estimate of post-construction missiles is less than 240,000 missiles, the generic missile inventories provided in Table 5-1 should be used for the Section 7.1 ΔCDF and ΔLERF calculations.
    - If the total missiles are not bounded by 240,000, a bounding site missile inventory should be determined and documented. This bounding missile inventory should be used for the Section 7.1 ΔCDF and ΔLERF calculations.

- A missile margin assessment (Section 7.4)~~sensitivity analysis~~ should be performed to evaluate the impact of the additional non-permanent construction-related missiles, that is, those missiles not already included in the permanent post-construction missiles. This would include missiles in construction lay-down areas that are currently inside the analysis range, but would eventually go into Category I structures or be removed completely. The total missile count for the missile margin assessment~~sensitivity analysis~~ should include the non-construction related missile inventory determined in accordance with Sections 3.4.2 and 3.4.4, and a reasonably bounding *estimate* of the number of non-permanent construction-related missiles (all within 2500' of a central reference point).

- The basis and assumptions used to determine the non-permanent construction-related missile estimate should be documented. An example of an acceptable method for estimating missile counts would be to perform walkdowns of limited sections of the construction area, determine average missile densities in those areas, and apply the missiles densities to the remainder of the construction area. Documentation should include some sample photographs of the construction area.

- Qualitative discussions, such as that of the proximity of the missiles to targets, should be included to support the basis for exclusion of the non-permanent missiles from the primary TMRE analysis of the as-built, as designed plant. Additionally, include a qualitative or quantitative discussion of the nature of the construction as short-term and the impact of the non-permanent construction-related missiles on risk over time. If engineering judgment does not support exclusion of the missiles from the primary TMRE analysis, then the missiles should be included in the permanent post-construction missile count. Also, a site may elect to include the non-permanent missiles in the permanent count as a matter of convenience~~ instead of performing the sensitivity analysis~~.

- The results of the ~~sensitivity analysis~~margin assessment (Section 7.4) shall be documented.

3.4.4 STRUCTURAL MISSILES

Commercial and industrial structures that are built to standard building codes will generally not withstand tornado winds greater than about 100 mph. The destruction of these structures generates additional missiles that should be accounted for in the TMRE. Each type and size of structure contains a number of missiles that can be estimated using the tables presented here (Tables 3-3 through 3-8); the basis for these tables is provided in Appendix C.

Missiles from turbine buildings (e.g., siding, laydown areas) should not be inventoried using the tables in this subsection. Missiles originating from turbine buildings should be counted separately. For example, the number of siding panels can be determined based on a review of turbine building structural drawings and walkdowns.

The contents of buildings were considered depending on building function. For example, the quantities of desks and furniture were estimated for office buildings, and quantities of pallets, drums, and shelving were estimated for warehouses. The building contents accounted for in Tables 3-3 through 3-8 are considered representative for all sites; therefore, validation of site-specific building contents is not required by individual licensees.

A short description and an example of each structure type are provided here.

Wood Framed Office Buildings and Warehouses (Tables 3-3 and 3-6) - Wooden buildings have roof, floor, and wall structural systems that are constructed of sawn lumber, plywood, or engineered wood; see Figure 3-1. These buildings are prone to partial or complete loss of roof and wall systems when subjected to severe winds. Potential missiles include wood planks and plywood debris.

Figure 3-1: Typical Wood-framed Construction

Trailers and Manufactured Buildings (Tables 3-4 and 3-8) – These are typically modular and have lightweight construction; see Figure 3-2. These buildings are not typically constructed on permanent foundations and are prone to uplift and roll-over under severe wind loads. Potential missiles include trailer roof and wall components, as well as steel channel framing (trailer).

Figure 3-2: Typical Trailer/Manufactured Building

Engineered and Pre-engineered Buildings (Tables 3-5 and 3-7) – Engineered buildings typically have roof, floor, and wall systems that are constructed with steel or concrete; see building on the left of Figure 3-3. Pre-engineered buildings (building on the right of Figure 3-3) are typically steel-framed structures with metal siding (e.g., Butler buildings). Potential missiles include steel siding and roof decking and framing members (e.g., wall and roof purlins).

Figure 3-3: Typical Engineered (left) and Pre-engineered (right) Buildings

Table 3-3. Potential Tornado Missile per Office Building, Wood-Framed

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	14	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	4	2	9
13	69	31	76
14	0	0	25
15	31	31	0
16	2	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**121**	**66**	**110**

Table 3-4. Potential Tornado Missile per Office Building, Manufactured (Pre-fab)

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	16	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	2	0	0
10	0	0	0
11	0	0	0
12	13	3	23
13	183	20	56
14	0	0	24
15	31	25	0
16	2	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**248**	**50**	**103**

Table 3-5. Potential Tornado Missile per Office Building, Engineered and Pre-Engineered

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	33	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	2	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	80	0	0
14	0	25	24
15	15	0	0
16	0	8	4
17	0	16	7
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**131**	**51**	**35**

Table 3-6. Potential Tornado Missile per Office Building, Construction Trailer

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	0	0	0
2	1	0	0
3	2	0	0
4	0	0	0
5	4	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	4	0	0
10	0	0	0
11	0	0	0
12	12	6	14
13	151	12	96
14	0	25	24
15	31	0	0
16	0	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**206**	**45**	**134**

Table 3-7. Potential Tornado Missile per Warehouse Building, Wood-Framed

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	27	0	0
2	1	0	0
3	1	0	0
4	0	0	0
5	5	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	6	0	0
10	0	0	0
11	0	0	0
12	6	2	4
13	30	20	78
14	0	31	24
15	20	0	0
16	0	0	0
17	0	0	0
18	2	1	0
19	2	1	0
20	1	0	0
21	2	0	0
22	0	0	0
23	0	0	0
Total	**103**	**55**	**106**

Table 3-8. Potential Tornado Missiles per Warehouse Building, Engineered and Pre-Engineered

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	18	0	0
2	1	0	0
3	1	0	0
4	0	0	0
5	5	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	6	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	16	0	0
14	0	25	25
15	12	0	0
16	0	5	4
17	5	16	8
18	2	1	0
19	2	1	0
20	1	0	0
21	2	0	0
22	0	0	0
23	0	0	0
Total	**71**	**48**	**37**

References

3.0 EPRI 3002008092, *Process for High Winds Walkdown and Vulnerability Assessments at Nuclear Power Plants*

4 DETERMINE SITE TORNADO HAZARD FREQUENCY

4.1 DATA SOURCES

NUREG/CR-4461, Rev. 2, was written to support the latest revision of Regulatory Guide 1.76, "Design-basis Tornado and Tornado Missiles for Nuclear Power Plants." This NUREG uses data on tornadoes which were reported in the contiguous United States from January 1950 through August 2003, which encompasses over fifty years of data. The wind speed estimates in this report are based on the Fujita Scale and the Enhanced Fujita Scale, both of which correlate wind speeds with damage caused by tornadoes.

4.2 BACKGROUND

The initiating event for the TMRE PRA model is the frequency of a tornado strike at the site. Each licensee should develop a site-specific tornado frequency. The tornadoes of interest are those tornadoes with a wind speed of approximately 100 mph or greater. For the purposes of the TMRE, the F'-scale (Fujita prime) will be used to classify tornadoes; this scale is somewhat different from the original Fujita Scale (F-Scale) and the Enhanced Fujita Scale (EF-Scale); refer to table 4-1 below. The F'-scale was chosen because the TMRE MIP values are based on simulations that used the F'-scale inputs to categorize the tornados.

Table 4-1: Fujita Tornado F Scale Intensity Wind Speed Relationships (mph)

Intensity	Description	Original Fujita	Fujita	Enhanced Fujita	F'
F0	Light damage	40 to 72	45 to 78	65 to 85	40—73
F1	Moderate damage	73 to 112	79 to 117	86 to 110	73-103
F2	Considerable damage	113 to 157	118 to 161	111 to 135	103-135
F3	Severe damage	158 to 206	162 to 209	136 to 165	135-168
F4	Devastating damage	207 to 260	210 to 261	166 to 200	168-209
F5	Incredible damage	261 to 318	262 to 317	>200	209-277
F6	Inconceivable	319-380			277-300

NUREG/CR-4461, Rev. 2, Table 6-1 provides each U.S. NPP site with tornado wind speeds associated with 10^{-5}, 10^{-6}, and 10^{-7} probabilities per year of a tornado missile strike. Excerpts of that table are shown below in Table 4-2. Additionally, the total tornado strike frequency (i.e., the frequency of any tornado with wind speed greater than 65 mph) is provided for all locations in the continental United States. Using this data, a site-specific tornado frequency curve (hazard curve) can be developed and the frequency of all tornadoes considered in the TMRE (F'2 through F'6) can be calculated.

Since F' probabilities are not directly available from this NUREG, they must be derived from the site-specific Fujita scale data. Using the Fujita scale data, as opposed to the Enhanced Fujita Scale data, results in higher, and therefore more conservative, strike frequencies.

4.3 HAZARD FREQUENCY CALCULATIONS

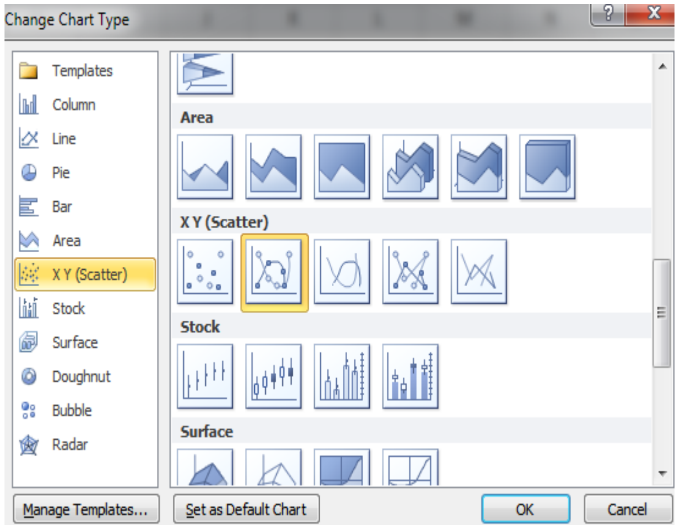
The F'-scale probabilities used in the TMRE method are based on the site-specific Fujita Scale data from NUREG/CR-4461, Rev. 2 (see examples in Table 4-2 below.) These data are used to develop an equation for the site-specific tornado hazard curve that is then used to calculate the yearly exceedance frequencies for each F' range, F'2 through F'6. The following example (Sections 4.3 thru 4.6) illustrates the process using the following data (1E-05 at 158mph, 1E-06 at 214mph, and 1E-07 at 264mph.)

Table 4-2: Excerpt of Site-Specific Fujita Scale Data (From NUREG/CR-4461, Rev. 2 Table 6-1)

		Fujita Scale (mph)		
Index	**Power Plant**	**1E-05**	**1E-06**	**1E-07**
46	**Peach Bottom**	139	199	250
47	**Perry**	186	240	288
48	**Pilgrim**	143	203	254
49	**Point Beach**	177	232	280
50	**Prairie Island**	192	245	293

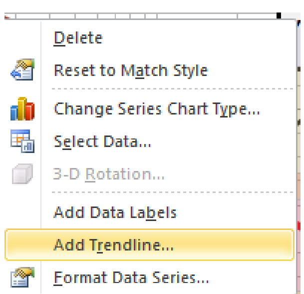
4.4 PLOT DATA POINTS

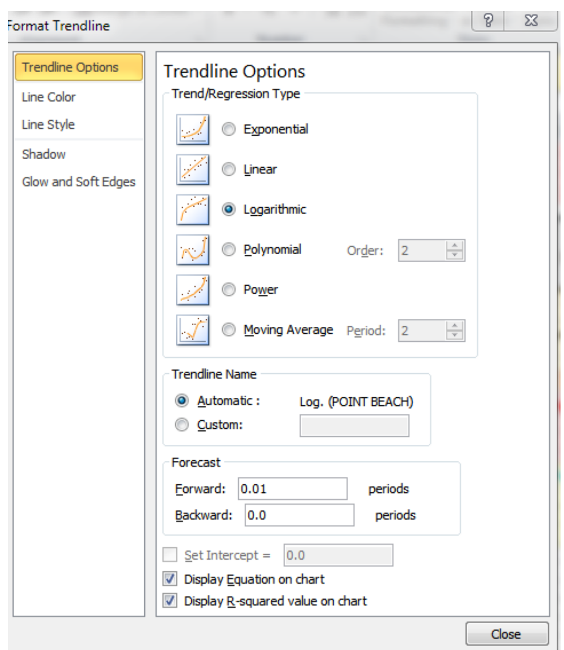
For this example, Microsoft Excel® is used to plot the data points, but other curve-fitting software packages would be acceptable. The three site-specific Fujita Scale data points are plotted using the Excel chart function "XY scatter." In this example the wind speed is plotted on the y-axis and the frequency is plotted on the x-axis, however, the axes can be swapped to reflect wind speed on the x-axis and frequency on the y-axis.



4.5 TRENDLINE EQUATION PLOT

Select the line plotted by these three points (i.e., right-click) to open the drop down window. Then, select the "Add Trendline" function from the list. From the "Format Trendline" window, select "Trendline Options." For this example, the "Logarithmic" trendline option was used along with the "Display Equation on chart" and "Display R-squared value on chart" options. The r-squared value should be >0.9.





The equation generated for the Example site is:

Miles per Hour (mph) = -23.02 * ln(Frequency) - 106

R-squared = 0.9989

Where Y=Miles per Hour (mph) and X=Frequency

NOTE: The equation above can be modified to solve for the Frequency variable (i.e., the Frequency variable is on the left-hand side of the equation.) This may facilitate the process since the final results from Section 4 will be site-specific tornado initiating event frequencies.

4.6 CALCULATE TORNADO EXCEEDANCE AND TORNADO BIN FREQUENCIES

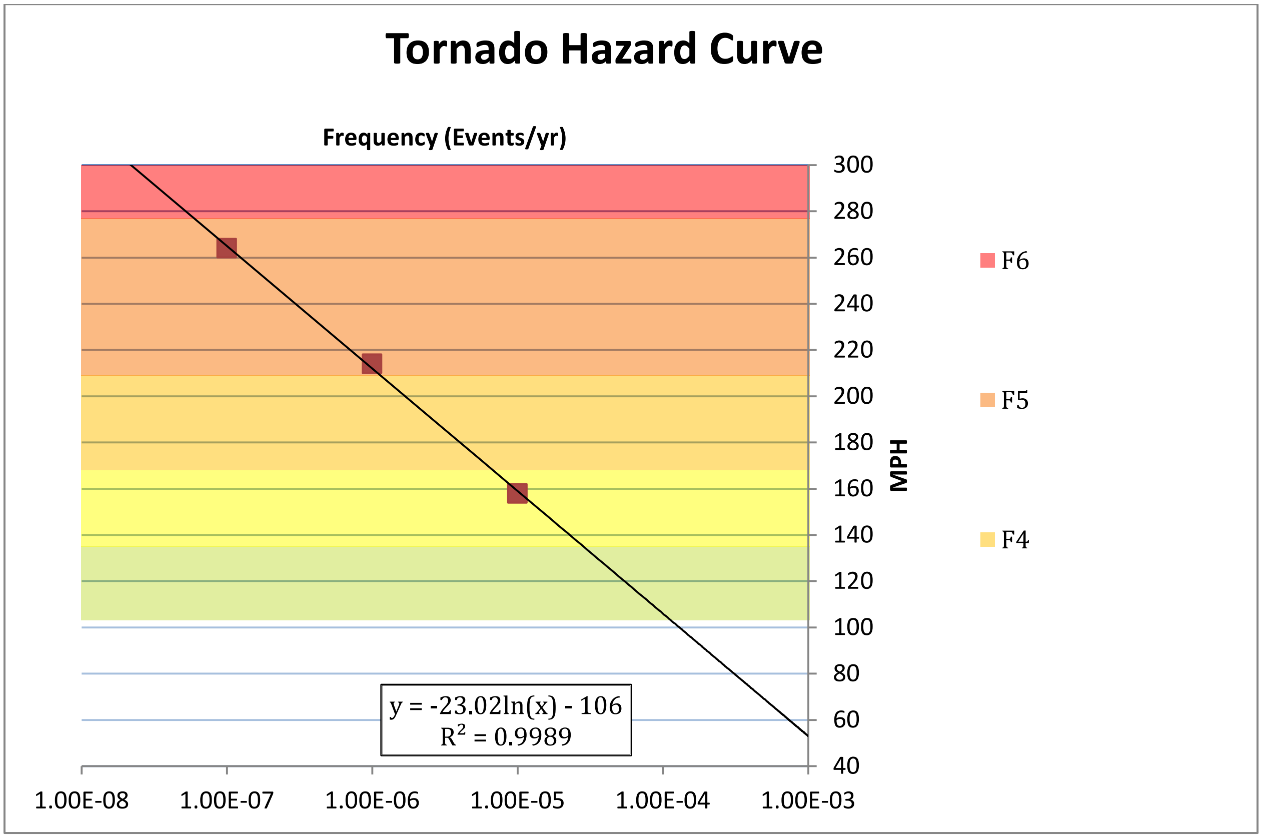
The three red blocks in Figure 4-1 are the three plotted example data points from Section 4.3 and the thin black line is the trendline developed from Section 4.5. To calculate the exceedance frequencies for each F' scale tornado (F'2 thru F'6), plug the lower range tornado speed into the trendline equation. Using the example data, for the F'2 tornado plug 103mph into the equation from Section 4.5 and the resulting exceedance frequency is 1.14E-04/year. Similarly for the F'3 tornado plug 135mph into the equation and the resulting exceedance frequency is 2.84E-05/year. These exceedance frequencies for each tornado F' scale is an intermediate step in deriving tornado bin frequencies, which are the final inputs into the TMRE model.

In order to get the F'2 tornado bin frequency, subtract the F'3 scale tornado exceedance frequency from the F'2 tornado exceedance frequency (i.e., 1.14E-04 – 2.84E-05 = 8.85E-05). See Table 4-3 below for the entire list of F' scale tornado exceedance frequencies and bin frequencies using the example data. Note that the F'6 tornado exceedance frequency and bin frequency are the same because there is not an associated F'7 scale tornado exceedance frequency to subtract from the F'6 exceedance frequency. The site-specific tornado bin frequencies are the tornado initiating event frequencies used in Section 6.2 when developing the TMRE PRA model.

Table 4-3

Intensity	Minimum MPH	Exceedance Frequency	Bin Frequency
F'2	103 mph	1.14E-04	8.85E-05
F'3	135 mph	2.84E-05	2.16E-05
F'4	168 mph	6.77E-06	5.63E-06
F'5	209 mph	1.14E-06	1.08E-06
F'6	277 mph	5.95E-08	5.95E-08

Figure 4-1 – Example Tornado Hazard Curve



5 EVALUATE TARGET AND MISSILE CHARACTERISTICS

New failure modes for SSCs that can be struck and damaged by a tornado missile will be added to the TMRE PRA model. This applies to SSCs that are required by the plant's licensing basis (nonconformances), as well as those SSCs that are not required to be protected, but are in the TMRE PRA model (vulnerabilities). Tornado missile failures do not need to be considered for SSCs protected by 18" reinforced concrete walls, 12" reinforced concrete roofs, and/or 1" steel plate. These thicknesses provide sufficient protection against direct strikes from tornado missiles to allow screening of these non-conforming SSCs (see Section B.6.3). However, this screening does not change the Plant Licensing Basis or allow future modifications to use a design thickness inconsistent with the Licensing Basis.

The failure probability of exposed SSCs is calculated using the Exposed Equipment Failure Probability (EEFP). The EEFP is the conditional probability that an exposed SSC is hit and failed by a tornado missile, given a tornado of a certain magnitude. For every applicable SSC, five EEFP values will be calculated, one each for tornado categories F'2 through F'6.

The EEFP is defined as:

EEFP = (MIP) x (# of Missiles) x (Target Exposed Area) x Fragility

The Missile Impact Parameters (MIP) is the probability of a tornado missile hit on a target, per target square area, per missile, per tornado (see Section 5.1). Generic MIP values are provided as part of the TMRE methodology and are described in more detail in Section 5.1 and Appendix B; MIP values are in Table 5-1. The MIP varies by the tornado category (i.e., F'2 through F'6) and the elevation of the target.

# of Missiles is the number of damaging missiles within about 2500 feet of the target SSCs. Generic values for the number of missiles (which vary by tornado intensity) are provided as part of the TMRE methodology and will be verified through the TMRE walkdown activity (Section 3). Some targets that are more robust (e.g., steel pipes and tanks) will use different missile inventories than less robust SSCs (e.g., electrical panels, instrumentation), since only certain types of missiles can damage robust targets. The missile inventories to use for each target SSC (depending on robustness) are described in Section 5.2 and Appendices B and C; and listed in Table 5-2. Generic total missile inventories are listed in Table 5-1 for each tornado category, F'2 through F'6.

Target Exposed Area (ft^2) is determined for each specific SSC, based on plant documentation and the TMRE walkdown. More information on calculating target areas is provided in Section 5.3.

Fragility is the conditional probability of the SSC failing to perform its function given that it is hit by a tornado missile. For the purposes of the TMRE, it is assumed to be 1.0 (i.e., the SSC is always failed if hit by a tornado missile).

NOTE: The variables and factors included in the EEFP were developed to provide a conservative estimate of SSC failure probability. The values provided in this guidance for the *MIP*, *# of Missiles* and *Fragility* variables were developed to be used together, and should not be modified. The conservatism in the EEFP is dependent on using the recommended values for all these variables. Each variable may not be conservative by itself, but the combination of variables used for different targets and tornado wind speeds is expected to provide a bounding estimate of the change in CDF associated with nonconforming SSCs. Appendices B and C provide the basis for the variables and Appendix A provides the results of benchmarking the TMRE against two RG 1.200 High Winds PRAs. Deviation from the recommended values could invalidate the benchmarking and result in non-conservative EEFPs and, hence, non-conservative ΔCDF and ΔLERF results. Therefore, all EEFP values described in this section must be used without modification, except for:

1. The total number of missiles, which may be increased if necessary based on the site-specific missile inventory.

2. The <30 ft MIP value can be used in cases where it is difficult to determine if the target is >30 ft above the reference elevation.

3. When taking credit for robust targets, a higher percentage can be used.

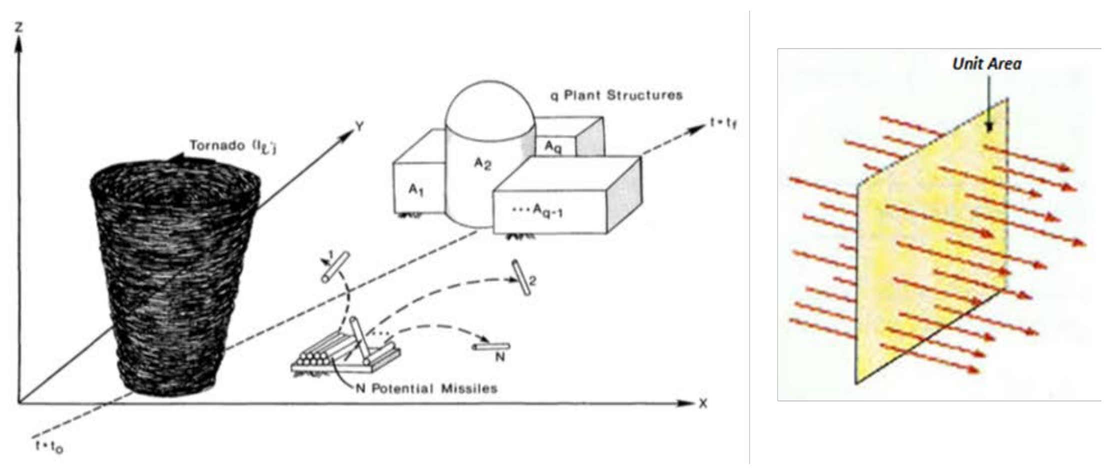
4. A target EEFP can be set to 1.0 to preclude performing a detailed analysis of target area, shielding, etc. If this is done, the impact of compliant case conservatisms should be addressed (see Section 7.2.3).

5.1 MISSILE IMPACT PARAMETER (MIP)

The *Missile Impact Parameter (MIP)* is defined as: The probability of a tornado-driven missile impact on an SSC per unit area of the SSC, per missile, per tornado. It can be thought of as the missile flux through a unit area, as shown in Figure 5-1.

MIP = Probability of Missile Hit / ft² / missile / tornado

Figure 5-1: Missile Impact Parameter



Generic MIP values are provided in Table 5-1 for use in the TMRE; the MIP values were developed to be applicable to all U.S. NPPs. MIP values were derived using published TORMIS data from EPRI NP-768 [Ref. 5.1]. The bases for the MIP values developed for the TMRE are provided in Appendix B.

MIP values vary with tornado intensity (i.e., F'-Scale) and the elevation of target. Separate MIP values are provided for each F'-Scale tornado from F'2 to F'6. As expected, MIP values generally increase with increasing tornado intensity, since the higher category tornadoes are expected to lift more missiles and make them airborne.

Separate MIP values are also provided for 'Near Ground' and 'Elevated' targets. Near Ground targets are less than or equal to 30' above the associated reference elevation, while elevated targets are those greater than 30' above the associated reference elevation. The MIP values for Near Ground targets are greater than for Elevated Targets. This is expected, since heavier missiles are less likely to be raised to higher elevations in the tornado wind field, and thus the number of missiles per unit area is lower for higher elevations.

Plant grade is typically chosen as the reference elevation. However, areas within the 2500 foot analysis radius having a higher elevation than plant grade must also be considered as a potential reference. In order to determine if the reference elevation should be plant grade or if a higher elevation should be used for a given target or set of targets, engineering judgment should be used to develop a reference elevation considering the following: distance of the elevated area from targets, trajectory from the elevated area to targets, percentage of total missiles contained within the elevated area, and types of missiles contained within the elevated area. Elevated portions of structures (e.g. 2nd level, roof) do not need to be considered as an "elevated area" in and of themselves if the primary source of missiles is structural in nature, including siding. However, structures situated on a surface above grade elevation should be discussed or otherwise included in missile count considerations. A plant may choose to use a higher elevation as the reference elevation without deviating from the methodology. The reference elevation and justification for choosing the value shall be documented.

Table 5-1: MIP Values and Missile Inventories for Use in the TMRE

Tornado Category	**Targets >30' above grade[1,2]**	**Targets ≤30' above grade[1,2]**	**Total Missile Inventory[3]**
F'2	5.8E-11	1.4E-10~~1.1E-10~~	155,000
F'3	2.0E-10	4.6E-10~~3.6E-10~~	155,000
F'4	3.4E-10	7.9E-10~~6.3E-10~~	205,000
F'5	8.7E-10	2.0E-09~~1.6E-09~~	240,000
F'6	1.3E-09	3.1E-09~~2.4E-09~~	240,000

(1) MIP values are in units of missile hit probability / ft^2 / missile / tornado

(2) The term grade here is meant to refer to the reference elevation. Typically, this is plant grade, although for some targets it may be different.

(3) Total Missile Inventory values in this table shall be used, unless the site-specific missile inventory is not bounded by 240,000 missiles. See Section 5.2 for more discussion of missile inventories.

5.2 Missile Inventories

Generic missile inventories are provided as part of this guidance for use in calculating EEFPs at all US NPP sites. Values are provided in Table 5-1, which are expected to be bounding for most sites. The total number of missiles will require verification through the TMRE walkdown (Section 3.4), to ensure that the missile inventories provided herein are appropriate to use for a specific plant.

The generic total number of missiles is 240,000. Since the origins of many of the missiles are from building deconstruction, which varies with tornado intensity, the total missile count varies with tornado intensity. Table 5-1 provides the total missile inventory by F'-scale. If the site walkdown confirms that 240,000 is bounding for the site[5] (see Section 3), then the variable *#Missiles* in the EEFP calculations is equal to the values provided in Table 5-1, for targets not defined as 'robust.' Robust target types are listed in Table 5-2 and the percentage of the total number of missiles for each robust target type is provided. These percentages are applied to the total number of missiles at each F'-scale, to reduce the missiles that are used in robust target EEFP calculations. The bases for the total number of missiles and the robust missile inventories are provided in Appendices B and C.

If the total missiles at a site are not bounded by 240,000, the number of missiles to use in the EEFP calculations (for targets that are not robust), should be the total number of missiles counted on site, rounded up at least to the nearest 5,000 missiles. For tornadoes below F'6, the calculations of structure-origin missiles can be determined using the fractions provided for the different building types (see Appendix C). The same robust target percentages provided in Table 5-2 are applied to the site-specific missile count.

5.2.1 MISSILE INVENTORY EXAMPLE

As an example, assume that a licensee performs a site missile inventory walkdown and determines that there are 291,000 missiles within 2500' of a central reference point, based on the guidelines provided in Section 3.4. The missiles consist of 91,000 zonal missiles (not associated with structures) and 200,000 structural missiles, based on calculations using Tables 3-3 through 3-8. The licensee chooses to assume 300,000 total missiles onsite. This is the missile inventory applied to the F'6 tornado EEFP calculations. Lower intensity tornadoes will have smaller inventories, based on the number and type of structures that contribute to the structural missiles. For the purpose of this example, the total missile inventory is:

- 100,000 zonal missiles (rounded up from 91,000)
- 200,000 structural missiles, consisting of:
    - 50,000 missiles from wood-framed buildings
    - 50,000 missiles from pre-manufactured buildings
    - 100,000 missiles from engineered and pre-engineered buildings

Figures 16, 17 and 18 in Appendix C provide missile release fractions for each intensity tornado. The fractions are presented in Table 5-1a as percentages.

[5] The site may be either a single unit or multi-unit site; there is no distinction in the total number of missiles based on the number of units at a site.

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Table 5-1a: Missile Release Fractions for Different Building Types

Tornado Intensity	Building Type		
	Wood-framed	Pre-manufactured	Engineered and Pre-engineered
F'2	10%	35%	1%
F'3	73%	95%	44%
F'4	96%	100%	77%
F'5	100%	100%	92%
F'6	100%	100%	100%

Based on these fractions and the number of missiles from each structure type, the missile inventories for each tornado intensity are calculated in Table 5-1b. These missile inventories would be used in the EEFP calculations for the example site.

Table 5-1b: Example Missile Inventory Calculation

Tornado Intensity	Zonal	Number of Missiles			
		Building Type			
		Wood-framed	Pre-manufactured	Engineered and Pre-engineered	Total
F'2	100,000	5,000	17,500	1,000	123,500
F'3	100,000	36,500	47,500	44,000	228,000
F'4	100,000	48,000	50,000	77,000	275,000
F'5	100,000	50,000	50,000	92,000	292,000
F'6	100,000	50,000	50,000	100,000	300,000

Note that robustness depends on the dimensions (primarily thickness, but also diameter for pipes) of the target and target failure mode. For each robust target, documentation should be provided justifying the robust category used for the target. If the target does not meet the specifications for any of the robust categories, the total number of missiles should be used to calculate the EEFP for that target.

Table 5-2: Missile Inventories for EEFP Calculations

Category	Target Description	Failure Mode	Percentage of Total Missiles
A	Steel Pipe – at least 16” diameter and 3/8” thickness	Crushing/Crimping of > 50%	5%
B	Steel Pipe – at least 16” diameter and thickness less than 3/8” but at least 0.125”	Crushing/Crimping of > 50%	55%
C	Steel Tank – at least 0.25” thickness	Penetration or Global Failure	40%
D	Steel Tank – less than 0.25” thickness	Penetration or Global Failure	50%
E	Steel Pipe – at least 10” diameter and 3/8” thickness	Penetration or Global Failure	35%
F	Steel Pipe – Less than 10” diameter or 3/8” thickness	Crushing/Crimping, Penetration, or Global Failure	50%
G	Steel Door	Penetration or Global Failure	45%
H	Concrete Roof – Reinforced, at least 8” thick	Penetration or Global Failure	1%
I	Concrete Roof – Reinforced, at least 4” thick	Penetration or Global Failure	20%
J	None (i.e., not a ‘robust’ target)	Any/All	100%
~~K~~	~~Concrete Wall – Reinforced, at least 12” thick~~	~~Perforation or Global Failure~~	~~0.5%~~
~~L~~	~~Steel Grating – At least 2” thick, bars at least 3/8”, bar opening less than 1” wide~~	~~Global Failure~~	~~10%~~
~~M~~	~~Steel Grating – At least 4” thick, bars at least 3/8”, bar opening less than 1” wide~~	~~Global Failure~~	~~1%~~

Failure modes listed in Table 5-2 are described:

- Crushing/Crimping of >50%: The pipe is crushed such that the flow area through the pipe is reduced no more than 50% of the original flow area. This failure mode would be used primarily for exhaust pipes (e.g., for diesel generators, steam relief valves).
- Penetration: Refers to localized perforation (or punching shear) and is dependent on pipe (or wall) thickness, rather than structural response of a pipe, tank, or concrete panel. Appendix C describes the empirical equations that are used for predicting this failure mode.
- Global Failure: Refers to the overall flexural response (or bending) of pipes, tanks, and concrete panels. These ‘global’ modes are influenced by structural section properties (wall thickness, diameter, etc.) as well as member span and boundary conditions. Appendix C describes the analytical models developed to predict deformations of pipes, tanks, and concrete panels

Ensure that credit is not taken for beneficial failure modes of SSCs struck by tornado missiles. For example, do not consider that an exhaust pipe will shear before being crimped, unless it is true for all missile types at all speeds. Exceptions are SSCs designed to fail to prevent an adverse failure mode (e.g., turbine building siding coming off to prevent structural failure, plastic piping designed to break/shear as opposed to being crushed).

Some examples for determining missile inventories for use in EEFP calculations, based on the type of component and results of the site-specific missile inventory, are provided in Table 5-3.

Table 5-3: Example Missile Inventories for Different Targets
(For F'6 Tornado EEFP Calculations)

No.	Target Description	Robust Target?	Failure Mode	Robust Category	#Missiles for EEFP(1)
1	Electrical panel	No	NA (Hit)	NA	240,000
2	Level Detector/Indicator	No	NA (Hit)	NA	240,000
3	Ventilation Fan	No	NA (Hit)	NA	240,000
4	Emergency Diesel Generator Exhaust Pipe: 16" diameter, 3/8" thick steel	Yes	Crimping/ Crushing >50%	A	12,000 (5% of 240,000)
5	Condensate Storage Tank: 3/8" thick steel	Yes	Penetration	C	96,000 (40% of 240,000)
6	Service Water Piping: 6" diameter, 3/16" thick steel	Yes	Penetration	F	120,000 (50% of 240,000)
7	Reinforced Concrete Roof: 6" thick	Yes	Penetration	I	48,000 (20% of 240,000)

(1) If 240,000 Total Missiles is not bounding, use site specific missile inventory for total missiles (robust percentages can still be applied).

5.3 Target Exposed Area

The *Target Exposed Area* is the area (ft^2) of an SSC that is exposed to being struck by a tornado missile (i.e., that has no or inadequate missile protection[6]) which can result in the failure of the SSC. Thus, it must be (1) exposed to tornado missiles and (2) if struck, will prevent the SSC from performing its function as modeled in the PRA. This section provides details on various types of SSCs and how their Target Exposed Area should be calculated for the EEFP.

5.3.1 Types of Targets and Calculations

The types of SSCs that should be considered vulnerable to tornado missile failures are those not located inside Category I structures. If an SSC is shielded by walls with 18" of reinforced concrete, roofs with 12" of reinforced concrete, and/or 1" of steel plate, no EEFP calculations are required (see Appendix B). Note that some SSCs inside Category I structures may still be vulnerable to tornado missiles from

[6] See Section 5.3.2 for a discussion of target shielding.

missiles entering through openings or penetrations in the walls or roofs of such structures. Additionally, roofs that are less than 12" thick reinforced concrete will also allow some missile penetration. These situations are discussed further in this subsection.

Some examples of the types of SSC exposed to tornado missiles are discussed here. For exposed SSCs outside Category I structures, the target area can generally be estimated using the smallest polyhedron(s) that encompasses the target. For SSCs inside Category I structures that can be hit by tornado missiles entering through a non-qualified penetration (e.g., access door, ventilation louver), the target area is the either the area of the opening or the area of the target (based on an encompassing polyhedron), whichever is smaller.

<u>Tanks</u>

The simplest, yet most conservative, approach for modeling a tank is to define a polyhedron that bounds the dimensions of the tank and its subcomponents (i.e., exposed tank discharge piping and valves, level detectors and indicators, or other critical SSCs associated with the tank).

A more refined method would model a tank as a cylinder, such that the surface area calculation for the tank is straightforward (i.e., Area = πdh, where d is the diameter and h is the height of the tank). The top of the tank can generally be neglected, since it would (1) require a vertical missile to penetrate the top of the tanks and (2) require the missile, having penetrated the top of the tank, to affect suction from the tank. Additional area should be added for critical SSCs or subcomponents associated with the tank. Note that some SSCs associated with a tank, such as a level detector cannot be considered as a robust target, so the total missile inventory would be used in the EEFP for that portion of the tank's total failure probability. Example 1 in Section 5.5 includes associated SSCs in the tank area calculation.

Since tanks may be more than 30 feet in height, the total tank failure probability can be calculated by summing the tank failure probability (EEFP) from near ground missile strikes (i.e., $\leq$30') with the EEFP from elevated missile strikes. Since the MIP values for elevated targets (>30') are less than the near ground MIP values, this will reduce the overall failure probability of the tank. Alternatively, different basic events for the near ground and elevated strikes may be developed.

Similar to excluding the top of the tank, portions of the tank above the normal water level or above the success criteria minimum water level (for the applicable event sequence(s)) can be excluded from tank failure probability calculations. If a missile were to penetrate the tank above the minimum required water level, the tank would still contain the volume of liquid needed for success.

For tank failure due to vertical missiles penetrating the top of tank or the side of a tank above the water level is that the missile, the analyst should consider whether such a missile can cause some failure of the tank suction after penetrating the tank. Missile velocity, even for very energetic missiles, decreases significantly after travelling through only a few feet of water, so the main concern would be plugging of the suction. Although this is considered unlikely, the analyst should qualitatively evaluate the potential.

An example of the lower part of a condensate storage tank is shown in Figure 5-2. The following are items of interest:

- The piping connected to the outside of the tank is the suction source for the pumps fed from the CST. If this exposed pipe or the isolation valve is damaged by a tornado missile, the tank would not perform its function to provide a water supply. Therefore, the EEFP associated with the piping and valve would need to be included in the total failure probability for the tank. Even if a polyhedron were drawn around the piping and the valve, it would not add much to the total area of the tank.

- The equipment highlighted by the red outline is a sample connection with heat tracing to keep it from freezing. If the sample connection were struck and sheared off, it would produce a leak in the tank. However the connection does not protrude much from the tank, and if that area of the tank were hit by a damaging missile, it would be considered to fail. So, this additional part of the tank could be neglected in the area calculation. Documentation would be expected to describe the basis for excluding the target.
- A pair of drain valves in series is protruding from the bottom of the tank and highlighted by a green outline. If the piping and valves were sheared off, this would result in draining the tank.
- A junction box and conduit for tank grounding are highlighted by a yellow outline. Failure of this equipment would not affect the PRA functionality of the tank.

Figure 5-2: Example Tank

Pipes

Pipes are similar to tanks, in that they can be considered cylindrical targets, such that Area = πdl, where d is the diameter and l is the length of pipe being considered. The analyst should determine whether exposed pipe ends (e.g., open exhaust pipe ends) should be considered in the area of the pipe. If exposed sections of pipes include additional SSCs that are required to function or not be failed, their failure probability should be added to the pipe failure probability. In some cases, these additional SSCs would not be considered robust (e.g., valve operators, flow detectors) and the total inventory of missiles would be used for that portion of the pipe's total failure probability. Manual and check valves can generally be considered robust, in the same category of the pipe. The analyst should document any assumptions regarding valves and other components associated with piping targets.

An example of exposed service water piping (the light blue colored pipe) is shown in Figure 5-3. Most of the surface area of this pipe could be hit by a tornado missile. However, an argument could be made that some portions of the piping (e.g., on the very far right of the picture) are very close to either the ground or a wall, and thus may not truly be exposed to a credible tornado missile flux. In such cases, a small portion of the pipe surface area may be excluded from EEFP calculations, although it is unlikely to result in a meaningful reduction. Any such reduction to the effective surface area must be documented with the engineering judgment used.

Figure 5-3: Example Piping

<u>Pumps/Compressors/Fans</u>

If a pump (or compressor or fan) and/or its subcomponents are exposed, the simplest solution is to consider a polyhedron(s) that encompasses the pump, motor, electrical subcomponents (e.g., cables, junction boxes, controllers), and any other exposed subcomponents whose failure would result in the failure of the pump. Although many pumps are typically sturdy and can withstand some mechanical shocks, the pump/compressor/fan and its subcomponents are considered not robust from the missile inventory perspective (i.e., the total missile inventory should be used in the EEFP). The surface area encompassing the pump/compressor/fan and its subcomponents should be relatively small, resulting in a relatively low EEFP. However, the licensee may perform more detailed calculations using the surface area of individual components.

An example of an exposed air compressor, its subcomponents, and support components is shown in Figure 5-4. This air compressor is inside a Category I building but is directly exposed to tornado missiles through a large 12' x 24' (288 ft^2) roll-up door in the building. If the compressor, any of its subcomponents, or the electrical and cooling water supports are struck by a damaging tornado missile, the compressor would not function. Therefore, a polyhedron encompassing all those SSCs would be used to determine the *Target Exposed Area* for the compressor EEFP. The bottom of the polyhedron would be excluded from the *Target Exposed Area* calculation since it is the floor of the building and a missile cannot hit the SSCs from the direction of the floor. Consideration could also be given to not including the far side of the compressor, from which missiles would not travel (the compressor is being viewed from the opening).

Figure 5-4: Example Air Compressor with Subcomponents

Valves

Although valve bodies and their connections to piping are generally robust, their operators, actuators, and support systems (e.g., instrument air, electrical power) are not. When calculating the target area for a valve, all the exposed subcomponents and applicable support components (e.g., solenoid valves, controllers, cables, instrument air tubing) need to be included in the total valve area. When determining the number of missiles, the full missile count can be used for the combined components and subcomponents, or the calculation can be refined to apply the correct missile counts to individual components. It is important to understand the impact of the failure of support systems on the desired function of the valve. If failure of the support system does not cause a functional failure of the valve, components associated with the support system do not need to be included in the total area used for the valve in the EEFP.

Targets Located Inside of a Category I Structure

Some targets located inside of a Category I structure may be vulnerable to missile hits due to openings in the structure that are not missile barriers or due to roofs that are less than 12” of reinforced concrete (see Appendix C for the basis of required roof thickness). In cases such as these, the target would be considered the surface area of the opening (e.g., door, ventilation louver, piping penetration) through which a missile can travel and strike the SSC in question. For roofs with SSCs below them, the target dimensions should be projected vertically to an area of the roof that is directly above the SSC or its subcomponents.

If the exposed area of a target inside the Category I structure is smaller than the opening through which a missile must pass to strike the target, then the exposed area of the target, when approached from the direction of the opening, should be used. Therefore, the area for vulnerable targets inside Category I structures should be the smaller of the area of the opening or the area of the target itself.

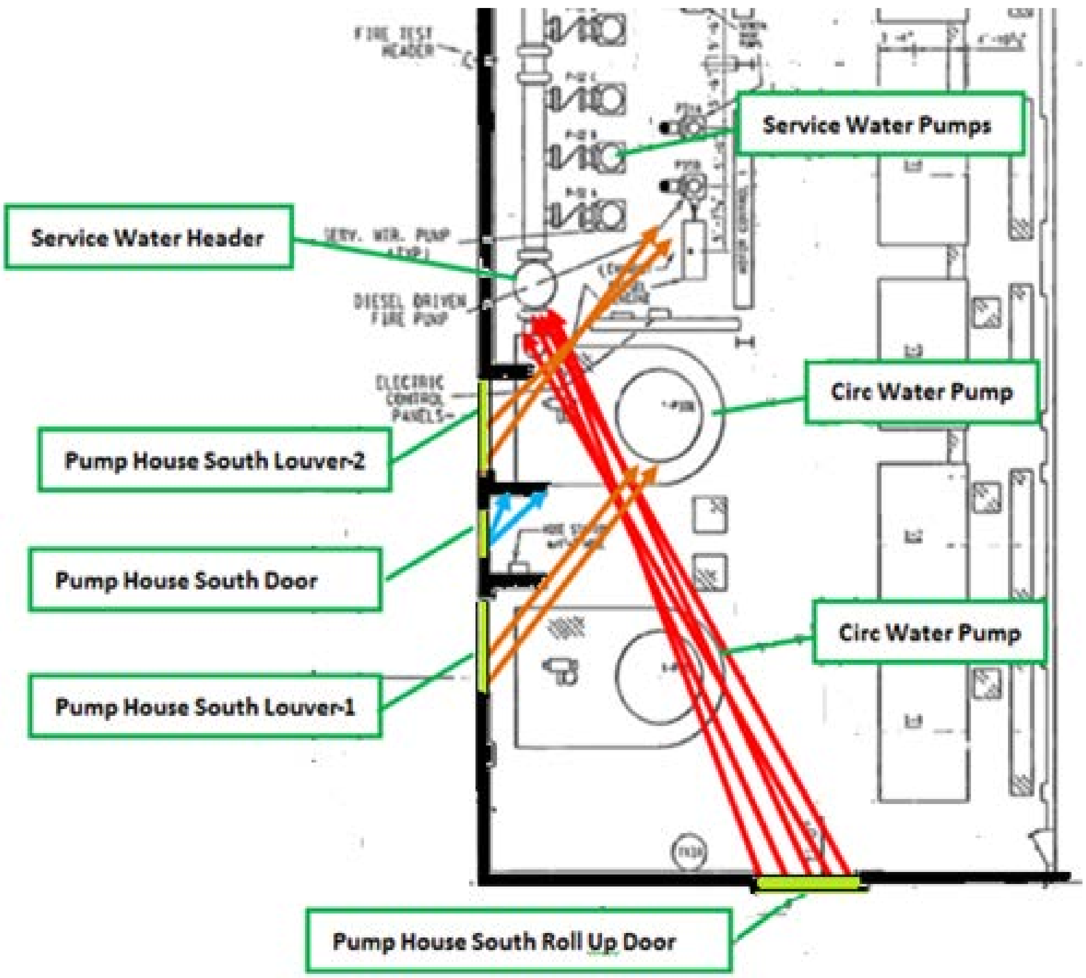
Figures 5-5 through 5-7 provide an example of targets (service water pumps and piping) inside a Category I pump house with unqualified openings (ventilation louvers, a personnel door, and a rollup door). Figure 5-5 shows the outside of the pump house; the light blue rollup door is made of thin sheet metal. Another view is shown in Figure 5-6; this view highlights the large ventilation louvers/openings. The rollup door and louvers will not stop most types of damaging tornado missiles.

Figure 5-5: Example of Service Water SSCs' Missile Exposure from Openings in Service Water Pump House

Figure 5-6: Example of Service Water SSCs' Missile Exposure from Openings in Service Water Pump House

Figure 5-7 shows examples of missile paths through the various openings in the pump house. As seen in this figure, intervening structures (walls and partitions) inside the pump house prevent missiles from the openings on the south side of the building from striking the service water header or pipes (missile paths shown in orange and blue lines). The only exposure of the service water SSCs to missiles is from the rollup doors (indicated in red lines), impacting the service water header. The exposed area of the service water header and supporting subcomponents (e.g., electric cables for isolation valves) is larger than the area of the roll-up door opening. The exposed area could be reduced, taking into account the circulating water pumps between the rollup door and the service water SSCs. However, unless it can be shown by additional analysis, those pumps may not provide a substantial barrier to prevent a missile from striking the service water header. Therefore, in this example, the area considered for the exposed service water system header would be the area of the rollup door.

Figure 5-7: Example of Service Water SSCs Missile Exposure from Openings in Service Water Pump House



Pumphouse Missile Path Through Louvers, Doors, and Roll-Up Doors

The service water pumps and piping inside a pump house (on the top left of Figure 5-7) are also vulnerable to vertical missiles striking the roof above them. The roof thickness for this pump house is less than 12" of reinforced concrete, which would allow missile penetration and potential damage to the service water SSCs. Therefore, they should be considered targets for vertical missiles. Example 3 in Section 5.5 describes modelling of these targets.

5.3.2 Target Shielding

When considering shielding in the context of the TMRE and EEFP, the analyst must consider all reasonable paths by which a tornado missile can strike an SSC. Unlike some design basis considerations, missiles are not limited to horizontal flight paths. Missiles can strike a target from essentially any angle, so that shielding, such as parapet walls or other horizontal missile protection, would not be considered complete shielding. Some targets may be shielded from all but vertical missiles.

Obviously, a missile cannot strike the portion of an SSC that is against the ground or a missile barrier, so those surfaces of an SSC would not be considered in the *Target Exposed Area* calculation. However, partial shielding is possible for SSCs that may be close to the ground or a missile barrier. For example, the portions of the service water piping shown on the far right side of Figure 5-3 could be considered partially shielded from missile originating from below or behind the piping (the pipe is very low to the ground and close to a solid wall behind it). This could be used to reduce the area of the pipe in the EEFP calculation.

Targets may be shielded from tornado missiles from specific directions, based on the location of the target with respect to other SSCs and barriers. The effect of shielding can be accounted for by use of the robust missile factors in Table 5-2 or by reducing the effective target surface area.

SSCs or other intermediate barriers blocking missile paths to a target can be considered as shielding or barriers, by considering the equivalent steel or concrete thickness. For the shielded portion of the target only, this would allow for a reduction in effective missiles. For example,

- Heat exchangers could provide the equivalent thickness of a steel door (category G in Table 5-2, which is equivalent to 0.1" of steel).
- Reinforced concrete walls or columns that are 12" thick could provide the equivalent thickness of 4" thickness roof (Category I of Table 5-2) for F'2 intensity only (wind speed below that used for vertical missile impact to roofs in Appendix C
- The sum of multiple intervening roof, floor, or wall thickness can be considered when screening a target or using of robust percentages (such as a 12" and 6" wall protecting a target is equivalent to an 18" wall)

SSCs may be shielded from missile strikes from certain directions, reducing the effective target area by excluding target surfaces or portions of surfaces. For example,

- A target located near large Class I structures that would preclude missiles from striking the targets from certain directions (e.g., piping or conduit mounted on a wall, exhaust stack located next to parapet wall, tank adjacent to a Class I building). In this case, the portion of the target shielded by the Class I structure would not be included in the target area calculation.
- Piping and supports could reduce the effective area of an opening or penetration, if the piping and support thickness is at least 1" of steel.

The basis for crediting shielding in reducing target surface area or providing equivalence to other robust targets/barriers should be justified and documented on a target-specific basis.

~~Submerged Targets~~

~~Submerged targets present a special case of tornado missile shielding. Submerged targets are shielded by water, significantly reducing the target exposure to damaging missiles. For a tornado missile to strike a target located underwater, it must:~~

- ~~Strike a particular area ('window') on the surface of the water that will allow it to hit the target, after travelling through the water from the point of entry~~
- ~~Strike the surface of the water at an orientation and trajectory that will allow it to hit the target, after traveling through the water from the point of entry~~
- ~~Maintain its integrity and shape after striking the surface of the water, so that it can travel on the correct trajectory through the water and hit the target~~
- ~~Be of sufficient energy to damage the target after striking the water surface and traveling through the water~~

~~The dynamics of missiles striking the water surface and traveling some distance through water is a complex function of the missile characteristics and target location. With the exception of missiles that have only a vertical velocity component striking the water directly above a submerged target, it is difficult to evaluate the likelihood that a submerged target can be struck and damaged by a tornado missile.~~

~~The EEFP calculation uses the MIP to determine the likelihood of a missile striking a target. The MIP is based on missiles traveling through the air and striking a target at any orientation or velocity. The calculation of a submerged target EEFP using the TMRE method is extremely conservative in nearly all cases. Thus, the TMRE methodology allows for the effective shielding of water on submerged targets to be evaluated qualitatively to support screening on a target-specific basis. The effective EEFP of nearly all submerged targets are expected to be very low, making such targets not risk significant. Generic bases for addressing submerged targets are presented in Appendix A. The generic discussions provided in Section A.8 should be supplemented with target-specific characteristics to support screening submerged targets. This generic screening discussion applies to submerged targets in which can only be struck by tornado missiles with trajectories containing both horizontal and vertical trajectory components (i.e., travel at an angle other than 90 degrees from the water surface)~~

~~Target-specific considerations include:~~

- ~~Target depth~~
- ~~The amount of water a missile must travel through to strike the target~~
- ~~Target size~~
- ~~Target robustness~~
- ~~Specific trajectories needed to hit the target~~
- ~~Intervening objects or barriers (e.g., screens, grates)~~
- ~~Location of target with respect to missiles~~

5.3.3 Target Elevation

Different MIP values are provided for Near Ground and Elevated targets in Table 5-1; the differences in MIP values due to target elevation are described in Section 5.1. For targets located completely above or below 30', the use of the correct MIP value will account for the likelihood that elevated targets are less likely to be hit by tornado missiles.

However, some tall targets, such as tanks, can span both elevation regions. For example, the tank in Figure 5-2 is approximately 36' tall. Therefore, approximately 17% of the tank is above 30' and the EEFP calculation can account for this by using the Near Ground MIP for the first 30' of the tank and the Elevated MIP for the last 6'. This will reduce the EEFP as compared to assuming that the entire tank area is associated with the Near Ground MIP, which is approximately a factor of 2 lower in the F'2 to F'4 range.

5.4 Target Fragilities

For the purposes of the EEFP, the fragility of an SSC is the conditional probability of the SSC failing, given that it is hit by a tornado missile. For the TMRE, all target fragilities are assumed to be 1.0. This is one of the factors that results in conservative EEFP calculations, as compared to the missile-induced failure probability of an SSC calculated in a HW PRA. This is especially true for more rugged SSCs at lower tornado intensities, where the expected failure probability is lower than at higher tornado intensities. However, some accounting for robust target fragilities is implied in the use of lower missile populations for robust targets.

5.5 Exposed Equipment Failure Probability (EEFP) Examples

Recall that the EEFP is defined as:

EEFP = (MIP) x (# of Missiles) x (Target Exposed Area) x Fragility

> *The Missile Impact Parameters (MIP)* are provided in Table 5-1. There are separate MIP values for each tornado category F'2 through F'6, and the MIP value also depends on the target elevation.
>
> Bounding values for *# of Missiles* are provided in Table 5-1, with different values for each tornado category F'2 through F'6. The missile inventories in Table 5-1 are total missiles, used for non-robust targets. For robust targets, a fraction or percentage of the total missiles that can damage each category of robust targets is provided in Table 5-2. The different categories are based on the target characteristics (e.g., thickness of steel). If the bounding values in Table 5-1 are not applicable to the plant, Section 5.2 provides instruction on how to use a site-specific inventory.
>
> *Target Exposed Area* is determined for each target based on the guidance provided in Section 5.3.
>
> *Fragility* is equal to 1.0.

Each SSC will have a separate EEFP for each tornado category F'2 through F'6. How this is accomplished depends on the method by which tornado missile failures are incorporated into the PRA model, as discussed in Section 6.5. The only difference between the EEFP values for the different tornado categories will be the MIP values and the number of missiles, the exposed area and fragility will be constant between tornado categories.

As described in Section 5.3, an SSC failure probability for a given tornado category may be the sum of multiple EEFPs, based on the complexity of the target area calculation. For example, a tank may include sections above and below 30' elevation. Another example would be an exposed pump that has an exposed motor controller, which is not adjacent to the pump.

The examples provided in this section include configurations that require multiple EEFP calculations for an SSC, per tornado category.

Example 1: Condensate Storage Tank from Figure 5-2. Calculate EEFP for F'2 tornadoes

This is a steel tank with the following dimensions: Diameter (d) = 40'; Wall Thickness = 3/8" at the bottom, tapering to 1/4" at the top; Height above grade (h) = 36'; Height of Water at Minimum Required Water Level (above grade) = 24'.

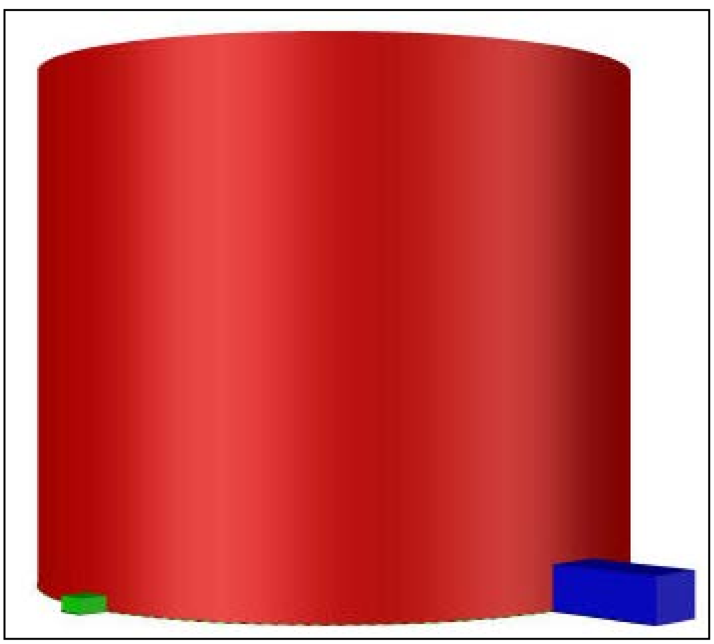
The components and subcomponents associated with the CST are:

Steel Pipe: 6" diameter, 3/8" thick, 8' long with a manual valve. This will be modeled as a rectangular polyhedron (blue box) in Figure 7-8.

Sample connection with heat tracing (highlighted by red outline in Figure 5-2). This is a very small target protruding less than 6" from the tank and the sample line is only ½"; if the tank were struck by a damaging missile in this area, the tank would be considered failed. Since it will add an inconsequential area to the tank if modeled and will not necessarily cause tank failure, it is excluded for simplicity.

Drain Valves (highlighted by green outline in Figure 5-2). These are also small targets, but they are larger than the sample connection protruding out from the tank by about 2'; they will result in significant water loss if they are sheared off by a tornado missile. The drain valves will be modeled as a rectangular polyhedron (green polyhedron) in Figure 5-8.

Figure 5-8: Simplified View of CST



EEFP1: Lower portion of the tank, from grade to 30' above grade.

Use Near to Ground MIP ($\leq$ 30') and missile inventories based on Table 5-1 and Category C from Table 5-2.

Area1 = πdh = π*40*30 = 3770 ft^2

EEFP1(F'2) = ~~1.1~~1.4E-10*(40%*155,000)*3770 = ~~2.6~~3.3E-2/tornado

EEFP2: Upper portion of the tank (30' – 36').

Use Elevated MIP (>30') and 25,000 missile inventories based on Table 5-1 and Category C from Table 5-2.

$Area^2$ = πdh = π*(40)*(36-30) = 754 ft^2

EEFP2(F'2) = 5.8E-11*(40%*155,000)*754 = 2.7E-3/tornado

EEFP3: Piping extending out from tank (blue box).

Use Near to Ground MIP ($\leq$ 30') and missile inventories based on Table 5-1 and Category F from Table 5-2. Manual valve is robust, assume the same level of robustness as the pipe. Bound pipe with a polyhedron with length(l) = 8', width(w) = 4' and height(h) = 4'.

Area3 = 2lh+wh+lw = 2*8*4 + 4*4 + 8*4 = 112 ft^2

EEFP3(F'2) = ~~1.1~~1.4E-10*(50%*155,000)*112 = ~~9.5E-4~~1.2E-3/tornado

EEFP4: Drain Valves (green box).

Use Near to Ground MIP ($\leq$ 30') and missile inventories based on Table 5-1 and Category F from Table 5-2. Manual valves are robust, equivalent to the pipe size (4" diameter x 3/8" thick). Pipe and valves bounded by box with length(l) = 2', width(w) = 1' and height(h) = 1'.

Area4 = = 2lh+wh+lw = 2*2*1 + 1*1 + 2*1 = 7 ft^2

EEFP4(F'2) = ~~1.1~~1.4E-10*(50%*155,000)*7 = ~~6.0~~7.6E-5/tornado

Therefore, the total failure probability of the CST for an F'2 tornado is:

EEFP(F'2) = EEFP1(F'2) + EEFP2(F'2) + EEFP3(F'2) + EEFP4(F'2) = ~~3.0~~3.7E-2/tornado

The bottom 30' of the tank is the primary contributor to the total EEFP (nearly 90%), due to the area of the tank. The EEFP for the piping protruding from the tank is about ½ the EEFP for the upper part of the tank, even though the upper part of the tank is nearly 6x the area. However, the EEFP for the upper part of the tank makes use of a lower MIP (due to elevation) and lower missile count (tank more robust than the piping). Finally, the drain valves contribute less than 0.5% to the total EEFP. This validates the decision to not include the sample connection in the total EEFP calculation.

Since the tank only needs to be filled to 24' above grade to provide adequate water supply, the tank area could be reduced by assuming that only the first 24' of the tank elevation above grade will result in failure if struck by a tornado missile. This would reduce EEFP1 and eliminate the need for calculating EEFP2, reducing the total EEFP for F'2 to ~~2.2~~2.6E-2/tornado, a 25% reduction.

Example 2: Air Compressor from Figure 5-4. Calculate EEFP for F'2 tornadoes

In calculating the target exposed area for the air compressor in Figure 5-4, an assumption is made that if any part of the compressor, the motor, electrical support equipment (e.g., control panel, wiring), cooling water piping, or compressed air piping is struck by a tornado missile, the compressor will fail. A simple way to model the compressor and its subcomponents would be to create a single rectangular polyhedron that encompasses the entire assembly, with additional areas to represent the cooling water and compressed air piping, as shown in Figure 5-9. The red box represents the compressor, motor, and attached subcomponents. The cooling water piping is the blue shape, the air inlet pipe is green, and the air discharge pipe is yellow.

Drawings were consulted and field measurements were taken; the dimensions of the objects are:

Compressor/motor/etc. (red): 10' width x 7' depth x 6' height

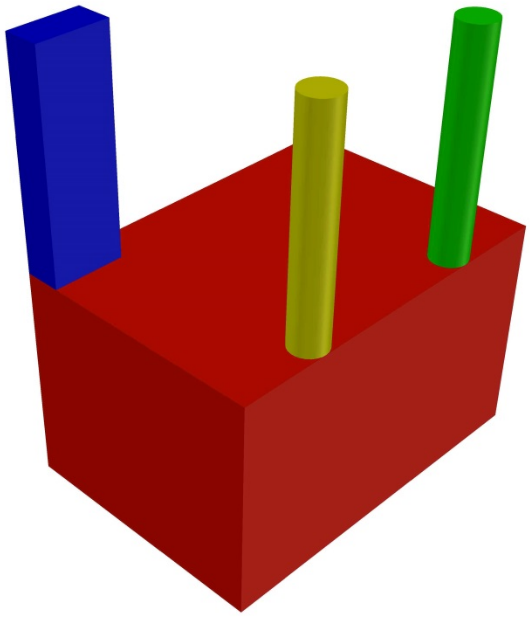
Service water pipe (blue): 2' width x 1' depth x 6' height

Air inlet pipe (green): 6" diameter x 6' height

Air discharge. pipe (yellow): 6" diameter x 6' height

Note that the views of the compressor in Figure 5-4 are from the direction of the roll-up door. Hence, the back of the compressor would not be exposed to missiles coming through the opening. Both sides of the compressor assembly and the top are exposed to missiles. Additionally, the back of the service water pipe, inlet air pipe, and air discharge pipe would not be exposed to missiles. Since the inlet and discharge pipes are treated as cylinders, the entire area of the cylinder (less the top and bottom ends) is used as a simplification. This simplification has minimal impact on the total area (see calculations below).

Figure 5-9: Simplified Representation of Compressor and Support Components



The total area of the individual targets in Figure 5-9 are:

Red: 1 x 10’ x 6’ + 2 x 7’ x 6’ + 1 x 7’ x 10’ = 214 ft^2

Blue: 1 x 2’ x 6’ + 2 x 1’ x 6’ = 24 ft^2

Green: π x 0.5’ x 6’ = 9.4 ft^2

Yellow: π x 0.5’ x 6’ = 9.4 ft^2

Therefore, the total area of the target is: 256.8 ft^2

Although the pipe targets associated with the compressor could potentially be considered robust, they are small contributors to the overall area. Therefore, the entire target is considered not robust, although this could be revisited if the target were determined to be risk significant. The entire target is located at less than 30’ elevation. Therefore:

EEFP(F’2) = ~~1.1~~1.4E-10*155,000*256.8 = ~~4.4~~5.6E-3/F’2 tornado

Note that the area of the opening, through which missiles could travel to strike the compressor, is 288 ft^2. This is about 10% larger than the calculated target area, but it could be used for the target area and is a simpler calculation. However, the purpose of this example was to provide a complex configuration for the purposes of illustrating the area calculations.

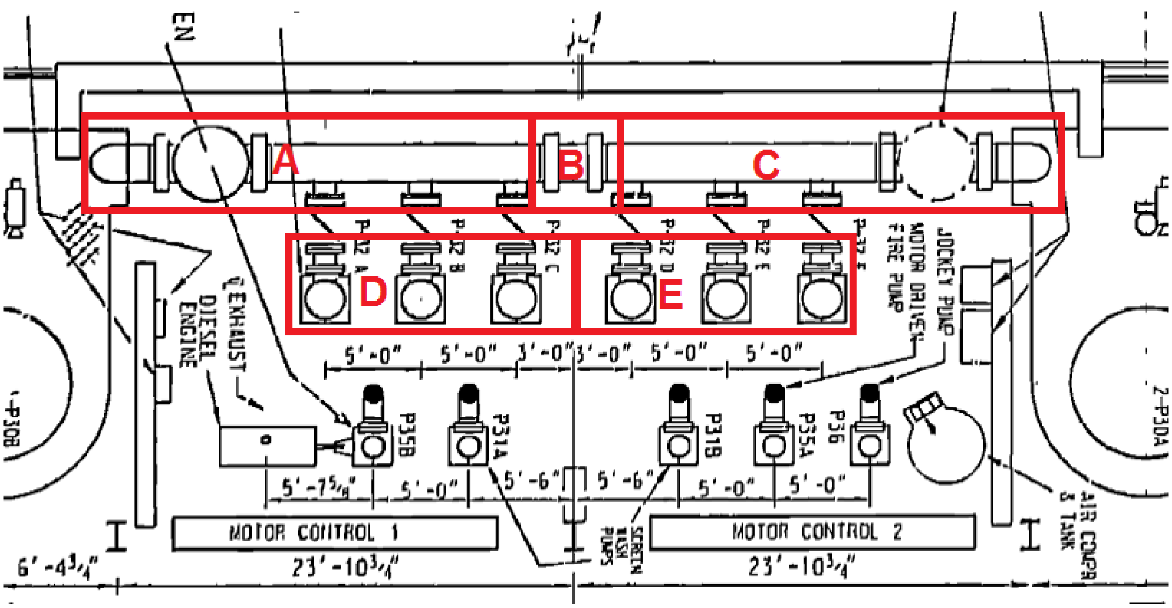
Example 3: Service Water SSCs from Figure 5-7. Calculate EEFP for all tornadoes (F'2 – F'6)

The service water piping and pumps in the pump house (partially represented in Figure 5-7) are vulnerable to missiles coming through the rollup door, as shown by the red lines in that figure. They are also vulnerable to vertical missiles striking and penetrating the roof above the SSCs.

Figure 5-10 shows areas outlined in red that are selected to represent targets in the pump house. These targets were chosen based on the system success criteria, which requires 3 service water pumps and one service water header, taking into account the ability to cross-tie headers. A rectangle bounding the SSCs is used to represent the target on the pump house roof. If that target is hit, the SSCs enclosed by the rectangle in Figure 5-10 are assumed to be hit. The headers (Targets A and C), the cross-tie (Target B) and the 2 sets of pumps (Targets D and E) are each modeled separately in the PRA.

From Figure 5-7, the header represented by Target A and three service water pumps represented by Target D can be hit from missiles coming through the roll-up door, in addition to those penetrating the roof. The area of the roll-up door is used as the target area (as opposed to the area of the header or pumps); the EEFP calculated based on the door area is assigned to both Target A and D. EEFPs for Targets B, C and E are calculated based on missile strikes on the roof, only.

Figure 5-10: Target Areas Encompassing Service Water Pumps and Piping



The elevation of the roof (not of the ultimate target SSCs) is used to choose the MIP (between near ground and elevated). The roof elevation is where the missile initially strikes, so the MIP appropriate to the roof elevation should be used. In this example, the roof is only 18' above grade, so the near ground MIP would be used, regardless.

The areas measured for these targets are:

A (roof): 750 ft^2 / (door): 45 ft^2

B: 568 ft^2

C: 750 ft^2

D (roof): 568 ft^2 / (door): 45 ft^2

E: 471 ft^2

In this example, the roof is constructed of 5" thick reinforced concrete. As such, only 20% of the total missiles can penetrate the roof (Category I from Table 5-2).

Missiles striking the rollup door can result in failure to Targets A and D, as described above. Since Target A is 16" service water piping, 35% of the total missiles (Category E from Table 5-2) could potentially be used in the EEFP calculation. However, there are motor and valve controls, as well as other support systems in the area that are not robust. Therefore, without further investigation, the total number of missiles from Table 5-1 will be used for the missiles hitting the roll-up door and ultimately damaging Target A. Since pumps are considered non-robust (see Section 5.3.1), the total missile inventories are used for Target D EEFP calculations.

The EEFPs for each target and F'-scale tornado are shown in Table 5-4. Note that the Target A EEFP from the roll-up door is about 30% of the EEFP from the roof. Even though the door target is relatively small, the fact that the total missile inventory is being used makes a difference.

Table 5-4: Pump House Target EEFP Values

		Target	**Target A (roof)**	**Target A (door)**	**Target B**	**Target C**	**Target D (roof)**	**Target D (door)**	**Target E**
		Target Area (ft^2)	750	45	568	750	568	45	471
		% of Missiles	20%	100%	20%	20%	20%	100%	20%
Tornado Category	**Near Ground MIP**	**Total Number of Missiles**							
F'2	1.4E-10~~1.1E-10~~	155,000	3.3E-03~~2.6E-03~~	9.8E-04~~7.7E-04~~	2.5E-03~~1.9E-03~~	3.3E-03~~2.6E-03~~	2.5E-03~~1.9E-03~~	9.8E-04~~7.7E-04~~	2.0E-03~~1.6E-03~~
F'3	4.6E-10~~3.6E-10~~	155,000	1.1E-02~~8.4E-03~~	3.2E-03~~2.5E-03~~	8.1E-03~~6.3E-03~~	1.1E-02~~8.4E-03~~	8.1E-03~~6.3E-03~~	3.2E-03~~2.5E-03~~	6.7E-03~~5.3E-03~~
F'4	7.9E-10~~6.3E-~~	205,000	2.4E-02~~1.9E-~~	7.3E-03~~5.8E-~~	1.8E-02~~1.5E-~~	2.4E-02~~1.9E-~~	1.8E-02~~1.5E-~~	7.3E-03~~5.8E-~~	1.5E-02~~1.2E-~~

	~~10~~		~~02~~	~~03~~	~~02~~	~~02~~	~~02~~	~~03~~	~~02~~
F'5	2.0E-09~~1.6E-09~~	240,000	7.2E-02~~5.8E-02~~	2.2E-02~~1.7E-02~~	5.5E-02~~4.4E-02~~	7.2E-02~~5.8E-02~~	5.5E-02~~4.4E-02~~	2.2E-02~~1.7E-02~~	4.5E-02~~3.6E-02~~
F'6	3.1E-09~~2.4E-09~~	240,000	1.1E-01~~8.6E-02~~	3.3E-02~~2.6E-02~~	8.5E-02~~6.5E-02~~	1.1E-01~~8.6E-02~~	8.5E-02~~6.5E-02~~	3.3E-02~~2.6E-02~~	7.0E-02~~5.4E-02~~

5.6 Correlation Between Targets

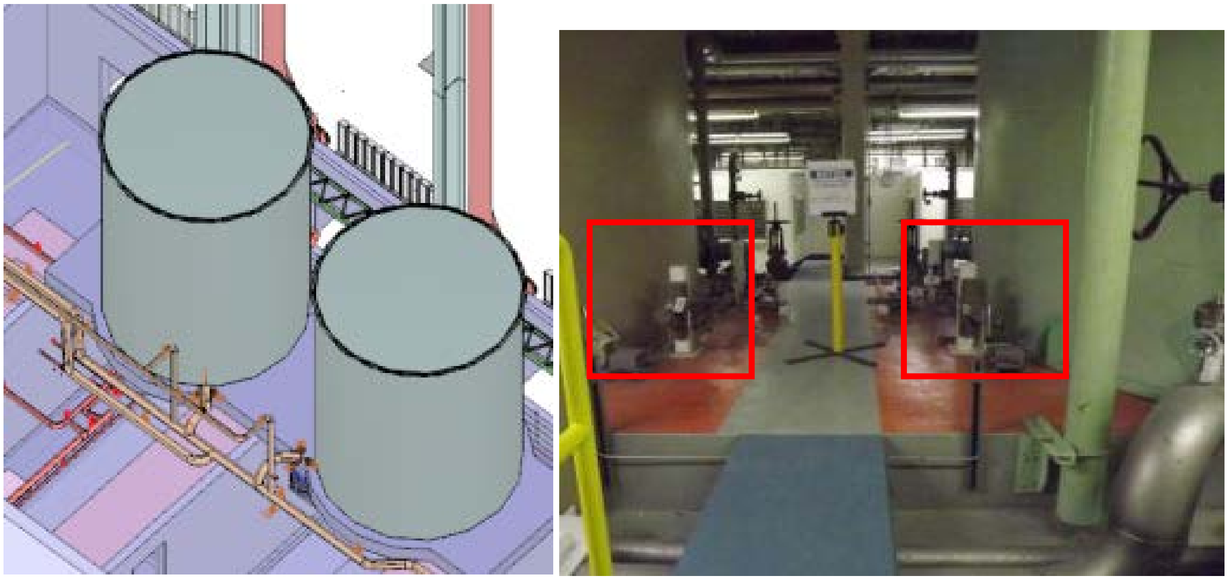
In some situations, two or more vulnerable SSCs may be physically situated in such a way that they may be considered "correlated." A correlated vulnerable target is susceptible to common mode failure. Correlated targets are typically located close together, such that a single missile is capable of striking and damaging more than one target, simultaneously.~~ All potentially correlated targets identified during walkdowns should be evaluated by the analyst when developing the TMRE PRA.~~ When considering the range of missiles capable of striking correlated targets, the full range should be initially considered. The list may be narrowed in scope based on other physical factors, such as elevation and shielding by buildings or other structures. ~~Documentation and justification should be provided for the disposition of potentially correlated targets.~~

In the cases of correlated targets, there are different approaches available for calculating the effective surface area. Once correlated targets have been identified, the surface area can first be calculated coarsely, and then refined appropriately as needed.

5.6.1 Correlated Tanks Example

Figure 5-11 shows an example of two tanks that have instrumentation in between the tanks that are vulnerable to a single missile strike (i.e., correlated). The instrumentation for each tank is highlighted with a red box in the picture on the right. Although unlikely, it is possible that a single missile can damage both sets of instrumentation such that both tanks would be considered unavailable.

Figure 5-11: Correlated Tanks with Instrumentation



A very conservative approximation would be to consider both tanks fully correlated, such that a rectangular polyhedron is used to encompass both tanks and the instrumentation. This is shown in Figure 5-12. The Target Exposed Area that would be calculated for this object would be very large and not representative of the area that of concern, i.e., the target area for the correlated targets. Furthermore, since the correlated targets are non-robust (instrumentation), the total missile inventory would be used in the EEFP calculation.

However, if this treatment provides acceptable risk calculations, it is conservative and can be easily justified. On the other hand, it is likely that the treatment will be too conservative, and another approach would need to be taken. Figure 5-13 provides an alternative and more realistic target configuration. In this figure, each tank is a separate target (in red), and the correlated target is the green box in between the two tanks. This treatment allows the tanks to be treated separately and as robust targets, thus allowing the use of lower missile counts. Furthermore, the common area that results in the failure of both tanks (in green) is much smaller and less likely to be risk significant.

Figure 5-12: Single Target Model for Correlated Tanks

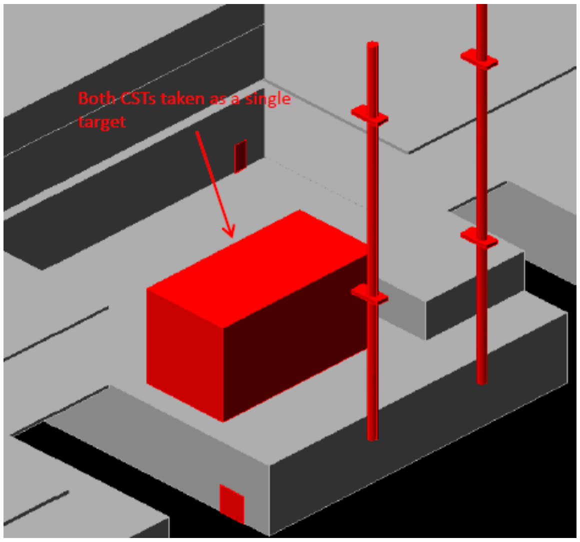
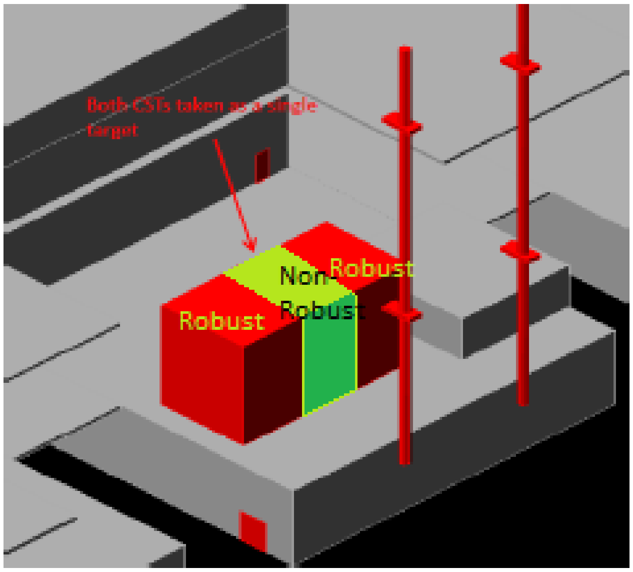


Figure 5-13: Single Target Model for Correlated Tanks

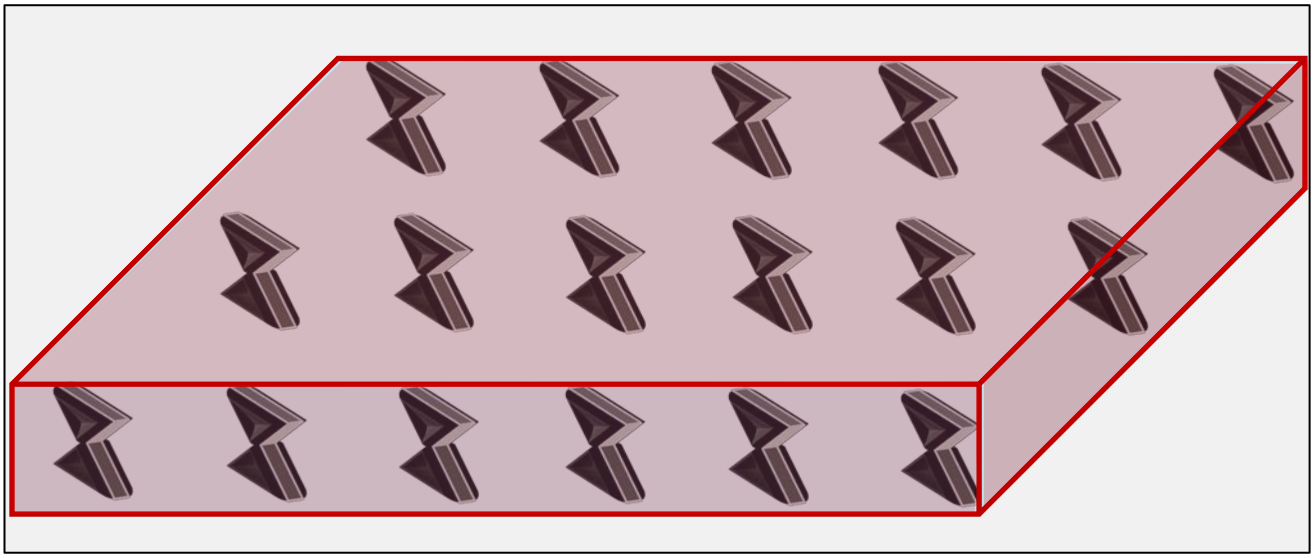


5.6.2 Correlated Safety Valves Example

In this example, consider a 3 by 6 array of Main Steam Safety Valves (MSSVs), where the individual valves are in close physical proximity to each other in two dimensions. Valves may be modeled individually or in groups. These approaches for correlating shown in this example can also be used for other situations, such as closely co-located and correlated steam relief exhaust stacks that penetrate a reinforced concrete roof.

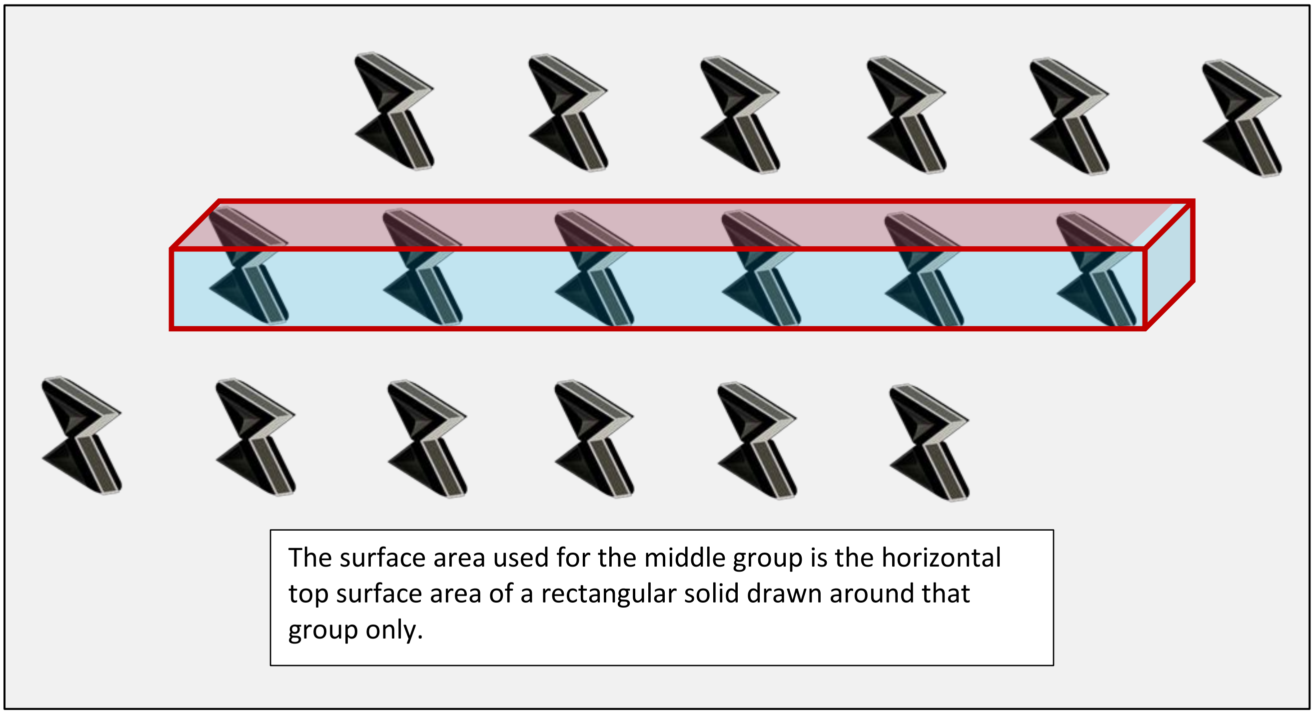
Similar the tank example in Section 5.6.1, all valves could be considered vulnerable to missiles from all directions. This is the starting point; to address target correlation, assuming each missile strike results in common mode failure of all targets (see Figure 5-14). This also assumes that the valves are close enough to each other that a single missile can indeed hit all the targets.

Figure 5-14: Correlation of Single Group of MSSVs



It is possible that the results of the initial calculation will show that the combined SSC is a dominant contributor, and therefore further refinement would be appropriate. For PRA models having success criteria requiring an individual MSSV group (e.g., per SG) to fail, the approach can be refined such that the correlation takes place at the group level only. In Figure 5-15, this would utilize three separate basic events to represent each of the three groups. The outer groups would utilize only the surface area that fully exposes each valve, that is, the top and the outer side of the rectangular solid. The middle group is exposed only from the top. The ends are not used because a single missile will not be able to damage the entire group when approaching from that direction.

Figure 5-15: Correlation of Three Separate Groups of MSSVs



More complex schemes and groupings are provided in Figures 5-16 and 5-17.

Figure 5-16: Complex Correlation Between MSSVs

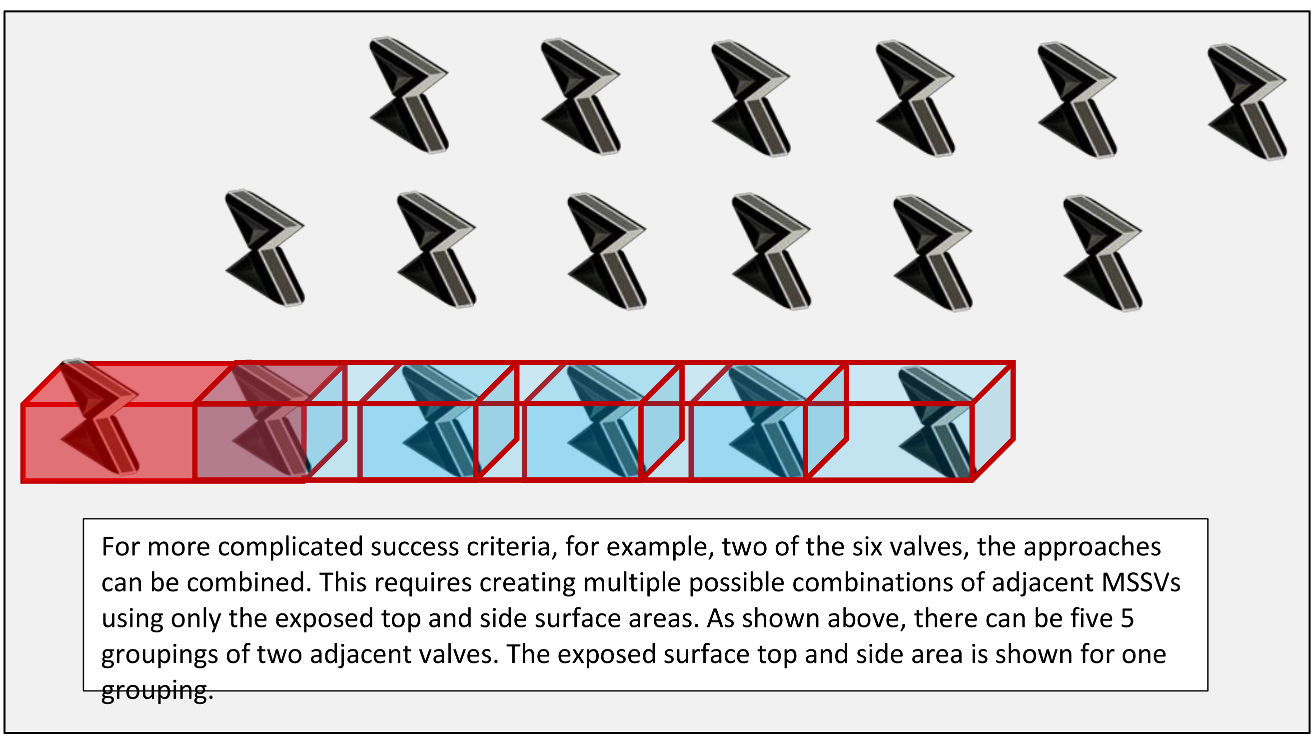
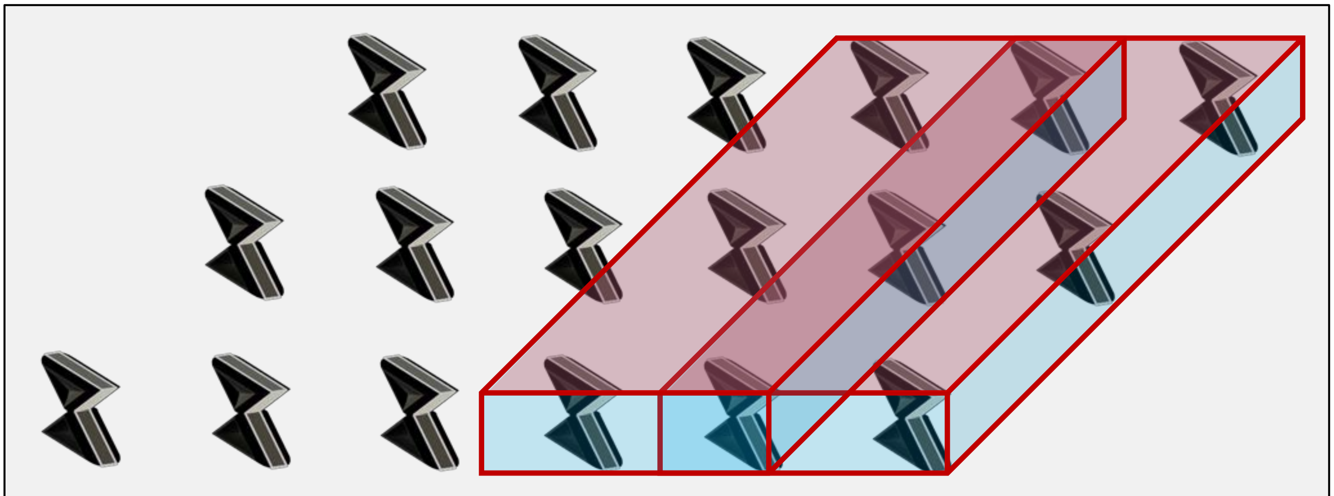


Figure 5-17: Complex Correlation Between MSSVs



For more complicated success criteria, for example, two of six valves, the approaches can be combined. This requires creating many possible combinations of adjacent MSSVs using only the exposed surface areas. Shown above are two combinations where vertical missiles could impact multiple groups.

6 DEVELOP TMRE PRA MODEL

This section provides the detailed guidance for developing the TMRE PRA Model. The TMRE PRA Model is used to calculate the risk associated with the SSCs that are nonconforming with respect to the TMP licensing basis, and is the basis for a risk-informed license application that is to be submitted in accordance with RG 1.174 [Ref. 6.1]. The TMRE PRA Model should be developed from the plant's peer reviewed internal events PRA model of record, since that model should contain the appropriate accident sequence logic and fault trees to be modified. Additionally, using a peer reviewed RG 1.200 PRA model will support adherence to the PRA technical adequacy requirements, after considering the self-assessment of the additional supporting requirements for the TMRE application provided in Section 6.8.

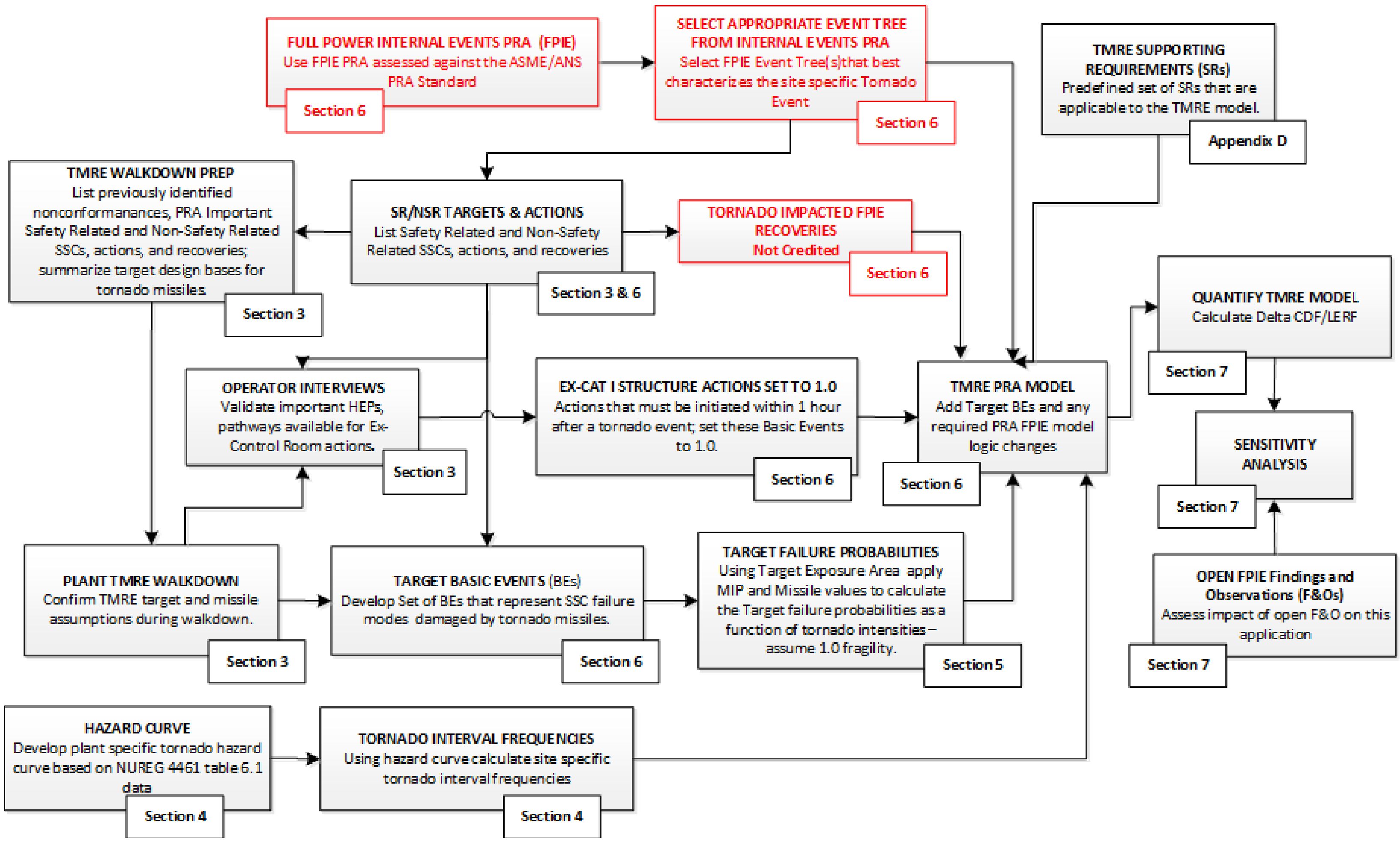
Figure 6-1 is the TMRE flowchart with the relevant actions highlighted for the TMRE PRA model development step of the process. The key elements of developing the TMRE PRA model are:

- Select the event trees and fault trees appropriate for modeling a tornado event from the Internal Events Model of Record (typically the Loss of Offsite Power (LOOP) accident sequence logic)
- Replace the LOOP initiating event with tornado initiating events (F'2 – F'6)
- Remove recovery and repair logic (or set failure probability to 1.0), as recovery and repair are not credited in the TMRE PRA
- Develop Compliant Case and Degraded Case logic or models
- Add tornado wind and missile failure modes to vulnerable SSCs, as appropriate, in the fault tree logic
- Set human error probabilities (HEP) to 1.0, for certain short term actions outside the main control room (MCR) and review transit paths for other ex-MRC operator actions.

6.1 EVENT TREE/FAULT TREE SELECTION

One of the assumptions of the TMRE method is that a tornado event that creates tornado missiles will, at a minimum, cause a Loss of Offsite Power (LOOP) and reactor trip. Therefore, one or more of the internal events PRA LOOP event trees and respective accident sequence logic should reasonably be expected to represent the tornado initiating events in the TMRE PRA. The PRA analyst should review other internal initiating events from the PRA model of record being used to ensure that either (1) a tornado event cannot cause another initiating event or (2) the impact of the initiating event can be represented in the logic selected to represent the tornado initiating event. An example of the second case is a support system loss (e.g., service water loss due to vulnerable service water system piping); the impact of the consequential loss of service water should be included in the accident sequence/fault tree logic in the TMRE PRA model. SSC failures from tornado winds and missiles, including secondary effects from failure of non-conforming SSCs (see Section 6.5.2), should be evaluated during the initiating event review.

Figure 6-1: TMRE Flowchart – Event Tree/Fault Tree Selection



Another assumption of the TMRE method is that the tornado-induced LOOP cannot be recovered. That is, offsite power remains unavailable following the event for the duration of the mission time. This should be taken into account when selecting the event trees and model logic used to represent the tornado event; the logic must allow for the failure of recovery of offsite power and any repair events. Additional consideration in the accident sequence model adapted for tornado events are:

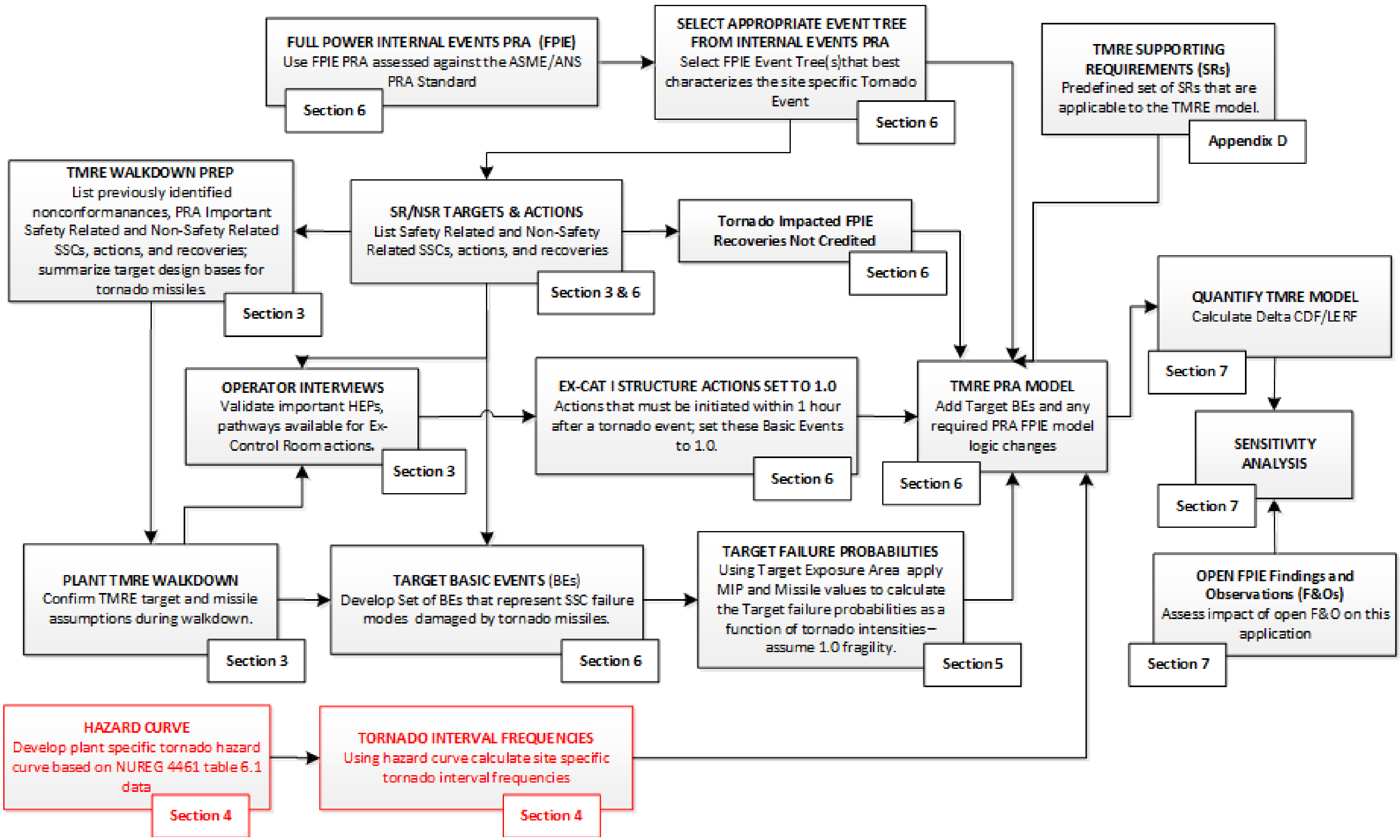
- Mission times may need to be adjusted for some basic events, based on the fact that offsite power recovery is not credited.
- Some time-phased dependencies may be affected due to the tornado winds and missiles potentially affecting multiple SSCs, with no credit for recovery.

Once the appropriate model logic has been selected, unneeded logic can be removed at the discretion of the analyst. The only initiating events quantified in the TMRE model will be tornado initiating events, using the model logic chosen to represent them.

6.2 Tornado Initiating Events

The initiating events for the TMRE PRA model are five tornado events, one each representing the F'-Scale tornado categories F'2 through F'6. These initiating events will replace the initiating events (e.g., LOOP) used in the selected event trees. For multi-unit sites, the tornado event should be assumed to result in a multi-unit LOOP event. Guidance for the development of the initiating event frequencies is contained in Section 4.

Figure 6-2: TMRE Flowchart – Tornado Initiating Events



6.3 COMPLIANT CASE AND DEGRADED CASE

RG 1.174 requires an evaluation of the change in risk (i.e., ΔCDF and ΔLERF) for different plant configurations. For the TMRE analysis, there are two configurations (cases) that need to be modeled and quantified before evaluating the change in risk associated with the TMP nonconforming SSCs. In this guidance, they are referred to as the "Compliant Case" and "Degraded Case." Both the cases are based on the same LOOP event tree (and/or other event trees identified in Section 6.1), with certain modifications.

- The Compliant Case represents the plant in full compliance with its tornado missile protection current licensing basis. Therefore, all nonconforming SSCs that are required to be protected against missiles are assumed to be so protected, even when reality determines the SSCs are not protected. In the Compliant Case, nonconforming SSCs are assumed to have no additional failure modes beyond those normally considered in the internal events PRA.

- The Degraded Case represents the current configuration of the plant (i.e., configuration with nonconforming conditions with respect to the tornado missile protection current licensing basis). As such, the TMRE PRA model will include additional tornado induced failure modes for all nonconforming SSCs. The failure probabilities for those additional tornado induced failure modes are based on EEFP calculations, as described in Section 5.

Some of the internal events PRA model changes needed to create the TMRE PRA model will be applicable to both the Compliant and Degraded Cases. These common changes are:

- The internal events PRA event trees and fault trees chosen to represent the tornado initiating events (Section 6.1)

- The tornado initiating events and their frequencies (Section 6.2)

- Offsite power recovery and repairs are not credited (Section 6.1)

- Certain non-feasible operator action HEPs will be set to 1.0 (Section 6.4)

- Non-Category I structures incapable of withstanding the forces associated with tornado winds greater than 103 mph (i.e., the lower wind speed associated with F'2 tornadoes) and exposed active NSR SSCs (e.g., pumps, compressors) are assumed to fail with a probability of 1.0 (Section 6.6).

- Turbine buildings and exposed passive NSR SSCs (e.g., tanks, pipes) should be evaluated to determine their capability to withstand tornado wind pressures. Failure probabilities for these structures will vary based on their strength (Section 6.6).

- Vulnerable but conforming components (i.e., those PRA modeled SSCs that are exposed to tornado missiles but are not nonconforming with respect to the TMP current licensing basis) will include tornado-missile induced failures based on EEFP calculations (Section 6.5)

Therefore, the primary difference between the Compliant and Degraded Cases is the treatment of nonconforming SSCs. In the Compliant Case, no changes are made in the fault trees for nonconforming

SSCs (even if they are vulnerable to tornado missiles); in the Degraded Case, tornado missile-induced failure modes are added to the failure logic for nonconforming SSCs.

Table 6-1 provides a summary of the different treatments for various parts of the TMRE PRA models/cases.

Table 6-1: Compliant Case vs. Degraded Case Model Changes

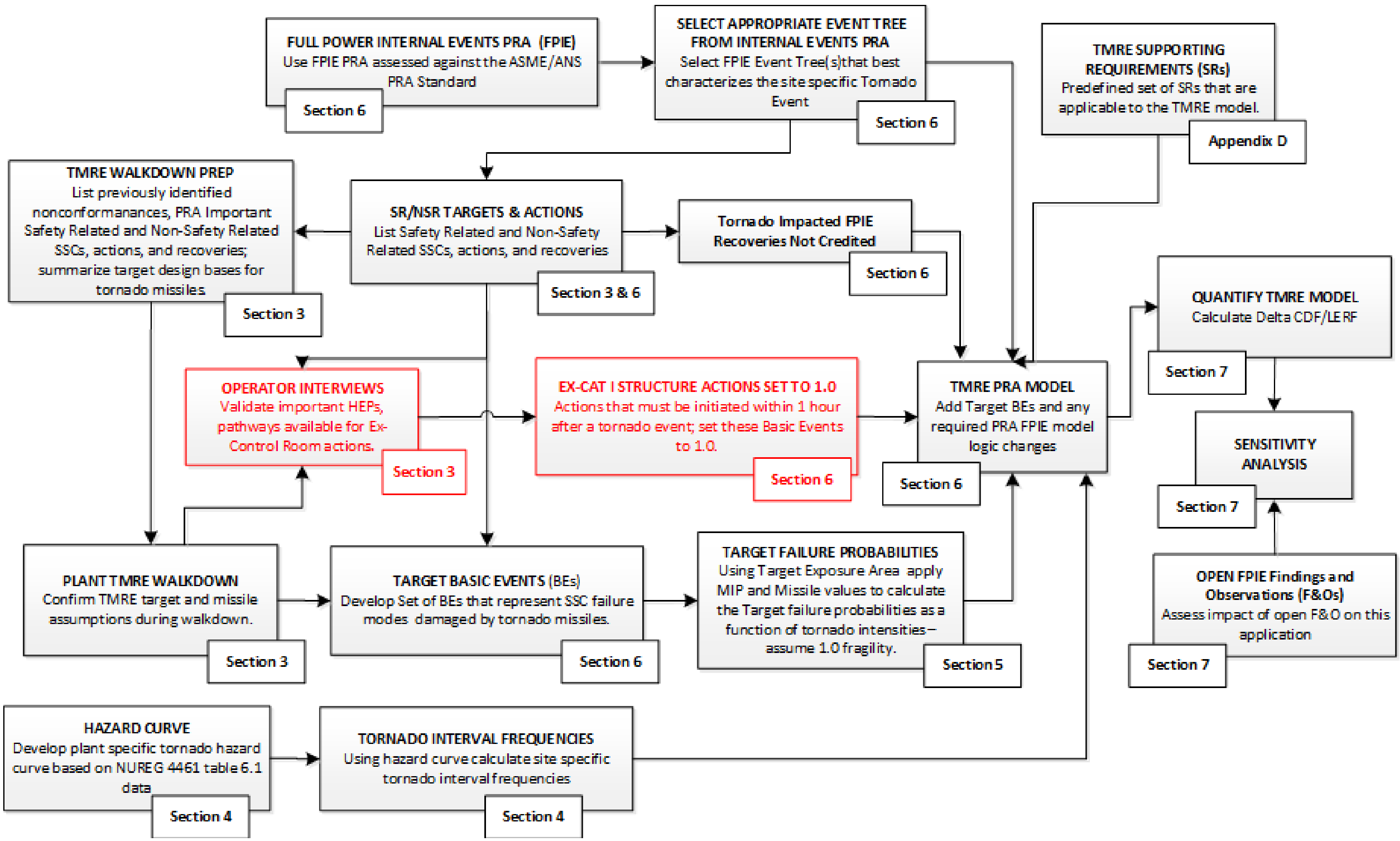
Type of SSC	**Failure Probability – Compliant Case**	**Failure Probability – Degraded Case**
• Switchyard • Non-Category I Buildings • SSCs in Category I Buildings (6.6.1 and 6.6.2)[(1)] • Short-term Operator Actions Outside MCR (6.4) • Exposed active NSR SSCs (6.6.3)[(1)]	1.0 with no recovery	1.0 with no recovery
Exposed passive NSR SSCs (6.6.4)[(1)]	• EEFP for tornado categories below calculated strength • 1.0 for tornado categories at or above calculated strength	• EEFP for tornado categories below calculated strength • 1.0 for tornado categories at or above calculated strength
Nonconformances	No new failures	EEFP
Other Vulnerabilities	EEFP	EEFP

Note (1): Although not designed as Category I, failures of turbine buildings and SSCs within them can be treated differently from other non-Category I buildings (see 6.6.2)

6.4 Impacts on Operator Action Human Error Probabilities

Tornado events at a nuclear site are very unlikely to have any impact on Category I structures, due to their robust construction and design margin. Thus, equipment and personnel inside Category I structures are not expected to be affected in the TMRE PRA. However, certain operator actions may have to be performed outside Category I structures or require the operators to transit outside Category I structures in order to get to the location to perform the action. For short term actions (i.e., those that need to be executed within 1 hour of the initiating event), the TMRE method assumes that the actions cannot be performed and thus the HEPs for those actions are set to 1.0.

Figure 6-3: TMRE Flowchart – Operator Actions



The rationale for this assumption is that during and immediately following a tornado event on site, areas outside Category I structures may not be safe due to high winds and debris/missiles. It is not expected that operators will endanger themselves in such situations. Furthermore, in the short time period following the tornado strike (assumed to be 1 hour in the TMRE method), there may be significant debris and damage to structures that could impede or prevent operators from transiting to and operating equipment outside Category I structures. Plant specific procedures may direct that personnel not exit Category I structures until a damage assessment is performed, which is assumed to take no longer than 1 hour following the tornado event. This introduces uncertainty into any detailed human reliability analysis of these actions. It is reasonable to apply a human error probability (HEP) of 1.0 to these short term actions in both the Compliant and Degraded Cases, because the aforementioned assumption is not overly conservative and the impact does not depend on tornado missile protection of SSCs.

The type of short term operator actions described above should have been identified as part of the HWEL development described in Section 3.3 The feasibility of actions involving transit or operation outside Category I structures more than 1 hour after the tornado event should be assessed and documented as described in Section 3.3.

Operator actions performed inside the control room or other Category I structures are assumed to be unaffected by the tornado event. Short term actions that are taken in response to the loss of offsite power should already consider the additional stress the operators may be under due to weather-related LOOP events. Longer term actions should not be affected as the immediate impact of the tornado event on operator stress and distractions should no longer be a factor on operator response.

If necessary, operators should be interviewed to ensure that the operator actions used in the internal events PRA are applicable to tornado events. Talk-throughs and simulator exercises may be used if actions are expected to vary substantially.

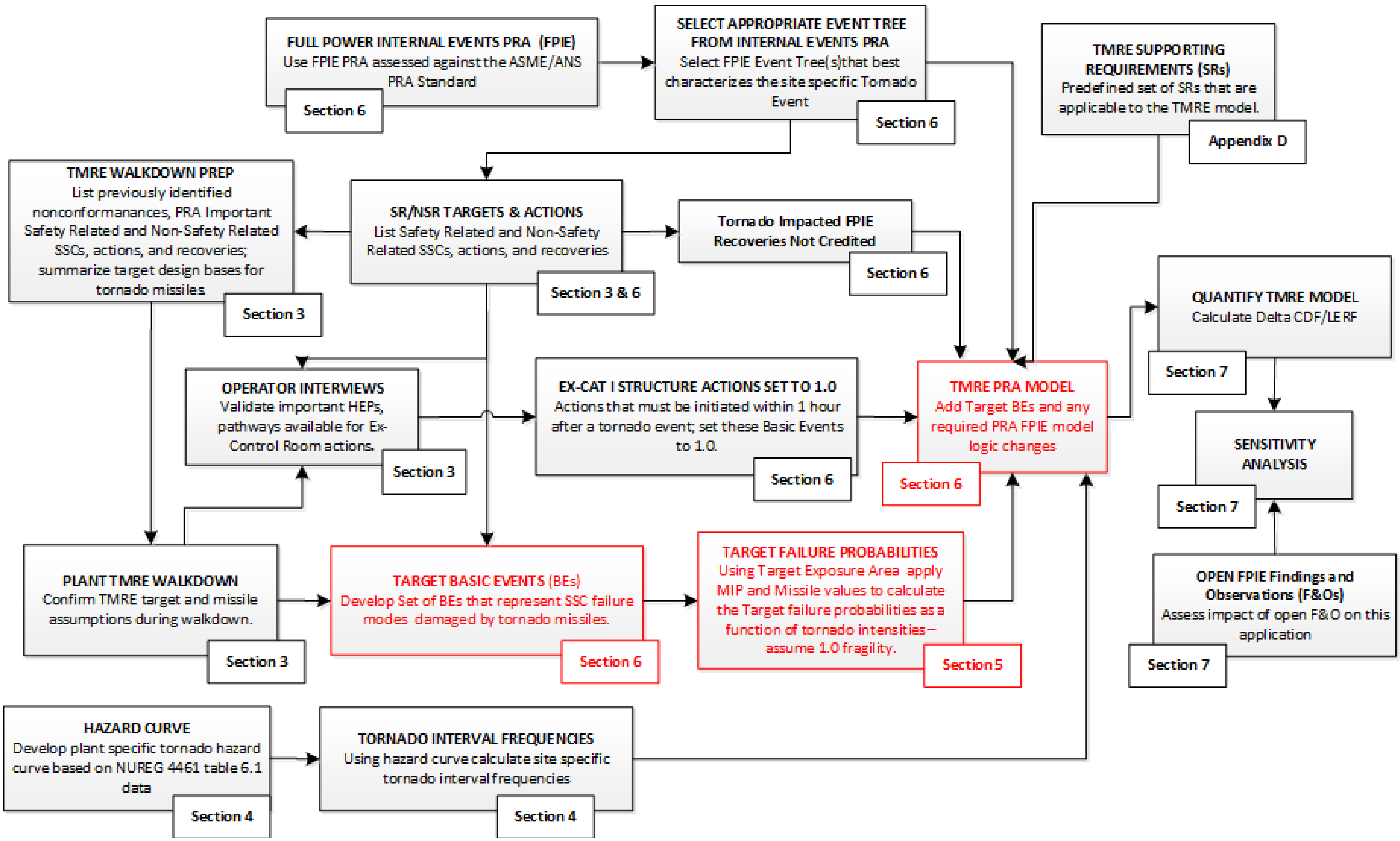
Operator actions performed in non-Category I structures that would have failed during a tornado event (see Section 6.6), should also be assumed to fail. However, the failure of the SSC being operated or manipulated should ensure that credit is not taken for these actions. Operator recovery actions to restore functions, systems, or components should not be credited unless an explicit basis accounting for tornado impacts on the site and the SSCs of concern is documented.

It is possible that new operator action dependencies will be created as a result of the TMRE model changes or due to new cut sets or combinations of failures associated with tornado events. The analyst should ensure that new operator action dependencies are appropriately accounted for in the TMRE PRA model.

6.5 Target Failures and Secondary Effects

The PRA logic models need to be modified to include tornado missile-induced failures for exposed SSCs. Tornado missile failures do not need to be considered for SSCs protected by 18” reinforced concrete walls, 12” reinforced concrete roofs, and/or 1” steel plate.

Figure 6-4: TMRE Flowchart – Target Impact Probabilities



6.5.1 FUNCTIONAL FAILURES

The TMRE PRA model should consider the functional failure of SSCs due to tornado missile strikes on unprotected SSCs. SSC failures from tornado missiles may need to be considered for failure modes not previously included in the internal events system models (e.g., due to low failure probability or low impact on system failure probability). Examples include:

- Flow diversions and/or leakage
- Tank vent failures (e.g., tank vent pipe crimping)
- Ventilation damper failures

The effect of the tornado missile damaging the SSC may be modeled at the component, train, or system level, depending on the functional failure resulting from the tornado missile impact and the details of the PRA model. Complex failure mode analysis is not required; in general, the failure modes considered in the TMRE are limited to the failure of the exposed equipment (i.e., the direct impact on the exposed SSC). Some examples are:

- A ventilation damper is exposed to tornado missiles; if the damper or its operator is struck by a tornado missile, it may fail to open or transfer shut (depending on the design of the damper and its operator). If the damper failure would prevent air flow to a room cooling fan, the failure could be modeled as failure of the damper to open/remain open or failure of the fan to operate.
- A tank vent is exposed to tornado missiles; if the vent is struck by a tornado missile, it could be crimped. If the loss of tank venting would result in tank failure or loss of suction from the tank, the failure could be modeled as failure of the tank to provide fluid to the systems requiring the tank inventory.
- A cooling water pipe is exposed to tornado missiles; if the pipe is struck by a tornado missile, it could be perforated causing a flow diversion and loss of cooling water. The impact of flow diversion and/or loss of cooling water would need to be determined and incorporated in the model. The impact could vary from no impact to complete system failure, depending on the pipe and system specifics (e.g., the size of the pipe, the capacity of the system pumps, whether the system is open or closed).

6.5.2 SECONDARY EFFECTS

Some secondary effects of tornado missile impacts on non-conforming SSCs should be evaluated and included in the TMRE PRA, if applicable. Specifically, flooding and combustion motor intake effects caused by tornado missile failures of fluid filled tanks and pipes (e.g., due to perforation of the tank or pipe) should be considered. The evaluation of these secondary effects is limited to missile impacts on non-conforming SSCs only (i.e., such secondary effects from missile impact on vulnerable but conforming SSCs do not need to be considered). Additional secondary effects, other than those associated with flooding and combustion motor intake effects, do not need to be evaluated as part of the TMRE.

An example of the secondary impact from flooding can be illustrated using the pipe example above. If the exposed pipe is non-conforming, the impact of flooding on other SSCs should be evaluated in addition to the direct failure on the system due to the missile strike:

- The analyst should determine if other SSCs in the TMRE PRA could be failed due to the potential flooding from the pipe perforation. The failure of the affected SSCs should be included in the TMRE model, if applicable.
- Assumptions and analyses regarding the flow rate from the pipe failure, the propagation paths, mitigation of the flooding, etc. should be documented. The internal flooding PRA model may provide a basis for the analysis.

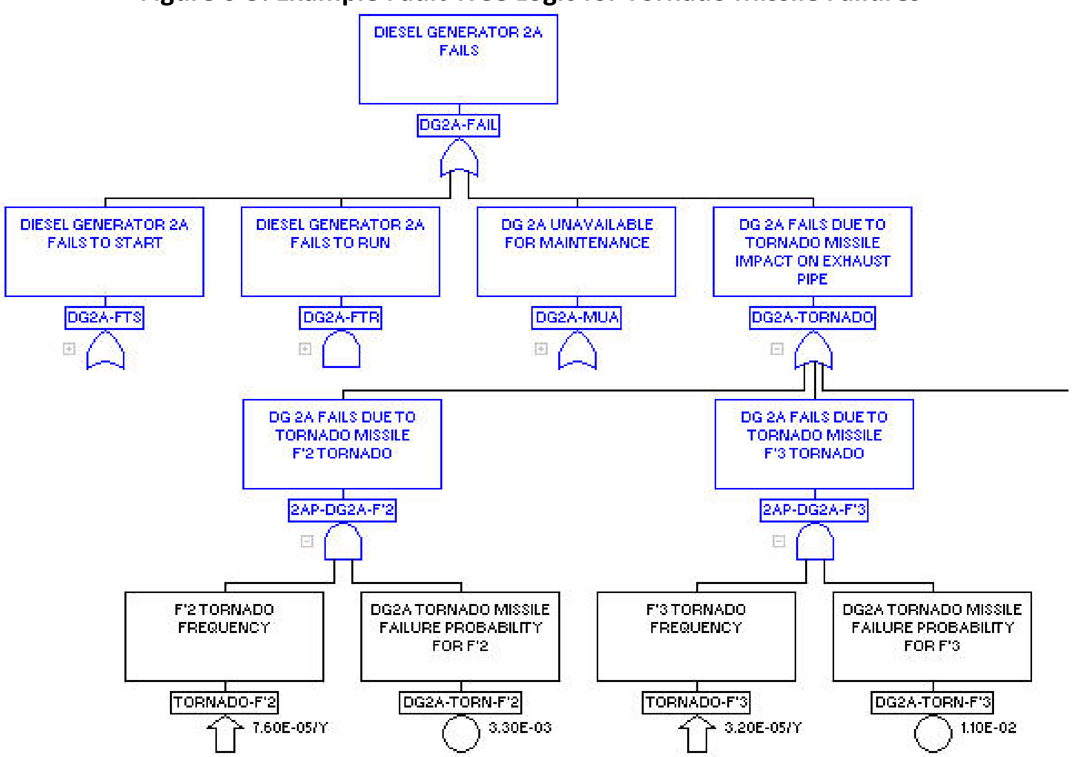
Examples of combustion motor effects are the loss of intake oxygen due to a missile induced rupture of a nearby inert gas tank, or re-direction of exhaust gases from an exhaust pipe perforated by a tornado missile. This failure mode is expected to be unlikely, and typically bounded by the relatively high failure rates of combustion motors. Additional plant-specific considerations that may facilitate screening of this secondary failure mode are:

- The proximity of the non-conforming SSC to the air intake for the combustion motor
- The capacity of the system (e.g., the size of the inert gas tank)
- The fact that tornado winds will disperse the inert or exhaust gas, preventing its concentration

6.5.3 Basic Event Modeling

The failure probability for a given SSC is determined using the EEFP calculation described in Section 5. Recall that the EEFP for each exposed SSC is calculated for each tornado category F’2 through F’6. The PRA model must be modified to ensure that the correct EEFP is used for an SSC based on the tornado category used for the initiating event. An example of how this can be accomplished in a CAFTA fault tree is shown in Figure 6-5.

Figure 6-5: Example Fault Tree Logic for Tornado Missile Failures



In this fault tree, a tornado missile failure basic event is added to the fault tree for each tornado category (only the F'2 and F'3 logic is shown here). The tornado missile failure basic event is placed under an AND gate with the appropriate category tornado initiating event. It is left to the analyst to determine the specific modeling method for incorporating tornado missile failures into their PRA models, and the level of detail of the tornado missile failure basic events. For example, one basic event could be used to represent all tornado missile failures of a given SSC or separate basic events could be included for the cause of each tornado missile failure of the SSC. Additionally, depending on the physical arrangement of the targets, multiple SSCs may sometimes be included under a single basic event (see Subsections 5.3.1 and 5.5 for examples).

Table 6-1 provides guidance for the Compliant Case and Degraded Case treatment of nonconforming SSCs and other vulnerable (but not nonconforming) SSCs.

6.6 Non-Category I Structures and Other NSR SSCs

Model changes are needed to account for the failure of non-Category I structures and other NSR SSCs that are not designed to withstand tornado wind pressures and atmospheric pressure changes. These changes are applicable to both the Compliant and Degraded Cases, as listed in Table 6-1.

1. Non-Category I structures and buildings that may house NSR SSCs, are often built to industrial or commercial building codes. As such, non-Category I buildings (with the exception of most turbine buildings) will generally not withstand wind pressure and atmospheric pressure changes associated with the tornado categories applicable to the TMRE. Therefore, these buildings and the SSCs inside the buildings should be considered to fail with a probability of 1.0 in the TMRE PRA.
2. Although turbine buildings are generally not Category I structures, their frames are typically designed to withstand significant forces. Turbine building siding is typically designed to become detached from the frame, to prevent failure of the structure from wind pressures (although it may expose SSCs inside the turbine building to tornado missiles). Therefore, failures of SSCs within a turbine building should follow the guidance for active and passive NSR SSCs provided in items 3 and 4, for tornado categories the turbine building structure can withstand.
3. Less robust, non-safety related SSCs (e.g., pumps, air compressors, generators, and other active components) located outside of structures or within turbine buildings, such that they are directly exposed to tornado wind pressures, should be failed in the TMRE PRA.
4. More robust SSCs (e.g., tanks, piping, passive valves, conduits) are generally sturdy enough to withstand tornado wind forces. This is especially true for steel tanks that are full, or mostly full, of liquid. Analyses should be done to verify that the SSCs are capable of withstanding tornado wind forces. Design calculations may be used to determine the wind speed at which such SSCs will fail. Failure probabilities for such SSCs should be set to 1.0 in both the compliant and degraded cases for wind speeds (based on tornado category) higher than the calculated strength. Tornado missile failure modes (i.e., based on an EEFP) need to be included for such SSCs, for the tornado categories that do not cause guaranteed failure of the SSC.

6.7 PRA Technical Adequacy

The assumption of the TMRE methodology is that the Internal Events model of record used as the basis for the TMRE model has been peer reviewed against the RG 1.200 [Ref. A.8] endorsed PRA standard.

Any open findings from the peer review that would impact the application of the model in the TMRE process should be addressed within the TMRE analysis.

In addition to the internal events technical adequacy, the details of the conversion process from the Internal Events PRA to the TMRE PRA should be documented and reviewed. The process should follow this guideline, and any deviations from the guideline should be well documented. Additional requirements associated with the conversion process and to address TMRE-specific modeling issues are provided in Appendix D. A cross-reference to the applicable section of this guidance document for each of the SRs is also provided in Appendix D.

7 QUANTIFY RISK, PERFORM SENSITIVITY ANALYSES, AND COMPARE TO THRESHOLDS

7.1 CDF AND LERF QUANTIFICATION

Per RG 1.174 [Ref. A.6], a risk-informed evaluation of the change in risk (e.g., ΔCDF) is included. For the purposes of the TMRE, a licensee needs to calculate this change in risk by comparing two different configurations: the Compliant Case (configuration with the plant built per the required design/licensing bases), and the Degraded Case (current plant configuration, including potential nonconformances for tornado missile protection).

The ΔCDF and ΔLERF are simply calculated as follows:

$$\Delta CDF = CDF_{Degraded} - CDF_{Compliant}$$

$$\Delta LERF = LERF_{Degraded} - LERF_{Compliant}$$

The configuration-specific CDFs and LERFs are quantified like any other PRA, in alignment with the relevant quantification (QU) Supporting Requirements from the ASME/ANS PRA Standard (see Appendix D for additional detail).

7.2 SENSITIVITY ANALYSES

In addition to the ΔCDF and ΔLERF results, a risk-informed evaluation should include a discussion on the sensitivity of those results to key assumptions and parameters, such that the uncertainties are well characterized and understood. For the purposes of TRME, there are two~~hree~~ types of sensitivity evaluations that may be relevant.

7.2.1 TMRE MISSILE DISTRIBUTION SENSITIVITY

A generic sensitivity has been identified during the development of the TMRE methodology. The sensitivity study should be performed and documented if the if the ΔCDF or ΔLERF between the compliant and the degraded case exceed 10^{-7}/yr or 10^{-8}/yr, respectively.

NOTE: The following procedure should be followed for determining the RAW of an SSC, with respect to meeting the conditions for performing this sensitivity. A given SSC will typically have separate and mutually exclusive tornado missile basic events for each tornado intensity. If this is the case:

- If any target basic event for F'4, F'5, or F'6 has a RAW greater than or equal to 2, then the sensitivity should be performed for that SSC for F'4 – F'6 tornadoes.
- For SSCs whose target basic event (for F'4, F'5, or F'6) RAWs are all less than 2, then the effective total RAW for that SSC is calculated as:

$$RAW_{Total} = 1 + (RAW_{F'4} - 1) + (RAW_{F'5} - 1) + (RAW_{F'6} - 1)$$

If RAW_{Total} for an SSC is greater than or equal to 2, then the sensitivity should be performed for that SSC for F'4 – F'6 tornadoes. This approach does not consider the importance of F'2 and F'3 SSC basic events, since they are not affected by the sensitivity calculation. However, it does account for the cumulative importance of the SSC for the F'4 through F'6 tornado intensities.

This sensitivity addresses the potential underestimation of target hit probabilities due to the missile distribution at the licensee's site, as compared to the missile distribution for the EPRI NP-768 Plant A simulations.

Procedure: For *highly exposed* SSCs with a tornado missile failure basic event RAW $\geq$ 2, multiply the basic event failure probability by 2.75 and recalculate ΔCDF and ΔLERF[7]. This only applies to tornado missile basic events for tornado categories F'4 , F'5, and F'6. Basic events for F'2 and F'3 tornado missile failures are not considered in this sensitivity.

For the purposes of this sensitivity study, the term *highly exposed* refers to an SSC for which all of the following characteristics apply:

- Is not located inside a Category I structure (i.e., they are outside or in a non-Category I structure)
- Is not protected against horizontal missiles
- Has an elevation less than 30' above the associated reference elevation

In addition to the conditions described above (*highly exposed* target with RAW $\geq$2), an additional MIP multiplier is required if a large number of missiles are close to such a target (defined as greater than 1,100 missiles within 100 feet of the target – see Section A.7.6). The potential concern with this situation is that the risk associated with a highly exposed and risk significant target with a large concentration of nearby missiles *may be* underestimated using the 2.75 MIP multiplier. A higher MIP may need to be applied to each target meeting these conditions when performing this sensitivity calculation.

However, prior to determining the target-specific MIP and performing a sensitivity, qualitative factors can ~~be provided~~considered to justify not applying a higher target-specific MIP. The justification for not applying a higher target-specific MIP should be documented and should address how certain factors~~, some listed below,~~ can mitigate the potentially higher frequency of missile impacts on the target. Considerations include the number, type, and location of the missiles with respect to the type of target and its location, as well as administrative controls that limit the number, type and location of missiles. Two examples illustrate situations where qualitative factors could preclude the need to apply a higher target-specific MIP:~~:~~

- The target in question is a 16" schedule-40 service water pipe and the local missile source consists primarily of 2x4 wood planks and plywood beams. Since the pipe is robust and cannot be damaged by the missiles nearby (see Table B-14, Category F), the local concentration of missiles does not warrant a higher target-specific MIP.~~Source of nearby missiles (i.e., structural vs. non-structural)~~
- The target in question is a DG exhaust pipe that is on the roof of a 20' high DG building. The roof has a parapet wall along the perimeter. The local missile source is a small pre-engineered

[7] The basis for the 2.75 MIP multiplier in this sensitivity study is provided in Section A.7.

1-story building 20 feet from the DG building. In order for one of the local missiles to damage the DG exhaust pipe, it must be heavy enough to cause damage to the target, must be lifted over 20' feet, and accelerated to a damaging speed in the short distance from the missile source to the DG building. Lighter missiles are more likely to be lifted and accelerated, but will not damage the target, while it is unlikely that heavier missiles (that are damaging) will ever hit the target due to their relative placement with respect to the target.~~Category of nearby missiles (e.g., rebar, pipe, plywood, planks)~~

- ~~Target robustness, especially with respect to the nearby missile categories~~
- ~~Target elevation~~
- ~~Administrative controls~~
- ~~Missile to target location aspects, including distance from target, intervening structures, etc.~~

After considering such qualitative factors, if the target(s) in question is considered susceptible to a MIP multiplier higher than 2.75, a target-specific MIP shall be calculated and included in the sensitivity study, with the other targets that meet the *highly exposed* and RAW $\geq$2 conditions. The MIP multiplier is calculated by determining the ratio of the local missile density (ρ_{Local}) with the average site missile density (ρ_{Avg}).

MIP Multiplier = $\rho_{Local} / \rho_{Avg}$

ρ_{Local} is the missile density within 100 feet of the target

ρ_{Avg} is the missile density for the site area (e.g., circle with 2500' radius from plant centerpoint) assuming 240,000 missiles, or the number of missiles used in the EEFP calculations, if greater than 240,000

The TMRE Missile Distribution Sensitivity is performed by applying either the generic MIP multiplier of 2.75 or the target-specific MIP multipliers to the appropriate basic events[8], recalculating the ΔCDF and ΔLERF, and comparing the results to the acceptance criteria.

~~7.2.2 Construction Missiles Sensitivity~~

~~As described in Section 3.4.3, a sensitivity analysis should be performed to evaluate the impact of additional non-permanent construction-related missiles (i.e., those missiles not already included in the permanent post-construction missiles) above the missile count used in the TMRE analys~~

7.2.2~~3~~ Compliant Case Conservatisms

The licensee should review cut sets in the top 90% of the TMRE compliant case to identify conservatisms related to equipment failures only (i.e., as opposed to offsite power recovery or operator actions assumptions in the compliant case) that could impact results and perform sensitivity studies to address

[8] Only one multiplier is applied to a basic event, either the 2.75 generic multiplier or the target-specific multiplier.

AS-A10, LE-C3 and SY-B7 in Appendix D. Specifically, consider that equipment failures in the compliant case may be masking changes in risk.

If the degraded case CDF and LERF are less than 10^{-6}/yr and 10^{-7}/yr, respectively, then the sensitivity analysis is easily performed by setting compliant case CDF and LERF to 0.0. This maximizes the ΔCDF and ΔLERF in the sensitivity and the results will be below the acceptance criteria.

In the event that this method would result in a ΔCDF or ΔLERF significantly greater than the acceptance criteria, the PRA analyst would need to evaluate the compliant case conservatisms and determine a more realistic sensitivity analysis to address the issue. This would be done on a case-by-case basis. The following are possible examples of sensitivity analyses, which are not intended to specify required methods nor are they a complete set of possible methods for the sensitivities:

1. Set the compliant case failure probabilities associated with conservative assumptions to 0.0 and calculate ΔCDF and ΔLERF (without changing the degraded case assumptions). This is the most conservative calculation of the impact of the specific assumption(s).
2. Estimate EEFPs for the affected SSCs in the compliant case and calculate ΔCDF and ΔLERF (without changing the degraded case assumptions). This is a more realistic evaluation of the impact of the assumption, yet still conservative.
3. Estimate EEFPs for the affected SSCs in the compliant case and degraded case, and calculate ΔCDF and ΔLERF. This approach will provide insights into the impact of the assumptions, and could be compared with the results of example method 2, above.

7.3 Comparison to Risk Metric Thresholds

The TMRE results should be evaluated against the "very small" change in risk thresholds given in Regulatory Guide 1.174 (ΔCDF 10^{-6}/yr and ΔLERF 10^{-7}/yr). Prior to completing this comparison, the licensee should ensure that quantification is completed consistent with QU-D5 and QU-D7.

If the risk acceptance guidelines for a "very small change" based on RG 1.174, Revision 3 are exceeded, then the TMRE analysis inputs may be refined as allowed by the TMRE methodology. ~~However, if the thresholds for change in CDF or change in LERF are still exceeded, then the planned plant change cannot be made without pursuing additional actions (e.g. design change reducing delta CDF/LERF below the risk acceptance guidelines or NRC prior approval through a license amendment request.)~~

TMRE analyses will also appropriately consider any necessary sensitivity analyses. In general, the results of a particular~~the~~ sensitivity study should confirm that the "very small" risk change guideline is still met even under the alternative assumption(s) (i.e., the change generally remains in the "very small" region). If the results of a sensitivity study exceed the acceptance guidelines, NRC approval is required.~~Acceptability of a sensitivity study that exceeds the "very small" risk change guideline will be evaluated, reviewed, and approved consistent with required station procedures and processes. Should any sensitivity result exceedance evaluation determine that there is not reasonable justification for the exceedance, this would require NRC prior approval through a license amendment request.~~

7.4 MISSILE MARGIN ASSESSMENT

The site missile inventory could fluctuate due to construction activities. If a proposed construction activity would cause the site missile inventory to increase above the missile count used in the TMRE analysis, an assessment is needed to verify the higher missile count still meets the risk metric thresholds in Section 7.3 or prior NRC approval would be required. Any TMRE analysis could use a missile inventory higher than actual to provide margin for future increases in missile population if desired.

7.5~~4~~ ADDRESSING RISK SIGNIFICANT TARGETS

To address risk-significant targets, the licensee should first, identify which SSCs (targets) are contributing most significantly to the risk metrics, and second, identify what assumptions were made regarding the target. Once these identifications are made, the risk-significant targets can be addressed in a variety of manners.

- If the SSC is considered robust, the licensee may use fewer missiles.
- If all or part of the SSC is elevated (>30'), the elevated MIP value may be lower.
- If part of the SSC is shielded or inconsequential, a smaller area could be used.
- Consider a plant modification to provide shielding

A combination of these approaches can be used to ensure that defense-in-depth and safety margins, relative to the most risk-significant targets, are maintained.

7.6~~5~~ DEFENSE-IN-DEPTH AND SAFETY MARGIN

TMRE Defense-in-depth

Defense-in-depth is an approach to designing and operating nuclear facilities that prevents and mitigates accidents that release radiation or hazardous materials. The key is creating multiple independent and redundant layers of defense to compensate for potential human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon.
The TMRE analysis should include a discussion of defense-in-depth, including the use of access controls, physical barriers, redundant and diverse means of achieving key safety functions, and emergency response measures. The analysis should reflect the actual design, construction, and operational practices of the plant. Some examples of elements of defense-in-depth and means to meet them are shown below. Elements of defense-in-depth examples:

1. A reasonable balance is preserved among prevention of core damage, prevention of containment failure, and consequence mitigation.

Demonstrate that no new accidents or transients are introduced with the change, and that the facility is still well protected from tornado missiles. Ensure that no fission product barriers or key safety functions are disproportionately impacted by potential tornado missile damage.

2. Over-reliance on programmatic activities as compensatory measures associated with the change in the license basis is avoided.

Existing or new programmatic activities that help to mitigate tornado impacts should be discussed. However, it should be demonstrated that such activities are not necessary to maintain adequate defense-in-depth. For example, plants that have abnormal weather procedures with actions to secure tornado missiles should not depend on their ability to conduct such activities in tornado conditions; the design should be such that adequate defense-in-depth is maintained without it. Other examples of activities that may improve defense-in-depth for some plants are as follows: missile reduction, missile relocation, ongoing administrative control of missiles, and development of processes to conduct repair of key plant equipment that may be damaged during a tornado.

3. System redundancy, independence and diversity are preserved commensurate with the expected frequency, consequences of challenges to the system and uncertainties.

While the expected frequency of tornado strikes is low and missile strike damage even lower, and while adherence to the single-failure criterion establishes an acceptable level of defense-in-depth, it is prudent to improve defense-in-depth to overcome uncertainties (tornado strike time and place, missile location and path, plant configuration, etc.) Such measures may include incorporation of flex equipment and strategies into severe weather procedures, ensuring access following a severe weather event, and planning maintenance of key equipment such that it does not occur during times of the year when occurrence of tornados is more likely. Licensees may consider using other risk-informed approaches for which they have been licensed such as a Surveillance Frequency Control Program to ensure optimum alignment of activities impacting key equipment.

4. Defenses against potential common-cause failures are preserved, and the potential for the introduction of new common-cause failure mechanisms is assessed.

Potential common cause failures from tornado missile impacts and the impact to defense-in-depth should be analyzed to show that adequate defense-in-depth is maintained. In practice, common cause failures from missiles may sometimes be used for convenience in the PRA model; these types of failures should be discussed in the context of plant design features that provide defense against such failures.

5. Independence of barriers is not degraded.

Evaluate the design to ensure that no single failure from a tornado missile would introduce dependence between any two of the following: fuel cladding, reactor coolant system, or the containment.

6. Defenses against human errors are preserved.

Where available, discuss where automatic safety function features are maintained following tornado missile damage, decreasing the reliance on human actions. Where existing human actions may be required or where new human actions are introduced for the purpose of maintaining defense-in-depth, discuss the training, procedures, staging/briefing activities, and design features that will be used to successfully carry out such actions such that the tornado impacts will not significantly increase error likelihood.

7. The intent of the plant's design criteria is maintained.

The analysis of non-conforming equipment should show that, following an LOSP, an impact to any single active or passive component from a tornado missile does not completely eliminate the ability to perform key safety functions. For example, a missile impact to a diesel generator exhaust stack in a plant with two trains of emergency AC power should not prevent both diesel generators from performing their function. Success criteria from the PRA may be used to demonstrate satisfaction of defense-in-depth where multiple redundant components are available to accomplish a safety function, but some are vulnerable to tornado missiles. Additionally, the application should address specific targets that comprise 10% of the risk analysis acceptance criteria.

TMRE Adequate Safety Margin

Engineering evaluation should assess whether the impact of the proposed LB change is consistent with the principle that sufficient safety margins are maintained. Given that the risk assessment has shown that the change is acceptable, the conservative approaches used in the assessment should also be discussed. Examples include conservative modeling of physical correlation, conservative non-use of target shielding, conservative use of generic missile counts, and conservative non-use of adjustments to missile counts for robust targets. Additionally, discuss instances where the target failure mode is unlikely to result in a loss of function for the SSC.

8 PERFORMANCE MONITORING

Application of the TMRE methodology results in limited changes to the site-specific licensing basis to resolve nonconforming conditions. Generally, this is expected to be a one-time change to the plant's licensing basis to address a small set of exposed SSCs required to be protected from tornado missiles. Application of the TMRE methodology provides a basis for concluding that the risk to the plant associated with those exposed SSCs is sufficiently low that additional tornado missile protection need not be provided. Application of TMRE does not provide a basis for modifications to remove existing tornado missile protection at any time or to omit protection for new configurations (e.g. design changes) that otherwise require tornado missile protection according to the plant licensing basis.

8.1 PLANT CONFIGURATION CHANGES

Station design control programs that meet 10 CFR 50 Appendix B will ensure that subsequent configuration changes are evaluated for their impact on the TMRE risk basis for accepting the identified nonconforming conditions. Licensees shall ensure via applicable station procedures and processes that plant changes that result in an increase to the site missile burden are evaluated for impact on the TMRE analysis results. Periodic PRA Internal Events model of record updates or plant changes that impact the PRA Internal Events model of record but do not change the site missile burden do not require a TMRE analysis update.

Permanent changes within the 2500' missile radius that increase the site missile burden beyond that used for the TMRE analysis should be incorporated into the TMRE analysis prior to making the permanent change. Non-permanent construction-related missiles should be addressed in the TMRE analysis as indicated in Sections 3.4.3 and 7.4.

Changes to previous non-conforming SSCs that would increase the target EEFP (e.g. effect the target exposed area by increasing the exposed exhaust pipe height, effect a robust missile percentage by changing the pipe material or thickness) are not allowed under TMRE. Only changes that result in increased site missile burden require a TMRE analysis update.

If the approved TMRE analysis is updated as a result of a design change that increased the site missile burden, the following three items below should be used in updating the TMRE analysis:

- The most current PRA Internal Events model of record should be used for the analysis.
- The most recent approved revision of NUREG/CR-4461 should be used to ensure the tornado initiating event frequencies reflect the site tornado hazard.
- The treatment of previously identified non-conforming conditions in the TMRE model will continue to modeled as non-conforming conditions in the degraded case. There may be exceptions in the following cases where the non-conforming targets:
    - Have been physically protected in such a way that they would no longer be considered non-conforming at the time of the revision and can be removed from the TMRE analysis, or
    - Would not otherwise be considered non-conforming at the time of the revision because engineering calculations have demonstrated that they are conforming

The evaluation of the results of the updated TMRE analysis will be conducted in accordance with Section 7.3. If the thresholds of ΔCDF 10^{-6}/yr or ΔLERF 10^{-7}/yr are exceeded based on an updated TMRE analysis, then the planned plant modification cannot be made without pursuing additional actions (e.g. design change reducing delta CDF/LERF below the risk acceptance guidelines, NRC prior approval through a license amendment request.)

8.2 FUTURE IDENTIFICATION OF NONCONFORMING CONDITIONS

Additional legacy nonconforming conditions that were missed during the initial TMRE analysis, where tornado missile protection is required but not provided, may be resolved using TMRE, if appropriate. TMRE is not to be used for nonconforming conditions created as a result of future modifications without separate review and approval by the NRC.

If TMRE has been approved for the plant, the methodology must be applied as specified in the amended license. The TMRE analysis must be updated to reflect the newly identified legacy conditions, and the additional conditions must be identified in the updated FSAR. As with all plant changes 10 CFR 50.59 shall be applied to determine whether NRC approval is required.

The evaluation of the results of the updated TMRE analysis will be conducted in accordance with Section 7.3.

8.3 TMRE RESULTS AND CUMULATIVE RISK

The TMRE model results (i.e., ΔCDF and ΔLERF) are not intended to be used as a quantitative contribution to the plant's cumulative risk (i.e., internal events model, external hazards such as fire, seismic, and high winds) for the following reasons:

- Conservative assumptions used during TMRE modeling could mask risk insights from other hazards.
- The TMRE model analyzes the increase in risk due to tornado missile protection non-conformances and is not a best estimate of the total risk due to tornado missiles (e.g., vulnerabilities in the HWEL use the same EEFP in the compliant and degraded cases).
- The frequencies of tornados and basic event probabilities (EEFPs) are generally much lower than other random failures (e.g., FTR, FTS, FTO, FTC) for the same components and result in a lower change in risk.

In future risk-informed decision-making activities licensees may need to consider, as appropriate, the risk associated with previous nonconforming conditions that remain unprotected against tornado missile impacts.

APPENDIX A: TECHNICAL BASIS FOR TMRE METHODOLOGY

A.1. INTRODUCTION

The Tornado Missile Risk Evaluator (TMRE) will be used to estimate the quantitative risk associated with tornado-generated missiles at U.S. nuclear power plants (NPP). It is built upon a plant-specific internal events Probabilistic Risk Assessment (PRA) model and is intended to follow RG 1.174 guidance [Ref. A.6] This appendix describes:

- The elements and basis of the TMRE methodology
- Technical considerations and conservatisms
- Results of benchmark studies at two sites, comparing the TMRE results with RG 1.200 High Winds (HW) PRA results
- The basis for two required sensitivity studies (described in Section 7.2)

A.2. ELEMENTS OF TMRE

The major elements of the TMRE are:

- The internal events PRA model and the modifications made to it
  - The assumption of a non-recoverable Loss of Offsite Power
  - Accounting for impacts on operator actions
  - Accounting for failure of exposed non-safety related Structures, Systems or Components (SSCs)
- Use of a site-specific tornado frequency
- Addition of missile failure events for SSCs exposed to tornado missiles, using the Exposed Equipment Failure Probability (EEFP)
  - Missile Impact Parameter (MIP)
  - Exposed target Area
  - Missile inventory, including robust target considerations
  - Assumption of target failure (i.e., fragility = 1.0)
- Quantification and Comparison to Risk Metrics
- Sensitivity Analyses
- PRA Technical Adequacy

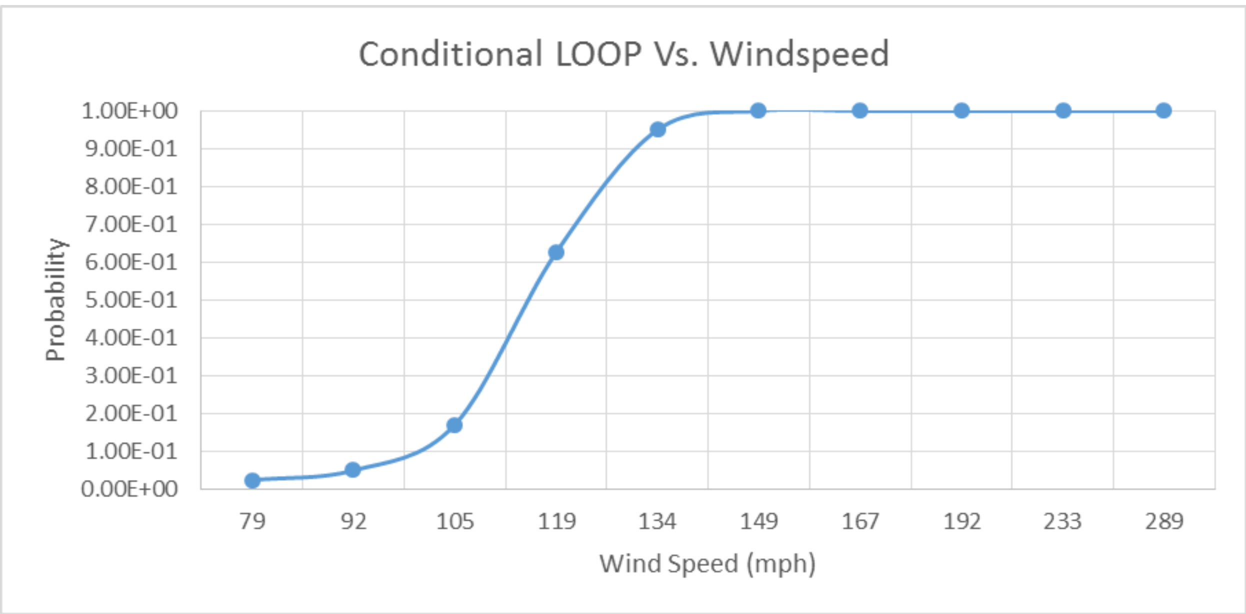
A.2.1 Modifications to the Internal Events PRA Model

Section 6 provides details on how the plant-specific internal events PRA model is modified for use in the TMRE. The use of the internal events PRA model in the TMRE follows the current standard practice in developing HW PRA models.

A.2.1.1 Non-recoverable Loss of Offsite Power (LOOP) Assumption

The significant difference in the TMRE method is that a LOOP is always assumed to occur in the TMRE, as opposed to using fragilities or other data to determine the likelihood of a LOOP. This is a reasonable assumption, given the likelihood of a LOOP event as a result of a site tornado strike of F'2 intensity or higher (i.e., greater than 103 mph). Figure A-1 shows the conditional LOOP probability (i.e., LOOP fragility) versus wind speed for a typical NPP [Ref. A.1]. Based on this curve, LOOP probability ranges from approximately 15% to 95% for F'2 tornado wind speeds (103 – 135 mph). The LOOP probability at the mean wind speed for F'2 (119 mph) is approximately 60%. Another study [Ref. A.2] showed that the probability of offsite failure approaches 1.0 at 112 mph.

Figure A-1: Conditional LOOP Probability



Furthermore, offsite power is assumed to be non-recoverable. This is consistent with current HW PRA assumptions; given a LOOP, no credit is given for offsite power recovery (i.e. non-recovery probability = 1.0) [Ref. A.2]. Although the assumption is somewhat conservative, it is reasonable to expect that offsite power will not be recovered or have a very high non-recovery probability if a tornado strikes the site and results in a LOOP. Note that tornado strikes offsite, which result in a LOOP due to transmission line or grid failure, are not considered tornado events in TMRE or HW PRAs.

The assumption that a LOOP occurs and is non-recoverable applies to both the Compliant and Degraded cases (see Section 6.3 for a discussion on Compliant and Degraded cases). This assumption challenges the mitigation capabilities of the plant, in that emergency power must survive tornado effects and operate for the full mission time, adequate cooling water supplies (e.g., condensate storage tanks) must survive, and balance of plant equipment (e.g., feedwater) is not available and cannot be recovered.

A.2.1.2 Impact on Operator Actions

The TMRE method requires that operator actions performed outside Category I structures be evaluated to ensure that they can be performed following a tornado event. Actions that cannot be performed (e.g., due to damage to non-Category I structures or non-safety related components) are set to fail (see Section 6.4). Short term operator actions (defined as occurring within 1 hour of the tornado event) that require transit or execution outside Category I structures are also assumed to fail in the TMRE method. These are reasonable assumptions and generally consistent with current high wind PRAs. Some considerations for failing such actions within 1 hour of the event ~~this treatment~~ are:

- There is some period of time following the event in which actions requiring transit or operation outside Category I structures is simply not feasible
- The time delay is affected not only by the conditions caused by the event (i.e., debris, damage, and destruction), but also by need to conduct post-event damage and safety assessments prior to dispatching operators outside protected structures.
- The uncertainty in the amount of damage and debris around the plant following the tornado event makes an exact time period impossible to define and justify
- Choosing a shorter time could underestimate the degraded case risk by crediting operator actions that could not be performed
- The risk increase from this assumption is expected to affect the degraded case more than the compliant case, since more SSCs (i.e., the non-conforming ones) will be failed in the degraded case sequences as compared to the compliant case
- The potential impact of masking risk increases due to a *potentially* conservative treatment in the compliant case is judged to be minimal, considering the points listed above
- Sensitivities to assess the potential impact of choosing 1 hour as the time period for failing ex-control room actions (as opposed to some other time frame) are impractical, lack technical justification, and would not provide any meaningful insight

Human Error Probabilities (HEP) changes are not made to other operator actions, such as those performed inside the main control room. This is different from current practice in HW PRAs (which evaluates all operator actions and makes changes to some of them), but is adequate for the TMRE:

- Currently, there is no detailed industry guidance for high wind human reliability analysis (HRA). The most relevant guidance document is the external events HRA EPRI guidance document [A.3] which is useful but not detailed for high wind HRA. The lack of a standard methodology results in significant judgment on the part of the HRA analysts, which would result in inconsistent application in the TMRE.

- Incremental changes to operator action HEPs as a result of degraded PSFs will typically be applicable to both the Compliant and Degraded Case, so the impact on the change in risk between the two cases should be insignificant.

- Long term actions~~, especially those~~ performed inside the control room or other Category I structures, should generally not be affected significantly, due to the short time frame in which the tornado is directly affecting the site.

- ~~Incremental changes to operator action HEPs as a result of degraded PSFs will typically be applicable to both the Compliant and Degraded Case, so the impact on the change in risk between the two cases should be insignificant.~~In addition to the factors discussed above, any changes to HEPs for long term actions requiring transit outside Category I structures are difficult to justify, are highly variable and uncertain, and are beyond the scope of the TMRE methodology.
  - Short term actions outside Category I structures are set to fail for all events, which is conservative, especially for lower intensity tornadoes.
  - Setting all actions requiring access to or transit through a non-Category I structure to fail may be conservative for certain intensity tornadoes, and does not take into account the potential success of such actions, dependent on the specific failure modes of such structures.
  - Repair actions are conservatively assumed to fail, unless specifically justified (see HR-H1/H2 in Appendix D).
  - Effects on long term actions outside Category I structures are highly dependent on the intensity of the tornado, the specific location and orientation of the tornado strike at the site, and the variability of the resultant debris field. Attempts to quantify changes to HEPs for such actions are speculative and subjective.

A.2.1.3 NON-CATEGORY I STRUCTURES AND EXPOSED NON-SAFETY RELATED SSCS

Section 6.6 provides guidance for addressing tornado wind impacts on SSCs that are not designed to withstand tornado wind pressures and atmospheric pressure changes.

It is reasonable to expect that non-Category I structures (i.e., those built to industrial or commercial building codes) will not withstand the wind pressures associated with F’2 or greater tornadoes[9]. While there is some likelihood that such a structure might withstand tornado wind pressures associated with an F’2 tornado, even engineered structures are likely to fail at higher intensity tornadoes. Figure C-17 shows the missile release fraction for engineered and pre-engineered structures. This fraction is a surrogate for the amount of damage likely to occur to an engineered or pre-engineered structure. Based on Figure C-17, F’3 tornadoes result in approximately 40% damage to such a structure, F’4 results in 80% damage, and F’5 and F’6 tornadoes result in greater than 90% damage. At 40% or greater damage, SSCs within the structure are exposed to tornado wind forces and may be directly damaged by structural collapse or debris. SSCs adjacent to the structure are likely impacted by the failure of the structure (e.g., structural collapse or large structural component impact), and therefore are conservatively assumed to fail with a probability of 1.0.

The assumption that active SSCs (e.g., pumps, compressors) exposed to tornado wind effects will fail at tornado intensities at or above F’2 is also reasonable. These types of components are not designed to

[9] Turbine buildings are typically not considered in this category, as the cladding or siding is designed to come off at a certain wind speed (e.g., 90 – 120 mph) to prevent structural failure of the building.

withstand such forces; they may become misaligned, support systems (e.g., electrical cables, junction boxes,) may be dislodged or uncoupled, or lightweight debris may affect the equipment operation.

Most such SSCs of this type are considered to be failed in both the Compliant and Degraded cases. This should generally lead to conservative results, but the impact of these assumptions should be evaluated to ensure the conservative assumptions do not mask significant increases in risk between the Compliant and Degraded cases. Section 7.2.3 provides guidance on performing sensitivity studies that addresses this specific issue.

A.2.2 SITE-SPECIFIC TORNADO HAZARD

Section 4 provides details on the calculation of the site-specific tornado frequencies to use in the TMRE model. NUREG/CR-4461 Revision 2 is recommended as the data source. This is the most recent public tornado hazard analysis performed by the NRC for the U.S NPPs., and includes tornado frequencies developed for each plant site.

A.2.3 THE EXPOSED EQUIPMENT FAILURE PROBABILITY

Section 5 and Appendix B provide details on the basis of EEFP calculation, the derivation and bases of the factors associated with the EEFP, and methods to perform SSC-specific EEFP calculations. The variables and factors included in the EEFP were developed in an effort to provide a conservative estimate of SSC failure probability. Section A.5 provides the results of two benchmark studies, comparing the EEFP to TORMIS-based SSC missile failure probabilities; see Tables A-4, A-6 and A-7. The MIP values, missile inventories and the assumption that SSCs hit by tornado missiles will fail (i.e., fragility = 1.0) were developed to be used together, and should not be modified. Although each variable may not be conservative by itself, the combination of variables used for different targets and tornado wind speeds provides a bounding estimate of the change in CDF associated with nonconforming SSCs (Section A.5 provides results of benchmark studies comparing TMRE results with the results of HW PRAs).

The details of the basis for each of the variables used in the EEFP calculation are provided in the guidance document:

- Section B.1 provides background and precedent for the use of a simplified analysis to determine a target missile hit probability. Appendix B describes additional details of the derivation of the Missile Impact Parameter (MIP) and Sections A.6 and A.7 of this appendix discuss uncertainties associated with the MIP.

- Section 5.3 describes the process for determining the target exposed area, used in the EEFP calculation, and provides example calculations. The target exposed area calculation described in Section 7.3 is realistic.

- Section 5.2 describes the method for determining the missile inventory to use in the EEFP calculations. Appendix B describes the basis for the generic and bounding missile inventory. Licensees are expected to validate the TMRE missile inventory is bounding; if this is not the case, a bounding site-specific missile inventory should be developed. The area surrounding the plant, which is used for the missile inventory, is consistent with the TORMIS simulations results in EPRI NP-768 [Ref. A.4] that are the basis for the MIP derivation.

- Target fragilities are assumed to be equal to 1.0; if a target is struck by a damaging missile, it is assumed to fail. Some consideration is given to robust targets, given that not all missiles included in the site missile inventory can damage certain targets (e.g., steel tanks and pipes, reinforced concrete roofs). The basis for the reduction of missile inventories for certain targets is provided in Appendices B and C.

A.2.4 Quantification and Comparison to Risk Metrics

CDF and LERF quantification is performed on two versions of the TMRE model, the Compliant Case and the Degraded Case. The primary difference between the two cases is the treatment of non-conformances. In the Compliant Case, each non-conforming SSC is assumed to be protected, such that tornado missiles cannot strike or damage the SSC. In the Degraded Case, failure of the non-conforming SSCs due to tornado missiles is represented by the EEFP. Other SSCs that may be failed by either tornado missiles or tornado wind pressure are treated the same in both the Compliant and Degraded cases. This includes failure of unprotected (vulnerable) safety related SSCs that are in compliance with the licensing basis.

The difference between the Compliant and Degraded case CDF and LERF (i.e., ΔCDF and ΔLERF) is the risk associated with not providing missile protection for the non-conforming SSCs. ΔCDF and ΔLERF are compared to the thresholds in RG 1.174 to determine the acceptability of the risk increase associated with not protecting non-conforming SSCs. This process is a typical application of RG 1.174 for risk-informed license changes.

A.2.5 TMRE PRA Technical Adequacy

The requirements for PRA technical adequacy, as applied to the TMRE PRA, are described in Section 6.7, Section 7.2 and Appendix D. The technical adequacy of the base internal events PRA must be addressed consistent with the ASME PRA Standard, the changes made to create the TMRE PRA must be evaluated against Appendix D, and the TMRE-specific calculations (e.g., EEFP) must be performed in accordance with this guidance document. Section 7.2 provides guidance on addressing open peer review Findings and Observations (F&Os) on the base internal events PRA.

A.3. Southwest Research Institute Review

During the development of the TMRE methodology, the NRC sponsored an independent evaluation of the TMRE method [Ref. A.5], specifically focusing on the derivation of MIP from EPRI NP-768 and the generic applicability of the TMRE MIP values to NPP sites in the U.S. The overall conclusions of the report state: “In general, we considered the MIP concept defensible. “

However, two issues were recommended for further analysis:

- “…additional work is necessary to address the problem of missile clusters of variable spread and variable distance to targets.” This concern is addressed in the Zonal vs Uniform sensitivity required in Section 7.2.1, based on the analysis provided in Section A.7 of this appendix.

- “Additional work is also needed to define MIP values that are independent of the building configuration.” The Southwest Research Institute report suggests that Target 6 in Plant A (NP-768) may be isolated enough to not be affected by other buildings. MIP values were derived from the different target buildings in NP-768 Plant A, and Target 4 was determined to have the highest MIP values (higher than Target 6, except for F'6). The MIP values derived from Target 4 are compared to the MIP values derived from all the buildings(see Section A.6 for more details).

A.4. Conservative Aspects of TMRE

Several conservative assumptions are discussed in Section A.2, with regards to the creation of the TMRE PRA model and the calculation of the EEFP. Some additional conservative aspects of the TMRE method are described here.

1. The MIP is derived from the single missile hit probability values in EPRI NP-768. Section B.2.1 describes how multiplying the single missile hit probability by the number of missiles (as is done in the EEFP) is likely conservative.

2. Separate MIP values are derived for elevated targets (nominally defined as 30' above associated reference elevation). Although the elevated MIP values are lower than the near ground MIP values, they are based on missile hit probabilities at all elevations, from the ground to the roof level of all targets in Plant A of NP-768. The Elevated Target MIP value derivation includes data from Target 6, whose surfaces are all completely below the 30' elevation; this tends to bias the MIP value higher.

3. Missile inventories for robust targets are conservative. Appendix C and Section B.6 describe the calculations used to determine the types of missiles that can damage robust targets. Two assumptions in the calculations used to determine missile damage to targets are:

    a. The missile is travelling at design speed. This assumption ensures that the damage caused by a missile on a target is realistic only for the highest intensity tornadoes (e.g., F'6) and is conservative for all lower intensity tornadoes. Since F'2 and F'3 tornadoes are much more frequent (e.g., by at least an order of magnitude) than higher intensity tornadoes, this conservatism can have a significant impact on the overall risk associated with missile hits on non-conforming targets.

    b. The missile strikes the target directly at a normal orientation (i.e., an ideal impact). Due to the chaotic nature of tornado winds, it is unlikely that a missile will strike a target directly. Indirect strikes will impart less energy on the target than assumed in the Appendix C calculations, such that a smaller percentage of the assumed missiles are likely to damage a robust target.

Sensitivity studies are directed in Section 7.2 to address:

- The potential for non-conservative ΔCDF and ΔLERF calculations due to conservative assumptions regarding SSC failures in the Compliant Case

- Missile distribution uncertainty potentially affecting the derivation of the MIP values

A.5. Benchmark Results

Benchmark studies were performed for two plants, to compare results using the TMRE methodology against the results associated with a peer reviewed TORMIS-based HW PRA. The following were compared:

- Total CDF/ΔCDF
- Dominant accident sequence CDF/ΔCDF contribution
- Individual SSC CDF/ΔCDF contribution
- Failure probability of individual SSCs at five different tornado intensities (F'2 through F'6)

It should be noted that even though the TMRE resulted in conservative overall results and a majority of the target comparisons were conservative to the TORMIS-based failure probabilities, the TORMIS-based analyses are already conservative[10]. Thus, the TMRE comparisons are being made to conservative benchmarks.

Additionally, the Plant X and Y TMRE PRA calculations for ΔCDF and CDF were performed using EEFPs based on NEI 17-02 Revision 1 Near Ground (<30') MIPs. The updated Near Ground MIPs in this revision (see Table 5-1) are approximately 30% higher than in Revision 1. Therefore, had the PRA calculations been re-performed with the higher EEFPs, there would be more margin between the TMRE and HW PRA results. However, the target failure probability comparisons provided in Tables A-3, A-6, and A-7 are based on the MIP values in Table 5-1 of this revision to NEI 17-02.

The two benchmark plants are denoted Plant X and Plant Y. Both plants showed conservative TMRE total CDF/ΔCDF compared to the HW PRA results[11]. Table A-1 provides a comparison of CDF/ΔCDF for both plants.[12]

Table A-1

Comparison of CDF and ΔCDF for Benchmark Plants

Plant	TMRE	HW PRA	Difference	Ratio
X	ΔCDF = 8.6E-7/yr	ΔCDF = 1.6E-7/yr	7.0E-7/yr	5.4
Y	CDF = 1.1E-5/yr	CDF = 2.0E-6/yr	9.0E-6/yr	5.5

Comparisons of sequence- and target-level CDF/ΔCDF contributions and target-level damage probabilities are provided in the subsections specific to each of the benchmark plants.

A.5.1 Plant X

[10] Several conservatisms are described in TORMIS analyses used for design basis applications. These same conservatisms are typically maintained in TORMIS analyses used to support HW PRAs.
[11] Plant X ΔCDF results in Tables A-1 and A-2 are based on EEFPs calculated using NEI 17-02 Rev. 0 robust missile percentages and NEI 17-02 Rev. 1 Near Ground (<30') MIPs. Plant Y CDF results in Tables A-4 and A-5 are based on EEFPs calculated using NEI 17-02 Rev. 1 Near Ground (<30') MIPs.
[12] Plant X computed the ΔCDF between the degraded and compliant cases, whereas Plant Y computed only the degraded case CDF.

Plant X is a dual unit PWR located in RG 1.76 [Ref. A.7] Region I. Only one unit is evaluated, since the units are more or less symmetric. Sequence level ΔCDF comparisons are provided in Table A-2. The comparison shows that the ΔCDF for the top 5 TMRE sequences are all conservative, when compared to the comparable HW PRA sequences.[13]

TABLE A-2

Comparison of Sequence-Level ΔCDF for Plant X

Sequence	Sequence Description	TMRE RANK	TMRE CDF (yr^{-1})	RG 1.200 RANK	RG 1.200 CDF (yr^{-1})	TMRE/ RG1.200
TI-004	LOOP with Loss of Aux Feed and F&B	1	6.6E-07	1	1.2E-07	5.4
SBO-098	LOOP (SBO) - Loss of Aux Feed and Alternate Power Supply	2	1.0E-07	4	6.4E-09	15.7
TI-003	LOOP and Loss of Aux Feed, with F&B success	3	5.1E-08	3	1.4E-08	3.6
LIFTWAY	Liftway Failure	4	4.7E-08	2	1.7E-08	2.8
S2-022	LOOP with Consequential Small LOCA	5	5.1E-09	6	8.2E-10	6.2
	Total CDF		8.6E-07		1.6E-07	5.4

Due to the method in which targets were grouped in the Plant X HW PRA, it is difficult to compare target-to-target damage probabilities for each of the targets; only a limited set of 6 targets (30 failure probabilities) could be readily compared directly. They are shown in Table A-3[14]. Target comparisons for F'2 and F'3 tornadoes are highlighted, since the majority of the risk is from F'2 and F'3 tornadoes. In many cases, the F'2 and F'3 failure probability ratios for a given target are the highest, but this is not always the case; for some targets, the highest ratio may be in F'4, F'5, or F'6 failure probabilities.

[13] Sequence 5 in the HW PRA is not modeled in the TMRE, since it was determined to not be modeled very conservatively and still not be significant to the HW PRA results.

[14] Although Plant X ΔCDF results are based on EEFPs calculated using NEI 17-02 Rev. 0 robust missile percentages, the TMRE failure probabilities in Table A-3 are based on robust missile percentages from Table 5-2 of this revision of NEI 17-02. Additionally, the Plant X ΔCDF results are based on EEFPs using the NEI 17-02 Rev. 1 Near Ground (<30') MIPs, the TMRE failure probabilities in Table A-3 are based on the Table 5-1 MIPs from this revision of NEI 17-02.

Of the 30 target failure probabilities compared, the TMRE failure probabilities were conservative to all but 3 of the TORMIS-based failure probabilities. Those failure probabilities are associated with F'4 through F'6 tornado missile failures of the turbine-driven AFW pump steam exhaust stack. If this SSC were determined to be risk significant and highly exposed, as defined in Section 7.2.1, performing the missile distribution (Z vs U) sensitivity analysis would increase the failure probabilities to above (or nearly equal, in the case of F'6) to the HW PRA failure probabilities. [Note: The turbine-driven AFW pump steam exhaust stack contributes less than 1% to the tornado missile risk.]

TABLE A-3

COMPARISON OF TARGET FAILURE PROBABILITIES FOR PLANT X

Target	Failure Modes	Size/Location	F' scale	TMRE Probability	RG 1.200 Probability	TMRE vs RG 1.200
Condensate Storage Tanks	Tank Perforation	Area ~ 3200 sq ft Elevation <30 ft	F'2	2.8E-02~~2.2E-02~~	4.6E-03	6.0~~4.7~~
			F'3	9.1E-02~~7.1E-02~~	2.0E-02	4.6~~3.6~~
			F'4	2.1E-01~~1.7E-01~~	1.1E-01	1.9~~1.5~~
			F'5	6.1E-01~~4.9E-01~~	3.9E-01	1.6~~1.3~~
			F'6	9.5E-01~~7.4E-01~~	6.9E-01	1.4~~1.1~~
PAB Liftway	Missile Hit	Area ~ 180 sq ft Elevation <30 ft	F'2	3.9E-03~~3.1E-03~~	1.3E-04	30~~24~~
			F'3	1.3E-02~~1.0E-02~~	3.7E-04	35~~27~~
			F'4	2.9E-02~~2.3E-02~~	1.4E-03	21~~17~~
			F'5	8.6E-02~~6.9E-02~~	3.4E-03	25~~20~~
			F'6	1.3E-01~~1.0E-01~~	4.9E-03	27~~21~~
Central SW Header	Pipe Perforation	Area ~ 470 sq ft Elevation < 30 ft	F'2	3.6E-03~~2.8E-03~~	1.5E-05	238~~187~~
			F'3	1.2E-02~~9.2E-03~~	3.1E-05	379~~297~~
			F'4	2.7E-02~~2.1E-02~~	9.2E-05	290~~231~~
			F'5	7.9E-	2.1E-04	377~~301~~

Target	Failure Modes	Size/Location	F' scale	TMRE Probability	RG 1.200 Probability	TMRE vs RG 1.200
				02~~6.3E-02~~		
			F'6	1.2E-01~~9.5E-02~~	3.8E-04	323~~250~~
West SW Header	Pipe Perforation	Area ~ 60 sq ft Elevation < 30 ft	F'2	4.4E-04~~3.5E-04~~	3.5E-06	127~~100~~
			F'3	1.5E-03~~1.1E-03~~	3.0E-05	49~~38~~
			F'4	3.3E-03~~2.6E-03~~	1.9E-04	17~~14~~
			F'5	9.8E-03~~7.9E-03~~	9.2E-04	10.7~~8.5~~
			F'6	1.5E-02~~1.2E-02~~	1.8E-03	8.5~~6.6~~
North SW Roof	Concrete Roof Perforation	Area ~ 750 sq ft Elevation < 30 ft	F'2	3.3E-03~~2.6E-03~~	1.5E-05	217~~171~~
			F'3	1.1E-02~~8.4E-03~~	2.9E-04	37~~29~~
			F'4	2.4E-02~~1.9E-02~~	7.7E-04	32~~25~~
			F'5	7.2E-02~~5.8E-02~~	1.5E-03	48~~38~~
			F'6	1.1E-01~~8.6E-02~~	2.3E-03	49~~38~~
TD AFW Pump Exhaust Stack	Exhaust Pipe Crushing	Area ~ 315 sq ft Elevation < 30 ft	F'2	3.4E-03~~2.7E-03~~	9.1E-04	3.8~~3.0~~
			F'3	1.1E-02~~8.8E-03~~	5.8E-03	1.9~~1.5~~
			F'4	2.6E-02~~2.0E-02~~	4.5E-02	0.6~~0.5~~

Target	Failure Modes	Size/Location	F' scale	TMRE Probability	RG 1.200 Probability	TMRE vs RG 1.200
			F'5	7.6E-02~~6.1E-02~~	2.5E-01	0.3~~0.2~~
			F'6	1.2E-01~~9.1E-02~~	5.0E-01	0.2~~0.2~~

A.5.2 Plant Y

Plant Y is a dual unit PWR, also located in RG 1. 76 Region I. Only one unit is compared, since the units are more or less symmetric. Sequence-level CDF comparisons are provided in Table A-4. The comparison shows that the TMRE CDF for 3 of the top 4 HW PRA sequences[15] are conservative, and one sequence is essentially the same (TMRE CDF for sequence TQX is 90% of the HW PRA CDF). Note that the absolute value of sequence TQX is less than 1E-8/yr.

Table A-4

Comparison of Sequence-Level ΔCDF for Plant Y

Sequence	Sequence Description	TMRE Rank	TMRE CDF (yr^{-1})	RG 1.200 Rank	RG 1.200 CDF (yr^{-1})	TMRE/ RG1.200
TBU	Transient with a loss of SSHR and injection fails	1	1.0E-05	1	1.9E-06	5.3
TQU	Transient LOCA with a failure of Injection	2	1.2E-07	2	9.1E-08	1.3
TQX	Transient LOCA with a failure of recirculation	3	6.2E-09	4	6.9E-09	0.9
TBX	Transient with a loss of SSHR and recirculation fails	4	3.7E-09	3	6.9E-10	5.4
ATWS	ATWS Sequence	NA	NA	5	5.4E-11	Not in TMRE
	Total CDF		1.1E-05		2.0E-06	5.5

[15] HW PRA Sequence 5 is not modeled in the TMRE PRA, due to its very low risk contribution (CDF less than 1E-10/yr).

Table A-5 compares the SSC contribution to CDF between the TMRE and HW PRA results, based on the combined Fussel-Vesely importance values across all five tornado intensities (F'2 through F'6). Truncation for CDF was set to 1E-11/yr; only the 8 SSCs shown in Table A-6 were included in the CDF cut sets. The TMRE CDF contributions for all 8 SSCs are conservative to the HW PRA CDF contributions.

TABLE A-5

COMPARISON OF SSC CONTRIBUTION TO CDF FOR PLANT Y

TARGET	TARGET DESCRIPTION	TMRE CDF (YR^{-1})	RG 1.200 CDF (YR^{-1})	TMRE/ RG1.200
MSLINE	MAIN STEAM LINES NEAR EDG AIR INTAKE	7.7E-06	2.3E-08	335
FWLINE	MAIN FEEDWATER LINES NEAR EDG AIR INTAKE	2.8E-06	1.8E-06	1.6
RWST	REFUELING WATER STORAGE TANK	1.9E-08	1.4E-09	14
EDG B	EMERGENCY DIESEL GENERATOR TRAIN B	3.1E-09	4.6E-10	6.7
EDG A	EMERGENCY DIESEL GENERATOR TRAIN A	2.8E-09	4.4E-10	6.4
BSW	BACKUP SERVICE WATER SUPPLY OUTDOOR VALVE IN A VALVE PIT	2.4E-09	5.2E-11	46
IA DC	FAILURE OF BACKUP IA HEADER	1.8E-09	1.4E-09	1.3
TDPEX	TURBINE DRIVEN PUMP STEAM EXHAUST LINE	NA(1)	NA(1)	NA

NOTES: (1) TRUNCATED IN TMRE AND RG 1.200 HW PRA

Tables A-6 and A-7[16] compare the TMRE target damage probabilities of 29 targets for five tornado intensities (145 failure probabilities) with the HW PRA target failure probabilities (based on TORMIS analyses). The top targets in Table A-6 are the same as those listed in Table A-5, i.e., the targets that contribute to tornado missile risk at Plant Y. Failures for the other SSCs (listed in Table A-7) are truncated in the CDF cut sets, i.e., they do not contribute to tornado missile risk. The targets in Table A-7 are provided here to compare failure probabilities only.

[16] Although Plant X ΔCDF results are based on EEFPs calculated using NEI 17-02 Rev. 0 robust missile percentages, the TMRE failure probabilities in Table A-3 are based on robust missile percentages from Table 5-2 of this revision of NEI 17-02. Additionally, the Plant X ΔCDF results are based on EEFPs using the NEI 17-02 Rev. 1 Near Ground (<30') MIPs, the TMRE failure probabilities in Table A-3 are based on the Table 5-1 MIPs from this revision of NEI 17-02.

TMRE failure probabilities for the 7 targets (35 failure probabilities) in Table A-5 are conservative to the HW PRA failure probabilities; this is expected, given the CDF contribution comparisons in Table A-5. Of the remaining 110 failure probability comparisons (in Table A-7), ~~14~~ 10 TMRE target failure probabilities are not conservative when compared to the TORMIS-based probabilities. These targets (which have negligible risk impact) are characterized as follows:

- F'2 4 SG PORVs with TORMIS failure probabilities ~1E-3
- F'3 ~~4~~ 3 SG PORVs with TORMIS failure probabilities ~2E-3
- F'4 SG PORV with TORMIS failure probability ~3 E-3

  Transformer/Load Center with TORMIS failure probability ~0.3
- F'5 Transformer/Load Center with TORMIS failure probability ~0.3~~Vent pipe with TORMIS failure probability ~7E-4~~

  ~~Transformer/Load Center with TORMIS failure probability ~0.3~~
- F'6 ~~Vent pipe with TORMIS failure probability ~1E-3~~None

  ~~Transformer/Load Center with TORMIS failure probability ~0.4~~

A review of these targets was performed; it is noted that most of these targets are within a factor of 2 of the TORMIS-based failure probabilities, and some are very close (within ~~10% –~~ ~20%). Since these are not important targets in the HW PRA, it is unlikely that much, if any, effort was made to reduce the fragilities or failure rates for these SSCs. This may be the reason why the HW PRA failure probabilities are higher than the TMRE failure probabilities.

If these targets were determined to be risk significant and highly exposed per Section 7.2.1, a sensitivity study would be performed. However, none of the targets with TMRE lower failure probabilities are significant to CDF in either the TMRE or HW PRA results (they do not contribute to CDF at a truncation of 1E-11/yr).

Table A-6

Comparison of Target Failure Probabilities for Plant Y

Target	Failure Modes	Size/Location	F' Scale	TMRE Probability	RG 1.200 Probability	TMRE/ RG 1.200
Main Steam Piping [MSLINE]	Pipe Perforation	Area ~ 7600 sq ft Elevation < 30 ft	F'2	5.8E-02~~4.5E-02~~	2.2E-07	266,789~~209,620~~
			F'3	1.9E-01~~1.5E-01~~	1.2E-04	1,559~~1,220~~
			F'4	4.3E-01~~3.4E-01~~	1.9E-03	227~~181~~
			F'5	1.0E+00~~1.0E+00~~	4.9E-03	206~~206~~
			F'6	1.0E+00~~1.0E+00~~	1.2E-02	82~~82~~
Main FW Piping [FWLINE]	Pipe Perforation	Area ~ 2800 sq ft Elevation < 30 ft	F'2	2.1E-02~~1.7E-02~~	9.8E-07	21,613~~16,982~~
			F'3	6.9E-02~~5.4E-02~~	3.9E-05	1,768~~1,384~~
			F'4	1.6E-01~~1.3E-01~~	6.1E-04	256~~204~~
			F'5	4.7E-01~~3.7E-01~~	1.8E-03	256~~205~~
			F'6	7.2E-01~~5.6E-01~~	4.3E-03	169~~131~~
Refueling Water Storage Tank [RWST]	Tank Perforation	Area ~ 3800 sq ft Elevation < 30 ft	F'2	3.3E-02~~2.6E-02~~	7.0E-04	47~~37~~
			F'3	1.1E-01~~8.4E-02~~	3.0E-03	35~~28~~
			F'4	2.4E-01~~1.9E-01~~	2.5E-02	9.9~~7.9~~
			F'5	7.2E-01~~5.8E-01~~	5.7E-02	13~~10~~
			F'6	1.0E+00~~8.7E-01~~	9.8E-02	10~~8.9~~
EDG B (Exhaust and Intake) [EDG B]	Penetrate Missile Barriers	Area ~ 150 sq ft Elevation < 30 ft	F'2	1.4E-03~~1.1E-03~~	2.0E-05	70~~55~~
			F'3	4.7E-03~~3.6E-03~~	2.5E-04	18~~14~~
			F'4	1.1E-02~~8.4E-03~~	1.9E-03	5.5~~4.4~~
			F'5	3.1E-02~~2.5E-02~~	3.5E-03	9.1~~7.3~~

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
			F'6	4.9E-02~~3.8E-02~~	6.2E-03	7.8~~6.1~~
EDG A (Exhaust and Intake) [EDG A]	Penetrate Missile Barriers	Area ~ 150 sq ft Elevation < 30 ft	F'2	1.4E-03~~1.1E-03~~	2.6E-05	55~~43~~
			F'3	4.7E-03~~3.6E-03~~	2.5E-04	19~~15~~
			F'4	1.1E-02~~8.4E-03~~	1.8E-03	5.8~~4.6~~
			F'5	3.1E-02~~2.5E-02~~	3.8E-03	8.3~~6.6~~
			F'6	4.9E-02~~3.8E-02~~	6.2E-03	7.8~~6.0~~
Service Water Piping and Valve (in Valve Pit) [BSW]	Pipe and Valve Perforation	Area ~ 35 sq ft Elevation < 30 ft	F'2	2.7E-04~~2.1E-04~~	5.0E-07	527~~414~~
			F'3	8.7E-04~~6.8E-04~~	6.6E-06	132~~103~~
			F'4	2.0E-03~~1.6E-03~~	8.7E-05	23~~18~~
			F'5	5.9E-03~~4.7E-03~~	1.6E-04	37~~30~~
			F'6	9.1E-03~~7.1E-03~~	1.7E-04	54~~42~~
Diesel-driven Air Compressors and Piping [IA DC]	Compressor and Pipe Hit	Area ~ 1200 sq ft Elevation < 30 ft	F'2	2.6E-02~~2.1E-02~~	1.2E-03	23~~18~~
			F'3	8.7E-02~~6.8E-02~~	6.4E-03	14~~11~~
			F'4	2.0E-01~~1.6E-01~~	4.2E-02	4.7~~3.7~~
			F'5	5.8E-01~~4.7E-01~~	7.8E-02	7.4~~6.0~~
			F'6	9.1E-01~~7.0E-01~~	1.2E-01	7.7~~6.0~~

TABLE A-7

COMPARISON OF NON-RISK SIGNIFICANT TARGET FAILURE PROBABILITIES FOR PLANT Y

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
TD AFW Pump Exhaust Stack [TDPEX]	Exhaust Pipe Crushing	Area ~ 170 sq ft Elevation > 30 ft	F'2	7.6E-05	0.0E+00	NA
			F'3	2.6E-04	3.4E-06	76
			F'4	5.9E-04	3.3E-05	18
			F'5	1.8E-03	1.8E-04	10
			F'6	2.6E-03	3.3E-04	8
SG A PORV and Exhaust Stack	Valve Hit and Pipe Crush	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.5E-04	1.4E-03	0.3
			F'3	1.2E-03	2.5E-03	0.5
			F'4	2.7E-03	3.4E-03	0.8
			F'5	8.1E-03	4.6E-03	1.8
			F'6	1.2E-02	6.4E-03	1.9
SG B PORV and Exhaust Stack	Valve Hit and Pipe Crush	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.5E-04	8.4E-04	0.4
			F'3	1.2E-03	1.6E-03	0.8
			F'4	2.7E-03	2.6E-03	1.1
			F'5	8.1E-03	3.6E-03	2.2
			F'6	1.2E-02	4.0E-03	3.0
SG C PORV and Exhaust Stack	Valve Hit and Pipe Crush	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.5E-04	6.5E-04	0.5
			F'3	1.2E-03	1.2E-03	1.0
			F'4	2.7E-03	2.0E-03	1.4
			F'5	8.1E-03	2.8E-03	2.8
			F'6	1.2E-02	3.0E-03	4.1
SG D PORV	Valve Hit	Area ~ 65 sq ft	F'2	3.5E-04	1.0E-03	0.3

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
and Exhaust Stack	and Pipe Crush	Elevation > 30 ft	F'3	1.2E-03	1.6E-03	0.8
			F'4	2.7E-03	2.0E-03	1.3
			F'5	8.1E-03	2.8E-03	2.9
			F'6	1.2E-02	4.1E-03	2.9
SG A PORV Block Valve and Piping to PORV	Valve Hit and Pipe Perforation	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.0E-04	1.4E-04	2.2
			F'3	1.0E-03	2.5E-04	4.2
			F'4	2.4E-03	5.8E-04	4.1
			F'5	7.1E-03	1.3E-03	5.4
			F'6	1.1E-02	2.4E-03	4.3
SG B PORV Block Valve and Piping to PORV	Valve Hit and Pipe Perforation	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.0E-04	2.3E-04	1.3
			F'3	1.0E-03	4.4E-04	2.4
			F'4	2.4E-03	6.7E-04	3.5
			F'5	7.1E-03	9.4E-04	8.0
			F'6	1.1E-02	1.4E-03	8.0
SG C PORV Block Valve and Piping to PORV	Valve Hit and Pipe Perforation	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.0E-04	2.9E-04	1.1
			F'3	1.0E-03	4.3E-04	2.4
			F'4	2.4E-03	4.4E-04	5.3
			F'5	7.1E-03	6.1E-04	12
			F'6	1.1E-02	8.0E-04	13
SG D PORV Block Valve and Piping to PORV	Valve Hit and Pipe Perforation	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.0E-04	2.7E-04	1.1
			F'3	1.0E-03	5.2E-04	2.0
			F'4	2.4E-03	6.6E-04	3.6

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
			F'5	7.1E-03	1.0E-03	7.1
			F'6	1.1E-02	2.0E-03	5.2
MSSV Train A Piping	Pipe Perforation	Area ~ 30 sq ft Elevation > 30 ft	F'2	2.3E-04	0.0E+00	NA
			F'3	7.8E-04	0.0E+00	NA
			F'4	1.8E-03	4.9E-06	360
			F'5	5.3E-03	2.1E-06	2,506
			F'6	7.9E-03	1.5E-06	5,385
MSSV Train B Piping	Pipe Perforation	Area ~ 50 sq ft Elevation > 30 ft	F'2	2.3E-04	0.0E+00	NA
			F'3	7.8E-04	8.6E-07	905
			F'4	1.8E-03	5.4E-06	327
			F'5	5.3E-03	3.1E-07	16,811
			F'6	7.9E-03	3.3E-05	238
MSSV Train C Piping	Pipe Perforation	Area ~ 30 sq ft Elevation > 30 ft	F'2	1.5E-04	0.0E+00	NA
			F'3	5.0E-04	0.0E+00	NA
			F'4	1.1E-03	2.5E-06	455
			F'5	3.4E-03	3.2E-06	1,070
			F'6	5.1E-03	4.8E-06	1,049
MSSV Train D Piping	Pipe Perforation	Area ~ 50 sq ft Elevation > 30 ft	F'2	1.5E-04	0.0E+00	NA
			F'3	5.0E-04	0.0E+00	NA
			F'4	1.1E-03	0.0E+00	NA
			F'5	3.4E-03	2.7E-05	127
			F'6	5.1E-03	3.3E-06	1,550

Target	Failure Modes	Size/Location	F' Scale	TMRE Probability	RG 1.200 Probability	TMRE/ RG 1.200
MSIV A	Air Supply Piping Crushing	Area ~ 190 sq ft Elevation > 30 ft	F'2	8.5E-04	0.0E+00	NA
			F'3	2.9E-03	2.7E-07	10,914
			F'4	6.6E-03	2.5E-07	26,419
			F'5	2.0E-02	2.2E-07	88,811
			F'6	2.9E-02	1.5E-06	20,088
MSIV B	Air Supply Piping Crushing	Area ~ 190 sq ft Elevation > 30 ft	F'2	8.5E-04	0.0E+00	NA
			F'3	2.9E-03	0.0E+00	NA
			F'4	6.6E-03	2.4E-06	2,741
			F'5	2.0E-02	2.8E-06	7,060
			F'6	2.9E-02	3.6E-06	8,147
MSIV C	Air Supply Piping Crushing	Area ~ 140 sq ft Elevation > 30 ft	F'2	6.3E-04	0.0E+00	NA
			F'3	2.2E-03	0.0E+00	NA
			F'4	4.9E-03	0.0E+00	NA
			F'5	1.5E-02	1.0E-06	14,689
			F'6	2.2E-02	4.9E-06	4,448
MSIV D	Air Supply Piping Crushing	Area ~ 140 sq ft Elevation > 30 ft	F'2	6.3E-04	0.0E+00	NA
			F'3	2.2E-03	4.0E-07	5,494
			F'4	4.9E-03	3.9E-07	12,575
			F'5	1.5E-02	3.8E-07	38,769
			F'6	2.2E-02	3.6E-07	60,331
Steam Dump Valves and	Valve Hit and	Area ~ 270 sq ft	F'2	3.2E-03~~2.5E-03~~	4.0E-04	7.8~~6.2~~

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
Piping to Condenser	Pipe Perforation	Elevation < 30 ft	F'3	1.0E-02~~8.1E-03~~	1.9E-03	5.5~~4.3~~
			F'4	2.4E-02~~1.9E-02~~	1.2E-02	2.0~~1.6~~
			F'5	7.0E-02~~5.6E-02~~	2.2E-02	3.2~~2.6~~
			F'6	1.1E-01~~8.4E-02~~	2.9E-02	3.7~~2.9~~
Condensate Storage Tank and Exposed Piping	Tank and Pipe Perforation	Area ~ 7000 sq ft Elevation varies	F'2	2.5E-02	6.0E-05	409
			F'3	8.5E-02	3.7E-04	230
			F'4	1.9E-01	1.3E-02	15
			F'5	5.7E-01	4.2E-02	14
			F'6	8.5E-01	9.2E-02	9.3
Condenser Hotwell Sumps	Steel Plate (Barrier) Penetration	Area ~ 170 sq ft Elevation < 30 ft	F'2	1.5E-03~~1.1E-03~~	0.0E+00	NA
			F'3	4.8E-03~~3.7E-03~~	5.0E-07	9,641~~7,545~~
			F'4	1.1E-02~~8.7E-03~~	1.1E-05	972~~775~~
			F'5	3.2E-02~~2.6E-02~~	3.6E-05	909~~727~~
			F'6	5.0E-02~~3.9E-02~~	1.4E-04	355~~275~~
(Buried) Diesel Fuel Oil Tank Vent	Vent Pipe Crushing	Area ~ 2 sq ft Elevation < 30 ft	F'2	4.1E-05~~3.2E-05~~	1.7E-05	2.4~~1.9~~
			F'3	1.3E-04~~1.1E-04~~	5.7E-05	2.3~~1.8~~

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
			F'4	3.1E-04~~2.4E-04~~	2.2E-04	1.4~~1.1~~
			F'5	9.0E-04~~7.2E-04~~	7.3E-04	1.2~~1.0~~
			F'6	1.4E-03~~1.1E-03~~	1.3E-03	1.1~~0.8~~
Transformer and Load Center in Turbine Building	Missile Hit	Area ~ 600 sq ft Elevation < 30 ft	F'2	1.3E-02~~1.0E-02~~	1.5E-03	8.7~~6.8~~
			F'3	4.2E-02~~3.3E-02~~	1.9E-02	2.2~~1.7~~
			F'4	9.5E-02~~7.6E-02~~	2.6E-01	0.4~~0.3~~
			F'5	2.8E-01~~2.3E-01~~	3.4E-01	0.8~~0.7~~
			F'6	4.4E-01~~3.4E-01~~	3.7E-01	1.2~~0.9~~

A.6 TARGET EXPOSURE MIP UNCERTAINTY

Comparing individual targets normalized hit probabilities (i.e., the MIP) in NP-768 Plant A to the average Plant A MIP (taken across all 7 targets), one specific target (#4) shows a significantly larger hit probability across most tornado intensities. The MIP could have been derived from this target, which would provide for the highest MIP value from all the NP-768 Plant A data. However, choosing the most conservative target hit probability was judged to be too conservative for application in the TMRE. Therefore, the average values were used. However, using a MIP derived from average hit probabilities could result in low EEFPs for certain highly exposed targets at a given site.

A.6.1. TARGET 4

The exposure of Target 4 to tornado missiles is very high, based on its orientation with respect to the most prevalent tornado path, which results in a very high missile flux against the south wall of Target 4 (~70% of the total area of Target 4). Table A-8 provides the derived MIP values for Target 4 only (less than 30' elevation), for F'4 – F'6 tornadoes.

TABLE A-8

TARGET 4 TORNADO MISSILE IMPACT PARAMETER (PER MISSILE PER FT^2 PER TORNADO INTERVAL FREQUENCY)

TORNADO INTENSITY	NRC REGION I	NRC REGION II	NRC REGION IIII
F'4	1.6E-09	1.6E-09	1.8E-09
F'5	2.9E-09	4.1E-09	N/A
F'6	4.7E-09	N/A	N/A

The ratios between the Target 4 derived MIP values in Table A-8 and the TMRE MIP values for near ground targets (i.e., less than 30' elevation) are ~~2.9~~2.3, ~~2.6~~2.1, and ~~2.0~~1.5 (for F'4, F'5, and F'6 tornadoes, respectively). The average of these ratios is ~~2.5~~2.0.

A.6.2 TARGET EXPOSURE CONCLUSIONS

For high exposed targets, a sensitivity could be performed by recalculating target EEFPs using a MIP multiplier of ~~2.5~~2.0x the nominal MIP values calculated for the Degraded Case by 2.5. However, the MIP multiplier of 2.75 applied to highly exposed targets to account for missile distribution uncertainty ("Z vs U") bounds the target exposure multiplier and accounts for the uncertainty. The modified EEFPs are calculated for F'4 through F'6 tornadoes only. For many targets, the TMRE based EEFPs are significantly greater than the TORMIS-based failure probabilities, as seen in Tables A-3, A-6 and A-7. This is likely due to the conservative assumption of the 1.0 failure probability for a missile hit at lower tornado intensities. This conservatism associated with this assumption is more pronounced at lower tornado intensities, because the likelihood of failure given a missile hit is much lower at low tornado intensities. Even for robust targets, where missile inventories are reduced to account for the fact that only certain missiles can fail a target, the basis for these calculations was missiles travelling at design speeds. Therefore, it is judged that the conservatism involved in applying an increased MIP across all tornado intensities would result in overly conservative results.

A.7 ZONAL VS. UNIFORM (Z VS U) SENSITIVITY

In addition to the TORMIS sensitivity studies documented in Appendix E, additional TORMIS simulations were performed to investigate the impact of missile distribution at a site on missile strike probability. Specifically, the sensitivity evaluated the impact of a "zonal" missile distribution versus a uniform missile distribution (referred to here as "Z vs U").

A.7.1. ZONAL AND UNIFORM MISSILE DISTRIBUTIONS

As previously discussed (see Appendix B) the TMRE MIP values were derived from missile hit probabilities in TORMIS simulations for Plant A in EPRI NP-768. For the simulations, missiles were assumed to be distributed uniformly throughout the area in and around Plant A. That is, the missiles were assumed to be distributed so that the missile density was constant across the entire area for missile origination. In reality, missiles are not distributed uniformly at a plant site; there are areas of high and low missile density.

The missile distribution at a given site may have an impact on the probability that a specific target is hit by a missile, all else being equal (this probability is represented by MIP). A set of TORMIS simulations was performed at the same two plants described in Appendix E. In this Z vs U study, two sets of simulations were run for each plant.

- Zonal Distribution – Missile hit frequencies were determined based on the actual missile distribution at the plants, when the missiles were inventoried there. As can be seen in Figures A-2 and A-3, the missiles are assigned to a zone around the plant; each plant contains approximately 20 zones. For this case, the number of missiles in each zone is represented by the red number (the first number) below the missile zone identifier. TORMIS simulations were performed at five tornado intensities, EF1 through EF5[17], and the target hit frequencies were determined.

- Uniform Distribution – The total missile population from the zonal distribution case was redistributed for this sensitivity, so that the missile density (i.e., missiles per ft^2) was constant in all zones. This was done to represent a missile distribution analogous to that in Plant A of NP-768. The uniform missile counts for each zone are provided in Figures A-2 and A-3 as blue numbers, below the zonal missile counts. TORMIS simulations were performed at five tornado intensities, EF1 through EF5, and the target hit frequencies, for the same targets in the zonal simulation, were determined.

FIGURE A-2
PLANT A ZONAL AND UNIFORM MISSILE DISTRIBUTIONS

[17] EF-scale tornado simulations were used in the sensitivity studies, since the TORMIS models were based on the EF-scale. Since the sensitivity studies are comparing the effect of missile distributions, using the F'-scale (which is similar to the EF-scale) shouldn't have an impact on the overall results and conclusions of the sensitivity studies.

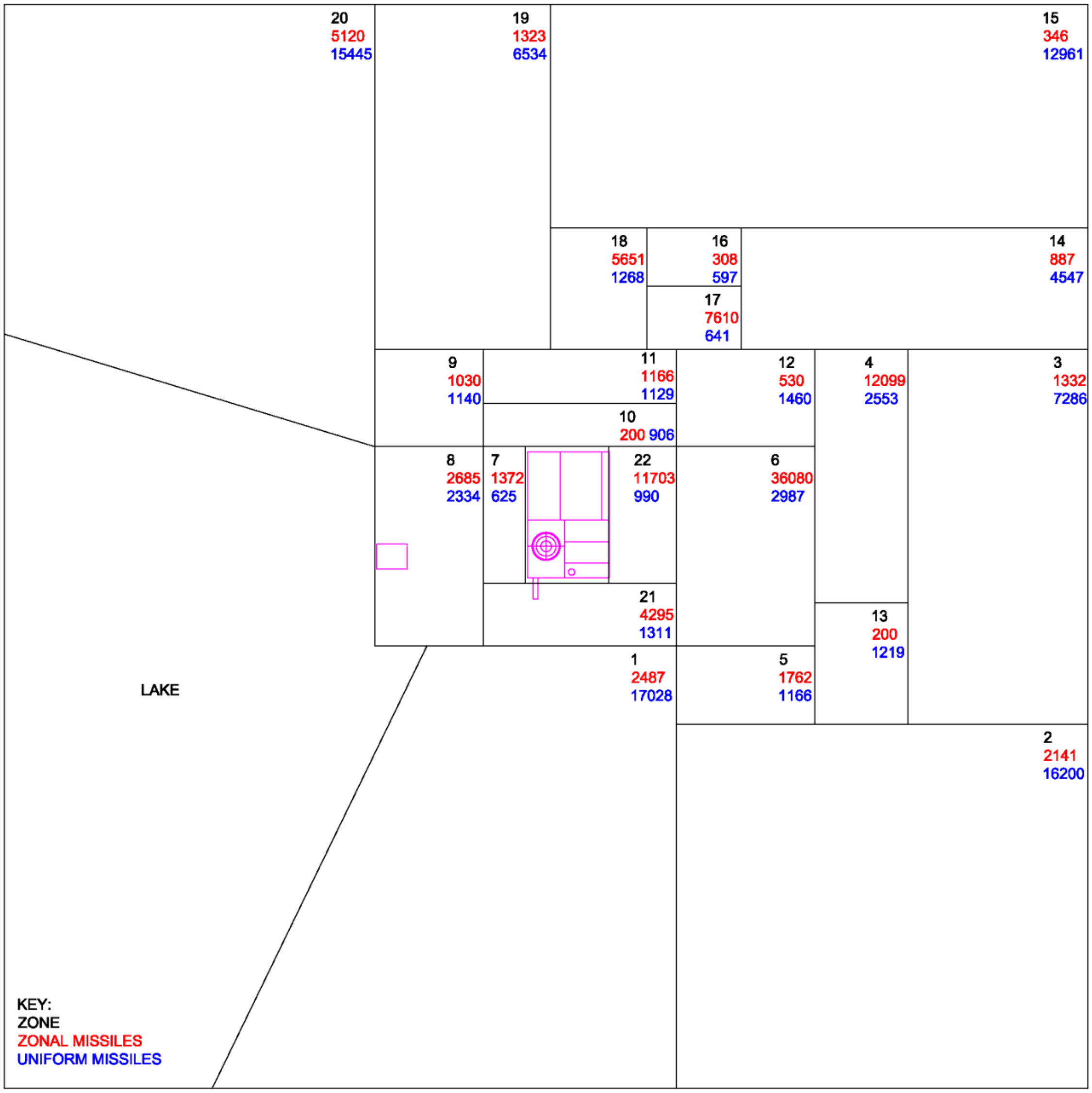
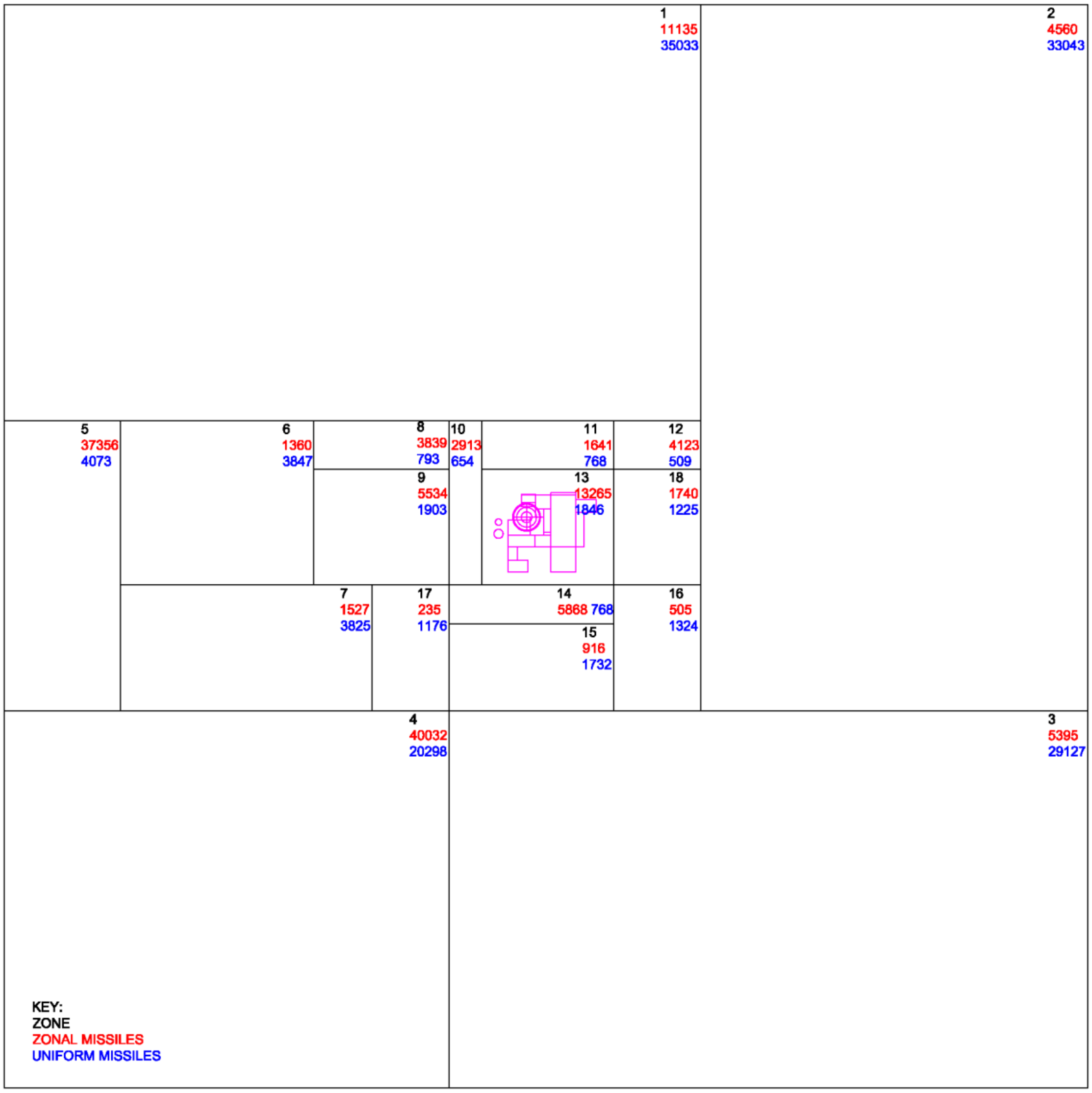

20
5120
15445
19
1323
6534
15
346
12961
18
5651
1268
16
308
597
17
7610
641
14
887
4547
9
1030
1140
11
1166
1129
10
200 906
12
530
1460
4
12099
2553
3
1332
7286
8
2685
2334
7
1372
625
22
11703
990
6
36080
2987
21
4295
1311
13
200
1219
1
2487
17028
5
1762
1166
2
2141
16200
LAKE
KEY:
ZONE
ZONAL MISSILES
UNIFORM MISSILES

FIGURE A-3
PLANT A ZONAL AND UNIFORM MISSILE DISTRIBUTIONS



A.7.2. ZONAL VS UNIFORM SIMULATION RESULTS

Ratios between zonal and uniform hit frequencies were calculated for each target, for each tornado intensity, as well as for each target across all tornado intensities. Several discrepancies were noted while reviewing the data, placing doubt on the efficacy of the simulations. On a macro scale, the simulations suggest that zonal missile distributions, as would be seen at an actual plant site, result in higher missile hit frequencies than uniform missile distributions. However, this was not the case for each target, and many of the simulation results provided conflicting data. The reason for the observed anomalies was not readily discerned, leading to a concern over use of the simulation results.

- A significant concern exists with targets that showed no missile hits in either zonal, uniform, or both sets of simulations. This results in ratios of 0 (if the zonal simulation recorded no hits) to undefined (if the uniform simulation recorded no hits). This phenomenon was more prevalent in the Plant B simulations, but it was inconsistent throughout all the simulations. Some targets had no hits for one EF-scale and missile distribution, but had hits for others.

- The trend of missile hit probabilities (i.e., hit frequency divided by tornado frequency) was inconsistent between EF-scales for individual targets. As seen in the NP-768 results and other current TORMIS analyses supporting high wind PRAs, missile hit probabilities on targets trend higher with higher intensity tornadoes. In very few cases this trend is not seen. However, many of the targets (again, more prevalent in the Plant B simulations) showed varying trends for increasing tornado intensities. This occurred for both uniform and zonal simulations, and often the trends were not consistent between the two missile distributions for the same target. This results in unpredictable trends in the ratio of zonal to uniform missile hit probabilities.

As noted previously, the high level results of the Z vs U sensitivity study suggest that a zonal missile distribution results in a higher missile hit frequency than a uniform distribution. This would further suggest that the MIPs derived from NP-768 may be different if a zonal missile distribution were simulated. However, MIPs derived from Plants B1 and B2 (which used a zonal distribution) are lower than those derived from Plant A (which used a uniform distribution).

The TORMIS sensitivity studies for Z vs U resulted in mixed and some unexplainable differences between zonal and uniform missile distributions. Further investigation (i.e., performing more or different simulations) may not have resolved the discrepancies. However, it was proposed that the simulation results could potentially be used to address the uncertainty associated with missile distributions, if the anomalous data (i.e., 0 missile hits or inconsistent trends, as described above) could be discarded and the remaining data proved meaningful.

A statistical analysis of the Z vs U target hit probability ratios was performed to evaluate whether the anomalous data could be discarded and the remaining data could be used to develop a Z vs U ratio suitable for application to the TMRE results. The ultimate goal is to decide what multiplier (if any) should be applied to the MIP values (and hence EEFP) for some targets.

The two primary concerns with the data were:

- Zero hit frequencies for some targets
- Inconsistent trends in hit probabilities for some targets

A.7.4. Target Categorization

The simulation data for each target and each EF-scale was reviewed and assigned to the bins listed below. The data is screened in the order shown below, so that each target is only assigned to one category. An example of each category is shown in Table A-9.

- Zero – Any target with a 0.0 hit frequency for zonal or uniform missile distributions, for any EF-scale, was assigned to this category. [Target 1 in Table A-9]
- X – Any target that showed an inconsistent trend in hit probability for more than one EF-scale, for either zonal or uniform distributions, was assigned to this category. [Targets 2 and 3 in Table A-9]

- 1 – Any target that showed an inconsistent trend in hit probability for only one EF-scale, for either zonal or uniform distributions, was assigned to this category. [Target 4 in Table A-9]

- OK – If the target is not assigned to any of the previous categories, it is assigned to this category. [Target 5 in Table A-9]

TABLE A-9
EXAMPLE TRENDS IN TARGET HIT PROBABILITY

ID	EF1	EF2	EF3	EF4	EF5	CATEGORY	COMMENTS
1	**1.4E-09**	**0.0E+00**	**1.8E-08**	**3.2E-07**	**7.6E-07**	**ZERO**	**EF2 = 0**
2	**1.2E-07**	**1.0E-07**	**3.4E-07**	**5.7E-06**	**2.1E-06**	**X**	**EF1-EF2 NEGATIVE TREND** **EF4-EF5 NEGATIVE TREND**
3	**8.3E-08**	**6.6E-08**	**6.1E-07**	**2.5E-07**	**7.0E-08**	**X**	**EF1-EF2 NEGATIVE TREND** **EF3-EF4 NEGATIVE TREND** **EF4-EF5 NEGATIVE TREND**
4	**1.9E-08**	**2.1E-08**	**5.2E-06**	**1.5E-06**	**3.2E-06**	**1**	**EF3-EF4 NEGATIVE TREND**
5	**2.0E-08**	**5.5E-08**	**7.5E-07**	**1.3E-06**	**1.4E-06**	**OK**	**OK**

Data was collected for 116 total targets in the TORMIS models for plants A and B. Table A-10 provides a breakdown of the number of targets assigned to each category.

- Approximately 50% of all targets had either a zero hit probability or an inconsistent trend for more than one EF-scale. It should be noted that many targets assigned to the Zero category had more than one negative trend and would otherwise be assigned to the X category. Additionally, many of the targets had more than one zero hit probability.

- Only 27% of the targets were categorized OK

- Approximately 50% of the targets had one or no inconsistent trends. The number of targets from each plant in this group (OK or 1) is relatively equal (27 in A, 31 in B).

TABLE A-10
TARGET CATEGORIES

	ZERO	X	1	OK	TOTAL
PLANT A	**5**	**14**	**13**	**14**	**46**
PLANT B	**21**	**18**	**14**	**17**	**70**
PLANTS A & B	**26**	**32**	**27**	**31**	**116**
PERCENTAGE (A&B)	**22%**	**28%**	**23%**	**27%**	**100%**

Tables A-11 and A-12 provide the Plant A and B targets, the Z vs U ratio for each target for the sum of tornado categories EF1 through EF5, and the Target Category assigned (based on the discussion above).

TABLE A-11
PLANT A TARGET Z VS U RATIOS AND CATEGORIES

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
1	Buried	2341	0.34	OK
2	Buried	883	2.49	1
3	Buried	1336	1.26	1
4	Buried	655	1.61	1
5	Buried	779	2.59	1
6	Buried	194	5.05	X
7	Buried	133	1.85	X
8	Buried	1587	1.75	1
9	Other-Horiz	81	2.50	X
10	Other-Horiz	25	1.23	X
11	Other-Horiz	45	1.72	X
12	Roof	25	0.34	Zero
13	Roof	25	1.27	Zero

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
14	Roof	25	2.41	X
15	Roof	25	1.41	Zero
16	Roof	25	0.64	Zero
17	Roof	25	1.24	X
18	Roof	33	0.88	Zero
19	Roof	25	1.35	1
20	Roof	390	1.83	OK
21	Roof	25	1.99	X
22	Roof	25	0.68	X
23	Roof	25	0.89	1
24	Roof	25	4.13	X
25	Roof	25	2.60	X
26	Roof	30	2.11	X
27	Wall > 30'	91	2.28	OK
28	Wall > 30'	25	2.11	1
29	Wall > 30'	91	2.18	1
30	Wall > 30'	192	2.24	OK
31	Wall > 30'	25	0.81	X
32	Wall > 30'	25	1.31	OK
33	Wall > 30'	25	1.40	1
34	Wall > 30'	25	2.48	OK
35	Wall > 30'	25	2.59	1
36	Wall > 30'	25	1.94	OK

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
37	Wall < 30'	25	2.23	1
38	Wall < 30'	25	1.41	X
39	Wall < 30'	110	2.23	OK
40	Wall < 30'	115	2.50	OK
41	Wall < 30'	25	1.55	OK
42	Wall < 30'	45	1.68	OK
43	Wall < 30'	95	4.33	OK
44	Wall < 30'	25	1.65	OK
45	Wall < 30'	25	1.80	OK
46	Wall < 30'	25	1.80	1

TABLE A-12
PLANT B TARGET Z VS U RATIOS AND CATEGORIES

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
1	Roof	25	5.12	Zero
2	Roof	25	1.01	X
3	Roof	25	0.94	Zero
4	Roof	25	1.36	X
5	Roof	25	0.92	X
6	Roof	80	0.71	X
7	Roof	25	3.00	X
8	Roof	80	1.87	X
9	Roof	25	0.55	Zero
10	Roof	25	20.33	Zero

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
11	Roof	207	1.97	1
12	Roof	207	1.92	OK
13	Roof	28	2.35	X
14	Roof	38	1.78	X
15	Roof	28	3.94	1
16	Roof	38	2.16	X
17	Roof	28	1.79	X
18	Roof	28	0.66	1
19	Wall > 30'	25	3.46	Zero
20	Wall > 30'	28	4.67	Zero
21	Wall > 30'	28	15.05	Zero
22	Wall > 30'	171	2.41	OK
23	Wall > 30'	25	8.49	Zero
24	Wall > 30'	30	3.05	Zero
25	Wall > 30'	28	1.64	X
26	Wall > 30'	437	2.35	OK
27	Wall > 30'	28	2.54	X
28	Wall > 30'	35	2.97	1
29	Wall > 30'	171	2.53	OK
30	Wall > 30'	28	5.00	OK
31	Wall > 30'	437	2.94	OK
32	Wall > 30'	25	4.86	1
33	Wall > 30'	437	2.30	OK

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
34	Wall > 30'	171	2.58	OK
35	Wall > 30'	27	5.75	OK
36	Wall > 30'	25	4.00	1
37	Wall > 30'	28	2.24	X
38	Wall > 30'	171	2.44	OK
39	Wall > 30'	132	2.39	1
40	Wall > 30'	28	18.31	X
41	Wall > 30'	437	2.41	OK
42	Wall > 30'	132	2.92	OK
43	Wall > 30'	28	2.75	X
44	Wall < 30'	30	0.86	Zero
45	Wall < 30'	30	3.16	Zero
46	Wall < 30'	40	Note 2	Zero
47	Wall < 30'	40	Note 2	Zero
48	Wall < 30'	40	0.48	Zero
49	Wall < 30'	42	0.51	Zero
50	Wall < 30'	42	2.31	Zero
51	Wall < 30'	54	2.31	Zero
52	Wall < 30'	50	11.39	Zero
53	Wall < 30'	42	18.39	Zero
54	Wall < 30'	50	15.55	Zero
55	Wall < 30'	35	4.62	X
56	Wall < 30'	40	16.39	Zero

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
57	Wall < 30'	28	1.68	X
58	Wall < 30'	35	1.75	1
59	Wall < 30'	60	3.40	1
60	Wall < 30'	123	3.00	OK
61	Wall < 30'	60	3.59	OK
62	Wall < 30'	25	3.29	OK
63	Wall < 30'	123	3.20	1
64	Wall < 30'	40	4.08	1
65	Wall < 30'	25	4.31	1
66	Wall < 30'	50	3.10	OK
67	Wall < 30'	25	6.45	OK
68	Wall < 30'	396	4.22	1
69	Wall < 30'	40	3.28	1
70	Wall < 30'	50	4.97	X

A.7.5. Statistical Analysis of Simulation Results

The following is a description of the statistical testing and results:

1. A 2-sample Kolomogorov-Smirnoff (KS) test with significance level α =0.05 was performed for the following pairs of data subsets:

    - OK and Zero/X

    - OK/1 and Zero/X

2. The 2-sample KS-test has null hypothesis H0: The two data sets come from a common distribution. The alternative hypothesis H1: The two data sets do not come from a common distribution. The separation of data is based on the following:

    a. The possibility that the TORMIS simulation was inadequate for the targets assigned to the Zero or X category. For example, the results may not have converged for those targets, resulting in erroneous trends and/or no hits.

    b. The NP-768 data shows that several targets (1, 2, 4, and 5) have one negative trend as tornado intensities increase. Thus, this may be expected behavior for the TORMIS simulation.

    c. Only considering the OK data may not provide sufficient data.

3. Comparing the OK and Zero/X subsets, the test statistic D, 0.27477, is greater than the critical value for α=0.05 (0.273114). This implies that the p-value of the test-statistic is less than 0.05. Thus, the null hypothesis is rejected in favor of the alternative. The two data sets (OK and Zero/X) are not from a common distribution.

4. Comparing the OK/1 and Zero/X subsets, the test statistic is slightly less than the critical value for α =0.05. We fail to reject the null hypothesis although it is noted that the difference between the D-value 0.218596 and the critical value c = 0.273114 is very small (0.009966).

5. Additionally, an adaptive KS-Goodness of Fit test with α =0.05 was performed for the following subsets of the data with null hypothesis H0: The data come from the fitted lognormal distribution. The alternative hypothesis is H1: The data do not come from the fitted lognormal distribution. The calculation was performed using the website: http://nrcoe.inl.gov/radscalc/Pages/CurveFit.aspx

    a. All data

    b. All data without X

    c. All data without Zero

    d. All data without 1

    e. All date without X and Zero (i.e., OK and 1 data)

f. All data without X and 1 (i.e., OK and Zero data)

g. All data without 1 and Zero (i.e., OK and X data)

h. All data without X, Zero and 1 (i.e., OK only)

6. For the case of ALL DATA, the null hypothesis is rejected (D-statistic = 0.1013 with critical value c=0.1004). The ALL DATA without 1 test also resulted in rejecting the null hypotheses (D-statistic = 0.1196 with critical value c = 0.1150).

7. For all other combinations, we fail to reject the null hypothesis. It is noted that in all cases, the lognormal fit was the best fit with regards to the D-statistic among the available curves (normal, lognormal, exponential, gamma, Weibull).

8. Based on the 2-sample and Goodness of Fit KS-test, the Zero and X data do not fit with the OK data. Thus, we choose to exclude the Zero and X data.

The following references provide information on the KS test statistics:

[1] https://onlinecourses.science.psu.edu/stat464/node/54

[2] http://www.itl.nist.gov/div898/software/dataplot/refman1/auxillar/ks2samp.htm

[3] http://sparky.rice.edu/astr360/kstest.pdf

[4] Romeau, Jorge Luis. Kolomogorov-Smirnov: A Goodness of Fit Test for Small Samples. START (Selected Topics in Assurance Related Technologies) Volume 10 Number 6.

Based on the results of the statistical testing described above, the Z vs U ratios for targets categorized as Zero or X will be discarded.

- The data categorized as OK (i.e., from test 5.h. above) could be used to determine the change in hit probabilities (and thus change in MIP) due to zonal missile distributions. The Z vs U ratio using only the OK data is 2.73. Figure A-4 and Table A-13 provide the curve fit results for this dataset.

- Although the null hypothesis that OK/1 and Zero/X were from different distributions was rejected, the difference between the D-value and the critical value were very small (see 4. above). In fact, the Z vs U ratio using the OK/1 data (from test 5.e. above) is similar to the OK data only; the mean is slightly smaller at 2.67. Figure A-5 and Table A-14 provide the curve fit results for this dataset.

- For information purposes, the all data (i.e., test 5.a. above) lognormal distribution curve fit results are provided in Figure A-6 and Table A-15. As can be seen, the mean is higher when considering all the data, although the variance and standard distribution are disproportionally larger. As noted the, Zero and X data are discarded, based on the results of the KS tests.

Therefore, a value of 2.75 is recommended for the Z vs U sensitivity. This is based on rounding up the mean from the OK dataset lognormal distribution (2.73).

FIGURE A-4
LOGNORMAL DISTRIBUTION FOR Z VS U RATIOS (OK CATEGORY)

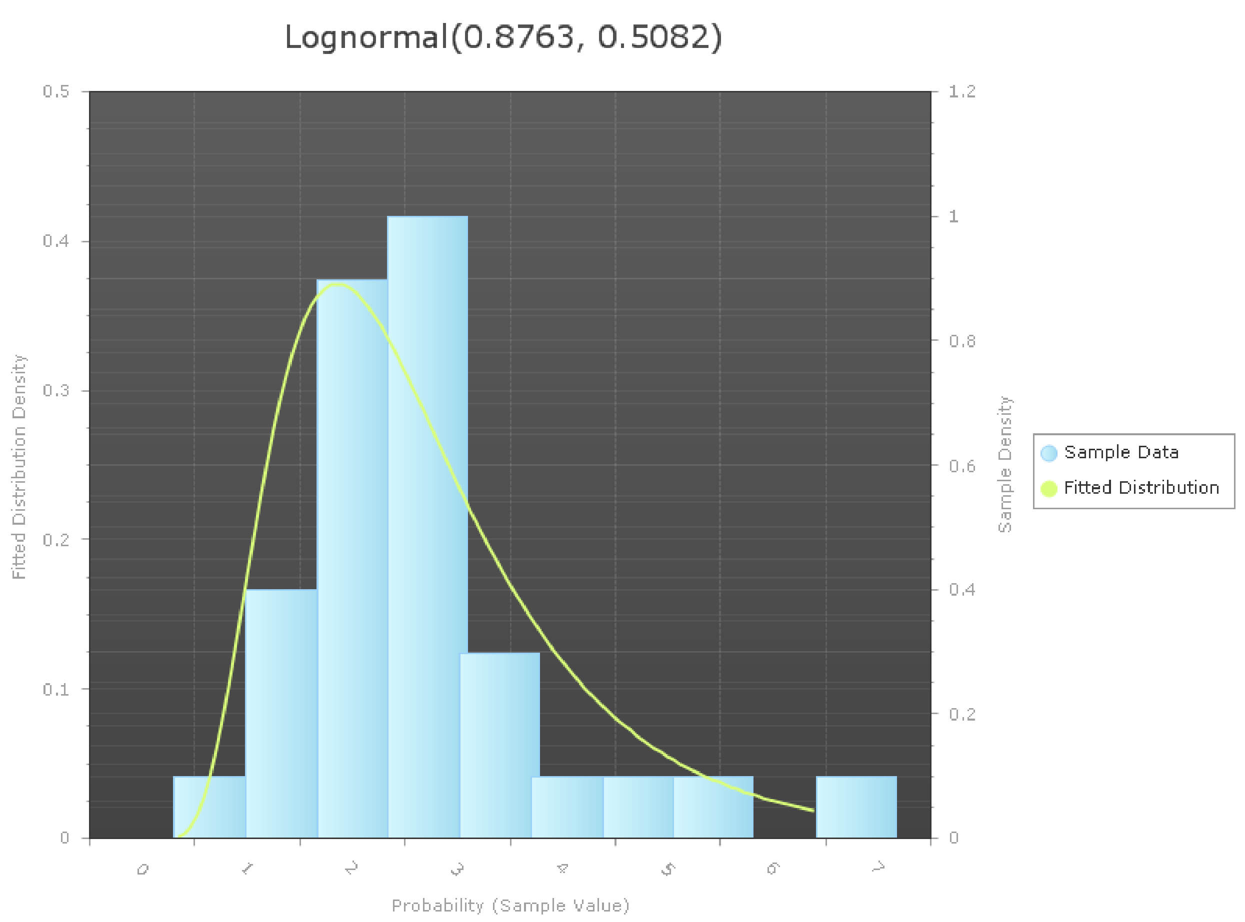


TABLE A-13
LOGNORMAL PARAMETERS FOR Z VS U RATIOS (OK CATEGORY)

Parameter	Input Values	Fitted Values
Mean	2.68	2.73
Median	2.41	2.40
Variance	1.54	2.20
Std. Deviation	1.24	1.48
Skewness	--	1.79
5th Percentile	--	1.04
95th Percentile	--	5.54

FIGURE A-5
LOGNORMAL DISTRIBUTION FOR Z VS U RATIOS (OK/1 CATEGORIES)

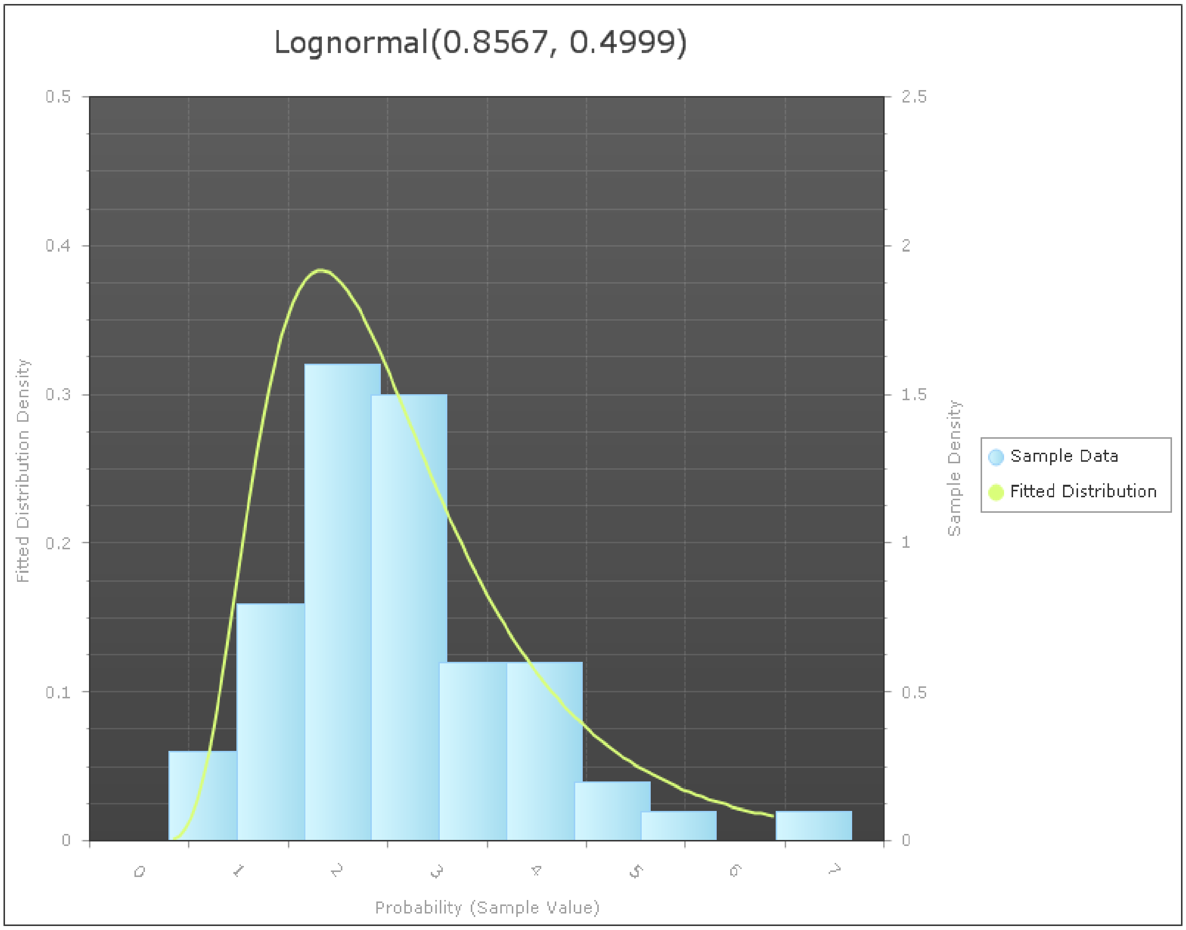


TABLE A-14
LOGNORMAL PARAMETERS FOR Z VS U RATIOS (OK/1 CATEGORIES)

Parameter	Input Values	Fitted Values
Mean	2.63	2.67
Median	2.41	2.36
Variance	1.41	2.02
Std. Deviation	1.19	1.42
Skewness		1.75
5th Percentile		1.04
95th Percentile		5.36

FIGURE A-6
LOGNORMAL DISTRIBUTION FOR Z VS U RATIOS (ALL DATA)

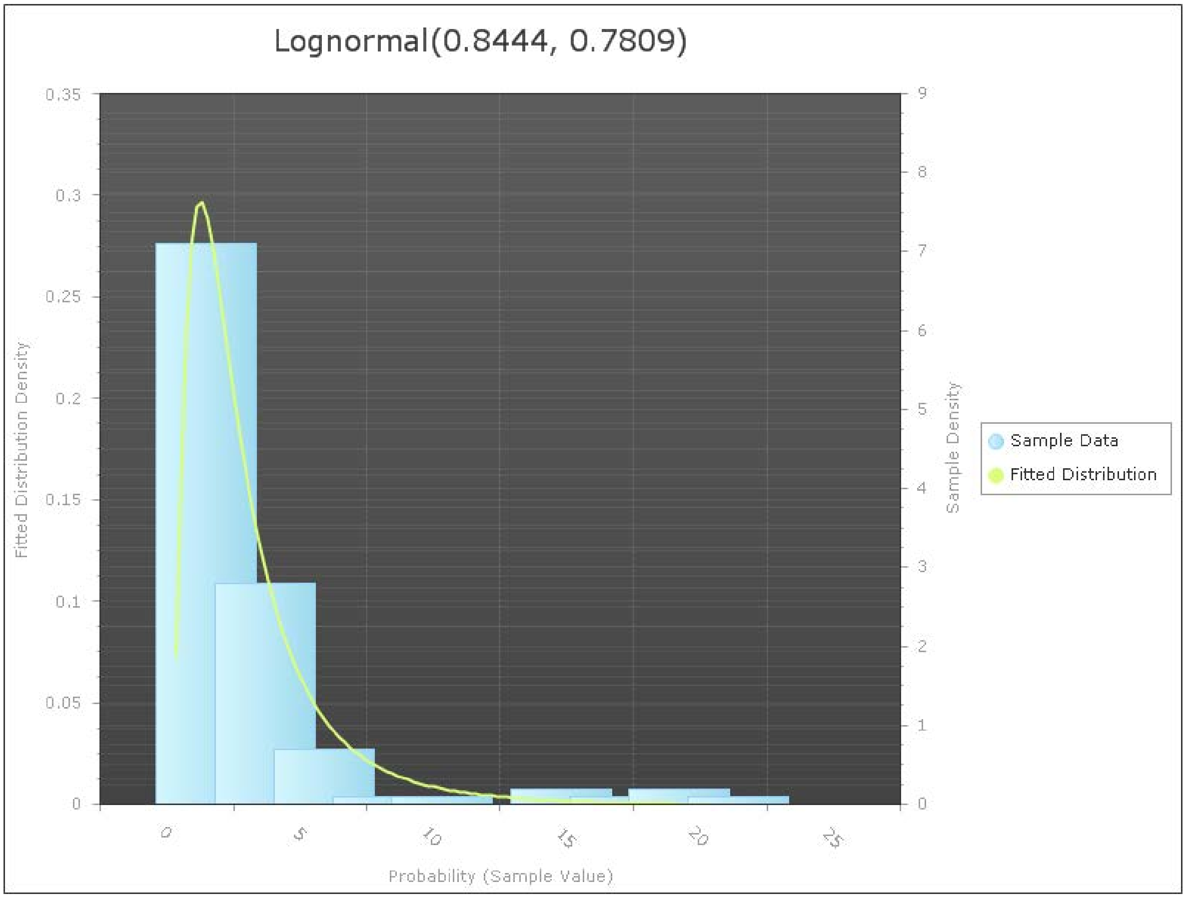


TABLE A-15
LOGNORMAL PARAMETERS FOR Z VS U RATIOS (ALL DATA)

Parameter	Input Values	Fitted Values
Mean	3.29	3.16
Median	2.31	2.33
Variance	13.6	8.37
Std. Deviation	3.69	2.89
Skewness		3.519
5th Percentile		0.64
95th Percentile		8.40

A.7.6. TARGET-SPECIFIC MIP CALCULATIONS

Based on the results of the analysis in Section A.7.5, target basic events that meet the criteria for the missile distribution sensitivity are adjusted using a 2.75 multiplier. The sensitivity analysis described in Section 7.2.1 requires additional analyses for targets with a large concentration of missiles close to the target. The parameters used to define this assessment are greater than 1,100 missiles within 100 feet of a highly exposed target.

- The selection of 100 feet is based on judgement
- The number of missiles (1,100) is based on an approximate missile density of 2.75 times the average density. If the local missile density is less than 2.75 times the average, then the nominal 2.75 multiplier for the sensitivity covers the configuration.

Assuming 240,000 missiles are present in the area surrounding the site (i.e., circle with 2500' radius), the missile density for 1.22E-2 missiles/ sq ft. A missile density 2.75 times higher in a 100' radius circle results in approximately 1,055 missiles. This is rounded to 1,100 missiles.

Determining a target-specific MIP multiplier based on the ratio of local missile density and average site missile density is based on recommendations provided in Reference A.5.

~~A.8 SUBMERGED TARGETS~~

~~The TMRE methodology is based on calculating target failure probabilities using EEFP, as described previously in this section. The EEFP is based on the Missile Impact Parameter (MIP), which is derived from tornado missile hit probabilities from missiles travelling through air. The missile hit probabilities are not affected by the missile velocities and orientation when they strike the target; the missile hit probabilities are for any missile type, velocity, trajectory, and orientation. However, for a missile to strike and damage a submerged target, it must typically fit a narrow set of parameters. Therefore, the calculation of EEFP using the MIP and other EEFP parameters provided in this section will greatly overestimate the missile failure probability of a submerged target. Even reducing the damaging missile population, using the robust missile percentages in Table 5-2, will result in significantly overestimating EEFPs for submerged targets.~~

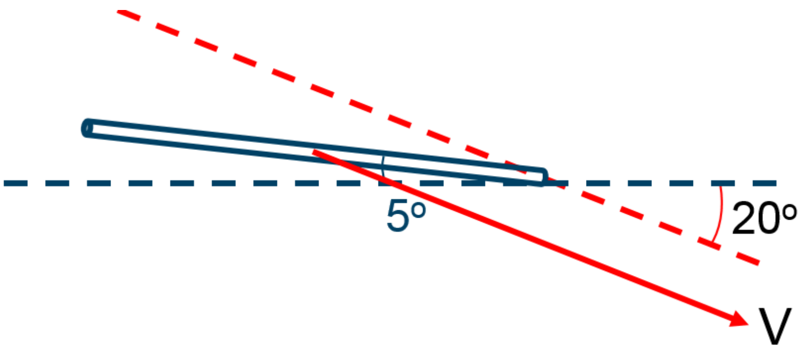
~~The following discussion provides a list of factors that reduce the effective EEFP of submerged targets and can support screening of such targets. The key consideration is the significant reduction in the number of missiles that can damage the target after striking the water surface.~~

~~Generally, missiles must enter the water within a specific area and at limited set of trajectories to strike a submerged target. This is analogous to a target inside a structure that can only be struck by missiles going through an opening in the structure. However, very few of the missiles striking the water surface will be able to hit and damage the submerged target. The effective damaging missile population for a submerged target is reduced by considering the following:~~

- ~~The missile must be traveling at a specific trajectory or range of trajectories, and must be oriented in such a way that it continues to travel through the water on the correct trajectory; otherwise, the missile will miss the target. For example, a missile oriented at a shallow angle with respect to the trajectory (Figure A-7) will tend to curve upward towards the water surface; at very shallow angles, the missile may skip off the surface of the water and not become submerged.~~

- ~~The missile must have sufficient energy when it strikes the water in order to retain the energy needed to reach the target and damage it. The missile speed at the time of water impact will depend on the missile type and target location. Missile speeds in lower intensity tornadoes may be inadequate to reach a submerged target. Even in optimal cases, significant energy is lost during water entry and travel through the water [A.10]. The energy lost during impact and in the water is affected by the missile shape, size, material, and other characteristics. Certain missiles (e.g., pipes, poles) will have lower drag in water, but most missiles do not travel through the water effectively.~~[18]
- ~~A tumbling or oscillating missile will lose additional energy in the water; its trajectory in the water will also be affected. For a missile to maintain energy through the water it needs to essentially have all of its energy aligned with the impact trajectory. Any energy component not aligned with the trajectory will cause the missile to lose significant energy both at water impact and due to drag through the water.~~
- ~~Missiles that deform or break apart upon striking the water surface (e.g., wood planks, siding, storage bins) will lose energy during impact, will lose their shape and/or become skewed, affecting their trajectory through the water. Some missiles may no longer be intact and would thus be unable to damage the target.~~[17]
- ~~Missile buoyancy will affect trajectory and energy of the missiles traveling through water.~~[17]

~~Figure A-7~~
~~Missile with Shallow Orientation with Respect to Trajectory~~



~~Considering all these factors, it is judged that only a small fraction of the missiles striking the surface of the water will damage the target. In order to hit a submerged target after striking the water surface in the correct place, a missile will have to be traveling at an adequate speed though the air, at the correct trajectory and orientation, and have the correct physical characteristics (e.g., size, shape, material). It is reasonable to assume that the fraction of missiles meeting these criteria are very much less than 1%.~~

[18] ~~Less than about 35% of all missiles (e.g., pipes, poles) at a typical site, based on a review of the missile types and their relative inventories in Table B-17, would be considered candidates to strike and damage submerged targets.~~

A.8~~9~~ REFERENCES

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[A.2] Twisdale, L., Vickery, P., Sciaudone, J., Banik, S., and Mizzen, D., "Advances in Wind Hazard and Fragility Methodologies for HW PRAs" PSA 2015 Paper, April 2015.

[A.3] A Preliminary Approach to Human Reliability Analysis for External Events with a Focus on Seismic, EPRI, Palo Alto, CA: 2012. 1025294.

[A.4] EPRI NP-768, Tornado Missile Risk Analysis, May 1978

[A.5] Analysis of Missile Impact Probability for Generic Tornado Hazard Assessments, Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses, July 29, 2016

[A.6] Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-informed Decisions on Plant Specific Changes to the Licensing Basis," Revision 3, January 2018

[A.7] Regulatory Guide 1.76, "Design-basis Tornado and Tornado Missiles for Nuclear Power Plants," Revision 1, March 2007.

[A.8] Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-informed Activities," Revision 2, March 2009.

[A.9] ASME/ANS RA-Sa-2009, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," Addendum A to RA-S-2008, ASME, New York, NY, American Nuclear Society, La Grange Park, Illinois, February 2009.

~~[A.10] Department of the Navy Bureau of Ordnance Contract No, NOrd 9612, Drag Studies in Water Entry of the MK 13-6 Torpedo, Report No. E 12.1, July 1951, Hydrodynamics Laboratory California Institute of Technology.~~

APPENDIX B: BASES FOR MIP AND MISSILE INVENTORIES

The purpose of the Tornado Missile Risk Evaluator (TMRE) is to provide a methodology that can be used at any U.S. nuclear power plant (NPP) to estimate the risk associated with SSCs exposed to tornado missiles. The methodology is designed to be relatively simple, conservative, and applicable to all plants, precluding the need to perform detailed tornado missile simulations.

Data from EPRI NP-768 [Ref. B.1] was used for previous simplified tornado missile risk analyses used in the TAP A-45 program [Refs. B.2, B.3, B.4, B.6, B.6, B.7]. Specifically, the probability of tornado missiles impacting targets was based in part on the results of the TORMIS simulations documented in EPRI NP-768 and 769 [Ref. B.8]. A summary and explanation of the previous studies can be found in EPRI 3002003107, *High Wind Risk Assessment Guidelines* [Ref. B.9].

The TMRE methodology uses the same source information from EPRI NP-768 to derive the Missile Impact Parameter (MIP). This appendix describes how the information presented in EPRI NP-768 is used to determine the MIP values for the TMRE.

In order to simplify and standardize the TMRE Exposed Equipment Failure Probability (EEFP) calculations, values for total missile inventory are based on a survey of ~~five~~ two US NPP missile walkdowns. These walkdowns were performed to support previous TORMIS analyses at different sites in the U.S. The maximum values from these missile surveys are used in the TMRE, given that the site-specific walkdown performed in support of the TMRE validates that this generic missile inventory is bounding (see Section 5).

B.1 BACKGROUND INFORMATION ON MISSILE IMPACT PARAMETER (MIP)

The probability of a tornado missile hit on an exposed SSC is dependent upon several variables: the tornado intensity, the likelihood of a tornado strike, the surface area of the target, and the number and type of potential missiles (i.e. the "missile inventory"). The MIP reflects the probability of a tornado missile hit on an SSC given a tornado missile strike and the category of the tornado; the MIP it is normalized for target surface area and missile inventory.

EPRI NP-768 and NP-769 document the TORMIS computer simulation software developed by EPRI to perform missile hazard studies. Three plant configurations were used and numerous sensitivity cases were performed, such as varying missile population sizes and missile types, Monte Carlo sampling sizes, missile transport phenomena variables, and wall thickness. The methodology uses random variables to model the inherent variations in tornado incidence, wind field characteristics, missile position and orientation, missile aerodynamics, and the distribution of the potential missile population. The TORMIS methodology uses missile time-history simulations to predict the response of the postulated missiles to the tornado as it passes through the plant area (see Figure B-1).

The performance of a detailed, plant-specific TORMIS study can be a resource intensive analysis, which may not be warranted for relatively insignificant risk contributors, such as small exposed SSCs [Refs. B.10, B.11]. Previous studies [Refs. B.2, B.3, B.4, B.5, B.6, B.7] used the TORMIS results presented in EPRI NP-768 to derive a normalized missile impact parameter that could be used to estimate the likelihood of an exposed SSC being struck by a tornado missile.

The TMRE MIP is developed using similar principles and assumptions as the previous work. However, there are several refinements and improvements in the development of the MIP. The calculations and rationale used to derive the TMRE MIP values are presented here.

B.1.1 Definition of Missile Impact Parameter (MIP)

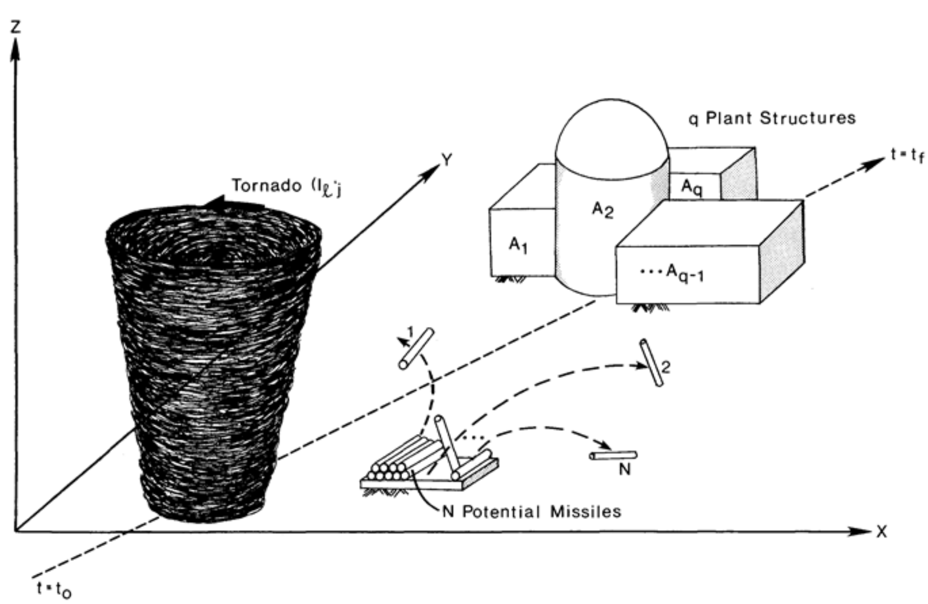
MIP is defined as the probability of a missile impact on an exposed SSC, per missile, per target area, per tornado:

MIP = Probability of missile impact / missile / target area / tornado

Using MIP, the conditional probability of a missile impact on a target during a given tornado can be estimated if the number of available missiles and the exposed surface area of the target are known. Based on a review of the NP-768 tornado missile hit probabilities, it is apparent that the hit probability varies by the tornado intensity. A higher intensity tornado will cause more missile hits on a target, all other variables being equal (e.g., target size and location, number of missiles). Thus, separate MIPs must be derived to account for tornado intensity.

The probability that a target is hit by a tornado-generated missile will approach unity as the size of the target increases, the number of missile increase, and the tornado intensity increases. A target strike probability calculated using MIP will reflect the likelihood that a target is struck by one or more missiles. A given target may be struck by many missiles during a single tornado event, but this probability does not specify the number of discrete missile hits experienced by a target.

Figure B-1: Illustration of EPRI TORMIS Tornado Missile Time-History Simulation [Ref. B.1]



B.2 Using EPRI NP-768 Data to Determine Missile Impact Parameter (MIP)

The results of the EPRI TORMIS studies documented in NP-768 contain missile impact frequencies and associated damage frequencies for various targets, missile population sizes, and assumed plant locations, including results from various sensitivity studies. The EPRI results compiled tens of thousands of missile history simulations to generate average probability densities. Target missile impact probability, missile damage probability, and other associated probabilities are provided in the EPRI studies for different tornado hazards (i.e., thus simulating different assumed plant locations) for three different plant configurations. For the purpose of MIP derivation, only the target impact/strike frequencies and probabilities are needed. The damage likelihood is accounted for separately in the TMRE methodology.

The normalized tornado missile impact probability is conditional upon a tornado strike at the site and should not be affected by the tornado hazard curve for the site. As described, the normalized tornado missile impact probability differs as a function of tornado wind speed (i.e., the tornado category), but the tornado frequency does not impact the conditional impact probability. From the results in NP-768, there are some numerical differences in the derived MIP values depending on the tornado region; the differences are the result of Monte Carlo sampling and associated modeling, and are not due to the tornado hazard frequency input. The resolution of the differences is described in Sections B.3.2 and B.4.

B.2.1 Normalizing EPRI NP-768 Missile Hit Probability

Recall from Section B.1.1 that MIP is the probability of missile hit per missile, per tornado, per ft^2. MIP is defined in this way to allow it to be applied universally for different size targets at different U.S. NPP sites that have different missile populations and tornado frequencies. This is similar to the rationale behind the normalized missile parameter developed in for the TAP A-45 tornado missile risk assessments [Refs. B.2 through B.7].

EPRI NP-768 provides hit frequencies for various targets based on TORMIS simulation runs. The variable of interest, from which MIP can be derived, is the TORMIS parameter H, which is defined as *"Impact Event Defined as Missile Hitting the Barrier"* [Ref. B.1]. Two values are provided for H in the NP-768 results, P and P^N. P is the single missile hit frequency for a target and P^N is defined as the multiple missile hit frequency; P^N accounts for the number of missiles in the simulation. MIP needs to be normalized based on the number of missiles, to allow for it to be used at sites with different populations. Thus, the single missile hit probability, P, is the parameter that is used to derive MIP.

EPRI NP-768 discusses the approach of multiplying a missile strike parameter (i.e., P) by the missile population, but notes that it is likely a conservative estimate:

> *The results from both case studies suggest that probability estimates for the assumed multiple missile threat can be conservatively calculated by multiplying the single missile values by the assumed number of missiles in the sampling population. For the first case study with a hypothetical multiple threat of 6000 available missiles, the degree of conservatism is a factor of two.* [Ref. B.1]

The reason for this is that the TORMIS sampling process integrates over a variety of missile types and locations; whereas, using a normalized tornado missile impact probability multiplied by a population of missiles assumes all missiles have the same entrainment and flight potential. Therefore, using P to derive MIP, and in turn multiplying the MIP by the number of missile on site (as part of the EEFP calculation) is conservative, with respect to this aspect of MIP.

In order to further normalize the NP-768 hit frequency to obtain MIP, the tornado frequency and the target area need to be accounted for. The tornado frequencies used in the TORMIS simulations are provided in NP-768 Table 3-4; the target dimensions, from which target areas can be determined, are also provided in NP-768.

B.2.2 Review of Single Missile Hit Probabilities (*H*-value P) for Plants A and B

In order to provide a conservative bias to the MIP, the simulations from NP-768 which resulted in the highest values for MIP (after normalizing *P* to tornado frequency and target area) were chosen. As previously noted, NP-768 simulations were performed for three plant configurations, Plant A, Plant B1, and Plant B2.

The tables in NP-768 which contain TORMIS simulation hit frequencies are:

Plant A: Tables 3-8 through 3-14 provide data for individual targets and Table 3-15 provides data for all targets combined (i.e., the sum of the probabilities for all targets at Plant A).

Plant B1: Table 3-23 provides data for individual targets and Table 3-24 provides data for all targets combined. Unlike Plant A, the individual target hit probabilities for Plant B1 are not broken down by tornado category. One combined hit probability for all tornado categories is provided for each target. Only the Plant B1 all target data in Table 3-24 has separate hit probabilities for each tornado category.

Plant B2: Table 3-25 provides data for individual targets and Table 3-26 provides data for all targets combined. Unlike Plant A, the individual target hit probabilities for Plant B2 are not broken down by tornado category. One combined hit probability for all tornado categories is provided for each target. Only the Plant B1 all target data in Table 3-26 has separate hit probabilities for each tornado category.

After deriving MIP from the single missile hit probabilities for each of these simulations, it was determined that Plant A resulted in higher overall MIP values. Therefore, Plant A data was chosen as the basis for MIP.

One potentially important difference between Plant A and Plants B1/B2 is the distribution of missiles used in the TORMIS simulations. Plant A simulations were performed with uniformly distributed missiles, i.e., the missile density is constant across the area of the site. Plant B missiles were distributed unevenly, so that some zones contained higher densities than other zones; this is described as a zonal missile distribution).

The impact of the different distributions (zonal versus uniform) was investigated in a sensitivity study documented in Appendix E. Based on this study, there is indication that unevenly distributed missile densities will affect the hit probabilities of certain targets. However, no direct correlation could be discerned from the data as to how a specific missile distribution would affect the hit probability of a specific target. In order to account for the uncertainties associated with the missile distribution at a site, the TMRE method directs that sensitivity calculations be performed to account for potentially higher hit probabilities on certain SSCs. Section 7.2.1 provides details of this sensitivity study and the criteria under which it is to be performed.

B.2.3 Selection of Target Missile Hit Probabilities (*P*) for Developing MIP

Plant A MIP values derived from individual target (i.e., Targets 1 through 7) hit frequencies in NP-768 vary significantly for the same tornado intensity. Although a derived MIP is normalized to target size, missile inventory, and tornado category, there are other factors that affect the hit probability from which MIP is derived. Factors include the location and orientation of the target with respect to the dominant tornado path, the variation in the degree of shielding from other targets/buildings, and different target elevations[19]. All these factors are expected to have an impact on the target hit probability. For example:

> In Plant A simulations from NP-768, the MIP derived for Target 1 (Containment Building) is the lowest. The containment building is surrounded by other buildings (see plant layout in Figure B-2), so only the upper part of the containment is exposed to tornado missiles. Since fewer missiles are present at higher elevations, the normalized tornado missile impact probabilities are lower in comparison to other targets.
>
> In Plant A simulations, Target 6 is the lowest elevation building and is unprotected by any other buildings. Target 6 would be expected to have a higher normalized tornado missile impact probability than most other targets, which it does. The target with the highest derived MIP value in NP-768 Plant A is Target 4.

Development of separate MIP values for different targets, based on individual NP-768 targets, would not be practical for application of the TMRE at a given NPP. Alternately, choosing the most conservative target MIP from NP-768 (Target 4) would lead to overly conservative results for many targets at a NPP. Therefore, the normalized tornado missile impact probability from ~~"~~"All Targets" in NP-768 (from Table 3-15) is proposed for use in the TMRE. This results in a MIP that is based on the combined hits on all modeled surfaces in NP-768, Plant A. Using the "All Targets" hit probabilities as the basis for MIP will result in conservative hit probabilities for certain targets at each NPP, while conservatism in other aspects of the TMRE (e.g., fragility values) can compensate for potential underestimates of missile hit probabilities for other targets. Section A.6 discusses the uncertainty associated with MIP values derived Target 4 and all targets.

B.3 DERIVATION AND CALCULATION OF THE MISSILE IMPACT PARAMETER (MIP)

The mean H-values for single missiles (*P*) for all targets are obtained from NP-768, Table 3-15; these values include the missile hit probabilities for all Plant A targets. Therefore, the selected hit values represent the various configurations and arrangements of the seven targets at Plant A.

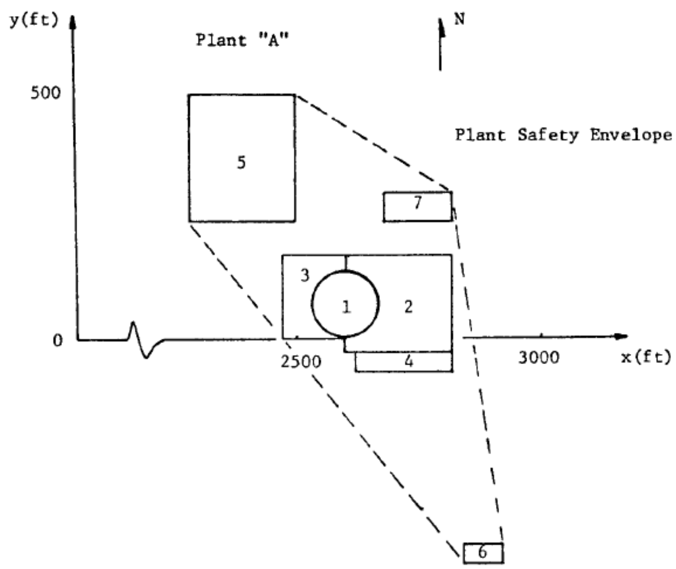
The MIP values are calculated by dividing the *H*-values in Table 3-15 of NP-768 by (a) the tornado frequencies in NP-768, Table 3-4, and (b) the total area for all Plant A targets. The derivation of the target areas are described in the Section B.3.1, and the resultant target areas are provided in Tables B-1 and B-2.

B.3.1 CALCULATION OF TARGET AREAS

Plant A has seven targets as shown in Figure B-2; dimensions of the targets (buildings) are provided in Table 3-1 of NP-768.

[19] Note that target size is not a factor that influences the MIP. Sensitivity studies documented in Appendix E were performed to validate this.

Figure B-2: Plant A Layout for TORMIS Simulation [Ref. B.1]



The surface area exposed to tornado missiles for each of the targets was calculated based on the dimensions provided in Table 3-1 of NP-768; the targets, their calculated areas, and notes regarding the calculations are provided in in Table B-1. The areas provided in Table B-1 include the building roofs. The total area for all Plant A targets is 341,078 ft^2.

Table B-1: NP-768 Plant A Total Target Areas

Target #	Target Description	Exposed Surface Area (ft^2)	Notes
1	Containment	70,372	See Figure B-2. The Area is equal to the portions of the containment cylindrical wall that are exposed (i.e., not covered by adjacent building) plus the containment dome (a half-sphere). The height of the exposed wall is equal to the height of the containment minus the radius of containment (the dome is assumed to be a half-sphere, so the height of the dome above the cylinder is equal to the radius) minus the height of the adjacent targets (2 and 3, which are of different heights).

Target #	Target Description	Exposed Surface Area (ft^2)	Notes
2	Auxiliary Building	80,503	See Figure B-2. The Area is equal to the area of two full walls (north and east), the exposed area of the west wall (subtracting the Target 1 and 3 areas), the area of the south wall not covered by Target 4, and the area of the roof. The area of the roof does not include the portion occupied by the containment semicircle on the west end.
3	Fuel Handling Building	40,203	See Figure B-2. The Area is equal to the area of three full walls (north, south and west) and the area of the roof. The east wall is not exposed, since Targets 1 and 2 are higher than Target 3. The area of the roof does not include the portion occupied by the containment semicircle on the east end.
4	Diesel Generator Building	22,000	The area includes three walls (east, south and west) and the roof. The north wall against Target 2 is not exposed.
5	Waste Processing Building	95,600	This target is a standalone rectangular building. The area includes all four walls and the roof.
6	SW Intake Structure	8,000	This target is a standalone rectangular building. The area includes all four walls and the roof.
7	Tanks Enclosure	24,400	This target is a standalone rectangular building. The area includes all four walls and the roof.
Total	**All Targets**	**341,078**	**Sum of areas for Targets 1 through 7 (including roof area).**

As noted, the target areas in Table B-1 include vertical wall and horizontal roof areas. Roofs tend to have fewer missile hits per square foot than a vertical wall, since the roofs are elevated and require missile trajectories that are higher than the roof in order to eventually strike it as a vertical missile. The data in NP-768 does not distinguish which surface of a target is struck.

Since the roofs can be a substantial portion of the building surface area, considering the entire target area when deriving MIP may tend to underestimate MIP, especially for targets that are near to the ground. To compensate for this, a second set of target areas were calculated that exclude the area of the roof. Table B-2 provides areas for the same seven targets as Table B-1, but does not include the roof areas, with one exception (Target 6).

The total area for all Plant A targets, excluding roof areas, is 185,984 ft^2. Excluding the containment building, the total area for Plant A targets, excluding roof areas, is 146,400 ft^2. The ~~use of these different~~ target areas from Tables B-1 and B-2 that are used ~~(i.e., with and without the roof area)~~ in deriving the MIP values ~~is~~ are described in Section B.4.

Table B-2: NP-768 Plant A Target Areas Excluding Roofs

Target #	Target Description	Exposed Surface Area (ft^2)	Notes
1	Containment	39,584	Without the dome (a half-sphere)
2	Auxiliary Bldg.	44,200	Without the roof
3	Fuel Handling Bldg.	25,800	Without the roof
4	Diesel Generator Bldg.	14,000	Without the roof
5	Waste Processing Bldg.	38,400	Without the roof
6	SW Intake Structure	8,000	Includes the roof, since the building is only 20 feet high
7	Tanks Enclosure	16,000	Without the roof
Total	**All Targets**	185,984	**Sum of areas for Targets 1 through 7 (without roofs).**
Total	**All Targets Except Containment**	146,400	**Sum of areas for Targets 2 through 7 (without roofs) – See Section B.4**

B.3.2 Selection of Conservative Tornado Region MIP

Ideally, the MIP should not differ between NRC Tornado Regions I, II, and III, since the only difference between the regions is the tornado frequency. The MIP is normalized by tornado frequency, so it should be consistent from one tornado region to the other. Since *P* is provided for each NRC Tornado Regions in NP-768 Table 3-15, MIP was derived for each region for each tornado category and compared. For F'2 and F'3 tornadoes, the derived MIP was consistent across NRC Tornado Regions. However, for F'4 through F'6, there were differences between derived MIPs. There is no specific discussion in NP-768 as to why the hit probability per missile/area/tornado would vary from one tornado region to another; the differences are believed to be the result of Monte Carlo sampling and associated modeling.

Nonetheless, in order to account for the uncertainty associated with these results, the highest derived MIP value for each F'-scale tornado across the three regions was selected for the TMRE.

B.3.3 Separate MIP Derivation for Elevated Targets and Near Ground Targets

Two factors are responsible for the decision to derive MIP values for different target elevations (near ground versus elevated):

- Elevated targets are less likely to be hit by a tornado missile compared to near the ground (where most missiles originate).
- The hit probability data in NP-768 includes hits on any target surface, including the roof.

Knowing that missile hit probability is less at a higher elevation than at a lower elevation, MIP values derived from the target hit probability divided by the entire target area would be biased to a smaller value. The missile hit probability data in NP-768 cannot be separated by target surface. However, deriving MIP using the entire hit probability, but only the vertical wall area (and not the roof area), would tend to bias MIP towards a larger value (since it would include all missile hits on a target but not the entire target area).

Calculating only one set of MIP values in this manner would result in conservative MIPs for elevated targets. Therefore, two sets of MIPs are derived, one for elevated targets and one for near ground targets. The different target areas in Tables B-1 and B-2 are used for the calculations.

B.3.4 Basis for Target Elevation Demarcation

The demarcation elevation of 30 feet is decoupled from the NP-768 data, since the NP-768 data provides no quantifiable insights into missile hit probability vs. elevation. Although it is understood that tornado missile flux is higher at low elevations and lower at high elevations (see Figure 3-3 in NP-768), the true variation of missile flux versus elevation is not known. Therefore, an assumed demarcation elevation was determined qualitatively, based on regulatory documents associated with tornado missiles.

30 feet was chosen as the elevation demarcation for MIP, based on demarcation for heavier missiles in design basis requirements (SRP Rev 0 Section 3.5.1.4 [Ref. 18] and RG 1.76 Rev 1 [Ref. 19]).

- *"Missiles A, B. C, D. and E are to be considered at all elevations and missiles F and G* [utility pole and automobile] *at elevations up to 30 feet above all grade levels within 1/2 mile of the facility structures."* [Ref. 18]
- *"The automobile missile is considered to impact at all altitudes less than 30 feet (9.14 meters) above all grade levels within 0.5 mile (0.8 kilometer) of the plant structures."* [Ref. 19].

The 30' demarcation is supported by the results of the Target Elevation Study documented in Appendix E. The results of the study compare favorably with the relative difference between the near ground and elevated MIP values. Table B-2a compares MIP values for elevated (>30' MIP) and near ground (≤30') targets, taken from Table B-5. The elevated MIP is approximately 40 to ~~55~~45% of the near ground MIP.

Table B-2a: Elevated and Near Ground Missile Impact Parameter Comparisons

Tornado	>30' MIP	≤30' MIP	Ratio (>30':≤30')
F'2	5.80E-11	1.4E-10~~1.10E-10~~	0.41~~0.53~~
F'3	2.00E-10	4.6E-10~~3.60E-10~~	0.43~~0.56~~
F'4	3.40E-10	7.9E-10~~6.30E-10~~	0.43~~0.54~~
F'5	8.70E-10	2.0E-09~~1.60E-09~~	0.44~~0.54~~
F'6	1.30E-09	3.1E-09~~2.40E-09~~	0.42~~0.54~~

The target elevation sensitivity cases, documented in Appendix E, were performed to validate that target hit probabilities for elevated targets were appreciably lower than for near ground targets. The Appendix E sensitivities were performed using actual plant TORMIS models and were set up to show a variety of targets with the same area at different elevations on different plant surfaces. The sensitivity cases were not specifically intended to provide validation of the exact ratio of hit probabilities, nor were they intended to validate the exact demarcation elevation between elevated and near ground MIPs. However, the results of the studies do confirm the relative difference in the elevated and near ground MIPs.

Appendix E, Figures 9 – 15, confirm that the target hit probability is generally smaller at higher elevations, which is expected.[20] Five of the seven target sets show that elevated targets (those with lower borders ranging from 26' – 50') have a lower hit probability than near ground targets; the ratios range from 20% to 65%. Results from two of the target sets are inconclusive, but those target sets are determined to be inadequate for this sensitivity (see discussion for Plant A North and South Walls in the Table B-2b). Therefore, the results of the elevation sensitivities in Appendix E are consistent with the relative differences between the near ground and elevated MIPs derived in Section B.4.

Table B-2b: Review of Appendix E Target Elevation Study Results

Plant	Wall	Results
A	East	The 38' target (elevation between 33' – 43') hit probability is about 65% of the near ground target, approximately the same as the MIP ratios in Table B-2a. The higher target (centerpoint at 78') is even lower at ~20% of the near ground target, and about 30% of the middle (38') target.
A	West	The first two targets are both below 30', and have essentially the same hit probability. The 55' target hit probability is about 65% of the near ground target, approximately the same as the MIP ratios in Table B-2a.
A	South	All targets on the south wall are relatively close to the ground, since the wall is relatively short. The highest target elevation is between 30' – 40'. The hit probabilities are essentially constant across all elevations. The hit probabilities on the south wall targets do not reflect a lower hit probability for elevated targets, although the height of the wall precluded evaluating targets much higher than 30' above grade. It should be noted that the south wall target is relatively close to the east side of the plant, which has a grade 35' lower than that on the south side. Thus, the relative heights of the targets on the south wall, with respect to missiles from the east side of the plant, are all above 35'.
A	North	All the targets on the north wall are more than 60' above the north side grade and over 90' above the east side grade. Therefore, all the target are elevated well above the majority of the missile sources, so the relative consistency in hit probabilities with elevation does not provide any useful information with respect to the question of elevated vs. near ground MIP.
B	North	[Similar configuration and results as Plant A West Wall] The results for this wall show that the 41' target (elevation between 36' – 46') hit probability is about 50% of the near ground target, approximately the same as the MIP ratios in Table B-2a. The first two targets (both below 26') show relatively consistent hit probabilities.

[20] Note: All targets had a height of 10'; the target elevations listed in Table E-5 and provided in Figures 9 – 15 are the centerpoint elevations for the targets.

Plant	Wall	Results
B	South	[Similar configuration and results as Plant A East Wall]. The 31' target (elevation between 26' – 36') hit probability is about 60% of the near ground target, approximately the same as the MIP ratios in Table B-2a. The higher target (centerpoint at 64') is even lower at ~40%.
B	West	[Similar configuration and results as Plant A West Wall and Plant B North Wall]. The results for this wall show that the 53.5' target (elevation between 48.5' – 58.5') hit probability is about 20% of the lowest target, much lower than the MIP ratios in Table B-2a; its hit probability is also only 30% of the middle target (23.5'). The 23.5' target (18.5' – 28.5') hit probability is about 70% of the lowest target.

Missiles exist at elevations above reference elevation; the initial elevation of the missiles can affect the variation in MIP with target elevation. The EPRI NP-768 missile insertion elevations are sampled from a uniform distribution that ranges from 5 to 50 feet. Therefore, there is an equal probability of a (non-car) missile being inserted from any height between 5 to 50 feet. In general, it is expected that higher missile injection heights will lead to higher missile hit probabilities, because the missiles would tend to fly farther and thus be more likely to encounter a target.

Missile elevation data from several sites was determined based on actual missile surveys. This data provides a comparison between the missile insertion heights from EPRI NP-768 and the actual missile elevations at a set of representative plants. Table B-2c compares the distribution of missiles injected at various heights in the NP-768 simulations (assuming a uniform distribution from 5 to 50 feet) with missile heights from the plant surveys. On average, approximately 2/3rds of site missiles are close to the ground (within 15' of grade), as compared to only 22% of the NP-768 missile insertion heights.

Table B-2c: Comparison of NP-768 and Actual Plant Missile Injection Heights

Injection Height	Percent of Total Missiles Average (based on Uniform Distribution)*	Percent of Missiles from Surveyed Plants*	Percent Range of Missiles from Surveyed Plants	Comments
5' to 15'	22%	66%	51% - 86%	Mostly zonal (loose) missiles plus missiles from deconstruction of 1-story structures or the 1st story of multi-story structures
15' to 30'	33%	15%	8% - 20%	Primarily Missiles from deconstruction of the 2nd story of multi-story structures
30' to 50'	44%	18%	7% - 29%	Primarily missiles from deconstruction of the 3rd story and higher or multi-story structures

* Percentages do not add to 100% due to rounding

Assuming that higher injection heights lead to higher hit probabilities (since missiles will travel farther leading to a higher likelihood of encountering a target), the plant data clearly bounds the injection height assumptions in NP-768. Therefore, it is reasonable to conclude that the MIPs provided in this guidance can be used for any plant, without the need to validate plant-specific missile injection heights.

B.4 MIP VALUES FOR USE IN THE TMRE

MIP values were derived from NP-768 Plant A single-missile hit probabilities (the *H*-value *P*), based on the data provided in NP-768 Table 3-15. MIP values are provided for each F'-scale tornado, from F'2 through F'6, for near ground and elevated targets.

The demarcation between near ground and elevated targets is 30 feet above the associated reference elevation for a target. This is typically plant grade, since most damaging missiles at a NPP originate at or near grade.

B.4.1 NEAR GROUND TARGET MIP

For TMRE targets near the ground (defined as less than 30' above reference elevation), the MIP is derived using the target areas listed in Table B-2, which generally excludes the area of the roof. Since missile hits on roofs are expected to be a small percentage of the total missile hits, excluding the roof areas while still counting all hits on the target, will provide a higher value that should be more representative of the lower elevation targets. One exception is Target 6, for which the roof area is included, since it is only 20 feet above grade.

Additionally, since Target 1 (the containment structure) has no exposed surfaces within 30 feet of the reference elevation, it was omitted from the surface area used to derive the Near Ground MIP. Figure B-2 shows that Target 1 is shielded by Target 2 to the east and Target 3 to the west. These buildings prevent missiles from striking the lower portions of Target 1. Since the height of Targets 2 and 3 are greater than 30 feet (80 and 60 feet, respectively), there is no exposed surface area for Target 1 that is below 30 feet. Therefore, the exposed surface area used for the Near Ground MIP derivations is 146,400 ft^2, from Table B-2.

Table B-3 provides the derived MIP values for the three tornado regions for Near Ground targets. The bolded values represent the highest values.

Table B-3: Plant "A" Tornado Missile Impact Parameters for Near Ground Targets

MIP (per missile per ft^2 per tornado interval frequency)			
F' Scale Category	**NRC Region I**	**NRC Region II**	**NRC Region III**
F'2	1.3E-10~~**1.1E-10**~~	**1.4E-10**~~1.1E-10~~	1.4E-10~~1.1E-10~~
F'3	4.5E-10~~**3.6E-10**~~	**4.6E-10**~~3.6E-10~~	4.6E-10~~3.6E-10~~
F'4	5.2E-10~~4.2E-10~~	5.3E-10~~4.1E-10~~	**7.9E-10**~~**6.3E-10**~~
F'5	**2.0E-09**~~**1.6E-09**~~	1.8E-09~~1.4E-09~~	N/A(1)
F'6	**3.1E-09**~~**2.4E-09**~~	N/A(1)	N/A(1)

(1)No hit values are provided in NP-768 Table 3-15 for these combinations of tornado category and NRC region

B.4.2 ELEVATED TARGET MIP

For the elevated MIP value (i.e., for targets greater than 30' above reference elevation), the area used to derive the MIP includes all the areas listed in Table B-1, which includes roof areas. Table B-4 provides the derived MIP values for the 3 tornado regions for Elevated targets. The bolded values represent the highest values.

Note that the Elevated Target MIP derivation includes data from Target 6, whose height is 20 feet. Therefore, none of the surface areas from Target 6 are above 30 feet. If Target 6 were eliminated from the Elevated Target MIP derivation, the MIP values would be lower.

Table B-4: Plant "A" Tornado Missile Impact Parameters for Elevated Targets

MIP (per missile per ft² per tornado interval frequency)			
F' Scale Category	**NRC Region I**	**NRC Region II**	**NRC Region III**
F'2	**5.8E-11**	5.8E-11	5.8E-11
F'3	**2.0E-10**	2.0E-10	2.0E-10
F'4	2.3E-10	2.3E-10	**3.4E-10**
F'5	**8.7E-10**	7.6E-10	N/A(1)
F'6	**1.3E-09**	N/A(1)	N/A(1)

(1)No hit values are provided in NP-768 Table 3-15 for these combinations of tornado category and NRC region

B.4.3 Summary of MIP Values

Table B-5 lists the MIP values for all targets; the MIP values provided herein are the highest values from Tables B-3 and B-4.

Table B-5: MIP Values for Use in the TMRE

MIP (per missile per ft² per tornado interval frequency)		
Tornado Category	**Targets >30' above grade(1)**	**Targets <u><</u>30' above grade(1)**
F'2	5.8E-11	~~1.1E-10~~1.4E-10
F'3	2.0E-10	~~3.6E-10~~4.6E-10
F'4	3.4E-10	~~6.3E-10~~7.9E-10
F'5	8.7E-10	~~1.6E-09~~2.0E-09
F'6	1.3E-09	~~2.4E-09~~3.1E-09

(1) The term grade here is meant to refer to the reference elevation. Typically, this is plant grade, although for some targets it may be different.

B.4.4 Potential for Statistical Correlation Between Targets

This section addresses statistical correlation between nearby targets. That is, for a given tornado strike on a site, nearby targets may be postulated to have a greater probability of being struck by separate missiles than the product of the two independent strike probabilities.

The consideration of correlated targets is not required as part of the TMRE method. Recent High Winds PRAs do not consider targets statistically correlated; all targets are considered independent unless they are so close to each other that they can be struck by the same missile. In those cases, the targets are grouped together as a single target. Therefore, it is reasonable that the TMRE does not consider statistical correlation between targets.

Correlation between nearby targets implies a greater probability for multiple targets to be struck by separate missiles, in the same tornado event, than the product of multiple independent strikes. That is, for two nearby targets A and B:

$$P_{missile}(A*B) > P_{missile}(A) * P_{missile}(B)$$

EPRI NP-768 [Ref. B.1] evaluated the probability of two adjacent targets (targets 6 and 8 in Plant B) being hit by separate missiles (i.e., the intersection probability $P^N(6\cap 8)$) and compared that to the probability of either target being hit by a missile (i.e., the union probability $P^N(6U8)$). NP-768, Table 3-23 provides the values for $P^N(6\cap 8)$ and $P^N(6U8)$ for Tornado Regions I – III.

The ratio of $P^N(6\cap 8) / P^N(6U8)$ represents the likelihood that both targets 6 and 8 will be hit by separate missiles given that either target 6 or 8 are hit. The value obtained for this ratio was 2.7E-3 for all three tornado regions (the fact that all three tornado regions have the same ratio is not unexpected). This ratio implies that, for the example in NP-768, the probability that statistically correlated missile strikes on two nearby targets is much less than 1% of the probability that either are hit.[21]

B.5 Missile Inventories

The EPRI NP-768 tornado simulations indicate that, for wind-driven missiles of sufficient mass to damage NPP SSCs, the mean transport distance is less than 350 feet. Missile transport beyond 1000 feet is rare, and transport beyond 2000 feet is very unlikely. The NP-768 missile hazard study considered missiles within approximately 2500 feet of the targets. In order to be consistent with the derivation of MIP from the TORMIS simulation data, the missile inventories used in the TMRE must also include missiles within approximately 2500 of targets.

The TMRE process was developed to be as standardized as possible for application across the U.S. NPP fleet. To support this goal and facilitate review and approval of TMRE results, generic missile inventory values are provided. Data from five U.S. NPP TORMIS analyses were used to develop the generic TMRE missile inventories; missile count walkdowns were performed to support the TORMIS analyses at these five sites in the U.S. The maximum values from these missile surveys [Refs, B.12, B.13, B.14, B.15, B.16] are used in the TMRE, given that the site-specific walkdown performed in support of the TMRE validates that this generic missile inventory is bounding (see Section 3). It is expected that the maximum values provided here will bound most sites.

Two general types of missiles are provided in each of the missile inventories: “zonal” and “structure” missiles.

In general, the zonal missiles are constant across the tornado intensity range. The difference in the ability of these types of missiles to become airborne and fly to the extent needed to hit and damage

[21] In a sensitivity study from a recent high winds PRA (that utilized TORMIS), two valves that were close to each other were evaluated for statistical correlation. The same ratio described here was calculated for these two targets and it varied from 1.3E-3 (EF1) to 2.9E-3 (EF5). This compares well with the correlation value determined from NP-768.

a target is accounted for in the MIP. The missile inventory data from the five plants show constant zonal missile inventories for all tornado categories.

The structure-based missiles are the result of weaker structures (steel- or wood-frame buildings constructed to standard building code requirements) deconstructing due to tornado winds. The amount of missiles created is dependent on the type of structure and the wind speeds associated with the tornado. Therefore, structure-based missile inventories tend to increase with increasing tornado intensity. The structure missile inventory data for three of the plants increase with tornado category, as expected. Structure missile data for two of the plants is constant; for these plants the maximum number of missiles associated with full structure deconstruction was used for all tornado categories.

Tables B-6 through B-10 provide the missile inventories from each of the five sites surveyed.

Table B-6: Missile Inventories for Plant 1

Tornado Category	Zonal Missiles	Structural Missiles	Total Missiles
F'2	38,267	67,799	106,066
F'3	38,267	67,799	106,066
F'4	38,267	67,799	106,066
F'5	38,267	67,799	106,066
F'6	38,267	67,799	106,066

Table B-7: Missile Inventories for Plant 2

Tornado Category	Zonal Missiles	Structural Missiles	Total Missiles
F'2	67,134	85,876	153,010
F'3	67,134	85,876	153,010
F'4	67,134	85,876	153,010
F'5	67,134	85,876	153,010
F'6	67,134	85,876	153,010

Table B-8: Missile Inventories for Plant 3

Tornado Category	Zonal Missiles	Structural Missiles	Total Missiles
F'2	92,851	2,814	95,665
F'3	92,851	35,375	128,226
F'4	92,851	108,526	201,377
F'5	92,851	139,555	232,406
F'6	92,851	139,555	232,406

Table B-9: Missile Inventories for Plant 4

Tornado Category	Zonal Missiles	Structural Missiles	Total Missiles
F'2	37,751	13,534	51,285
F'3	37,751	81,826	119,577
F'4	37,751	162,821	200,572
F'5	37,751	201,123	238,874
F'6	37,751	201,123	238,874

Table B-10: Missile Inventories for Plant 5

Tornado Category	Zonal Missiles	Structural Missiles	Total Missiles
F'2	75,369	4,636	80,005
F'3	75,369	33,095	108,464
F'4	75,369	101,511	176,880
F'5	75,369	127,734	203,103
F'6	75,369	127,734	203,103

Table B-11 lists the maximum number of missiles for each tornado category, F'2 through F'6, from Tables B-6 through B-10. The final column lists the total missile inventory for use in the TMRE, based on rounding up the highest value to the nearest 5,000 missiles.

Table B-11: Total Missile Inventories for Use in the TMRE

Tornado Category	Maximum Missiles from Sample	TMRE Missile Inventory
F'2	153,010 (Plant B)	155,000
F'3	153,010 (Plant B)	155,000
F'4	201,377 (Plant C)	205,000
F'5	238,874 (Plant D)	240,000
F'6	238,874 (Plant D)	240,000

B.6 MISSILES AFFECTING ROBUST TARGETS

SSCs that are robust in nature are not affected by all potential tornado missiles. The number of missiles used in the EEFP calculation can be adjusted to account for the population of missiles that can damage an SSC. Targets considered robust for the purpose of the TMRE include steel tanks, steel pipes, reinforced concrete roofs, and metal doors. A set of robust targets were evaluated in Appendix C against the spectrum of missile types considered in the TMRE. The results of the calculations documented in Table C.6 were consolidated to determine the percentage of the total missile inventory for each type of robust target. The final values determined are listed in Table B-18. The process used to develop this table is described in this section. For SSCs not considered robust (i.e., that do not meet the descriptions in Table B-13), the full missile inventories listed in Table B-11 are used in the EEFP calculations.

B.6.1 CATEGORIZING ROBUST TARGETS

A variety of SSCs with different characteristics were evaluated for different failure modes in Appendix C. In order to simplify the results of the Appendix C calculations, some similar SSC types were binned together, using the characteristics of the least robust target type for that group. This consolidated the robust target types into nine categories designated Category A through I, and K through M, defined in Table B-13. Table B-12 provides the grouping of target types from the results of Section C6.

Table B-12: Robust Target Descriptions

Description[1]	Failure Mode	Diameter (inches)	Thickness (inches)	Assigned Category
Diesel Generator Exhaust Pipe	Crushing > 50%	36	0.375	A
SG Steam Relief Valve Tailpipe	Crushing > 50%	16	0.50	A
Turbine Driven Feedwater Pump Exhaust Piping	Crushing > 50%	20	0.375	A
Steam Generator Power Operated RV Exh Pipe	Crushing > 50%	18	0.375	A
Diesel Generator Air intake (small)	Crushing > 50%	16	0.125	B
Diesel Generator Air intake (large)	Crushing > 50%	48	0.125	B
Diesel Generator Exh Silencer	Crushing > 50%	22	0.375	A
Condensate Storage Tank (t=0.25")	Perforation or Global	NA	0.25	C
Diesel Fuel Oil Tank (t=0.133")	Perforation or Global	NA	0.133	D
Diesel Fuel Oil Tank (t=0.145")	Perforation or Global	NA	0.145	D
Condensate Storage Tank (t=0.375")	Perforation or Global	NA	0.375	C
Low Pressure Water Pipe	Perforation or Global	6	0.237	F
Low Pressure Water Pipe	Perforation or Global	10	0.237	F
Main Steam Piping (t=0.985")	Perforation or Global	36	0.985	E
Room Door (t=0.1")[2]	Perforation or Global	NA	0.1	G
Low Pressure Water Pipe	Perforation or Global	18	0.375	E
High Pressure Water Pipe	Perforation or Global	10	0.432	E
Concrete roofs[3]				
8" reinforced concrete roof[3]	Perforation	NA	8.0	H
4" reinforced concrete roof with steel decking[4]	Perforation	NA	4.0	I

Description(1)	Failure Mode	Diameter (inches)	Thickness (inches)	Assigned Category
~~Vertical Barriers~~				
~~12" reinforced concrete wall~~	~~Perforation or Global~~	~~NA~~	~~12.0~~	~~K~~
~~2" x 3/8" steel grating(5)~~	~~Global~~	~~NA~~	~~2.0~~	~~L~~
~~4" x 3/8" steel grating(5)~~	~~Global~~	~~NA~~	~~4.0~~	~~M~~

Notes:
(1) All piping, tanks, and the room door are steel
(2) Steel door is a standard 16 or 18 gauge door, with equivalent thickness of 0.1" steel. Thicknesses based on SD-108 (each inside and outside face steel sheet varies between 0.042" (18 gauge) and 0.053" (16 gauge) [Ref. B-17].
(3) Only applies to roofs, not walls; reduced missile speeds (assuming vertical missiles) were used to calculate perforation.
(4) Steel decking not credited in evaluation
~~(5) Bar spacing assumed to be 1" on-center~~

Table B-13: Robust Target Descriptions

Category	Target Description	Failure Mode
A	Steel Pipe – at least 16" diameter and 3/8" thickness	Crushing/Crimping of > 50%
B	Steel Pipe – at least 16" diameter and thickness less than 3/8" but at least 0.125"	Crushing/Crimping of > 50%
C	Steel Tank – at least 0.25" thickness	Penetration or Global Failure
D	Steel Tank – less than 0.25" thickness	Penetration or Global Failure
E	Steel Pipe – at least 10" diameter and 3/8" thickness	Penetration or Global Failure
F	Steel Pipe – Less than 10" diameter or 3/8" thickness	Penetration or Global Failure
G	Steel Door	Penetration or Global Failure
H	Concrete Roof – Reinforced, at least 8" thick	Penetration or Global Failure
I	Concrete Roof – Reinforced, at least 4" thick	Penetration or Global Failure
J	Not robust	NA
~~K~~	~~Concrete Wall – Reinforced, at least 12" thick~~	~~Perforation or Global Failure~~
~~L~~	~~Steel Grating – At least 2" thick, bars at least 3/8", bar opening less than 1" wide~~	~~Global Failure~~
~~M~~	~~Steel Grating – At least 4" thick, bars at least 3/8", bar opening less than 1" wide~~	~~Global Failure~~

The table in Section C6 provides indication of the damage produced by each missile type for each target. The missile set which causes failure for each of the robust target categories in Table B-13 is based on the most limiting case for each category. If a missile type causes damage to any of the targets in the category, it is assumed to cause damage for the whole category. Table B-14 provides a matrix of missile types that damage each target category. Filled cells in the matrix indicate that the missile type causes failure of the target category type.

Table B-14: Robust Target Missile Matrix

Missile Type	Robust Category Type								
	A	B	C	D	E	F	G	H	I
1 - Rebar			■	■	■	■	■		■
2 - Gas Cylinder	■	■	■	■	■	■	■		
3 - Drum, tank		■		■		■			
4 - Utility Pole	■	■	■	■	■	■	■		■
5 - Cable Reel		■		■		■			
6 - 3" Pipe		■	■	■	■	■	■		
7 - 6" Pipe	■	■	■	■	■	■	■		■
8 - 12" Pipe	■	■	■	■	■	■	■		■
9 - Storage bin	■	■	■	■		■	■		■
10 - Concrete Paver		■							
11 - Concrete Block									
12 - Wood Beam		■		■		■			
13 - Wood Plank									
14 - Metal Siding		■							
15 - Plywood Sheet									
16 - Wide Flange	■	■	■	■	■	■	■		■
17 - Channel Section		■	■	■	■	■	■		
18 - Small Equipment		■	■	■		■	■		
19 - Large Equipment	■	■	■	■	■	■	■		■
20 - Frame/Grating									
21 - Large Steel Frame	■	■	■	■	■	■	■		■
22 - Vehicle	■	■	■	■	■	■	■	■	■
23 - Tree		■		■		■	■		

■ Indicates that missile type fails the target category

B.6.2 Missile Type Inventories

In order to provide a simplified and consistent percentage of missile types for the TMRE application, generic missile inventories were developed. Specific missile type counts were taken from 2 plant missile inventories (from Plants 1 and 2), provided in Tables B-15 and B-16. Table B-15 provides the inventory of unrestrained (zonal) missiles and Table B-16 provides the restrained (structural) missile inventory[22]; see Section B.5 for a discussion of these terms.

Table B-15: Unrestrained Missile Inventories

Missile Type	**Plant 1**	**Plant 2**
1 - Rebar	15,707	23417
2 - Gas Cylinder	444	1149
3 - Drum, tank	369	448
4 - Utility Pole	50	0
5 - Cable Reel(1)	150	150
6 - 3" Pipe	4,404	4,754
7 - 6" Pipe	418	855
8 - 12" Pipe	278	25
9 - Storage bin(2)	250	250
10 - Concrete Paver	0	4,240
11 - Concrete Block(3)	5,000	5,000
12 - Wood Beam	557	260
13 - Wood Plank	4,400	19,990
14 - Metal Siding	2,270	261
15 - Plywood Sheet	5,561	8,655
16 - Wide Flange	219	249
17 - Channel Section	880	1,953
18 - Small Equipment(4)	200	200
19 - Large Equipment	450	329
20 - Frame/Grating	0	108
21 - Large Steel Frame(5)	150	150
22 - Vehicle	960	1,695
23 - Tree	1,300	0
TOTAL	**44,017**	**74,138**

[22] The missile inventory data for Plants 1 and 2, provided in Tables B-15 and B-16 were reported as unrestrained and restrained populations. These are equivalent to zonal and structural missiles, the terminology used in this guidance. Regardless, the total values for each missile type are used (Table B-17), so the delineation between restrained and unrestrained does not have an impact.

Table B-16: Restrained Missile Inventories

Missile Type	Plant 1	Plant 2
1 - Rebar	1,545	2,271
2 - Gas Cylinder	0	0
3 - Drum, tank	0	0
4 - Utility Pole	37	226
5 - Cable Reel(1)	600	600
6 - 3" Pipe	15,034	14,762
7 - 6" Pipe	354	456
8 - 12" Pipe	0	90
9 - Storage bin(2)	2,500	2,500
10 - Concrete Paver(6)	2,500	2,500
11 - Concrete Block(3)	25,000	25,000
12 - Wood Beam	4,053	217
13 - Wood Plank	75	1,192
14 - Metal Siding	24,867	30,650
15 - Plywood Sheet	2,975	9,247
16 - Wide Flange	200	285
17 - Channel Section	11,509	10,259
18 - Small Equipment(4)	1,500	1,500
19 - Large Equipment(7)	400	400
20 - Frame/Grating(8)	3,000	3,000
21 - Large Steel Frame(5)	700	700
22 - Vehicle	0	0
23 - Tree	7,150	14,738
TOTAL	**103,999**	**120,593**

Notes for Tables B-15 and B-16[23]:

(1) No cable reels counted for either plant; assumed 150 for unrestrained and 600 for restrained, per plant.

(2) No storage bins counted for either plant; assumed 250 for unrestrained and 2,500 for restrained, per plant.

(3) No concrete blocks counted for either plant; assumed 5,000 for unrestrained and 25,000 for restrained, per plant.

(4) No small equipment counted for either plant; assumed 200 for unrestrained and 1,500 for restrained, per plant.

(5) No steel frames counted for either plant; assumed 150 for unrestrained and 700 for restrained, per plant.

(6) No structural concrete pavers for either plant; assumed 2,500 per plant (restrained only)

(7) No large equipment from structures for either plant; assumed 400 per plant (restrained only)

[23] No inventories for certain missile types were provided for Plants 1 and 2; estimates were made based on walkdown experience at other sites.

(8) No frame/grating from structures for either plant; assumed 700 per plant (restrained only)

In order to determine the generic percentage for each missile type, the totals for each missile type from the unrestrained and restrained missiles were combined and averaged (between the two plants). The averages were normalized to determine the percentage of each missile type, which is provided in Table B-17. Note: the sum of the values in Table B-17 is greater than 100% due to rounding.

Table B-17: Average Missile Type Inventory

Missile Type	**Percentage**
1 - Rebar	13%
2 - Gas Cylinder	0.5%
3 - Drum, tank	0.2%
4 - Utility Pole	0.1%
5 - Cable Reel	0.4%
6 - 3” Pipe	11%
7 - 6” Pipe	0.6%
8 - 12” Pipe	0.1%
9 - Storage bin	1.6%
10 - Concrete Paver	2.7%
11 - Concrete Block	18%
12 - Wood Beam	1.5%
13 - Wood Plank	7.5%
14 - Metal Siding	17%
15 - Plywood Sheet	7.7%
16 - Wide Flange	0.3%
17 - Channel Section	7.2%
18 - Small Equipment	1.0%
19 - Large Equipment	0.5%
20 - Frame/Grating	1.8%
21 - Large Steel Frame	0.5%
22 - Vehicle	0.8%
23 - Tree	6.8%
TOTAL	**100%**

Combining the results from Table B-14 and Table B-17 provides the percentage of missiles that can damage each robust target category, as shown in Table B-18.

Table B-18 Missile Damage Capability

Category	Target Description	Failure Mode	Calculated Percentage	Final Percentage
A	Steel Pipe – at least 16" diameter and 3/8" thickness	Crushing/Crimping of > 50%	5%	**5%**
B	Steel Pipe – at least 16" diameter and thickness less than 3/8" but at least 0.125"	Crushing/Crimping of > 50%	53%	**55%**
C	Steel Tank – at least 0.25" thickness	Penetration or Global Failure	37%	**40%**
D	Steel Tank – less than 0.25" thickness	Penetration or Global Failure	46%	**50%**
E	Steel Pipe – at least 10" diameter and 3/8" thickness	Penetration or Global Failure	34%	**35%**
F	Steel Pipe – Less than 10" diameter or 3/8" thickness	Penetration or Global Failure	46%	**50%**
G	Steel Door	Penetration or Global Failure	44%	**45%**
H	Concrete Roof – Reinforced, at least 8" thick	Penetration or Global Failure	1%	**1%**
I	Concrete Roof – Reinforced, at least 4" thick	Penetration or Global Failure	17%	**20%**
J	Not Robust	NA	NA	**NA**
~~K~~	~~Concrete Wall – Reinforced, at least 12" thick~~	~~Perforation~~	~~0.1%~~	~~**0.5%**~~
~~L~~	~~Steel Grating – At least 2" thick, bars at least 3/8", bar opening less than 1" wide~~	~~Global~~	~~10%~~	~~**10%**~~
~~M~~	~~Steel Grating – At least 4" thick, bars at least 3/8", bar opening less than 1" wide~~	~~Global~~	~~0.5%~~	~~**1%**~~

B.6.3 Reinforced Concrete and Steel Plate Tornado Missile Barriers

The TMRE considers certain barriers to provide complete protection from tornado missiles, allowing SSCs protected by these barriers to be screened. The barriers are 18" reinforced concrete walls, 12" reinforced concrete roofs, and 1" plate steel.

Table 1 of NUREG 0800, Section 3.5.3 [B-20] provides minimum barrier thickness requirements for local damage prediction against tornado generated missiles. For RG 1.76 Region I (the most conservative tornado wind speeds), the minimum wall thickness is 16.9" and the minimum roof thickness is 12.3" (~12.0"), assuming 4,000 psi concrete strength. Reinforced concrete walls at nuclear plants typically exceed 4,000 psi strength. Also note that roofs typically contain steel decking, providing added protection against tornado missiles.

Furthermore, the results of the EPRI NP-768 simulation studies show a very low likelihood of damage to wall structures from tornado generated missiles. The EPRI "Plant A" simulations did not result in any penetrations by tornado missiles of concrete walls at least 18" thick. Calculations using the methods described in Appendix C of this document also support the exclusion of tornado missiles protected by 18" reinforced concrete walls and 12" reinforced concrete roofs.

Credit for 1" steel plate to provide tornado missile protection is consistent with current high wind PRAs. The Appendix C results for tornado missile impacts on steel pipe and tank targets confirm that the 1" criterion is reasonable.

B.7 References

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18. NUREG-75/087, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, May 1980

19. Regulatory Guide 1.76, Design-basis Tornado and Tornado Missiles for Nuclear Power Plants, Revision 1, March 2017)

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APPENDIX C: BASES FOR TARGET ROBUSTNESS AND MISSILE CHARACTERISTICS

C.1 PURPOSE

The purpose of this report appendix is to provide a summary of the technical approach for evaluating the robustness of typical Nuclear Power Plant (NPP) Structures, Systems, and Components (SSC) against the effects of wind-borne missile impacts. The range of SSCs, or 'targets', that was considered in this evaluation includes those that are commonly evaluated in high-wind risk evaluations, such as piping, liquid storage tanks, metal doors, and reinforced concrete roofs.

The spectrum of wind-borne missiles considered in this evaluation is based on the types of missiles described in Table 3-2 of this report. The missiles include a range of non-deformable and deformable wind projectiles: wood timbers, steel pipes, construction equipment, small trees, masonry units, pavers, and an automobile. The weights of these missiles ranged from 8 lbs. to 4,000 lbs.

The maximum horizontal missile impact velocity considered in this evaluation is 230 mph, which bounds most of the missile impact velocities described in the 1975 Standard Review Plan (SRP) Section 3.5.1. The maximum vertical missile impact velocity is 153 mph (2/3 x 230 mph) for reinforced concrete roof impacts. A review of more recent regulatory guidance pertaining to wind-borne missiles, including RG 1.76 (2007)) and RG 1.221 (2011), finds that the 230 mph horizontal impact velocity is slightly conservative. The highest horizontal missile impact speed cited in the most current NRC guidance is 92 mph (RG 1.76) for tornado winds and 209 mph (RG 1.221) for hurricane winds.

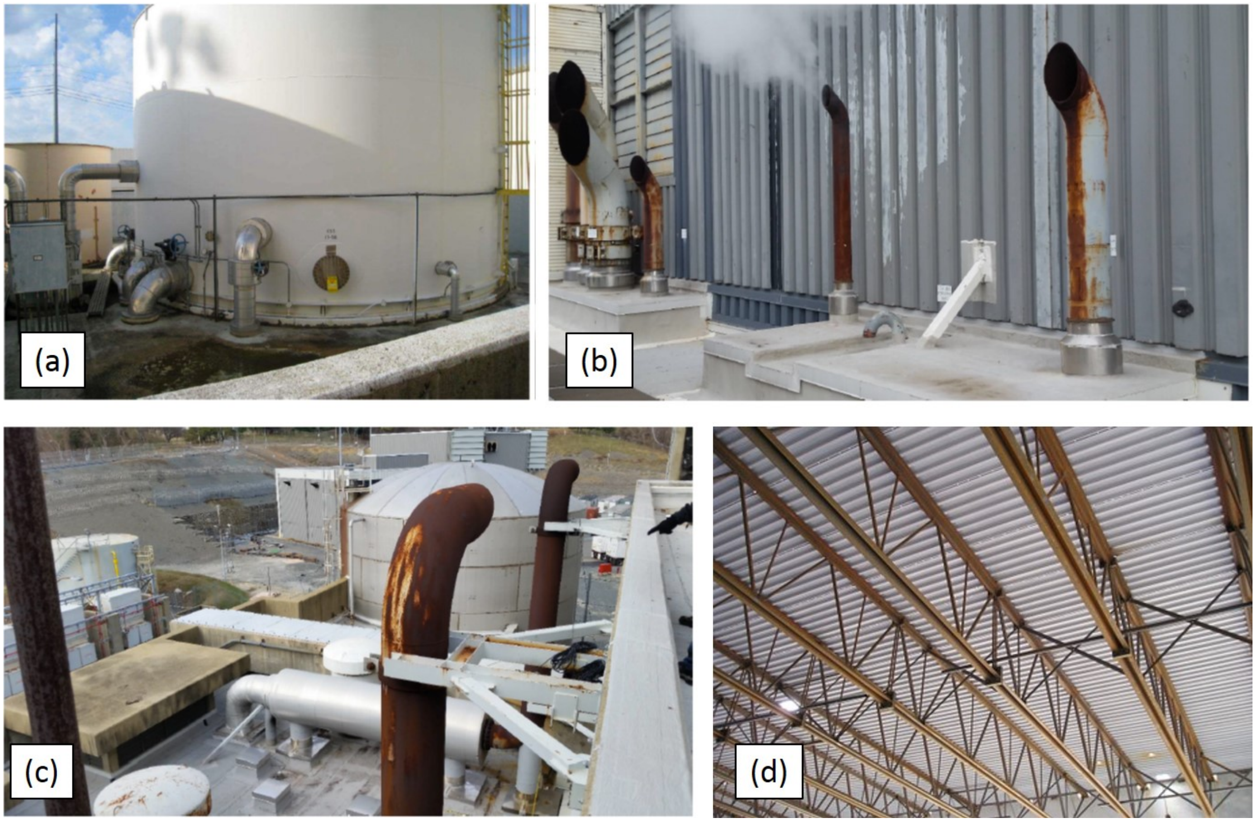
The results of these analyses are used to estimate the number of missiles that could cause damage to pipe, tank, steel door, and concrete targets. A summary of the number of damaging missiles for each of these targets is shown in Figure 5-2 of this report.

C.2. BACKGROUND

The design of nuclear power plant facilities includes the effects missile impacts on structures, systems, and components. SRP Section 3.5.3 [1] provides guidance and acceptance criteria for the evaluation of barrier design procedures to ensure conformance with 10 CFR 50, Appendix A, General Design Criteria 2 and 4. This SRP section provides acceptance criteria for the prediction of local damage and overall response of safety-significant missile barrier. SRP Section 3.5.3 also references the acceptable use of the empirical equations, such as the Ballistic Research Lab (BRL) equation(s), to estimate effects of missile penetration on steel and concrete structures. This SRP section also requires an evaluation of overall (or global) structural effects. Both local and global evaluations were done for each target evaluated.

The targets assumed in this evaluation were representative of piping, tanks, doors, and reinforced concrete roofs. The piping targets had diameters and thicknesses ranging from 6-48 inches and 0.125-0.985 inches, respectively. The range of tank wall thicknesses ranged from 0.125 to 0.378 inches. All steel targets were conservatively assumed to have a design yield strength of 30,000 psi. Reinforced concrete roofs were assumed to have thicknesses of 4 and 8 inches and corresponding spans were assumed to be 4-ft and 20-ft, respectively. Figure C-1 indicates examples of potential wind-borne missile targets.

Figure C-1. Representative targets[24]: (a) condensate storage tank, (b) steam exhaust stacks, (c) diesel generator mufflers, and (d) steel composite concrete roof (interior view)



C.3. APPROACH

The impact of a missile onto a target is a complex dynamic problem. The phenomena typically involve nonlinear material behavior and high strain rates for both the missile and target. The problem of wind-driven missiles is further complicated, because these missiles are not engineered to penetrate a hardened target (i.e., remain rigid). Rather, these missiles are typically deformable such that they are susceptible to fail by buckling or shattering before they can penetrate a target. Detailed nonlinear finite-element analysis methods can be utilized for evaluating missile impacts, but due to the complexity of this class of problem and lack of relevant experimental tests (for validation purposes), uncertainty in final results is not necessarily reduced. Nonetheless, as missile impact is considered in the design of nuclear power plant structures, NRC and industry guidance exist for developing approximate demands on structures without requiring sophisticated analysis methods. Standard practice methods include the use of single degree-of-freedom models for representing the target capacity (force-displacement) and the use of forcing functions to represent the missile impact.

As the number of EPRI missile and target combinations to be analyzed was more than 400 (~23 missiles x 19 targets), a pragmatic approach was developed for the TMRE to estimate target damage. The approach relies on an analytical approach that is consistent with the NRC SRP Section 3.5.3 [1]. The approach makes accounts for missile characteristics such as impact speed, missile mass, and target

[24] Source: EPRI walkdown report [6]

characteristics such as stiffness, ultimate capacity, and mass. The analysis of pipe crimping was benchmarked to two relevant experiments.

While median material properties were assumed to develop a best-estimate of target capacity, conservative assumptions were made with respect to missile strike location and orientation. It was assumed that missile impacts are normal to the target surface and that the axis of the missile is parallel to the line of flight. For impacts on pipes, the effectiveness of the missile impact degrades significantly as the strike location is offset from the centerline of the pipe.

Target Response

For the analysis of local effects (penetration/perforation) on the targets considered in this evaluation, the BRL equations were relied upon. Section C3.1 describes the approach for evaluating local effects.

For the evaluation of overall (or global) impact effects on NPP structures, each target was idealized as a single-degree-of-freedom (SDOF) lumped mass model. The relatively high-velocity impact scenarios (>100 mph), were assumed to be plastic (consistent with SRP Section 3.5.4) resulting in the missile mass being included in the effective mass of the target. The initial condition of the SDOF equation-of-motion is initial velocity, which is derived based on the conservation of momentum between the missile and target. Numerical integration of the SDOF equation of motion is performed to estimate target displacement as a function of time. The subsequent target response (displacements, strains, etc.) can be compared to allowable limits. The lumped mass modeling approach is a common engineering dynamic analysis tool [12] and has been used in the design nuclear of power plants [7].

It is recognized that some design methods rely on idealizing the missile with a forcing function (force versus time) rather than estimating an initial target velocity. However, the forcing function approach, which relies on a rigid (non-moving) target, can provide overly conservative force estimates for compliant structures. For design purposes, members can be made sufficiently stiff to resist the assumed forcing function. For evaluating existing SSCs, which are likely compliant targets, the initial velocity approach is a reasonable alternative. A comparison of results between models making use of a forcing function or an initial velocity condition showed reasonable agreement in predicted displacements.

Modes of Failure

The failure modes considered for the targets varied depending on target type (Table C-1). Steel pipe sections were evaluated for both local effects and global effects. Local effects relate to localized perforation (or punching shear) and is dependent on pipe (or wall) thickness, rather than structural response of a pipe, tank, or concrete panel. For this evaluation, these effects were assessed with the use of empirical equations. Global effects relate to the overall flexural response (or bending) of pipes, tanks, and concrete panels. These 'global' modes are influenced by structural section properties (wall thickness, diameter, etc.) as well as member span and boundary conditions. Global effects also relate to pipe crushing and crimping, as both circumferential and longitudinal pipe response are factors.

For piping targets, the critical section was assumed to be the location of missile impact. As piping configurations and support conditions vary considerably, it was considered reasonable to idealize the pipe boundary conditions for two cases. For vent pipe cases, the pipe is assumed to be supported on one end by a fully-clamped condition and free (or unsupported) on the opposite end. These boundary conditions realistically represent a cantilevered vent pipe. For wetted (or fluid-filled) pipe cases, the pipe is assumed to be fixed-supported on one end and pinned or simply-supported on the opposite end.

Liquid-filled steel tanks were also evaluated for perforation and flexural failure of the shell in the vicinity of the missile impact (Section C3.3). The added mass of the tank fluid (water) was considered in the dynamic model, but the stiffening effect (incompressible fluid) is conservatively neglected. The tanks were conservatively modeled as ring structures, so the additional stiffness contributed from the top/bottom of the tanks were not considered.

Reinforced concrete roofs were evaluated for local perforation and overall slab response (Section C3.4). Rotations at the slab supports were compared to ASCE allowable limits [13].

Table C-1 - Significant Evaluation Assumptions

Target Type	Relevant Failure Modes	Assumptions
Stacks and Exhaust Pipes	Crimping/crushing at impact location	Cantilevered pipe support. Missile impact near end of pipe (1-pipe diameter away)
Fluid/Steam Pipes	Perforation and crimping/crushing at impact location	Pipe supported on both ends. Missile impact at center span
Tanks	Perforation and global*	Impact at mid-height of tank shell. Added mass of fluid accounted for.
Doors	Perforation and global**	Impact at center of door. Sandwich panel idealized as isotropic plate.
RC Roofs	Perforation and global***	Impact at center of roof slab. Supporting beams or bar joists not considered.

*Circumferential stiffness and flexural capacity of tank considered
**Flexural stiffness and capacity of door panel considered
***Flexural and shear failure of roof panel considered

C.3.1 Perforation Evaluation

The local effects of missile perforation were considered for all targets except for stacks and exhaust pipes. The functionality of stack and exhaust piping was judged to be more limited by crushing or crimping failure modes. Perforation effects on steel targets were assessed using the BRL equation:

$$T = \frac{\left(\frac{MV_s^2}{2}\right)^{2/3}}{672D_m}$$

$T =$ steel plate thickness to just perforate (inches)
$M =$ Mass of the missile $(\mathrm{lb} - \mathrm{sec}^2/\mathrm{ft})$
$V_s =$ striking velocity of the missile normal to target surface $\left(\frac{\mathrm{ft}}{\mathrm{sec}}\right)$
$D_m =$ diameter of missile (in)

As perforation of a pipe or tank wall requires penetration of steel material, it was assumed that only missiles comprised of steel materials (pipes, beams, etc.) are capable of a perforation failure mode. While deformable missiles are not likely to cause a perforation failure mode, these missiles were evaluated for their propensity to cause global structural damage (e.g., crushing/crimping).

For realistic analysis, missile impact velocity was assumed to be weight dependent, as described in NRC SRP (1975) Section 3.5.1.4 (Table C-2). This table indicates that as missile weight increases, horizontal impact velocity decreases. For this evaluation, a linear velocity-weight correlation was used (Figure C-3), which conservatively bounded most of the SRP missile types.

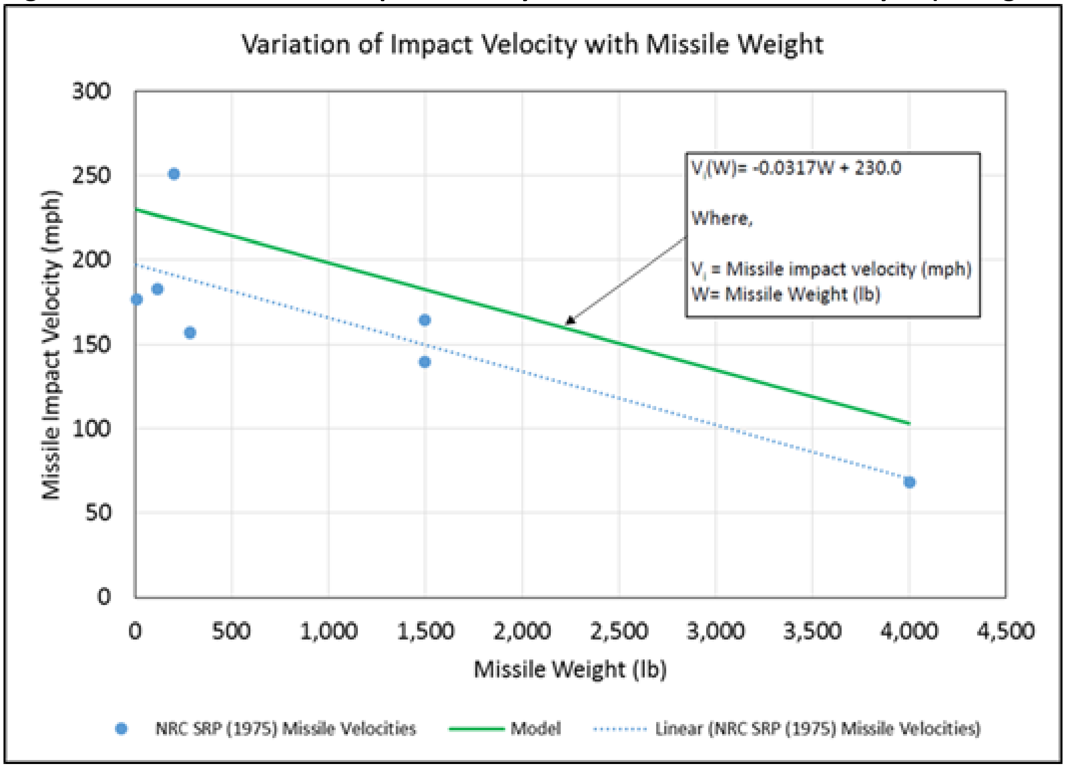
SRP Section 3.5.1.4, November 24, 1975 "NO TUMBLING" MISSILE SPECTRUM B

		Horizontal Velocity ft/sec
A.	Wood plank, 4 in. x 12 in. x 12 ft, weight 200 lb.	368
B.	Steel pipe, 3 in. diameter, schedule 40, 15 ft long, weight 115 lb.	268
C.	Steel Rod, 1 in. diameter x 3 ft long, weight 8 lb.	259
D.	Steel pipe, 6 in. diameter, schedule 40, 15 ft long, weight 285 lb.	230
E.	Steel pipe, 12 in. diameter, schedule 40, 30 ft long weight 1500 lb.	205
F.	Utility pole, 14 in. diameter, 35 ft long, weight 1500 lb.	241
G.	Automobile, frontal area 20 ft^2, weight 4000 lb.	100

Table C-2. SRP (1975) missile spectrum indicating variation of horizontal velocity with missile type. Conversion to miles-per-hour (mph) also shown.

Description	Horizontal Velocity (ft./sec)	Horizontal Velocity (mph)
4"x12" x 12 ft. long; 200 lb.	368	251
3" dia; Schedule 40, 15 ft. long; 115 lb.	268	183
1" dia; 3 ft. long, 8 lb.	259	177
6" dia; Schedule 40; 15 ft. long; 285 lb.	230	157
12" dia; Schedule 40; 30 ft. long; 1500 lb.	205	140
14" dia; 35 ft. long; 1500 lb.	241	164
Frontal area 20 ft^2; 4000 lb.	100	68

Figure C-3. Assumed missile impact velocity correlation used in this analysis (solid green line)



Concrete Perforation

Perforation on concrete targets was assessed by the BRL formula [11]. For the concrete material, median values of compressive strength were assumed. Median strength, aging, and dynamic increase factors were assumed to be 1.15, 1.2, and 1.25, respectively [9]. For the reinforced concrete targets evaluated, concrete design strength was assumed to be 3,500 psi. Thus, for perforation calculations, a value of 6,037 psi was assumed (3,500 psi x 1.15 x 1.20 x 1.25 = 6,037 psi). In the case of deformable missiles, the limiting perforation thicknesses were reduced by 30% in accordance with DOE guidance [11].

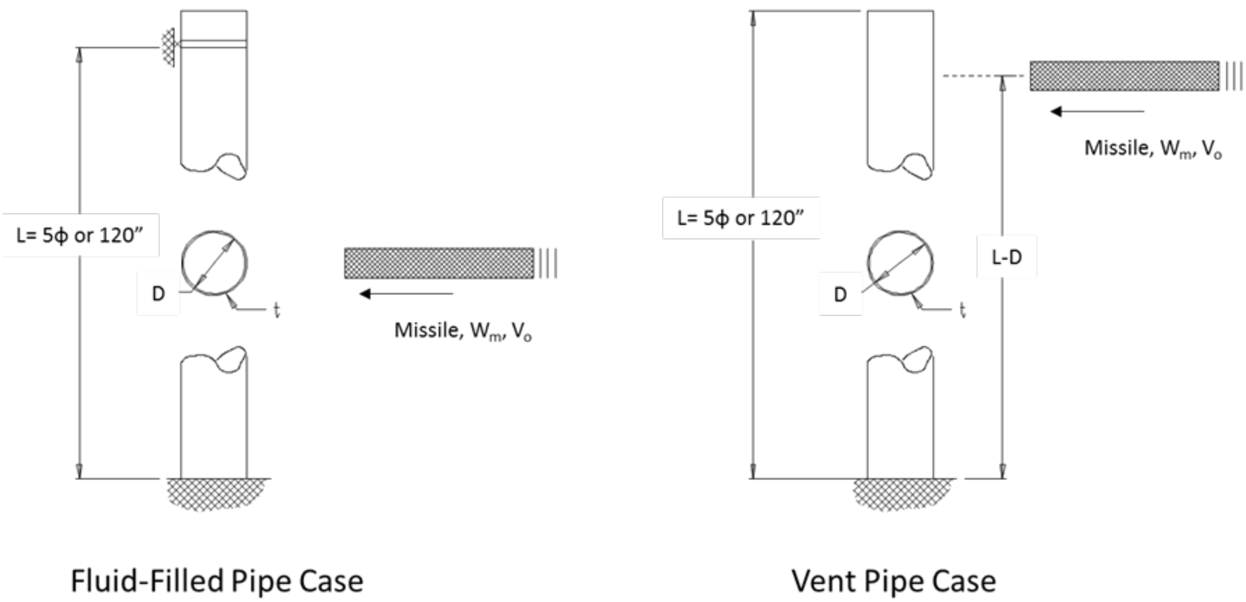
$$T = \frac{427}{\sqrt{f'_c}} \frac{W}{D_m{}^{1.8}} \left(\frac{V_s}{1{,}000}\right)^{1.33}$$

$T =$ thickness of concrete element to be just perforated (in)
$W =$ weight of missile (lb)
$D_m =$ diameter of missile (in)
$V_s =$ striking velocity of missile $\left(\frac{ft}{s}\right)$
$f'_c =$ compressive strength of concrete (psi)

C.3.2 Pipe Crushing and Crimping

All steel pipe sections where evaluated for local crushing and crimping effects. Fluid-filled pipes were assumed to be fixed at one end and simple supported on the opposite end (Figure C-4). Vent pipe cases assumed to have a cantilevered support condition (i.e., supported at base only). The pipe spans were assumed to be the maximum value of five pipe diameters or 120 inches. The 120-inch span corresponds to a realistic unsupported pipe length.

Figure C-4. Missile impact on a pipe target



Pipe Impact Model

When a missile impacts a target, significant forces are developed at the target interfaces. These forces decelerate the missile and accelerate the target. The impact scenarios considered in this evaluation and judged to result in plastic impact, where the missile remains in contact with the target.

A simplified pipe impact model was developed to evaluate the radial deflection of a thin-walled pipe subjected to a concentrated force. The model assumes linear elastic properties for the pipe and accounts for nonlinear behavior through the use of bi-linear force-deflection curve. Viscous damping was assumed to account for energy dissipation due to the large-strains and deformations involved. The method was benchmarked to two physical experiments (discussed below) and reasonable results were obtained. The model does not account for the resisting effects of membrane tension under larger deformations. This is judged to be a conservative bias.

The pipe target is represented as a single-degree-of-freedom model with a bilinear spring and viscous damper (Figure C-5). The bilinear resistance function represents the radial stiffness of the pipe and the plastic moment capacity of the pipe section. The derivation of the linear stiffness and plastic moment capacity is shown in Section C7.0. To account for strain rate effects, a dynamic increase factor was applied to yield stress of the steel pipe material.

The equation of motion of the pipe target is solved as an initial velocity problem and numerically integrated using a 4th-order Runge Kutta method [5]. The velocity of the combined system after the collision is derived from conservation of momentum.

$$M_m V_m = (M_m + M_t) V_o$$

$$V_o = \frac{M_m V_m}{M_m + M_t}$$

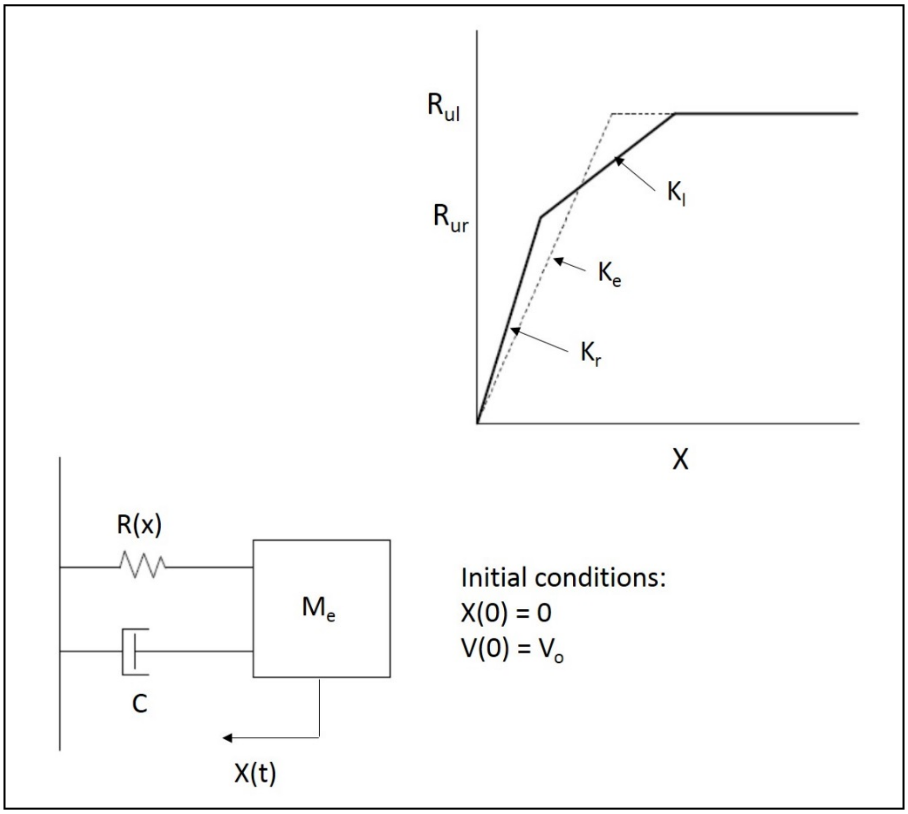
M_m = Missile mass
M_t = Target mass
V_m = Missile impact velocity
V_o = Target velocity

Impact velocities were assumed to be horizontal and the missile was assumed to impact normal to the target surface. For highly-deformable missiles (plywood, grating, siding, etc.), the weight was reduced to 30% of the total mass to account for energy absorbed to crushing, buckling, etc. (Table C-2). DOE guidance on aircraft impact [11] describes that for highly-deformable missiles (e.g., aircraft fuselage), a significant portion of impact energy is dissipated in deforming the missile. The effective mass will be significantly less than the total mass of the missile. DOE guidance limits the reduction to 30% of the total missile mass.

Table C-2 - Effective Mass Factor

Missile Characterization	Example Missiles	Effective Mass factor
Non-Deformable (essentially rigid)	rebar, gas cylinder, steel pipe, steel beam,	0.9
Deformable (higher rigidity, but susceptible to crushing)	toolbox, utility pole, cable reel, paver, concrete block, sawn lumber, small motor, concrete mixer, pallet rack, vehicle, concrete pipe	0.5
Highly-Deformable (low rigidity and crush strength)	Metal siding, plywood, 20' tree, tank drum, steel grating	0.3

Figure C-5. Analytical model which utilizes a bi-linear resistance function



The pipe radial stiffness, K_r, and ultimate capacity, R_{ur}, is approximated below. Note that the details of their derivation are provided in Section C7.0.

$$\mathrm{K_r} = \frac{9.28\ \mathrm{E\ b\ t^3}}{D^3}$$

$$\mathrm{R_{ur}} = \frac{4\ \mathrm{b\ t^2\ F_y}}{D}$$

For the cantilevered pipe support conditions, the longitudinal stiffness, K_l, and longitudinal flexural capacity, R_{ul}, are derived using conventional beam relationships:

$$\mathrm{K_l} = \frac{3\ \mathrm{E\ I}}{(L-D)^3}$$

$$\mathrm{R_{ul}} = \frac{2.4\ \mathrm{F_y\ I}}{\mathrm{D}\ (L-D)}$$

Similarly, for fluid-filled pipe support conditions, the longitudinal stiffness, K_l, and longitudinal flexural capacity, R_{ul}, are derived using conventional beam relationships:

$$K_l = \frac{106\, E\, I}{L^3}$$

$$R_{ul} = \frac{14.4\, F_y\, I}{D\, L}$$

K_r = pipe radial stiffness $\left({}^{lb}/_{in}\right)$
K_l = pipe longitudinal stiffness $\left({}^{lb}/_{in}\right)$
R_{ur} = maximum radial crush resistance (lb)
R_{ul} = maximum longitudinal resistance (lb)
E = pipe material elastic modulus $\left(\frac{lb}{in^2}\right)$
F_y = pipe material yield stress $\left(\frac{lb}{in^2}\right)$
b = effective length of pipe (in); [comensurate with size of impacting missile]
t = pipe wall thickness (in)
D = mean pipe diameter (in)
I = pipe moment of inertia (in^4)
L = pipe span (in)

An equivalent pipe stiffness is derived by assuming the radial and longitudinal stiffnesses act in series:

$$\frac{1}{K_E} = \frac{1}{K_r} + \frac{1}{K_l}$$

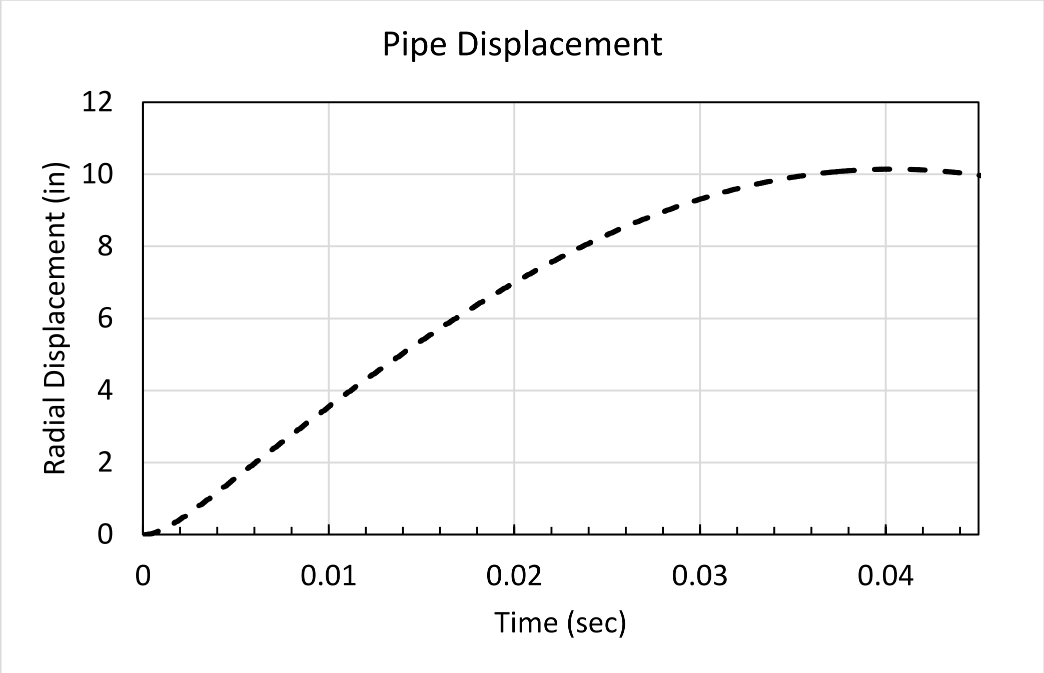
The equation-of-motion and initial conditions for the pipe system, shown in Figure C-5, is:

$$M_e\ddot{x} + C\dot{x} + R(x) = 0$$

$$x(0) = 0$$
$$\dot{x}(0) = V_t$$

The system is solved as an initial velocity problem using a Runge-Kutta numerical integration method [5]. The maximum displacement is estimated (Figure C-6.) and compared to an assumed limiting value. A displacement of more than 0.5 times the pipe diameter is considered failure of the pipe. A viscous damper was assumed in the model to represent the significant energy dissipation resulting from a highly nonlinear impact event. Critical damping values for both steel and concrete targets were assumed to be 15%, consistent with stress levels beyond yield and significant permanent deformation.

Figure C-6. Example model displacement response.

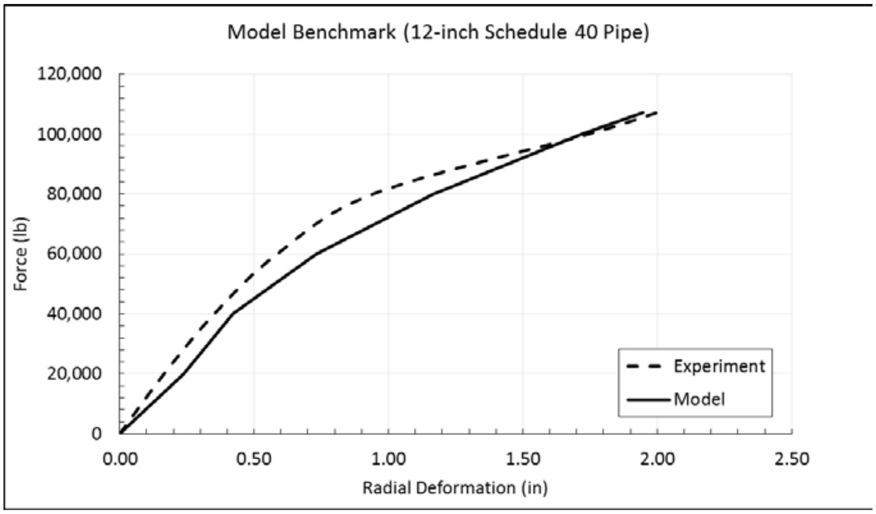


Benchmarking

To improve confidence in model predictions, comparisons of model results were made for two separate and relevant pipe impact experiments. The selected experiments involved the impact crush testing of thin steel tubes. The purpose of the experiments was to investigate offshore pipelines subjected to accidental loads, such as impacts from trawl gear or anchors. Due to the large radial deformations under impact conditions, it was judged that these experiments are relevant to problems involving wind-borne missile impacts on piping.

The first experiment involved drop testing of large weights (150 lbs) onto a 12-inch diameter steel pipe [14]. This test series involved the measurement of impact forces and pipe displacements for Grade 60 steel pipes. These measured forces and displacements where compared to those predicted using the simplified modeling approach. Model predictions agreed reasonably well with the test (Figure C-7). Based on a comparison of internal work (i.e., integral of the force-displacement curve), the model uncertainty is approximately 12%.

Figure C-7. Comparison of experiment and model results.



The second experiment involved pendulum impact tests on steel pipe sections [15] (Figures C-8 through C-10). The pipe sections were smaller in scale, but had thickness-to-diameter ratios comparable to exhaust pipes. The impactor was a heavy rigid steel anvil (weighing more than 3,000 lbs) attached to a trolley, which was capable of low impact speeds (less than 15 mph). Force and displacement transducers were used to measure impact force and pipe deformation, respectively. Some of the tested pipes had crush depths (or dents) greater than 50-percent of the pipe diameter. Six simplified analytical models were developed to represent each of the six test scenarios. Comparison of analytical model and experimental results is shown in Figure C-11. The estimated uncertainty in model results is approximately 25%, which is judged to be satisfactory, in light of the large pipe deformations involved.

Figure C-8. Pipe crimping experiment; impactor seen on the left side of the figure; source [15]

Figure C-9. Experimental setup; source [15]

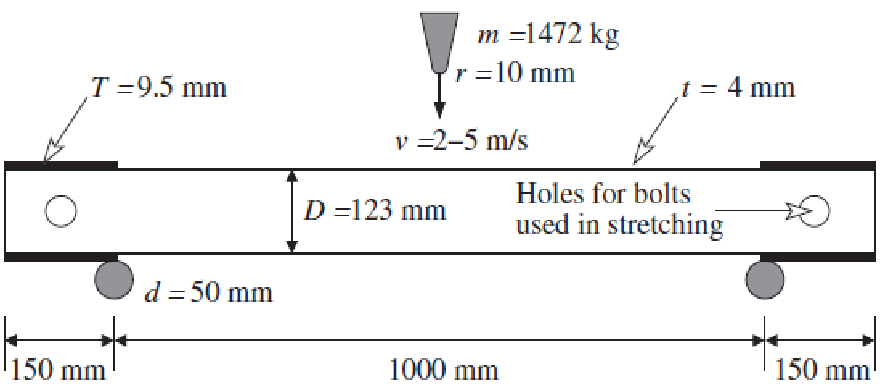


Figure C-10. Dynamic impact test showing pipe crimping; source [15]

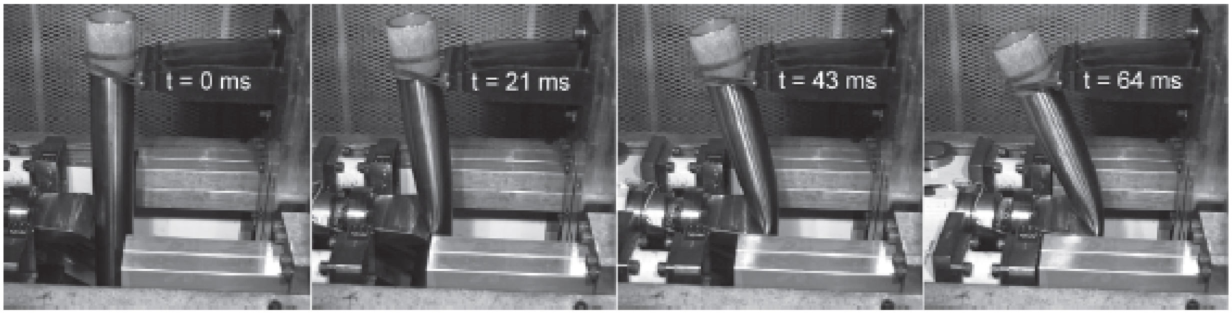
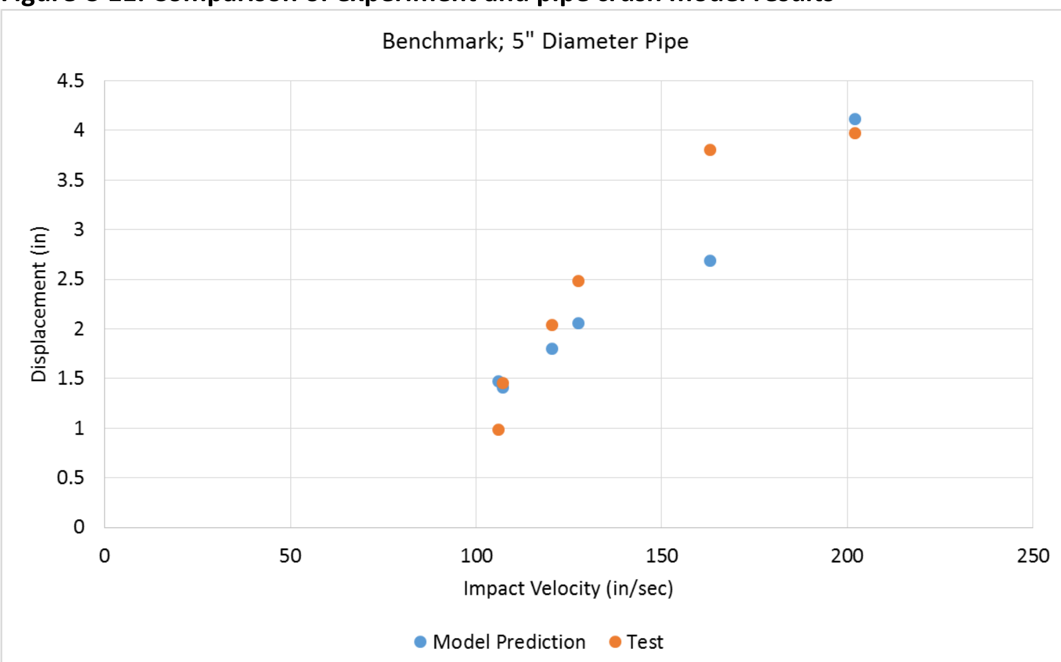


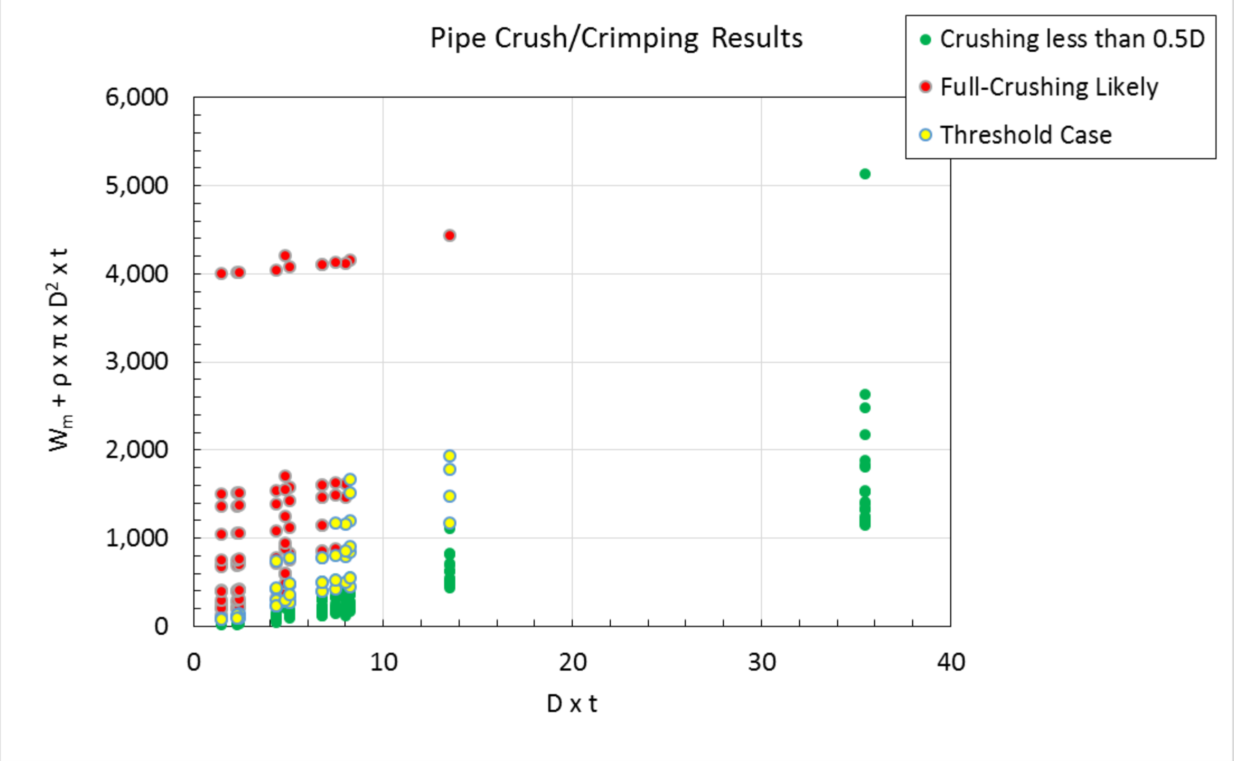
Figure C-11. Comparison of experiment and pipe crush model results



Model Results

Using the analytical model, various cases were run considering a wide range of missile types and pipes of various diameter and wall thicknesses. The results for the range of missile types and steel pipe targets considered in the TMRE are shown in Section C.8. In addition, the results are also shown in Figure C-12 below, which can be used to estimate pipe crush for wider range of impact scenarios. The green data points represent those cases that had pipe deformations less or equal to 0.5 times the pipe diameter. The yellow data points represent threshold cases were the pipe deformation was greater than 0.5 times the pipe diameter but less than full crimping. The red data points represent cases where the pipe is estimated to be completely crushed/crimped.

Figure C-12. Pipe impact evaluation results (6 in < D < 48 in) and (0.125 in < t < 0.98 in); Nominal impact velocity = 230 mph



C.3.3 Evaluation of Liquid-Filled Steel Tanks

Liquid-filled steel tanks were also evaluated for perforation and flexural failure of the shell in the vicinity of the missile impact (Table C-3). The added mass of the tank fluid (water) was considered in the dynamic model, but the stiffening effect (incompressible fluid) is conservatively neglected. The circular tank shells were modeled as ring structures and the additional stiffness contribution from the top enclosure and bottom foundation restraint were not considered. The exclusion of cylinder height in estimating tank stiffness is judged to be conservative.

Table C-3. Liquid-filled tank parameters

Tank Description	Tank Diameter (in)	Tank Shell Thickness (in)
CST	576	0.375
CST	576	0.250
Diesel Fuel Oil Tank	120	0.250
Diesel Fuel Oil Tank	120	0.145
Diesel Fuel Oil Tank	120	0.133

The evaluation of tanks was performed using the same analytical model as described in Section C3.2. The tank stiffness was approximated from the circumferential flexural shell frequency described by Den Hartog [8].

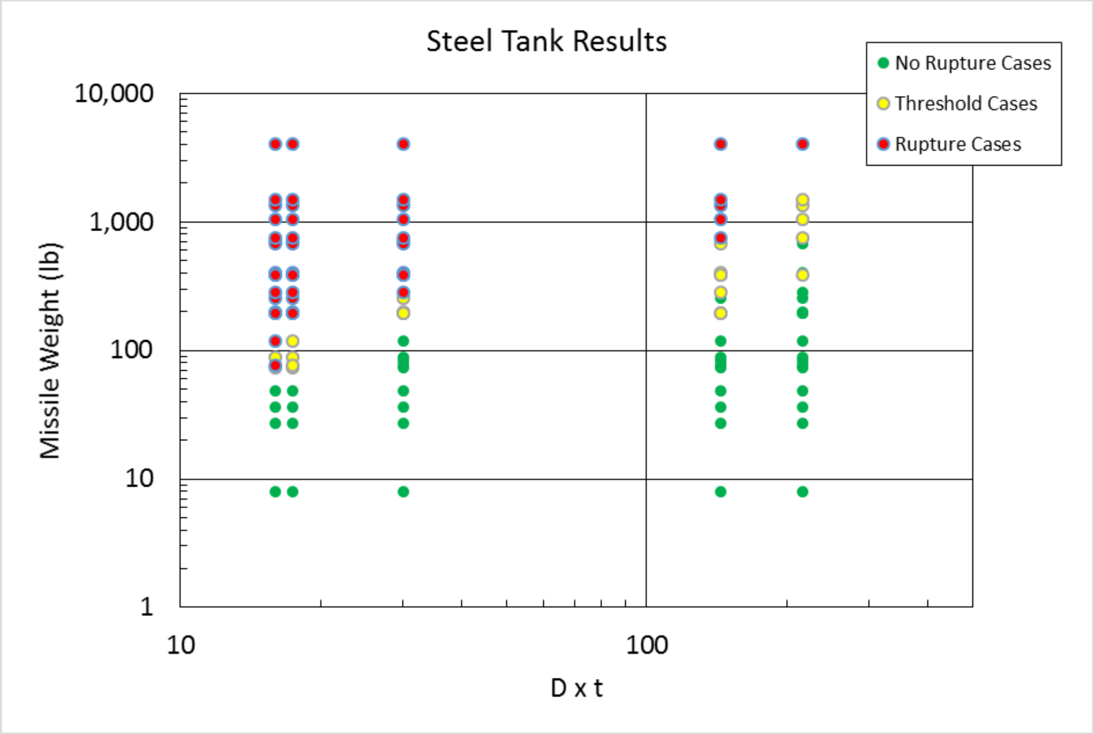
$$\omega_n = \frac{n(n^2-1)}{\sqrt{1+n^2}}\sqrt{\frac{EI}{\gamma r^4}}$$

ω_n = natural tank shell frequency
n = number of full sine waves
E = material modulus
γ = mass per unit length
r = tank radius
The mass of water was accounted for by 'smearing' the water mass to the mass of the tank shell. The tank stiffness is estimated from:
$k_{tank} = m_{eff}\omega_n{}^2$
$m_{eff} = m_{tank\ shell} + m_{water}$
The ultimate capacity of the tank shell was assumed to be:
$R_{u\_tank} = 4\pi M_p$ [7] ;
where M_p is the plastic moment capacity of the tank shell

The effective mass of the tank was assumed to be ¼ shell area for large tanks and ½ shell area for smaller tanks. The maximum displacement for the tank shell was assumed to be 3 times the elastic displacement (ductility μ~3.0). This is judged to be conservative as ASCE standards allow for ductility ratios greater than 10.0 [13].

The results for the range of missile types and steel tank targets considered in the TMRE are shown in Section C.8. In addition, the results are also shown in Figure C-13 below, which can be used to estimate tank rupture for wider range of impact scenarios. The green data points represent cases where rupture is not likely (μ<1.0) and yellow data points represent threshold cases were rupture is not likely, but strain values are elevated (1.0<μ<3.0). The red data points represent cases were rupture may occur due to large displacements of the tank shell (μ>3.0).

Figure C-13. **Steel tank results: (120 in < D < 576 in) and (0.133 in < t < 0.375 in, Nominal impact velocity = 230 mph)**



C.3.4 Evaluation of Reinforced Concrete Roofs

An evaluation of reinforced concrete roofs was performed using the same dynamic modeling approach as was utilized for the evaluation of pipes and tanks. Roof slab stiffnesses and load capacities were evaluated for two roof thickness (4 and 8-inches). These thicknesses were selected based on common roof construction observed in NPP designs. The respective spans for the 4 and 8 inch roofs were 4 ft. and 20 ft., respectively. The 4-inch thick roof is assumed to be composite steel construction with steel bar joists spaced at 48-inches. The assumed roof design parameters are shown in Table 4 below. As missile impact was assumed to strike mid-span of the slab, the bar joists were not explicitly considered. The 8-inch thick roof is assumed to be ordinary reinforced concrete. The roof spans were assumed to be designed as one-way members and impact was also assumed to occur at the mid-span location. Empirical equations were used to evaluate perforation (Section C3.1). Scabbing (or spalling of concrete) was not evaluated, as most concrete roofs have metal decking on the underside of the slab. This decking confines the concrete cover over reinforcement and prevents the effects for scabbing.

Table C-4. Assumed reinforced concrete roof parameters

Parameter	4-inch RC Roof	8-inch RC Roof
Span (ft.)	4	20
Design Live Load (psf)	50	50
Concrete compressive strength (psi)	4,000	4,000
Steel reinforcement strength (psi)	40,000	40,000
Steel reinforcement ratio	0.002	0.008

Results

The results for the range of missile types and concrete roofs considered in the TMRE are shown in Table C-5, below. In addition, the results are also shown in Figure C-14 below, which can be used to estimate concrete roof damage for wider range of impact scenarios.

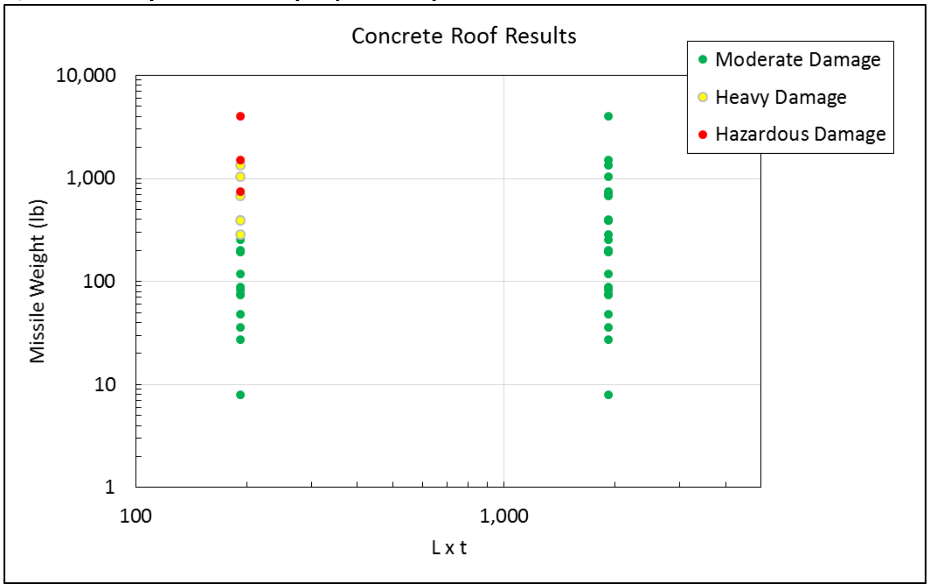
The green data points indicate cases where only moderate damage is expected (slight cracking) and the yellow data points indicate cases where heavy damage would be expected (significant cracking, but no structural failure. The red data points indicate cases where the roof slab is likely to fail structurally, resulting in hazardous debris into the space below.

In some cases, mostly where missile weights are much greater than 500 lbs, the 4-inch thick concrete roof slab is susceptible to failure. However, the 8 inch thick concrete roof slab is not susceptible to overall failure from most of the missiles analyzed. Despite the longer span of the 8-inch roof slab (20 ft.), the mass of the roof contributes to a significant amount of inertia (keeping displacements small).

Table C-5. Results for reinforced concrete roof impacts

Missile	Minimum Perforation Thickness (in)	4" Roof Slab Edge rotation [2]	8" Roof Slab Edge rotation [3]	Evaluation
# 8 Rebar	6.1			Perforation failure of 4" slab
Gas Cyl (290 lb)	3.3			No failure of 4" or 8" slab
Tank Drum (500 lb)	1.6			No failure of 4" or 8" slab
Utility Pole (1500 lb)	7.7			Perforation failure of 4" slab; 8" slab OK as equation conservative for timber missiles
Cable Reel (253 lb)	0.3			No failure of 4" or 8" slab
3" pipe (76 lb)	6.0			Perforation failure of 4" slab not likely due to low stiffness of pipe (30% reduction not credited). Steel decking also not credited
6" pipe (284 lb)	6.8			Perforation failure of 4" slab
12" pipe (744 lb)	5.0			Panel (global) failure of 4" slab
Tool bx (675 lb)	0.5			Flexural failure of 4"; No failure 8" slab
Paver (88 lb)	1.6			No failure of 4" or 8" slab
Conc blk (36 lb)	0.5			No failure of 4" or 8" slab
4x12 timber (200 lb)	3.6			No failure of 4" or 8" slab
2x12 plank (27 lb)	0.9			No failure of 4" or 8" slab
Metal siding (125 lb)	1.2			No failure of 4" or 8" slab
7/8" plywood (84 lb)	1.7			No failure of 4" or 8" slab
W14x26 (390 lb)	4.8			Flexural failure of 4" slab; No failure of 8" slab
C6x13 (195 lb)	11.4			Irregular cross-section results in unrealistic result. Alternative Chang formula (DOE-STD-3014-96) indicates limiting thickness of 3.4"; assume no failure as steel decking not credited
small motor (388 lb)	0.5			No failure of 4" or 8" slab
conc mixer (1,350 lb)	0.8			Flexural failure of 4"; No failure 8" slab
steel grating (74 lb)	2.5			No failure of 4" or 8" slab
pallet rack (1,040 lb)	0.2			Flexural failure of 4"; No failure 8" slab
vehicle (4,000 lb)	0.4			Panel (global) failure of 4" slab; 8" also assumed to fail as a conservative measure
20' tree (700 lb)	11.0			Perforation failure of 4" slab not likely due to low stiffness of tree branches
*Green is max rotation < 0.210 radians [ASCE 59-11]				
*Red is max rotation > 0.210 radians [ASCE 59-11]				
[2] 4 ft span assumed for 4" slab				
[3] 20 ft span assumed for 8" slab				

Figure C-14. Concrete roof results (48 in < L < 240 in) and (4.0 in < t < 8.0 in); Nominal impact velocity = 2/3 x 230 mph or 153 mph (vertical)



~~C.3.5 EVALUATION OF VERTICAL BARRIERS~~

~~An evaluation of vertical barriers, typical of nuclear power plant sites, was performed. The evaluation focused on a typical 12-inch thick reinforced concrete wall and two steel grating designs (i.e., 2-inch and 4-inch thick grating. Steel grating systems are commonly used to provide wind debris protection of wall openings. The analysis approach was similar to performed for concrete roof panels (Section C3.4).~~

~~Reinforced concrete wall panel stiffness and load capacity were evaluated for a representative 12-inch thick wall. This wall thickness was selected based on observations of common exterior wall construction details for several NPP designs. The wall panel was assumed to measure 20' by 20', which was also based on commonly observed wall heights and spans. Consistent with the assumptions made in concrete roof evaluations (Table C-4), the concrete compressive strength was assumed to be 4,000 psi and the reinforcement strength was assumed to be 40,000 psi. Empirical equations were used to evaluate the local effects of perforation (Section C3.1). Results for the reinforced concrete wall panel are described in Table C-5a below and included in Section C.6.~~

~~Evaluations of two representative steel grating systems were performed. These systems were assumed to have thicknesses of 2-inches and 4-inches, respectively. Bar thickness was assumed to be 3/8-inch, which is typical for thicker grating systems. Bar spacing was assumed to be 1-inch on-center, which is also common in thicker steel grating systems. This bar spacing also provides protection for the 1-inch rebar missile (from Table 3-2). The steel grating panels were assumed to have a height of 10-ft, which is representative of those protecting wall openings. The panel was conservatively assumed to behave in one-way action. Steel material strength was assumed to be 40,000 psi, and global panel failure was assumed to be based on exceeding allowable deformation limits, similar to those assumed for concrete panels (i.e., support rotation limit = 0.21 radians). Localized failure modes are precluded by the orientation of the steel bar grating. Because wind-borne missile impacts have to occur on the edges of the steel bars rather than the faces, localized penetration-type failure modes (which are typical for plates) are precluded. Results for the steel grating systems are shown in Section C.6.~~

~~Table C-5a. Results for concrete wall impacts~~

~~Missile~~	~~Minimum Perforation Thickness (in)~~	~~12" Wall Panel Edge rotation [1]~~	~~Evaluation [2]~~
~~# 8 Rebar~~	~~9.7~~	-	~~No Perforation failure of 12" panel~~
~~Gas Cyl (290 lb)~~	~~5.3~~	-	~~No Perforation failure of 12" panel~~
~~Tank Drum (500 lb)~~	~~2.5~~	-	~~No Perforation failure of 12" panel~~
~~Utility Pole (1500 lb)~~	~~12.4~~		~~Perforation failure of 12" panel~~
~~Cable Reel (253 lb)~~	~~0.5~~	-	~~No Perforation failure of 12" panel~~
~~3" pipe (76 lb)~~	~~9.5~~	-	~~No Perforation failure of 12" panel~~
~~6" pipe (284 lb)~~	~~10.9~~	-	~~No Perforation failure of 12" panel~~
~~12" pipe (744 lb)~~	~~8.0~~	-	~~No Perforation failure of 12" panel~~
~~Tool bx (675 lb)~~	~~0.8~~	-	~~No Perforation failure of 12" panel~~
~~Paver (88 lb)~~	~~2.6~~	-	~~No Perforation failure of 12" panel~~
~~Conc blk (36 lb)~~	~~0.8~~	-	~~No Perforation failure of 12" panel~~
~~4x12 timber (200 lb)~~	~~5.8~~	-	~~No Perforation failure of 12" panel~~
~~2x12 plank (27 lb)~~	~~1.5~~	-	~~No Perforation failure of 12" panel~~
~~Metal siding (125 lb)~~	~~2.0~~	-	~~No Perforation failure of 12" panel~~
~~7/8" plywood (84 lb)~~	~~2.8~~	-	~~No Perforation failure of 12" panel~~
~~W14x26 (390 lb)~~	~~7.8~~	-	~~No Perforation failure of 12" panel~~
~~C6x13 (195 lb)~~	~~18.3~~	-	~~Irregular cross-section results in unrealistic result. Alternative Chang formula (DOE-STD-3014-96) indicates limiting thickness of 4.3"; assume no perforation failure.~~
~~small motor (388 lb)~~	~~0.8~~	-	~~No Perforation failure of 12" panel~~
~~conc mixer (1,350 lb)~~	~~1.2~~	-	~~No Perforation failure of 12" panel~~
~~steel grating (74 lb)~~	~~4.1~~	-	~~No Perforation failure of 12" panel~~
~~pallet rack (1,040 lb)~~	~~0.3~~	-	~~No Perforation failure of 12" panel~~
~~vehicle (4,000 lb)~~	~~0.7~~	-	~~No Perforation failure of 12" panel~~
~~20' tree (700 lb)~~	~~17.6~~	-	~~Perforation failure of 12" panel not likely due to low stiffness of tree branches~~

~~*Green is max rotation < 0.210 radians [ASCE 59-11]~~
~~*Red is max rotation > 0.210 radians [ASCE 59-11]~~
~~[1] 20' x 20' wall panel assumed~~
~~[2] No global failure for any missiles~~

C.4 DEBRIS FROM DAMAGED STRUCTURES

Wind pressures from tornadoes can be sufficiently high to cause structural damage to portions of building structures. Damage can range from localized (pieces of siding) to complete failure of the wall and roof systems. Debris from these damaged buildings can generate additional missile hazards. FEMA [16] has developed wind pressure fragility functions for various building types (wood framed, manufactured, pre-engineered, and engineered). For each building type, FEMA assessed the likelihood of damage for key structural components (roof and walls) for a range of wind speeds (typically 60-200 mph).

As these types of buildings are found on power plant sites, an estimation of number of available missiles for each building type was performed. The number of available missiles was estimated from typical construction practices (e.g., wood framing at 16-inch centers for wood buildings, and plywood sheets measuring 32 square feet). Based on a representative building for each construction type, the total number of building components was approximated. For example, the numbers of wall studs, roof rafters, and floor joists, were estimated for wood offices and warehouses (Figure C-15). In addition, the contents of buildings were considered depending on building function. The quantities of desks and furniture were estimated for office buildings, and quantities of pallets, drums, and shelving were estimated for warehouses. The results for potential tornado missiles per building type are shown in Tables C-9 through C-14, below. A walkdown of a warehouse at a nuclear power plant confirmed that the quantities shown below are generally representative of a typical warehouse.

To help clarify the approach used for estimating the total number of building components, an example evaluation of a pre-engineered metal warehouse building is provided below. The approach is similar for the other building types (wood-framed and manufactured).

Pre-Engineered Metal Warehouse Building
The metal warehouse building type is commonly found on nuclear power plant sites. The assumed building measures 80-ft x 40-ft in plan-view and has a height of 16-ft. The configuration of the building, including key structural elements, is shown on Figure C-16. The design and construction of the building was assumed to be consistent with that of typical metal building systems (Figure C-17). The key building dimensions and areas are shown in Table C-6 below.

Building Contents
The contents of the building were assumed to representative of construction equipment/supplies or items used in outages (tool bins, cable reels, lumber, generators, etc.). The quantities of stored items

were based mainly on filling available shelf and floor area. Based on the warehouse general arrangement, the building is judged to be moderately stocked and not sparsely loaded. Table C-7 indicates the assumed building contents and quantities. Table C-8 provides a summary of potential missiles from both structural and stored contents and provides the missile count on a per 1,000 square foot building area.

Figure C-15. Typical wood building construction

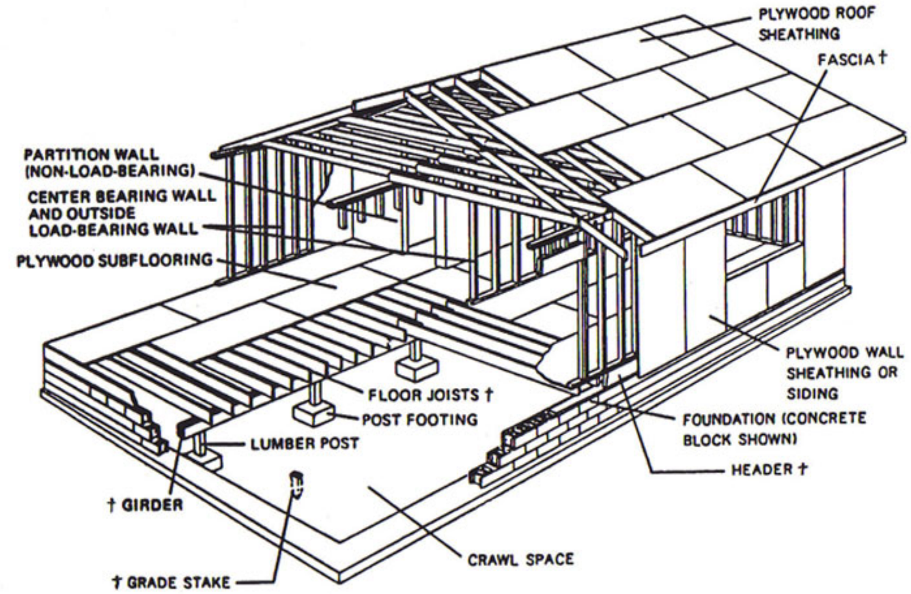


Figure C-16. Assumed layout of representative metal warehouse building

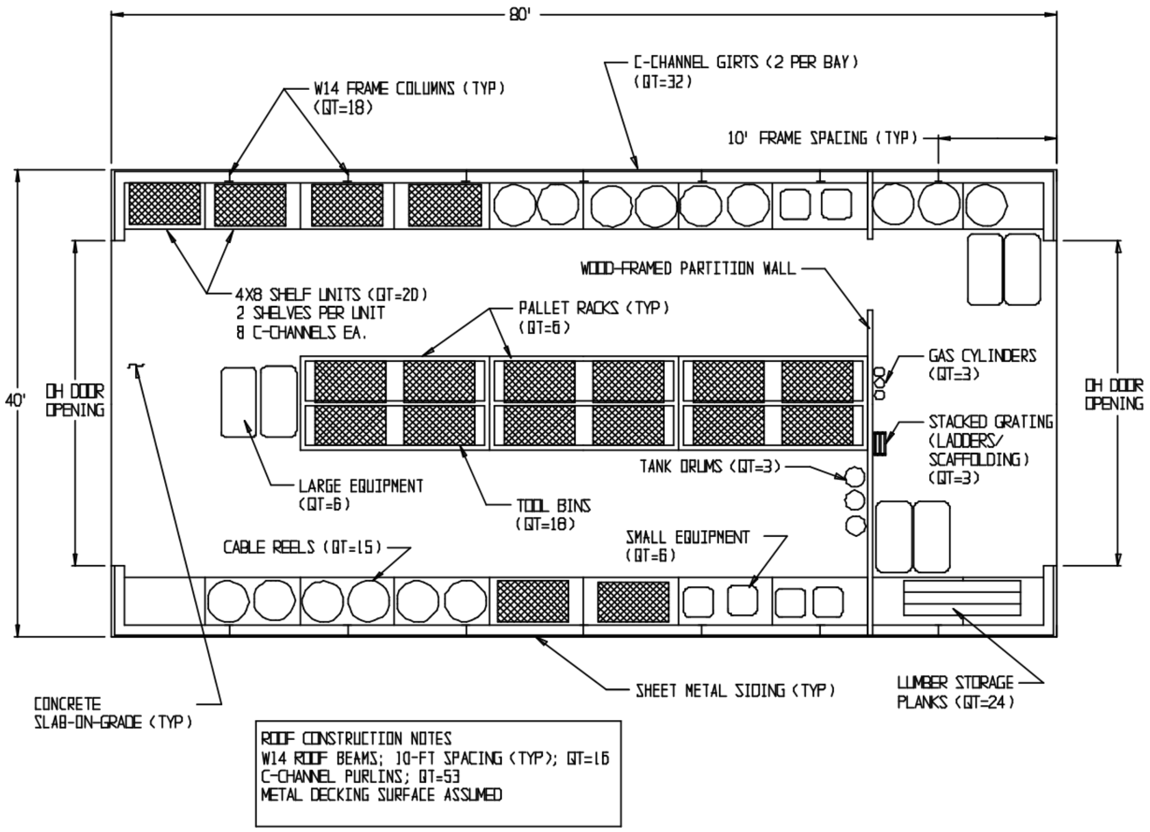


Figure C-17. Typical structural configuration for a metal building system

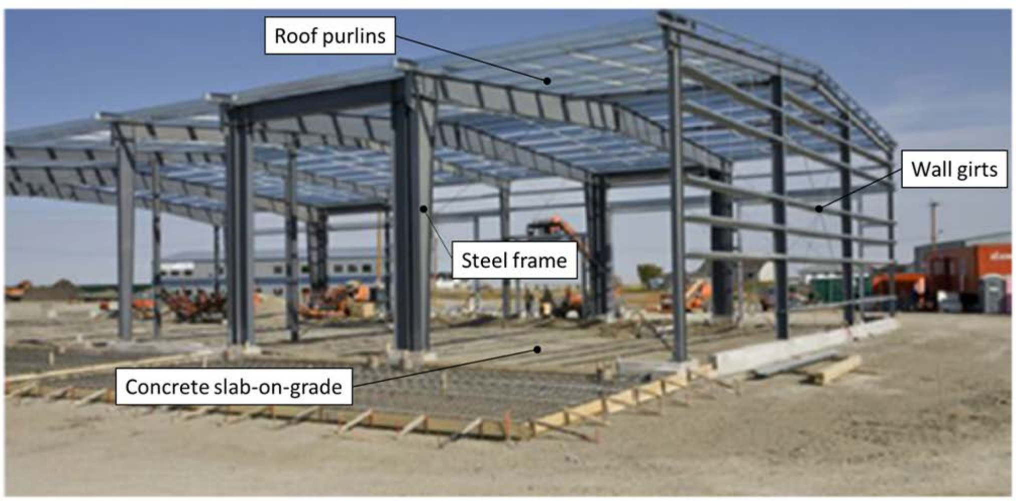


Table C-6. Key building parameters

Pre-Engineered/Engineered Building (Warehouse)	
Building length (ft)	80
Building width (ft)	40
Building height (ft)	16
Exterior wall length (ft)	240
Roof area (sf)	3,200
Exterior wall area (sf)	3,840
Floor area (sf)	3,200

Table C-7. Building Content Quantities

Building Contents	EPRI Missile No.	Assumed Quantity
Gas cylinder	2	3
Drum, tank	3	3
Cable Reel	5	15
Metal storage bin	9	18
Small equipment	18	6
Large equipment	19	6
Steel grating/ladders/scaffolding	20	3
Large steel frame	21	6
Wood planks	13	24

Table C-8. Summary of Building Missiles (per 1,000 ft^2)

EPRI Missile	Missile Description	Pre-Engineered/Engineered Building (Warehouse)		
		Missiles per 1,000 ft^2 Floor Area	Missiles per 1,000 ft^2 Roof Area	Missiles per 1,000 ft^2 Wall Area
1	Rebar	18	0	0
2	Gas Cylinder	1	0	0
3	Drum, tank	1	0	0
4	Utility pole	0	0	0
5	Cable reel	5	0	0
6	3" pipe	0	0	0
7	6" pipe	0	0	0
8	12" pipe	0	0	0
9	Metal storage bin	6	0	0
10	Concrete paver	0	0	0
11	Concrete masonry units	0	0	0
12	Wood beam (4x12)	0	0	0
13	Wood plank	16	0	0
14	Metal siding	0	25	25
15	7/8" plywood	12	0	0
16	Wide flange beam (W14x26)	0	5	4
17	Channel Section (C6x13)	5	16	8
18	Small Equip	2	1	0
19	Large Equip	2	1	0
20	Steel grating	1	0	0
21	Large steel frame	2	0	0
22	Vehicle	0	0	0
23	Tree	0	0	0
	Total	**71**	**48**	**37**

The release fraction, or number of missiles released, for a range of wind speeds was estimated for each building type. The release fractions were based on the FEMA damage probabilities for building components subjected to high winds. As the number of wind-driven missiles should increase as the probability of building damage increases, it was assumed that release fraction correlated to the probability of damage for the most severe building damage state (e.g., complete roof or wall failure). The estimated release fractions for wood framed, manufactured, and engineered building types are shown in Figures C-18 through C-20 below.

Table C-9. Potential Tornado Missile per Office Building, Wood-Framed

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	14	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	4	2	9
13	69	31	76
14	0	0	25
15	31	31	0
16	2	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**121**	**66**	**110**

Table C-10. Potential Tornado Missile per Office Building, Manufactured (Pre-fab)

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	16	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	2	0	0
10	0	0	0
11	0	0	0
12	13	3	23
13	183	20	56
14	0	0	24
15	31	25	0
16	2	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**248**	**50**	**103**

Table C-11. Potential Tornado Missile per Office Building, Engineered and Pre-Engineered

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	33	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	2	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	80	0	0
14	0	25	24
15	15	0	0
16	0	8	4
17	0	16	7
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**131**	**51**	**35**

Table C-12. Potential Tornado Missile per Office Building, Construction Trailer

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	0	0	0
2	1	0	0
3	2	0	0
4	0	0	0
5	4	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	4	0	0
10	0	0	0
11	0	0	0
12	12	6	14
13	151	12	96
14	0	25	24
15	31	0	0
16	0	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**206**	**45**	**134**

Table C-13. Potential Tornado Missile per Warehouse Building, Wood-Framed

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	27	0	0
2	1	0	0
3	1	0	0
4	0	0	0
5	5	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	6	0	0
10	0	0	0
11	0	0	0
12	6	2	4
13	30	20	78
14	0	31	24
15	20	0	0
16	0	0	0
17	0	0	0
18	2	1	0
19	2	1	0
20	1	0	0
21	2	0	0
22	0	0	0
23	0	0	0
Total	**103**	**55**	**106**

Table C-14. Potential Tornado Missiles per Warehouse Building, Engineered and Pre-Engineered

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	18	0	0
2	1	0	0
3	1	0	0
4	0	0	0
5	5	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	6	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	16	0	0
14	0	25	25
15	12	0	0
16	0	5	4
17	5	16	8
18	2	1	0
19	2	1	0
20	1	0	0
21	2	0	0
22	0	0	0
23	0	0	0
Total	**71**	**48**	**37**

Figure C-18. Missile release fractions for wooden buildings

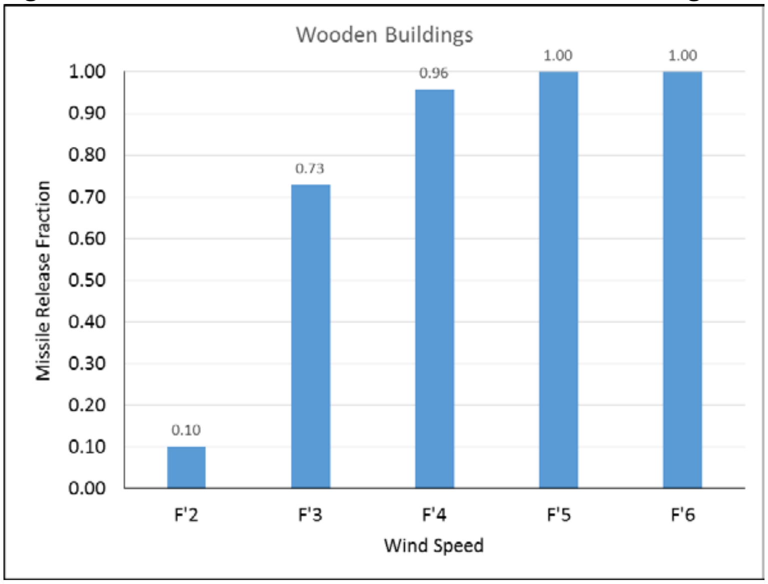


Figure C-19. Missile release fractions for trailers and manufactured buildings

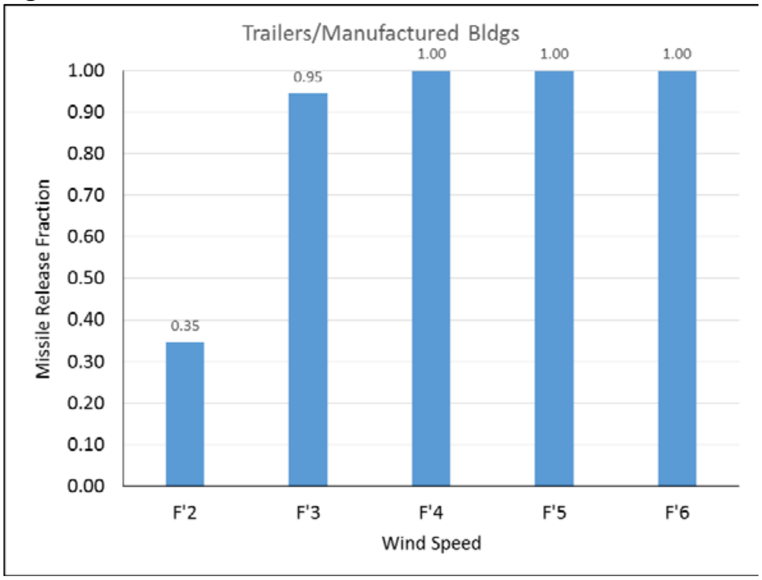
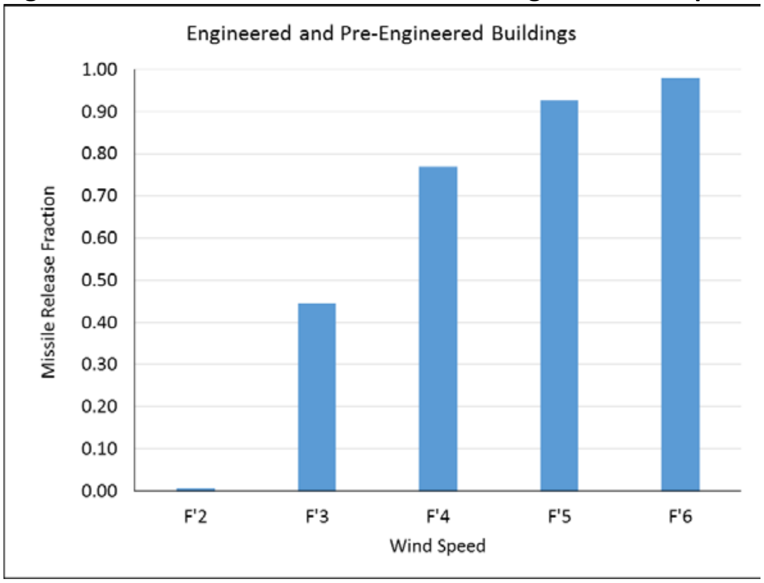


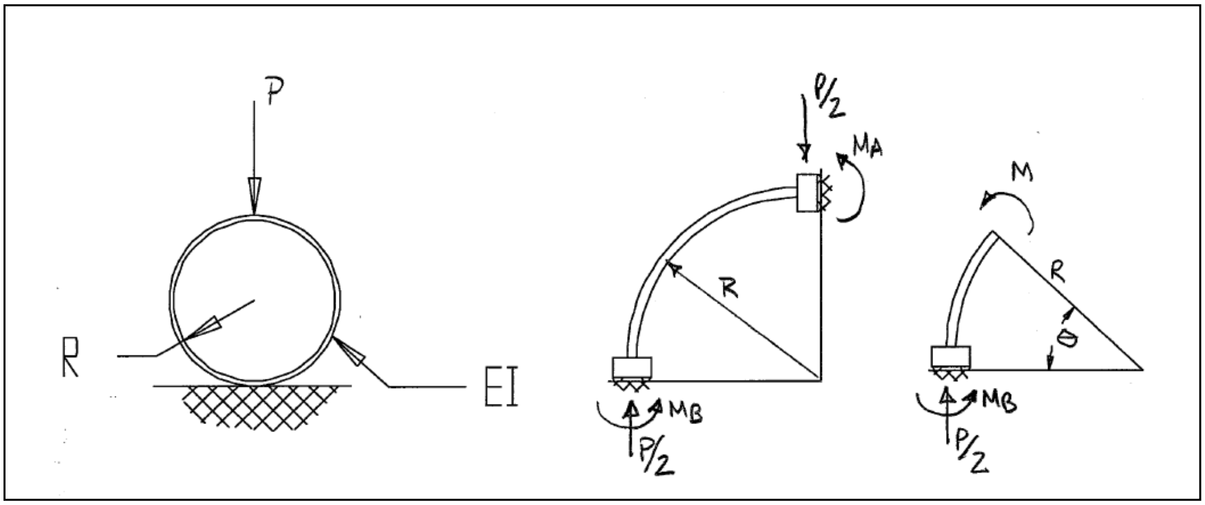
Figure C-20. Missile release fractions for engineered and pre-engineered buildings



C.5 DERIVATION OF PIPE RADIAL STIFFNESS AND ULTIMATE CAPACITY

An analytical model was developed to approximate the radial stiffness and capacity of a typical pipe segment (Figure C-21).

Figure C-21. Assumed pipe boundary condition and free-body diagram to obtain internal member actions



First step is to solve for radial displacement due to concentrated force, P

$$\frac{\partial U}{\partial P} = 2\int_0^{\pi/2} \frac{M}{EI}\frac{\partial M}{\partial P}\,R\,d\theta$$

Figure 15 (c) depicts the internal resisting moment in the pipe section. Solving for M:

$$M = \frac{PR}{2}(1-\cos\theta) - M_B$$

$$\frac{\partial M}{\partial P} = \frac{R}{2}\,(1-\cos\theta)$$

$$\frac{\partial U}{\partial P} = \frac{2}{EI}\int_0^{\pi/2} \left[\frac{PR}{2}(1-\cos\theta) - M_B\right]\left[\frac{R}{2}\,(1-\cos\theta)\right]\,R\,d\theta$$

$$\frac{\partial U}{\partial P} = \frac{2}{EI}\left[\frac{PR^3\theta}{4} - \frac{PR^3\sin\theta}{2} + \frac{PR^3}{4}\left(\frac{\theta}{2}+\frac{\sin 2\theta}{4}\right) - \frac{M_B R^2\theta}{2} + \frac{M_B R^2\sin\theta}{2}\,M_B\right]\Bigg|\begin{cases}\pi/2\\0\end{cases}$$

Evaluating integral at 0 and π/2, the radial displacement is:

$$\frac{\partial U}{\partial P} = \frac{2}{EI}\,[0.088PR^3\ - 0.285\,M_B R^2]$$

Solve for unknown reaction moment, M_B:

$$\frac{\partial M}{\partial M_B} = 0 = \int_0^{\pi/2} \frac{M}{EI}\frac{\partial M}{\partial M_B}\,R\,d\theta$$

$$M = \frac{PR}{2}(1-\cos\theta) - M_B$$

$$\frac{\partial M}{\partial M_B} = -1$$

$$\frac{\partial U}{\partial P} = 0 = \int_0^{\pi/2} \left[\frac{PR}{2}(1-\cos\theta) - M_B\right][-1]\ \ R\,d\theta$$

$$\frac{\partial U}{\partial P} = 0 = \left[\frac{-PR^2\theta}{2} - \frac{PR^2\sin\theta}{2} + M_B R\theta\right]\Bigg|\begin{cases}\pi/2\\0\end{cases}$$

Evaluating integral at 0 and π/2, the resisting moment, M_B, can be solved for:

$$0 = -0.285PR^2 + 1.57M_B R$$

$$M_B = 0.181PR$$

Substitute M_B into previous displacement equation:

$$\frac{\partial U}{\partial P} = \frac{2}{EI}\,[0.088PR^3\ - 0.285(0.181PR)\,R^2]$$

$$\frac{\partial U}{\partial P} = \frac{0.072PR^3}{EI}$$

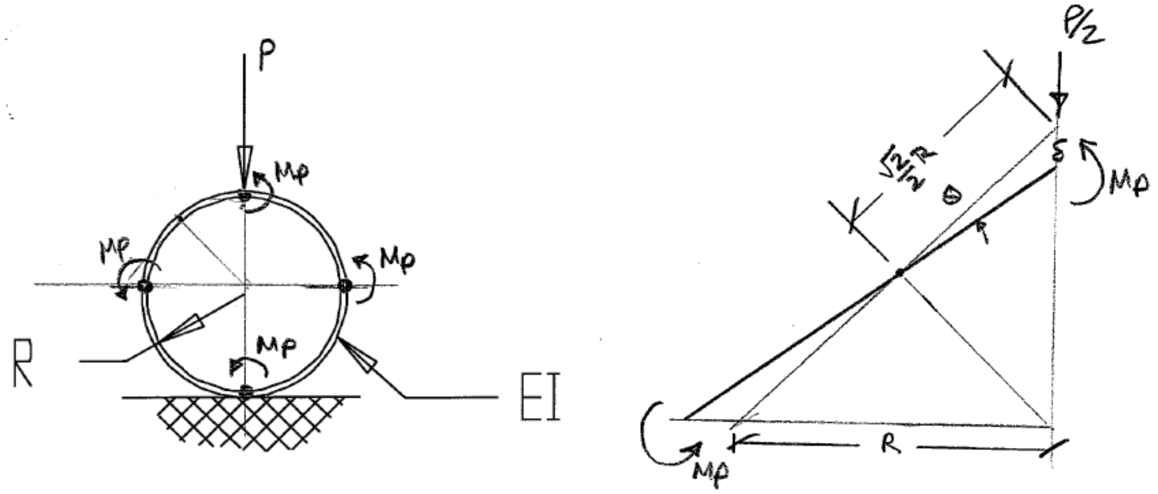
Substituting: $2R = D; I = \frac{1}{12}\,b\,t^3$

The radial stiffness, K_r, can be solved for:

$$K_r = \frac{9.28\,E\,b\,t^3}{D^3}$$

The principle of virtual work is used to estimate the plastic moment capacity of pipe section:

Figure C-22. Assumed locations of plastic moments and moment-virtual displacement relationship.



From virtual work, Figure 22(b):

$$\frac{P}{2}\,\delta = 4M_p\,\theta$$

$$\delta = \frac{\sqrt{2}}{2} R \text{ x } \sqrt{2}\,\theta$$

$$\delta = R\theta$$

$$PR\theta = 8M_p\theta$$

The critical concentrated pipe load is therefore:

$$P = \frac{16M_p}{D}$$

The plastic moment of the pipe segment is estimated to be:

$$M_p = \frac{bt^2}{4}\,F_y$$

The critical concentrated pipe demand is alternatively expressed as:

$$P = \frac{4bt^2}{D}\,F_y$$

C.6 TARGET DAMAGE APPROXIMATIONS

Description	Rebar	Gas Cylinder	Tank Drum	Utility Pole	Cable Reel	3" pipe (schedule 40)
Diesel Generator Exhaust Pipe						
SG Power Operated Relief Valve Tailpipe						
Turbine Driven Feedwater pump exhaust piping						
Steam Generator Power Operated RV Exh Pipe						
Diesel Generator Air intake (small)						
Diesel Generator Air intake (large)						
Diesel Generator Exh Silencer						
Condensate Storage Tank (t=0.25")						
Diesel Fuel Oil Tank (t=0.133")						
Diesel Fuel Oil Tank (t=0.145")						
Condensate Storage Tank (t=0.375")						
Well water piping (t=0.237")						
Condensate Piping (t=0.237")						
Main Steam Piping (t=0.985")						
Diesel Fuel Oil Storage Tank (t=0.25")						
Room Door (t=0.1")						
Service Water Piping (t=0.375")						
Aux Feedwater Piping (t=0.432")						
Concrete Roofs						
8" reinforced						
4" reinforced with steel decking						
~~**Vertical Barriers**~~						
~~12" reinforced concrete wall~~	-	-	-	-	-	-
~~2"x 3/8" steel grating~~	-	-	-	-	-	-
~~4" x 3/8" steel grating~~						

Legend

Less than or equal to 50% crushing	
Greater than 50% crushing	
100% crushing	
Failure by perforation or crushing more than 50%	
Failure of concrete panels or steel grating	

Description	6" pipe (schedule 40)	12" pipe (schedule 40)	Storage Bin	Concrete Paver	Concrete block	4x12 timber
Diesel Generator Exhaust Pipe						
SG Power Operated Relief Valve Tailpipe						
Turbine Driven Feedwater pump exhaust piping						
Steam Generator Power Operated RV Exh Pipe						
Diesel Generator Air intake (small)						
Diesel Generator Air intake (large)						
Diesel Generator Exh Silencer						
Condensate Storage Tank (t=0.25")						
Diesel Fuel Oil Tank (t=0.133")						
Diesel Fuel Oil Tank (t=0.145")						
Condensate Storage Tank (t=0.375")						
Well water piping (t=0.237")						
Condensate Piping (t=0.237")						
Main Steam Piping (t=0.985")						
Diesel Fuel Oil Storage Tank (t=0.25")						
Room Door (t=0.1")						
Service Water Piping (t=0.375")						
Aux Feedwater Piping (t=0.432")						
Concrete roofs						
8" reinforced						
4" reinforced with steel decking						
~~**Vertical Barriers**~~						
~~12" reinforced concrete wall~~	-	-	-	-	-	-
~~2"x 3/8" steel grating~~	-	-	-	-	-	-
~~4" x 3/8" steel grating~~						

Legend

Less than or equal to 50% crushing	
Greater than 50% crushing	
100% crushing	
Failure by perforation or crushing more than 50%	
Failure of concrete panels or steel grating	

Description	2x12	Metal siding	7/8" plywood	Wide Flange (WF 14x26	Channel Section C6x13	Small equipment
Diesel Generator Exhaust Pipe						
SG Power Operated Relief Valve Tailpipe						
Turbine Driven Feedwater pump exhaust piping						
Steam Generator Power Operated RV Exh Pipe						
Diesel Generator Air intake (small)						
Diesel Generator Air intake (large)						
Diesel Generator Exh Silencer						
Condensate Storage Tank (t=0.25")						
Diesel Fuel Oil Tank (t=0.133")						
Diesel Fuel Oil Tank (t=0.145")						
Condensate Storage Tank (t=0.375")						
Well water piping (t=0.237")						
Condensate Piping (t=0.237")						
Main Steam Piping (t=0.985")						
Diesel Fuel Oil Storage Tank (t=0.25")						
Room Door (t=0.1")						
Service Water Piping (t=0.375")						
Aux Feedwater Piping (t=0.432")						
Concrete roofs						
8" reinforced						
4" reinforced with steel decking						
~~**Vertical Barriers**~~						
~~12" reinforced concrete wall~~	-	-	-	-	-	-
~~2"x 3/8" steel grating~~	-	-	-	-	-	-
~~4" x 3/8" steel grating~~						

Legend

Less than or equal to 50% crushing	
Greater than 50% crushing	
100% crushing	
Failure by perforation or crushing more than 50%	
Failure of concrete panels or steel grating	

Description	Large equipment	Frame/steel grating	Large steel frame	Vehicle	Tree
Diesel Generator Exhaust Pipe					
SG Power Operated Relief Valve Tailpipe					
Turbine Driven Feedwater pump exhaust piping					
Steam Generator Power Operated RV Exh Pipe					
Diesel Generator Air intake (small)					
Diesel Generator Air intake (large)					
Diesel Generator Exh Silencer					
Condensate Storage Tank (t=0.25")					
Diesel Fuel Oil Tank (t=0.133")					
Diesel Fuel Oil Tank (t=0.145")					
Condensate Storage Tank (t=0.375")					
Well water piping (t=0.237")					
Condensate Piping (t=0.237")					
Main Steam Piping (t=0.985")					
Diesel Fuel Oil Storage Tank (t=0.25")					
Room Door (t=0.1")					
Service Water Piping (t=0.375")					
Aux Feedwater Piping (t=0.432")					
Concrete Roofs					
8" reinforced					
4" reinforced with steel decking					
~~Vertical Barriers~~					
~~12" reinforced concrete wall~~	-	-	-	-	-
~~2"x 3/8" steel grating~~	-	-	-	-	-
~~4" x 3/8" steel grating~~					

Legend

Less than or equal to 50% crushing	
Greater than 50% crushing	
100% crushing	
Failure by perforation or crushing more than 50%	
Failure of concrete panels or steel grating	

C.7 CONCLUSIONS

The impact of a missile onto a target is a complex dynamic problem. The phenomena typically involve nonlinear material behavior and high strain rates for both the missile and target. The problem of wind-driven missiles is further complicated, because these missiles are not engineered penetrators that are designed to penetrate a hardened target (i.e., remain rigid). In many cases, detailed finite element analysis are required to evaluate both missile and target response. However, such analyses are resource intensive and due to lack of experimental validation, these more detailed analysis may not significantly reduce uncertainty in results.

As the number of EPRI missile and target combinations to be analyzed was more than 400 (~23 missiles x 19 targets), a pragmatic approach was developed to evaluate target robustness. The approach relies on an analytical approach that is consistent with the NRC SRP Section 3.5.3 [1]. The approach makes accounts for missile characteristics such as impact speed, missile mass, and target characteristics such as stiffness, ultimate capacity, and mass. The analysis of pipe crimping was benchmarked to two relevant experiments.

While median material properties were assumed to develop a best-estimate of target response, the following conservative assumptions were made:

- The assumed maximum missile impact speed, of 230 mph, exceeds current SRP missile speeds. The highest horizontal missile impact speed cited in the most current NRC guidance is 92 mph (RG 1.76) for tornado winds and 209 mph (RG 1.221) for hurricane winds.

- For piping scenarios, it was assumed that missile impacts are normal to the target surface and that the axis of the missile is parallel to the line of flight. For impacts on pipes, the effectiveness of the missile impact degrades significantly as the strike location is offset from the centerline of the pipe.

- For impacts on liquid-filled steel tanks, the tank stiffness did not credit the added contribution of the tank end-closure and foundation restraint. The stiffening effect of the entrained liquid was also not credited.

- For impacts on thinner concrete roofs (4-inches), the effect of the steel decking was not credited. Steel decking tends to limit concrete spalling, increase confinement, thereby improving resistance to impact scenarios. Impact was also assumed to be normal to the roof surface, rather than the more realistic case of having an angle of incidence.

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APPENDIX D: TECHNICAL BASIS FOR TMRE METHODOLOGY

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
IE-A	*The initiating event analysis shall provide a reasonably complete identification of initiating events.*		
IE-A1	*Tornado initiating events will be consistent with the intervals defined in the TMRE process. TMRE considers all tornadoes will result in a LOOP. Tornado initiating event frequencies will be based on a hazard curve that uses site specific data provided in Table 6.1 of NUREG 4461 [IE-C1].*	TMRE process should ensure that the initiating events caused by extreme winds that give rise to significant accident sequences and accurately capture the additional risk of the unprotected SSCs (that should be protected per the CLB) are identified and used for this application.	4.3, 6.2
IE-A10	*For multi-unit sites with shared systems, INCLUDE multi-unit site initiators (e.g., multi-unit LOOP events or total loss of service water) that may impact the model.*		6.2
IE-B	*The initiating event analysis shall group the initiating events so that events in the same group have similar mitigation requirements (i.e., the requirements for most events in the group are less restrictive than the limiting mitigation requirements for the group) to facilitate an efficient but realistic estimation of CDF*		

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
IE-B5	*DO NOT SUBSUME multi-unit initiating events if they impact mitigation capability. Two unit sites should consider proximity of each unit to each other, the footprint of potential tornadoes for the region, and the systems shared between each unit.*		6.2
IE-C	*The initiating event analysis shall estimate the annual frequency of each initiating event or initiating event group.*	The tornado IEFs should be based on a hazard curve that uses site-specific data, such as found in NUREG-4461.	
IE-C1	*Tornado initiating event frequencies will be based on a hazard curve that uses site specific data provided in Table 6.1 of NUREG 4461*		4.1
IE-C3	*Do not credit recovery of offsite power.*	Same comment as AS-A10	6.1, Appendix A
IE-C15	*CHARACTERIZE the uncertainty in the tornado initiating event frequencies and PROVIDE mean values for use in the quantification of the PRA results. NUREG 4461, data includes uncertainty.*		4.3
AS-A	*Utilize the accident sequences (typically LOOP) provided in the internal events model and adjust as necessary to consider the consequences of a tornado event.*		
AS-A1	*Modify the internal events accident sequences in compliance with this SR*		6.1, 6.3, 6.4, 6.5

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
AS-A3	*Review the FPIE success criteria and modify the associated system models as necessary to account for the tornado event and its consequences.*		6.1, 6.3, 6.4, 6.5
AS-A4	*Review the FPIE success criteria and modify the associated operator actions as necessary to account for the tornado event and its consequences.*		6.4
AS-A5	*Modify the FPIE accident sequence model in a manner that is consistent with the plant-specific: system design, EOPs, abnormal procedures, and plant transient response. Account for system functions that, as a consequence of the tornado event, will not be operable or potentially degraded, and operator actions that will not be possible or impeded.*		6.1, 6.3, 6.4, 6.5

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
AS-A10	*Capability Category I. In modifying the accident sequence models, INCLUDE, for each tornado initiating event, INDIVIDUAL EVENTS IN THE ACCIDENT SEQUENCE SUFFICIENT TO BOUND SYSTEM OPERATION, TIMING, AND OPERATOR ACTIONS NECESSARY FOR KEY SAFETY FUNCTIONS.*	In constructing the accident sequence models, support system modeling, etc. realistic criteria or assumptions should be used, unless a conservative approach can be justified. Use of conservative assumptions in the base model can distort the results and may not be conservative for delta CDF/LERF calculation. While use of conservative or bounding assumptions in PRA models is acceptable, a qualitative or quantitative assessment may be needed to show that those assumptions do not underestimate delta CDF/LERF estimates.	6.3, 7.2.3, Appendix A
AS-B	*Dependencies that can impact the ability of the mitigating systems to operate and function shall be addressed.*		
AS-B1	*For each tornado event, IDENTIFY mitigating systems impacted by the occurrence of the initiator and the extent of the impact. INCLUDE the impact of initiating events on mitigating systems in the accident progression either in the accident sequence models or in the system models.*		6.1, 6.3, 6.5, 6.6

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
AS-B3	*IDENTIFY the phenomenological conditions created by the accident progression. Also high winds and rains after the tornado event could result in hazardous conditions (e.g. debris and structural instabilities) for actions outside the control room.*		5.6, 6.3, 6.4, 6.6
AS-B7	*Review FPIE time phased dependencies to identify model changes needed to address all the concurrent system functions failed by the tornado event; e.g. LOOP, instrument air, fire protection……etc. Do not model offsite recovery.*		6.1
SC-A	*The overall success criteria for the PRA and the system, structure, component, and human action success criteria used in the PRA shall be defined and referenced, and shall be consistent with the features, procedures, and operating philosophy of the plant.*		
SC-A4	*Consider impact on both units for the same tornado including the mitigating systems that are shared.*		6.1

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
SY-A	*The systems analysis shall provide a reasonably complete treatment of the causes of system failure and unavailability modes represented in the initiating events analysis and sequence definition*		
SY-A4	*Capability Category II. Walkdowns focusing on targets vulnerable to tornado missiles will be performed. Walkdown will include a missile inventory and a review of pathways available to the operators for ex-control room actions.*		*Section 3*
SY-A11	*New basic events will be added to address all the failure modes of the system targets exposed to tornado missiles; safety-related and non-safety related.* *The exclusions of SY-A15 do not apply for SSCs impacted by tornado missiles.*		6.3, 6.5, 6.6

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
SY-A12	*DO NOT INCLUDE in a system model component failures that would be beneficial to system operation, unless omission would distort the results. For example, do not assume a vent pipe will be sheered by a high energy missile verses crimped unless it can be shown this is true for all missiles at all speeds. Exceptions would be components that are intentionally designed to "fail" favorably when struck by a missile; e.g. a frangible plastic pipe used as a vent is designed to break off and not crimp when struck by a missile.*		*5.2*
SY-A13	*Consider the target's potential to cause a flow diversion when struck by a tornado missile.*		*6.5*
SY-A14	*Missile targets will be assessed for all failure modes - some new failure modes may be identified that are not in the FPIE model.* *The exclusions of SY-A15 do not apply for SSCs impacted by tornado missiles.*		*6.5*

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
SY-A15	*The failure of SSCs due to tornado missiles shall not use the exclusions of SY-A15.*	The failure by tornado missiles should be included in the model for all unprotected targets that are supposed to be protected according to the CLB and any unprotected targets that are not in the CLB but are in the PRA model. This is to facilitate sensitivity studies regarding possible correlation of tornado missile damage across systems. It is not expected that the number of basic events added to the model for this analysis will be so large that this screening is necessary.	6.5
SY-A17	*Certain post initiator HFEs will be modified to account for the tornado event.*		6.4
SY-B	*The thermal/hydraulic, structural, and other supporting engineering bases shall be capable of providing success criteria and event timing sufficient for quantification of CDF and LERF, determination of the relative impact of success criteria on SSC and human actions, and the impact of uncertainty on this determination.*		

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
SY-B7	*Capability Category I. BASE support system modeling on the use of CONSERVATIVE SUCCESS CRITERIA AND TIMING. Sensitivity studies will be performed to identify where conservative assumptions may be distorting risk and adjusted accordingly.*	Same comment as AS-A10	7.2.3
SY-B8	*Consider spatial relationships between components to identify correlated failures. Where the same missile can impact targets that are in close proximity to each other.*		5.6
SY-B14	*Statistical correlation of tornado missile damage between redundant and spatially separated components is NOT required.*	The industry indicated in earlier discussions that information is available to show that statistical correlation of tornado missile damage for specially separated components is insignificant. Until that information is reviewed and accepted by the staff, this SR should be met (spans all capability categories) and dependent failures of multiple SSCs should be considered.	Appendix B.4.4
SY-B15	*INCLUDE new operator interface dependencies across systems or trains related to the tornado event, if applicable.*		*6.4*

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
HR-E	*A systematic review of the relevant procedures shall be used to identify the set of operator responses required for each of the tornado accident sequences*		
HR-E3	*Operators will be interviewed (if necessary) to assess the need for changes to operator actions for the tornado initiating events.*		*6.4*
HR-E4	*Operators talk-throughs or simulator observations will be conducted (if necessary) to assess the need for changes to operator actions for the tornado initiating events.* *[Note: this applies to new sequences or failure combinations not accounted for in the internal events model. It is not intended that operator action timing needs be changed due to the tornado event alone]*		*6.4*
HR-G	*The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence.*		

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
HR-G5	*Operators will be interviewed and simulator observations conducted (if necessary) to assess the need for changes to operator action timing as a result of the tornado event.* *[Note: this applies to new sequences or failure combinations not accounted for in the internal events model. It is not intended that operator action timing needs be changed due to the tornado event alone]*		*6.4*
HR-G7	*For new operator action dependencies identified as part of QU-C1, ASSESS the degree of dependence, and calculate a joint human error probability that reflects the dependence.*		*6.4*
HR-H	*Recovery actions (at the cut set or scenario level) shall be modeled only if it has been demonstrated that the action is plausible and feasible for those scenarios to which they are applied. Estimates of probabilities of failure shall address dependency on prior human failures in the scenario.*		
HR-H1/H2	*Do not credit recovery actions to restore functions, systems, or components unless an explicit basis accounting for tornado impacts on the site and the SSCs of concern is provided.*		*6.4*

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
DA-A	*Each parameter shall be clearly defined in terms of the logic model, basic event boundary, and the model used to evaluate event probability.*		
DA-A1	*Develop new basic events for tornado missile targets (all failure modes) in accordance with this SR.*		6.3, 6.5, 6.6
QU-A	*The level 1 quantification shall quantify core damage frequency and shall support the quantification of LERF.*		
QU-A5	*Do not credit recovery actions to restore functions, systems, or components unless an explicit basis accounting for tornado impacts on the site and the SSCs of concern is provided.*		6.4
QU-C	*Model quantification shall determine that all identified dependencies are addressed appropriately.*		
QU-C1	*Identify new operator action dependencies created as a result of the changes to the internal events PRA model or failures associated with tornado events.*		6.4

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
QU-D	*The quantification results shall be reviewed, and significant contributors to CDF (and LERF), such as initiating events, accident sequences, and basic events (equipment unavailabilities and human failure events), shall be identified. The results shall be traceable to the inputs and assumptions made in the PRA.*		
QU-D5	*Review nonsignificant cut set or sequences to determine the sequences are valid*		*7.3*
QU-D7	*Review BE importance to make sure they make logical sense.*		*7.3*
QU-E	*Uncertainties in the PRA results shall be characterized. Sources of model uncertainty and related assumptions shall be identified, and their potential impact on the results understood.*		
QU-E1	*Identify sources of uncertainty related to MIP and missiles*		7.1 *Also see Appendices A and B for bases.*
QU-E2	*Identify assumptions made that are different than those in the internal events model*		Section 6
QU-E4	*Identify how the model uncertainty is affected by assumptions related to MIP and missiles*		7.1, Appendix A

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
LE-C	*The accident progression analysis shall include identification of those sequences that would result in a large early release.*		7.1, 7.3
LE-C3	*Do not credit recovery of offsite power. Do not credit recovery actions to restore functions, systems, or components unless an explicit basis accounting for tornado impacts on the site and the SSCs of concern is provided.*	Same comment as AS-A10	6.3, 7.2.3, Appendix A
Multiple SRs		Changes made for application of the PRA to tornado missile impact risk determination such as those to initiating event analysis, accident sequences, systems analysis, human reliability analysis, and parameter estimation should be documented, as described in various documentation SRs for each HLR. The documentation should be sufficient to understand basis and facilitate review. Examples of such SRs include IE-D1 through IE-D3, SY-C1 through SY-C3, and DA-E1 through DA-E3. It is recognized that the documentation of changes to the PRA and their basis will be captured in the change to the plant's licensing basis.	Section 8

APPENDIX E: TMRE METHODOLOGY SENSITVITY STUDIES

E.1 OBJECTIVES

The objective of this Appendix is to examine the sensitivity of MIP values to target size, target elevation, and the distribution of missiles inventory around the plant. The results are used to support the derivation of MIP values.

E.2 METHODOLOGY OVERVIEW

The sensitivity studies are performed using TORMIS code for two operating power plants.. Missile hit probabilities for selected targets are post processed and compared for the sake of understanding the effects of target sizes, target elevations and missile inventory distribution on the MIP.

The following points provide a high level overview of the methodology used:

1. Two existing nuclear power plants models (Plant A and Plant B) are selected for this study. Plants models were developed previously and permission has been obtained from plant owners for their use. Plant A is located in NRC region 1 and EPRI region A. Plant B is located in NRC region 1and border of EPRI regions A and B.

2. All sensitivity studies used the Enhanced Fujita Scale EF1 through EF5. This is consistent with RG. 1.76 revision 1 and is in alignment of industry practices in recent TORMIS analyses submitted to the NRC. For each EF scale two thousands randomly generated tornados are simulated. For each tornado, two thousands five hundred missiles are sampled. It is acknowledged that in recent years the number of simulations are in the order of ten millions. However, for this study, the number of simulation for each EF scale is judged to be adequate as relative values are of interest not the actual hit probabilities. .

3. Statistical convergence is attained by performing multiple analysis sets for each EF scale. That is, seven sets of analyses for the study of zonal vs uniform distribution of missiles, four sets of analyses for the studies of target elevation and target sizes. Consequently, the total number of simulations for the zonal vs uniform study is seven hundred millions for plants A and B combined and is two hundred millions each for the studies of target elevation and target sizes. Total number of simulation is calculated as follows (5,000,000 * 5(EFs) * 7(sets) * 2(uniform and zonal) * 2 (plants A and B) = 700,000,000.

4. Though a significant portion of Plants A and B missiles are restrained missiles, for simplification, this study assumes all missiles are free.

   The Missile types have been given a missile type that is consistent with TORMIS list of missiles. TORMIS missile sets (i.e. missile types defined in TORMIS code) are shown in Table 2-2 of Ref. (Np 768)

5. The results are based on TORMIS reported P (A) (i.e. single missile hit probability) for summation of events 2 and 7. Event 7 is “Auto” hit probability and Event 2 is hit probability for all other missiles.

E.3 DESCRIPTION OF PLANT MODELS

Plant A

Figure E-1 shows a 3D view of the TORMIS model for Plant A showing modeled power block structures. The Model includes 22 missile zones and encompass an area of 5000'X 5000'. Missile population from missile survey is in excess of 100,000 missiles. Missile population includes missiles that are located on top of the buildings in access of 4,340 missiles. The zonal area of Plant A is 19,771,450 ft^2.

Figure E-2 shows a plan view of missile zones along with number of missiles in each missile zone and missile building tops. The distribution of missiles in each zone is the actual distribution based on an actual plant walkdown.

Table E-1 lists missile description of plant A and the corresponding TORMIS missile types as designated by the walkdown personnel. Table E-2 list in a tabulated format the missile distribution shown in Figure E-2.

Figure E-1. 3D View of Plant A

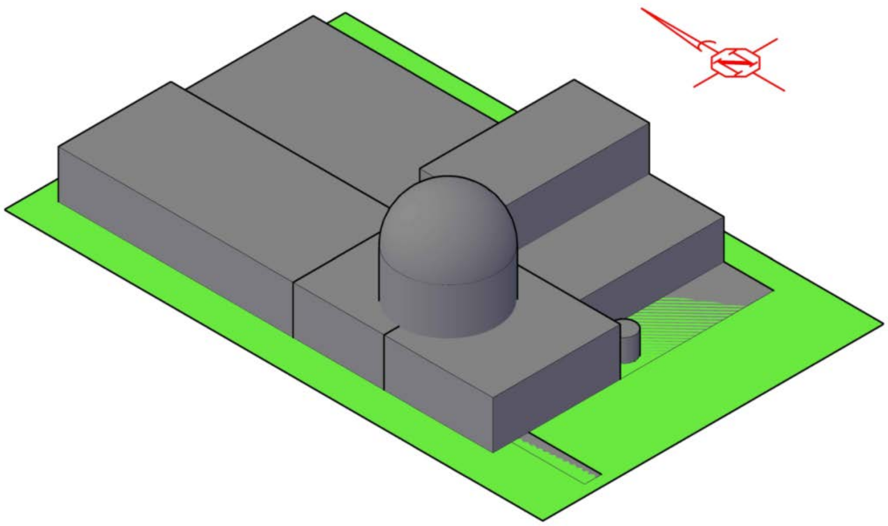


Figure E-2. Plant A missile zones and number of missiles in each zone

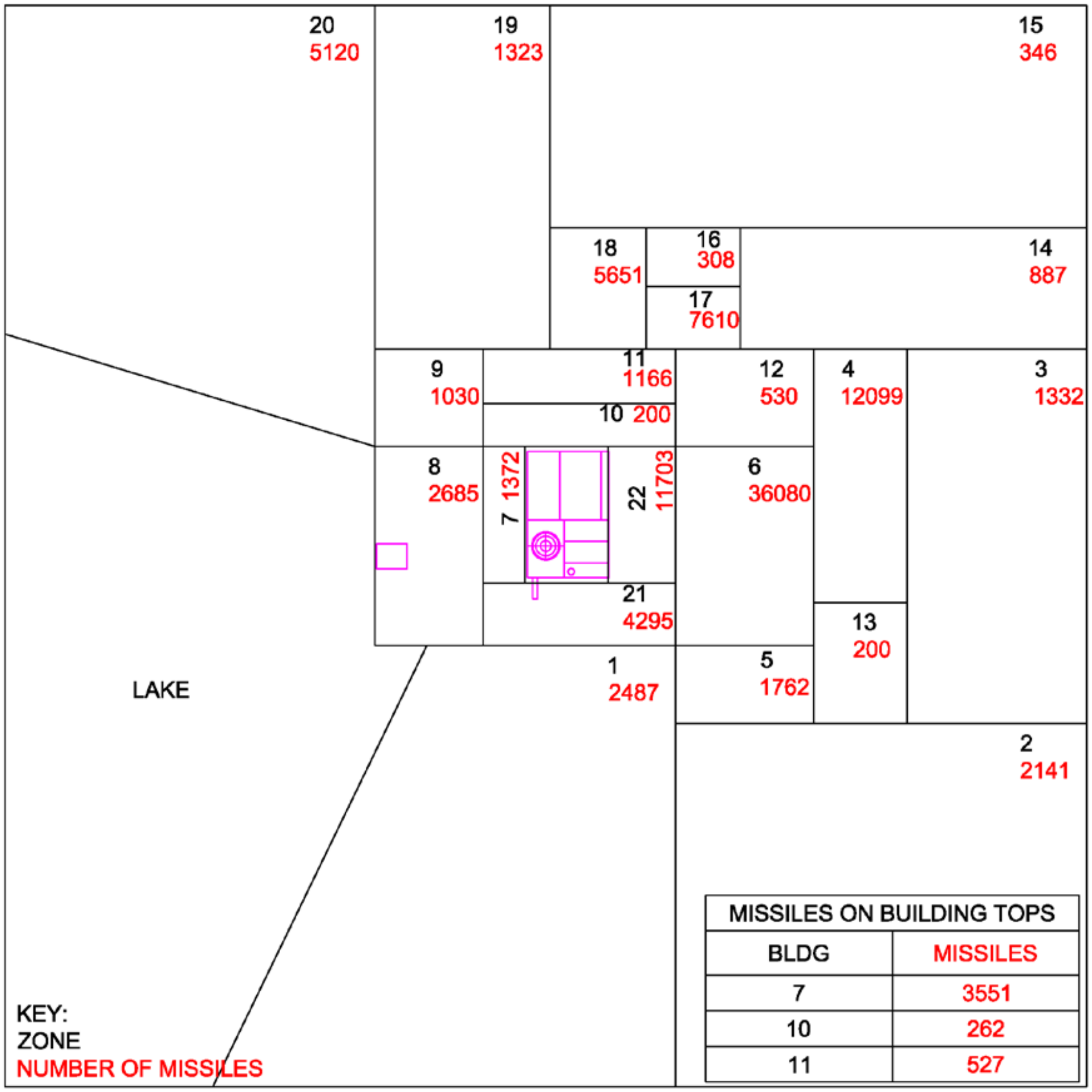


Table E-1. Missile description for Plant A

Type No.	Missile Description	TORMIS Missile Set No.
1	1"Φ steel rod L = 2' - 4'	1
2	1"Φ steel rod, L = 10' - 20'	1
3	8"Φ gas bottle, L = 5'	1
4	24"Φ drums, L = 3'	1
5	8"Φ wood post, L = 10' - 15'	2
6	14"Φ wood post, L = 30' - 40'	2
7	1"Φ steel pipe, L =10' - 20'	3
8	3"Φ steel pipe, L = 8' - 12'	3
9	6"Φ steel pipe, L = 10' - 20'	3
10	12"Φ steel pipe, L = 10' - 20'	3
11	4"x4" wood post, L = 8' - 12'	6
12	6"x1" wood plank, L = 4' - 8'	9
13	12"x4" wood plank, L = 8' - 16'	9
14	4'x1" steel plate, L = 4' - 8'	10
15	4'x1" wood plate, L = 4' - 8'	11
16	4' x 20 ga steel plate, L = 10' - 20'	12
17	W8x10 steel wide flange, L = 10' - 20'	14
18	2x2x1/4 steel angle, L = 10' - 20'	15
19	C8x11.5 steel channel, L = 15' - 25'	16
20	Automobile	25
21	Trees, d = 8", L = 10' - 40'	26

Table E-2. Missile Distribution for Plant A

		Missile Type Number																				
Zone Number	Number of Missiles	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	2487	0	8	0	0		3	6	681	0	0	0	0	0	0	0	678	0	0	11	0	1100
2	2141	0	16	0	4	32	30	33	658	0	0	0	0	0	0	0	707	0	0	61	0	600
3	1332	0	16	0	25	1		28	506	0	0	0	0	0	0	0	554	0	0	52	0	150
4	12099	3840	64	0	0		3	324	2153	11	0	50	180	50	100	2170	2363	0	10	661	120	0
5	1762	0	32	0	0	3	0	46	531	43	0	0	320	20	1	0	613	0	0	103	0	50
6	36080	7139	366	424	310	17	0	1860	4635	168	78	85	1640	2780	329	3671	9094	19	180	3170	65	50
7	1372	150	32	0	0	0	0	32	224	4	0	0	0	0	0	150	323	0	400	57	0	0
8	2685	0	64	0	0	5	0	102	977	2	0	0	0	0	0	0	1201	0	0	234	0	100
9	1030	0	0	0	0	10	0	0	260		0	0	0	0	0	0	260	0	0	0	500	0
10	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200
11	1166	0	0	0	0	0	0	0	510	4	0	0	0	0	0	0	552	0	0	0	0	100
12	530	0	0	0	0	0	0	0	200		0	0	0	0	0	0	200	0	0	0	30	100
13	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200
14	887	18	0	0	0	0	2	0	321	1	0	0	0	0	0	7	330	0	100	8	0	100
15	346	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	25	0	0	300
16	308	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	200	100
17	7610	1600	16	0	10	0	0	240	1021	2	0	0	0	0	0	1600	2626	0	0	470	25	0
18	5651	0	0	0	0	6	0		520	325	0	0	0	0	0	0	500	200	4000	0	0	100
19	1323	44	32	0	0	4	0	16	204	2	0	0	0	0	0	45	247	0	600	29	0	100
20	5120	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	5100
21	4295	738	48	0	0	0	0	70	378	10	0	0	0	1450		693	776	0	0	132	0	0
22	11703	20	2048	20	20	20	20	2207	407	200	200	2000	200	200	20	200	2855	200	200	646	20	0

Plant B

Figure E-3 shows a 3D view of the TORMIS model for Plant B showing modeled power block structures. The Model includes 18 missile zones and encompasses an area of 5000'X5000'. Missile population from missile survey is 141,944 missiles. Missile population includes missiles that are located on top of the buildings in access of 11,766 missiles. The zonal area of Plant B is 19,771,450 ft^2.

Figure E-4 shows a plan view of missile zones along with number of missiles in each missile zone and missile building tops. The distribution of missiles in each zone is the actual distribution based on an actual plant walkdown.

Table E-3 lists missile description of plant B and the corresponding TORMIS missile type as designated by the walkdown personnel. Table E-3 lists in a tabulated format the missile distribution shown in Figure E-4.

Figure E-3. 3D View of Plant B

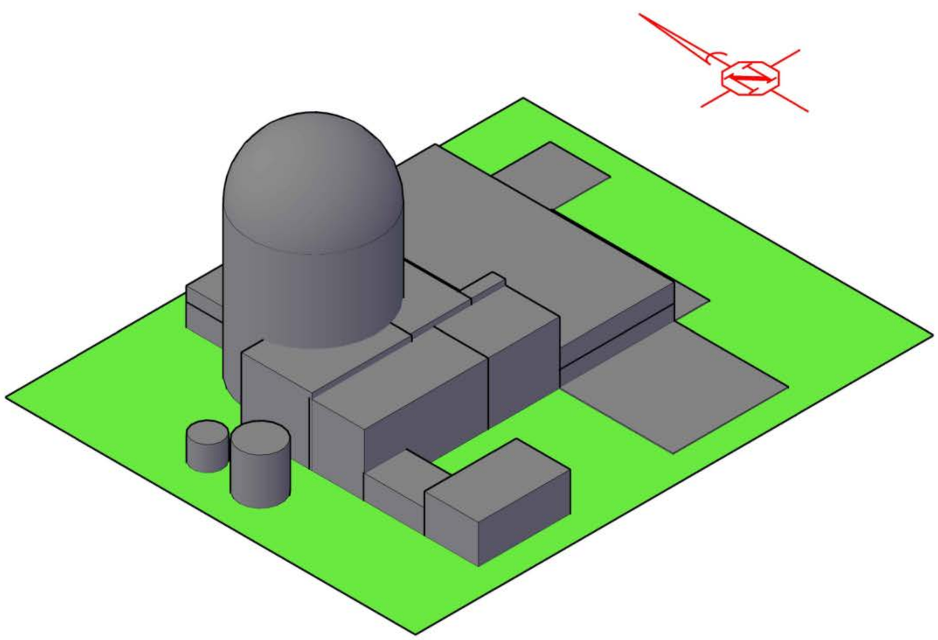
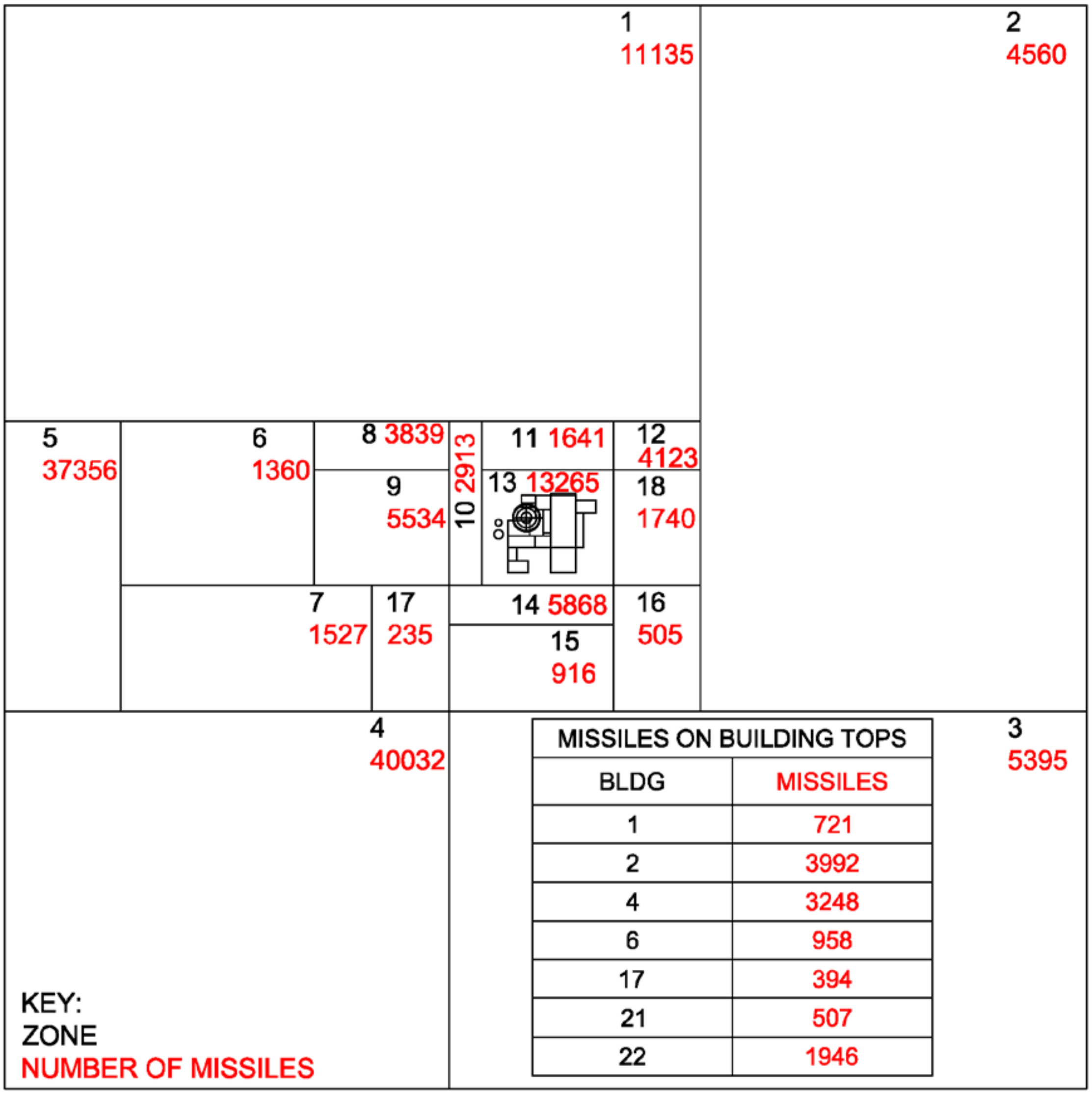


Figure E-4. Plant B missile zones and number of missiles in each zone



MISSILES ON BUILDING TOPS	
BLDG	MISSILES
1	721
2	3992
4	3248
6	958
17	394
21	507
22	1946

Table E-3. Missile description for Plant B

Type No.	Missile Description	TORMIS Missile Set No.
1	1"Φ steel rod L = 2' - 4'	1
2	1"Φ steel rod, L = 10' - 20'	1
3	8"Φ gas bottle, L = 5'	1
4	24"Φ drums, L = 3'	1
5	8"Φ wood post, L = 10' - 15'	2
6	14"Φ wood post, L = 30' - 40'	2
7	1"Φ steel pipe, L =10' - 20'	3
8	3"Φ steel pipe, L = 8' - 12'	3
9	6"Φ steel pipe, L = 10' - 20'	3
10	12"Φ steel pipe, L = 10' - 20'	3
11	4"x4" wood post, L = 8' - 12'	6
12	6"x1" wood plank, L = 4' - 8'	9
13	12"x4" wood plank, L = 8' - 16'	9
14	4'x1" steel plate, L = 4' - 8'	10
15	4'x1" wood plate, L = 4' - 8'	11
16	4' x 20 ga steel plate, L = 10' - 20'	12
17	W8x10 steel wide flange, L = 10' - 20'	14
18	2x2x1/4 steel angle, L = 10' - 20'	15
19	C8x11.5 steel channel, L = 15' - 25'	16
20	Gratting and ladders, L=15' - 25' 2"X1" thick	22
21	3"Φ PVC pipe, L = 8' - 12'	3
22	12"Φ 5 gallon plastic container, L = 18", W=32 lbs	2
23	1'-6" x 2" Concrete panels, L=2' - 3'	8
24	Automobile	25
25	Trees, d = 8", L = 10' - 40'	26

Table E-4. Missile distribution for Plant B

		Missile Type Number																								
Zone Number	**Number of Missiles**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1	11135	400	0	0	0	5	0	0	1266	20	0	0	0	0	0	0	824	273	378	0	129	0	0	0	0	7840
2	4560	0	0	0	0	10	0	0	400	0	0	0	0	0	0	0	400	0	0	0	0	0	0	0	0	3750
3	5395	0	32	0	0	3	0	184	283	160	0	0	750	70	0	120	302	100	0	72	101	0	0	0	0	3218
4	40032	6662	768	216	322	5	75	1170	3009	340	25	885	13160	55	110	2809	6206	67	1687	1331	105	25	600	100	250	50
5	37356	10984	48	0	0	20	50	464	3792	20	0	0	0	0	0	10984	8865	0	600	964	0	0	0	0	525	40
6	1360	50	0	0	0	10	0	0	150	100	50	0	0	0	0	0	0	0	900	0	0	0	0	0	0	100
7	1527	146	0	0	0	15	35	0	109	0	0	40	0	0	0	56	259	12	335	20	0	0	0	0	500	0
8	3839	0	16	15	82	0	21	566	720	0	0	200	575	50	100	100	304	0	0	590	0	110	0	240	150	0
9	5534	0	10	0	0	0	30	5	626	100	0	12	10	0	0	0	476	0	600	50	0	0	0	3600	15	0
10	2913	234	47	0	0	0	0	136	345	10	0	150	400	0	0	282	1040	10	0	259	0	0	0	0	0	0
11	1641	288	0	30	0	2	10	0	437	4	0	0	0	0	0	188	512	25	45	50	0	0	0	0	50	0
12	4123	606	73	30	11	0	4	592	439	0	0	0	30	5	0	296	1031	3	360	243	0	80	0	300	20	0
13	13265	3314	48	50	18	2	0	542	1232	450	0	55	2775	60	67	1634	1320	15	748	860	0	0	50	0	25	0
14	5868	276	74	100	15	0	1	189	740	91	40	0	2015	155	12	501	1191	25	140	251	2	0	50	0	0	0
15	916	110	62	8	0	0	0	67	65	2	0	20	105	0	40	20	185	4	3	59	0	6	0	0	160	0
16	505	0	0	0	0	5	0	0	190	0	0	0	0	0	0	0	190	0	0	0	0	0	0	0	0	120
17	235	0	0	0	0	5	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	220
18	1740	0	80	0	0	0	0	80	236	4	0	0	0	0	0	0	1007	0	0	233	0	0	0	0	0	100

Details of the Sensitivity Studies

Target Elevation Study

The objective of this study is to examine the impact of target elevation on targets hit probabilities. In this study both plants A and B models are used. The targets are created on an open wall with varied elevations without changing targets size.

For plant A four targets are considered on north, south, east and west walls of the plant, see Figure E-5. For plant B, three targets are considered, one on each of the north south and west walls. The east wall of plant B is blocked by turbine building. Missile inventory in Tables E-2 and E-4 for plants A and B are used. All missiles are assumed to be free missiles (i.e. not restrained). The total number of simulation for this study for both plants is two hundred millions. Table E-5 shows the size and location for the targets considered. All targets have a width of 20 feet and a height of 10 feet. Target elevations are considered to be the horizontal center line of the targets with respect to the ground. Figure E-5 and E-6 show the 3D view of the target locations for plant A. Figure E-7 and E-8 show the 3D view of the target locations for plant B.

As expected the sensitivity results show that in general as target elevation increases, hit probability is decreases.

Table E-5. Target sizes and location for target elevation study

Plant A	Size	Elev 1	Elev 2	Elev 3
East Wall	20'WX10'H	8'	38'	78'
West Wall	20'WX10'H	5'	25'	55'
North Wall	20'WX10'H	68'	78'	103'
South Wall	20'WX10'H	5'	20'	35'
Plant A	**Size**	**Elev 1**	**Elev 2**	**Elev 3**
East Wall	N/A	N/A	N/A	N/A
West Wall	20'WX10'H	8.5'	23.5'	53.5'
North Wall	20'WX10'H	6'	21'	41'
South Wall	20'WX10'H	6'	31'	64'

Figure 5. Plant A East and South Wall Targets

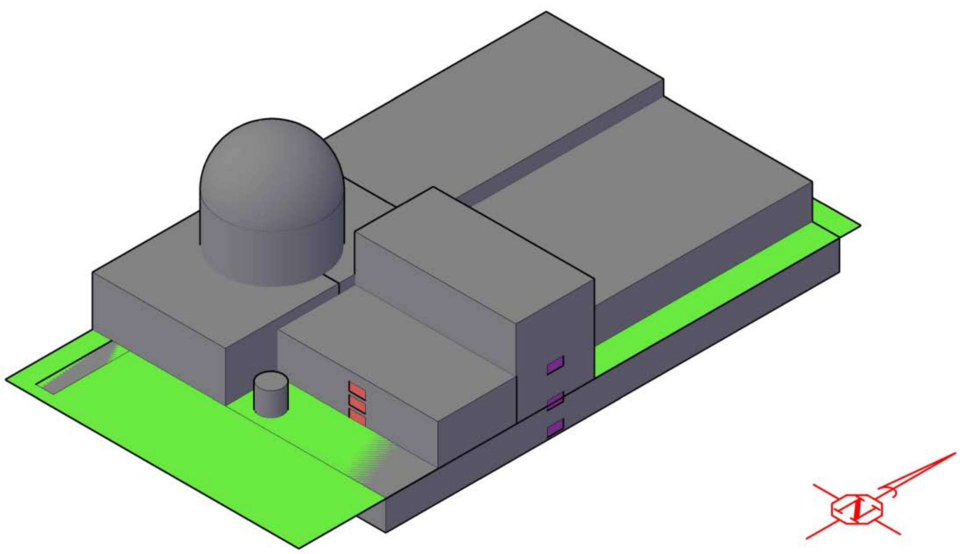


Figure 6. Plant A North and West Wall targets

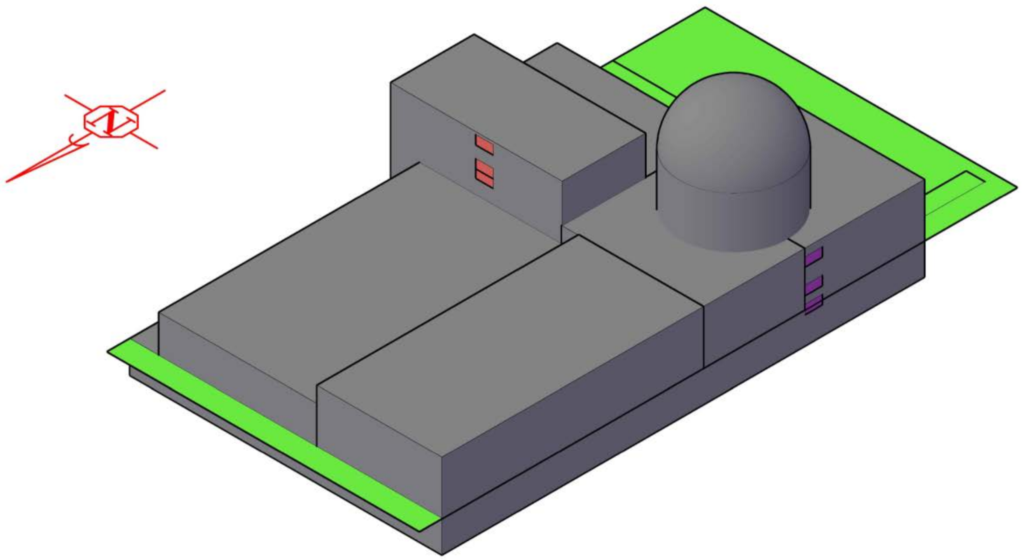


Figure 7. Plant B South Wall Targets

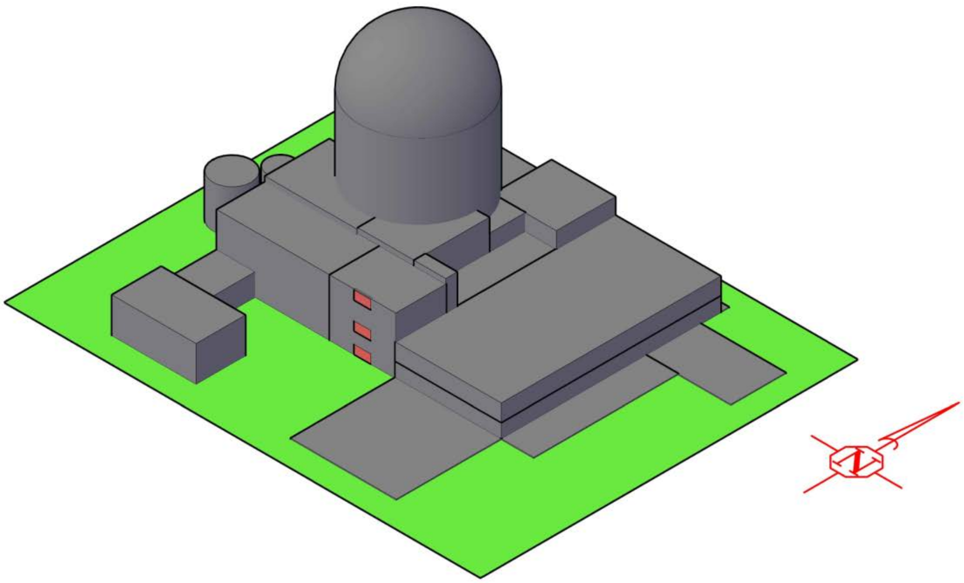


Figure 8. Plant B North and West Wall Targets

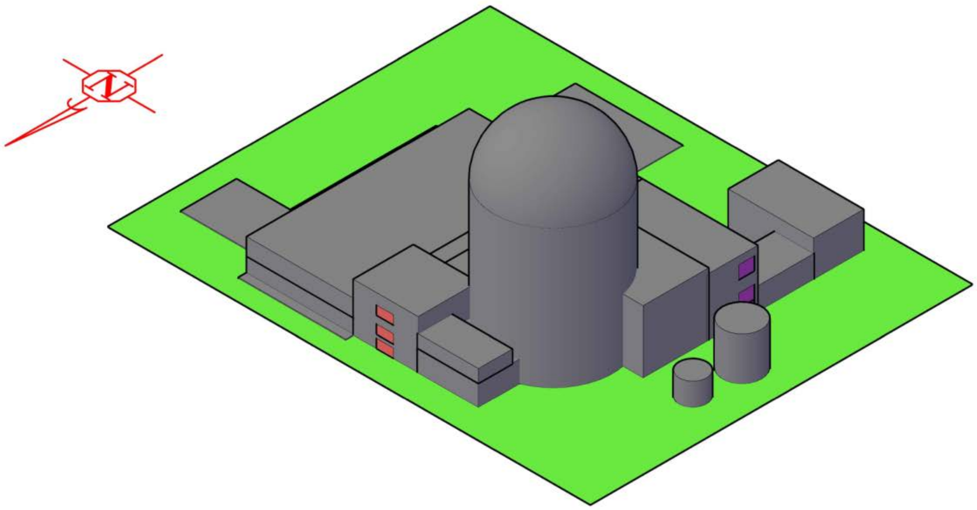


Figure 9. Plant A East Wall Hit Probability for all EFs

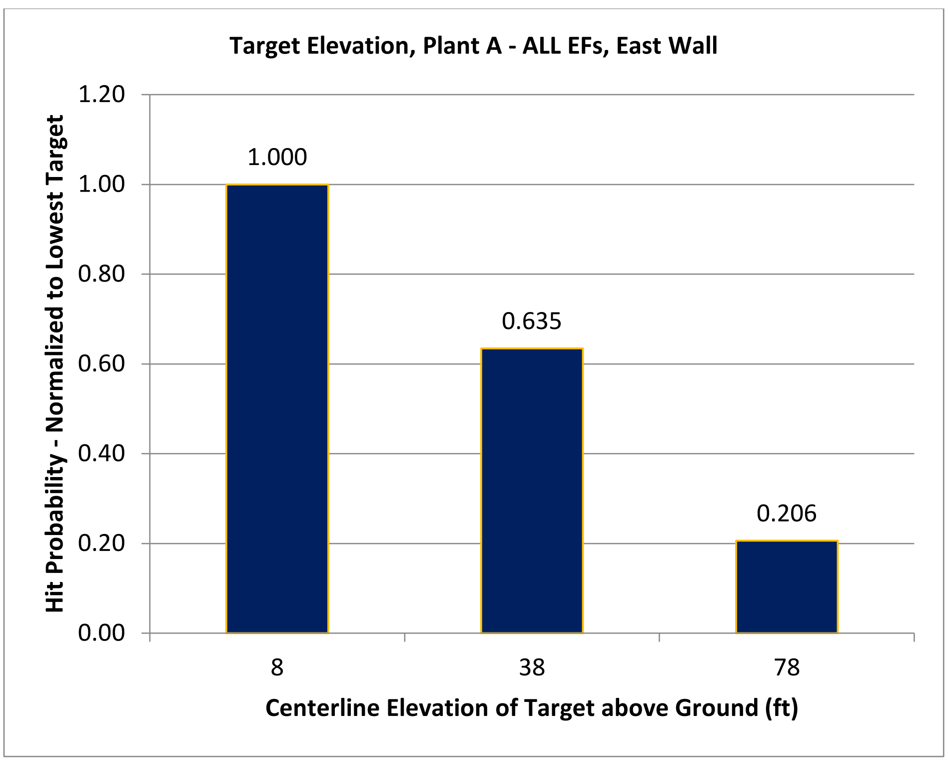


Figure 10. Plant A West Wall Hit Probability for all EFs

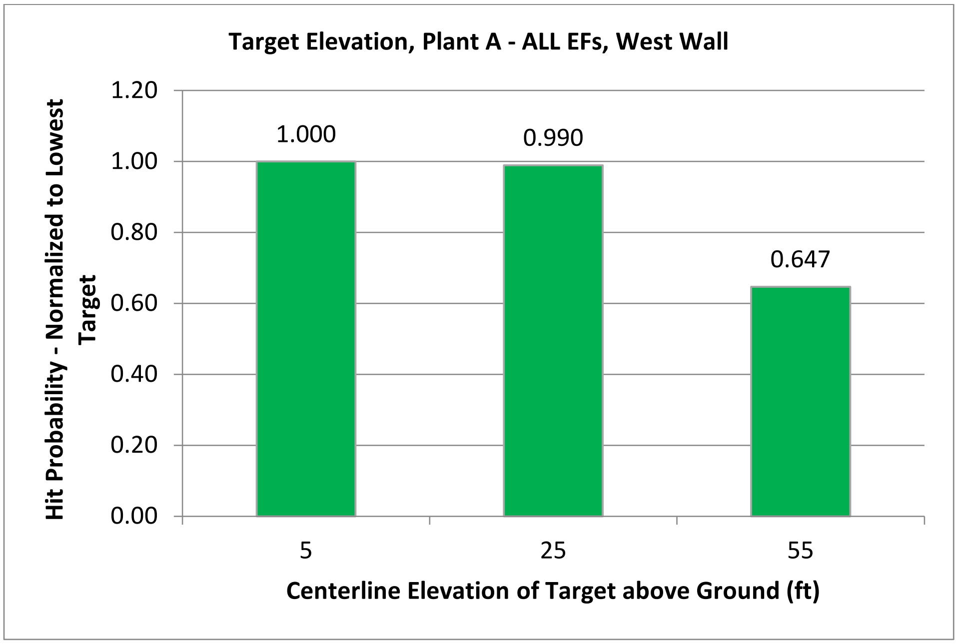


Figure 11. Plant A South Wall Hit Probability for all EFs

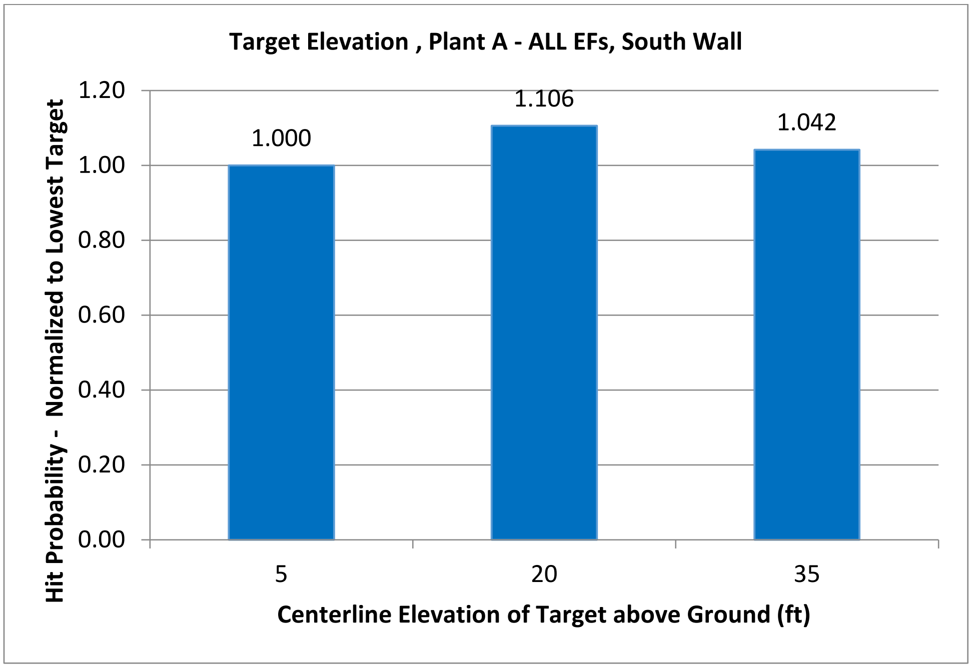


Figure 12. Plant A North Wall Hit Probability for all EFs

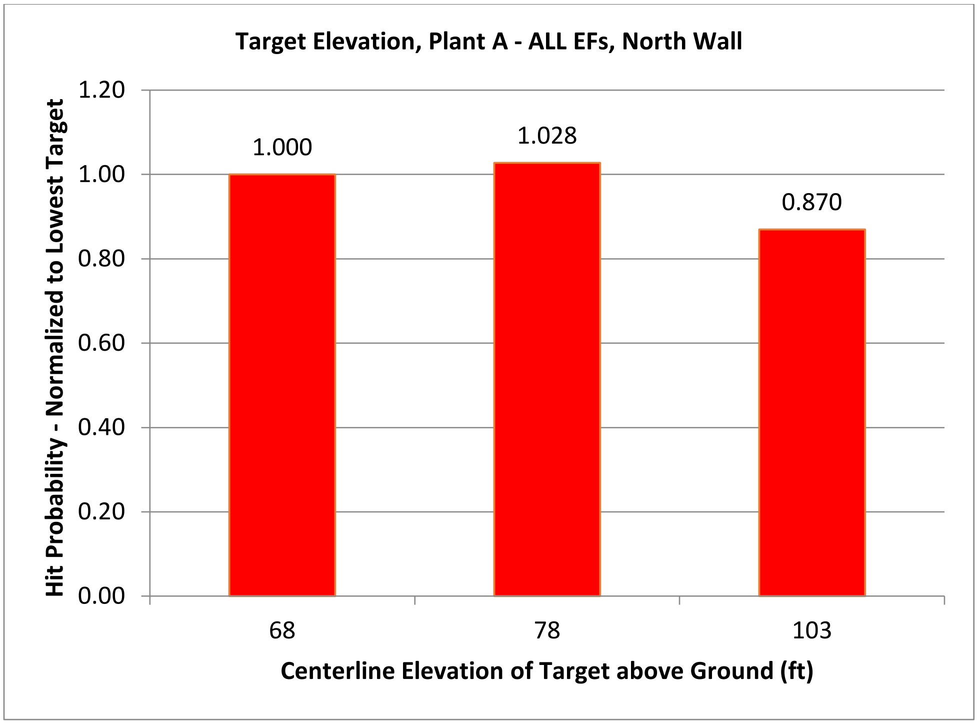


Figure 13. Plant B North Wall Hit Probability for all EFs

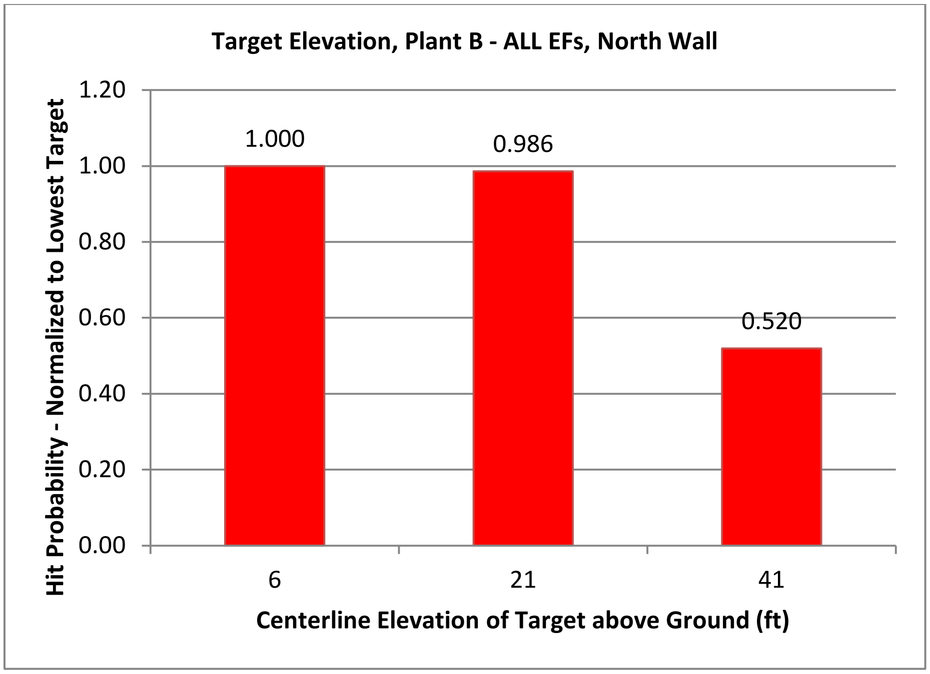


Figure 14. Plant B South Wall Hit Probability for all EFs

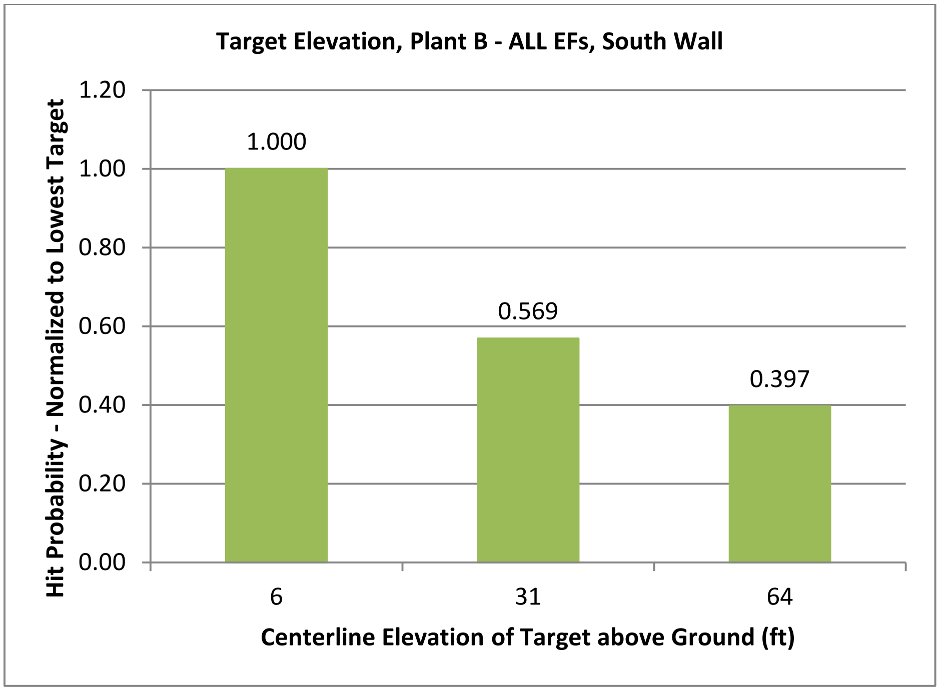
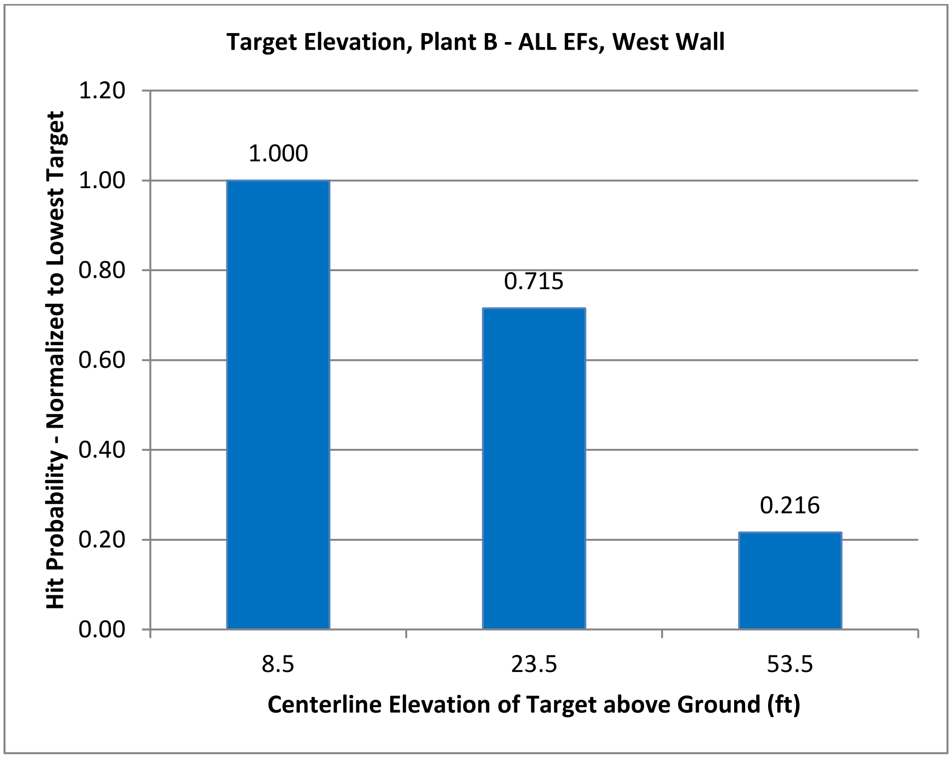


Figure 15. Plant B West Wall Hit Probability for all EFs



Target Size Study

The objective of this study is to examine the impact of target size on targets hit probabilities. In this study, both plants A and B models are used. Targets are created with varying widths and preserving target heights and elevations. Eight targets are created for each of the plant models. ,

Missile inventory in Tables E-2 and E-4 for plants A and B are used. All missiles are assumed to be free missiles (i.e. not restrained). The total number of simulations for this study for both plants is two hundred millions. South wall targets for plant A has a constant height of 20 ft. The width was varied to produce targets with 40, 100, 600, 2400 ft^2 respectively.

Targets on east wall for plant A has a constant height of 40 ft. The width was varied to produce targets with 60, 200, 2000, 4000 ft^2 respectively. Targets on North wall for plant B has a constant height of 40 ft. The width was varied to produce targets with 40, 120, 400, 2400 ft^2 respectively. Targets on west wall for plant B has a constant height of 30 ft. The width was varied to produce targets with the following areas 30, 90, 300, 1500 ft^2 respectively. Figures 16 and 17 show 3D view of targets for plant A. Figures 18 and 19 show 3D view of targets for plant B. Table 6 shows target sizes considered in this study. Results show that hit probability per unit area does not appreciably change with target size for targets with similar exposure, elevation, and height.

Table E-6. Target sizes and location for target elevation study

Plant A	Height (ft)	Area 1 (ft^2)	Area 2 (ft^2)	Area 3 (ft^2)	Area 4 (ft^2)
South Wall	20	40	100	600	2400
East Wall	40	60	200	2000	4000
Plant B					
North Wall	40	40	120	400	2400
West Wall	30	30	90	300	1500

Figure 16. Plant A Targets showing variations in size

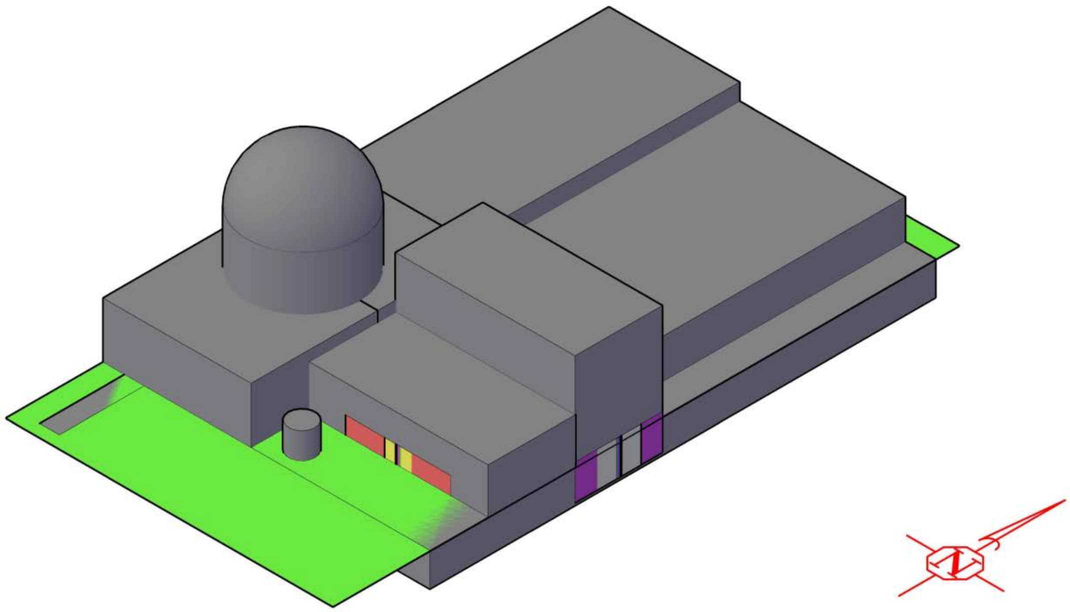


Figure 17. Close-up plant A targets showing variations in size

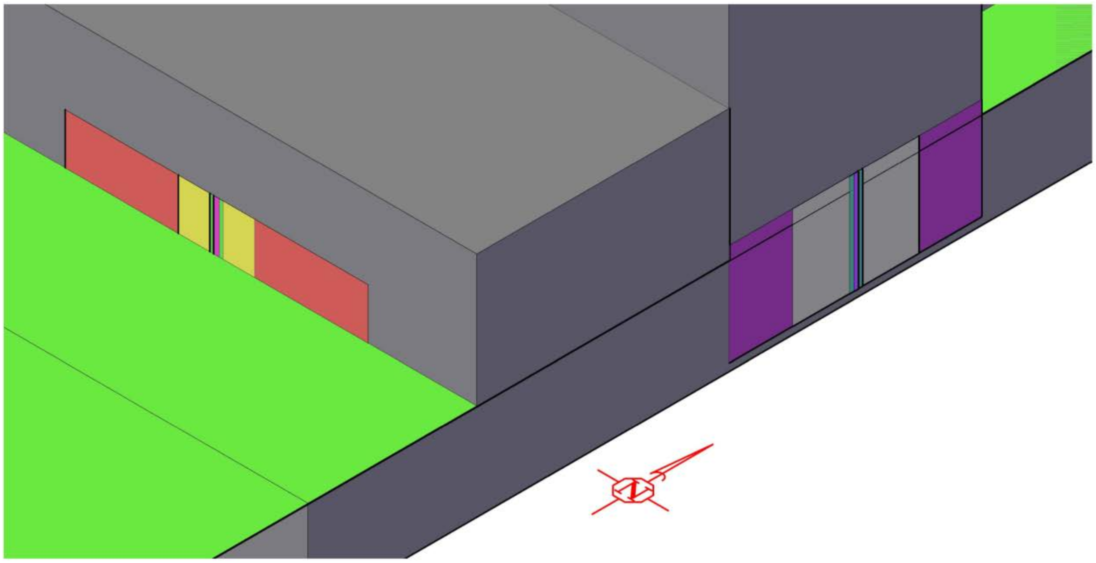


Figure 18. Plant B Targets showing variations in size

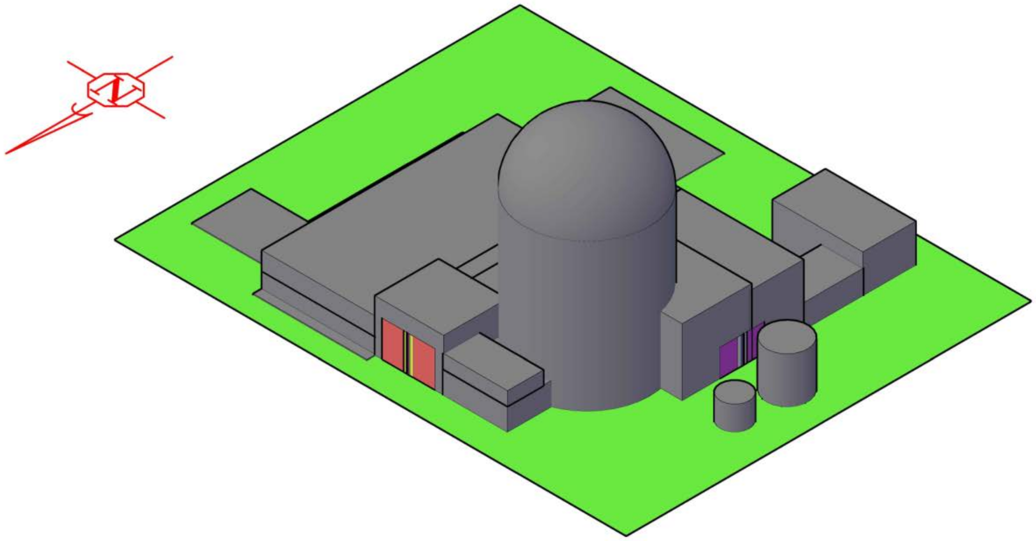


Figure 19. Close-up plant B targets showing variations in size

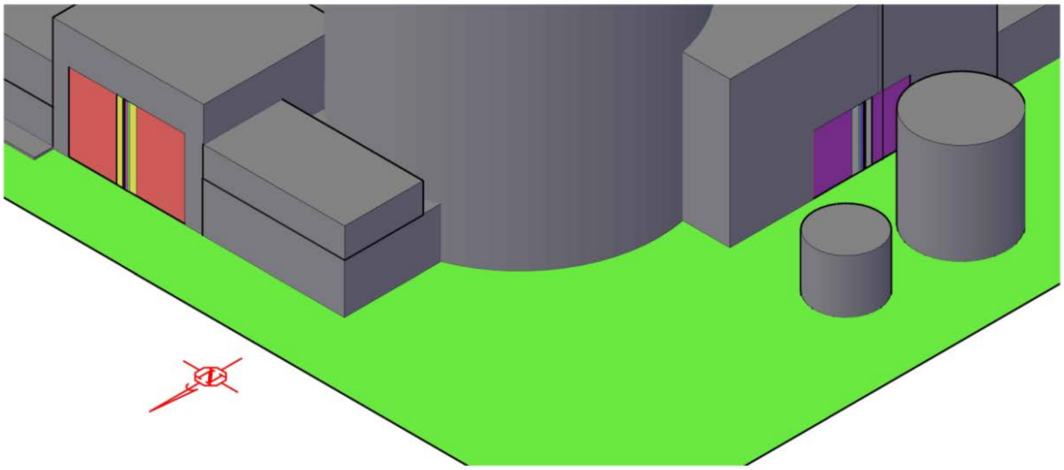


Figure 20. Normalized Plant A South Wall Hit Probability for all EFs

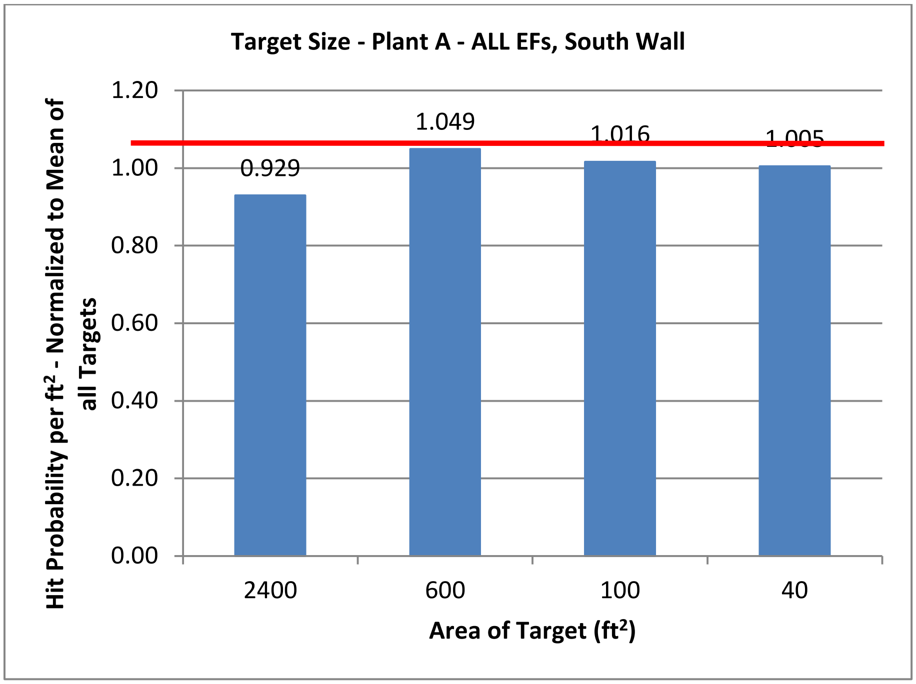


Figure 21. Normalized Plant A East Wall Hit Probability for all EFs

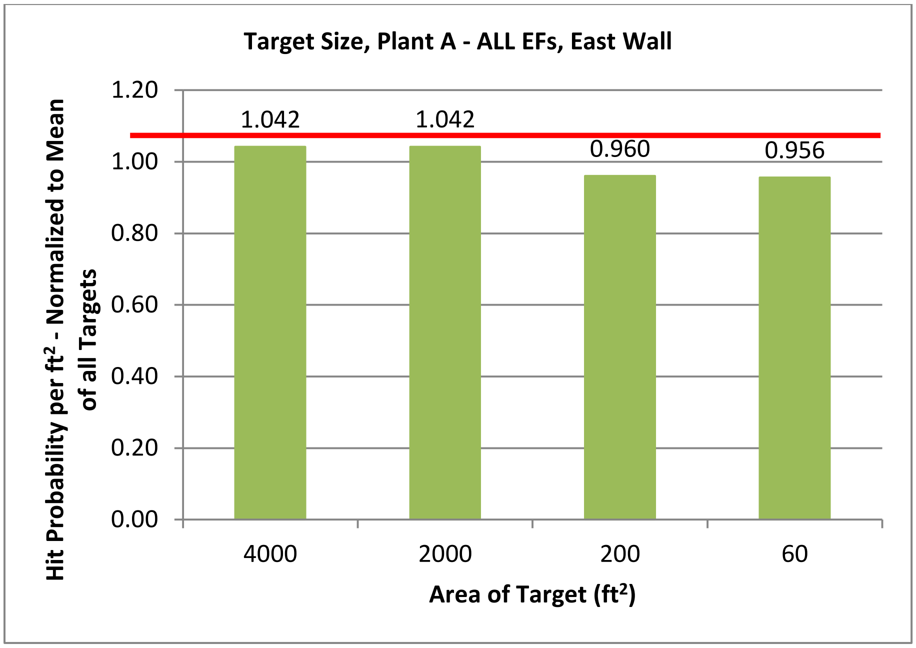


Figure 22. Normalized Plant B North Wall Hit Probability for all EFs

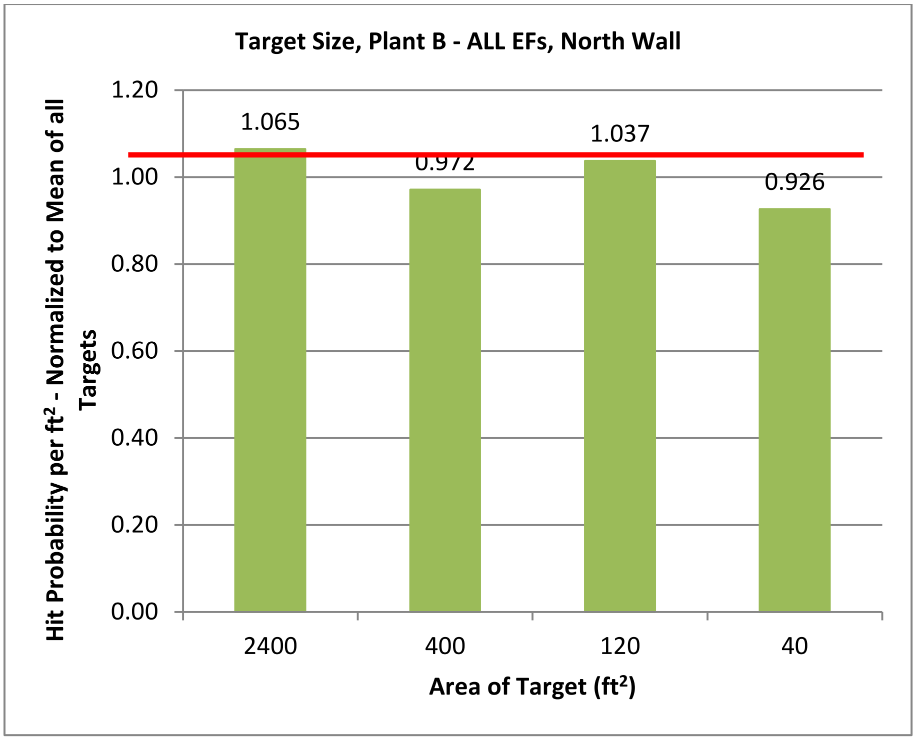
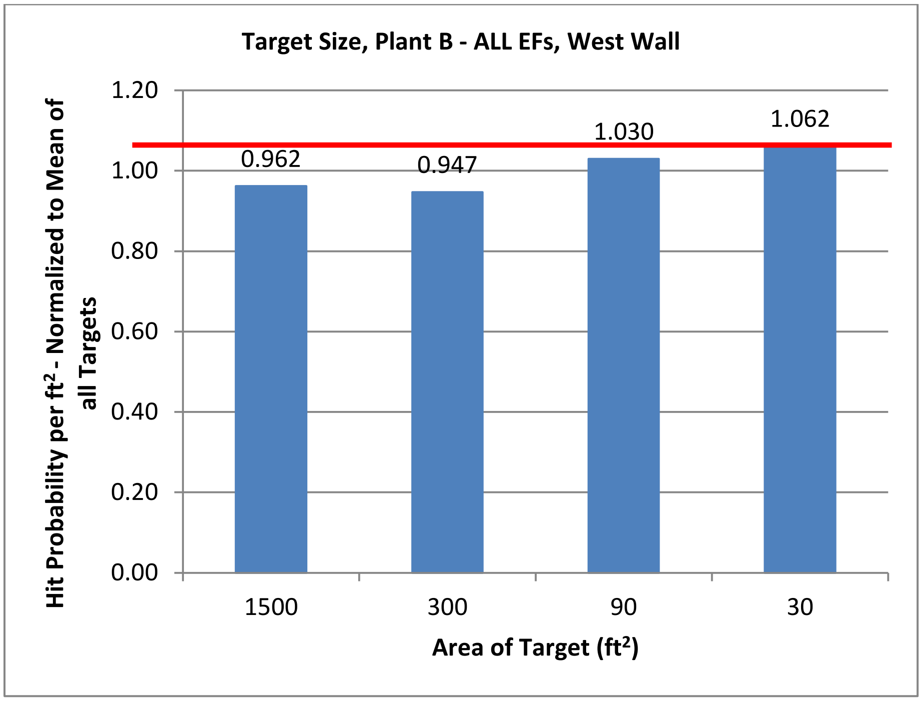


Figure 23. Normalized Plant B West Wall Hit Probability for all EFs



Missiles Distribution

The objective of this study is to examine target hit probabilities sensitivity to missile distribution. Two distribution schemes are examined zonal and uniform.

Uniform missile distribution, means that all zones have a constant missile density. On the other hand, for zonal missile distribution each zone has a different number of missiles and the missile density varies. For this study, no missile stratification is used since the use of stratification technique would negate the nature of uniform missile distribution. The zonal area of the plant A is 19,771,450 ft2 with a total of 100,327 missiles. The zonal area of the plant B is 31,360,000 ft2 with a total of 141,944 missiles. Missiles injected from top of buildings are excluded since uniform distribution of these missiles is unrealistic.

Zonal versus uniform missile and zones distribution for plants A and B are shown in Figures 24 and 25 respectively. Each zone has three designated numbers, the top number is the zone number, the middle number is the number of missiles in each zone (zonal distribution), and the bottom number is the number of missiles considering uniform distribution of missiles around the plant.

Results and conclusions of this study are discussed further in Appendix A.

Figure 24. Plant A zonal versus uniform missile distribution

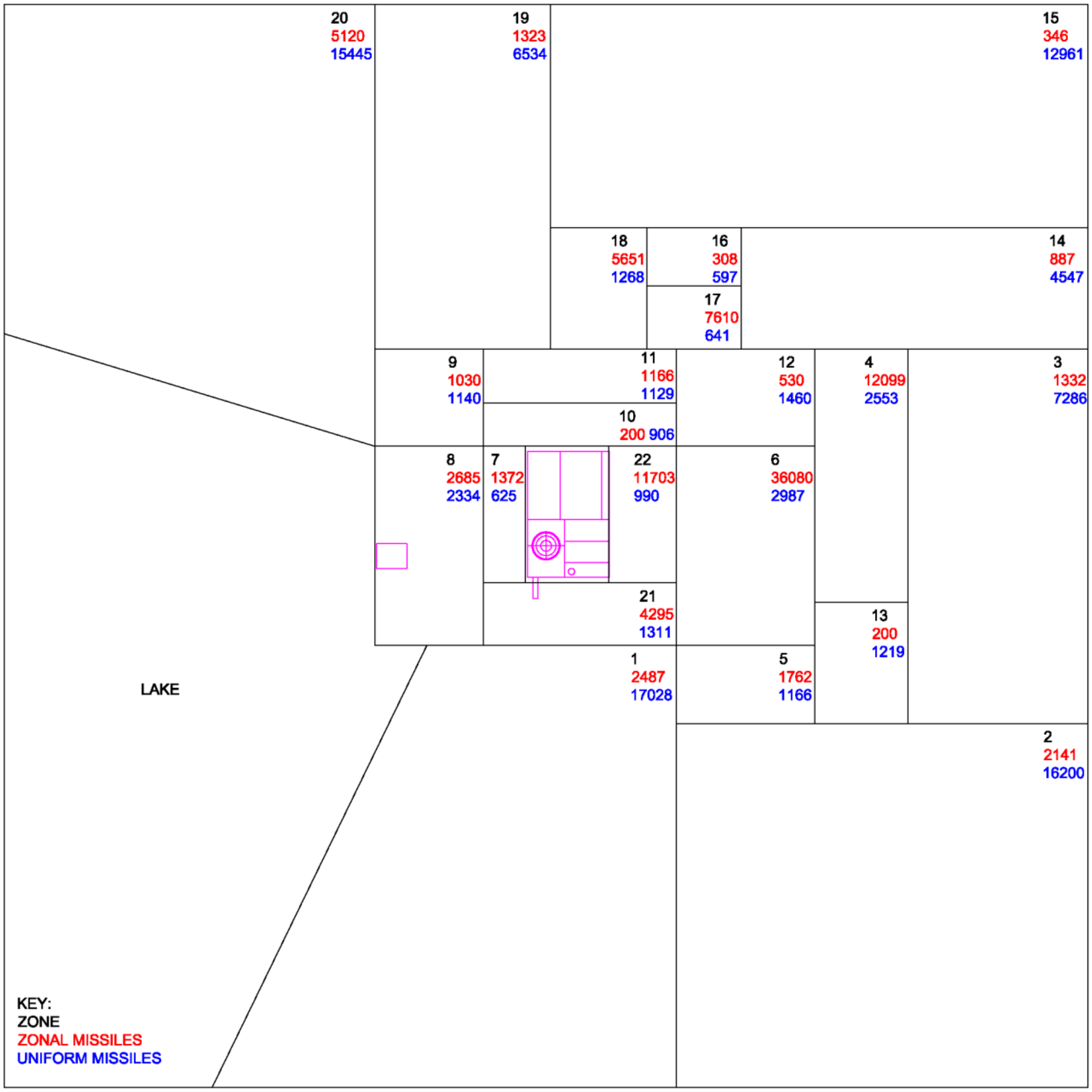
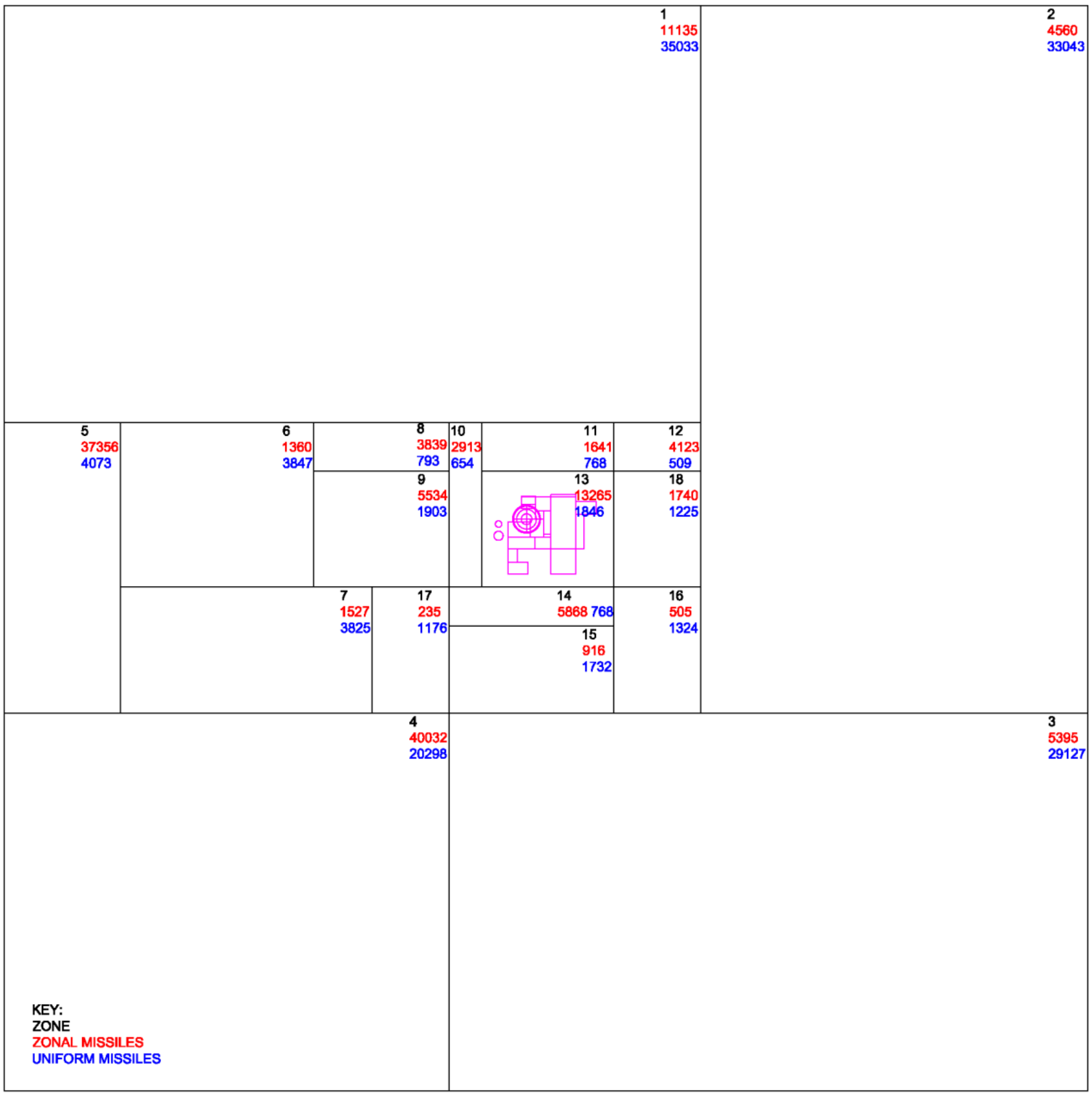


Figure 25. Plant B zonal versus uniform missile distribution



Serial: RA-18-0106

Shearon Harris Nuclear Power Plant, Unit 1
Docket No. 50-400 / Renewed License No. NPF-63

License Amendment Request to Incorporate Tornado Missile Risk Evaluator into Licensing Basis – Supplement and Request for Additional Information Response (EPID L-2017-LLA-0355)

Enclosure 3

Clean Copy of NEI 17-02, Rev. 1B

TORNADO MISSILE RISK EVALUATOR (TMRE) INDUSTRY GUIDANCE DOCUMENT

Prepared by the Nuclear Energy Institute
September 2018

Executive Summary

This Nuclear Energy Institute (NEI) guidance document establishes an acceptable risk-informed methodology for identifying and evaluating the safety significance associated with structures, systems and components (SSCs) that are exposed to potential tornado-generated missiles. The methodology, called the Tornado Missile Risk Evaluator (TMRE) was developed to provide NEI membership with a simple, cost-effective tool to address questions concerning vulnerability to tornado missiles. This document provides guidance on the identification of these vulnerabilities at a nuclear power plant site, the development and application of a TMRE model for the site, and a process for resolving discrepancies against licensing basis requirements. Overall the methodology provides a path forward to resolve low safety significant nonconforming conditions associated with tornado missile protection requirements of the licensing basis.

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Use and Applicability of this Guidance Document

The purpose of this document is to provide references, summations, examples and rationales in enough detail to enable the user to develop a TMRE model for their power plant with minimum effort and without the necessity for reliance on contractors or consultants. NEI estimates that the TMRE can be implemented and adopted with an expenditure of approximately 400-700 person-hours. Wherever possible, the TMRE methods and parameters have been simplified with the development of generic, bounding inputs that can be used by all plants. In some cases, plant-specific inputs must be used, and these are identified for the user with guidance on where/how to obtain the input. The use of this guideline, or the information it contains, is not mandatory.

Revision Table

Revision	Description of Changes	Date Modified	Responsible Person
0	Initial Issuance	June 2017	S. Vaughn
1	Editorial changes, fixed several errors in Appendices A, B and C, and removed Sections 2, 4, and 10 and Appendix F because they were considered not within scope of the TMRE methodology	September 2017	S. Vaughn
1A	Incorporated changes based on pilot LAR responses to requests for additional information, feedback from public meetings in 2017 and 2018, and other editorial and calculation corrections.	July 2018	S. Vaughn
1B	Incorporated changes based on staff feedback from Revision 1A review	September 2018	S. Vaughn

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1. INTRODUCTION

The Tornado Missile Risk Evaluator (TMRE) is designed to provide operators of commercial nuclear power plants a cost-effective method to conservatively assess the risks posed by tornado-generated missiles. The TMRE is a hybrid methodology comprised of two key elements: (1) a deterministic element to establish the likelihood that a specific structure, system, or component (SSC) (or "target") will be struck and damaged by tornado-generated missile; and (2) a probabilistic element to assess the impact of the missile damage on the core damage and large early release frequencies.

The output of the deterministic element is a calculated Exposed Equipment Failure Probability (EEFP) that is based largely on a simplified generic relationship between tornado strength and the population of materials at a typical nuclear power plant that may become airborne during a tornado. Site-specific inputs to the EEFP include the likelihood of a tornado striking the site and the size and location of the target SSC being evaluated.

The probabilistic element uses the existing plant-specific peer-reviewed internal events probabilistic risk assessment (PRA) model to evaluate the impact of the loss of a target SSC. The risk assessment methods and acceptance criteria of the Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.174 are used to determine whether risks posed by potential tornado missiles at a site warrant protective measures.

Use of the TMRE is a new methodology as defined in Title 10 of the Code of Federal Regulations (10 CFR) 50.59, requiring NRC review and approval. This guidance document describes how to develop and apply the TMRE and how to adopt the TMRE in the plant-specific licensing basis.

1.1 BACKGROUND

The need for the TMRE originated with NRC's issuance of Regulatory Issue Summary (RIS) 2015-06, which reminded licensees of the need to comply with the plant-specific licensing basis for protection against tornado missiles. The RIS cited several examples where NRC issued violations for licensees failing to provide protection for SSCs that were exposed to potential tornado missiles. Examples of exposed SSCs included safety-related vent pipes for emergency diesel generator exhausts, diesel fuel oil storage tanks, and exhaust pipes for auxiliary feedwater and reactor core isolation cooling systems. The NRC typically cited 10 CFR 50, Appendix A, General Design Criterion 2, along with general statements in the station Updated Final Safety Analysis Report (UFSAR) regarding protection against the effects of tornadoes, as the basis for the violation.

The problem posed by RIS 2015-06 for many licensees is that in many cases, the licensing basis is stated in general terms without sufficient detail to provide clarity and predictability on how protection from tornado missiles was deemed adequate by NRC during the plant licensing phase. This allows questions to be raised whether safety-related components that are exposed to the elements met NRC regulatory requirements. This situation is exacerbated by the fact that NRC requirements for tornado missile protection evolved substantially over the years, and the level of detail in which the issue was described in plant UFSARs grew from almost no description at all to detailed descriptions of tornado missile characteristics and the design standards adopted for protection from them.

NRC explored the safety significance of the variations in protection from tornado missiles during the Systematic Evaluation Program (SEP) in the 1980s. Specifically, the NRC evaluated selected plants that were licensed prior to the issuance of the NRC Standard Review Plan (SRP) to determine whether plants of this vintage should be required to take additional measures to upgrade their level of protection. The conclusion reached by the SEP was that tornado missiles did not pose a significant risk to public health and safety to warrant generic regulatory action.

With the advent of Fukushima, additional interest was focused on protection from external events of all types. New methods to assess the risks of beyond design basis seismic, flooding, and high wind events were developed and updated.

The requirements for protection against external events described in the licensing basis are deterministic and must be met to maintain safety margins and defense-in-depth. On the other hand, the NRC recognizes the merits of alternative methodologies to determine the need for physical protection from tornado missiles, such as TORMIS, developed by EPRI during the 1980s and approved for use at several plants. Subsequent to the issuance of RIS 2015-06, NRC expressed willingness to consider risk-informed approaches to address this issue.

1.2 Purpose

The purpose of the TMRE is to present NRC with a RG 1.174 risk-informed option to assess the risk posed by tornado missiles at any site to determine whether additional physical protection is warranted. Because it is risk-informed, the TMRE can be applied regardless of the vintage of the plant or the content of the plant's licensing basis.

The impetus and foundation for the TMRE is the NRC-approved methodology developed for use at Calvert Cliffs in 1995. The Calvert Cliffs approach used a simplified method to calculate the likelihood that a SSC would be rendered unavailable by a missile strike during the passage of a tornado and then used the plant internal events PRA to evaluate a core damage frequency contribution from the event. This was then related to a threshold for exceeding 10 CFR Part 100 doses offsite.

1.3 Overview and Comments

This guidance document is a compilation of the structure of the TMRE methodology (Section 2), and a step-by-step explanation of how to develop and deploy the TMRE at a site (Sections 3 through 8). Several appendices are provided to amplify elements of the guidance where warranted.

1.4 Abbreviations

AOV – air operated valve
BE – basic event
CAP – corrective action program
CDF – core damage frequency
CLB – current licensing basis
DB – design basis
EEFP - exposed equipment failure probability
EGM – enforcement guidance memorandum
EPRI – Electric Power Research Institute
FSAR – final safety analysis report
HEP – human error probability
HW – high winds

HWEL – high winds equipment list
IA – instrument air
LAR – license amendment request
LERF – large early release frequency
LOOP – loss of off-site power
LOS – line of sight
MCC – motor control center
MFW – main feed water
MIP – missile impact parameter
MOV – motor operated valve
NEI – Nuclear Energy Institute
NPP – nuclear power plant
NRC – Nuclear Regulatory Commission
NUREG - U.S. Nuclear Regulatory Commission technical report designation
PRA – probabilistic risk assessment
PSAR – preliminary safety analysis report
RG – regulatory guide
RIS – regulatory issue summary
RWST – reactor water storage tank
SEP – safety evaluation program
SSC – system, structure, component
SSEL – safe shutdown equipment list
SR – supporting requirement
SW – service water
TMRE – tornado missile risk evaluator
UFSAR – updated final safety analysis report

1.5 DEFINITIONS

Correlation - The relationship between two or more SSCs that infers that by nature of their proximity to each other they could be damaged by a single tornado missile.

Exposed Equipment Failure Probability (EEFP) - The conditional probability that an exposed SSC is hit and failed by a tornado missile, given a tornado of a certain magnitude.

High Winds Equipment List (HWEL) - List of potential vulnerabilities, vulnerabilities, and nonconforming SSCs identified during the walkdown that can be evaluated using the TMRE to determine the risk of leaving them unprotected.

Missile Impact Parameter (MIP) - The probability of a tornado missile hit on a target, per target unit surface area, per missile, per tornado.

Reference Elevation - The elevation used to determine the 30 foot demarcation for elevated targets.

TMRE PRA - An adaption of the plant internal events PRA suitable for use in the TMRE.

TMRE Walkdown - A plant walkdown focused on collecting physical information to characterize exposed SSCs and the plant missile population for use in developing the TMRE model for the plant.

Vertical Missile - Any missile that has a non-horizontal velocity component.

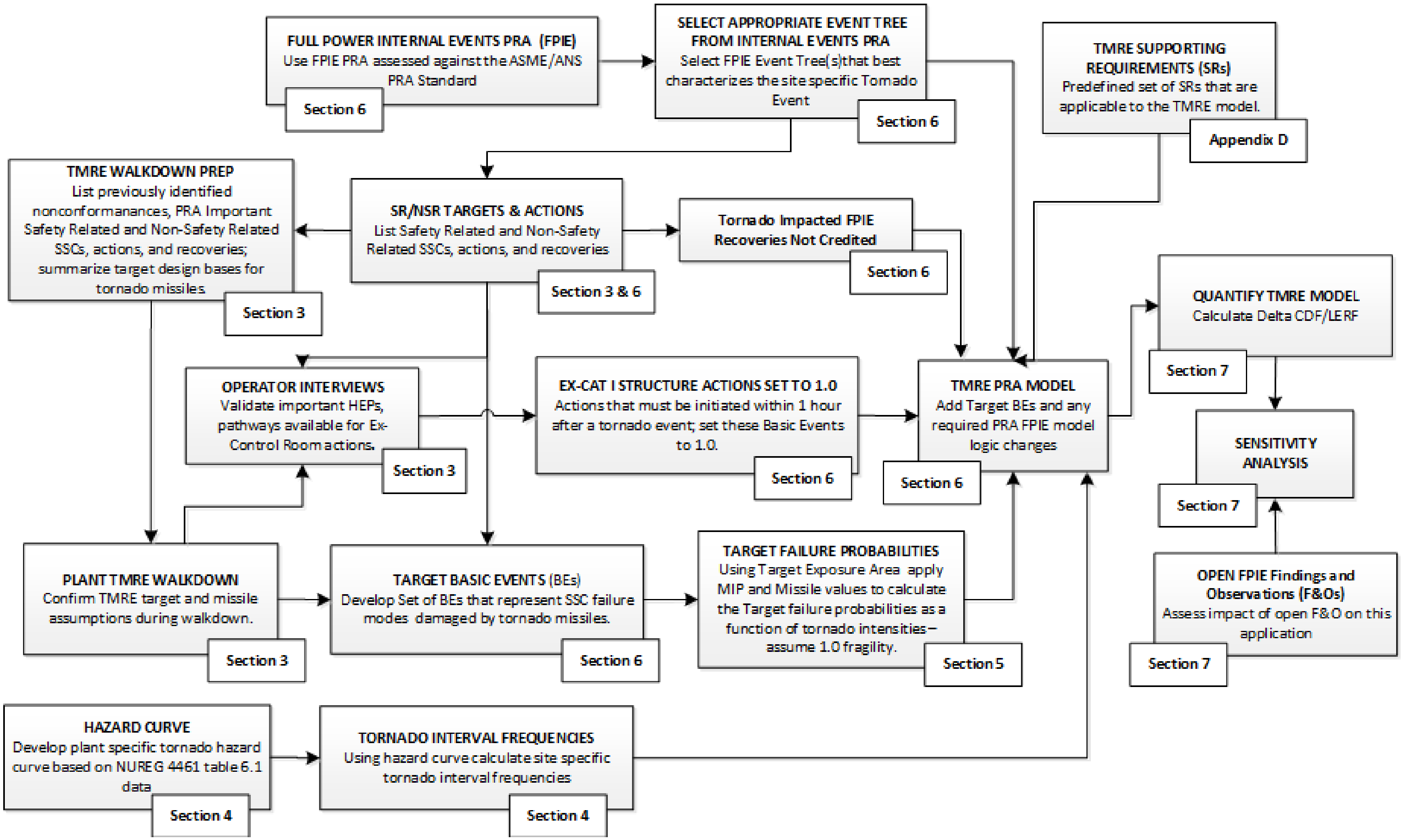
2 OVERVIEW OF TORNADO MISSILE RISK EVALUATOR METHODOLOGY

The Tornado Missile Risk Evaluator (TMRE) will be used to estimate the quantitative risk associated with tornado-generated missiles at U.S. nuclear power plants (NPP). It makes use of the licensee's internal events Probabilistic Risk Assessment (PRA) model, which is modified to reflect the anticipated effects of the passage of a tornado over the site. The TMRE involves three major steps:

- Site walkdowns are performed to gather relevant information regarding the SSCs that are not protected against tornado-generated missiles and missile characteristics.
- Failure probabilities for exposed SSCs important to safe shutdown are calculated using the Exposed Equipment Failure Probability (EEFP). This calculation takes into account the number of missiles that are damaging to the SSC, the exposed area of the SSC, and the Missile Impact Parameter (MIP), a parameter that relates the likelihood of a missile striking a target, based on the tornado intensity. If a damaging missile strikes an exposed SSC, it is assumed to fail.
- The increases in core damage frequency (ΔCDF) and large early release frequency (ΔLERF) are calculated using the "TMRE PRA" and compared to acceptance criteria in RG 1.174 [Ref. 2.4].

Figure 2-1 provides an overview of the process, which is described in detail in Sections 3 through 7.

Figure 2-1: TMRE Flowchart



2.1 PERFORM TMRE WALKDOWN

The TMRE Walkdown is used to gather physical data associated with vulnerable and nonconforming SSCs, and to identify any other SSCs that are modeled in the PRA but are not protected from tornado winds or missiles. Additionally, the walkdown is used to validate the missile inventories, used in the EEFP calculations, as bounding for the site. The TMRE walkdown process includes pre-walkdown activities, a "Vulnerable SSC Walkdown," and a "Missile Walkdown."

2.1.1 PRE-WALKDOWN ACTIVITIES

Prior to sending personnel out on a walkdown, several activities are recommended to ensure that a complete walkdown is performed in an efficient manner. Preparations are needed primarily for the walkdown activities associated with identifying and characterizing vulnerable SSCs; less effort is needed to prepare for the missile count verification part of the walkdown.

The Vulnerable SSC Walkdown includes reviewing any previously identified potential vulnerabilities and nonconforming SSCs, to collect any data needed for the TMRE model. The Vulnerable SSC Walkdown will also search for and evaluate any SSCs credited in the TMRE PRA model that are not protected from tornado winds or missiles. Although these SSCs may not be required to be protected by the plant's licensing basis, their ability to function during a tornado event needs to be evaluated to ensure they are properly modeled in the TMRE PRA.

This guideline recommends the development of an HWEL, which provides the walkdown team with a list of SSCs to review during the walkdown. The initial HWEL will contain the list of previously identified potential vulnerable and nonconforming SSCs and a list of potentially unprotected PRA SSCs. During the TMRE walkdown, additional SSCs may be identified that will be added to the HWEL (e.g., PRA SSCs that were initially considered to be protected, but evidence from the walkdown indicated otherwise).

The HWEL development is detailed in Section 3, which is based primarily on the EPRI HW Walkdown Guidance (EPRI 3002008092, "Process for High Winds Walkdown and Vulnerability Assessments at Nuclear Power Plants" [Ref. 2.1]). It includes identifying potentially unprotected SSCs in the PRA and determining their location. This is done prior to walkdowns using plant documentation.

2.1.2 VULNERABLE SSC WALKDOWN

The Vulnerable SSC Walkdown is performed to gather information on HWEL SSCs that are exposed to tornado missiles. The walkdown will determine which SSCs are vulnerable to tornado missiles and will be used to collect data, such as the exposed SSC "target" location, elevation, surface area, and construction details, and the type and location of any local structures that may provide a shielding effect. The data collected is needed for the TMRE model, specifically to determine the EEFP. It can also aid in development of modeling approaches for specific configurations, such as when SSCs are physically correlated. The EEFP is used to calculate the probabilities for SSC failure that are used in the TMRE PRA model; the EEFP is briefly discussed in Section 2.4, and described in detail in Section 5.

2.1.3 MISSILE WALKDOWN

The second major goal of the TMRE Walkdown is to perform a missile count. Objects within approximately 2500 feet of a common reference point (e.g., the center of containment) that can become airborne during a tornado event at the site are identified and counted. Twenty-three different missiles types are identified, each with a different capability to damage an exposed SSC. In addition to loose objects outside of structures (e.g., construction material), missiles can also be created by structures (e.g., warehouses, Butler buildings) and their contents, when those structures are not capable of withstanding tornado wind pressure effects and disassemble during a tornado. This walkdown is typically separate from the Vulnerable SSC Walkdown. Section 3.4 provides details on how the missile counts are performed.

2.2 DETERMINE SITE TORNADO HAZARD FREQUENCY

The initiating events for the TMRE PRA model are tornadoes at the site. Each licensee should develop site-specific tornado frequencies for applicable tornadoes. The tornadoes of interest are those tornadoes with a wind speed of approximately 100 mph or greater. For the purposes of the TMRE, the F'-scale (Fujita prime) will be used to classify tornadoes; this scale is somewhat different from the original Fujita Scale (F-Scale) and the Enhanced Fujita Scale (EF-Scale). The differences between these scales and the rationale for choosing the F'-scale are discussed further in Sections 4 and 5.

NUREG/CR-4461, Revision 2 [Ref. 2.2] is the recommended source of tornado data for developing the site-specific tornado frequencies to be used in the TMRE PRA. Each U.S. NPP site is provided with tornado wind speeds associated with 10^{-5}, 10^{-6}, and 10^{-7} probabilities per year of a tornado missile strike. Additionally, the total tornado strike frequency (i.e., the frequency of any tornado with wind speed greater than 65 mph) is provided for all locations in the continental United States. Using this data, a site-specific tornado frequency curve (hazard curve) can be developed, and the frequency of all tornadoes considered in the TMRE (F'2 through F'6) can be calculated. Details on the process of determining tornado frequencies for use in the TMRE are provided in Section 4.

2.3 EVALUATE TARGET AND MISSILE CHARACTERISTICS

Failures of SSCs that can be struck and damaged by a tornado missile will be added as new basic events to the TMRE PRA model. Tornado missile failures do not need to be considered for SSCs protected by 18" reinforced concrete walls, 12" reinforced concrete roofs, and/or 1" steel plate. The failure probability of these SSCs is calculated using the Exposed Equipment Failure Probability (EEFP). The EEFP is the conditional probability that an exposed SSC is hit and failed by a tornado missile, given a tornado of a certain magnitude. A single SSC will have five EEFP values calculated, one for each tornado category, F'2 through F'6.

The EEFP is defined as:

$$EEFP = (MIP)\ x\ (\#\ of\ Missiles)\ x\ (Target\ Exposed\ Area)\ x\ Fragility$$

Where:

The *Missile Impact Parameter (MIP)* is the probability of a damaging tornado missile hit on a target, per target unit surface area, per missile, per tornado. Generic MIP values are provided as part of the

TMRE methodology and are described in more detail in Section 5.1 and Appendix B. The MIP varies by the tornado category (i.e., F'2 through F'6) and the elevation of the target.

# of Missiles is the number of damaging missiles within approximately 2500 feet of a common reference point, such as the center of containment. Generic values for the total number of missiles are provided as part of the TMRE methodology and will be verified as bounding through the TMRE walkdown activity. More robust targets (e.g., steel pipes and tanks) will not use the entire missile inventory that can damage less robust SSCs (e.g., electrical panels, instrumentation), since only certain types of missiles can damage robust targets. Robust targets are subdivided into categories based on their characteristics (basically the thickness of the SSC's steel or concrete). Depending on the target's category of robustness, a certain fraction of the total missile inventory will be used in the EEFP calculations for that target. Missile inventories also vary by F'-scale, which takes into account the number of missiles produced by building deconstruction for each tornado category. The missile inventories to use for each type of target and each F'-scale tornado are described in Section 5.2. Further details are provided in Appendices B and C.

Target Exposed Area is determined for each SSC, based on plant documentation and information collected during the Vulnerable SSC Walkdown. More information on target areas is provided in Section 5.

Fragility is the conditional probability of the SSC failing to perform its function given that it is hit by a damaging tornado missile. For the purposes of the TMRE, it is assumed to be 1.0 (i.e., always failed if hit by a damaging tornado missile).

Plant-specific data used as input to the EEFP calculations (e.g., size of the SSC and its elevation) will be based on plant documents and drawings, plus information gathered during the TMRE Walkdowns. Details and examples of SSC exposed area calculations and EEFP calculations are provided in Section 5. Target Exposed Area is a direct input to the EEFP calculation and can typically be determined using drawings and other plant documents. Additional measurements may be made during the walkdowns. Shielding near or around an SSC may have the effect of reducing the amount of the target area actually exposed to missiles.

Target elevation affects the MIP value used in the EEFP for a given SSC. For targets that are less than or equal to 30 feet above the reference elevation, the 'Near Ground' MIP value is used. Targets greater than 30 feet above the reference elevation are considered 'Elevated' targets and may use the Elevated MIP values. Elevated MIP values are less than the Near Ground MIP values. The basis for the MIP values and the dependence on elevation are described in detail in Appendix B. The reference elevation and justification for choosing the value shall be documented. The target elevation can be determined from plant documents, but should also be confirmed by walkdown.

2.4 DEVELOP TMRE PRA MODEL

The plant's at-power internal events PRA model of record is typically used as the basis for the TMRE model. Since F'2 tornadoes (i.e., tornadoes with wind speeds greater than or equal to 103 mph) are very likely to result in a Loss of Offsite Power (LOOP) to the plant, the LOOP event tree is typically chosen as the portion of the internal events PRA used for the TMRE PRA. This is similar to how at-power High Winds (HW) PRA models are developed. The analyst must ensure that the correct event tree(s) is chosen for the TMRE PRA, based on knowledge of the site-specific PRA model. The details for the PRA model changes needed to develop the TMRE PRA are provided in Section 6.

As described in Section 2.3, tornado events are used as initiating events in the TMRE PRA model. Each tornado from F’2 to F’6 will be represented as an initiating event, having a specific frequency. This is necessary, because the MIP values (and hence the EEFPs) are based on the tornado category. Since the missile strike failures are conditional on the tornado category, the tornado initiating event category must match the EEFP for that category, for each SSC.

Two PRA model cases are developed for the TMRE, the Compliant Case and the Degraded Case. Both of the cases are based on the same LOOP event tree, with certain typical modifications. For example:

- No offsite power recovery is credited in either the Compliant Case or the Degraded Case models.
- Operator actions that require transit or action outside Seismic Category I structures within the first hour of the event are assumed to fail (i.e., failure probability set to 1.0).
- Basic events are added for certain SSCs that are not protected against tornado missiles and/or winds (these are in addition to those nonconforming SSCs).

The main difference between the two models/cases is as follows:

- The Compliant Case represents the plant as if it met the current licensing basis with respect to tornado missile protection. Therefore, any nonconforming SSCs would be assumed protected against tornado missiles, and thus would not have additional tornado missile-induced failure modes in the Compliant Case.
- The Degraded Case represents the plant as it currently exists (the as-built, as-operated plant). Therefore, each of the nonconforming SSCs will need to have additional basic events added to represent the failure likelihood of the SSC due to tornado missiles. The basic events values are from the EEFP calculations, described in Section 2.4.

The specific changes to the PRA models and the differences between the Compliant Case and Degraded Case are provided in Section 6.

As part of the TMRE PRA model development, certain PRA Standard [Ref. 2.3] Supporting Requirements (SR) will need to be addressed, specifically for the TMRE PRA. These SRs are provided in tables in Section 6.

2.5 Quantify Risk, Perform Sensitivity Analyses, and Compare to Thresholds

The TMRE results are based on quantifying the Compliant and Degraded Case PRA models for CDF and LERF. The risk increase (ΔCDF and ΔLERF) is determined by subtracting the Compliant Case value from the Degraded Case value. ΔCDF and ΔLERF are compared to the acceptance criteria of RG 1.174 [Ref. 2.4].

If ΔCDF or ΔLERF are close to or exceed the thresholds of RG 1.174, refinements to the Compliant and/or Degraded Case PRAs may be appropriate. An example may be to refine the EEFP for certain SSCs by accounting for partial shielding of SSCs.

Quantification continues until the risk thresholds are met or no additional PRA/TMRE work can be done to provide an effective reduction in ΔCDF and/or ΔLERF. If further reductions to ΔCDF and ΔLERF are not possible, the licensee will need to decide whether physical modifications should be made and to which SSCs. The preliminary TMRE results may be used to guide the modification effort.

Sensitivity studies may be needed to determine the impact of certain TMRE or site-specific PRA model assumptions. TMRE-related sensitivity studies are recommended in Section 7. Key assumptions and open issues associated with the internal events PRA and applicable to the TMRE application may require sensitivity studies. This will be a plant-specific issue, based on the status of the underlying internal events PRA (e.g., open peer review findings).

2.6 Performance Monitoring

Application of TMRE does not provide a basis for modifications to remove existing tornado missile protection or to omit protection for new configurations that otherwise require tornado missile protection according to the plant licensing basis. Design Control programs that meet 10 CFR 50 Appendix B will ensure that subsequent configuration changes are evaluated for their impact on the TMRE risk basis for accepting the identified nonconforming conditions. The TMRE risk basis must continue to be met (i.e. "very small" risk change per RG 1.174.)

2.7 References

2.1 EPRI 3002008092, *Process for High Winds Walkdown and Vulnerability Assessments at Nuclear Power Plants*

2.2 NUREG/CR-4461, *Tornado Climatology of the Contiguous United States,* Rev. 2, US Nuclear Regulatory Commission, February 2007.

2.3 American Society of Mechanical Engineers/American Nuclear Society, *Standard for Level 1 / Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications,* ASME/ANS RA-Sb-2009, 2013.

2.4 U.S. Nuclear Regulatory Commission, *An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant Specific Changes To the Licensing Basis,* Regulatory Guide 1.174, Revision 3, January 2018.

3 PERFORM PLANT TMRE WALKDOWN

The TMRE Walkdown is performed after the list of nonconforming SSCs has been identified. The purpose of the TMRE Walkdown is to gather physical data associated with the nonconforming SSCs and any other SSCs that are modeled in the PRA but are not protected from tornado winds or missiles, and to validate the number of missiles to use in EEFP calculations. A significant portion of the walkdown task is performed prior to going out in the field for the actual walkdown; the preparation for the walkdown, which includes the development of a HWEL, is also described in this section.

TMRE Walkdown is broken into two phases: the Vulnerable SSC Walkdown and the Tornado Missile Walkdown. These two phases can be performed in parallel and generally do not affect each other. As such, separate personnel can be assigned to the two teams and they can proceed more or less independently. Additionally, the Tornado Missile Walkdown team does not require the same experience level as the Vulnerable SSC Walkdown. Sections 3.1 through 3.2 describe the preparations and walkdown for vulnerable SSCs. Section 3.3 describes the walkdown activities performed to help determine ex-control room operator action feasibility, which is typically performed as part of the Vulnerable SSC walkdown. Section 3.4 describes the Tornado Missile Walkdown preparation and execution.

Much of the information provided in this section can also be found in EPRI 3002008092, *Process for High Winds Walkdown and Vulnerability Assessments at Nuclear Power Plants* [Ref. 3.1].

3.1 VULNERABLE SSC WALKDOWN PREPARATION

Prior to sending personnel out on a walkdown, several activities are recommended to ensure that the walkdown is performed completely and in an efficient manner. The Vulnerable SSC Walkdown will review previously identified nonconforming SSCs to collect and verify any data needed for the TMRE model. The Vulnerable SSC Walkdown will also be used to locate and evaluate unprotected SSCs that are credited in the TMRE PRA model. Although all SSCs may not be required to be protected by the plant's licensing basis, SSCs that are credited in the TMRE PRA must be evaluated to ensure that they can function during a tornado event.

Development of a HWEL is recommended; the HWEL will provide the walkdown team with an initial list of SSCs to review during the walkdown. The HWEL is generally developed by PRA analysts familiar with the internal events PRA model, with support from design personnel. The initial HWEL should contain the list of vulnerable SSCs to include previously identified nonconforming SSCs and those that are not explicitly modeled in the PRA. It will also include a list of potentially unprotected SSCs that are in the TMRE PRA. Additional TMRE PRA SSCs may be identified during the walkdown that that will need to be added to the HWEL. For example, some SSCs may initially be thought to be protected, but determined to be unprotected during the walkdown. The final HWEL will be based on the work done prior to the walkdown and any additional information (e.g., other unprotected SSCs) collected during the walkdown.

An example HWEL is shown in Table 3-1. It includes the following information:

- **Equipment ID:** This is the equipment identifier for the SSC. This is typically taken from the plant equipment identification system, but other IDs can be used.

- **Equipment Description:** This is a text description of the SSC.

- **Basic Event:** This is the PRA basic event ID that the failure of the SSC will be assigned.
- **BE Description:** This is the text description of the basic event.
- **Building:** This is the building that houses the SSC.
- **Elevation:** This is the floor elevation designator for the location of the SSC.
- **Location:** This provides more details on the location of the SSC. It may be a room number, fire or flood zone number, row and column intersection, or grid position.
- **Normal Position:** This column identifies the normal state (normally closed, normally open, normally running, etc.) of the SSC during at-power operations.
- **PRA Desired Position:** This column identifies the desired state (open, closed, etc.) of the SSC for successful function in the TMRE PRA.
- **MOV/AOV Failed Position:** This identifies the valve failed state due to loss of power and/or air. This applies to MOVs, AOVs and similar valves (e.g., with solenoid or hydraulic operators). It is important to include this information in the HWEL for the walkdown team.
- **Correlated SSCs:** Notes of possible SSC correlations identified during the HWEL creation should be entered here, and any correlation information obtained during the walkdown should be added.

Table 3-1: Example of HWEL Entries

Equipment ID	Equipment Description	Basic Event (BE)	BE Description	Building	Elevation	Location	Normal Position	PRA Desired Position	MOV/ AOV Failed Position	Correlated SSCs
IA-001	IA Compressor Outlet Valve	IA001XC	Valve IA-001 Transfers Closed	Turbine	240’	TH/12	Open	Open	N/A	N/A
SW-P01A	Service Water Pump A	SWP1AF R	Service Water Pump A Fails to Run	Intake	200’	IA/14	On	On	N/A	N/A
MFW-P01B	Main Feedwater Pump B	FWP1BF R	Main Feedwater Pump B Fails to Run	Turbine	219’	TC/8	On	On	N/A	N/A
RWST	Reactor Water Storage Tank	RWSTCF	RWST Catastrophic Failure	Yard	219’	Near Aux Building	Available	Available	N/A	N/A
1A1-3	MCC 1A1-3	MCC1A 13	MCC 1A1-3 Fails	Turbine	240’	TA/20	Energized	Energize d	N/A	N/A
SW-10A	Service Water Discharge Valve A	SW10AF O	Valve SW-10A Fails to Open	Yard	205’	SW Pit	Open	Open	As-Is	In the SW Pit 3’ from SW-10B
SW-10B	Service Water Discharge Valve B	SW10BF O	Valve SW-10B Fails to Open	Yard (SW Pit)	205’	(SW Pit)	Open	Open	As-Is	In the SW Pit 3’ from SW-10A

As noted, the HWEL will include potentially vulnerable SSCs from the TMRE PRA. This will require initial work to create the TMRE PRA, at least to the degree that is needed to support HWEL development. Section 6.1 describes the initial step of selecting the event trees from the internal events PRA model that will be used to form the TMRE PRA model. After completing the step described in Section 6.1, the analyst will be able to determine what SSCs will be included in the TMRE PRA. The SSCs considered in the TMRE PRA and the previously identified nonconforming SSCs form the initial list of SSCs to consider for the HWEL. The following steps are taken to refine the HWEL:

a. Screen out SSCs that are not included in the selected accident sequences (if not already done in the Section 6.1 steps) and non-equipment basic events.
b. Screen out SSCs that are located inside Category I structures and that are located away from vulnerable openings or features (e.g., ventilation louvers, roll-up doors).
c. Screen SSCs that are dependent on offsite power, since the TMRE assumes there will be a non-recoverable loss of offsite power.
d. Determine SSC location, normal position, desired position (from the TMRE PRA), and failed position (for MOVs and AOVs).

Following these steps, an initial HWEL will be developed; it will then be used to support the Vulnerable SSC Walkdown.

Prior to the walkdown, any ex-control room human failure events (HFE) should be identified. These actions will need to be reviewed with an operator and the operator locations, transit pathways and operation locations will need to be evaluated as part of the walkdown. The following information should be reviewed with an operator prior to the walkdown:

a. Operator action task (e.g., switch CST suction for AFW pumps)
b. Operator action location, where the action takes place
c. Normal location of the operator(s) at the time of the event. If the site procedures have specific locations for operators to take shelter during a tornado, those should be the starting location for the operators. Otherwise, potential operator locations will need to be considered.
d. Potential pathways for the operator to transit from their initial location to the action location.

3.2 Vulnerable SSC Walkdown

The purpose of the Vulnerable SSC Walkdown is to locate and document all potentially vulnerable and previously identified nonconforming SSCs and any TMRE PRA SSCs that are not protected from tornado missiles. Additionally, actions performed outside of the control room (ex-control room actions) will be reviewed to verify that station personnel can safely get from their initial location to the action location after a tornado has struck the plant.

3.2.1 Personnel for Vulnerable SSC Walkdown

The Vulnerable SSC Walkdown should be performed by a team consisting of personnel familiar with the plant systems, personnel responsible for the TMRE PRA, and a civil or structural engineer familiar with the plant. Structural personnel provide expertise to identify screening characteristics applicable to SSCs. Risk assessment personnel participate in the walkdowns to provide insights on the failure modes of the equipment in the TMRE PRA, as well as to have hands-on experience with the SSCs that will be modeled. If the walkdown will be conducted primarily by vendors/contractors, it is recommended that the plant PRA personnel be actively involved in the process.

As stated previously, the Vulnerable SSC Walkdown can be performed independently from the Tornado Missile Walkdown. The personnel recommendations for the Tornado Missile Walkdown are discussed in Section 3.4.1.

3.2.2 VULNERABLE SSC IDENTIFICATION AND DATA COLLECTION

The initial HWEL, developed in accordance with Section 3.1, is the roadmap for the Vulnerable SSC Walkdown. It should list all the SSCs that need to be identified and reviewed during the walkdown, both previously identified potentially nonconforming SSCs and additional TMRE PRA SSCs that may be exposed to tornado missiles. The HWEL should not be considered static; any additional SSCs in the TMRE PRA that are exposed to tornado missiles and not on the HWEL should be added. Any incorrect or missing information can also be noted while in the field, for updates to the HWEL.

3.2.3 SSC FAILURE MODES

In addition to SSCs being vulnerable to tornado missile strikes, other failure modes and configurations of interest should be noted during the walkdown:

- Active (e.g., pumps, compressors) or passive (e.g., tanks, piping) components that are outside or in areas where they are exposed directly to tornado wind forces.
- Components inside non-Category I structures; these SSCs will be damaged when the structure collapses, or exposed to tornado wind pressures from walls or siding failure.
- SSCs adjacent to non-Category I SSCs, that may be impacted when the non-Category I SSC collapses.
- SSCs that could be affected by flooding or combustion motor intake effects, due to tornado missile failure of non-conforming fluid-filled tanks or pipes (i.e., secondary effects.)

These situations should be noted and documented during the walkdown. The treatment of SSC failures in the TMRE model is described in Sections 6.5 and 6.6. The selection of the representative initiating event(s) and event tree(s) should also take these failures into account.

3.2.4 WALKDOWN ACTIVITIES AND DOCUMENTATION

Each of the SSCs on the HWEL should be located, and information on the SSC should be collected, to support the incorporation of the SSC EEFP in the TMRE PRA model. The information to be collected is described below. Both field notes and photographs should be taken while performing the walkdowns. In order to limit the need for additional walkdowns or document reviews later, quality notes supplemented with numerous photographs should be taken to provide necessary documentation from the walkdown. Notes and dispositions regarding specific SSCs can be added to the HWEL. Documentation from the walkdown will also serve as useful information in the future, if plant modifications are performed which could alter the conclusions derived from the TMRE.

The walkdown activities should consist of the following:

a. Locate and identify the SSC; verify that the SSC is located where it is documented to be. Note any support systems or subcomponents, such as electrical cabling, instrument air lines, and controllers.

b. Photograph the SSC, including its surroundings. Ensure that any subcomponents or support systems identified are photographed. Example photographs are provided in Section 4 of the EPRI walkdown guidance, EPRI 3002008092 [Ref.3.1].

c. Document and describe barriers that could prevent or limit exposure of the SSC to tornado missiles; Photograph any barriers that could prevent tornado missiles from impacting the SSC. This may include barriers or shielding designed to protect an SSC from tornado missiles, as well as other SSCs that may preclude or limit the exposure of the target SSC to missiles (e.g., buildings, large sturdy components).

d. Identify directions from which tornado missiles could come from to strike the target. This may best be done with sketches and notes, in addition to photographs of the area surrounding the SSC. For SSCs inside Category I structures, note whether there is a line of sight from an opening to the SSC.

e. Determine and/or verify the dimensions of the target SSCs, including any subcomponents or support systems. It is helpful to have the dimensions from drawings or other documents prior to the walkdown, so that the walkdown can be used for confirmation. Determine the dimensions of any openings that allow the SSC to be exposed to a tornado missile.

f. Determine the proximity and potential correlation to other target SSCs. For the purpose of the TMRE, correlated targets are SSCs that can be struck by the same tornado missile.[1] Photographs of SSCs that are close together (correlated or not) are useful for documenting the decision made regarding correlation.[1]

g. Note any nearby large inventories of potential tornado missiles. Relocation of large groups of potential missiles in close proximity to exposed risk significant SSCs may be considered to improve defense in depth. The intent of this is not to count missiles, since that is done in a separate walkdown.

h. Proximity of non-Category I structures to exposed target SSCs should be documented. A non-Category I structure may collapse or tip-over and cause damage to an SSC.

i. Identify vent paths for tanks that may be exposed to atmospheric pressure changes (APC). These should be noted during the documentation and drawing review, but verified and documented as part of the walkdown.

j. Look for additional issues affecting credited equipment or other potential vulnerabilities that may not have been previously identified.

General information on walkdowns can also be found in EPRI 3002008092, *Process for High Winds Walkdown and Vulnerability Assessments at Nuclear Power Plants* [Ref. 3.1].

[1] If targets are correlated, the entire area of the correlated targets should be determined, and one EEFP will be calculated for the correlated targets, to be used to fail all correlated SSCs.

3.3 Ex-Control Room Action Feasibility

Ex-control room HFEs should have been identified during the development of the HWEL (see Section 3.1). Operator actions performed outside of Category I structures or requiring the operator to transit outside Category I structures should be evaluated for the TMRE. These types of operator actions that need to be performed within 1 hour of the tornado event are assumed to be failed. However, actions requiring transit or operation outside Category I buildings after 1 hour may also be affected by the tornado, especially for higher category tornadoes. For example, access paths may be blocked or debris may prevent easy access to some equipment. Primary and alternate paths for operator transit should be identified and verified with operations staff. Paths should be verified during the walkdown and any relevant notes should be taken. Examples of items to note are the number of pathways available for the operator (taking into account where operators typically shelter during a tornado event), whether the equipment will be accessible, and whether timing is expected to be affected. Ex-control room operator actions that are performed inside Category I buildings and do not require transit outside of Category I buildings are considered to be unaffected.

The results of the operator interviews and the walkdown notes should be reviewed by a Human Reliability Analyst. It is not expected that longer term action (greater than 1 hour) human error probabilities will be noticeably impacted by the tornado event. Section A.2.1.2 provides considerations for not changing the Human Error Probabilities (HEP) of such actions. The results of the ex-control room action feasibility evaluation should be documented to justify the treatment of such actions in the TMRE model.

3.4 Tornado Missile Identification and Classification

One of the key inputs to the EEFP is the number of missiles capable of damaging exposed SSCs. In order to simplify the calculations, Section 5.1 provides generic values for the number of missiles to include in the EEFP calculation. The Tornado Missile Walkdown is performed to verify that the number of missiles recommended in Table 5-1 is bounding for the site being evaluated. This walkdown is recommended to be performed separately from the Vulnerable SSC Walkdown; it can be performed in parallel with the Vulnerable SSC Walkdown or at a different time.

3.4.1 Tornado Missile Walkdown Personnel

Personnel performing the Tornado Missile Walkdown do not require PRA expertise or knowledge, and structural engineering experience is not required. The personnel only need to be trained on the methods for identifying and counting potential missiles. This section and Section 4.3 of EPRI 3002008092 provide adequate information to support training Tornado Missile Walkdown personnel.

3.4.2 Non-structural Missile Inventory

The Tornado Missile Walkdown should cover the entire plant area, out to a distance of 2500 feet from a common reference point, such as the center of the containment. If there are target SSCs more than 1500 feet from the reference point, additional verification of missile populations near those SSCs may be required. Recommendations for this situation are discussed at the end of this section.[2]

[2] The bases for the areas and distances considered for the TMRE missile inventory are provided in Appendix B.

The survey area may be divided into zones to simplify record keeping and allow multiple teams (if desired) to perform the walkdown. Zones should be defined by geographic or well-recognized landmarks, to minimize the potential for double-counting or overlooking missiles. A plant layout drawing and/or satellite image of the plant can be marked up to indicate the zones. The number of zones can vary from a few (5 - 7) to about 30.

Although High Winds PRAs generally require the type and number of missiles to be counted, only the total number of missiles are required to be counted for the TMRE PRA. However, it may be beneficial to count the types of missiles, for record-keeping purposes and for potential use in the future. The types of missiles are listed in Table 3-2, including examples of which objects would be binned as a certain missile type. Not every potential missile is listed in this table, so other objects that can become missiles should be binned with the closest missile type. A similar list of missile types is provided as Table 4-2 in EPRI 3002008092 and an example missile inventory table (including nominal dimensions for the missiles) is provided in Table 4-3 of the same EPRI report.[3]

In the case of targets greater than 1500 feet from the plant area reference point, a qualitative evaluation of the missile inventory within 2500 feet of the outlying target(s) should be done. The intent of this evaluation is to determine whether the missile inventory used for the TMRE is applicable to all the targets. If the missile inventory/density surrounding an outlying target is judged to be comparable to (or bounded by) the missile inventory determined from the missile survey out to 2500 feet from the reference point, then no further action is required. Otherwise, a missile inventory should be determined for the area out to 2500 feet from any outlying target.

[3] Missile Type 10 in Table 3-2 is not included in EPRI 3002008092. The Dumpster/Storage Container missile type in EPRI 3002008092 is not included here; they can be binned as vehicles (Missile Type 22).

Table 3-2: Potential Tornado Missile Type

Type	Missile Description and Nominal Dimensions	Nominal Weight (lbs)	Example Missiles
1	Rebar: Steel, 1” dia x 3’ long	8	Rebar
2	Gas Cylinder: Steel, 10” dia x 5’ tall	290	Gas Cylinder
3	Drum, tank: Steel 20” dia x 5’ tall	500	55-gallon drum
4	Utility Pole: Wood, 13.5” dia x 35’ long	1500	Wooden light pole or ‘telephone pole’
5	Cable Reel: Wood, 42” dia x 1.8’ wide	253	Cable Reel
6	3” Pipe: Steel, 3.5” dia x 10’ long	76	Fence posts, conduit, sprinkler piping
7	6” Pipe: Steel, 6.63” dia x 15’ long	284	Larger pipes
8	12” Pipe: Steel, 12.75” dia x 15’ long	744	Steel light poles or utility poles
9	Storage bin: Steel 3.5’ x 3’ x 6’	675	Small metal containers, ‘gang boxes’, filing cabinets
10	Concrete Paver	88	Concrete Roof Pavers
11	Concrete Block: 8” x 8” x 16”	36	Cinder blocks
12	Wood Beam: 4” x 12” x 12’	200	Thick wood beams, wood posts
13	Wood Plank: 1” x 12” x 10’	27	Thinner wood planks, 2 x 4s
14	Metal Siding	125	Building siding, steel plates
15	Plywood Sheet: 7/8” x 4’ x 8” -	84	Plywood sheets
16	Wide Flange: Steel, 14” WF x 15’	390	Angle iron, larger I-beams
17	Channel Section: Steel, 6” C x 15’	195	C-beams
18	Small Equipment: 2.5’ x 2.5’ x 3’	388	Small portable generators, small pumps
19	Large Equipment: 4 ‘x 3’ x 6’	1350	Lathe, small concrete mixers, larger generators and pumps
20	Frame/Grating: Steel, 2’ x 1” x 12’	74	Ladders, scaffolding, floor grating
21	Large Steel Frame: 10’ x 4’ x 16’	1040	Warehouse shelving, pallet racks
22	Vehicle: Examples – 5.5’ x 5.5’ x 16’	4000	Cars, trucks, sea van containers, trash dumpsters
23	Trees 8” dia x 20’ tall	700	Trees[4]

[4] For forested areas or large stands of trees, counts are typically estimated by determining the area of interest (e.g., via satellite image) and assuming a certain tree density.

Note that the dimensions provided in Table 3-2 are nominal dimensions, used to help classify objects that do not fit the exact description of the missile. For example, a steel light pole that is 10” in diameter and 20’ high could be classified as a Type 8 (12” pipe) missile.
The following (and similar) items are either lightweight, sufficiently massive, or fixed; thus, they pose no significant threat to NPP SSCs; they should not be counted as missiles:

- Soft materials, such as insulation, foam, cardboard, etc.
- Small and light objects, such as plastic fittings, light gauge metal fasteners, ventilation louvers, etc.
- Small plants and trees, bushes, etc.
- Very heavy equipment (main transformer, turbine generator, etc.)
- Cement or concrete pads or building foundations

3.4.3 Non-Permanent Missiles

Outages

Prior to and during NPP outages, additional equipment is brought onsite, staged in laydown areas, and left outdoors (e.g., scaffolding, construction material, construction trailers). Although this additional equipment may lead to a higher total missile inventory than was surveyed as part of the TMRE walkdown, it is not necessary to explicitly account for the additional outage-related missiles in the TMRE missile inventory. Moreover, many outage related missiles, if not staged during the time that walkdowns are performed, would be counted as part of laydown areas or included in warehouse inventory. In many cases, equipment used during outages is stored elsewhere on site during non-outage times to prevent having to purchase new outage support equipment before each outage.

Sites that develop a missile count of less than 240,000 missiles still use 240,000 missiles in their TMRE analysis and have built in margin that can account for potential increases in missiles during outage preparation and staging. Additionally, outages are of relatively short duration compared to the operational time at a NPP. Sites have procedures that require securing equipment and potential missile sources in the event of forecasted severe weather. Additionally, the increased manpower onsite during outage periods provides for more available personnel to help secure potential missile sources. Based on these factors, the impact to the tornado missile risk posed by additional outage-related missiles is minimal.

Construction

The TMRE risk estimates will be used in a risk-informed change the permanent licensing basis for the plant, for nonconforming SSCs. Although construction at a site may temporarily add to the missile inventory used in TMRE, the new licensing basis should reflect the state of the as-built and as-operated plant configuration, and not have to change as short-term configurations or activities occur at the plant site.

Construction is typically a short-term condition relative to the operating life of the plant. Additional non-permanent missiles do not need to be included in the missile inventory for the TMRE CDF and LERF calculations (i.e., those calculations performed in Section 7.1). A similar consideration is discussed above for outages. However, the expected final site configuration (i.e., after construction is completed) should be evaluated to ensure that the missile count used in the TMRE continues to be bounding or if the missile count input should be updated. For example, if non-Category I structures are being built, the missile count from the final structures within the required range needs to be determined and included in the site-specific missile inventory. These are called “permanent post-construction missiles.”

The guidance for periods of construction is:

- The expected missile inventory for the post-construction site should be *estimated*, using walkdown results for the non-construction areas, information in Sections 3.4.2 and 3.4.4, along with design and construction information. The basis and assumptions used for the estimated number of permanent post-construction missiles shall be documented. Bounding and conservative estimates are recommended, to account for uncertainty.
    - If the inventory of current missiles (those counted outside the construction area) plus the estimate of post-construction missiles is less than 240,000 missiles, the generic missile inventories provided in Table 5-1 should be used for the Section 7.1 ΔCDF and ΔLERF calculations.
    - If the total missiles are not bounded by 240,000, a bounding site missile inventory should be determined and documented. This bounding missile inventory should be used for the Section 7.1 ΔCDF and ΔLERF calculations.

- A missile margin assessment (Section 7.4) should be performed to evaluate the impact of the additional non-permanent construction-related missiles, that is, those missiles not already included in the permanent post-construction missiles. This would include missiles in construction lay-down areas that are currently inside the analysis range, but would eventually go into Category I structures or be removed completely. The total missile count for the missile margin assessment should include the non-construction related missile inventory determined in accordance with Sections 3.4.2 and 3.4.4, and a reasonably bounding *estimate* of the number of non-permanent construction-related missiles (all within 2500’ of a central reference point).

- The basis and assumptions used to determine the non-permanent construction-related missile estimate should be documented. An example of an acceptable method for estimating missile counts would be to perform walkdowns of limited sections of the construction area, determine average missile densities in those areas, and apply the missiles densities to the remainder of the construction area. Documentation should include some sample photographs of the construction area.

- Qualitative discussions, such as that of the proximity of the missiles to targets, should be included to support the basis for exclusion of the non-permanent missiles from the primary TMRE analysis of the as-built, as designed plant. Additionally, include a qualitative or quantitative discussion of the nature of the construction as short-term and the impact of the non-permanent construction-related missiles on risk over time. If engineering judgment does not support exclusion of the missiles from the primary TMRE analysis, then the missiles should be included in the permanent post-construction missile count. Also, a site may elect to include the non-permanent missiles in the permanent count as a matter of convenience.

- The results of the margin assessment (Section 7.4) shall be documented.

3.4.4 Structural Missiles

Commercial and industrial structures that are built to standard building codes will generally not withstand tornado winds greater than about 100 mph. The destruction of these structures generates additional missiles that should be accounted for in the TMRE. Each type and size of structure contains a number of missiles that can be estimated using the tables presented here (Tables 3-3 through 3-8); the basis for these tables is provided in Appendix C.

Missiles from turbine buildings (e.g., siding, laydown areas) should not be inventoried using the tables in this subsection. Missiles originating from turbine buildings should be counted separately. For example, the number of siding panels can be determined based on a review of turbine building structural drawings and walkdowns.

The contents of buildings were considered depending on building function. For example, the quantities of desks and furniture were estimated for office buildings, and quantities of pallets, drums, and shelving were estimated for warehouses. The building contents accounted for in Tables 3-3 through 3-8 are considered representative for all sites; therefore, validation of site-specific building contents is not required by individual licensees.

A short description and an example of each structure type are provided here.

<u>Wood Framed Office Buildings and Warehouses (Tables 3-3 and 3-6)</u> - Wooden buildings have roof, floor, and wall structural systems that are constructed of sawn lumber, plywood, or engineered wood; see Figure 3-1. These buildings are prone to partial or complete loss of roof and wall systems when subjected to severe winds. Potential missiles include wood planks and plywood debris.

Figure 3-1: Typical Wood-framed Construction

<u>Trailers and Manufactured Buildings (Tables 3-4 and 3-8)</u> – These are typically modular and have lightweight construction; see Figure 3-2. These buildings are not typically constructed on permanent foundations and are prone to uplift and roll-over under severe wind loads. Potential missiles include trailer roof and wall components, as well as steel channel framing (trailer).

Figure 3-2: Typical Trailer/Manufactured Building

Engineered and Pre-engineered Buildings (Tables 3-5 and 3-7) – Engineered buildings typically have roof, floor, and wall systems that are constructed with steel or concrete; see building on the left of Figure 3-3. Pre-engineered buildings (building on the right of Figure 3-3) are typically steel-framed structures with metal siding (e.g., Butler buildings). Potential missiles include steel siding and roof decking and framing members (e.g., wall and roof purlins).

Figure 3-3: Typical Engineered (left) and Pre-engineered (right) Buildings

Table 3-3. Potential Tornado Missile per Office Building, Wood-Framed

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	14	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	4	2	9
13	69	31	76
14	0	0	25
15	31	31	0
16	2	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**121**	**66**	**110**

Table 3-4. Potential Tornado Missile per Office Building, Manufactured (Pre-fab)

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	16	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	2	0	0
10	0	0	0
11	0	0	0
12	13	3	23
13	183	20	56
14	0	0	24
15	31	25	0
16	2	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**248**	**50**	**103**

Table 3-5. Potential Tornado Missile per Office Building, Engineered and Pre-Engineered

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	33	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	2	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	80	0	0
14	0	25	24
15	15	0	0
16	0	8	4
17	0	16	7
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**131**	**51**	**35**

Table 3-6. Potential Tornado Missile per Office Building, Construction Trailer

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	0	0	0
2	1	0	0
3	2	0	0
4	0	0	0
5	4	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	4	0	0
10	0	0	0
11	0	0	0
12	12	6	14
13	151	12	96
14	0	25	24
15	31	0	0
16	0	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**206**	**45**	**134**

Table 3-7. Potential Tornado Missile per Warehouse Building, Wood-Framed

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	27	0	0
2	1	0	0
3	1	0	0
4	0	0	0
5	5	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	6	0	0
10	0	0	0
11	0	0	0
12	6	2	4
13	30	20	78
14	0	31	24
15	20	0	0
16	0	0	0
17	0	0	0
18	2	1	0
19	2	1	0
20	1	0	0
21	2	0	0
22	0	0	0
23	0	0	0
Total	**103**	**55**	**106**

Table 3-8. Potential Tornado Missiles per Warehouse Building, Engineered and Pre-Engineered

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	18	0	0
2	1	0	0
3	1	0	0
4	0	0	0
5	5	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	6	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	16	0	0
14	0	25	25
15	12	0	0
16	0	5	4
17	5	16	8
18	2	1	0
19	2	1	0
20	1	0	0
21	2	0	0
22	0	0	0
23	0	0	0
Total	**71**	**48**	**37**

References

3.0 EPRI 3002008092, *Process for High Winds Walkdown and Vulnerability Assessments at Nuclear Power Plants*

4 DETERMINE SITE TORNADO HAZARD FREQUENCY

4.1 DATA SOURCES

NUREG/CR-4461, Rev. 2, was written to support the latest revision of Regulatory Guide 1.76, “Design-basis Tornado and Tornado Missiles for Nuclear Power Plants." This NUREG uses data on tornadoes which were reported in the contiguous United States from January 1950 through August 2003, which encompasses over fifty years of data. The wind speed estimates in this report are based on the Fujita Scale and the Enhanced Fujita Scale, both of which correlate wind speeds with damage caused by tornadoes.

4.2 BACKGROUND

The initiating event for the TMRE PRA model is the frequency of a tornado strike at the site. Each licensee should develop a site-specific tornado frequency. The tornadoes of interest are those tornadoes with a wind speed of approximately 100 mph or greater. For the purposes of the TMRE, the F’-scale (Fujita prime) will be used to classify tornadoes; this scale is somewhat different from the original Fujita Scale (F-Scale) and the Enhanced Fujita Scale (EF-Scale); refer to table 4-1 below. The F’-scale was chosen because the TMRE MIP values are based on simulations that used the F’-scale inputs to categorize the tornados.

Table 4-1: Fujita Tornado F Scale Intensity Wind Speed Relationships (mph)

Intensity	Description	Original Fujita	Fujita	Enhanced Fujita	F’
F0	Light damage	40 to 72	45 to 78	65 to 85	40—73
F1	Moderate damage	73 to 112	79 to 117	86 to 110	73-103
F2	Considerable damage	113 to 157	118 to 161	111 to 135	103-135
F3	Severe damage	158 to 206	162 to 209	136 to 165	135-168
F4	Devastating damage	207 to 260	210 to 261	166 to 200	168-209
F5	Incredible damage	261 to 318	262 to 317	>200	209-277
F6	Inconceivable	319-380			277-300

NUREG/CR-4461, Rev. 2, Table 6-1 provides each U.S. NPP site with tornado wind speeds associated with 10^{-5}, 10^{-6}, and 10^{-7} probabilities per year of a tornado missile strike. Excerpts of that table are shown below in Table 4-2. Additionally, the total tornado strike frequency (i.e., the frequency of any tornado with wind speed greater than 65 mph) is provided for all locations in the continental United States. Using this data, a site-specific tornado frequency curve (hazard curve) can be developed and the frequency of all tornadoes considered in the TMRE (F’2 through F’6) can be calculated.

Since F’ probabilities are not directly available from this NUREG, they must be derived from the site-specific Fujita scale data. Using the Fujita scale data, as opposed to the Enhanced Fujita Scale data, results in higher, and therefore more conservative, strike frequencies.

4.3 Hazard Frequency Calculations

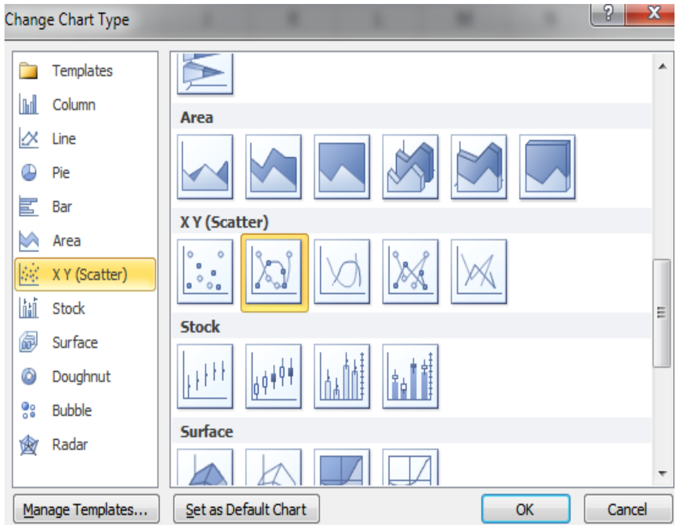
The F’-scale probabilities used in the TMRE method are based on the site-specific Fujita Scale data from NUREG/CR-4461, Rev. 2 (see examples in Table 4-2 below.) These data are used to develop an equation for the site-specific tornado hazard curve that is then used to calculate the yearly exceedance frequencies for each F’ range, F’2 through F’6. The following example (Sections 4.3 thru 4.6) illustrates the process using the following data (1E-05 at 158mph, 1E-06 at 214mph, and 1E-07 at 264mph.)

Table 4-2: Excerpt of Site-Specific Fujita Scale Data (From NUREG/CR-4461, Rev. 2 Table 6-1)

		Fujita Scale (mph)		
Index	**Power Plant**	**1E-05**	**1E-06**	**1E-07**
46	**Peach Bottom**	139	199	250
47	**Perry**	186	240	288
48	**Pilgrim**	143	203	254
49	**Point Beach**	177	232	280
50	**Prairie Island**	192	245	293

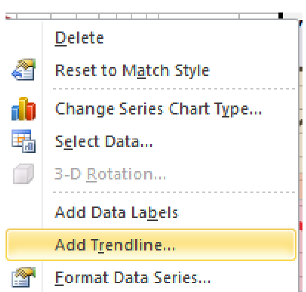
4.4 Plot Data Points

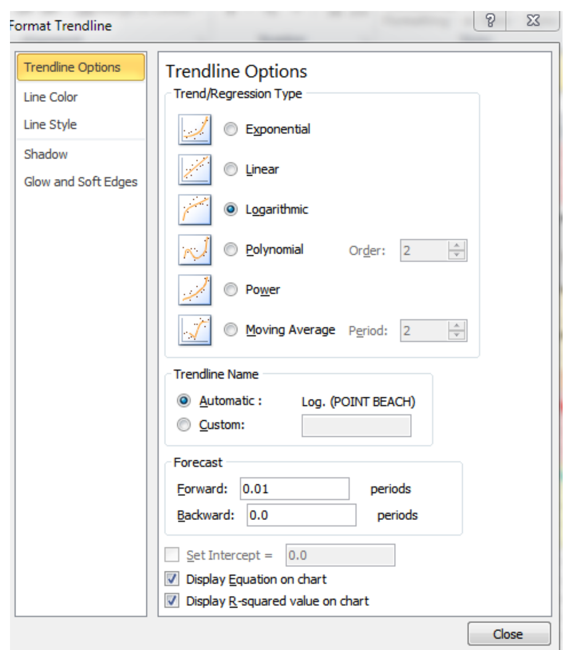
For this example, Microsoft Excel® is used to plot the data points, but other curve-fitting software packages would be acceptable. The three site-specific Fujita Scale data points are plotted using the Excel chart function “XY scatter.” In this example the wind speed is plotted on the y-axis and the frequency is plotted on the x-axis, however, the axes can be swapped to reflect wind speed on the x-axis and frequency on the y-axis.



4.5 Trendline Equation Plot

Select the line plotted by these three points (i.e., right-click) to open the drop down window. Then, select the "Add Trendline" function from the list. From the "Format Trendline" window, select "Trendline Options." For this example, the "Logarithmic" trendline option was used along with the "Display Equation on chart" and "Display R-squared value on chart" options. The r-squared value should be >0.9.





The equation generated for the Example site is:

Miles per Hour (mph) = -23.02 * ln(Frequency) - 106

R-squared = 0.9989

Where Y=Miles per Hour (mph) and X=Frequency

NOTE: The equation above can be modified to solve for the Frequency variable (i.e., the Frequency variable is on the left-hand side of the equation.) This may facilitate the process since the final results from Section 4 will be site-specific tornado initiating event frequencies.

4.6 CALCULATE TORNADO EXCEEDANCE AND TORNADO BIN FREQUENCIES

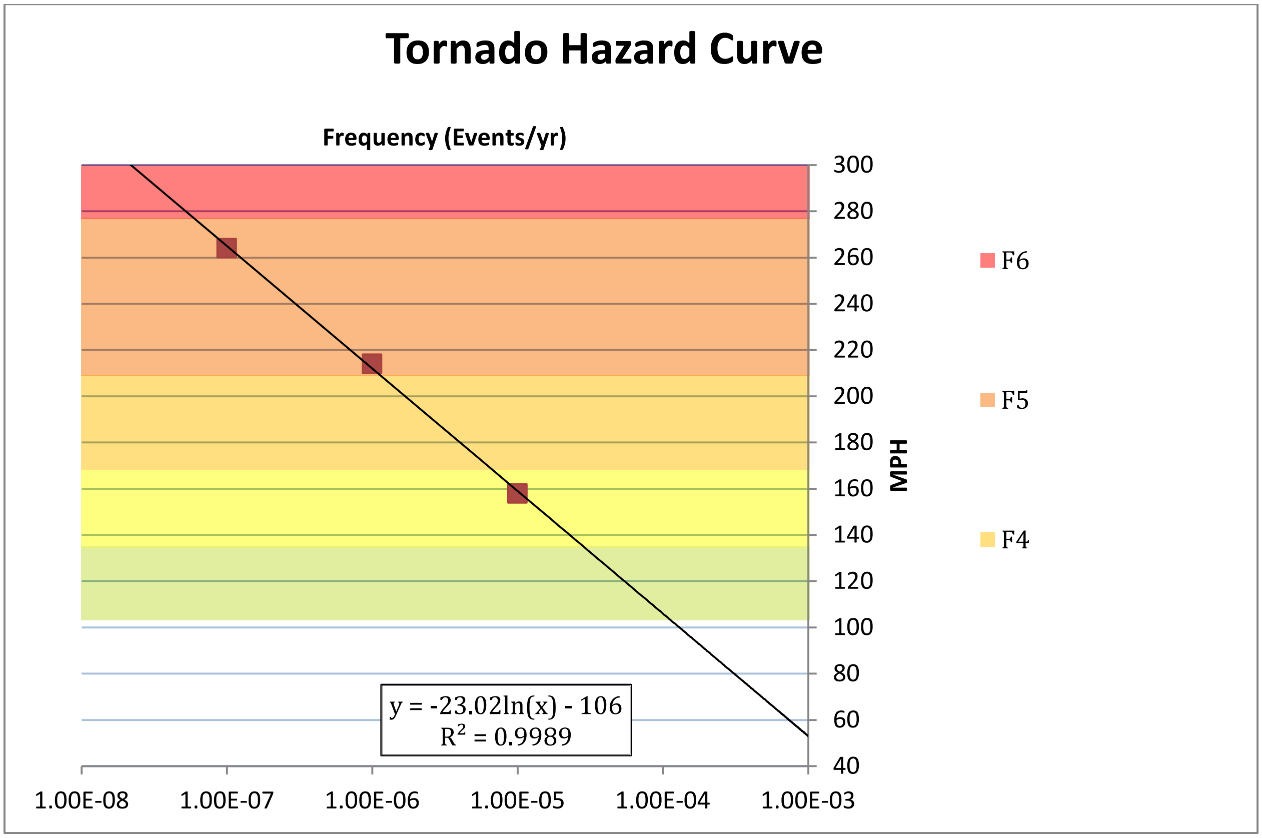
The three red blocks in Figure 4-1 are the three plotted example data points from Section 4.3 and the thin black line is the trendline developed from Section 4.5. To calculate the exceedance frequencies for each F' scale tornado (F'2 thru F'6), plug the lower range tornado speed into the trendline equation. Using the example data, for the F'2 tornado plug 103mph into the equation from Section 4.5 and the resulting exceedance frequency is 1.14E-04/year. Similarly for the F'3 tornado plug 135mph into the equation and the resulting exceedance frequency is 2.84E-05/year. These exceedance frequencies for each tornado F' scale is an intermediate step in deriving tornado bin frequencies, which are the final inputs into the TMRE model.

In order to get the F'2 tornado bin frequency, subtract the F'3 scale tornado exceedance frequency from the F'2 tornado exceedance frequency (i.e., 1.14E-04 – 2.84E-05 = 8.85E-05). See Table 4-3 below for the entire list of F' scale tornado exceedance frequencies and bin frequencies using the example data. Note that the F'6 tornado exceedance frequency and bin frequency are the same because there is not an associated F'7 scale tornado exceedance frequency to subtract from the F'6 exceedance frequency. The site-specific tornado bin frequencies are the tornado initiating event frequencies used in Section 6.2 when developing the TMRE PRA model.

Table 4-3

Intensity	Minimum MPH	Exceedance Frequency	Bin Frequency
F'2	103 mph	1.14E-04	8.85E-05
F'3	135 mph	2.84E-05	2.16E-05
F'4	168 mph	6.77E-06	5.63E-06
F'5	209 mph	1.14E-06	1.08E-06
F'6	277 mph	5.95E-08	5.95E-08

Figure 4-1 – Example Tornado Hazard Curve



5 EVALUATE TARGET AND MISSILE CHARACTERISTICS

New failure modes for SSCs that can be struck and damaged by a tornado missile will be added to the TMRE PRA model. This applies to SSCs that are required by the plant's licensing basis (nonconformances), as well as those SSCs that are not required to be protected, but are in the TMRE PRA model (vulnerabilities). Tornado missile failures do not need to be considered for SSCs protected by 18" reinforced concrete walls, 12" reinforced concrete roofs, and/or 1" steel plate. These thicknesses provide sufficient protection against direct strikes from tornado missiles to allow screening of these non-conforming SSCs (see Section B.6.3). However, this screening does not change the Plant Licensing Basis or allow future modifications to use a design thickness inconsistent with the Licensing Basis.

The failure probability of exposed SSCs is calculated using the Exposed Equipment Failure Probability (EEFP). The EEFP is the conditional probability that an exposed SSC is hit and failed by a tornado missile, given a tornado of a certain magnitude. For every applicable SSC, five EEFP values will be calculated, one each for tornado categories F'2 through F'6.

The EEFP is defined as:

EEFP = (MIP) x (# of Missiles) x (Target Exposed Area) x Fragility

The Missile Impact Parameters (MIP) is the probability of a tornado missile hit on a target, per target square area, per missile, per tornado (see Section 5.1). Generic MIP values are provided as part of the TMRE methodology and are described in more detail in Section 5.1 and Appendix B; MIP values are in Table 5-1. The MIP varies by the tornado category (i.e., F'2 through F'6) and the elevation of the target.

# of Missiles is the number of damaging missiles within about 2500 feet of the target SSCs. Generic values for the number of missiles (which vary by tornado intensity) are provided as part of the TMRE methodology and will be verified through the TMRE walkdown activity (Section 3). Some targets that are more robust (e.g., steel pipes and tanks) will use different missile inventories than less robust SSCs (e.g., electrical panels, instrumentation), since only certain types of missiles can damage robust targets. The missile inventories to use for each target SSC (depending on robustness) are described in Section 5.2 and Appendices B and C; and listed in Table 5-2. Generic total missile inventories are listed in Table 5-1 for each tornado category, F'2 through F'6.

Target Exposed Area (ft^2) is determined for each specific SSC, based on plant documentation and the TMRE walkdown. More information on calculating target areas is provided in Section 5.3.

Fragility is the conditional probability of the SSC failing to perform its function given that it is hit by a tornado missile. For the purposes of the TMRE, it is assumed to be 1.0 (i.e., the SSC is always failed if hit by a tornado missile).

NOTE: The variables and factors included in the EEFP were developed to provide a conservative estimate of SSC failure probability. The values provided in this guidance for the *MIP*, *# of Missiles* and *Fragility* variables were developed to be used together, and should not be modified. The conservatism in the EEFP is dependent on using the recommended values for all these variables. Each variable may not be conservative by itself, but the combination of variables used for different targets and tornado wind speeds is expected to provide a bounding estimate of the change in CDF associated with nonconforming SSCs. Appendices B and C provide the basis for the variables and Appendix A provides the results of benchmarking the TMRE against two RG 1.200 High Winds PRAs. Deviation from the recommended values could invalidate the benchmarking and result in non-conservative EEFPs and, hence, non-conservative ΔCDF and ΔLERF results. Therefore, all EEFP values described in this section must be used without modification, except for:

1. The total number of missiles, which may be increased if necessary based on the site-specific missile inventory.

2. The <30 ft MIP value can be used in cases where it is difficult to determine if the target is >30 ft above the reference elevation.

3. When taking credit for robust targets, a higher percentage can be used.

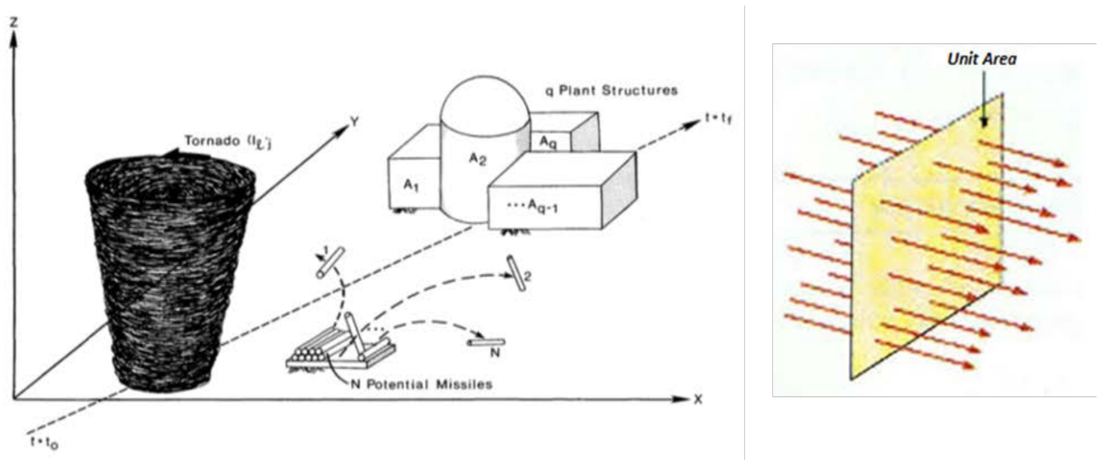
4. A target EEFP can be set to 1.0 to preclude performing a detailed analysis of target area, shielding, etc. If this is done, the impact of compliant case conservatisms should be addressed (see Section 7.2.3).

5.1 MISSILE IMPACT PARAMETER (MIP)

The *Missile Impact Parameter (MIP)* is defined as: The probability of a tornado-driven missile impact on an SSC per unit area of the SSC, per missile, per tornado. It can be thought of as the missile flux through a unit area, as shown in Figure 5-1.

MIP = Probability of Missile Hit / ft^2 / missile / tornado

Figure 5-1: Missile Impact Parameter



Generic MIP values are provided in Table 5-1 for use in the TMRE; the MIP values were developed to be applicable to all U.S. NPPs. MIP values were derived using published TORMIS data from EPRI NP-768 [Ref. 5.1]. The bases for the MIP values developed for the TMRE are provided in Appendix B.

MIP values vary with tornado intensity (i.e., F'-Scale) and the elevation of target. Separate MIP values are provided for each F'-Scale tornado from F'2 to F'6. As expected, MIP values generally increase with increasing tornado intensity, since the higher category tornadoes are expected to lift more missiles and make them airborne.

Separate MIP values are also provided for 'Near Ground' and 'Elevated' targets. Near Ground targets are less than or equal to 30' above the associated reference elevation, while elevated targets are those greater than 30' above the associated reference elevation. The MIP values for Near Ground targets are greater than for Elevated Targets. This is expected, since heavier missiles are less likely to be raised to higher elevations in the tornado wind field, and thus the number of missiles per unit area is lower for higher elevations.

Plant grade is typically chosen as the reference elevation. However, areas within the 2500 foot analysis radius having a higher elevation than plant grade must also be considered as a potential reference. In order to determine if the reference elevation should be plant grade or if a higher elevation should be used for a given target or set of targets, engineering judgment should be used to develop a reference elevation considering the following: distance of the elevated area from targets, trajectory from the elevated area to targets, percentage of total missiles contained within the elevated area, and types of missiles contained within the elevated area. Elevated portions of structures (e.g. 2nd level, roof) do not need to be considered as an "elevated area" in and of themselves if the primary source of missiles is structural in nature, including siding. However, structures situated on a surface above grade elevation should be discussed or otherwise included in missile count considerations. A plant may choose to use a higher elevation as the reference elevation without deviating from the methodology. The reference elevation and justification for choosing the value shall be documented.

Table 5-1: MIP Values and Missile Inventories for Use in the TMRE

Tornado Category	**Targets >30' above grade[1,2]**	**Targets ≤30' above grade[1,2]**	**Total Missile Inventory[3]**
F'2	5.8E-11	1.4E-10	155,000
F'3	2.0E-10	4.6E-10	155,000
F'4	3.4E-10	7.9E-10	205,000
F'5	8.7E-10	2.0E-09	240,000
F'6	1.3E-09	3.1E-09	240,000

(1) MIP values are in units of missile hit probability / ft^2 / missile / tornado

(2) The term grade here is meant to refer to the reference elevation. Typically, this is plant grade, although for some targets it may be different.

(3) Total Missile Inventory values in this table shall be used, unless the site-specific missile inventory is not bounded by 240,000 missiles. See Section 5.2 for more discussion of missile inventories.

5.2 MISSILE INVENTORIES

Generic missile inventories are provided as part of this guidance for use in calculating EEFPs at all US NPP sites. Values are provided in Table 5-1, which are expected to be bounding for most sites. The total number of missiles will require verification through the TMRE walkdown (Section 3.4), to ensure that the missile inventories provided herein are appropriate to use for a specific plant.

The generic total number of missiles is 240,000. Since the origins of many of the missiles are from building deconstruction, which varies with tornado intensity, the total missile count varies with tornado intensity. Table 5-1 provides the total missile inventory by F'-scale. If the site walkdown confirms that 240,000 is bounding for the site[5] (see Section 3), then the variable *#Missiles* in the EEFP calculations is equal to the values provided in Table 5-1, for targets not defined as 'robust.' Robust target types are listed in Table 5-2 and the percentage of the total number of missiles for each robust target type is provided. These percentages are applied to the total number of missiles at each F'-scale, to reduce the missiles that are used in robust target EEFP calculations. The bases for the total number of missiles and the robust missile inventories are provided in Appendices B and C.

If the total missiles at a site are not bounded by 240,000, the number of missiles to use in the EEFP calculations (for targets that are not robust), should be the total number of missiles counted on site, rounded up at least to the nearest 5,000 missiles. For tornadoes below F'6, the calculations of structure-origin missiles can be determined using the fractions provided for the different building types (see Appendix C). The same robust target percentages provided in Table 5-2 are applied to the site-specific missile count.

5.2.1 Missile Inventory Example

As an example, assume that a licensee performs a site missile inventory walkdown and determines that there are 291,000 missiles within 2500' of a central reference point, based on the guidelines provided in Section 3.4. The missiles consist of 91,000 zonal missiles (not associated with structures) and 200,000 structural missiles, based on calculations using Tables 3-3 through 3-8. The licensee chooses to assume 300,000 total missiles onsite. This is the missile inventory applied to the F'6 tornado EEFP calculations. Lower intensity tornadoes will have smaller inventories, based on the number and type of structures that contribute to the structural missiles. For the purpose of this example, the total missile inventory is:

- 100,000 zonal missiles (rounded up from 91,000)
- 200,000 structural missiles, consisting of:
    - 50,000 missiles from wood-framed buildings
    - 50,000 missiles from pre-manufactured buildings
    - 100,000 missiles from engineered and pre-engineered buildings

Figures 16, 17 and 18 in Appendix C provide missile release fractions for each intensity tornado. The fractions are presented in Table 5-1a as percentages.

[5] The site may be either a single unit or multi-unit site; there is no distinction in the total number of missiles based on the number of units at a site.

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Table 5-1a: Missile Release Fractions for Different Building Types

Tornado Intensity	Building Type: Wood-framed	Pre-manufactured	Engineered and Pre-engineered
F'2	10%	35%	1%
F'3	73%	95%	44%
F'4	96%	100%	77%
F'5	100%	100%	92%
F'6	100%	100%	100%

Based on these fractions and the number of missiles from each structure type, the missile inventories for each tornado intensity are calculated in Table 5-1b. These missile inventories would be used in the EEFP calculations for the example site.

Table 5-1b: Example Missile Inventory Calculation

		Number of Missiles			
		Building Type			
Tornado Intensity	Zonal	Wood-framed	Pre-manufactured	Engineered and Pre-engineered	Total
F'2	100,000	5,000	17,500	1,000	123,500
F'3	100,000	36,500	47,500	44,000	228,000
F'4	100,000	48,000	50,000	77,000	275,000
F'5	100,000	50,000	50,000	92,000	292,000
F'6	100,000	50,000	50,000	100,000	300,000

Note that robustness depends on the dimensions (primarily thickness, but also diameter for pipes) of the target and target failure mode. For each robust target, documentation should be provided justifying the robust category used for the target. If the target does not meet the specifications for any of the robust categories, the total number of missiles should be used to calculate the EEFP for that target.

Table 5-2: Missile Inventories for EEFP Calculations

Category	Target Description	Failure Mode	Percentage of Total Missiles
A	Steel Pipe – at least 16” diameter and 3/8” thickness	Crushing/Crimping of > 50%	5%
B	Steel Pipe – at least 16” diameter and thickness less than 3/8” but at least 0.125”	Crushing/Crimping of > 50%	55%
C	Steel Tank – at least 0.25” thickness	Penetration or Global Failure	40%
D	Steel Tank – less than 0.25” thickness	Penetration or Global Failure	50%
E	Steel Pipe – at least 10” diameter and 3/8” thickness	Penetration or Global Failure	35%
F	Steel Pipe – Less than 10” diameter or 3/8” thickness	Crushing/Crimping, Penetration, or Global Failure	50%
G	Steel Door	Penetration or Global Failure	45%
H	Concrete Roof – Reinforced, at least 8” thick	Penetration or Global Failure	1%
I	Concrete Roof – Reinforced, at least 4” thick	Penetration or Global Failure	20%
J	None (i.e., not a ‘robust’ target)	Any/All	100%

Failure modes listed in Table 5-2 are described:

- Crushing/Crimping of >50%: The pipe is crushed such that the flow area through the pipe is reduced no more than 50% of the original flow area. This failure mode would be used primarily for exhaust pipes (e.g., for diesel generators, steam relief valves).
- Penetration: Refers to localized perforation (or punching shear) and is dependent on pipe (or wall) thickness, rather than structural response of a pipe, tank, or concrete panel. Appendix C describes the empirical equations that are used for predicting this failure mode.
- Global Failure: Refers to the overall flexural response (or bending) of pipes, tanks, and concrete panels. These ‘global’ modes are influenced by structural section properties (wall thickness, diameter, etc.) as well as member span and boundary conditions. Appendix C describes the analytical models developed to predict deformations of pipes, tanks, and concrete panels

Ensure that credit is not taken for beneficial failure modes of SSCs struck by tornado missiles. For example, do not consider that an exhaust pipe will shear before being crimped, unless it is true for all missile types at all speeds. Exceptions are SSCs designed to fail to prevent an adverse failure mode (e.g., turbine building siding coming off to prevent structural failure, plastic piping designed to break/shear as opposed to being crushed).

Some examples for determining missile inventories for use in EEFP calculations, based on the type of component and results of the site-specific missile inventory, are provided in Table 5-3.

Table 5-3: Example Missile Inventories for Different Targets (For F'6 Tornado EEFP Calculations)

No.	Target Description	Robust Target?	Failure Mode	Robust Category	#Missiles for EEFP[(1)]
1	Electrical panel	No	NA (Hit)	NA	240,000
2	Level Detector/Indicator	No	NA (Hit)	NA	240,000
3	Ventilation Fan	No	NA (Hit)	NA	240,000
4	Emergency Diesel Generator Exhaust Pipe: 16" diameter, 3/8" thick steel	Yes	Crimping/ Crushing >50%	A	12,000 (5% of 240,000)
5	Condensate Storage Tank: 3/8" thick steel	Yes	Penetration	C	96,000 (40% of 240,000)
6	Service Water Piping: 6" diameter, 3/16" thick steel	Yes	Penetration	F	120,000 (50% of 240,000)
7	Reinforced Concrete Roof: 6" thick	Yes	Penetration	I	48,000 (20% of 240,000)

(1) If 240,000 Total Missiles is not bounding, use site specific missile inventory for total missiles (robust percentages can still be applied).

5.3 Target Exposed Area

The *Target Exposed Area* is the area (ft^2) of an SSC that is exposed to being struck by a tornado missile (i.e., that has no or inadequate missile protection[6]) which can result in the failure of the SSC. Thus, it must be (1) exposed to tornado missiles and (2) if struck, will prevent the SSC from performing its function as modeled in the PRA. This section provides details on various types of SSCs and how their Target Exposed Area should be calculated for the EEFP.

5.3.1 Types of Targets and Calculations

The types of SSCs that should be considered vulnerable to tornado missile failures are those not located inside Category I structures. If an SSC is shielded by walls with 18" of reinforced concrete, roofs with 12" of reinforced concrete, and/or 1" of steel plate, no EEFP calculations are required (see Appendix B). Note that some SSCs inside Category I structures may still be vulnerable to tornado missiles from missiles entering through openings or penetrations in the walls or roofs of such structures. Additionally, roofs that are less than 12" thick reinforced concrete will also allow some missile penetration. These situations are discussed further in this subsection.

Some examples of the types of SSC exposed to tornado missiles are discussed here. For exposed SSCs outside Category I structures, the target area can generally be estimated using the smallest polyhedron(s) that encompasses the target. For SSCs inside Category I structures that can be hit by tornado missiles entering through a non-qualified penetration (e.g., access door, ventilation louver), the

[6] See Section 5.3.2 for a discussion of target shielding.

target area is the either the area of the opening or the area of the target (based on an encompassing polyhedron), whichever is smaller.

Tanks

The simplest, yet most conservative, approach for modeling a tank is to define a polyhedron that bounds the dimensions of the tank and its subcomponents (i.e., exposed tank discharge piping and valves, level detectors and indicators, or other critical SSCs associated with the tank).

A more refined method would model a tank as a cylinder, such that the surface area calculation for the tank is straightforward (i.e., Area = πdh, where d is the diameter and h is the height of the tank). The top of the tank can generally be neglected, since it would (1) require a vertical missile to penetrate the top of the tanks and (2) require the missile, having penetrated the top of the tank, to affect suction from the tank. Additional area should be added for critical SSCs or subcomponents associated with the tank. Note that some SSCs associated with a tank, such as a level detector cannot be considered as a robust target, so the total missile inventory would be used in the EEFP for that portion of the tank's total failure probability. Example 1 in Section 5.5 includes associated SSCs in the tank area calculation.

Since tanks may be more than 30 feet in height, the total tank failure probability can be calculated by summing the tank failure probability (EEFP) from near ground missile strikes (i.e., ≤30') with the EEFP from elevated missile strikes. Since the MIP values for elevated targets (>30') are less than the near ground MIP values, this will reduce the overall failure probability of the tank. Alternatively, different basic events for the near ground and elevated strikes may be developed.

Similar to excluding the top of the tank, portions of the tank above the normal water level or above the success criteria minimum water level (for the applicable event sequence(s)) can be excluded from tank failure probability calculations. If a missile were to penetrate the tank above the minimum required water level, the tank would still contain the volume of liquid needed for success.

For tank failure due to vertical missiles penetrating the top of tank or the side of a tank above the water level is that the missile, the analyst should consider whether such a missile can cause some failure of the tank suction after penetrating the tank. Missile velocity, even for very energetic missiles, decreases significantly after travelling through only a few feet of water, so the main concern would be plugging of the suction. Although this is considered unlikely, the analyst should qualitatively evaluate the potential.

An example of the lower part of a condensate storage tank is shown in Figure 5-2. The following are items of interest:

- The piping connected to the outside of the tank is the suction source for the pumps fed from the CST. If this exposed pipe or the isolation valve is damaged by a tornado missile, the tank would not perform its function to provide a water supply. Therefore, the EEFP associated with the piping and valve would need to be included in the total failure probability for the tank. Even if a polyhedron were drawn around the piping and the valve, it would not add much to the total area of the tank.
- The equipment highlighted by the red outline is a sample connection with heat tracing to keep it from freezing. If the sample connection were struck and sheared off, it would produce a leak in the tank. However the connection does not protrude much from the tank, and if that area of the tank were hit by a damaging missile, it would be considered to fail. So, this additional part of the

tank could be neglected in the area calculation. Documentation would be expected to describe the basis for excluding the target.

- A pair of drain valves in series is protruding from the bottom of the tank and highlighted by a green outline. If the piping and valves were sheared off, this would result in draining the tank.
- A junction box and conduit for tank grounding are highlighted by a yellow outline. Failure of this equipment would not affect the PRA functionality of the tank.

Figure 5-2: Example Tank

<u>Pipes</u>

Pipes are similar to tanks, in that they can be considered cylindrical targets, such that Area = πdl, where d is the diameter and l is the length of pipe being considered. The analyst should determine whether exposed pipe ends (e.g., open exhaust pipe ends) should be considered in the area of the pipe. If exposed sections of pipes include additional SSCs that are required to function or not be failed, their failure probability should be added to the pipe failure probability. In some cases, these additional SSCs would not be considered robust (e.g., valve operators, flow detectors) and the total inventory of missiles would be used for that portion of the pipe's total failure probability. Manual and check valves can generally be considered robust, in the same category of the pipe. The analyst should document any assumptions regarding valves and other components associated with piping targets.

An example of exposed service water piping (the light blue colored pipe) is shown in Figure 5-3. Most of the surface area of this pipe could be hit by a tornado missile. However, an argument could be made that some portions of the piping (e.g., on the very far right of the picture) are very close to either the ground or a wall, and thus may not truly be exposed to a credible tornado missile flux. In such cases, a small portion of the pipe surface area may be excluded from EEFP calculations, although it is unlikely to result in a meaningful reduction. Any such reduction to the effective surface area must be documented with the engineering judgment used.

Figure 5-3: Example Piping

Pumps/Compressors/Fans

If a pump (or compressor or fan) and/or its subcomponents are exposed, the simplest solution is to consider a polyhedron(s) that encompasses the pump, motor, electrical subcomponents (e.g., cables, junction boxes, controllers), and any other exposed subcomponents whose failure would result in the failure of the pump. Although many pumps are typically sturdy and can withstand some mechanical shocks, the pump/compressor/fan and its subcomponents are considered not robust from the missile inventory perspective (i.e., the total missile inventory should be used in the EEFP). The surface area encompassing the pump/compressor/fan and its subcomponents should be relatively small, resulting in a relatively low EEFP. However, the licensee may perform more detailed calculations using the surface area of individual components.

An example of an exposed air compressor, its subcomponents, and support components is shown in Figure 5-4. This air compressor is inside a Category I building but is directly exposed to tornado missiles through a large 12’ x 24’ (288 ft^2) roll-up door in the building. If the compressor, any of its subcomponents, or the electrical and cooling water supports are struck by a damaging tornado missile, the compressor would not function. Therefore, a polyhedron encompassing all those SSCs would be used to determine the *Target Exposed Area* for the compressor EEFP. The bottom of the polyhedron would be excluded from the *Target Exposed Area* calculation since it is the floor of the building and a missile cannot hit the SSCs from the direction of the floor. Consideration could also be given to not including the far side of the compressor, from which missiles would not travel (the compressor is being viewed from the opening).

Figure 5-4: Example Air Compressor with Subcomponents

Valves

Although valve bodies and their connections to piping are generally robust, their operators, actuators, and support systems (e.g., instrument air, electrical power) are not. When calculating the target area for a valve, all the exposed subcomponents and applicable support components (e.g., solenoid valves, controllers, cables, instrument air tubing) need to be included in the total valve area. When determining the number of missiles, the full missile count can be used for the combined components and subcomponents, or the calculation can be refined to apply the correct missile counts to individual components. It is important to understand the impact of the failure of support systems on the desired function of the valve. If failure of the support system does not cause a functional failure of the valve, components associated with the support system do not need to be included in the total area used for the valve in the EEFP.

Targets Located Inside of a Category I Structure

Some targets located inside of a Category I structure may be vulnerable to missile hits due to openings in the structure that are not missile barriers or due to roofs that are less than 12” of reinforced concrete (see Appendix C for the basis of required roof thickness). In cases such as these, the target would be considered the surface area of the opening (e.g., door, ventilation louver, piping penetration) through which a missile can travel and strike the SSC in question. For roofs with SSCs below them, the target dimensions should be projected vertically to an area of the roof that is directly above the SSC or its subcomponents.

If the exposed area of a target inside the Category I structure is smaller than the opening through which a missile must pass to strike the target, then the exposed area of the target, when approached from the direction of the opening, should be used. Therefore, the area for vulnerable targets inside Category I structures should be the smaller of the area of the opening or the area of the target itself.

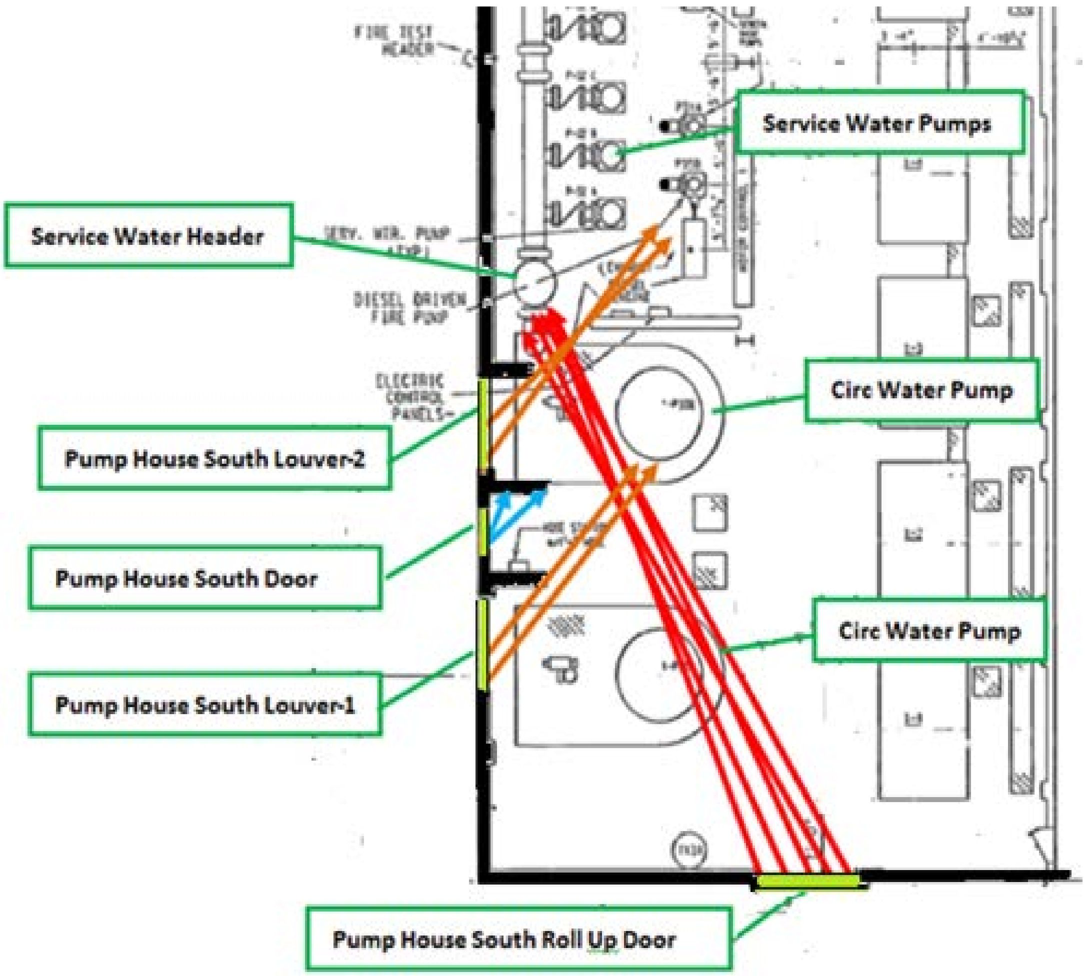
Figures 5-5 through 5-7 provide an example of targets (service water pumps and piping) inside a Category I pump house with unqualified openings (ventilation louvers, a personnel door, and a rollup door). Figure 5-5 shows the outside of the pump house; the light blue rollup door is made of thin sheet metal. Another view is shown in Figure 5-6; this view highlights the large ventilation louvers/openings. The rollup door and louvers will not stop most types of damaging tornado missiles.

Figure 5-5: Example of Service Water SSCs' Missile Exposure from Openings in Service Water Pump House

Figure 5-6: Example of Service Water SSCs' Missile Exposure from Openings in Service Water Pump House

Figure 5-7 shows examples of missile paths through the various openings in the pump house. As seen in this figure, intervening structures (walls and partitions) inside the pump house prevent missiles from the openings on the south side of the building from striking the service water header or pipes (missile paths shown in orange and blue lines). The only exposure of the service water SSCs to missiles is from the rollup doors (indicated in red lines), impacting the service water header. The exposed area of the service water header and supporting subcomponents (e.g., electric cables for isolation valves) is larger than the area of the roll-up door opening. The exposed area could be reduced, taking into account the circulating water pumps between the rollup door and the service water SSCs. However, unless it can be shown by additional analysis, those pumps may not provide a substantial barrier to prevent a missile from striking the service water header. Therefore, in this example, the area considered for the exposed service water system header would be the area of the rollup door.

Figure 5-7: Example of Service Water SSCs Missile Exposure from Openings in Service Water Pump House



Pumphouse Missile Path Through Louvers, Doors, and Roll-Up Doors

The service water pumps and piping inside a pump house (on the top left of Figure 5-7) are also vulnerable to vertical missiles striking the roof above them. The roof thickness for this pump house is less than 12" of reinforced concrete, which would allow missile penetration and potential damage to the service water SSCs. Therefore, they should be considered targets for vertical missiles. Example 3 in Section 5.5 describes modelling of these targets.

5.3.2 Target Shielding

When considering shielding in the context of the TMRE and EEFP, the analyst must consider all reasonable paths by which a tornado missile can strike an SSC. Unlike some design basis considerations, missiles are not limited to horizontal flight paths. Missiles can strike a target from essentially any angle, so that shielding, such as parapet walls or other horizontal missile protection, would not be considered complete shielding. Some targets may be shielded from all but vertical missiles.

Obviously, a missile cannot strike the portion of an SSC that is against the ground or a missile barrier, so those surfaces of an SSC would not be considered in the *Target Exposed Area* calculation. However, partial shielding is possible for SSCs that may be close to the ground or a missile barrier. For example, the portions of the service water piping shown on the far right side of Figure 5-3 could be considered partially shielded from missile originating from below or behind the piping (the pipe is very low to the ground and close to a solid wall behind it). This could be used to reduce the area of the pipe in the EEFP calculation.

Targets may be shielded from tornado missiles from specific directions, based on the location of the target with respect to other SSCs and barriers. The effect of shielding can be accounted for by use of the robust missile factors in Table 5-2 or by reducing the effective target surface area.

SSCs or other intermediate barriers blocking missile paths to a target can be considered as shielding or barriers, by considering the equivalent steel or concrete thickness. For the shielded portion of the target only, this would allow for a reduction in effective missiles. For example,

- Heat exchangers could provide the equivalent thickness of a steel door (category G in Table 5-2, which is equivalent to 0.1” of steel).
- Reinforced concrete walls or columns that are 12” thick could provide the equivalent thickness of 4” thickness roof (Category I of Table 5-2) for F’2 intensity only (wind speed below that used for vertical missile impact to roofs in Appendix C
- The sum of multiple intervening roof, floor, or wall thickness can be considered when screening a target or using of robust percentages (such as a 12” and 6” wall protecting a target is equivalent to an 18” wall)

SSCs may be shielded from missile strikes from certain directions, reducing the effective target area by excluding target surfaces or portions of surfaces. For example,

- A target located near large Class I structures that would preclude missiles from striking the targets from certain directions (e.g., piping or conduit mounted on a wall, exhaust stack located next to parapet wall, tank adjacent to a Class I building). In this case, the portion of the target shielded by the Class I structure would not be included in the target area calculation.
- Piping and supports could reduce the effective area of an opening or penetration, if the piping and support thickness is at least 1” of steel.

The basis for crediting shielding in reducing target surface area or providing equivalence to other robust targets/barriers should be justified and documented on a target-specific basis.

5.3.3 Target Elevation

Different MIP values are provided for Near Ground and Elevated targets in Table 5-1; the differences in MIP values due to target elevation are described in Section 5.1. For targets located completely above or below 30’, the use of the correct MIP value will account for the likelihood that elevated targets are less likely to be hit by tornado missiles.

However, some tall targets, such as tanks, can span both elevation regions. For example, the tank in Figure 5-2 is approximately 36’ tall. Therefore, approximately 17% of the tank is above 30’ and the EEFP calculation can account for this by using the Near Ground MIP for the first 30’ of the tank and the Elevated MIP for the last 6’. This will reduce the EEFP as compared to assuming that the entire tank area is associated with the Near Ground MIP, which is approximately a factor of 2 lower in the F’2 to F’4 range.

5.4 TARGET FRAGILITIES

For the purposes of the EEFP, the fragility of an SSC is the conditional probability of the SSC failing, given that it is hit by a tornado missile. For the TMRE, all target fragilities are assumed to be 1.0. This is one of the factors that results in conservative EEFP calculations, as compared to the missile-induced failure probability of an SSC calculated in a HW PRA. This is especially true for more rugged SSCs at lower tornado intensities, where the expected failure probability is lower than at higher tornado intensities. However, some accounting for robust target fragilities is implied in the use of lower missile populations for robust targets.

5.5 EXPOSED EQUIPMENT FAILURE PROBABILITY (EEFP) EXAMPLES

Recall that the EEFP is defined as:

EEFP = (MIP) x (# of Missiles) x (Target Exposed Area) x Fragility

> *The Missile Impact Parameters (MIP)* are provided in Table 5-1. There are separate MIP values for each tornado category F’2 through F’6, and the MIP value also depends on the target elevation.
>
> Bounding values for *# of Missiles* are provided in Table 5-1, with different values for each tornado category F’2 through F’6. The missile inventories in Table 5-1 are total missiles, used for non-robust targets. For robust targets, a fraction or percentage of the total missiles that can damage each category of robust targets is provided in Table 5-2. The different categories are based on the target characteristics (e.g., thickness of steel). If the bounding values in Table 5-1 are not applicable to the plant, Section 5.2 provides instruction on how to use a site-specific inventory.
>
> *Target Exposed Area* is determined for each target based on the guidance provided in Section 5.3.
>
> *Fragility* is equal to 1.0.

Each SSC will have a separate EEFP for each tornado category F’2 through F’6. How this is accomplished depends on the method by which tornado missile failures are incorporated into the PRA model, as discussed in Section 6.5. The only difference between the EEFP values for the different tornado categories will be the MIP values and the number of missiles, the exposed area and fragility will be constant between tornado categories.

As described in Section 5.3, an SSC failure probability for a given tornado category may be the sum of multiple EEFPs, based on the complexity of the target area calculation. For example, a tank may include sections above and below 30’ elevation. Another example would be an exposed pump that has an exposed motor controller, which is not adjacent to the pump.

The examples provided in this section include configurations that require multiple EEFP calculations for an SSC, per tornado category.

Example 1: Condensate Storage Tank from Figure 5-2. Calculate EEFP for F’2 tornadoes

This is a steel tank with the following dimensions: Diameter (d) = 40’; Wall Thickness = 3/8” at the bottom, tapering to 1/4” at the top; Height above grade (h) = 36’; Height of Water at Minimum Required Water Level (above grade) = 24’.

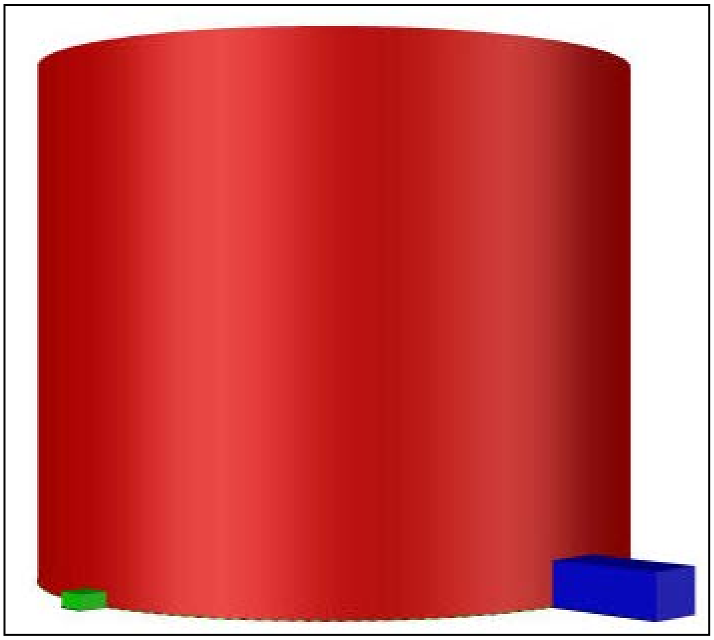
The components and subcomponents associated with the CST are:

Steel Pipe: 6” diameter, 3/8” thick, 8’ long with a manual valve. This will be modeled as a rectangular polyhedron (blue box) in Figure 7-8.

Sample connection with heat tracing (highlighted by red outline in Figure 5-2). This is a very small target protruding less than 6” from the tank and the sample line is only ½”; if the tank were struck by a damaging missile in this area, the tank would be considered failed. Since it will add an inconsequential area to the tank if modeled and will not necessarily cause tank failure, it is excluded for simplicity.

Drain Valves (highlighted by green outline in Figure 5-2). These are also small targets, but they are larger than the sample connection protruding out from the tank by about 2’; they will result in significant water loss if they are sheared off by a tornado missile. The drain valves will be modeled as a rectangular polyhedron (green polyhedron) in Figure 5-8.

Figure 5-8: Simplified View of CST



EEFP1: Lower portion of the tank, from grade to 30' above grade.

Use Near to Ground MIP ($\leq$ 30') and missile inventories based on Table 5-1 and Category C from Table 5-2.

Area1 = πdh = π*40*30 = 3770 ft^2

EEFP1(F'2) = 1.4E-10*(40%*155,000)*3770 = 3.3E-2/tornado

EEFP2: Upper portion of the tank (30' – 36').

Use Elevated MIP (>30') and 25,000 missile inventories based on Table 5-1 and Category C from Table 5-2.

Area^2 = πdh = π*(40)*(36-30) = 754 ft^2

EEFP2(F'2) = 5.8E-11*(40%*155,000)*754 = 2.7E-3/tornado

EEFP3: Piping extending out from tank (blue box).

Use Near to Ground MIP ($\leq$ 30') and missile inventories based on Table 5-1 and Category F from Table 5-2. Manual valve is robust, assume the same level of robustness as the pipe. Bound pipe with a polyhedron with length(l) = 8', width(w) = 4' and height(h) = 4'.

Area3 = 2lh+wh+lw = 2*8*4 + 4*4 + 8*4 = 112 ft^2

EEFP3(F'2) = 1.4E-10*(50%*155,000)*112 = 1.2E-3/tornado

EEFP4: Drain Valves (green box).

Use Near to Ground MIP ($\leq$ 30') and missile inventories based on Table 5-1 and Category F from Table 5-2. Manual valves are robust, equivalent to the pipe size (4" diameter x 3/8" thick). Pipe and valves bounded by box with length(l) = 2', width(w) = 1' and height(h) = 1'.

Area4 = = 2lh+wh+lw = 2*2*1 + 1*1 + 2*1 = 7 ft^2

EEFP4(F'2) = 1.4E-10*(50%*155,000)*7 = 7.6E-5/tornado

Therefore, the total failure probability of the CST for an F'2 tornado is:

EEFP(F'2) = EEFP1(F'2) + EEFP2(F'2) + EEFP3(F'2) + EEFP4(F'2) = 3.7E-2/tornado

The bottom 30' of the tank is the primary contributor to the total EEFP (nearly 90%), due to the area of the tank. The EEFP for the piping protruding from the tank is about ½ the EEFP for the upper part of the tank, even though the upper part of the tank is nearly 6x the area. However, the EEFP for the upper part of the tank makes use of a lower MIP (due to elevation) and lower missile count (tank more robust than the piping). Finally, the drain valves contribute less than 0.5% to the total EEFP. This validates the decision to not include the sample connection in the total EEFP calculation.

Since the tank only needs to be filled to 24’ above grade to provide adequate water supply, the tank area could be reduced by assuming that only the first 24’ of the tank elevation above grade will result in failure if struck by a tornado missile. This would reduce EEFP1 and eliminate the need for calculating EEFP2, reducing the total EEFP for F’2 to 2.6E-2/tornado, a 25% reduction.

Example 2: Air Compressor from Figure 5-4. Calculate EEFP for F’2 tornadoes

In calculating the target exposed area for the air compressor in Figure 5-4, an assumption is made that if any part of the compressor, the motor, electrical support equipment (e.g., control panel, wiring), cooling water piping, or compressed air piping is struck by a tornado missile, the compressor will fail. A simple way to model the compressor and its subcomponents would be to create a single rectangular polyhedron that encompasses the entire assembly, with additional areas to represent the cooling water and compressed air piping, as shown in Figure 5-9. The red box represents the compressor, motor, and attached subcomponents. The cooling water piping is the blue shape, the air inlet pipe is green, and the air discharge pipe is yellow.

Drawings were consulted and field measurements were taken; the dimensions of the objects are:

Compressor/motor/etc. (red): 10’ width x 7’ depth x 6’ height

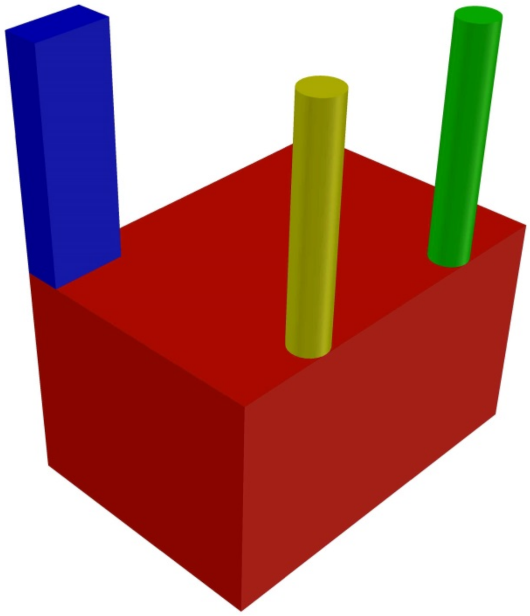
Service water pipe (blue): 2’ width x 1’ depth x 6’ height

Air inlet pipe (green): 6” diameter x 6’ height

Air discharge. pipe (yellow): 6” diameter x 6’ height

Note that the views of the compressor in Figure 5-4 are from the direction of the roll-up door. Hence, the back of the compressor would not be exposed to missiles coming through the opening. Both sides of the compressor assembly and the top are exposed to missiles. Additionally, the back of the service water pipe, inlet air pipe, and air discharge pipe would not be exposed to missiles. Since the inlet and discharge pipes are treated as cylinders, the entire area of the cylinder (less the top and bottom ends) is used as a simplification. This simplification has minimal impact on the total area (see calculations below).

Figure 5-9: Simplified Representation of Compressor and Support Components



The total area of the individual targets in Figure 5-9 are:

Red: 1 x 10’ x 6’ + 2 x 7’ x 6’ + 1 x 7’ x 10’ = 214 ft^2

Blue: 1 x 2’ x 6’ + 2 x 1’ x 6’ = 24 ft^2

Green: π x 0.5’ x 6’ = 9.4 ft^2

Yellow: π x 0.5’ x 6’ = 9.4 ft^2

Therefore, the total area of the target is: 256.8 ft^2

Although the pipe targets associated with the compressor could potentially be considered robust, they are small contributors to the overall area. Therefore, the entire target is considered not robust, although this could be revisited if the target were determined to be risk significant. The entire target is located at less than 30’ elevation. Therefore:

EEFP(F’2) = 1.4E-10*155,000*256.8 = 5.6E-3/F’2 tornado

Note that the area of the opening, through which missiles could travel to strike the compressor, is 288 ft^2. This is about 10% larger than the calculated target area, but it could be used for the target area and is a simpler calculation. However, the purpose of this example was to provide a complex configuration for the purposes of illustrating the area calculations.

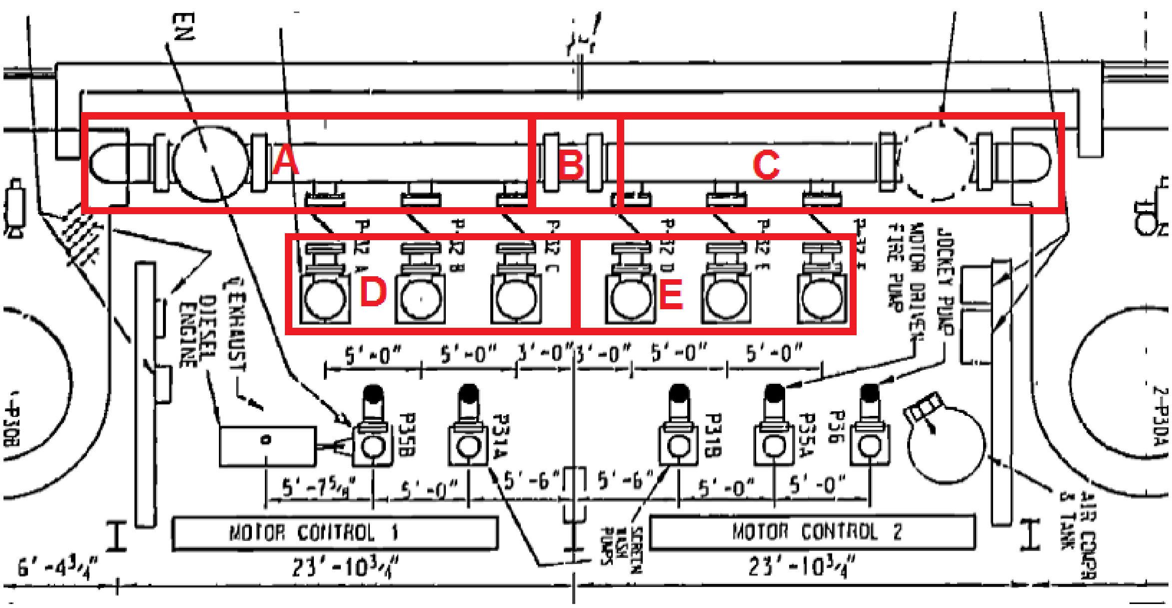
Example 3: Service Water SSCs from Figure 5-7. Calculate EEFP for all tornadoes (F'2 – F'6)

The service water piping and pumps in the pump house (partially represented in Figure 5-7) are vulnerable to missiles coming through the rollup door, as shown by the red lines in that figure. They are also vulnerable to vertical missiles striking and penetrating the roof above the SSCs.

Figure 5-10 shows areas outlined in red that are selected to represent targets in the pump house. These targets were chosen based on the system success criteria, which requires 3 service water pumps and one service water header, taking into account the ability to cross-tie headers. A rectangle bounding the SSCs is used to represent the target on the pump house roof. If that target is hit, the SSCs enclosed by the rectangle in Figure 5-10 are assumed to be hit. The headers (Targets A and C), the cross-tie (Target B) and the 2 sets of pumps (Targets D and E) are each modeled separately in the PRA.

From Figure 5-7, the header represented by Target A and three service water pumps represented by Target D can be hit from missiles coming through the roll-up door, in addition to those penetrating the roof. The area of the roll-up door is used as the target area (as opposed to the area of the header or pumps); the EEFP calculated based on the door area is assigned to both Target A and D. EEFPs for Targets B, C and E are calculated based on missile strikes on the roof, only.

Figure 5-10: Target Areas Encompassing Service Water Pumps and Piping



The elevation of the roof (not of the ultimate target SSCs) is used to choose the MIP (between near ground and elevated). The roof elevation is where the missile initially strikes, so the MIP appropriate to the roof elevation should be used. In this example, the roof is only 18' above grade, so the near ground MIP would be used, regardless.

The areas measured for these targets are:

A (roof): 750 ft^2 / (door): 45 ft^2

B: 568 ft^2

C: 750 ft^2

D (roof): 568 ft^2 / (door): 45 ft^2

E: 471 ft^2

In this example, the roof is constructed of 5" thick reinforced concrete. As such, only 20% of the total missiles can penetrate the roof (Category I from Table 5-2).

Missiles striking the rollup door can result in failure to Targets A and D, as described above. Since Target A is 16" service water piping, 35% of the total missiles (Category E from Table 5-2) could potentially be used in the EEFP calculation. However, there are motor and valve controls, as well as other support systems in the area that are not robust. Therefore, without further investigation, the total number of missiles from Table 5-1 will be used for the missiles hitting the roll-up door and ultimately damaging Target A. Since pumps are considered non-robust (see Section 5.3.1), the total missile inventories are used for Target D EEFP calculations.

The EEFPs for each target and F'-scale tornado are shown in Table 5-4. Note that the Target A EEFP from the roll-up door is about 30% of the EEFP from the roof. Even though the door target is relatively small, the fact that the total missile inventory is being used makes a difference.

Table 5-4: Pump House Target EEFP Values

		Target	**Target A (roof)**	**Target A (door)**	**Target B**	**Target C**	**Target D (roof)**	**Target D (door)**	**Target E**
		Target Area (ft^2)	750	45	568	750	568	45	471
		% of Missiles	20%	100%	20%	20%	20%	100%	20%
Tornado Category	**Near Ground MIP**	**Total Number of Missiles**							
F'2	1.4E-10	155,000	3.3E-03	9.8E-04	2.5E-03	3.3E-03	2.5E-03	9.8E-04	2.0E-03
F'3	4.6E-10	155,000	1.1E-02	3.2E-03	8.1E-03	1.1E-02	8.1E-03	3.2E-03	6.7E-03
F'4	7.9E-10	205,000	2.4E-02	7.3E-03	1.8E-02	2.4E-02	1.8E-02	7.3E-03	1.5E-02
F'5	2.0E-09	240,000	7.2E-02	2.2E-02	5.5E-02	7.2E-02	5.5E-02	2.2E-02	4.5E-02
F'6	3.1E-09	240,000	1.1E-01	3.3E-02	8.5E-02	1.1E-01	8.5E-02	3.3E-02	7.0E-02

5.6 CORRELATION BETWEEN TARGETS

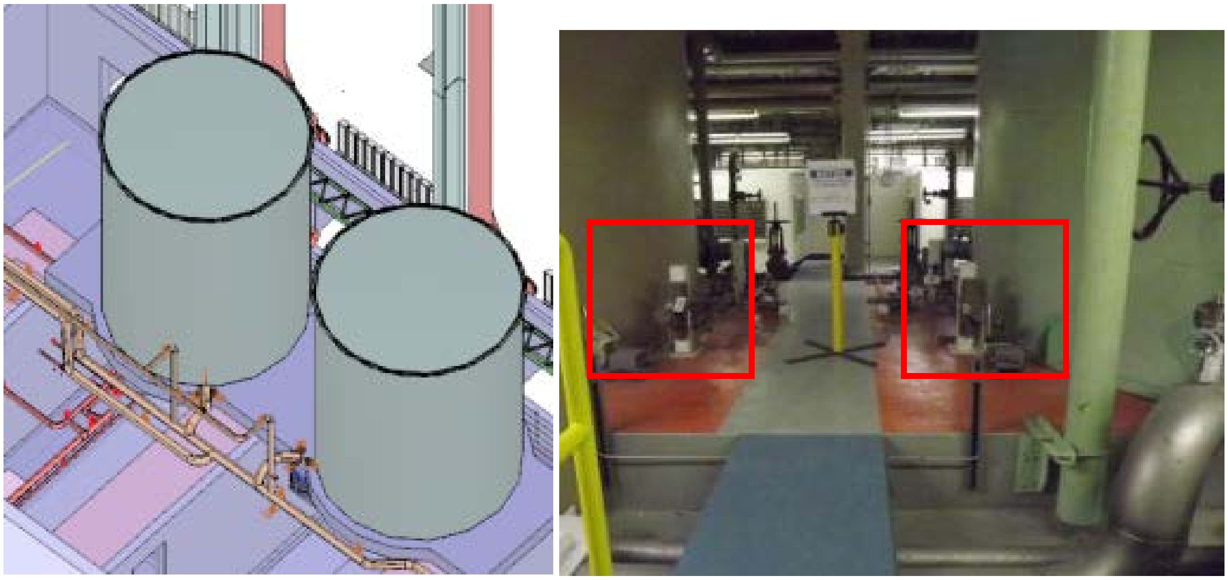
In some situations, two or more vulnerable SSCs may be physically situated in such a way that they may be considered "correlated." A correlated vulnerable target is susceptible to common mode failure. Correlated targets are typically located close together, such that a single missile is capable of striking and damaging more than one target, simultaneously. When considering the range of missiles capable of striking correlated targets, the full range should be initially considered. The list may be narrowed in scope based on other physical factors, such as elevation and shielding by buildings or other structures.

In the cases of correlated targets, there are different approaches available for calculating the effective surface area. Once correlated targets have been identified, the surface area can first be calculated coarsely, and then refined appropriately as needed.

5.6.1 CORRELATED TANKS EXAMPLE

Figure 5-11 shows an example of two tanks that have instrumentation in between the tanks that are vulnerable to a single missile strike (i.e., correlated). The instrumentation for each tank is highlighted with a red box in the picture on the right. Although unlikely, it is possible that a single missile can damage both sets of instrumentation such that both tanks would be considered unavailable.

Figure 5-11: Correlated Tanks with Instrumentation



A very conservative approximation would be to consider both tanks fully correlated, such that a rectangular polyhedron is used to encompass both tanks and the instrumentation. This is shown in Figure 5-12. The Target Exposed Area that would be calculated for this object would be very large and not representative of the area that of concern, i.e., the target area for the correlated targets. Furthermore, since the correlated targets are non-robust (instrumentation), the total missile inventory would be used in the EEFP calculation.

However, if this treatment provides acceptable risk calculations, it is conservative and can be easily justified. On the other hand, it is likely that the treatment will be too conservative, and another approach would need to be taken. Figure 5-13 provides an alternative and more realistic target configuration. In this figure, each tank is a separate target (in red), and the correlated target is the green box in between the two tanks. This treatment allows the tanks to be treated separately and as robust targets, thus allowing the use of lower missile counts. Furthermore, the common area that results in the failure of both tanks (in green) is much smaller and less likely to be risk significant.

Figure 5-12: Single Target Model for Correlated Tanks

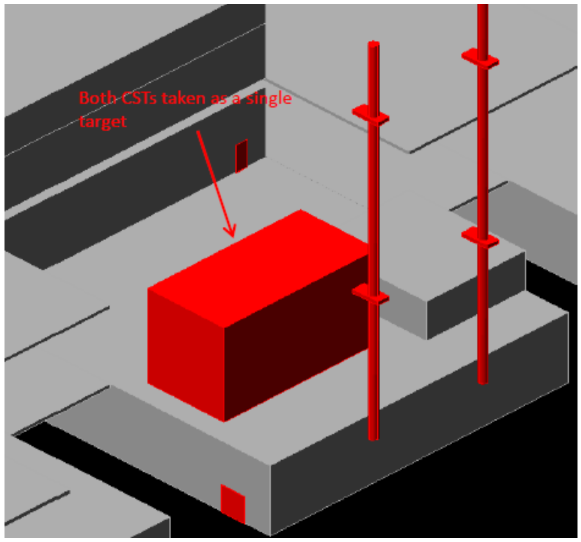
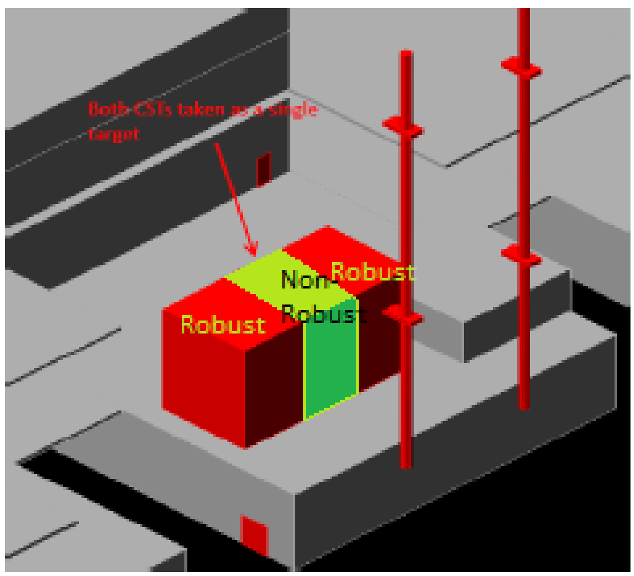


Figure 5-13: Single Target Model for Correlated Tanks

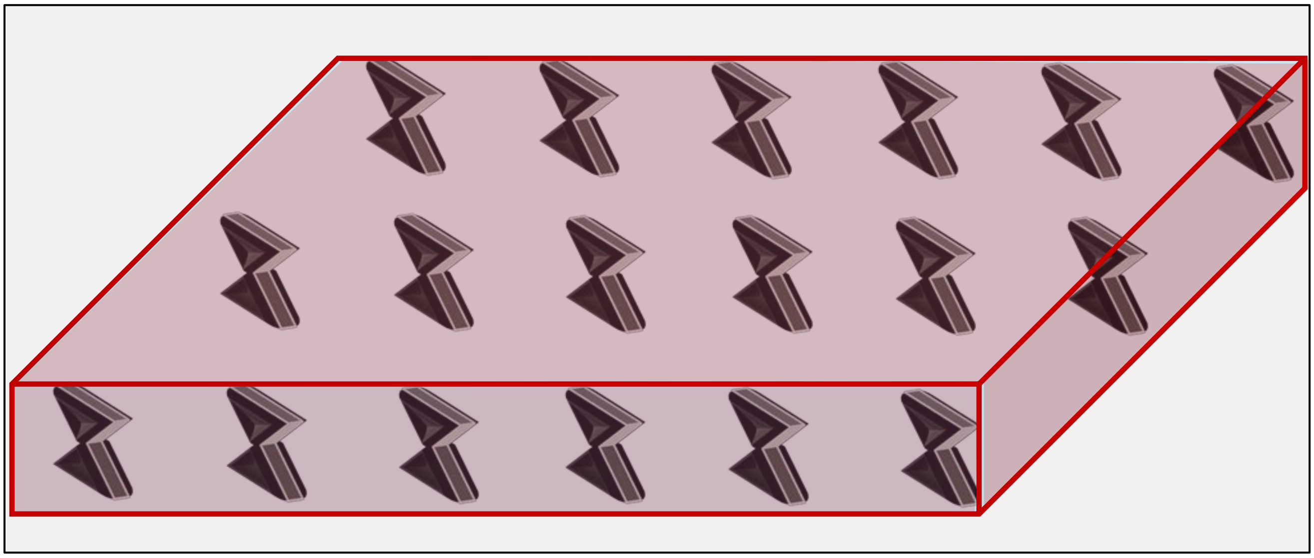


5.6.2 CORRELATED SAFETY VALVES EXAMPLE

In this example, consider a 3 by 6 array of Main Steam Safety Valves (MSSVs), where the individual valves are in close physical proximity to each other in two dimensions. Valves may be modeled individually or in groups. These approaches for correlating shown in this example can also be used for other situations, such as closely co-located and correlated steam relief exhaust stacks that penetrate a reinforced concrete roof.

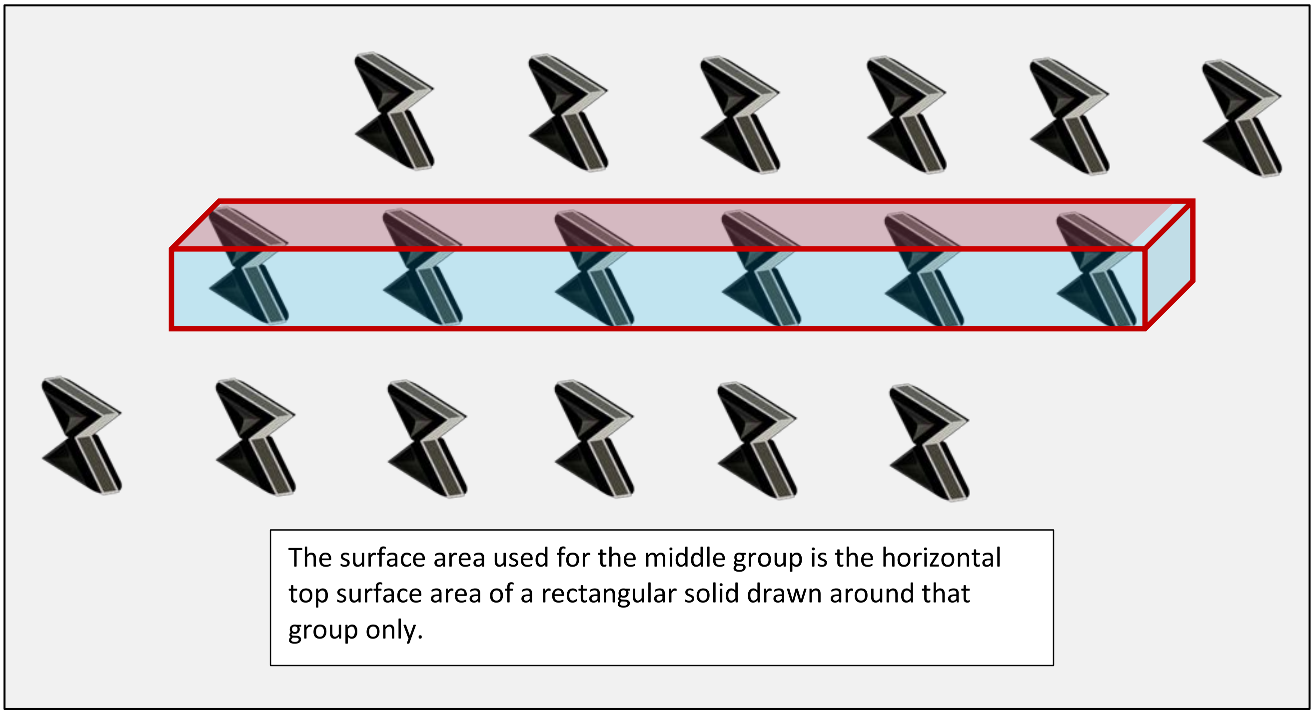
Similar the tank example in Section 5.6.1, all valves could be considered vulnerable to missiles from all directions. This is the starting point; to address target correlation, assuming each missile strike results in common mode failure of all targets (see Figure 5-14). This also assumes that the valves are close enough to each other that a single missile can indeed hit all the targets.

Figure 5-14: Correlation of Single Group of MSSVs



It is possible that the results of the initial calculation will show that the combined SSC is a dominant contributor, and therefore further refinement would be appropriate. For PRA models having success criteria requiring an individual MSSV group (e.g., per SG) to fail, the approach can be refined such that the correlation takes place at the group level only. In Figure 5-15, this would utilize three separate basic events to represent each of the three groups. The outer groups would utilize only the surface area that fully exposes each valve, that is, the top and the outer side of the rectangular solid. The middle group is exposed only from the top. The ends are not used because a single missile will not be able to damage the entire group when approaching from that direction.

Figure 5-15: Correlation of Three Separate Groups of MSSVs



More complex schemes and groupings are provided in Figures 5-16 and 5-17.

Figure 5-16: Complex Correlation Between MSSVs

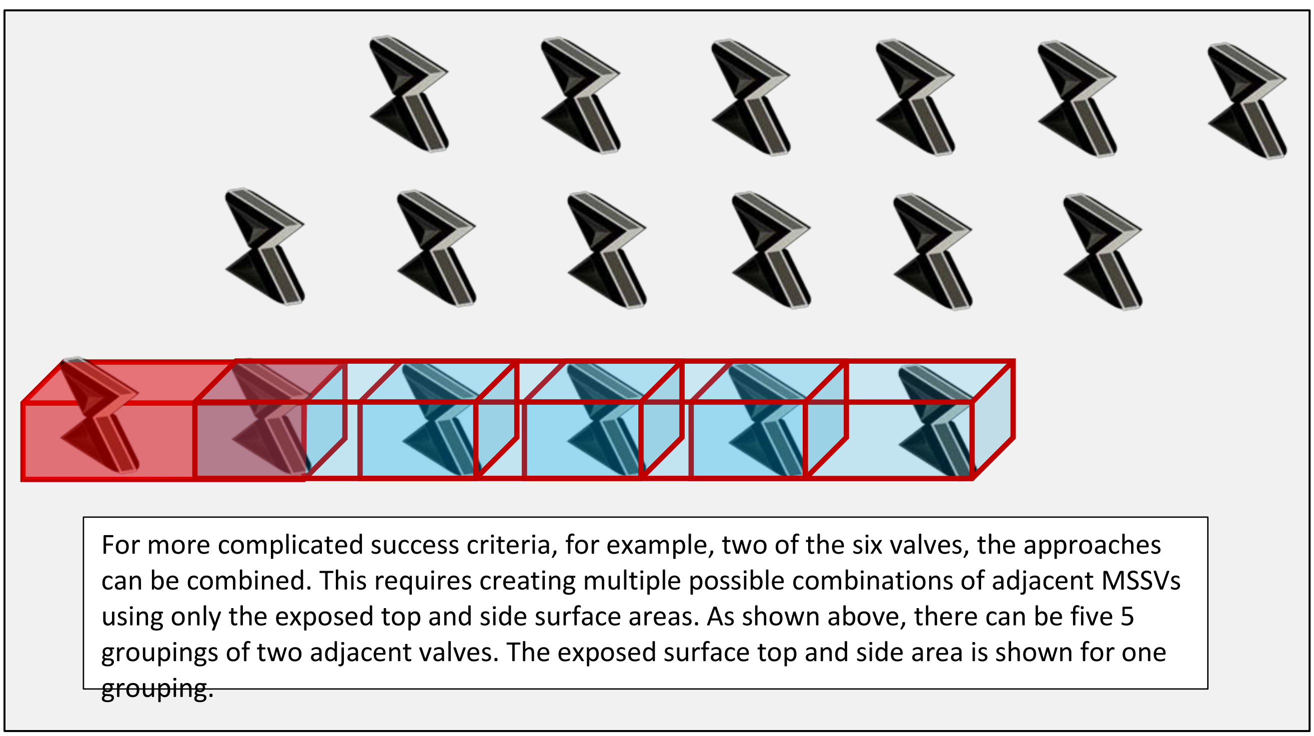
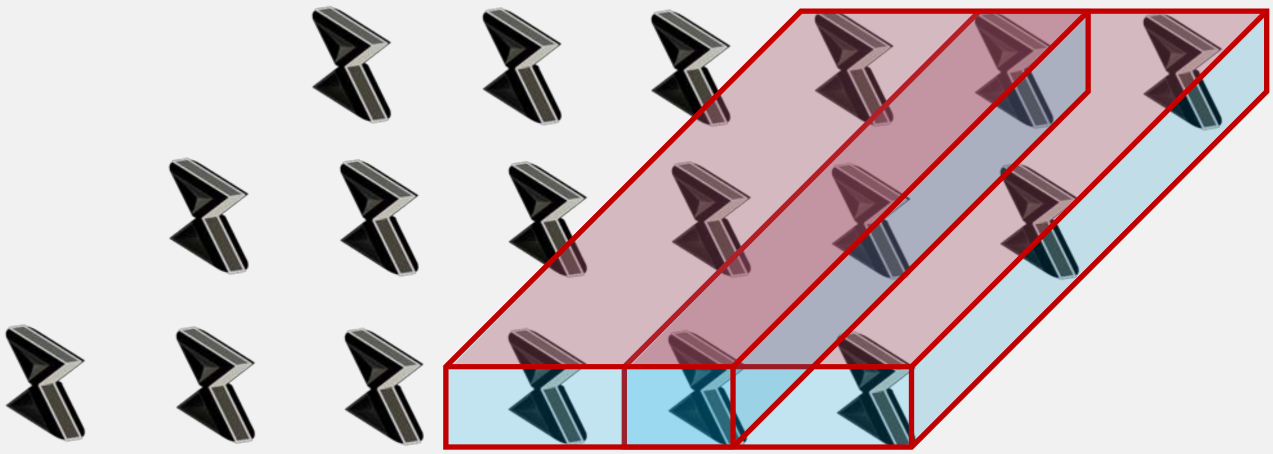


Figure 5-17: Complex Correlation Between MSSVs



For more complicated success criteria, for example, two of six valves, the approaches can be combined. This requires creating many possible combinations of adjacent MSSVs using only the exposed surface areas. Shown above are two combinations where vertical missiles could impact multiple groups.

6 DEVELOP TMRE PRA MODEL

This section provides the detailed guidance for developing the TMRE PRA Model. The TMRE PRA Model is used to calculate the risk associated with the SSCs that are nonconforming with respect to the TMP licensing basis, and is the basis for a risk-informed license application that is to be submitted in accordance with RG 1.174 [Ref. 6.1]. The TMRE PRA Model should be developed from the plant's peer reviewed internal events PRA model of record, since that model should contain the appropriate accident sequence logic and fault trees to be modified. Additionally, using a peer reviewed RG 1.200 PRA model will support adherence to the PRA technical adequacy requirements, after considering the self-assessment of the additional supporting requirements for the TMRE application provided in Section 6.8.

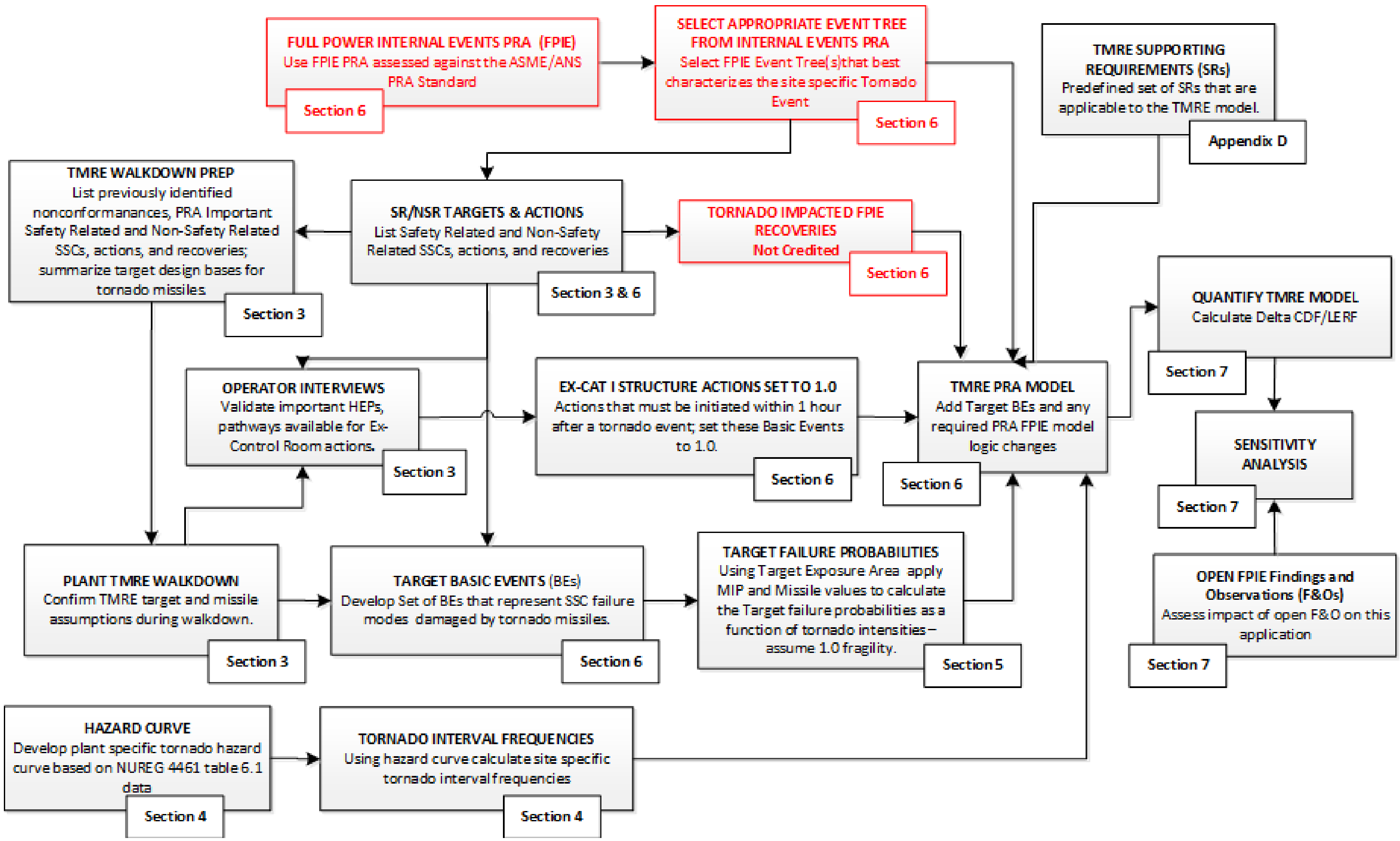
Figure 6-1 is the TMRE flowchart with the relevant actions highlighted for the TMRE PRA model development step of the process. The key elements of developing the TMRE PRA model are:

- Select the event trees and fault trees appropriate for modeling a tornado event from the Internal Events Model of Record (typically the Loss of Offsite Power (LOOP) accident sequence logic)
- Replace the LOOP initiating event with tornado initiating events (F'2 – F'6)
- Remove recovery and repair logic (or set failure probability to 1.0), as recovery and repair are not credited in the TMRE PRA
- Develop Compliant Case and Degraded Case logic or models
- Add tornado wind and missile failure modes to vulnerable SSCs, as appropriate, in the fault tree logic
- Set human error probabilities (HEP) to 1.0, for certain short term actions outside the main control room (MCR) and review transit paths for other ex-MRC operator actions.

6.1 EVENT TREE/FAULT TREE SELECTION

One of the assumptions of the TMRE method is that a tornado event that creates tornado missiles will, at a minimum, cause a Loss of Offsite Power (LOOP) and reactor trip. Therefore, one or more of the internal events PRA LOOP event trees and respective accident sequence logic should reasonably be expected to represent the tornado initiating events in the TMRE PRA. The PRA analyst should review other internal initiating events from the PRA model of record being used to ensure that either (1) a tornado event cannot cause another initiating event or (2) the impact of the initiating event can be represented in the logic selected to represent the tornado initiating event. An example of the second case is a support system loss (e.g., service water loss due to vulnerable service water system piping); the impact of the consequential loss of service water should be included in the accident sequence/fault tree logic in the TMRE PRA model. SSC failures from tornado winds and missiles, including secondary effects from failure of non-conforming SSCs (see Section 6.5.2), should be evaluated during the initiating event review.

Figure 6-1: TMRE Flowchart – Event Tree/Fault Tree Selection



Another assumption of the TMRE method is that the tornado-induced LOOP cannot be recovered. That is, offsite power remains unavailable following the event for the duration of the mission time. This should be taken into account when selecting the event trees and model logic used to represent the tornado event; the logic must allow for the failure of recovery of offsite power and any repair events. Additional consideration in the accident sequence model adapted for tornado events are:

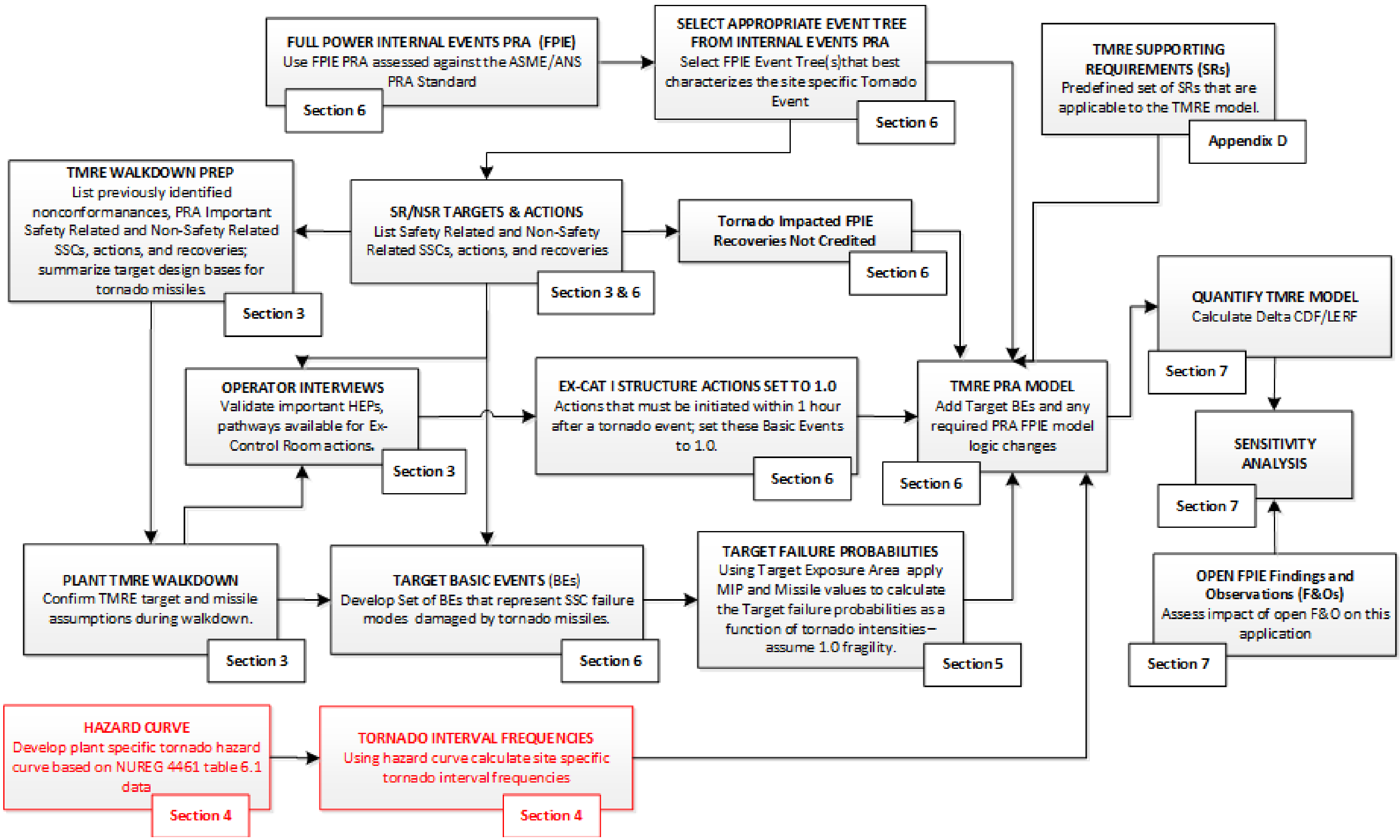
- Mission times may need to be adjusted for some basic events, based on the fact that offsite power recovery is not credited.
- Some time-phased dependencies may be affected due to the tornado winds and missiles potentially affecting multiple SSCs, with no credit for recovery.

Once the appropriate model logic has been selected, unneeded logic can be removed at the discretion of the analyst. The only initiating events quantified in the TMRE model will be tornado initiating events, using the model logic chosen to represent them.

6.2 Tornado Initiating Events

The initiating events for the TMRE PRA model are five tornado events, one each representing the F'-Scale tornado categories F'2 through F'6. These initiating events will replace the initiating events (e.g., LOOP) used in the selected event trees. For multi-unit sites, the tornado event should be assumed to result in a multi-unit LOOP event. Guidance for the development of the initiating event frequencies is contained in Section 4.

Figure 6-2: TMRE Flowchart – Tornado Initiating Events



6.3 COMPLIANT CASE AND DEGRADED CASE

RG 1.174 requires an evaluation of the change in risk (i.e., ΔCDF and ΔLERF) for different plant configurations. For the TMRE analysis, there are two configurations (cases) that need to be modeled and quantified before evaluating the change in risk associated with the TMP nonconforming SSCs. In this guidance, they are referred to as the "Compliant Case" and "Degraded Case." Both the cases are based on the same LOOP event tree (and/or other event trees identified in Section 6.1), with certain modifications.

- The Compliant Case represents the plant in full compliance with its tornado missile protection current licensing basis. Therefore, all nonconforming SSCs that are required to be protected against missiles are assumed to be so protected, even when reality determines the SSCs are not protected. In the Compliant Case, nonconforming SSCs are assumed to have no additional failure modes beyond those normally considered in the internal events PRA.

- The Degraded Case represents the current configuration of the plant (i.e., configuration with nonconforming conditions with respect to the tornado missile protection current licensing basis). As such, the TMRE PRA model will include additional tornado induced failure modes for all nonconforming SSCs. The failure probabilities for those additional tornado induced failure modes are based on EEFP calculations, as described in Section 5.

Some of the internal events PRA model changes needed to create the TMRE PRA model will be applicable to both the Compliant and Degraded Cases. These common changes are:

- The internal events PRA event trees and fault trees chosen to represent the tornado initiating events (Section 6.1)

- The tornado initiating events and their frequencies (Section 6.2)

- Offsite power recovery and repairs are not credited (Section 6.1)

- Certain non-feasible operator action HEPs will be set to 1.0 (Section 6.4)

- Non-Category I structures incapable of withstanding the forces associated with tornado winds greater than 103 mph (i.e., the lower wind speed associated with F'2 tornadoes) and exposed active NSR SSCs (e.g., pumps, compressors) are assumed to fail with a probability of 1.0 (Section 6.6).

- Turbine buildings and exposed passive NSR SSCs (e.g., tanks, pipes) should be evaluated to determine their capability to withstand tornado wind pressures. Failure probabilities for these structures will vary based on their strength (Section 6.6).

- Vulnerable but conforming components (i.e., those PRA modeled SSCs that are exposed to tornado missiles but are not nonconforming with respect to the TMP current licensing basis) will include tornado-missile induced failures based on EEFP calculations (Section 6.5)

Therefore, the primary difference between the Compliant and Degraded Cases is the treatment of nonconforming SSCs. In the Compliant Case, no changes are made in the fault trees for nonconforming

SSCs (even if they are vulnerable to tornado missiles); in the Degraded Case, tornado missile-induced failure modes are added to the failure logic for nonconforming SSCs.

Table 6-1 provides a summary of the different treatments for various parts of the TMRE PRA models/cases.

Table 6-1: Compliant Case vs. Degraded Case Model Changes

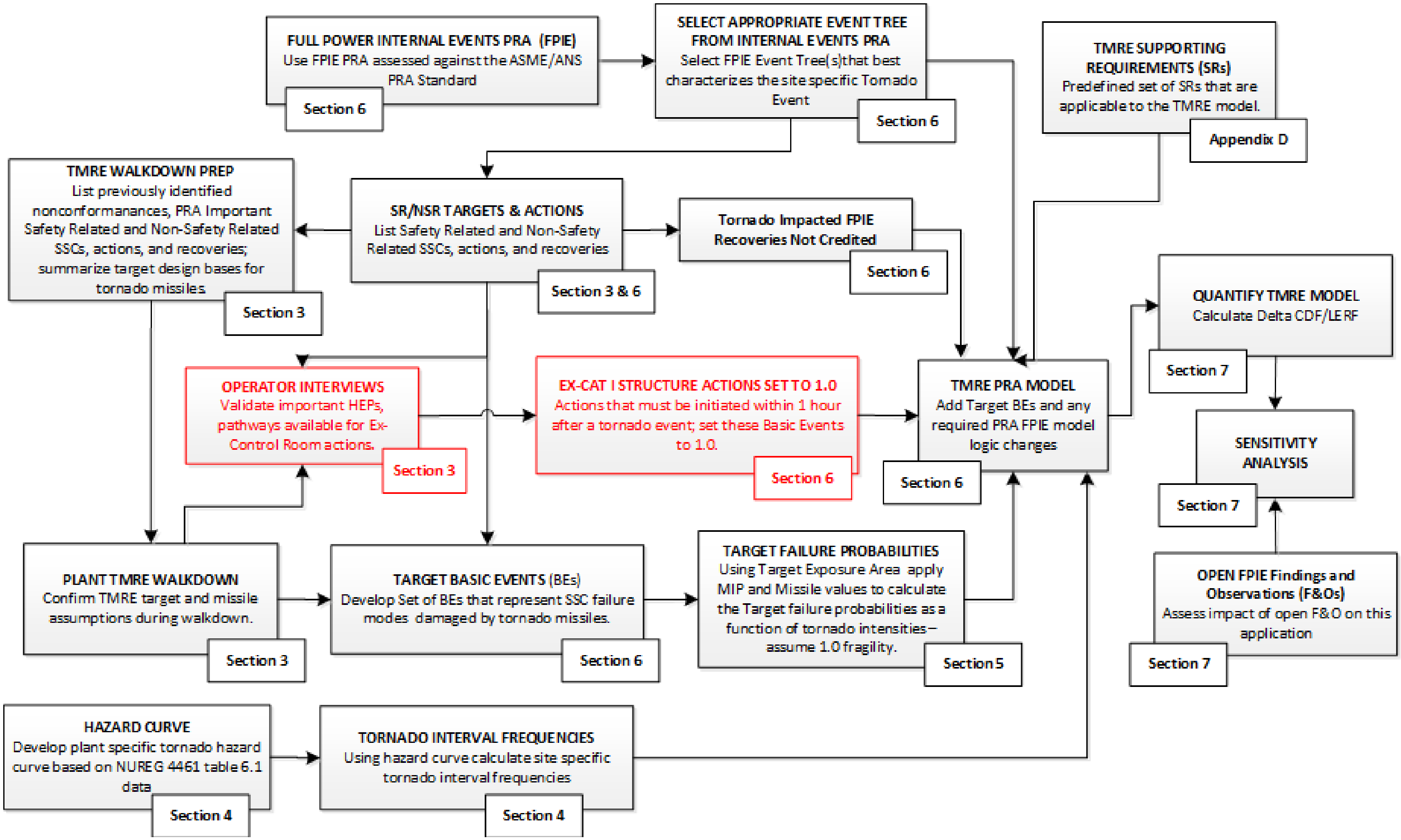
Type of SSC	**Failure Probability – Compliant Case**	**Failure Probability – Degraded Case**
• Switchyard • Non-Category I Buildings • SSCs in Category I Buildings (6.6.1 and 6.6.2)(1) • Short-term Operator Actions Outside MCR (6.4) • Exposed active NSR SSCs (6.6.3)(1)	1.0 with no recovery	1.0 with no recovery
Exposed passive NSR SSCs (6.6.4)(1)	• EEFP for tornado categories below calculated strength • 1.0 for tornado categories at or above calculated strength	• EEFP for tornado categories below calculated strength • 1.0 for tornado categories at or above calculated strength
Nonconformances	No new failures	EEFP
Other Vulnerabilities	EEFP	EEFP

Note (1): Although not designed as Category I, failures of turbine buildings and SSCs within them can be treated differently from other non-Category I buildings (see 6.6.2)

6.4 Impacts on Operator Action Human Error Probabilities

Tornado events at a nuclear site are very unlikely to have any impact on Category I structures, due to their robust construction and design margin. Thus, equipment and personnel inside Category I structures are not expected to be affected in the TMRE PRA. However, certain operator actions may have to be performed outside Category I structures or require the operators to transit outside Category I structures in order to get to the location to perform the action. For short term actions (i.e., those that need to be executed within 1 hour of the initiating event), the TMRE method assumes that the actions cannot be performed and thus the HEPs for those actions are set to 1.0.

Figure 6-3: TMRE Flowchart – Operator Actions



The rationale for this assumption is that during and immediately following a tornado event on site, areas outside Category I structures may not be safe due to high winds and debris/missiles. It is not expected that operators will endanger themselves in such situations. Furthermore, in the short time period following the tornado strike (assumed to be 1 hour in the TMRE method), there may be significant debris and damage to structures that could impede or prevent operators from transiting to and operating equipment outside Category I structures. Plant specific procedures may direct that personnel not exit Category I structures until a damage assessment is performed, which is assumed to take no longer than 1 hour following the tornado event. This introduces uncertainty into any detailed human reliability analysis of these actions. It is reasonable to apply a human error probability (HEP) of 1.0 to these short term actions in both the Compliant and Degraded Cases, because the aforementioned assumption is not overly conservative and the impact does not depend on tornado missile protection of SSCs.

The type of short term operator actions described above should have been identified as part of the HWEL development described in Section 3.3 The feasibility of actions involving transit or operation outside Category I structures more than 1 hour after the tornado event should be assessed and documented as described in Section 3.3.

Operator actions performed inside the control room or other Category I structures are assumed to be unaffected by the tornado event. Short term actions that are taken in response to the loss of offsite power should already consider the additional stress the operators may be under due to weather-related LOOP events. Longer term actions should not be affected as the immediate impact of the tornado event on operator stress and distractions should no longer be a factor on operator response.

If necessary, operators should be interviewed to ensure that the operator actions used in the internal events PRA are applicable to tornado events. Talk-throughs and simulator exercises may be used if actions are expected to vary substantially.

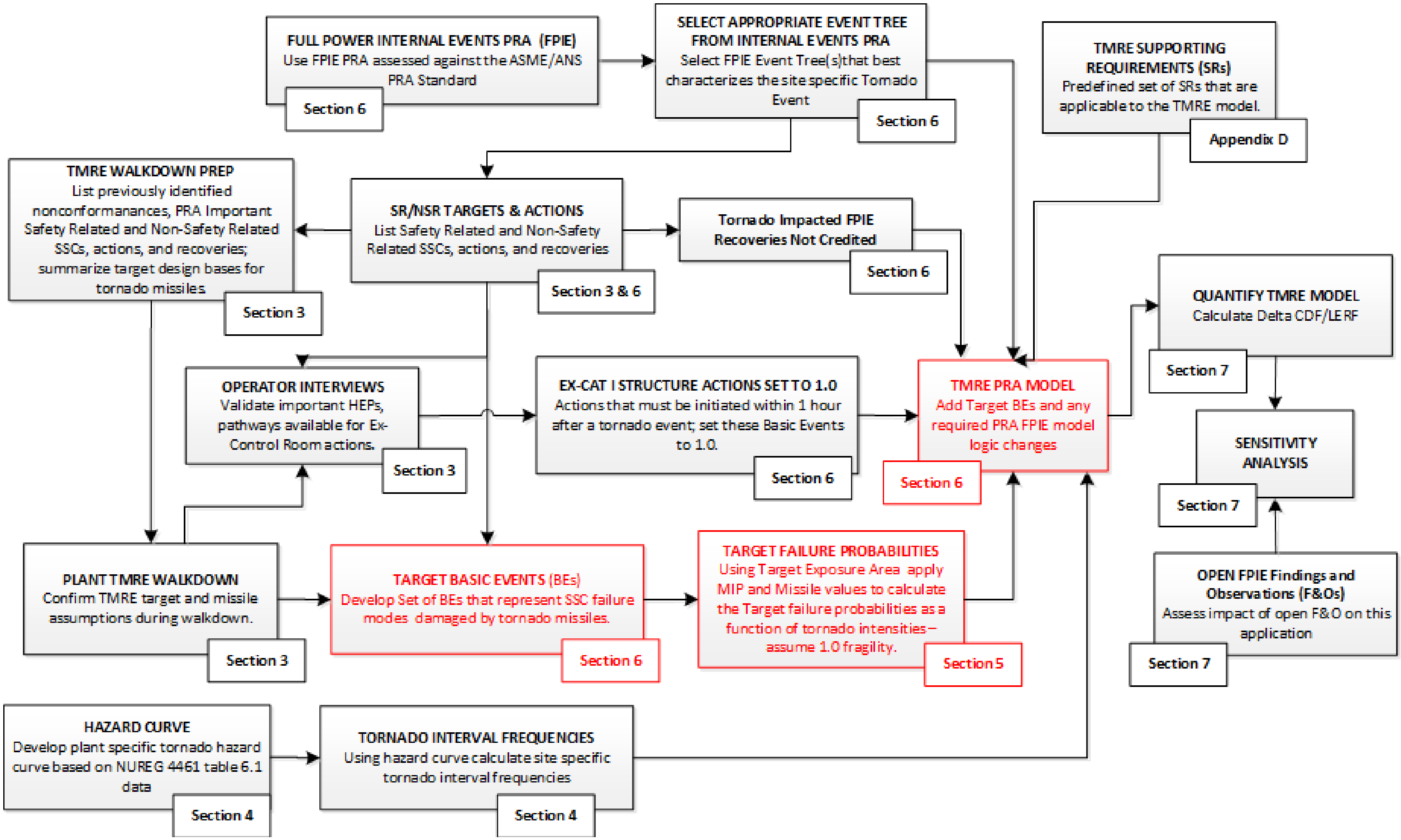
Operator actions performed in non-Category I structures that would have failed during a tornado event (see Section 6.6), should also be assumed to fail. However, the failure of the SSC being operated or manipulated should ensure that credit is not taken for these actions. Operator recovery actions to restore functions, systems, or components should not be credited unless an explicit basis accounting for tornado impacts on the site and the SSCs of concern is documented.

It is possible that new operator action dependencies will be created as a result of the TMRE model changes or due to new cut sets or combinations of failures associated with tornado events. The analyst should ensure that new operator action dependencies are appropriately accounted for in the TMRE PRA model.

6.5 Target Failures and Secondary Effects

The PRA logic models need to be modified to include tornado missile-induced failures for exposed SSCs. Tornado missile failures do not need to be considered for SSCs protected by 18” reinforced concrete walls, 12” reinforced concrete roofs, and/or 1” steel plate.

Figure 6-4: TMRE Flowchart – Target Impact Probabilities



6.5.1 FUNCTIONAL FAILURES

The TMRE PRA model should consider the functional failure of SSCs due to tornado missile strikes on unprotected SSCs. SSC failures from tornado missiles may need to be considered for failure modes not previously included in the internal events system models (e.g., due to low failure probability or low impact on system failure probability). Examples include:

- Flow diversions and/or leakage
- Tank vent failures (e.g., tank vent pipe crimping)
- Ventilation damper failures

The effect of the tornado missile damaging the SSC may be modeled at the component, train, or system level, depending on the functional failure resulting from the tornado missile impact and the details of the PRA model. Complex failure mode analysis is not required; in general, the failure modes considered in the TMRE are limited to the failure of the exposed equipment (i.e., the direct impact on the exposed SSC). Some examples are:

- A ventilation damper is exposed to tornado missiles; if the damper or its operator is struck by a tornado missile, it may fail to open or transfer shut (depending on the design of the damper and its operator). If the damper failure would prevent air flow to a room cooling fan, the failure could be modeled as failure of the damper to open/remain open or failure of the fan to operate.
- A tank vent is exposed to tornado missiles; if the vent is struck by a tornado missile, it could be crimped. If the loss of tank venting would result in tank failure or loss of suction from the tank, the failure could be modeled as failure of the tank to provide fluid to the systems requiring the tank inventory.
- A cooling water pipe is exposed to tornado missiles; if the pipe is struck by a tornado missile, it could be perforated causing a flow diversion and loss of cooling water. The impact of flow diversion and/or loss of cooling water would need to be determined and incorporated in the model. The impact could vary from no impact to complete system failure, depending on the pipe and system specifics (e.g., the size of the pipe, the capacity of the system pumps, whether the system is open or closed).

6.5.2 SECONDARY EFFECTS

Some secondary effects of tornado missile impacts on non-conforming SSCs should be evaluated and included in the TMRE PRA, if applicable. Specifically, flooding and combustion motor intake effects caused by tornado missile failures of fluid filled tanks and pipes (e.g., due to perforation of the tank or pipe) should be considered. The evaluation of these secondary effects is limited to missile impacts on non-conforming SSCs only (i.e., such secondary effects from missile impact on vulnerable but conforming SSCs do not need to be considered). Additional secondary effects, other than those associated with flooding and combustion motor intake effects, do not need to be evaluated as part of the TMRE.

An example of the secondary impact from flooding can be illustrated using the pipe example above. If the exposed pipe is non-conforming, the impact of flooding on other SSCs should be evaluated in addition to the direct failure on the system due to the missile strike:

- The analyst should determine if other SSCs in the TMRE PRA could be failed due to the potential flooding from the pipe perforation. The failure of the affected SSCs should be included in the TMRE model, if applicable.
- Assumptions and analyses regarding the flow rate from the pipe failure, the propagation paths, mitigation of the flooding, etc. should be documented. The internal flooding PRA model may provide a basis for the analysis.

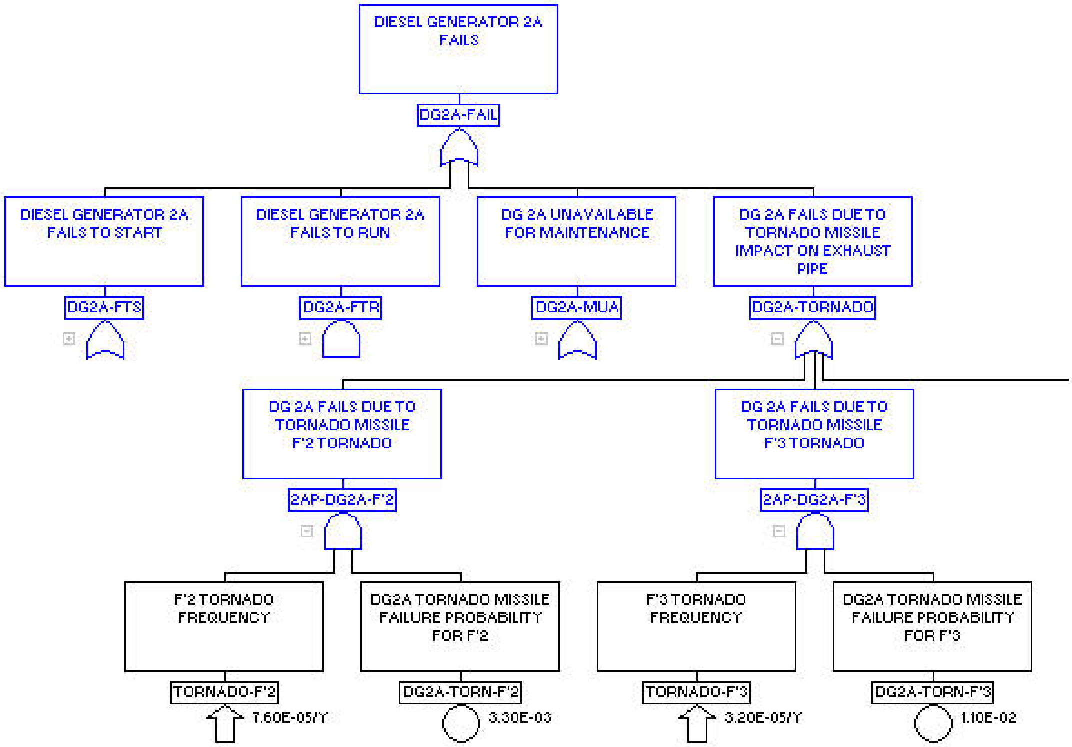
Examples of combustion motor effects are the loss of intake oxygen due to a missile induced rupture of a nearby inert gas tank, or re-direction of exhaust gases from an exhaust pipe perforated by a tornado missile. This failure mode is expected to be unlikely, and typically bounded by the relatively high failure rates of combustion motors. Additional plant-specific considerations that may facilitate screening of this secondary failure mode are:

- The proximity of the non-conforming SSC to the air intake for the combustion motor
- The capacity of the system (e.g., the size of the inert gas tank)
- The fact that tornado winds will disperse the inert or exhaust gas, preventing its concentration

6.5.3 Basic Event Modeling

The failure probability for a given SSC is determined using the EEFP calculation described in Section 5. Recall that the EEFP for each exposed SSC is calculated for each tornado category F'2 through F'6. The PRA model must be modified to ensure that the correct EEFP is used for an SSC based on the tornado category used for the initiating event. An example of how this can be accomplished in a CAFTA fault tree is shown in Figure 6-5.

Figure 6-5: Example Fault Tree Logic for Tornado Missile Failures



In this fault tree, a tornado missile failure basic event is added to the fault tree for each tornado category (only the F'2 and F'3 logic is shown here). The tornado missile failure basic event is placed under an AND gate with the appropriate category tornado initiating event. It is left to the analyst to determine the specific modeling method for incorporating tornado missile failures into their PRA models, and the level of detail of the tornado missile failure basic events. For example, one basic event could be used to represent all tornado missile failures of a given SSC or separate basic events could be included for the cause of each tornado missile failure of the SSC. Additionally, depending on the physical arrangement of the targets, multiple SSCs may sometimes be included under a single basic event (see Subsections 5.3.1 and 5.5 for examples).

Table 6-1 provides guidance for the Compliant Case and Degraded Case treatment of nonconforming SSCs and other vulnerable (but not nonconforming) SSCs.

6.6 NON-CATEGORY I STRUCTURES AND OTHER NSR SSCS

Model changes are needed to account for the failure of non-Category I structures and other NSR SSCs that are not designed to withstand tornado wind pressures and atmospheric pressure changes. These changes are applicable to both the Compliant and Degraded Cases, as listed in Table 6-1.

1. Non-Category I structures and buildings that may house NSR SSCs, are often built to industrial or commercial building codes. As such, non-Category I buildings (with the exception of most turbine buildings) will generally not withstand wind pressure and atmospheric pressure changes associated with the tornado categories applicable to the TMRE. Therefore, these buildings and the SSCs inside the buildings should be considered to fail with a probability of 1.0 in the TMRE PRA.
2. Although turbine buildings are generally not Category I structures, their frames are typically designed to withstand significant forces. Turbine building siding is typically designed to become detached from the frame, to prevent failure of the structure from wind pressures (although it may expose SSCs inside the turbine building to tornado missiles). Therefore, failures of SSCs within a turbine building should follow the guidance for active and passive NSR SSCs provided in items 3 and 4, for tornado categories the turbine building structure can withstand.
3. Less robust, non-safety related SSCs (e.g., pumps, air compressors, generators, and other active components) located outside of structures or within turbine buildings, such that they are directly exposed to tornado wind pressures, should be failed in the TMRE PRA.
4. More robust SSCs (e.g., tanks, piping, passive valves, conduits) are generally sturdy enough to withstand tornado wind forces. This is especially true for steel tanks that are full, or mostly full, of liquid. Analyses should be done to verify that the SSCs are capable of withstanding tornado wind forces. Design calculations may be used to determine the wind speed at which such SSCs will fail. Failure probabilities for such SSCs should be set to 1.0 in both the compliant and degraded cases for wind speeds (based on tornado category) higher than the calculated strength. Tornado missile failure modes (i.e., based on an EEFP) need to be included for such SSCs, for the tornado categories that do not cause guaranteed failure of the SSC.

6.7 PRA TECHNICAL ADEQUACY

The assumption of the TMRE methodology is that the Internal Events model of record used as the basis for the TMRE model has been peer reviewed against the RG 1.200 [Ref. A.8] endorsed PRA standard.

Any open findings from the peer review that would impact the application of the model in the TMRE process should be addressed within the TMRE analysis.

In addition to the internal events technical adequacy, the details of the conversion process from the Internal Events PRA to the TMRE PRA should be documented and reviewed. The process should follow this guideline, and any deviations from the guideline should be well documented. Additional requirements associated with the conversion process and to address TMRE-specific modeling issues are provided in Appendix D. A cross-reference to the applicable section of this guidance document for each of the SRs is also provided in Appendix D.

7 QUANTIFY RISK, PERFORM SENSITIVITY ANALYSES, AND COMPARE TO THRESHOLDS

7.1 CDF AND LERF QUANTIFICATION

Per RG 1.174 [Ref. A.6], a risk-informed evaluation of the change in risk (e.g., ΔCDF) is included. For the purposes of the TMRE, a licensee needs to calculate this change in risk by comparing two different configurations: the Compliant Case (configuration with the plant built per the required design/licensing bases), and the Degraded Case (current plant configuration, including potential nonconformances for tornado missile protection).

The ΔCDF and ΔLERF are simply calculated as follows:

$\Delta CDF = CDF_{Degraded} - CDF_{Compliant}$

$\Delta LERF = LERF_{Degraded} - LERF_{Compliant}$

The configuration-specific CDFs and LERFs are quantified like any other PRA, in alignment with the relevant quantification (QU) Supporting Requirements from the ASME/ANS PRA Standard (see Appendix D for additional detail).

7.2 SENSITIVITY ANALYSES

In addition to the ΔCDF and ΔLERF results, a risk-informed evaluation should include a discussion on the sensitivity of those results to key assumptions and parameters, such that the uncertainties are well characterized and understood. For the purposes of TRME, there are two types of sensitivity evaluations that may be relevant.

7.2.1 TMRE MISSILE DISTRIBUTION SENSITIVITY

A generic sensitivity has been identified during the development of the TMRE methodology. The sensitivity study should be performed and documented if the if the ΔCDF or ΔLERF between the compliant and the degraded case exceed 10^{-7}/yr or 10^{-8}/yr, respectively.

NOTE: The following procedure should be followed for determining the RAW of an SSC, with respect to meeting the conditions for performing this sensitivity. A given SSC will typically have separate and mutually exclusive tornado missile basic events for each tornado intensity. If this is the case:

- If any target basic event for F'4, F'5, or F'6 has a RAW greater than or equal to 2, then the sensitivity should be performed for that SSC for F'4 – F'6 tornadoes.
- For SSCs whose target basic event (for F'4, F'5, or F'6) RAWs are all less than 2, then the effective total RAW for that SSC is calculated as:

$RAW_{Total} = 1 + (RAW_{F'4} - 1) + (RAW_{F'5} - 1) + (RAW_{F'6} - 1)$

If RAW_{Total} for an SSC is greater than or equal to 2, then the sensitivity should be performed for that SSC for F'4 – F'6 tornadoes. This approach does not consider the importance of F'2 and F'3 SSC basic events, since they are not affected by the sensitivity calculation. However, it does account for the cumulative importance of the SSC for the F'4 through F'6 tornado intensities.

This sensitivity addresses the potential underestimation of target hit probabilities due to the missile distribution at the licensee's site, as compared to the missile distribution for the EPRI NP-768 Plant A simulations.

Procedure: For *highly exposed* SSCs with a tornado missile failure basic event RAW $\geq$ 2, multiply the basic event failure probability by 2.75 and recalculate ΔCDF and ΔLERF[7]. This only applies to tornado missile basic events for tornado categories F'4 , F'5, and F'6. Basic events for F'2 and F'3 tornado missile failures are not considered in this sensitivity.

For the purposes of this sensitivity study, the term *highly exposed* refers to an SSC for which all of the following characteristics apply:

- Is not located inside a Category I structure (i.e., they are outside or in a non-Category I structure)
- Is not protected against horizontal missiles
- Has an elevation less than 30' above the associated reference elevation

In addition to the conditions described above (*highly exposed* target with RAW $\geq$2), an additional MIP multiplier is required if a large number of missiles are close to such a target (defined as greater than 1,100 missiles within 100 feet of the target – see Section A.7.6). The potential concern with this situation is that the risk associated with a highly exposed and risk significant target with a large concentration of nearby missiles *may be* underestimated using the 2.75 MIP multiplier. A higher MIP may need to be applied to each target meeting these conditions when performing this sensitivity calculation.

However, prior to determining the target-specific MIP and performing a sensitivity, qualitative factors can considered to justify not applying a higher target-specific MIP. The justification for not applying a higher target-specific MIP should be documented and should address how certain factors can mitigate the potentially higher frequency of missile impacts on the target. Considerations include the number, type, and location of the missiles with respect to the type of target and its location, as well as administrative controls that limit the number, type and location of missiles. Two examples illustrate situations where qualitative factors could preclude the need to apply a higher target-specific MIP:

- The target in question is a 16" schedule-40 service water pipe and the local missile source consists primarily of 2x4 wood planks and plywood beams. Since the pipe is robust and cannot be damaged by the missiles nearby (see Table B-14, Category F), the local concentration of missiles does not warrant a higher target-specific MIP.
- The target in question is a DG exhaust pipe that is on the roof of a 20' high DG building. The roof has a parapet wall along the perimeter. The local missile source is a small pre-engineered 1-story building 20 feet from the DG building. In order for one of the local missiles to damage the DG exhaust pipe, it must be heavy enough to cause damage to the target, must be lifted

[7] The basis for the 2.75 MIP multiplier in this sensitivity study is provided in Section A.7.

over 20' feet, and accelerated to a damaging speed in the short distance from the missile source to the DG building. Lighter missiles are more likely to be lifted and accelerated, but will not damage the target, while it is unlikely that heavier missiles (that are damaging) will ever hit the target due to their relative placement with respect to the target.

After considering such qualitative factors, if the target(s) in question is considered susceptible to a MIP multiplier higher than 2.75, a target-specific MIP shall be calculated and included in the sensitivity study, with the other targets that meet the *highly exposed* and RAW $\geq$2 conditions. The MIP multiplier is calculated by determining the ratio of the local missile density (ρ_{Local}) with the average site missile density (ρ_{Avg}).

MIP Multiplier = $\rho_{Local} / \rho_{Avg}$

ρ_{Local} is the missile density within 100 feet of the target

ρ_{Avg} is the missile density for the site area (e.g., circle with 2500' radius from plant centerpoint) assuming 240,000 missiles, or the number of missiles used in the EEFP calculations, if greater than 240,000

The TMRE Missile Distribution Sensitivity is performed by applying either the generic MIP multiplier of 2.75 or the target-specific MIP multipliers to the appropriate basic events[8], recalculating the ΔCDF and ΔLERF, and comparing the results to the acceptance criteria.

7.2.2 Compliant Case Conservatisms

The licensee should review cut sets in the top 90% of the TMRE compliant case to identify conservatisms related to equipment failures only (i.e., as opposed to offsite power recovery or operator actions assumptions in the compliant case) that could impact results and perform sensitivity studies to address AS-A10, LE-C3 and SY-B7 in Appendix D. Specifically, consider that equipment failures in the compliant case may be masking changes in risk.

If the degraded case CDF and LERF are less than 10^{-6}/yr and 10^{-7}/yr, respectively, then the sensitivity analysis is easily performed by setting compliant case CDF and LERF to 0.0. This maximizes the ΔCDF and ΔLERF in the sensitivity and the results will be below the acceptance criteria.

In the event that this method would result in a ΔCDF or ΔLERF significantly greater than the acceptance criteria, the PRA analyst would need to evaluate the compliant case conservatisms and determine a more realistic sensitivity analysis to address the issue. This would be done on a case-by-case basis. The following are possible examples of sensitivity analyses, which are not intended to specify required methods nor are they a complete set of possible methods for the sensitivities:

[8] Only one multiplier is applied to a basic event, either the 2.75 generic multiplier or the target-specific multiplier.

1. Set the compliant case failure probabilities associated with conservative assumptions to 0.0 and calculate ΔCDF and ΔLERF (without changing the degraded case assumptions). This is the most conservative calculation of the impact of the specific assumption(s).
2. Estimate EEFPs for the affected SSCs in the compliant case and calculate ΔCDF and ΔLERF (without changing the degraded case assumptions). This is a more realistic evaluation of the impact of the assumption, yet still conservative.
3. Estimate EEFPs for the affected SSCs in the compliant case and degraded case, and calculate ΔCDF and ΔLERF. This approach will provide insights into the impact of the assumptions, and could be compared with the results of example method 2, above.

7.3 Comparison to Risk Metric Thresholds

The TMRE results should be evaluated against the "very small" change in risk thresholds given in Regulatory Guide 1.174 (ΔCDF 10^{-6}/yr and ΔLERF 10^{-7}/yr). Prior to completing this comparison, the licensee should ensure that quantification is completed consistent with QU-D5 and QU-D7.

If the risk acceptance guidelines for a "very small change" based on RG 1.174, Revision 3 are exceeded, then the TMRE analysis inputs may be refined as allowed by the TMRE methodology.

TMRE analyses will also appropriately consider any necessary sensitivity analyses. In general, the results of a particular sensitivity study should confirm that the "very small" risk change guideline is still met even under the alternative assumption(s) (i.e., the change generally remains in the "very small" region). If the results of a sensitivity study exceed the acceptance guidelines, NRC approval is required.

7.4 Missile Margin Assessment

The site missile inventory could fluctuate due to construction activities. If a proposed construction activity would cause the site missile inventory to increase above the missile count used in the TMRE analysis, an assessment is needed to verify the higher missile count still meets the risk metric thresholds in Section 7.3 or prior NRC approval would be required. Any TMRE analysis could use a missile inventory higher than actual to provide margin for future increases in missile population if desired.

7.5 Addressing Risk Significant Targets

To address risk-significant targets, the licensee should first, identify which SSCs (targets) are contributing most significantly to the risk metrics, and second, identify what assumptions were made regarding the target. Once these identifications are made, the risk-significant targets can be addressed in a variety of manners.

- If the SSC is considered robust, the licensee may use fewer missiles.
- If all or part of the SSC is elevated (>30'), the elevated MIP value may be lower.
- If part of the SSC is shielded or inconsequential, a smaller area could be used.
- Consider a plant modification to provide shielding

A combination of these approaches can be used to ensure that defense-in-depth and safety margins, relative to the most risk-significant targets, are maintained.

7.6 DEFENSE-IN-DEPTH AND SAFETY MARGIN

TMRE Defense-in-depth

Defense-in-depth is an approach to designing and operating nuclear facilities that prevents and mitigates accidents that release radiation or hazardous materials. The key is creating multiple independent and redundant layers of defense to compensate for potential human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon.
The TMRE analysis should include a discussion of defense-in-depth, including the use of access controls, physical barriers, redundant and diverse means of achieving key safety functions, and emergency response measures. The analysis should reflect the actual design, construction, and operational practices of the plant. Some examples of elements of defense-in-depth and means to meet them are shown below. Elements of defense-in-depth examples:

1. A reasonable balance is preserved among prevention of core damage, prevention of containment failure, and consequence mitigation.

Demonstrate that no new accidents or transients are introduced with the change, and that the facility is still well protected from tornado missiles. Ensure that no fission product barriers or key safety functions are disproportionately impacted by potential tornado missile damage.

2. Over-reliance on programmatic activities as compensatory measures associated with the change in the license basis is avoided.

Existing or new programmatic activities that help to mitigate tornado impacts should be discussed. However, it should be demonstrated that such activities are not necessary to maintain adequate defense-in-depth. For example, plants that have abnormal weather procedures with actions to secure tornado missiles should not depend on their ability to conduct such activities in tornado conditions; the design should be such that adequate defense-in-depth is maintained without it. Other examples of activities that may improve defense-in-depth for some plants are as follows: missile reduction, missile relocation, ongoing administrative control of missiles, and development of processes to conduct repair of key plant equipment that may be damaged during a tornado.

3. System redundancy, independence and diversity are preserved commensurate with the expected frequency, consequences of challenges to the system and uncertainties.

While the expected frequency of tornado strikes is low and missile strike damage even lower, and while adherence to the single-failure criterion establishes an acceptable level of defense-in-depth, it is prudent to improve defense-in-depth to overcome uncertainties (tornado strike time and place, missile location and path, plant configuration, etc.) Such measures may include incorporation of flex equipment and strategies into severe weather procedures, ensuring access following a severe weather event, and planning maintenance of key equipment such that it does not occur during times of the year when occurrence of tornados is more likely. Licensees may consider using other risk-informed approaches for which they have been licensed such as a Surveillance Frequency Control Program to ensure optimum alignment of activities impacting key equipment.

4. Defenses against potential common-cause failures are preserved, and the potential for the introduction of new common-cause failure mechanisms is assessed.

Potential common cause failures from tornado missile impacts and the impact to defense-in-depth should be analyzed to show that adequate defense-in-depth is maintained. In practice, common cause failures from missiles may sometimes be used for convenience in the PRA model; these types of failures should be discussed in the context of plant design features that provide defense against such failures.

5. Independence of barriers is not degraded.

Evaluate the design to ensure that no single failure from a tornado missile would introduce dependence between any two of the following: fuel cladding, reactor coolant system, or the containment.

6. Defenses against human errors are preserved.

Where available, discuss where automatic safety function features are maintained following tornado missile damage, decreasing the reliance on human actions. Where existing human actions may be required or where new human actions are introduced for the purpose of maintaining defense-in-depth, discuss the training, procedures, staging/briefing activities, and design features that will be used to successfully carry out such actions such that the tornado impacts will not significantly increase error likelihood.

7. The intent of the plant's design criteria is maintained.

The analysis of non-conforming equipment should show that, following an LOSP, an impact to any single active or passive component from a tornado missile does not completely eliminate the ability to perform key safety functions. For example, a missile impact to a diesel generator exhaust stack in a plant with two trains of emergency AC power should not prevent both diesel generators from performing their function. Success criteria from the PRA may be used to demonstrate satisfaction of defense-in-depth where multiple redundant components are available to accomplish a safety function, but some are vulnerable to tornado missiles. Additionally, the application should address specific targets that comprise 10% of the risk analysis acceptance criteria.

TMRE Adequate Safety Margin

Engineering evaluation should assess whether the impact of the proposed LB change is consistent with the principle that sufficient safety margins are maintained. Given that the risk assessment has shown that the change is acceptable, the conservative approaches used in the assessment should also be discussed. Examples include conservative modeling of physical correlation, conservative non-use of target shielding, conservative use of generic missile counts, and conservative non-use of adjustments to missile counts for robust targets. Additionally, discuss instances where the target failure mode is unlikely to result in a loss of function for the SSC.

8 PERFORMANCE MONITORING

Application of the TMRE methodology results in limited changes to the site-specific licensing basis to resolve nonconforming conditions. Generally, this is expected to be a one-time change to the plant's licensing basis to address a small set of exposed SSCs required to be protected from tornado missiles. Application of the TMRE methodology provides a basis for concluding that the risk to the plant associated with those exposed SSCs is sufficiently low that additional tornado missile protection need not be provided. Application of TMRE does not provide a basis for modifications to remove existing tornado missile protection at any time or to omit protection for new configurations (e.g. design changes) that otherwise require tornado missile protection according to the plant licensing basis.

8.1 PLANT CONFIGURATION CHANGES

Station design control programs that meet 10 CFR 50 Appendix B will ensure that subsequent configuration changes are evaluated for their impact on the TMRE risk basis for accepting the identified nonconforming conditions. Licensees shall ensure via applicable station procedures and processes that plant changes that result in an increase to the site missile burden are evaluated for impact on the TMRE analysis results. Periodic PRA Internal Events model of record updates or plant changes that impact the PRA Internal Events model of record but do not change the site missile burden do not require a TMRE analysis update.

Permanent changes within the 2500' missile radius that increase the site missile burden beyond that used for the TMRE analysis should be incorporated into the TMRE analysis prior to making the permanent change. Non-permanent construction-related missiles should be addressed in the TMRE analysis as indicated in Sections 3.4.3 and 7.4.

Changes to previous non-conforming SSCs that would increase the target EEFP (e.g. effect the target exposed area by increasing the exposed exhaust pipe height, effect a robust missile percentage by changing the pipe material or thickness) are not allowed under TMRE. Only changes that result in increased site missile burden require a TMRE analysis update.

If the approved TMRE analysis is updated as a result of a design change that increased the site missile burden, the following three items below should be used in updating the TMRE analysis:

- The most current PRA Internal Events model of record should be used for the analysis.
- The most recent approved revision of NUREG/CR-4461 should be used to ensure the tornado initiating event frequencies reflect the site tornado hazard.
- The treatment of previously identified non-conforming conditions in the TMRE model will continue to modeled as non-conforming conditions in the degraded case. There may be exceptions in the following cases where the non-conforming targets:
    - Have been physically protected in such a way that they would no longer be considered non-conforming at the time of the revision and can be removed from the TMRE analysis, or
    - Would not otherwise be considered non-conforming at the time of the revision because engineering calculations have demonstrated that they are conforming

The evaluation of the results of the updated TMRE analysis will be conducted in accordance with Section 7.3. If the thresholds of ΔCDF 10^{-6}/yr or ΔLERF 10^{-7}/yr are exceeded based on an updated TMRE analysis, then the planned plant modification cannot be made without pursuing additional actions (e.g. design change reducing delta CDF/LERF below the risk acceptance guidelines, NRC prior approval through a license amendment request.)

8.2 FUTURE IDENTIFICATION OF NONCONFORMING CONDITIONS

Additional legacy nonconforming conditions that were missed during the initial TMRE analysis, where tornado missile protection is required but not provided, may be resolved using TMRE, if appropriate. TMRE is not to be used for nonconforming conditions created as a result of future modifications without separate review and approval by the NRC.

If TMRE has been approved for the plant, the methodology must be applied as specified in the amended license. The TMRE analysis must be updated to reflect the newly identified legacy conditions, and the additional conditions must be identified in the updated FSAR. As with all plant changes 10 CFR 50.59 shall be applied to determine whether NRC approval is required.

The evaluation of the results of the updated TMRE analysis will be conducted in accordance with Section 7.3.

8.3 TMRE RESULTS AND CUMULATIVE RISK

The TMRE model results (i.e., ΔCDF and ΔLERF) are not intended to be used as a quantitative contribution to the plant's cumulative risk (i.e., internal events model, external hazards such as fire, seismic, and high winds) for the following reasons:

- Conservative assumptions used during TMRE modeling could mask risk insights from other hazards.
- The TMRE model analyzes the increase in risk due to tornado missile protection non-conformances and is not a best estimate of the total risk due to tornado missiles (e.g., vulnerabilities in the HWEL use the same EEFP in the compliant and degraded cases).
- The frequencies of tornados and basic event probabilities (EEFPs) are generally much lower than other random failures (e.g., FTR, FTS, FTO, FTC) for the same components and result in a lower change in risk.

In future risk-informed decision-making activities licensees may need to consider, as appropriate, the risk associated with previous nonconforming conditions that remain unprotected against tornado missile impacts.

APPENDIX A: TECHNICAL BASIS FOR TMRE METHODOLOGY

A.1. Introduction

The Tornado Missile Risk Evaluator (TMRE) will be used to estimate the quantitative risk associated with tornado-generated missiles at U.S. nuclear power plants (NPP). It is built upon a plant-specific internal events Probabilistic Risk Assessment (PRA) model and is intended to follow RG 1.174 guidance [Ref. A.6] This appendix describes:

- The elements and basis of the TMRE methodology
- Technical considerations and conservatisms
- Results of benchmark studies at two sites, comparing the TMRE results with RG 1.200 High Winds (HW) PRA results
- The basis for two required sensitivity studies (described in Section 7.2)

A.2. Elements of TMRE

The major elements of the TMRE are:

- The internal events PRA model and the modifications made to it
    - The assumption of a non-recoverable Loss of Offsite Power
    - Accounting for impacts on operator actions
    - Accounting for failure of exposed non-safety related Structures, Systems or Components (SSCs)
- Use of a site-specific tornado frequency
- Addition of missile failure events for SSCs exposed to tornado missiles, using the Exposed Equipment Failure Probability (EEFP)
    - Missile Impact Parameter (MIP)
    - Exposed target Area
    - Missile inventory, including robust target considerations
    - Assumption of target failure (i.e., fragility = 1.0)
- Quantification and Comparison to Risk Metrics
- Sensitivity Analyses
- PRA Technical Adequacy

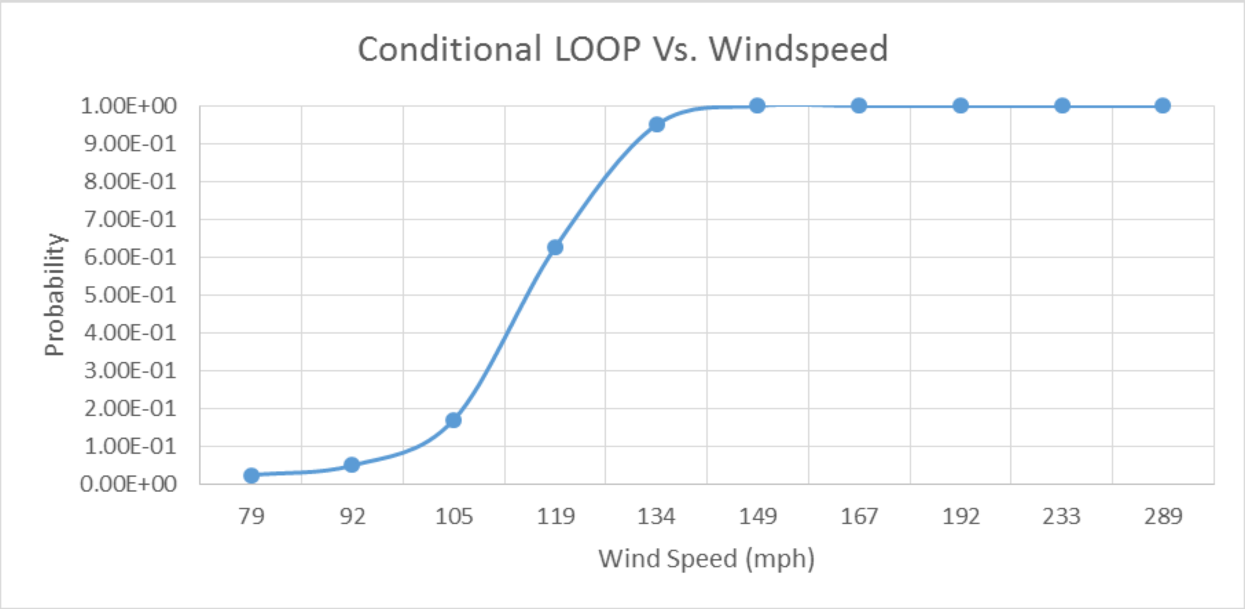
A.2.1 Modifications to the Internal Events PRA Model

Section 6 provides details on how the plant-specific internal events PRA model is modified for use in the TMRE. The use of the internal events PRA model in the TMRE follows the current standard practice in developing HW PRA models.

A.2.1.1 Non-recoverable Loss of Offsite Power (LOOP) Assumption

The significant difference in the TMRE method is that a LOOP is always assumed to occur in the TMRE, as opposed to using fragilities or other data to determine the likelihood of a LOOP. This is a reasonable assumption, given the likelihood of a LOOP event as a result of a site tornado strike of F'2 intensity or higher (i.e., greater than 103 mph). Figure A-1 shows the conditional LOOP probability (i.e., LOOP fragility) versus wind speed for a typical NPP [Ref. A.1]. Based on this curve, LOOP probability ranges from approximately 15% to 95% for F'2 tornado wind speeds (103 – 135 mph). The LOOP probability at the mean wind speed for F'2 (119 mph) is approximately 60%. Another study [Ref. A.2] showed that the probability of offsite failure approaches 1.0 at 112 mph.

Figure A-1: Conditional LOOP Probability



Furthermore, offsite power is assumed to be non-recoverable. This is consistent with current HW PRA assumptions; given a LOOP, no credit is given for offsite power recovery (i.e. non-recovery probability = 1.0) [Ref. A.2]. Although the assumption is somewhat conservative, it is reasonable to expect that offsite power will not be recovered or have a very high non-recovery probability if a tornado strikes the site and results in a LOOP. Note that tornado strikes offsite, which result in a LOOP due to transmission line or grid failure, are not considered tornado events in TMRE or HW PRAs.

The assumption that a LOOP occurs and is non-recoverable applies to both the Compliant and Degraded cases (see Section 6.3 for a discussion on Compliant and Degraded cases). This assumption challenges the mitigation capabilities of the plant, in that emergency power must survive tornado effects and operate for the full mission time, adequate cooling water supplies (e.g., condensate storage tanks) must survive, and balance of plant equipment (e.g., feedwater) is not available and cannot be recovered.

A.2.1.2 Impact on Operator Actions

The TMRE method requires that operator actions performed outside Category I structures be evaluated to ensure that they can be performed following a tornado event. Actions that cannot be performed (e.g., due to damage to non-Category I structures or non-safety related components) are set to fail (see Section 6.4). Short term operator actions (defined as occurring within 1 hour of the tornado event) that require transit or execution outside Category I structures are also assumed to fail in the TMRE method. These are reasonable assumptions and generally consistent with current high wind PRAs. Some considerations for failing such actions within 1 hour of the event are:

- There is some period of time following the event in which actions requiring transit or operation outside Category I structures is simply not feasible
- The time delay is affected not only by the conditions caused by the event (i.e., debris, damage, and destruction), but also by need to conduct post-event damage and safety assessments prior to dispatching operators outside protected structures.
- The uncertainty in the amount of damage and debris around the plant following the tornado event makes an exact time period impossible to define and justify
- Choosing a shorter time could underestimate the degraded case risk by crediting operator actions that could not be performed
- The risk increase from this assumption is expected to affect the degraded case more than the compliant case, since more SSCs (i.e., the non-conforming ones) will be failed in the degraded case sequences as compared to the compliant case
- The potential impact of masking risk increases due to a *potentially* conservative treatment in the compliant case is judged to be minimal, considering the points listed above
- Sensitivities to assess the potential impact of choosing 1 hour as the time period for failing ex-control room actions (as opposed to some other time frame) are impractical, lack technical justification, and would not provide any meaningful insight

Human Error Probabilities (HEP) changes are not made to other operator actions, such as those performed inside the main control room. This is different from current practice in HW PRAs (which evaluates all operator actions and makes changes to some of them), but is adequate for the TMRE:

- Currently, there is no detailed industry guidance for high wind human reliability analysis (HRA). The most relevant guidance document is the external events HRA EPRI guidance document [A.3] which is useful but not detailed for high wind HRA. The lack of a standard methodology results in significant judgment on the part of the HRA analysts, which would result in inconsistent application in the TMRE.

- Incremental changes to operator action HEPs as a result of degraded PSFs will typically be applicable to both the Compliant and Degraded Case, so the impact on the change in risk between the two cases should be insignificant.

- Long term actions performed inside the control room or other Category I structures, should generally not be affected significantly, due to the short time frame in which the tornado is directly affecting the site.

- In addition to the factors discussed above, any changes to HEPs for long term actions requiring transit outside Category I structures are difficult to justify, are highly variable and uncertain, and are beyond the scope of the TMRE methodology.

    - Short term actions outside Category I structures are set to fail for all events, which is conservative, especially for lower intensity tornadoes.

    - Setting all actions requiring access to or transit through a non-Category I structure to fail may be conservative for certain intensity tornadoes, and does not take into account the potential success of such actions, dependent on the specific failure modes of such structures.

    - Repair actions are conservatively assumed to fail, unless specifically justified (see HR-H1/H2 in Appendix D).

    - Effects on long term actions outside Category I structures are highly dependent on the intensity of the tornado, the specific location and orientation of the tornado strike at the site, and the variability of the resultant debris field. Attempts to quantify changes to HEPs for such actions are speculative and subjective.

A.2.1.3 NON-CATEGORY I STRUCTURES AND EXPOSED NON-SAFETY RELATED SSCS

Section 6.6 provides guidance for addressing tornado wind impacts on SSCs that are not designed to withstand tornado wind pressures and atmospheric pressure changes.

It is reasonable to expect that non-Category I structures (i.e., those built to industrial or commercial building codes) will not withstand the wind pressures associated with F'2 or greater tornadoes[9]. While there is some likelihood that such a structure might withstand tornado wind pressures associated with an F'2 tornado, even engineered structures are likely to fail at higher intensity tornadoes. Figure C-17 shows the missile release fraction for engineered and pre-engineered structures. This fraction is a surrogate for the amount of damage likely to occur to an engineered or pre-engineered structure. Based on Figure C-17, F'3 tornadoes result in approximately 40% damage to such a structure, F'4 results in 80% damage, and F'5 and F'6 tornadoes result in greater than 90% damage. At 40% or greater damage, SSCs within the structure are exposed to tornado wind forces and may be directly damaged by structural collapse or debris. SSCs adjacent to the structure are likely impacted by the failure of the structure (e.g., structural collapse or large structural component impact), and therefore are conservatively assumed to fail with a probability of 1.0.

The assumption that active SSCs (e.g., pumps, compressors) exposed to tornado wind effects will fail at tornado intensities at or above F'2 is also reasonable. These types of components are not designed to withstand such forces; they may become misaligned, support systems (e.g., electrical cables, junction boxes,) may be dislodged or uncoupled, or lightweight debris may affect the equipment operation.

Most such SSCs of this type are considered to be failed in both the Compliant and Degraded cases. This should generally lead to conservative results, but the impact of these assumptions should be evaluated to ensure the conservative assumptions do not mask significant increases in risk between the Compliant

[9] Turbine buildings are typically not considered in this category, as the cladding or siding is designed to come off at a certain wind speed (e.g., 90 – 120 mph) to prevent structural failure of the building.

and Degraded cases. Section 7.2.3 provides guidance on performing sensitivity studies that addresses this specific issue.

A.2.2 Site-specific Tornado Hazard

Section 4 provides details on the calculation of the site-specific tornado frequencies to use in the TMRE model. NUREG/CR-4461 Revision 2 is recommended as the data source. This is the most recent public tornado hazard analysis performed by the NRC for the U.S NPPs., and includes tornado frequencies developed for each plant site.

A.2.3 The Exposed Equipment Failure Probability

Section 5 and Appendix B provide details on the basis of EEFP calculation, the derivation and bases of the factors associated with the EEFP, and methods to perform SSC-specific EEFP calculations. The variables and factors included in the EEFP were developed in an effort to provide a conservative estimate of SSC failure probability. Section A.5 provides the results of two benchmark studies, comparing the EEFP to TORMIS-based SSC missile failure probabilities; see Tables A-4, A-6 and A-7. The MIP values, missile inventories and the assumption that SSCs hit by tornado missiles will fail (i.e., fragility = 1.0) were developed to be used together, and should not be modified. Although each variable may not be conservative by itself, the combination of variables used for different targets and tornado wind speeds provides a bounding estimate of the change in CDF associated with nonconforming SSCs (Section A.5 provides results of benchmark studies comparing TMRE results with the results of HW PRAs).

The details of the basis for each of the variables used in the EEFP calculation are provided in the guidance document:

- Section B.1 provides background and precedent for the use of a simplified analysis to determine a target missile hit probability. Appendix B describes additional details of the derivation of the Missile Impact Parameter (MIP) and Sections A.6 and A.7 of this appendix discuss uncertainties associated with the MIP.

- Section 5.3 describes the process for determining the target exposed area, used in the EEFP calculation, and provides example calculations. The target exposed area calculation described in Section 7.3 is realistic.

- Section 5.2 describes the method for determining the missile inventory to use in the EEFP calculations. Appendix B describes the basis for the generic and bounding missile inventory. Licensees are expected to validate the TMRE missile inventory is bounding; if this is not the case, a bounding site-specific missile inventory should be developed. The area surrounding the plant, which is used for the missile inventory, is consistent with the TORMIS simulations results in EPRI NP-768 [Ref. A.4] that are the basis for the MIP derivation.

- Target fragilities are assumed to be equal to 1.0; if a target is struck by a damaging missile, it is assumed to fail. Some consideration is given to robust targets, given that not all missiles included in the site missile inventory can damage certain targets (e.g., steel tanks and pipes, reinforced concrete roofs). The basis for the reduction of missile inventories for certain targets is provided in Appendices B and C.

A.2.4 Quantification and Comparison to Risk Metrics

CDF and LERF quantification is performed on two versions of the TMRE model, the Compliant Case and the Degraded Case. The primary difference between the two cases is the treatment of non-conformances. In the Compliant Case, each non-conforming SSC is assumed to be protected, such that tornado missiles cannot strike or damage the SSC. In the Degraded Case, failure of the non-conforming SSCs due to tornado missiles is represented by the EEFP. Other SSCs that may be failed by either tornado missiles or tornado wind pressure are treated the same in both the Compliant and Degraded cases. This includes failure of unprotected (vulnerable) safety related SSCs that are in compliance with the licensing basis.

The difference between the Compliant and Degraded case CDF and LERF (i.e., ΔCDF and ΔLERF) is the risk associated with not providing missile protection for the non-conforming SSCs. ΔCDF and ΔLERF are compared to the thresholds in RG 1.174 to determine the acceptability of the risk increase associated with not protecting non-conforming SSCs. This process is a typical application of RG 1.174 for risk-informed license changes.

A.2.5 TMRE PRA Technical Adequacy

The requirements for PRA technical adequacy, as applied to the TMRE PRA, are described in Section 6.7, Section 7.2 and Appendix D. The technical adequacy of the base internal events PRA must be addressed consistent with the ASME PRA Standard, the changes made to create the TMRE PRA must be evaluated against Appendix D, and the TMRE-specific calculations (e.g., EEFP) must be performed in accordance with this guidance document. Section 7.2 provides guidance on addressing open peer review Findings and Observations (F&Os) on the base internal events PRA.

A.3. Southwest Research Institute Review

During the development of the TMRE methodology, the NRC sponsored an independent evaluation of the TMRE method [Ref. A.5], specifically focusing on the derivation of MIP from EPRI NP-768 and the generic applicability of the TMRE MIP values to NPP sites in the U.S. The overall conclusions of the report state: "In general, we considered the MIP concept defensible. "

However, two issues were recommended for further analysis:

- "…additional work is necessary to address the problem of missile clusters of variable spread and variable distance to targets." This concern is addressed in the Zonal vs Uniform sensitivity required in Section 7.2.1, based on the analysis provided in Section A.7 of this appendix.

- "Additional work is also needed to define MIP values that are independent of the building configuration." The Southwest Research Institute report suggests that Target 6 in Plant A (NP-768) may be isolated enough to not be affected by other buildings. MIP values were derived from the different target buildings in NP-768 Plant A, and Target 4 was determined to have the highest MIP values (higher than Target 6, except for F'6). The MIP values derived from Target 4 are compared to the MIP values derived from all the buildings(see Section A.6 for more details).

A.4. Conservative Aspects of TMRE

Several conservative assumptions are discussed in Section A.2, with regards to the creation of the TMRE PRA model and the calculation of the EEFP. Some additional conservative aspects of the TMRE method are described here.

1. The MIP is derived from the single missile hit probability values in EPRI NP-768. Section B.2.1 describes how multiplying the single missile hit probability by the number of missiles (as is done in the EEFP) is likely conservative.

2. Separate MIP values are derived for elevated targets (nominally defined as 30' above associated reference elevation). Although the elevated MIP values are lower than the near ground MIP values, they are based on missile hit probabilities at all elevations, from the ground to the roof level of all targets in Plant A of NP-768. The Elevated Target MIP value derivation includes data from Target 6, whose surfaces are all completely below the 30' elevation; this tends to bias the MIP value higher.

3. Missile inventories for robust targets are conservative. Appendix C and Section B.6 describe the calculations used to determine the types of missiles that can damage robust targets. Two assumptions in the calculations used to determine missile damage to targets are:

    a. The missile is travelling at design speed. This assumption ensures that the damage caused by a missile on a target is realistic only for the highest intensity tornadoes (e.g., F'6) and is conservative for all lower intensity tornadoes. Since F'2 and F'3 tornadoes are much more frequent (e.g., by at least an order of magnitude) than higher intensity tornadoes, this conservatism can have a significant impact on the overall risk associated with missile hits on non-conforming targets.

    b. The missile strikes the target directly at a normal orientation (i.e., an ideal impact). Due to the chaotic nature of tornado winds, it is unlikely that a missile will strike a target directly. Indirect strikes will impart less energy on the target than assumed in the Appendix C calculations, such that a smaller percentage of the assumed missiles are likely to damage a robust target.

Sensitivity studies are directed in Section 7.2 to address:

- The potential for non-conservative ΔCDF and ΔLERF calculations due to conservative assumptions regarding SSC failures in the Compliant Case

- Missile distribution uncertainty potentially affecting the derivation of the MIP values

A.5. Benchmark Results

Benchmark studies were performed for two plants, to compare results using the TMRE methodology against the results associated with a peer reviewed TORMIS-based HW PRA. The following were compared:

- Total CDF/ΔCDF

- Dominant accident sequence CDF/ΔCDF contribution

- Individual SSC CDF/ΔCDF contribution

- Failure probability of individual SSCs at five different tornado intensities (F'2 through F'6)

It should be noted that even though the TMRE resulted in conservative overall results and a majority of the target comparisons were conservative to the TORMIS-based failure probabilities, the TORMIS-based analyses are already conservative[10]. Thus, the TMRE comparisons are being made to conservative benchmarks.

Additionally, the Plant X and Y TMRE PRA calculations for ΔCDF and CDF were performed using EEFPs based on NEI 17-02 Revision 1 Near Ground (≤30') MIPs. The updated Near Ground MIPs in this revision (see Table 5-1) are approximately 30% higher than in Revision 1. Therefore, had the PRA calculations been re-performed with the higher EEFPs, there would be more margin between the TMRE and HW PRA results. However, the target failure probability comparisons provided in Tables A-3, A-6, and A-7 are based on the MIP values in Table 5-1 of this revision to NEI 17-02.

The two benchmark plants are denoted Plant X and Plant Y. Both plants showed conservative TMRE total CDF/ΔCDF compared to the HW PRA results[11]. Table A-1 provides a comparison of CDF/ΔCDF for both plants.[12]

TABLE A-1

Comparison of CDF and ΔCDF for Benchmark Plants

Plant	TMRE	HW PRA	Difference	Ratio
X	ΔCDF = 8.6E-7/yr	ΔCDF = 1.6E-7/yr	7.0E-7/yr	5.4
Y	CDF = 1.1E-5/yr	CDF = 2.0E-6/yr	9.0E-6/yr	5.5

Comparisons of sequence- and target-level CDF/ΔCDF contributions and target-level damage probabilities are provided in the subsections specific to each of the benchmark plants.

A.5.1 PLANT X

Plant X is a dual unit PWR located in RG 1.76 [Ref. A.7] Region I. Only one unit is evaluated, since the units are more or less symmetric. Sequence level ΔCDF comparisons are provided in Table A-2. The comparison shows that the ΔCDF for the top 5 TMRE sequences are all conservative, when compared to the comparable HW PRA sequences.[13]

TABLE A-2

[10] Several conservatisms are described in TORMIS analyses used for design basis applications. These same conservatisms are typically maintained in TORMIS analyses used to support HW PRAs.

[11] Plant X ΔCDF results in Tables A-1 and A-2 are based on EEFPs calculated using NEI 17-02 Rev. 0 robust missile percentages and NEI 17-02 Rev. 1 Near Ground (≤30') MIPs. Plant Y CDF results in Tables A-4 and A-5 are based on EEFPs calculated using NEI 17-02 Rev. 1 Near Ground (≤30') MIPs.

[12] Plant X computed the ΔCDF between the degraded and compliant cases, whereas Plant Y computed only the degraded case CDF.

[13] Sequence 5 in the HW PRA is not modeled in the TMRE, since it was determined to not be modeled very conservatively and still not be significant to the HW PRA results.

Comparison of Sequence-Level ΔCDF for Plant X

Sequence	Sequence Description	TMRE RANK	TMRE CDF (yr^{-1})	RG 1.200 RANK	RG 1.200 CDF (yr^{-1})	TMRE/ RG1.200
TI-004	LOOP with Loss of Aux Feed and F&B	1	6.6E-07	1	1.2E-07	5.4
SBO-098	LOOP (SBO) - Loss of Aux Feed and Alternate Power Supply	2	1.0E-07	4	6.4E-09	15.7
TI-003	LOOP and Loss of Aux Feed, with F&B success	3	5.1E-08	3	1.4E-08	3.6
LIFTWAY	Liftway Failure	4	4.7E-08	2	1.7E-08	2.8
S2-022	LOOP with Consequential Small LOCA	5	5.1E-09	6	8.2E-10	6.2
	Total CDF		8.6E-07		1.6E-07	5.4

Due to the method in which targets were grouped in the Plant X HW PRA, it is difficult to compare target-to-target damage probabilities for each of the targets; only a limited set of 6 targets (30 failure probabilities) could be readily compared directly. They are shown in Table A-3[14]. Target comparisons for F'2 and F'3 tornadoes are highlighted, since the majority of the risk is from F'2 and F'3 tornadoes. In many cases, the F'2 and F'3 failure probability ratios for a given target are the highest, but this is not always the case; for some targets, the highest ratio may be in F'4, F'5, or F'6 failure probabilities.

Of the 30 target failure probabilities compared, the TMRE failure probabilities were conservative to all but 3 of the TORMIS-based failure probabilities. Those failure probabilities are associated with F'4 through F'6 tornado missile failures of the turbine-driven AFW pump steam exhaust stack. If this SSC were determined to be risk significant and highly exposed, as defined in Section 7.2.1, performing the missile distribution (Z vs U) sensitivity analysis would increase the failure probabilities to above (or nearly equal, in the case of F'6) to the HW PRA failure probabilities. [Note: The turbine-driven AFW pump steam exhaust stack contributes less than 1% to the tornado missile risk.]

[14] Although Plant X ΔCDF results are based on EEFPs calculated using NEI 17-02 Rev. 0 robust missile percentages, the TMRE failure probabilities in Table A-3 are based on robust missile percentages from Table 5-2 of this revision of NEI 17-02. Additionally, the Plant X ΔCDF results are based on EEFPs using the NEI 17-02 Rev. 1 Near Ground ($\leq$30') MIPs, the TMRE failure probabilities in Table A-3 are based on the Table 5-1 MIPs from this revision of NEI 17-02.

TABLE A-3

COMPARISON OF TARGET FAILURE PROBABILITIES FOR PLANT X

Target	Failure Modes	Size/Location	F' scale	TMRE Probability	RG 1.200 Probability	TMRE vs RG 1.200
Condensate Storage Tanks	Tank Perforation	Area ~ 3200 sq ft Elevation <30 ft	F'2	2.8E-02	4.6E-03	6.0
			F'3	9.1E-02	2.0E-02	4.6
			F'4	2.1E-01	1.1E-01	1.9
			F'5	6.1E-01	3.9E-01	1.6
			F'6	9.5E-01	6.9E-01	1.4
PAB Liftway	Missile Hit	Area ~ 180 sq ft Elevation <30 ft	F'2	3.9E-03	1.3E-04	30
			F'3	1.3E-02	3.7E-04	35
			F'4	2.9E-02	1.4E-03	21
			F'5	8.6E-02	3.4E-03	25
			F'6	1.3E-01	4.9E-03	27
Central SW Header	Pipe Perforation	Area ~ 470 sq ft Elevation < 30 ft	F'2	3.6E-03	1.5E-05	238
			F'3	1.2E-02	3.1E-05	379
			F'4	2.7E-02	9.2E-05	290
			F'5	7.9E-02	2.1E-04	377
			F'6	1.2E-01	3.8E-04	323
West SW Header	Pipe Perforation	Area ~ 60 sq ft Elevation < 30 ft	F'2	4.4E-04	3.5E-06	127
			F'3	1.5E-03	3.0E-05	49
			F'4	3.3E-03	1.9E-04	17
			F'5	9.8E-03	9.2E-04	10.7
			F'6	1.5E-02	1.8E-03	8.5
North SW Roof	Concrete Roof	Area ~ 750 sq ft	F'2	3.3E-03	1.5E-05	217

Target	Failure Modes	Size/Location	F' scale	TMRE Probability	RG 1.200 Probability	TMRE vs RG 1.200
	Perforation	Elevation < 30 ft	F'3	1.1E-02	2.9E-04	37
			F'4	2.4E-02	7.7E-04	32
			F'5	7.2E-02	1.5E-03	48
			F'6	1.1E-01	2.3E-03	49
TD AFW Pump Exhaust Stack	Exhaust Pipe Crushing	Area ~ 315 sq ft Elevation < 30 ft	F'2	3.4E-03	9.1E-04	3.8
			F'3	1.1E-02	5.8E-03	1.9
			F'4	2.6E-02	4.5E-02	0.6
			F'5	7.6E-02	2.5E-01	0.3
			F'6	1.2E-01	5.0E-01	0.2

A.5.2 PLANT Y

Plant Y is a dual unit PWR, also located in RG 1. 76 Region I. Only one unit is compared, since the units are more or less symmetric. Sequence-level CDF comparisons are provided in Table A-4. The comparison shows that the TMRE CDF for 3 of the top 4 HW PRA sequences[15] are conservative, and one sequence is essentially the same (TMRE CDF for sequence TQX is 90% of the HW PRA CDF). Note that the absolute value of sequence TQX is less than 1E-8/yr.

TABLE A-4

COMPARISON OF SEQUENCE-LEVEL ΔCDF FOR PLANT Y

SEQUENCE	SEQUENCE DESCRIPTION	TMRE RANK	TMRE CDF (YR^{-1})	RG 1.200 RANK	RG 1.200 CDF (YR^{-1})	TMRE/ RG1.200
TBU	Transient with a loss of SSHR and injection fails	1	1.0E-05	1	1.9E-06	5.3
TQU	Transient LOCA with a failure of Injection	2	1.2E-07	2	9.1E-08	1.3

[15] HW PRA Sequence 5 is not modeled in the TMRE PRA, due to its very low risk contribution (CDF less than 1E-10/yr).

SEQUENCE	SEQUENCE DESCRIPTION	TMRE RANK	TMRE CDF (YR^{-1})	RG 1.200 RANK	RG 1.200 CDF (YR^{-1})	TMRE/ RG1.200
TQX	Transient LOCA with a failure of recirculation	3	6.2E-09	4	6.9E-09	0.9
TBX	Transient with a loss of SSHR and recirculation fails	4	3.7E-09	3	6.9E-10	5.4
ATWS	ATWS Sequence	NA	NA	5	5.4E-11	Not in TMRE
	Total CDF		1.1E-05		2.0E-06	5.5

Table A-5 compares the SSC contribution to CDF between the TMRE and HW PRA results, based on the combined Fussel-Vesely importance values across all five tornado intensities (F'2 through F'6). Truncation for CDF was set to 1E-11/yr; only the 8 SSCs shown in Table A-6 were included in the CDF cut sets. The TMRE CDF contributions for all 8 SSCs are conservative to the HW PRA CDF contributions.

TABLE A-5

COMPARISON OF SSC CONTRIBUTION TO CDF FOR PLANT Y

TARGET	TARGET DESCRIPTION	TMRE CDF (YR^{-1})	RG 1.200 CDF (YR^{-1})	TMRE/ RG1.200
MSLINE	**MAIN STEAM LINES NEAR EDG AIR INTAKE**	**7.7E-06**	**2.3E-08**	**335**
FWLINE	**MAIN FEEDWATER LINES NEAR EDG AIR INTAKE**	**2.8E-06**	**1.8E-06**	**1.6**
RWST	**REFUELING WATER STORAGE TANK**	**1.9E-08**	**1.4E-09**	**14**
EDG B	**EMERGENCY DIESEL GENERATOR TRAIN B**	**3.1E-09**	**4.6E-10**	**6.7**
EDG A	**EMERGENCY DIESEL GENERATOR TRAIN A**	**2.8E-09**	**4.4E-10**	**6.4**
BSW	**BACKUP SERVICE WATER SUPPLY OUTDOOR VALVE IN A VALVE PIT**	**2.4E-09**	**5.2E-11**	**46**
IA DC	**FAILURE OF BACKUP IA HEADER**	**1.8E-09**	**1.4E-09**	**1.3**

TARGET	TARGET DESCRIPTION	TMRE CDF (YR^{-1})	RG 1.200 CDF (YR^{-1})	TMRE/ RG1.200
TDPEX	TURBINE DRIVEN PUMP STEAM EXHAUST LINE	NA(1)	NA(1)	NA

NOTES: (1) TRUNCATED IN TMRE AND RG 1.200 HW PRA

Tables A-6 and A-7[16] compare the TMRE target damage probabilities of 29 targets for five tornado intensities (145 failure probabilities) with the HW PRA target failure probabilities (based on TORMIS analyses). The top targets in Table A-6 are the same as those listed in Table A-5, i.e., the targets that contribute to tornado missile risk at Plant Y. Failures for the other SSCs (listed in Table A-7) are truncated in the CDF cut sets, i.e., they do not contribute to tornado missile risk. The targets in Table A-7 are provided here to compare failure probabilities only.

TMRE failure probabilities for the 7 targets (35 failure probabilities) in Table A-5 are conservative to the HW PRA failure probabilities; this is expected, given the CDF contribution comparisons in Table A-5. Of the remaining 110 failure probability comparisons (in Table A-7), 10 TMRE target failure probabilities are not conservative when compared to the TORMIS-based probabilities. These targets (which have negligible risk impact) are characterized as follows:

- F'2 4 SG PORVs with TORMIS failure probabilities ~1E-3
- F'3 3 SG PORVs with TORMIS failure probabilities ~2E-3
- F'4 SG PORV with TORMIS failure probability ~3 E-3

  Transformer/Load Center with TORMIS failure probability ~0.3
- F'5 Transformer/Load Center with TORMIS failure probability ~0.3
- F'6 None

A review of these targets was performed; it is noted that most of these targets are within a factor of 2 of the TORMIS-based failure probabilities, and some are very close (within ~20%). Since these are not important targets in the HW PRA, it is unlikely that much, if any, effort was made to reduce the fragilities or failure rates for these SSCs. This may be the reason why the HW PRA failure probabilities are higher than the TMRE failure probabilities.

If these targets were determined to be risk significant and highly exposed per Section 7.2.1, a sensitivity study would be performed. However, none of the targets with TMRE lower failure probabilities are significant to CDF in either the TMRE or HW PRA results (they do not contribute to CDF at a truncation of 1E-11/yr).

[16] Although Plant X ΔCDF results are based on EEFPs calculated using NEI 17-02 Rev. 0 robust missile percentages, the TMRE failure probabilities in Table A-3 are based on robust missile percentages from Table 5-2 of this revision of NEI 17-02. Additionally, the Plant X ΔCDF results are based on EEFPs using the NEI 17-02 Rev. 1 Near Ground (≤30') MIPs, the TMRE failure probabilities in Table A-3 are based on the Table 5-1 MIPs from this revision of NEI 17-02.

TABLE A-6

COMPARISON OF TARGET FAILURE PROBABILITIES FOR PLANT Y

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
Main Steam Piping [MSLINE]	Pipe Perforation	Area ~ 7600 sq ft Elevation < 30 ft	F'2	5.8E-02	2.2E-07	266,789
			F'3	1.9E-01	1.2E-04	1,559
			F'4	4.3E-01	1.9E-03	227
			F'5	1.0E+00	4.9E-03	206
			F'6	1.0E+00	1.2E-02	82
Main FW Piping [FWLINE]	Pipe Perforation	Area ~ 2800 sq ft Elevation < 30 ft	F'2	2.1E-02	9.8E-07	21,613
			F'3	6.9E-02	3.9E-05	1,768
			F'4	1.6E-01	6.1E-04	256
			F'5	4.7E-01	1.8E-03	256
			F'6	7.2E-01	4.3E-03	169
Refueling Water Storage Tank [RWST]	Tank Perforation	Area ~ 3800 sq ft Elevation < 30 ft	F'2	3.3E-02	7.0E-04	47
			F'3	1.1E-01	3.0E-03	35
			F'4	2.4E-01	2.5E-02	9.9
			F'5	7.2E-01	5.7E-02	13
			F'6	1.0E+00	9.8E-02	10
EDG B (Exhaust and Intake) [EDG B]	Penetrate Missile Barriers	Area ~ 150 sq ft Elevation < 30 ft	F'2	1.4E-03	2.0E-05	70
			F'3	4.7E-03	2.5E-04	18
			F'4	1.1E-02	1.9E-03	5.5
			F'5	3.1E-02	3.5E-03	9.1
			F'6	4.9E-02	6.2E-03	7.8

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
EDG A (Exhaust and Intake) [EDG A]	Penetrate Missile Barriers	Area ~ 150 sq ft Elevation < 30 ft	F'2	1.4E-03	2.6E-05	55
			F'3	4.7E-03	2.5E-04	19
			F'4	1.1E-02	1.8E-03	5.8
			F'5	3.1E-02	3.8E-03	8.3
			F'6	4.9E-02	6.2E-03	7.8
Service Water Piping and Valve (in Valve Pit) [BSW]	Pipe and Valve Perforation	Area ~ 35 sq ft Elevation < 30 ft	F'2	2.7E-04	5.0E-07	527
			F'3	8.7E-04	6.6E-06	132
			F'4	2.0E-03	8.7E-05	23
			F'5	5.9E-03	1.6E-04	37
			F'6	9.1E-03	1.7E-04	54
Diesel-driven Air Compressors and Piping [IA DC]	Compressor and Pipe Hit	Area ~ 1200 sq ft Elevation < 30 ft	F'2	2.6E-02	1.2E-03	23
			F'3	8.7E-02	6.4E-03	14
			F'4	2.0E-01	4.2E-02	4.7
			F'5	5.8E-01	7.8E-02	7.4
			F'6	9.1E-01	1.2E-01	7.7

TABLE A-7

COMPARISON OF NON-RISK SIGNIFICANT TARGET FAILURE PROBABILITIES FOR PLANT Y

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
TD AFW Pump Exhaust Stack [TDPEX]	Exhaust Pipe Crushing	Area ~ 170 sq ft Elevation > 30 ft	F'2	7.6E-05	0.0E+00	NA
			F'3	2.6E-04	3.4E-06	76
			F'4	5.9E-04	3.3E-05	18
			F'5	1.8E-03	1.8E-04	10
			F'6	2.6E-03	3.3E-04	8
SG A PORV and Exhaust Stack	Valve Hit and Pipe Crush	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.5E-04	1.4E-03	0.3
			F'3	1.2E-03	2.5E-03	0.5
			F'4	2.7E-03	3.4E-03	0.8
			F'5	8.1E-03	4.6E-03	1.8
			F'6	1.2E-02	6.4E-03	1.9
SG B PORV and Exhaust Stack	Valve Hit and Pipe Crush	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.5E-04	8.4E-04	0.4
			F'3	1.2E-03	1.6E-03	0.8
			F'4	2.7E-03	2.6E-03	1.1
			F'5	8.1E-03	3.6E-03	2.2
			F'6	1.2E-02	4.0E-03	3.0
SG C PORV and Exhaust Stack	Valve Hit and Pipe Crush	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.5E-04	6.5E-04	0.5
			F'3	1.2E-03	1.2E-03	1.0
			F'4	2.7E-03	2.0E-03	1.4
			F'5	8.1E-03	2.8E-03	2.8
			F'6	1.2E-02	3.0E-03	4.1
SG D PORV	Valve Hit	Area ~ 65 sq ft	F'2	3.5E-04	1.0E-03	0.3

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
and Exhaust Stack	and Pipe Crush	Elevation > 30 ft	F'3	1.2E-03	1.6E-03	0.8
			F'4	2.7E-03	2.0E-03	1.3
			F'5	8.1E-03	2.8E-03	2.9
			F'6	1.2E-02	4.1E-03	2.9
SG A PORV Block Valve and Piping to PORV	Valve Hit and Pipe Perforation	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.0E-04	1.4E-04	2.2
			F'3	1.0E-03	2.5E-04	4.2
			F'4	2.4E-03	5.8E-04	4.1
			F'5	7.1E-03	1.3E-03	5.4
			F'6	1.1E-02	2.4E-03	4.3
SG B PORV Block Valve and Piping to PORV	Valve Hit and Pipe Perforation	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.0E-04	2.3E-04	1.3
			F'3	1.0E-03	4.4E-04	2.4
			F'4	2.4E-03	6.7E-04	3.5
			F'5	7.1E-03	9.4E-04	8.0
			F'6	1.1E-02	1.4E-03	8.0
SG C PORV Block Valve and Piping to PORV	Valve Hit and Pipe Perforation	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.0E-04	2.9E-04	1.1
			F'3	1.0E-03	4.3E-04	2.4
			F'4	2.4E-03	4.4E-04	5.3
			F'5	7.1E-03	6.1E-04	12
			F'6	1.1E-02	8.0E-04	13
SG D PORV Block Valve and Piping to PORV	Valve Hit and Pipe Perforation	Area ~ 65 sq ft Elevation > 30 ft	F'2	3.0E-04	2.7E-04	1.1
			F'3	1.0E-03	5.2E-04	2.0
			F'4	2.4E-03	6.6E-04	3.6

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
			F'5	7.1E-03	1.0E-03	7.1
			F'6	1.1E-02	2.0E-03	5.2
MSSV Train A Piping	Pipe Perforation	Area ~ 30 sq ft Elevation > 30 ft	F'2	2.3E-04	0.0E+00	NA
			F'3	7.8E-04	0.0E+00	NA
			F'4	1.8E-03	4.9E-06	360
			F'5	5.3E-03	2.1E-06	2,506
			F'6	7.9E-03	1.5E-06	5,385
MSSV Train B Piping	Pipe Perforation	Area ~ 50 sq ft Elevation > 30 ft	F'2	2.3E-04	0.0E+00	NA
			F'3	7.8E-04	8.6E-07	905
			F'4	1.8E-03	5.4E-06	327
			F'5	5.3E-03	3.1E-07	16,811
			F'6	7.9E-03	3.3E-05	238
MSSV Train C Piping	Pipe Perforation	Area ~ 30 sq ft Elevation > 30 ft	F'2	1.5E-04	0.0E+00	NA
			F'3	5.0E-04	0.0E+00	NA
			F'4	1.1E-03	2.5E-06	455
			F'5	3.4E-03	3.2E-06	1,070
			F'6	5.1E-03	4.8E-06	1,049
MSSV Train D Piping	Pipe Perforation	Area ~ 50 sq ft Elevation > 30 ft	F'2	1.5E-04	0.0E+00	NA
			F'3	5.0E-04	0.0E+00	NA
			F'4	1.1E-03	0.0E+00	NA
			F'5	3.4E-03	2.7E-05	127
			F'6	5.1E-03	3.3E-06	1,550

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
MSIV A	Air Supply Piping Crushing	Area ~ 190 sq ft Elevation > 30 ft	F'2	8.5E-04	0.0E+00	NA
			F'3	2.9E-03	2.7E-07	10,914
			F'4	6.6E-03	2.5E-07	26,419
			F'5	2.0E-02	2.2E-07	88,811
			F'6	2.9E-02	1.5E-06	20,088
MSIV B	Air Supply Piping Crushing	Area ~ 190 sq ft Elevation > 30 ft	F'2	8.5E-04	0.0E+00	NA
			F'3	2.9E-03	0.0E+00	NA
			F'4	6.6E-03	2.4E-06	2,741
			F'5	2.0E-02	2.8E-06	7,060
			F'6	2.9E-02	3.6E-06	8,147
MSIV C	Air Supply Piping Crushing	Area ~ 140 sq ft Elevation > 30 ft	F'2	6.3E-04	0.0E+00	NA
			F'3	2.2E-03	0.0E+00	NA
			F'4	4.9E-03	0.0E+00	NA
			F'5	1.5E-02	1.0E-06	14,689
			F'6	2.2E-02	4.9E-06	4,448
MSIV D	Air Supply Piping Crushing	Area ~ 140 sq ft Elevation > 30 ft	F'2	6.3E-04	0.0E+00	NA
			F'3	2.2E-03	4.0E-07	5,494
			F'4	4.9E-03	3.9E-07	12,575
			F'5	1.5E-02	3.8E-07	38,769
			F'6	2.2E-02	3.6E-07	60,331
Steam Dump Valves and Piping to	Valve Hit and Pipe	Area ~ 270 sq ft Elevation < 30	F'2	3.2E-03	4.0E-04	7.8
			F'3	1.0E-02	1.9E-03	5.5

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
Condenser	Perforation	ft	F'4	2.4E-02	1.2E-02	2.0
			F'5	7.0E-02	2.2E-02	3.2
			F'6	1.1E-01	2.9E-02	3.7
Condensate Storage Tank and Exposed Piping	Tank and Pipe Perforation	Area ~ 7000 sq ft Elevation varies	F'2	2.5E-02	6.0E-05	409
			F'3	8.5E-02	3.7E-04	230
			F'4	1.9E-01	1.3E-02	15
			F'5	5.7E-01	4.2E-02	14
			F'6	8.5E-01	9.2E-02	9.3
Condenser Hotwell Sumps	Steel Plate (Barrier) Penetration	Area ~ 170 sq ft Elevation < 30 ft	F'2	1.5E-03	0.0E+00	NA
			F'3	4.8E-03	5.0E-07	9,641
			F'4	1.1E-02	1.1E-05	972
			F'5	3.2E-02	3.6E-05	909
			F'6	5.0E-02	1.4E-04	355
(Buried) Diesel Fuel Oil Tank Vent	Vent Pipe Crushing	Area ~ 2 sq ft Elevation < 30 ft	F'2	4.1E-05	1.7E-05	2.4
			F'3	1.3E-04	5.7E-05	2.3
			F'4	3.1E-04	2.2E-04	1.4
			F'5	9.0E-04	7.3E-04	1.2
			F'6	1.4E-03	1.3E-03	1.1
Transformer and Load Center in Turbine Building	Missile Hit	Area ~ 600 sq ft Elevation < 30 ft	F'2	1.3E-02	1.5E-03	8.7
			F'3	4.2E-02	1.9E-02	2.2
			F'4	9.5E-02	2.6E-01	0.4
			F'5	2.8E-01	3.4E-01	0.8

TARGET	FAILURE MODES	SIZE/LOCATION	F' SCALE	TMRE PROBABILITY	RG 1.200 PROBABILITY	TMRE/ RG 1.200
			F'6	4.4E-01	3.7E-01	1.2

A.6 TARGET EXPOSURE MIP UNCERTAINTY

Comparing individual targets normalized hit probabilities (i.e., the MIP) in NP-768 Plant A to the average Plant A MIP (taken across all 7 targets), one specific target (#4) shows a significantly larger hit probability across most tornado intensities. The MIP could have been derived from this target, which would provide for the highest MIP value from all the NP-768 Plant A data. However, choosing the most conservative target hit probability was judged to be too conservative for application in the TMRE. Therefore, the average values were used. However, using a MIP derived from average hit probabilities could result in low EEFPs for certain highly exposed targets at a given site.

A.6.1. TARGET 4

The exposure of Target 4 to tornado missiles is very high, based on its orientation with respect to the most prevalent tornado path, which results in a very high missile flux against the south wall of Target 4 (~70% of the total area of Target 4). Table A-8 provides the derived MIP values for Target 4 only (less than 30' elevation), for F'4 – F'6 tornadoes.

TABLE A-8

TARGET 4 TORNADO MISSILE IMPACT PARAMETER (PER MISSILE PER FT^2 PER TORNADO INTERVAL FREQUENCY)

TORNADO INTENSITY	NRC REGION I	NRC REGION II	NRC REGION IIII
F'4	1.6E-09	1.6E-09	1.8E-09
F'5	2.9E-09	4.1E-09	N/A
F'6	4.7E-09	N/A	N/A

The ratios between the Target 4 derived MIP values in Table A-8 and the TMRE MIP values for near ground targets (i.e., less than 30' elevation) are 2.3, 2.1, and 1.5 (for F'4, F'5, and F'6 tornadoes, respectively). The average of these ratios is 2.0.

A.6.2 TARGET EXPOSURE CONCLUSIONS

For high exposed targets, a sensitivity could be performed by recalculating target EEFPs using a MIP multiplier of 2.0x the nominal MIP values calculated for the Degraded Case by 2.5. However, the MIP multiplier of 2.75 applied to highly exposed targets to account for missile distribution uncertainty ("Z vs U") bounds the target exposure multiplier and accounts for the uncertainty. The modified EEFPs are calculated for F'4 through F'6 tornadoes only. For many targets, the TMRE based EEFPs are significantly greater than the TORMIS-based failure probabilities, as seen in Tables A-3, A-6 and A-7. This is likely due to the conservative assumption of the 1.0 failure probability for a missile hit at lower tornado intensities. This conservatism associated with this assumption is more pronounced at lower tornado intensities, because the likelihood of failure given a missile hit is much lower at low tornado intensities. Even for robust targets, where missile inventories are reduced to account for the fact that only certain missiles can fail a target, the basis for these calculations was missiles travelling at design speeds. Therefore, it is judged that the conservatism involved in applying an increased MIP across all tornado intensities would result in overly conservative results.

A.7 ZONAL VS. UNIFORM (Z VS U) SENSITIVITY

In addition to the TORMIS sensitivity studies documented in Appendix E, additional TORMIS simulations were performed to investigate the impact of missile distribution at a site on missile strike probability. Specifically, the sensitivity evaluated the impact of a "zonal" missile distribution versus a uniform missile distribution (referred to here as "Z vs U").

A.7.1. ZONAL AND UNIFORM MISSILE DISTRIBUTIONS

As previously discussed (see Appendix B) the TMRE MIP values were derived from missile hit probabilities in TORMIS simulations for Plant A in EPRI NP-768. For the simulations, missiles were assumed to be distributed uniformly throughout the area in and around Plant A. That is, the missiles were assumed to be distributed so that the missile density was constant across the entire area for missile origination. In reality, missiles are not distributed uniformly at a plant site; there are areas of high and low missile density.

The missile distribution at a given site may have an impact on the probability that a specific target is hit by a missile, all else being equal (this probability is represented by MIP). A set of TORMIS simulations was performed at the same two plants described in Appendix E. In this Z vs U study, two sets of simulations were run for each plant.

- Zonal Distribution – Missile hit frequencies were determined based on the actual missile distribution at the plants, when the missiles were inventoried there. As can be seen in Figures A-2 and A-3, the missiles are assigned to a zone around the plant; each plant contains approximately 20 zones. For this case, the number of missiles in each zone is represented by the red number (the first number) below the missile zone identifier. TORMIS simulations were performed at five tornado intensities, EF1 through EF5[17], and the target hit frequencies were determined.

- Uniform Distribution – The total missile population from the zonal distribution case was redistributed for this sensitivity, so that the missile density (i.e., missiles per ft^2) was constant in all zones. This was done to represent a missile distribution analogous to that in Plant A of NP-768. The uniform missile counts for each zone are provided in Figures A-2 and A-3 as blue

[17] EF-scale tornado simulations were used in the sensitivity studies, since the TORMIS models were based on the EF-scale. Since the sensitivity studies are comparing the effect of missile distributions, using the F'-scale (which is similar to the EF-scale) shouldn't have an impact on the overall results and conclusions of the sensitivity studies.

numbers, below the zonal missile counts. TORMIS simulations were performed at five tornado intensities, EF1 through EF5, and the target hit frequencies, for the same targets in the zonal simulation, were determined.

FIGURE A-2
PLANT A ZONAL AND UNIFORM MISSILE DISTRIBUTIONS

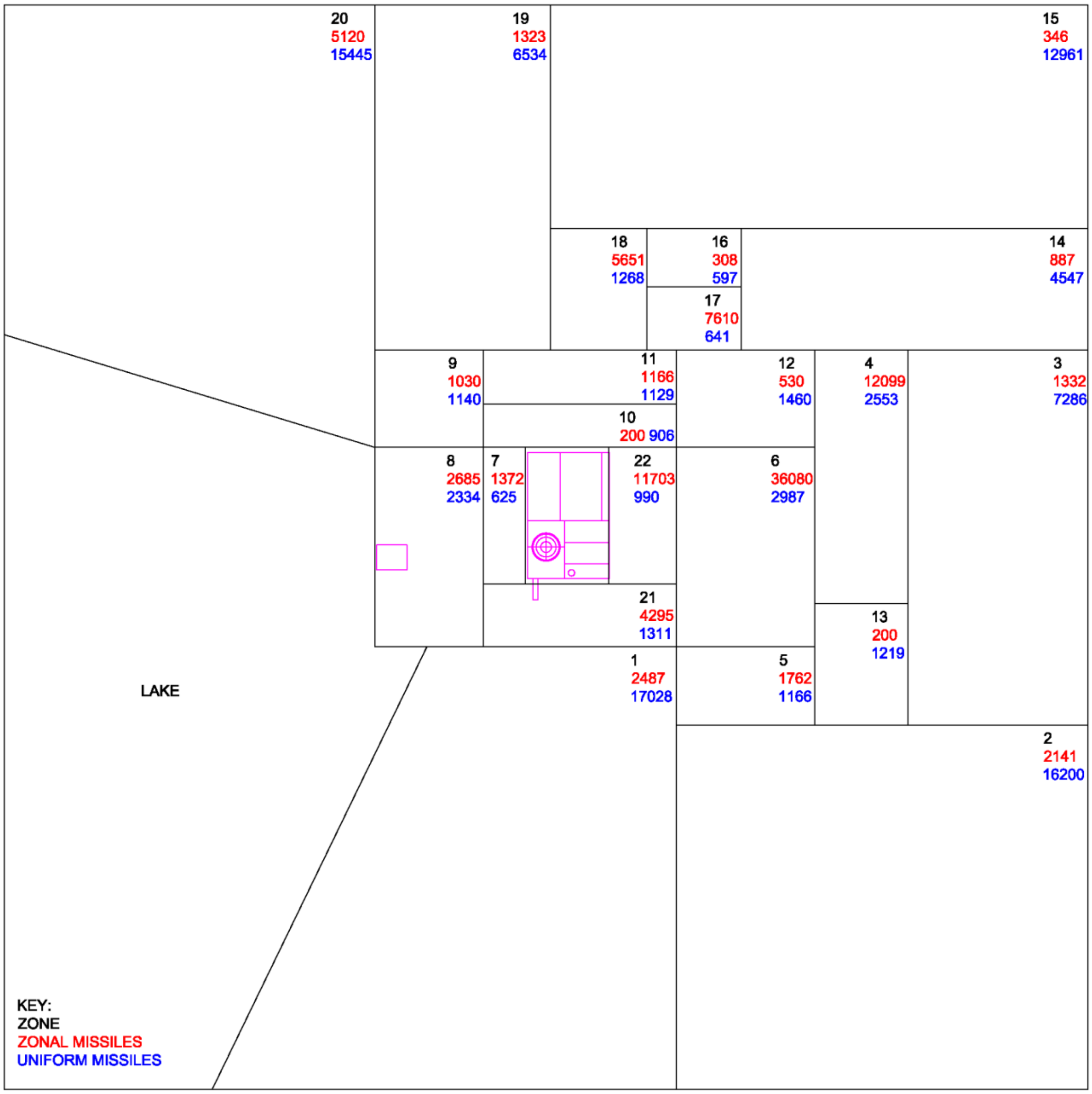
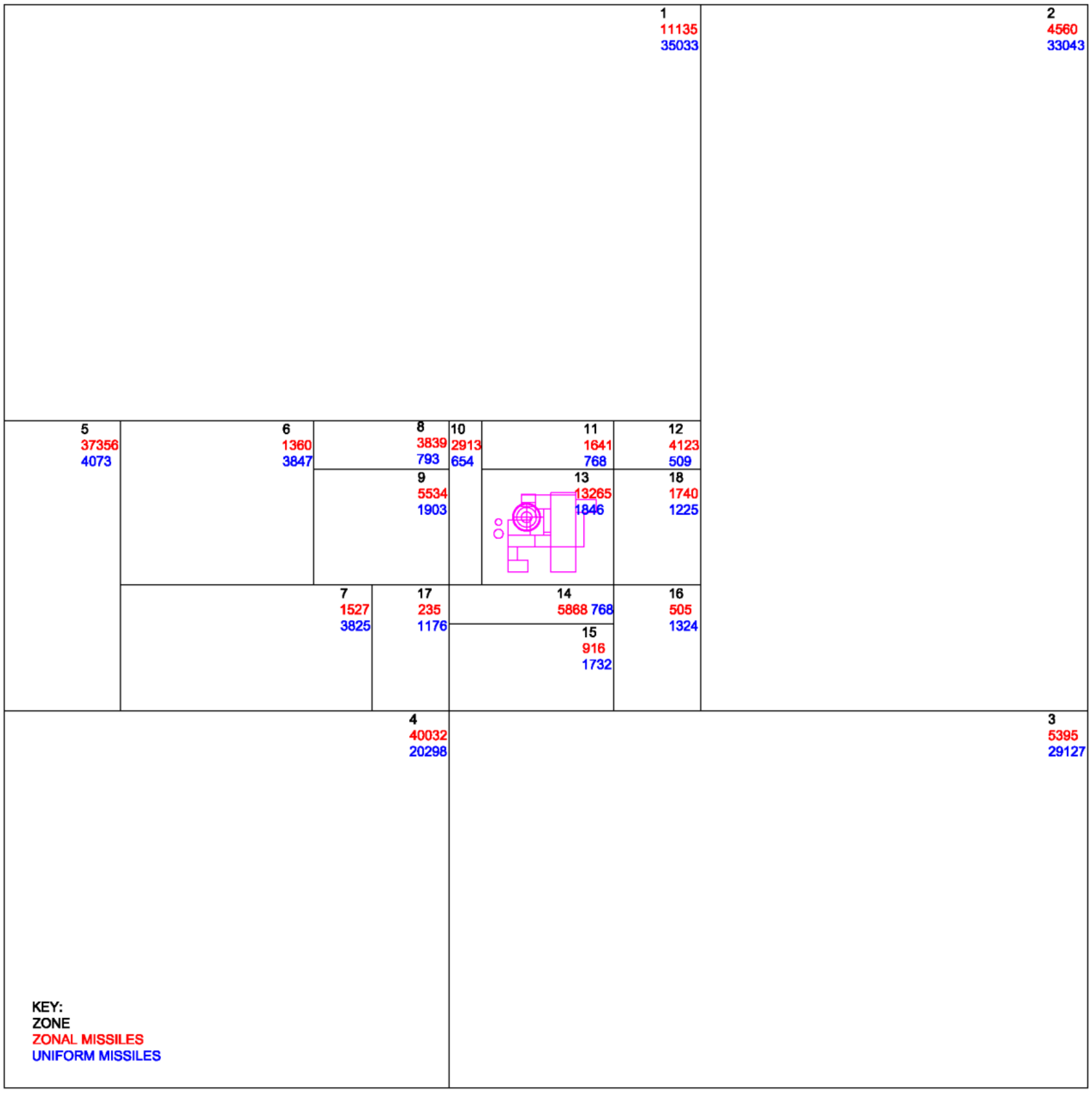


FIGURE A-3
PLANT A ZONAL AND UNIFORM MISSILE DISTRIBUTIONS



A.7.2. ZONAL VS UNIFORM SIMULATION RESULTS

Ratios between zonal and uniform hit frequencies were calculated for each target, for each tornado intensity, as well as for each target across all tornado intensities. Several discrepancies were noted while reviewing the data, placing doubt on the efficacy of the simulations. On a macro scale, the simulations suggest that zonal missile distributions, as would be seen at an actual plant site, result in higher missile hit frequencies than uniform missile distributions. However, this was not the case for each target, and many of the simulation results provided conflicting data. The reason for the observed anomalies was not readily discerned, leading to a concern over use of the simulation results.

- A significant concern exists with targets that showed no missile hits in either zonal, uniform, or both sets of simulations. This results in ratios of 0 (if the zonal simulation recorded no hits) to undefined (if the uniform simulation recorded no hits). This phenomenon was more prevalent in the Plant B simulations, but it was inconsistent throughout all the simulations. Some targets had no hits for one EF-scale and missile distribution, but had hits for others.

- The trend of missile hit probabilities (i.e., hit frequency divided by tornado frequency) was inconsistent between EF-scales for individual targets. As seen in the NP-768 results and other current TORMIS analyses supporting high wind PRAs, missile hit probabilities on targets trend higher with higher intensity tornadoes. In very few cases this trend is not seen. However, many of the targets (again, more prevalent in the Plant B simulations) showed varying trends for increasing tornado intensities. This occurred for both uniform and zonal simulations, and often the trends were not consistent between the two missile distributions for the same target. This results in unpredictable trends in the ratio of zonal to uniform missile hit probabilities.

As noted previously, the high level results of the Z vs U sensitivity study suggest that a zonal missile distribution results in a higher missile hit frequency than a uniform distribution. This would further suggest that the MIPs derived from NP-768 may be different if a zonal missile distribution were simulated. However, MIPs derived from Plants B1 and B2 (which used a zonal distribution) are lower than those derived from Plant A (which used a uniform distribution).

The TORMIS sensitivity studies for Z vs U resulted in mixed and some unexplainable differences between zonal and uniform missile distributions. Further investigation (i.e., performing more or different simulations) may not have resolved the discrepancies. However, it was proposed that the simulation results could potentially be used to address the uncertainty associated with missile distributions, if the anomalous data (i.e., 0 missile hits or inconsistent trends, as described above) could be discarded and the remaining data proved meaningful.

A statistical analysis of the Z vs U target hit probability ratios was performed to evaluate whether the anomalous data could be discarded and the remaining data could be used to develop a Z vs U ratio suitable for application to the TMRE results. The ultimate goal is to decide what multiplier (if any) should be applied to the MIP values (and hence EEFP) for some targets.

The two primary concerns with the data were:

- Zero hit frequencies for some targets
- Inconsistent trends in hit probabilities for some targets

A.7.4. Target Categorization

The simulation data for each target and each EF-scale was reviewed and assigned to the bins listed below. The data is screened in the order shown below, so that each target is only assigned to one category. An example of each category is shown in Table A-9.

- Zero – Any target with a 0.0 hit frequency for zonal or uniform missile distributions, for any EF-scale, was assigned to this category. [Target 1 in Table A-9]
- X – Any target that showed an inconsistent trend in hit probability for more than one EF-scale, for either zonal or uniform distributions, was assigned to this category. [Targets 2 and 3 in Table A-9]

- 1 – Any target that showed an inconsistent trend in hit probability for only one EF-scale, for either zonal or uniform distributions, was assigned to this category. [Target 4 in Table A-9]

- OK – If the target is not assigned to any of the previous categories, it is assigned to this category. [Target 5 in Table A-9]

TABLE A-9
EXAMPLE TRENDS IN TARGET HIT PROBABILITY

ID	EF1	EF2	EF3	EF4	EF5	CATEGORY	COMMENTS
1	1.4E-09	0.0E+00	1.8E-08	3.2E-07	7.6E-07	ZERO	EF2 = 0
2	1.2E-07	1.0E-07	3.4E-07	5.7E-06	2.1E-06	X	EF1-EF2 NEGATIVE TREND EF4-EF5 NEGATIVE TREND
3	8.3E-08	6.6E-08	6.1E-07	2.5E-07	7.0E-08	X	EF1-EF2 NEGATIVE TREND EF3-EF4 NEGATIVE TREND EF4-EF5 NEGATIVE TREND
4	1.9E-08	2.1E-08	5.2E-06	1.5E-06	3.2E-06	1	EF3-EF4 NEGATIVE TREND
5	2.0E-08	5.5E-08	7.5E-07	1.3E-06	1.4E-06	OK	OK

Data was collected for 116 total targets in the TORMIS models for plants A and B. Table A-10 provides a breakdown of the number of targets assigned to each category.

- Approximately 50% of all targets had either a zero hit probability or an inconsistent trend for more than one EF-scale. It should be noted that many targets assigned to the Zero category had more than one negative trend and would otherwise be assigned to the X category. Additionally, many of the targets had more than one zero hit probability.

- Only 27% of the targets were categorized OK

- Approximately 50% of the targets had one or no inconsistent trends. The number of targets from each plant in this group (OK or 1) is relatively equal (27 in A, 31 in B).

TABLE A-10
TARGET CATEGORIES

	ZERO	X	1	OK	TOTAL
PLANT A	5	14	13	14	46
PLANT B	21	18	14	17	70
PLANTS A & B	26	32	27	31	116
PERCENTAGE (A&B)	22%	28%	23%	27%	100%

Tables A-11 and A-12 provide the Plant A and B targets, the Z vs U ratio for each target for the sum of tornado categories EF1 through EF5, and the Target Category assigned (based on the discussion above).

TABLE A-11
PLANT A TARGET Z VS U RATIOS AND CATEGORIES

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
1	Buried	2341	0.34	OK
2	Buried	883	2.49	1
3	Buried	1336	1.26	1
4	Buried	655	1.61	1
5	Buried	779	2.59	1
6	Buried	194	5.05	X
7	Buried	133	1.85	X
8	Buried	1587	1.75	1
9	Other-Horiz	81	2.50	X
10	Other-Horiz	25	1.23	X
11	Other-Horiz	45	1.72	X
12	Roof	25	0.34	Zero
13	Roof	25	1.27	Zero

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
14	Roof	25	2.41	X
15	Roof	25	1.41	Zero
16	Roof	25	0.64	Zero
17	Roof	25	1.24	X
18	Roof	33	0.88	Zero
19	Roof	25	1.35	1
20	Roof	390	1.83	OK
21	Roof	25	1.99	X
22	Roof	25	0.68	X
23	Roof	25	0.89	1
24	Roof	25	4.13	X
25	Roof	25	2.60	X
26	Roof	30	2.11	X
27	Wall > 30'	91	2.28	OK
28	Wall > 30'	25	2.11	1
29	Wall > 30'	91	2.18	1
30	Wall > 30'	192	2.24	OK
31	Wall > 30'	25	0.81	X
32	Wall > 30'	25	1.31	OK
33	Wall > 30'	25	1.40	1
34	Wall > 30'	25	2.48	OK
35	Wall > 30'	25	2.59	1
36	Wall > 30'	25	1.94	OK

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
37	Wall < 30'	25	2.23	1
38	Wall < 30'	25	1.41	X
39	Wall < 30'	110	2.23	OK
40	Wall < 30'	115	2.50	OK
41	Wall < 30'	25	1.55	OK
42	Wall < 30'	45	1.68	OK
43	Wall < 30'	95	4.33	OK
44	Wall < 30'	25	1.65	OK
45	Wall < 30'	25	1.80	OK
46	Wall < 30'	25	1.80	1

TABLE A-12
PLANT B TARGET Z VS U RATIOS AND CATEGORIES

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
1	Roof	25	5.12	Zero
2	Roof	25	1.01	X
3	Roof	25	0.94	Zero
4	Roof	25	1.36	X
5	Roof	25	0.92	X
6	Roof	80	0.71	X
7	Roof	25	3.00	X
8	Roof	80	1.87	X
9	Roof	25	0.55	Zero
10	Roof	25	20.33	Zero

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
11	Roof	207	1.97	1
12	Roof	207	1.92	OK
13	Roof	28	2.35	X
14	Roof	38	1.78	X
15	Roof	28	3.94	1
16	Roof	38	2.16	X
17	Roof	28	1.79	X
18	Roof	28	0.66	1
19	Wall > 30'	25	3.46	Zero
20	Wall > 30'	28	4.67	Zero
21	Wall > 30'	28	15.05	Zero
22	Wall > 30'	171	2.41	OK
23	Wall > 30'	25	8.49	Zero
24	Wall > 30'	30	3.05	Zero
25	Wall > 30'	28	1.64	X
26	Wall > 30'	437	2.35	OK
27	Wall > 30'	28	2.54	X
28	Wall > 30'	35	2.97	1
29	Wall > 30'	171	2.53	OK
30	Wall > 30'	28	5.00	OK
31	Wall > 30'	437	2.94	OK
32	Wall > 30'	25	4.86	1
33	Wall > 30'	437	2.30	OK

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
34	Wall > 30'	171	2.58	OK
35	Wall > 30'	27	5.75	OK
36	Wall > 30'	25	4.00	1
37	Wall > 30'	28	2.24	X
38	Wall > 30'	171	2.44	OK
39	Wall > 30'	132	2.39	1
40	Wall > 30'	28	18.31	X
41	Wall > 30'	437	2.41	OK
42	Wall > 30'	132	2.92	OK
43	Wall > 30'	28	2.75	X
44	Wall < 30'	30	0.86	Zero
45	Wall < 30'	30	3.16	Zero
46	Wall < 30'	40	Note 2	Zero
47	Wall < 30'	40	Note 2	Zero
48	Wall < 30'	40	0.48	Zero
49	Wall < 30'	42	0.51	Zero
50	Wall < 30'	42	2.31	Zero
51	Wall < 30'	54	2.31	Zero
52	Wall < 30'	50	11.39	Zero
53	Wall < 30'	42	18.39	Zero
54	Wall < 30'	50	15.55	Zero
55	Wall < 30'	35	4.62	X
56	Wall < 30'	40	16.39	Zero

Target #	Target Type	Surface Area (sq. ft)	Ratio = Zonal / Uniform	Category
57	Wall < 30'	28	1.68	X
58	Wall < 30'	35	1.75	1
59	Wall < 30'	60	3.40	1
60	Wall < 30'	123	3.00	OK
61	Wall < 30'	60	3.59	OK
62	Wall < 30'	25	3.29	OK
63	Wall < 30'	123	3.20	1
64	Wall < 30'	40	4.08	1
65	Wall < 30'	25	4.31	1
66	Wall < 30'	50	3.10	OK
67	Wall < 30'	25	6.45	OK
68	Wall < 30'	396	4.22	1
69	Wall < 30'	40	3.28	1
70	Wall < 30'	50	4.97	X

A.7.5. Statistical Analysis of Simulation Results

The following is a description of the statistical testing and results:

1. A 2-sample Kolomogorov-Smirnoff (KS) test with significance level α =0.05 was performed for the following pairs of data subsets:

    - OK and Zero/X
    - OK/1 and Zero/X

2. The 2-sample KS-test has null hypothesis H0: The two data sets come from a common distribution. The alternative hypothesis H1: The two data sets do not come from a common distribution. The separation of data is based on the following:

    a. The possibility that the TORMIS simulation was inadequate for the targets assigned to the Zero or X category. For example, the results may not have converged for those targets, resulting in erroneous trends and/or no hits.

    b. The NP-768 data shows that several targets (1, 2, 4, and 5) have one negative trend as tornado intensities increase. Thus, this may be expected behavior for the TORMIS simulation.

    c. Only considering the OK data may not provide sufficient data.

3. Comparing the OK and Zero/X subsets, the test statistic D, 0.27477, is greater than the critical value for α=0.05 (0.273114). This implies that the p-value of the test-statistic is less than 0.05. Thus, the null hypothesis is rejected in favor of the alternative. The two data sets (OK and Zero/X) are not from a common distribution.

4. Comparing the OK/1 and Zero/X subsets, the test statistic is slightly less than the critical value for α =0.05. We fail to reject the null hypothesis although it is noted that the difference between the D-value 0.218596 and the critical value c = 0.273114 is very small (0.009966).

5. Additionally, an adaptive KS-Goodness of Fit test with α =0.05 was performed for the following subsets of the data with null hypothesis H0: The data come from the fitted lognormal distribution. The alternative hypothesis is H1: The data do not come from the fitted lognormal distribution. The calculation was performed using the website: http://nrcoe.inl.gov/radscalc/Pages/CurveFit.aspx

    a. All data

    b. All data without X

    c. All data without Zero

    d. All data without 1

    e. All date without X and Zero (i.e., OK and 1 data)

f. All data without X and 1 (i.e., OK and Zero data)

g. All data without 1 and Zero (i.e., OK and X data)

h. All data without X, Zero and 1 (i.e., OK only)

6. For the case of ALL DATA, the null hypothesis is rejected (D-statistic = 0.1013 with critical value c=0.1004). The ALL DATA without 1 test also resulted in rejecting the null hypotheses (D-statistic = 0.1196 with critical value c = 0.1150).

7. For all other combinations, we fail to reject the null hypothesis. It is noted that in all cases, the lognormal fit was the best fit with regards to the D-statistic among the available curves (normal, lognormal, exponential, gamma, Weibull).

8. Based on the 2-sample and Goodness of Fit KS-test, the Zero and X data do not fit with the OK data. Thus, we choose to exclude the Zero and X data.

The following references provide information on the KS test statistics:

[1] https://onlinecourses.science.psu.edu/stat464/node/54

[2] http://www.itl.nist.gov/div898/software/dataplot/refman1/auxillar/ks2samp.htm

[3] http://sparky.rice.edu/astr360/kstest.pdf

[4] Romeau, Jorge Luis. Kolomogorov-Smirnov: A Goodness of Fit Test for Small Samples. START (Selected Topics in Assurance Related Technologies) Volume 10 Number 6.

Based on the results of the statistical testing described above, the Z vs U ratios for targets categorized as Zero or X will be discarded.

- The data categorized as OK (i.e., from test 5.h. above) could be used to determine the change in hit probabilities (and thus change in MIP) due to zonal missile distributions. The Z vs U ratio using only the OK data is 2.73. Figure A-4 and Table A-13 provide the curve fit results for this dataset.

- Although the null hypothesis that OK/1 and Zero/X were from different distributions was rejected, the difference between the D-value and the critical value were very small (see 4. above). In fact, the Z vs U ratio using the OK/1 data (from test 5.e. above) is similar to the OK data only; the mean is slightly smaller at 2.67. Figure A-5 and Table A-14 provide the curve fit results for this dataset.

- For information purposes, the all data (i.e., test 5.a. above) lognormal distribution curve fit results are provided in Figure A-6 and Table A-15. As can be seen, the mean is higher when considering all the data, although the variance and standard distribution are disproportionally larger. As noted the, Zero and X data are discarded, based on the results of the KS tests.

Therefore, a value of 2.75 is recommended for the Z vs U sensitivity. This is based on rounding up the mean from the OK dataset lognormal distribution (2.73).

FIGURE A-4
LOGNORMAL DISTRIBUTION FOR Z VS U RATIOS (OK CATEGORY)

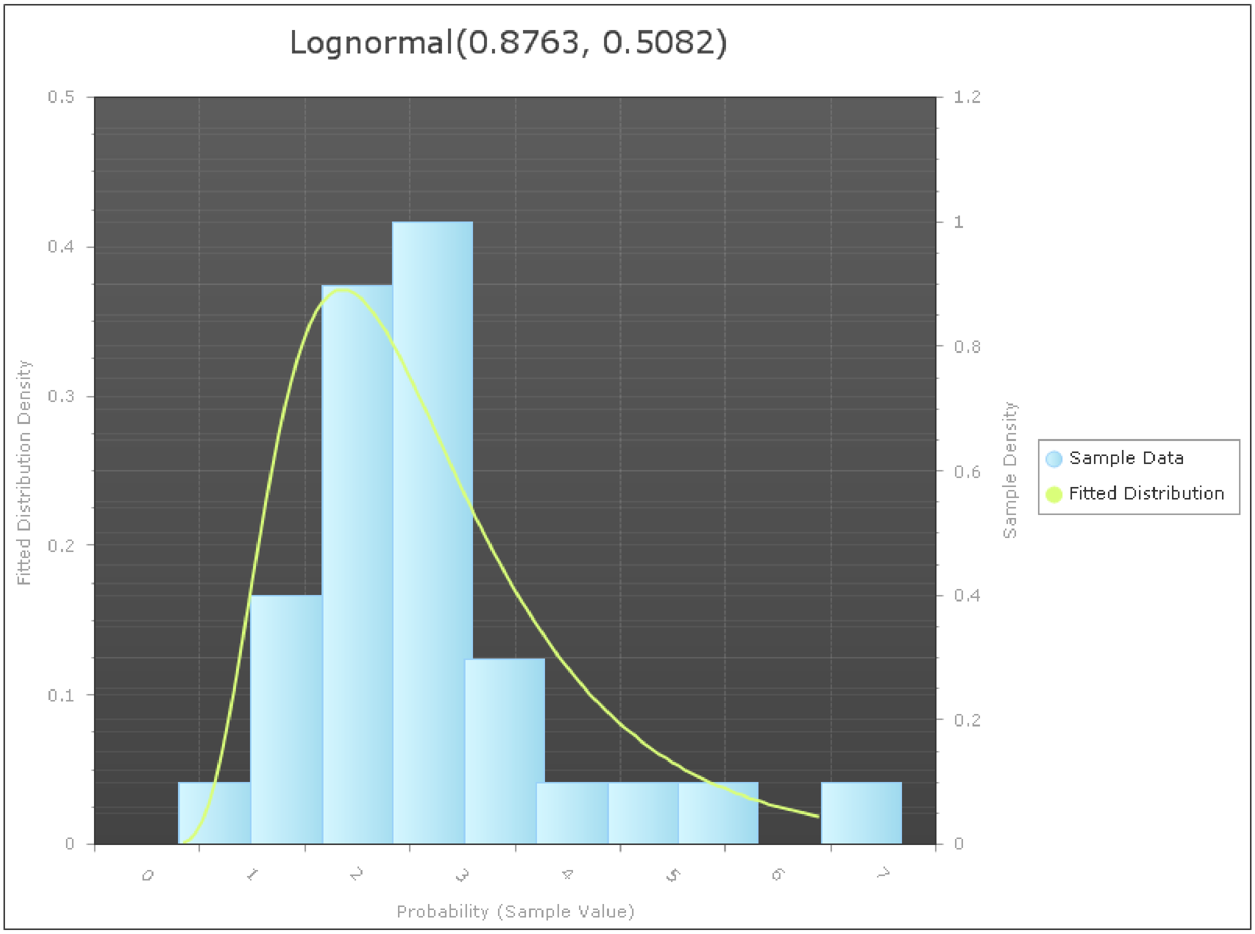


TABLE A-13
LOGNORMAL PARAMETERS FOR Z VS U RATIOS (OK CATEGORY)

Parameter	Input Values	Fitted Values
Mean	2.68	2.73
Median	2.41	2.40
Variance	1.54	2.20
Std. Deviation	1.24	1.48
Skewness	--	1.79
5th Percentile	--	1.04
95th Percentile	--	5.54

FIGURE A-5
LOGNORMAL DISTRIBUTION FOR Z VS U RATIOS (OK/1 CATEGORIES)

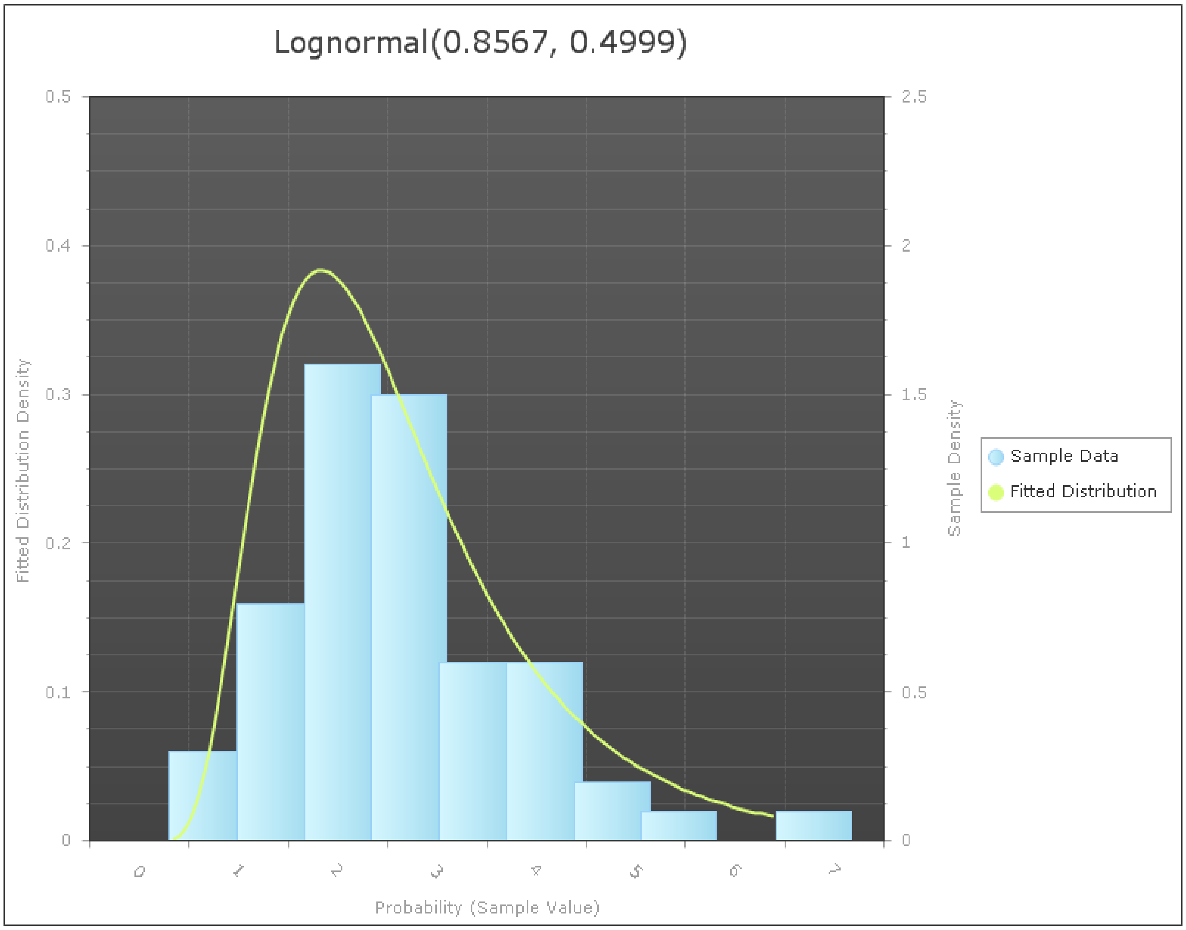


TABLE A-14
LOGNORMAL PARAMETERS FOR Z VS U RATIOS (OK/1 CATEGORIES)

Parameter	Input Values	Fitted Values
Mean	2.63	2.67
Median	2.41	2.36
Variance	1.41	2.02
Std. Deviation	1.19	1.42
Skewness		1.75
5th Percentile		1.04
95th Percentile		5.36

FIGURE A-6
LOGNORMAL DISTRIBUTION FOR Z VS U RATIOS (ALL DATA)

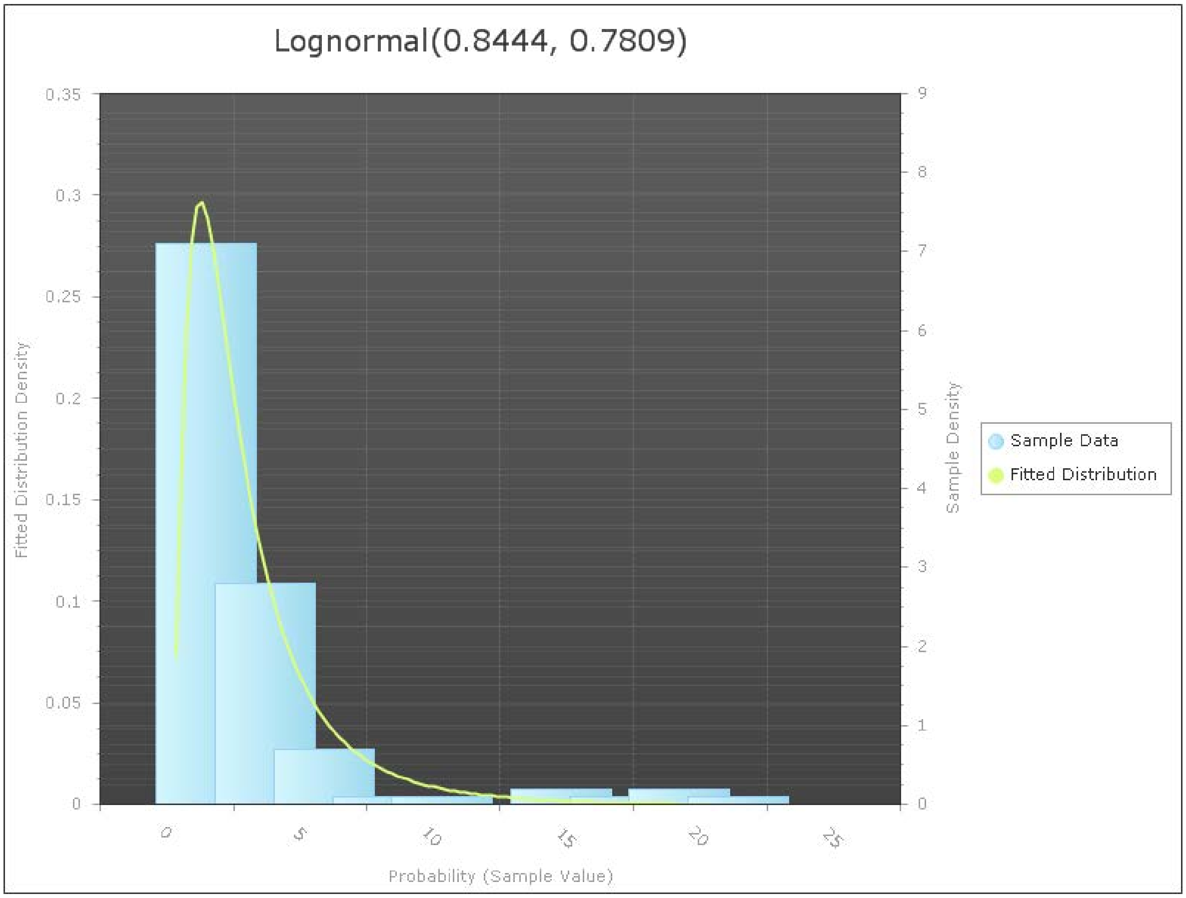


TABLE A-15
LOGNORMAL PARAMETERS FOR Z VS U RATIOS (ALL DATA)

Parameter	Input Values	Fitted Values
Mean	3.29	3.16
Median	2.31	2.33
Variance	13.6	8.37
Std. Deviation	3.69	2.89
Skewness		3.519
5th Percentile		0.64
95th Percentile		8.40

A.7.6. TARGET-SPECIFIC MIP CALCULATIONS

Based on the results of the analysis in Section A.7.5, target basic events that meet the criteria for the missile distribution sensitivity are adjusted using a 2.75 multiplier. The sensitivity analysis described in Section 7.2.1 requires additional analyses for targets with a large concentration of missiles close to the target. The parameters used to define this assessment are greater than 1,100 missiles within 100 feet of a highly exposed target.

- The selection of 100 feet is based on judgement
- The number of missiles (1,100) is based on an approximate missile density of 2.75 times the average density. If the local missile density is less than 2.75 times the average, then the nominal 2.75 multiplier for the sensitivity covers the configuration.

Assuming 240,000 missiles are present in the area surrounding the site (i.e., circle with 2500' radius), the missile density for 1.22E-2 missiles/ sq ft. A missile density 2.75 times higher in a 100' radius circle results in approximately 1,055 missiles. This is rounded to 1,100 missiles.

Determining a target-specific MIP multiplier based on the ratio of local missile density and average site missile density is based on recommendations provided in Reference A.5.

A.8 REFERENCES

[A.1] Mironenko, A. and Lovelace, N., “High Wind PRA Development and Lessons Learned from Implementation,” PSA 2015 Paper 12074, April 27, 2015.

[A.2] Twisdale, L., Vickery, P., Sciaudone, J., Banik, S., and Mizzen, D., “Advances in Wind Hazard and Fragility Methodologies for HW PRAs” PSA 2015 Paper, April 2015.

[A.3] A Preliminary Approach to Human Reliability Analysis for External Events with a Focus on Seismic, EPRI, Palo Alto, CA: 2012. 1025294.

[A.4] EPRI NP-768, Tornado Missile Risk Analysis, May 1978

[A.5] Analysis of Missile Impact Probability for Generic Tornado Hazard Assessments, Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses, July 29, 2016

[A.6] Regulatory Guide 1.174, “An Approach for Using Probabilistic Risk Assessment in Risk-informed Decisions on Plant Specific Changes to the Licensing Basis,” Revision 3, January 2018

[A.7] Regulatory Guide 1.76, “Design-basis Tornado and Tornado Missiles for Nuclear Power Plants,” Revision 1, March 2007.

[A.8] Regulatory Guide 1.200, “An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-informed Activities,” Revision 2, March 2009.

[A.9] ASME/ANS RA-Sa-2009, “Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications,” Addendum A to RA-S-2008, ASME, New York, NY, American Nuclear Society, La Grange Park, Illinois, February 2009.

APPENDIX B: BASES FOR MIP AND MISSILE INVENTORIES

The purpose of the Tornado Missile Risk Evaluator (TMRE) is to provide a methodology that can be used at any U.S. nuclear power plant (NPP) to estimate the risk associated with SSCs exposed to tornado missiles. The methodology is designed to be relatively simple, conservative, and applicable to all plants, precluding the need to perform detailed tornado missile simulations.

Data from EPRI NP-768 [Ref. B.1] was used for previous simplified tornado missile risk analyses used in the TAP A-45 program [Refs. B.2, B.3, B.4, B.6, B.6, B.7]. Specifically, the probability of tornado missiles impacting targets was based in part on the results of the TORMIS simulations documented in EPRI NP-768 and 769 [Ref. B.8]. A summary and explanation of the previous studies can be found in EPRI 3002003107, *High Wind Risk Assessment Guidelines* [Ref. B.9].

The TMRE methodology uses the same source information from EPRI NP-768 to derive the Missile Impact Parameter (MIP). This appendix describes how the information presented in EPRI NP-768 is used to determine the MIP values for the TMRE.

In order to simplify and standardize the TMRE Exposed Equipment Failure Probability (EEFP) calculations, values for total missile inventory are based on a survey of two US NPP missile walkdowns. These walkdowns were performed to support previous TORMIS analyses at different sites in the U.S. The maximum values from these missile surveys are used in the TMRE, given that the site-specific walkdown performed in support of the TMRE validates that this generic missile inventory is bounding (see Section 5).

B.1 BACKGROUND INFORMATION ON MISSILE IMPACT PARAMETER (MIP)

The probability of a tornado missile hit on an exposed SSC is dependent upon several variables: the tornado intensity, the likelihood of a tornado strike, the surface area of the target, and the number and type of potential missiles (i.e. the “missile inventory”). The MIP reflects the probability of a tornado missile hit on an SSC given a tornado missile strike and the category of the tornado; the MIP it is normalized for target surface area and missile inventory.

EPRI NP-768 and NP-769 document the TORMIS computer simulation software developed by EPRI to perform missile hazard studies. Three plant configurations were used and numerous sensitivity cases were performed, such as varying missile population sizes and missile types, Monte Carlo sampling sizes, missile transport phenomena variables, and wall thickness. The methodology uses random variables to model the inherent variations in tornado incidence, wind field characteristics, missile position and orientation, missile aerodynamics, and the distribution of the potential missile population. The TORMIS methodology uses missile time-history simulations to predict the response of the postulated missiles to the tornado as it passes through the plant area (see Figure B-1).

The performance of a detailed, plant-specific TORMIS study can be a resource intensive analysis, which may not be warranted for relatively insignificant risk contributors, such as small exposed SSCs [Refs. B.10, B.11]. Previous studies [Refs. B.2, B.3, B.4, B.5, B.6, B.7] used the TORMIS results presented in EPRI NP-768 to derive a normalized missile impact parameter that could be used to estimate the likelihood of an exposed SSC being struck by a tornado missile.

The TMRE MIP is developed using similar principles and assumptions as the previous work. However, there are several refinements and improvements in the development of the MIP. The calculations and rationale used to derive the TMRE MIP values are presented here.

B.1.1 Definition of Missile Impact Parameter (MIP)

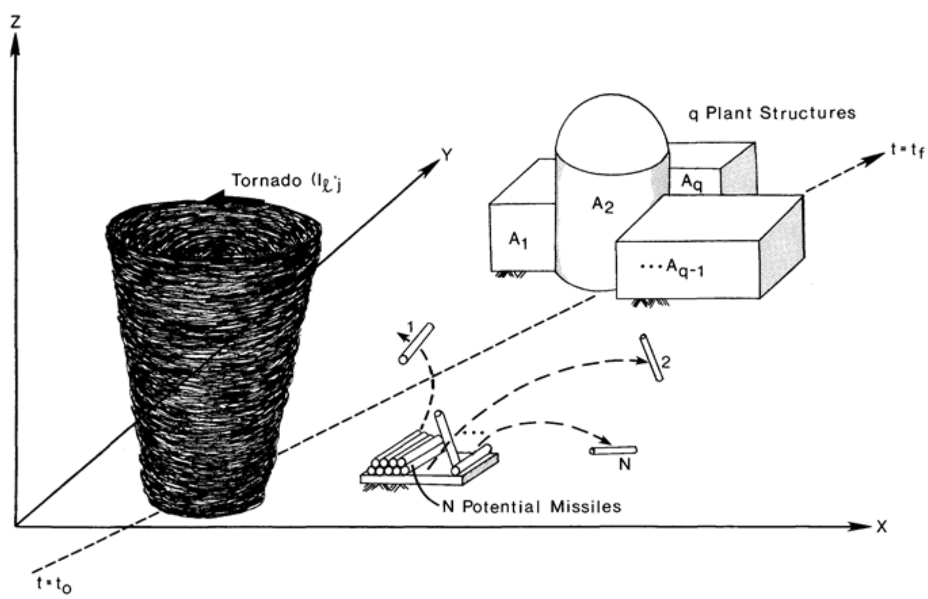
MIP is defined as the probability of a missile impact on an exposed SSC, per missile, per target area, per tornado:

MIP = Probability of missile impact / missile / target area / tornado

Using MIP, the conditional probability of a missile impact on a target during a given tornado can be estimated if the number of available missiles and the exposed surface area of the target are known. Based on a review of the NP-768 tornado missile hit probabilities, it is apparent that the hit probability varies by the tornado intensity. A higher intensity tornado will cause more missile hits on a target, all other variables being equal (e.g., target size and location, number of missiles). Thus, separate MIPs must be derived to account for tornado intensity.

The probability that a target is hit by a tornado-generated missile will approach unity as the size of the target increases, the number of missile increase, and the tornado intensity increases. A target strike probability calculated using MIP will reflect the likelihood that a target is struck by one or more missiles. A given target may be struck by many missiles during a single tornado event, but this probability does not specify the number of discrete missile hits experienced by a target.

Figure B-1: Illustration of EPRI TORMIS Tornado Missile Time-History Simulation [Ref. B.1]



B.2 Using EPRI NP-768 Data to Determine Missile Impact Parameter (MIP)

The results of the EPRI TORMIS studies documented in NP-768 contain missile impact frequencies and associated damage frequencies for various targets, missile population sizes, and assumed plant locations, including results from various sensitivity studies. The EPRI results compiled tens of thousands of missile history simulations to generate average probability densities. Target missile impact probability, missile damage probability, and other associated probabilities are provided in the EPRI studies for different tornado hazards (i.e., thus simulating different assumed plant locations) for three different plant configurations. For the purpose of MIP derivation, only the target impact/strike frequencies and probabilities are needed. The damage likelihood is accounted for separately in the TMRE methodology.

The normalized tornado missile impact probability is conditional upon a tornado strike at the site and should not be affected by the tornado hazard curve for the site. As described, the normalized tornado missile impact probability differs as a function of tornado wind speed (i.e., the tornado category), but the tornado frequency does not impact the conditional impact probability. From the results in NP-768, there are some numerical differences in the derived MIP values depending on the tornado region; the differences are the result of Monte Carlo sampling and associated modeling, and are not due to the tornado hazard frequency input. The resolution of the differences is described in Sections B.3.2 and B.4.

B.2.1 Normalizing EPRI NP-768 Missile Hit Probability

Recall from Section B.1.1 that MIP is the probability of missile hit per missile, per tornado, per ft^2. MIP is defined in this way to allow it to be applied universally for different size targets at different U.S. NPP sites that have different missile populations and tornado frequencies. This is similar to the rationale behind the normalized missile parameter developed in for the TAP A-45 tornado missile risk assessments [Refs. B.2 through B.7].

EPRI NP-768 provides hit frequencies for various targets based on TORMIS simulation runs. The variable of interest, from which MIP can be derived, is the TORMIS parameter H, which is defined as *"Impact Event Defined as Missile Hitting the Barrier"* [Ref. B.1]. Two values are provided for H in the NP-768 results, P and P^N. P is the single missile hit frequency for a target and P^N is defined as the multiple missile hit frequency; P^N accounts for the number of missiles in the simulation. MIP needs to be normalized based on the number of missiles, to allow for it to be used at sites with different populations. Thus, the single missile hit probability, P, is the parameter that is used to derive MIP.

EPRI NP-768 discusses the approach of multiplying a missile strike parameter (i.e., P) by the missile population, but notes that it is likely a conservative estimate:

> *The results from both case studies suggest that probability estimates for the assumed multiple missile threat can be conservatively calculated by multiplying the single missile values by the assumed number of missiles in the sampling population. For the first case study with a hypothetical multiple threat of 6000 available missiles, the degree of conservatism is a factor of two.* [Ref. B.1]

The reason for this is that the TORMIS sampling process integrates over a variety of missile types and locations; whereas, using a normalized tornado missile impact probability multiplied by a population of missiles assumes all missiles have the same entrainment and flight potential. Therefore, using P to derive MIP, and in turn multiplying the MIP by the number of missile on site (as part of the EEFP calculation) is conservative, with respect to this aspect of MIP.

In order to further normalize the NP-768 hit frequency to obtain MIP, the tornado frequency and the target area need to be accounted for. The tornado frequencies used in the TORMIS simulations are provided in NP-768 Table 3-4; the target dimensions, from which target areas can be determined, are also provided in NP-768.

B.2.2 Review of Single Missile Hit Probabilities (*H*-value P) for Plants A and B

In order to provide a conservative bias to the MIP, the simulations from NP-768 which resulted in the highest values for MIP (after normalizing *P* to tornado frequency and target area) were chosen. As previously noted, NP-768 simulations were performed for three plant configurations, Plant A, Plant B1, and Plant B2.

The tables in NP-768 which contain TORMIS simulation hit frequencies are:

Plant A: Tables 3-8 through 3-14 provide data for individual targets and Table 3-15 provides data for all targets combined (i.e., the sum of the probabilities for all targets at Plant A).

Plant B1: Table 3-23 provides data for individual targets and Table 3-24 provides data for all targets combined. Unlike Plant A, the individual target hit probabilities for Plant B1 are not broken down by tornado category. One combined hit probability for all tornado categories is provided for each target. Only the Plant B1 all target data in Table 3-24 has separate hit probabilities for each tornado category.

Plant B2: Table 3-25 provides data for individual targets and Table 3-26 provides data for all targets combined. Unlike Plant A, the individual target hit probabilities for Plant B2 are not broken down by tornado category. One combined hit probability for all tornado categories is provided for each target. Only the Plant B1 all target data in Table 3-26 has separate hit probabilities for each tornado category.

After deriving MIP from the single missile hit probabilities for each of these simulations, it was determined that Plant A resulted in higher overall MIP values. Therefore, Plant A data was chosen as the basis for MIP.

One potentially important difference between Plant A and Plants B1/B2 is the distribution of missiles used in the TORMIS simulations. Plant A simulations were performed with uniformly distributed missiles, i.e., the missile density is constant across the area of the site. Plant B missiles were distributed unevenly, so that some zones contained higher densities than other zones; this is described as a zonal missile distribution).

The impact of the different distributions (zonal versus uniform) was investigated in a sensitivity study documented in Appendix E. Based on this study, there is indication that unevenly distributed missile densities will affect the hit probabilities of certain targets. However, no direct correlation could be discerned from the data as to how a specific missile distribution would affect the hit probability of a specific target. In order to account for the uncertainties associated with the missile distribution at a site, the TMRE method directs that sensitivity calculations be performed to account for potentially higher hit probabilities on certain SSCs. Section 7.2.1 provides details of this sensitivity study and the criteria under which it is to be performed.

B.2.3 Selection of Target Missile Hit Probabilities (*P*) for Developing MIP

Plant A MIP values derived from individual target (i.e., Targets 1 through 7) hit frequencies in NP-768 vary significantly for the same tornado intensity. Although a derived MIP is normalized to target size, missile inventory, and tornado category, there are other factors that affect the hit probability from which MIP is derived. Factors include the location and orientation of the target with respect to the dominant tornado path, the variation in the degree of shielding from other targets/buildings, and different target elevations[19]. All these factors are expected to have an impact on the target hit probability. For example:

> In Plant A simulations from NP-768, the MIP derived for Target 1 (Containment Building) is the lowest. The containment building is surrounded by other buildings (see plant layout in Figure B-2), so only the upper part of the containment is exposed to tornado missiles. Since fewer missiles are present at higher elevations, the normalized tornado missile impact probabilities are lower in comparison to other targets.
>
> In Plant A simulations, Target 6 is the lowest elevation building and is unprotected by any other buildings. Target 6 would be expected to have a higher normalized tornado missile impact probability than most other targets, which it does. The target with the highest derived MIP value in NP-768 Plant A is Target 4.

Development of separate MIP values for different targets, based on individual NP-768 targets, would not be practical for application of the TMRE at a given NPP. Alternately, choosing the most conservative target MIP from NP-768 (Target 4) would lead to overly conservative results for many targets at a NPP. Therefore, the normalized tornado missile impact probability from "All Targets" in NP-768 (from Table 3-15) is proposed for use in the TMRE. This results in a MIP that is based on the combined hits on all modeled surfaces in NP-768, Plant A. Using the "All Targets" hit probabilities as the basis for MIP will result in conservative hit probabilities for certain targets at each NPP, while conservatism in other aspects of the TMRE (e.g., fragility values) can compensate for potential underestimates of missile hit probabilities for other targets. Section A.6 discusses the uncertainty associated with MIP values derived Target 4 and all targets.

B.3 DERIVATION AND CALCULATION OF THE MISSILE IMPACT PARAMETER (MIP)

The mean H-values for single missiles (*P*) for all targets are obtained from NP-768, Table 3-15; these values include the missile hit probabilities for all Plant A targets. Therefore, the selected hit values represent the various configurations and arrangements of the seven targets at Plant A.

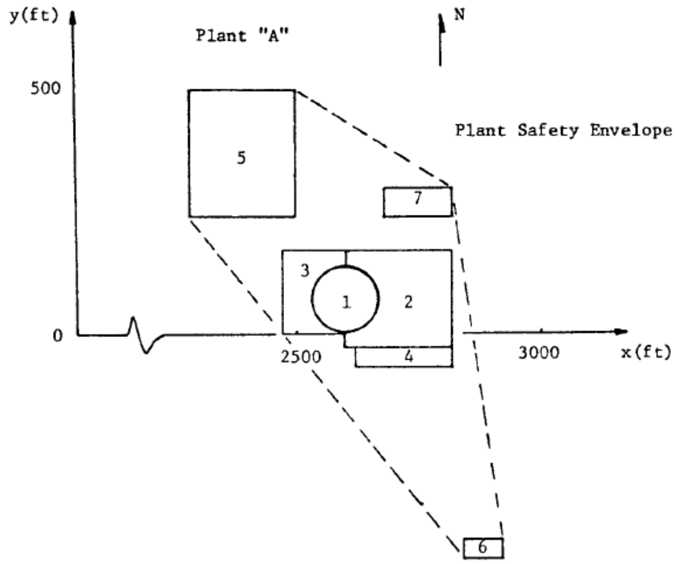
The MIP values are calculated by dividing the *H*-values in Table 3-15 of NP-768 by (a) the tornado frequencies in NP-768, Table 3-4, and (b) the total area for all Plant A targets. The derivation of the target areas are described in the Section B.3.1, and the resultant target areas are provided in Tables B-1 and B-2.

B.3.1 CALCULATION OF TARGET AREAS

Plant A has seven targets as shown in Figure B-2; dimensions of the targets (buildings) are provided in Table 3-1 of NP-768.

[19] Note that target size is not a factor that influences the MIP. Sensitivity studies documented in Appendix E were performed to validate this.

Figure B-2: Plant A Layout for TORMIS Simulation [Ref. B.1]



The surface area exposed to tornado missiles for each of the targets was calculated based on the dimensions provided in Table 3-1 of NP-768; the targets, their calculated areas, and notes regarding the calculations are provided in in Table B-1. The areas provided in Table B-1 include the building roofs. The total area for all Plant A targets is 341,078 ft^2.

Table B-1: NP-768 Plant A Total Target Areas

Target #	Target Description	Exposed Surface Area (ft^2)	Notes
1	Containment	70,372	See Figure B-2. The Area is equal to the portions of the containment cylindrical wall that are exposed (i.e., not covered by adjacent building) plus the containment dome (a half-sphere). The height of the exposed wall is equal to the height of the containment minus the radius of containment (the dome is assumed to be a half-sphere, so the height of the dome above the cylinder is equal to the radius) minus the height of the adjacent targets (2 and 3, which are of different heights).

Target #	Target Description	Exposed Surface Area (ft^2)	Notes
2	Auxiliary Building	80,503	See Figure B-2. The Area is equal to the area of two full walls (north and east), the exposed area of the west wall (subtracting the Target 1 and 3 areas), the area of the south wall not covered by Target 4, and the area of the roof. The area of the roof does not include the portion occupied by the containment semicircle on the west end.
3	Fuel Handling Building	40,203	See Figure B-2. The Area is equal to the area of three full walls (north, south and west) and the area of the roof. The east wall is not exposed, since Targets 1 and 2 are higher than Target 3. The area of the roof does not include the portion occupied by the containment semicircle on the east end.
4	Diesel Generator Building	22,000	The area includes three walls (east, south and west) and the roof. The north wall against Target 2 is not exposed.
5	Waste Processing Building	95,600	This target is a standalone rectangular building. The area includes all four walls and the roof.
6	SW Intake Structure	8,000	This target is a standalone rectangular building. The area includes all four walls and the roof.
7	Tanks Enclosure	24,400	This target is a standalone rectangular building. The area includes all four walls and the roof.
Total	**All Targets**	**341,078**	**Sum of areas for Targets 1 through 7 (including roof area).**

As noted, the target areas in Table B-1 include vertical wall and horizontal roof areas. Roofs tend to have fewer missile hits per square foot than a vertical wall, since the roofs are elevated and require missile trajectories that are higher than the roof in order to eventually strike it as a vertical missile. The data in NP-768 does not distinguish which surface of a target is struck.

Since the roofs can be a substantial portion of the building surface area, considering the entire target area when deriving MIP may tend to underestimate MIP, especially for targets that are near to the ground. To compensate for this, a second set of target areas were calculated that exclude the area of the roof. Table B-2 provides areas for the same seven targets as Table B-1, but does not include the roof areas, with one exception (Target 6).

The total area for all Plant A targets, excluding roof areas, is 185,984 ft^2. Excluding the containment building, the total area for Plant A targets, excluding roof areas, is 146,400 ft^2. The target areas from Tables B-1 and B-2 that are used in deriving the MIP values are described in Section B.4.

Table B-2: NP-768 Plant A Target Areas Excluding Roofs

Target #	**Target Description**	**Exposed Surface Area (ft^2)**	**Notes**
1	Containment	39,584	Without the dome (a half-sphere)
2	Auxiliary Bldg.	44,200	Without the roof
3	Fuel Handling Bldg.	25,800	Without the roof
4	Diesel Generator Bldg.	14,000	Without the roof
5	Waste Processing Bldg.	38,400	Without the roof
6	SW Intake Structure	8,000	Includes the roof, since the building is only 20 feet high
7	Tanks Enclosure	16,000	Without the roof
Total	**All Targets**	185,984	**Sum of areas for Targets 1 through 7 (without roofs).**
Total	**All Targets Except Containment**	146,400	**Sum of areas for Targets 2 through 7 (without roofs) – See Section B.4**

B.3.2 Selection of Conservative Tornado Region MIP

Ideally, the MIP should not differ between NRC Tornado Regions I, II, and III, since the only difference between the regions is the tornado frequency. The MIP is normalized by tornado frequency, so it should be consistent from one tornado region to the other. Since *P* is provided for each NRC Tornado Regions in NP-768 Table 3-15, MIP was derived for each region for each tornado category and compared. For F'2 and F'3 tornadoes, the derived MIP was consistent across NRC Tornado Regions. However, for F'4 through F'6, there were differences between derived MIPs. There is no specific discussion in NP-768 as to why the hit probability per missile/area/tornado would vary from one tornado region to another; the differences are believed to be the result of Monte Carlo sampling and associated modeling.

Nonetheless, in order to account for the uncertainty associated with these results, the highest derived MIP value for each F'-scale tornado across the three regions was selected for the TMRE.

B.3.3 Separate MIP Derivation for Elevated Targets and Near Ground Targets

Two factors are responsible for the decision to derive MIP values for different target elevations (near ground versus elevated):

- Elevated targets are less likely to be hit by a tornado missile compared to near the ground (where most missiles originate).
- The hit probability data in NP-768 includes hits on any target surface, including the roof.

Knowing that missile hit probability is less at a higher elevation than at a lower elevation, MIP values derived from the target hit probability divided by the entire target area would be biased to a smaller value. The missile hit probability data in NP-768 cannot be separated by target surface. However, deriving MIP using the entire hit probability, but only the vertical wall area (and not the roof area), would tend to bias MIP towards a larger value (since it would include all missile hits on a target but not the entire target area).

Calculating only one set of MIP values in this manner would result in conservative MIPs for elevated targets. Therefore, two sets of MIPs are derived, one for elevated targets and one for near ground targets. The different target areas in Tables B-1 and B-2 are used for the calculations.

B.3.4 Basis for Target Elevation Demarcation

The demarcation elevation of 30 feet is decoupled from the NP-768 data, since the NP-768 data provides no quantifiable insights into missile hit probability vs. elevation. Although it is understood that tornado missile flux is higher at low elevations and lower at high elevations (see Figure 3-3 in NP-768), the true variation of missile flux versus elevation is not known. Therefore, an assumed demarcation elevation was determined qualitatively, based on regulatory documents associated with tornado missiles.

30 feet was chosen as the elevation demarcation for MIP, based on demarcation for heavier missiles in design basis requirements (SRP Rev 0 Section 3.5.1.4 [Ref. 18] and RG 1.76 Rev 1 [Ref. 19]).

- *"Missiles A, B. C, D. and E are to be considered at all elevations and missiles F and G* [utility pole and automobile] *at elevations up to 30 feet above all grade levels within 1/2 mile of the facility structures."* [Ref. 18]
- *"The automobile missile is considered to impact at all altitudes less than 30 feet (9.14 meters) above all grade levels within 0.5 mile (0.8 kilometer) of the plant structures."* [Ref. 19].

The 30' demarcation is supported by the results of the Target Elevation Study documented in Appendix E. The results of the study compare favorably with the relative difference between the near ground and elevated MIP values. Table B-2a compares MIP values for elevated (>30' MIP) and near ground (≤30') targets, taken from Table B-5. The elevated MIP is approximately 40 to 45% of the near ground MIP.

Table B-2a: Elevated and Near Ground Missile Impact Parameter Comparisons

Tornado	>30' MIP	≤30' MIP	Ratio (>30':≤30')
F'2	5.80E-11	1.4E-10	0.41
F'3	2.00E-10	4.6E-10	0.43
F'4	3.40E-10	7.9E-10	0.43
F'5	8.70E-10	2.0E-09	0.44
F'6	1.30E-09	3.1E-09	0.42

The target elevation sensitivity cases, documented in Appendix E, were performed to validate that target hit probabilities for elevated targets were appreciably lower than for near ground targets. The Appendix E sensitivities were performed using actual plant TORMIS models and were set up to show a variety of targets with the same area at different elevations on different plant surfaces. The sensitivity cases were not specifically intended to provide validation of the exact ratio of hit probabilities, nor were they intended to validate the exact demarcation elevation between elevated and near ground MIPs. However, the results of the studies do confirm the relative difference in the elevated and near ground MIPs.

Appendix E, Figures 9 – 15, confirm that the target hit probability is generally smaller at higher elevations, which is expected.[20] Five of the seven target sets show that elevated targets (those with lower borders ranging from 26' – 50') have a lower hit probability than near ground targets; the ratios range from 20% to 65%. Results from two of the target sets are inconclusive, but those target sets are determined to be inadequate for this sensitivity (see discussion for Plant A North and South Walls in the Table B-2b). Therefore, the results of the elevation sensitivities in Appendix E are consistent with the relative differences between the near ground and elevated MIPs derived in Section B.4.

Table B-2b: Review of Appendix E Target Elevation Study Results

Plant	Wall	Results
A	East	The 38' target (elevation between 33' – 43') hit probability is about 65% of the near ground target, approximately the same as the MIP ratios in Table B-2a. The higher target (centerpoint at 78') is even lower at ~20% of the near ground target, and about 30% of the middle (38') target.
A	West	The first two targets are both below 30', and have essentially the same hit probability. The 55' target hit probability is about 65% of the near ground target, approximately the same as the MIP ratios in Table B-2a.
A	South	All targets on the south wall are relatively close to the ground, since the wall is relatively short. The highest target elevation is between 30' – 40'. The hit probabilities are essentially constant across all elevations. The hit probabilities on the south wall targets do not reflect a lower hit probability for elevated targets, although the height of the wall precluded evaluating targets much higher than 30' above grade. It should be noted that the south wall target is relatively close to the east side of the plant, which has a grade 35' lower than that on the south side. Thus, the relative heights of the targets on the south wall, with respect to missiles from the east side of the plant, are all above 35'.
A	North	All the targets on the north wall are more than 60' above the north side grade and over 90' above the east side grade. Therefore, all the target are elevated well above the majority of the missile sources, so the relative consistency in hit probabilities with elevation does not provide any useful information with respect to the question of elevated vs. near ground MIP.
B	North	[Similar configuration and results as Plant A West Wall] The results for this wall show that the 41' target (elevation between 36' – 46') hit probability is about 50% of the near ground target, approximately the same as the MIP ratios in Table B-2a. The first two targets (both below 26') show relatively consistent hit probabilities.
B	South	[Similar configuration and results as Plant A East Wall]. The 31' target (elevation between 26' – 36') hit probability is about 60% of the near ground target, approximately the same as the MIP ratios in Table B-2a. The higher target (centerpoint at 64') is even lower at ~40%.

[20] Note: All targets had a height of 10'; the target elevations listed in Table E-5 and provided in Figures 9 – 15 are the centerpoint elevations for the targets.

Plant	Wall	Results
B	West	[Similar configuration and results as Plant A West Wall and Plant B North Wall]. The results for this wall show that the 53.5’ target (elevation between 48.5’ – 58.5’) hit probability is about 20% of the lowest target, much lower than the MIP ratios in Table B-2a; its hit probability is also only 30% of the middle target (23.5’). The 23.5’ target (18.5’ – 28.5’) hit probability is about 70% of the lowest target.

Missiles exist at elevations above reference elevation; the initial elevation of the missiles can affect the variation in MIP with target elevation. The EPRI NP-768 missile insertion elevations are sampled from a uniform distribution that ranges from 5 to 50 feet. Therefore, there is an equal probability of a (non-car) missile being inserted from any height between 5 to 50 feet. In general, it is expected that higher missile injection heights will lead to higher missile hit probabilities, because the missiles would tend to fly farther and thus be more likely to encounter a target.

Missile elevation data from several sites was determined based on actual missile surveys. This data provides a comparison between the missile insertion heights from EPRI NP-768 and the actual missile elevations at a set of representative plants. Table B-2c compares the distribution of missiles injected at various heights in the NP-768 simulations (assuming a uniform distribution from 5 to 50 feet) with missile heights from the plant surveys. On average, approximately 2/3rds of site missiles are close to the ground (within 15’ of grade), as compared to only 22% of the NP-768 missile insertion heights.

Table B-2c: Comparison of NP-768 and Actual Plant Missile Injection Heights

Injection Height	Percent of Total Missiles Average (based on Uniform Distribution)*	Percent of Missiles from Surveyed Plants*	Percent Range of Missiles from Surveyed Plants	Comments
5’ to 15’	22%	66%	51% - 86%	Mostly zonal (loose) missiles plus missiles from deconstruction of 1-story structures or the 1st story of multi-story structures
15’ to 30’	33%	15%	8% - 20%	Primarily Missiles from deconstruction of the 2nd story of multi-story structures
30’ to 50’	44%	18%	7% - 29%	Primarily missiles from deconstruction of the 3rd story and higher or multi-story structures

* Percentages do not add to 100% due to rounding

Assuming that higher injection heights lead to higher hit probabilities (since missiles will travel farther leading to a higher likelihood of encountering a target), the plant data clearly bounds the injection height assumptions in NP-768. Therefore, it is reasonable to conclude that the MIPs provided in this guidance can be used for any plant, without the need to validate plant-specific missile injection heights.

B.4 MIP VALUES FOR USE IN THE TMRE

MIP values were derived from NP-768 Plant A single-missile hit probabilities (the *H*-value *P*), based on the data provided in NP-768 Table 3-15. MIP values are provided for each F'-scale tornado, from F'2 through F'6, for near ground and elevated targets.

The demarcation between near ground and elevated targets is 30 feet above the associated reference elevation for a target. This is typically plant grade, since most damaging missiles at a NPP originate at or near grade.

B.4.1 NEAR GROUND TARGET MIP

For TMRE targets near the ground (defined as less than 30' above reference elevation), the MIP is derived using the target areas listed in Table B-2, which generally excludes the area of the roof. Since missile hits on roofs are expected to be a small percentage of the total missile hits, excluding the roof areas while still counting all hits on the target, will provide a higher value that should be more representative of the lower elevation targets. One exception is Target 6, for which the roof area is included, since it is only 20 feet above grade.

Additionally, since Target 1 (the containment structure) has no exposed surfaces within 30 feet of the reference elevation, it was omitted from the surface area used to derive the Near Ground MIP. Figure B-2 shows that Target 1 is shielded by Target 2 to the east and Target 3 to the west. These buildings prevent missiles from striking the lower portions of Target 1. Since the height of Targets 2 and 3 are greater than 30 feet (80 and 60 feet, respectively), there is no exposed surface area for Target 1 that is below 30 feet. Therefore, the exposed surface area used for the Near Ground MIP derivations is 146,400 ft^2, from Table B-2.

Table B-3 provides the derived MIP values for the three tornado regions for Near Ground targets. The bolded values represent the highest values.

Table B-3: Plant "A" Tornado Missile Impact Parameters for Near Ground Targets

MIP (per missile per ft^2 per tornado interval frequency)			
F' Scale Category	**NRC Region I**	**NRC Region II**	**NRC Region III**
F'2	1.3E-10	**1.4E-10**	1.4E-10
F'3	4.5E-10	**4.6E-10**	4.6E-10
F'4	5.2E-10	5.3E-10	**7.9E-10**
F'5	**2.0E-09**	1.8E-09	N/A[(1)]
F'6	**3.1E-09**	N/A[(1)]	N/A[(1)]

[(1)]No hit values are provided in NP-768 Table 3-15 for these combinations of tornado category and NRC region

B.4.2 ELEVATED TARGET MIP

For the elevated MIP value (i.e., for targets greater than 30' above reference elevation), the area used to derive the MIP includes all the areas listed in Table B-1, which includes roof areas. Table B-4 provides the derived MIP values for the 3 tornado regions for Elevated targets. The bolded values represent the highest values.

Note that the Elevated Target MIP derivation includes data from Target 6, whose height is 20 feet. Therefore, none of the surface areas from Target 6 are above 30 feet. If Target 6 were eliminated from the Elevated Target MIP derivation, the MIP values would be lower.

Table B-4: Plant "A" Tornado Missile Impact Parameters for Elevated Targets

MIP (per missile per ft^2 per tornado interval frequency)			
F' Scale Category	**NRC Region I**	**NRC Region II**	**NRC Region III**
F'2	**5.8E-11**	5.8E-11	5.8E-11
F'3	**2.0E-10**	2.0E-10	2.0E-10
F'4	2.3E-10	2.3E-10	**3.4E-10**
F'5	**8.7E-10**	7.6E-10	N/A(1)
F'6	**1.3E-09**	N/A(1)	N/A(1)

(1)No hit values are provided in NP-768 Table 3-15 for these combinations of tornado category and NRC region

B.4.3 Summary of MIP Values

Table B-5 lists the MIP values for all targets; the MIP values provided herein are the highest values from Tables B-3 and B-4.

Table B-5: MIP Values for Use in the TMRE

MIP (per missile per ft^2 per tornado interval frequency)		
Tornado Category	**Targets >30' above grade(1)**	**Targets ≤30' above grade(1)**
F'2	5.8E-11	1.4E-10
F'3	2.0E-10	4.6E-10
F'4	3.4E-10	7.9E-10
F'5	8.7E-10	2.0E-09
F'6	1.3E-09	3.1E-09

(1) The term grade here is meant to refer to the reference elevation. Typically, this is plant grade, although for some targets it may be different.

B.4.4 Potential for Statistical Correlation Between Targets

This section addresses statistical correlation between nearby targets. That is, for a given tornado strike on a site, nearby targets may be postulated to have a greater probability of being struck by separate missiles than the product of the two independent strike probabilities.

The consideration of correlated targets is not required as part of the TMRE method. Recent High Winds PRAs do not consider targets statistically correlated; all targets are considered independent unless they are so close to each other that they can be struck by the same missile. In those cases, the targets are grouped together as a single target. Therefore, it is reasonable that the TMRE does not consider statistical correlation between targets.

Correlation between nearby targets implies a greater probability for multiple targets to be struck by separate missiles, in the same tornado event, than the product of multiple independent strikes. That is, for two nearby targets A and B:

$$P_{missile}(A*B) > P_{missile}(A) * P_{missile}(B)$$

EPRI NP-768 [Ref. B.1] evaluated the probability of two adjacent targets (targets 6 and 8 in Plant B) being hit by separate missiles (i.e., the intersection probability $P^N(6\cap 8)$) and compared that to the probability of either target being hit by a missile (i.e., the union probability $P^N(6U8)$). NP-768, Table 3-23 provides the values for $P^N(6\cap 8)$ and $P^N(6U8)$ for Tornado Regions I – III.

The ratio of $P^N(6\cap 8) / P^N(6U8)$ represents the likelihood that both targets 6 and 8 will be hit by separate missiles given that either target 6 or 8 are hit. The value obtained for this ratio was 2.7E-3 for all three tornado regions (the fact that all three tornado regions have the same ratio is not unexpected). This ratio implies that, for the example in NP-768, the probability that statistically correlated missile strikes on two nearby targets is much less than 1% of the probability that either are hit.[21]

B.5 Missile Inventories

The EPRI NP-768 tornado simulations indicate that, for wind-driven missiles of sufficient mass to damage NPP SSCs, the mean transport distance is less than 350 feet. Missile transport beyond 1000 feet is rare, and transport beyond 2000 feet is very unlikely. The NP-768 missile hazard study considered missiles within approximately 2500 feet of the targets. In order to be consistent with the derivation of MIP from the TORMIS simulation data, the missile inventories used in the TMRE must also include missiles within approximately 2500 of targets.

The TMRE process was developed to be as standardized as possible for application across the U.S. NPP fleet. To support this goal and facilitate review and approval of TMRE results, generic missile inventory values are provided. Data from five U.S. NPP TORMIS analyses were used to develop the generic TMRE missile inventories; missile count walkdowns were performed to support the TORMIS analyses at these five sites in the U.S. The maximum values from these missile surveys [Refs, B.12, B.13, B.14, B.15, B.16] are used in the TMRE, given that the site-specific walkdown performed in support of the TMRE validates that this generic missile inventory is bounding (see Section 3). It is expected that the maximum values provided here will bound most sites.

Two general types of missiles are provided in each of the missile inventories: “zonal” and “structure” missiles.

In general, the zonal missiles are constant across the tornado intensity range. The difference in the ability of these types of missiles to become airborne and fly to the extent needed to hit and damage

[21] In a sensitivity study from a recent high winds PRA (that utilized TORMIS), two valves that were close to each other were evaluated for statistical correlation. The same ratio described here was calculated for these two targets and it varied from 1.3E-3 (EF1) to 2.9E-3 (EF5). This compares well with the correlation value determined from NP-768.

a target is accounted for in the MIP. The missile inventory data from the five plants show constant zonal missile inventories for all tornado categories.

The structure-based missiles are the result of weaker structures (steel- or wood-frame buildings constructed to standard building code requirements) deconstructing due to tornado winds. The amount of missiles created is dependent on the type of structure and the wind speeds associated with the tornado. Therefore, structure-based missile inventories tend to increase with increasing tornado intensity. The structure missile inventory data for three of the plants increase with tornado category, as expected. Structure missile data for two of the plants is constant; for these plants the maximum number of missiles associated with full structure deconstruction was used for all tornado categories.

Tables B-6 through B-10 provide the missile inventories from each of the five sites surveyed.

Table B-6: Missile Inventories for Plant 1

Tornado Category	Zonal Missiles	Structural Missiles	Total Missiles
F'2	38,267	67,799	106,066
F'3	38,267	67,799	106,066
F'4	38,267	67,799	106,066
F'5	38,267	67,799	106,066
F'6	38,267	67,799	106,066

Table B-7: Missile Inventories for Plant 2

Tornado Category	Zonal Missiles	Structural Missiles	Total Missiles
F'2	67,134	85,876	153,010
F'3	67,134	85,876	153,010
F'4	67,134	85,876	153,010
F'5	67,134	85,876	153,010
F'6	67,134	85,876	153,010

Table B-8: Missile Inventories for Plant 3

Tornado Category	Zonal Missiles	Structural Missiles	Total Missiles
F'2	92,851	2,814	95,665
F'3	92,851	35,375	128,226
F'4	92,851	108,526	201,377
F'5	92,851	139,555	232,406
F'6	92,851	139,555	232,406

Table B-9: Missile Inventories for Plant 4

Tornado Category	Zonal Missiles	Structural Missiles	Total Missiles
F'2	37,751	13,534	51,285
F'3	37,751	81,826	119,577
F'4	37,751	162,821	200,572
F'5	37,751	201,123	238,874
F'6	37,751	201,123	238,874

Table B-10: Missile Inventories for Plant 5

Tornado Category	Zonal Missiles	Structural Missiles	Total Missiles
F'2	75,369	4,636	80,005
F'3	75,369	33,095	108,464
F'4	75,369	101,511	176,880
F'5	75,369	127,734	203,103
F'6	75,369	127,734	203,103

Table B-11 lists the maximum number of missiles for each tornado category, F'2 through F'6, from Tables B-6 through B-10. The final column lists the total missile inventory for use in the TMRE, based on rounding up the highest value to the nearest 5,000 missiles.

Table B-11: Total Missile Inventories for Use in the TMRE

Tornado Category	Maximum Missiles from Sample	TMRE Missile Inventory
F'2	153,010 (Plant B)	155,000
F'3	153,010 (Plant B)	155,000
F'4	201,377 (Plant C)	205,000
F'5	238,874 (Plant D)	240,000
F'6	238,874 (Plant D)	240,000

B.6 Missiles Affecting Robust Targets

SSCs that are robust in nature are not affected by all potential tornado missiles. The number of missiles used in the EEFP calculation can be adjusted to account for the population of missiles that can damage an SSC. Targets considered robust for the purpose of the TMRE include steel tanks, steel pipes, reinforced concrete roofs, and metal doors. A set of robust targets were evaluated in Appendix C against the spectrum of missile types considered in the TMRE. The results of the calculations documented in Table C.6 were consolidated to determine the percentage of the total missile inventory for each type of robust target. The final values determined are listed in Table B-18. The process used to develop this table is described in this section. For SSCs not considered robust (i.e., that do not meet the descriptions in Table B-13), the full missile inventories listed in Table B-11 are used in the EEFP calculations.

B.6.1 Categorizing Robust Targets

A variety of SSCs with different characteristics were evaluated for different failure modes in Appendix C. In order to simplify the results of the Appendix C calculations, some similar SSC types were binned together, using the characteristics of the least robust target type for that group. This consolidated the robust target types into nine categories designated Category A through I, and K through M, defined in Table B-13. Table B-12 provides the grouping of target types from the results of Section C6.

Table B-12: Robust Target Descriptions

Description[(1)]	Failure Mode	Diameter (inches)	Thickness (inches)	Assigned Category
Diesel Generator Exhaust Pipe	Crushing > 50%	36	0.375	A
SG Steam Relief Valve Tailpipe	Crushing > 50%	16	0.50	A
Turbine Driven Feedwater Pump Exhaust Piping	Crushing > 50%	20	0.375	A
Steam Generator Power Operated RV Exh Pipe	Crushing > 50%	18	0.375	A
Diesel Generator Air intake (small)	Crushing > 50%	16	0.125	B
Diesel Generator Air intake (large)	Crushing > 50%	48	0.125	B
Diesel Generator Exh Silencer	Crushing > 50%	22	0.375	A
Condensate Storage Tank (t=0.25")	Perforation or Global	NA	0.25	C
Diesel Fuel Oil Tank (t=0.133")	Perforation or Global	NA	0.133	D
Diesel Fuel Oil Tank (t=0.145")	Perforation or Global	NA	0.145	D
Condensate Storage Tank (t=0.375")	Perforation or Global	NA	0.375	C
Low Pressure Water Pipe	Perforation or Global	6	0.237	F
Low Pressure Water Pipe	Perforation or Global	10	0.237	F
Main Steam Piping (t=0.985")	Perforation or Global	36	0.985	E
Room Door (t=0.1")[(2)]	Perforation or Global	NA	0.1	G
Low Pressure Water Pipe	Perforation or Global	18	0.375	E
High Pressure Water Pipe	Perforation or Global	10	0.432	E

Concrete roofs[(3)]

8" reinforced concrete roof[(3)]	Perforation	NA	8.0	H
4" reinforced concrete roof with steel decking[(4)]	Perforation	NA	4.0	I

Notes:
(1) All piping, tanks, and the room door are steel
(2) Steel door is a standard 16 or 18 gauge door, with equivalent thickness of 0.1” steel. Thicknesses based on SD-108 (each inside and outside face steel sheet varies between 0.042” (18 gauge) and 0.053” (16 gauge) [Ref. B-17].
(3) Only applies to roofs, not walls; reduced missile speeds (assuming vertical missiles) were used to calculate perforation.
(4) Steel decking not credited in evaluation

Table B-13: Robust Target Descriptions

Category	Target Description	Failure Mode
A	Steel Pipe – at least 16” diameter and 3/8” thickness	Crushing/Crimping of > 50%
B	Steel Pipe – at least 16” diameter and thickness less than 3/8” but at least 0.125”	Crushing/Crimping of > 50%
C	Steel Tank – at least 0.25” thickness	Penetration or Global Failure
D	Steel Tank – less than 0.25” thickness	Penetration or Global Failure
E	Steel Pipe – at least 10” diameter and 3/8” thickness	Penetration or Global Failure
F	Steel Pipe – Less than 10” diameter or 3/8” thickness	Penetration or Global Failure
G	Steel Door	Penetration or Global Failure
H	Concrete Roof – Reinforced, at least 8” thick	Penetration or Global Failure
I	Concrete Roof – Reinforced, at least 4” thick	Penetration or Global Failure
J	Not robust	NA

The table in Section C6 provides indication of the damage produced by each missile type for each target. The missile set which causes failure for each of the robust target categories in Table B-13 is based on the most limiting case for each category. If a missile type causes damage to any of the targets in the category, it is assumed to cause damage for the whole category. Table B-14 provides a matrix of missile types that damage each target category. Filled cells in the matrix indicate that the missile type causes failure of the target category type.

Table B-14: Robust Target Missile Matrix

Missile Type	Robust Category Type								
	A	B	C	D	E	F	G	H	I
1 - Rebar			■	■	■	■	■		■
2 - Gas Cylinder	■	■	■	■	■	■	■		
3 - Drum, tank		■		■		■			
4 - Utility Pole	■	■	■	■	■	■	■		■
5 - Cable Reel		■		■		■			

Missile Type	Robust Category Type								
	A	B	C	D	E	F	G	H	I
6 - 3” Pipe		■	■	■	■	■	■		
7 - 6” Pipe	■	■	■	■	■	■	■		■
8 - 12” Pipe	■	■	■	■	■	■	■		■
9 - Storage bin	■	■	■	■		■	■		■
10 - Concrete Paver		■							
11 - Concrete Block									
12 - Wood Beam		■		■		■			
13 - Wood Plank									
14 - Metal Siding		■							
15 - Plywood Sheet									
16 - Wide Flange	■	■	■	■	■	■	■		■
17 - Channel Section		■	■	■	■	■	■		
18 - Small Equipment		■	■	■		■	■		
19 - Large Equipment	■	■	■	■	■	■	■		■
20 - Frame/Grating									
21 - Large Steel Frame	■	■	■	■	■	■	■		■
22 - Vehicle	■	■	■	■	■	■	■	■	■
23 - Tree		■		■		■	■		

■ Indicates that missile type fails the target category

B.6.2 MISSILE TYPE INVENTORIES

In order to provide a simplified and consistent percentage of missile types for the TMRE application, generic missile inventories were developed. Specific missile type counts were taken from 2 plant missile inventories (from Plants 1 and 2), provided in Tables B-15 and B-16. Table B-15 provides the inventory of unrestrained (zonal) missiles and Table B-16 provides the restrained (structural) missile inventory[22]; see Section B.5 for a discussion of these terms.

Table B-15: Unrestrained Missile Inventories

Missile Type	Plant 1	Plant 2
1 - Rebar	15,707	23417
2 - Gas Cylinder	444	1149
3 - Drum, tank	369	448
4 - Utility Pole	50	0
5 - Cable Reel(1)	150	150

[22] The missile inventory data for Plants 1 and 2, provided in Tables B-15 and B-16 were reported as unrestrained and restrained populations. These are equivalent to zonal and structural missiles, the terminology used in this guidance. Regardless, the total values for each missile type are used (Table B-17), so the delineation between restrained and unrestrained does not have an impact.

Missile Type	Plant 1	Plant 2
6 - 3” Pipe	4,404	4,754
7 - 6” Pipe	418	855
8 - 12” Pipe	278	25
9 - Storage bin(2)	250	250
10 - Concrete Paver	0	4,240
11 - Concrete Block(3)	5,000	5,000
12 - Wood Beam	557	260
13 - Wood Plank	4,400	19,990
14 - Metal Siding	2,270	261
15 - Plywood Sheet	5,561	8,655
16 - Wide Flange	219	249
17 - Channel Section	880	1,953
18 - Small Equipment(4)	200	200
19 - Large Equipment	450	329
20 - Frame/Grating	0	108
21 - Large Steel Frame(5)	150	150
22 - Vehicle	960	1,695
23 - Tree	1,300	0
TOTAL	**44,017**	**74,138**

Table B-16: Restrained Missile Inventories

Missile Type	Plant 1	Plant 2
1 - Rebar	1,545	2,271
2 - Gas Cylinder	0	0
3 - Drum, tank	0	0
4 - Utility Pole	37	226
5 - Cable Reel(1)	600	600
6 - 3" Pipe	15,034	14,762
7 - 6" Pipe	354	456
8 - 12" Pipe	0	90
9 - Storage bin(2)	2,500	2,500
10 - Concrete Paver(6)	2,500	2,500
11 - Concrete Block(3)	25,000	25,000
12 - Wood Beam	4,053	217
13 - Wood Plank	75	1,192
14 - Metal Siding	24,867	30,650
15 - Plywood Sheet	2,975	9,247
16 - Wide Flange	200	285
17 - Channel Section	11,509	10,259
18 - Small Equipment(4)	1,500	1,500
19 - Large Equipment(7)	400	400
20 - Frame/Grating(8)	3,000	3,000
21 - Large Steel Frame(5)	700	700
22 - Vehicle	0	0
23 - Tree	7,150	14,738
TOTAL	**103,999**	**120,593**

Notes for Tables B-15 and B-16[23]:

(1) No cable reels counted for either plant; assumed 150 for unrestrained and 600 for restrained, per plant.

(2) No storage bins counted for either plant; assumed 250 for unrestrained and 2,500 for restrained, per plant.

(3) No concrete blocks counted for either plant; assumed 5,000 for unrestrained and 25,000 for restrained, per plant.

(4) No small equipment counted for either plant; assumed 200 for unrestrained and 1,500 for restrained, per plant.

(5) No steel frames counted for either plant; assumed 150 for unrestrained and 700 for restrained, per plant.

(6) No structural concrete pavers for either plant; assumed 2,500 per plant (restrained only)

(7) No large equipment from structures for either plant; assumed 400 per plant (restrained only)

[23] No inventories for certain missile types were provided for Plants 1 and 2; estimates were made based on walkdown experience at other sites.

(8) No frame/grating from structures for either plant; assumed 700 per plant (restrained only)

In order to determine the generic percentage for each missile type, the totals for each missile type from the unrestrained and restrained missiles were combined and averaged (between the two plants). The averages were normalized to determine the percentage of each missile type, which is provided in Table B-17. Note: the sum of the values in Table B-17 is greater than 100% due to rounding.

Table B-17: Average Missile Type Inventory

Missile Type	Percentage
1 - Rebar	13%
2 - Gas Cylinder	0.5%
3 - Drum, tank	0.2%
4 - Utility Pole	0.1%
5 - Cable Reel	0.4%
6 - 3" Pipe	11%
7 - 6" Pipe	0.6%
8 - 12" Pipe	0.1%
9 - Storage bin	1.6%
10 - Concrete Paver	2.7%
11 - Concrete Block	18%
12 - Wood Beam	1.5%
13 - Wood Plank	7.5%
14 - Metal Siding	17%
15 - Plywood Sheet	7.7%
16 - Wide Flange	0.3%
17 - Channel Section	7.2%
18 - Small Equipment	1.0%
19 - Large Equipment	0.5%
20 - Frame/Grating	1.8%
21 - Large Steel Frame	0.5%
22 - Vehicle	0.8%
23 - Tree	6.8%
TOTAL	**100%**

Combining the results from Table B-14 and Table B-17 provides the percentage of missiles that can damage each robust target category, as shown in Table B-18.

Table B-18 Missile Damage Capability

Category	Target Description	Failure Mode	Calculated Percentage	Final Percentage
A	Steel Pipe – at least 16" diameter and 3/8" thickness	Crushing/Crimping of > 50%	5%	**5%**
B	Steel Pipe – at least 16" diameter and thickness less than 3/8" but at least 0.125"	Crushing/Crimping of > 50%	53%	**55%**
C	Steel Tank – at least 0.25" thickness	Penetration or Global Failure	37%	**40%**
D	Steel Tank – less than 0.25" thickness	Penetration or Global Failure	46%	**50%**
E	Steel Pipe – at least 10" diameter and 3/8" thickness	Penetration or Global Failure	34%	**35%**
F	Steel Pipe – Less than 10" diameter or 3/8" thickness	Penetration or Global Failure	46%	**50%**
G	Steel Door	Penetration or Global Failure	44%	**45%**
H	Concrete Roof – Reinforced, at least 8" thick	Penetration or Global Failure	1%	**1%**
I	Concrete Roof – Reinforced, at least 4" thick	Penetration or Global Failure	17%	**20%**
J	Not Robust	NA	NA	**NA**

B.6.3 Reinforced Concrete and Steel Plate Tornado Missile Barriers

The TMRE considers certain barriers to provide complete protection from tornado missiles, allowing SSCs protected by these barriers to be screened. The barriers are 18" reinforced concrete walls, 12" reinforced concrete roofs, and 1" plate steel.

Table 1 of NUREG 0800, Section 3.5.3 [B-20] provides minimum barrier thickness requirements for local damage prediction against tornado generated missiles. For RG 1.76 Region I (the most conservative tornado wind speeds), the minimum wall thickness is 16.9" and the minimum roof thickness is 12.3" (~12.0"), assuming 4,000 psi concrete strength. Reinforced concrete walls at nuclear plants typically exceed 4,000 psi strength. Also note that roofs typically contain steel decking, providing added protection against tornado missiles.

Furthermore, the results of the EPRI NP-768 simulation studies show a very low likelihood of damage to wall structures from tornado generated missiles. The EPRI "Plant A" simulations did not result in any penetrations by tornado missiles of concrete walls at least 18" thick. Calculations using the methods described in Appendix C of this document also support the exclusion of tornado missiles protected by 18" reinforced concrete walls and 12" reinforced concrete roofs.

Credit for 1” steel plate to provide tornado missile protection is consistent with current high wind PRAs. The Appendix C results for tornado missile impacts on steel pipe and tank targets confirm that the 1” criterion is reasonable.

B.7 References

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4. NUREG/CR-4710, Shutdown Decay Heat Removal Analysis of a Combustion Engineering 2-Loop Pressurized Water Reactor, US Nuclear Regulatory Commission, August 1987.

5. NUREG/CR-4762, Shutdown Decay Heat Removal Analysis of a Westinghouse 3-Loop Pressurized Water Reactor, US Nuclear Regulatory Commission, March 1987.

6. NUREG/CR-4458, Shutdown Decay Heat Removal Analysis of a Westinghouse 2-Loop Pressurized Water Reactor, US Nuclear Regulatory Commission, March 1987.

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10. Enforcement Guidance Memorandum 15-002, Revision 1: Enforcement Discretion for Tornado-generated Missile Protection Non-compliance, U.S. NRC, February 7, 2017.

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12. Exelon Nuclear Analysis No. IP-S-0246, Tornado Missile Hazard Analysis for Clinton Power Station (EC 366599 Rev. 0), 10/25/07.

13. Davis-Besse Nuclear Power Station Unit 1, Walkdown Report Potential Tornado Missile Population, Revision 0, 8/22/07

14. Data extracted from Southern Nuclear calculation SC-SNC346922-001 Version 1.0., regarding tornado missiles at Joseph M. Farley Nuclear Power Plant.

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16. DTE Energy NRC-13-0002, Proposed License Amendment to Revise the Fermi 2 Licensing Bases for Protection from Tornado-Generated Missiles, January 11, 2013

17. Steel Door Institute, Recommended Selection and Usage Guide for Standard Steel Doors, Technical Data Series SDI 108-10, Reaffirmed 2014.

18. NUREG-75/087, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, May 1980

19. Regulatory Guide 1.76, Design-basis Tornado and Tornado Missiles for Nuclear Power Plants, Revision 1, March 2017)

20. NUREG-0800, US NRC Standard Review Plan, Section 3.5.3 Barrier Design Procedures, Revision 3, March 2007.

APPENDIX C: BASES FOR TARGET ROBUSTNESS AND MISSILE CHARACTERISTICS

C.1 PURPOSE

The purpose of this report appendix is to provide a summary of the technical approach for evaluating the robustness of typical Nuclear Power Plant (NPP) Structures, Systems, and Components (SSC) against the effects of wind-borne missile impacts. The range of SSCs, or 'targets', that was considered in this evaluation includes those that are commonly evaluated in high-wind risk evaluations, such as piping, liquid storage tanks, metal doors, and reinforced concrete roofs.

The spectrum of wind-borne missiles considered in this evaluation is based on the types of missiles described in Table 3-2 of this report. The missiles include a range of non-deformable and deformable wind projectiles: wood timbers, steel pipes, construction equipment, small trees, masonry units, pavers, and an automobile. The weights of these missiles ranged from 8 lbs. to 4,000 lbs.

The maximum horizontal missile impact velocity considered in this evaluation is 230 mph, which bounds most of the missile impact velocities described in the 1975 Standard Review Plan (SRP) Section 3.5.1. The maximum vertical missile impact velocity is 153 mph (2/3 x 230 mph) for reinforced concrete roof impacts. A review of more recent regulatory guidance pertaining to wind-borne missiles, including RG 1.76 (2007)) and RG 1.221 (2011), finds that the 230 mph horizontal impact velocity is slightly conservative. The highest horizontal missile impact speed cited in the most current NRC guidance is 92 mph (RG 1.76) for tornado winds and 209 mph (RG 1.221) for hurricane winds.

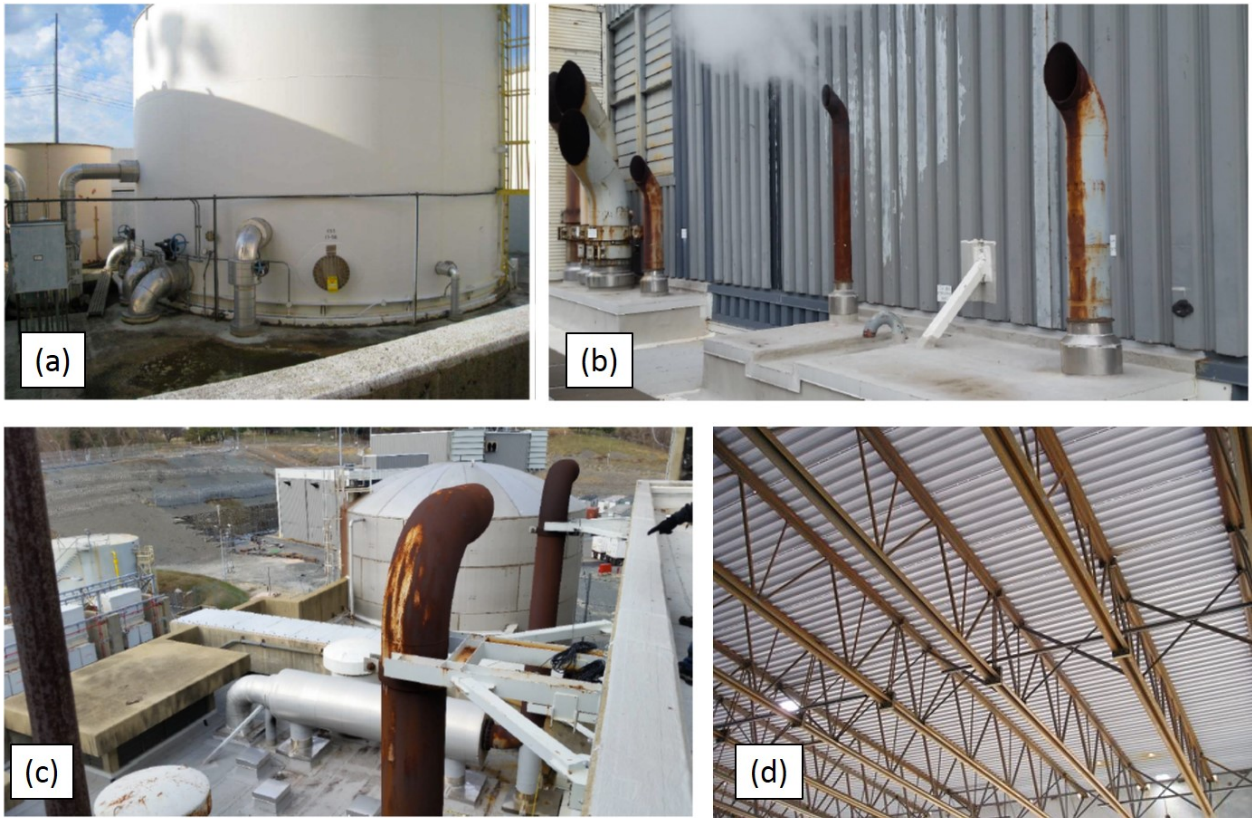
The results of these analyses are used to estimate the number of missiles that could cause damage to pipe, tank, steel door, and concrete targets. A summary of the number of damaging missiles for each of these targets is shown in Figure 5-2 of this report.

C.2. BACKGROUND

The design of nuclear power plant facilities includes the effects missile impacts on structures, systems, and components. SRP Section 3.5.3 [1] provides guidance and acceptance criteria for the evaluation of barrier design procedures to ensure conformance with 10 CFR 50, Appendix A, General Design Criteria 2 and 4. This SRP section provides acceptance criteria for the prediction of local damage and overall response of safety-significant missile barrier. SRP Section 3.5.3 also references the acceptable use of the empirical equations, such as the Ballistic Research Lab (BRL) equation(s), to estimate effects of missile penetration on steel and concrete structures. This SRP section also requires an evaluation of overall (or global) structural effects. Both local and global evaluations were done for each target evaluated.

The targets assumed in this evaluation were representative of piping, tanks, doors, and reinforced concrete roofs. The piping targets had diameters and thicknesses ranging from 6-48 inches and 0.125-0.985 inches, respectively. The range of tank wall thicknesses ranged from 0.125 to 0.378 inches. All steel targets were conservatively assumed to have a design yield strength of 30,000 psi. Reinforced concrete roofs were assumed to have thicknesses of 4 and 8 inches and corresponding spans were assumed to be 4-ft and 20-ft, respectively. Figure C-1 indicates examples of potential wind-borne missile targets.

Figure C-1. Representative targets[24]: (a) condensate storage tank, (b) steam exhaust stacks, (c) diesel generator mufflers, and (d) steel composite concrete roof (interior view)



C.3. Approach

The impact of a missile onto a target is a complex dynamic problem. The phenomena typically involve nonlinear material behavior and high strain rates for both the missile and target. The problem of wind-driven missiles is further complicated, because these missiles are not engineered to penetrate a hardened target (i.e., remain rigid). Rather, these missiles are typically deformable such that they are susceptible to fail by buckling or shattering before they can penetrate a target. Detailed nonlinear finite-element analysis methods can be utilized for evaluating missile impacts, but due to the complexity of this class of problem and lack of relevant experimental tests (for validation purposes), uncertainty in final results is not necessarily reduced. Nonetheless, as missile impact is considered in the design of nuclear power plant structures, NRC and industry guidance exist for developing approximate demands on structures without requiring sophisticated analysis methods. Standard practice methods include the use of single degree-of-freedom models for representing the target capacity (force-displacement) and the use of forcing functions to represent the missile impact.

As the number of EPRI missile and target combinations to be analyzed was more than 400 (~23 missiles x 19 targets), a pragmatic approach was developed for the TMRE to estimate target damage. The approach relies on an analytical approach that is consistent with the NRC SRP Section 3.5.3 [1]. The approach makes accounts for missile characteristics such as impact speed, missile mass, and target

[24] Source: EPRI walkdown report [6]

characteristics such as stiffness, ultimate capacity, and mass. The analysis of pipe crimping was benchmarked to two relevant experiments.

While median material properties were assumed to develop a best-estimate of target capacity, conservative assumptions were made with respect to missile strike location and orientation. It was assumed that missile impacts are normal to the target surface and that the axis of the missile is parallel to the line of flight. For impacts on pipes, the effectiveness of the missile impact degrades significantly as the strike location is offset from the centerline of the pipe.

Target Response

For the analysis of local effects (penetration/perforation) on the targets considered in this evaluation, the BRL equations were relied upon. Section C3.1 describes the approach for evaluating local effects.

For the evaluation of overall (or global) impact effects on NPP structures, each target was idealized as a single-degree-of-freedom (SDOF) lumped mass model. The relatively high-velocity impact scenarios (>100 mph), were assumed to be plastic (consistent with SRP Section 3.5.4) resulting in the missile mass being included in the effective mass of the target. The initial condition of the SDOF equation-of-motion is initial velocity, which is derived based on the conservation of momentum between the missile and target. Numerical integration of the SDOF equation of motion is performed to estimate target displacement as a function of time. The subsequent target response (displacements, strains, etc.) can be compared to allowable limits. The lumped mass modeling approach is a common engineering dynamic analysis tool [12] and has been used in the design nuclear of power plants [7].

It is recognized that some design methods rely on idealizing the missile with a forcing function (force versus time) rather than estimating an initial target velocity. However, the forcing function approach, which relies on a rigid (non-moving) target, can provide overly conservative force estimates for compliant structures. For design purposes, members can be made sufficiently stiff to resist the assumed forcing function. For evaluating existing SSCs, which are likely compliant targets, the initial velocity approach is a reasonable alternative. A comparison of results between models making use of a forcing function or an initial velocity condition showed reasonable agreement in predicted displacements.

Modes of Failure

The failure modes considered for the targets varied depending on target type (Table C-1). Steel pipe sections were evaluated for both local effects and global effects. Local effects relate to localized perforation (or punching shear) and is dependent on pipe (or wall) thickness, rather than structural response of a pipe, tank, or concrete panel. For this evaluation, these effects were assessed with the use of empirical equations. Global effects relate to the overall flexural response (or bending) of pipes, tanks, and concrete panels. These 'global' modes are influenced by structural section properties (wall thickness, diameter, etc.) as well as member span and boundary conditions. Global effects also relate to pipe crushing and crimping, as both circumferential and longitudinal pipe response are factors.

For piping targets, the critical section was assumed to be the location of missile impact. As piping configurations and support conditions vary considerably, it was considered reasonable to idealize the pipe boundary conditions for two cases. For vent pipe cases, the pipe is assumed to be supported on one end by a fully-clamped condition and free (or unsupported) on the opposite end. These boundary conditions realistically represent a cantilevered vent pipe. For wetted (or fluid-filled) pipe cases, the pipe is assumed to be fixed-supported on one end and pinned or simply-supported on the opposite end.

Liquid-filled steel tanks were also evaluated for perforation and flexural failure of the shell in the vicinity of the missile impact (Section C3.3). The added mass of the tank fluid (water) was considered in the dynamic model, but the stiffening effect (incompressible fluid) is conservatively neglected. The tanks were conservatively modeled as ring structures, so the additional stiffness contributed from the top/bottom of the tanks were not considered.

Reinforced concrete roofs were evaluated for local perforation and overall slab response (Section C3.4). Rotations at the slab supports were compared to ASCE allowable limits [13].

Table C-1 - Significant Evaluation Assumptions

Target Type	Relevant Failure Modes	Assumptions
Stacks and Exhaust Pipes	Crimping/crushing at impact location	Cantilevered pipe support. Missile impact near end of pipe (1-pipe diameter away)
Fluid/Steam Pipes	Perforation and crimping/crushing at impact location	Pipe supported on both ends. Missile impact at center span
Tanks	Perforation and global*	Impact at mid-height of tank shell. Added mass of fluid accounted for.
Doors	Perforation and global**	Impact at center of door. Sandwich panel idealized as isotropic plate.
RC Roofs	Perforation and global***	Impact at center of roof slab. Supporting beams or bar joists not considered.

*Circumferential stiffness and flexural capacity of tank considered
**Flexural stiffness and capacity of door panel considered
***Flexural and shear failure of roof panel considered

C.3.1 PERFORATION EVALUATION

The local effects of missile perforation were considered for all targets except for stacks and exhaust pipes. The functionality of stack and exhaust piping was judged to be more limited by crushing or crimping failure modes. Perforation effects on steel targets were assessed using the BRL equation:

$$T = \frac{\left(\frac{MV_s^2}{2}\right)^{2/3}}{672D_m}$$

$T =$ steel plate thickness to just perforate (inches)
$M =$ Mass of the missile $(\mathrm{lb} - \mathrm{sec}^2/\mathrm{ft})$
$V_s =$ striking velocity of the missile normal to target surface $\left(\frac{\mathrm{ft}}{\mathrm{sec}}\right)$
$D_m =$ diameter of missile (in)

As perforation of a pipe or tank wall requires penetration of steel material, it was assumed that only missiles comprised of steel materials (pipes, beams, etc.) are capable of a perforation failure mode. While deformable missiles are not likely to cause a perforation failure mode, these missiles were evaluated for their propensity to cause global structural damage (e.g., crushing/crimping).

For realistic analysis, missile impact velocity was assumed to be weight dependent, as described in NRC SRP (1975) Section 3.5.1.4 (Table C-2). This table indicates that as missile weight increases, horizontal impact velocity decreases. For this evaluation, a linear velocity-weight correlation was used (Figure C-3), which conservatively bounded most of the SRP missile types.

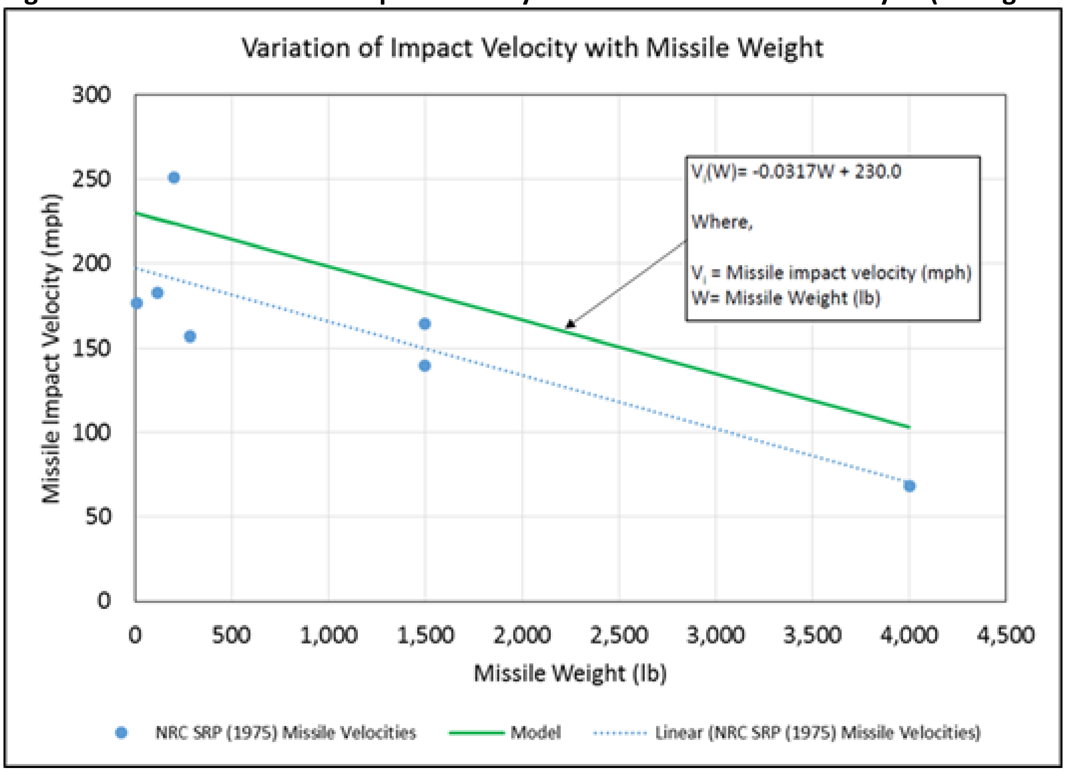
SRP Section 3.5.1.4, November 24, 1975 "NO TUMBLING" MISSILE SPECTRUM B

		Horizontal Velocity ft/sec
A.	Wood plank, 4 in. x 12 in. x 12 ft, weight 200 lb.	368
B.	Steel pipe, 3 in. diameter, schedule 40, 15 ft long, weight 115 lb.	268
C.	Steel Rod, 1 in. diameter x 3 ft long, weight 8 lb.	259
D.	Steel pipe, 6 in. diameter, schedule 40, 15 ft long, weight 285 lb.	230
E.	Steel pipe, 12 in. diameter, schedule 40, 30 ft long weight 1500 lb.	205
F.	Utility pole, 14 in. diameter, 35 ft long, weight 1500 lb.	241
G.	Automobile, frontal area 20 ft^2, weight 4000 lb.	100

Table C-2. SRP (1975) missile spectrum indicating variation of horizontal velocity with missile type. Conversion to miles-per-hour (mph) also shown.

Description	Horizontal Velocity (ft./sec)	Horizontal Velocity (mph)
4"x12" x 12 ft. long; 200 lb.	368	251
3" dia; Schedule 40, 15 ft. long; 115 lb.	268	183
1" dia; 3 ft. long, 8 lb.	259	177
6" dia; Schedule 40; 15 ft. long; 285 lb.	230	157
12" dia; Schedule 40; 30 ft. long; 1500 lb.	205	140
14" dia; 35 ft. long; 1500 lb.	241	164
Frontal area 20 ft^2; 4000 lb.	100	68

Figure C-3. Assumed missile impact velocity correlation used in this analysis (solid green line)



Concrete Perforation

Perforation on concrete targets was assessed by the BRL formula [11]. For the concrete material, median values of compressive strength were assumed. Median strength, aging, and dynamic increase factors were assumed to be 1.15, 1.2, and 1.25, respectively [9]. For the reinforced concrete targets evaluated, concrete design strength was assumed to be 3,500 psi. Thus, for perforation calculations, a value of 6,037 psi was assumed (3,500 psi x 1.15 x 1.20 x 1.25 = 6,037 psi). In the case of deformable missiles, the limiting perforation thicknesses were reduced by 30% in accordance with DOE guidance [11].

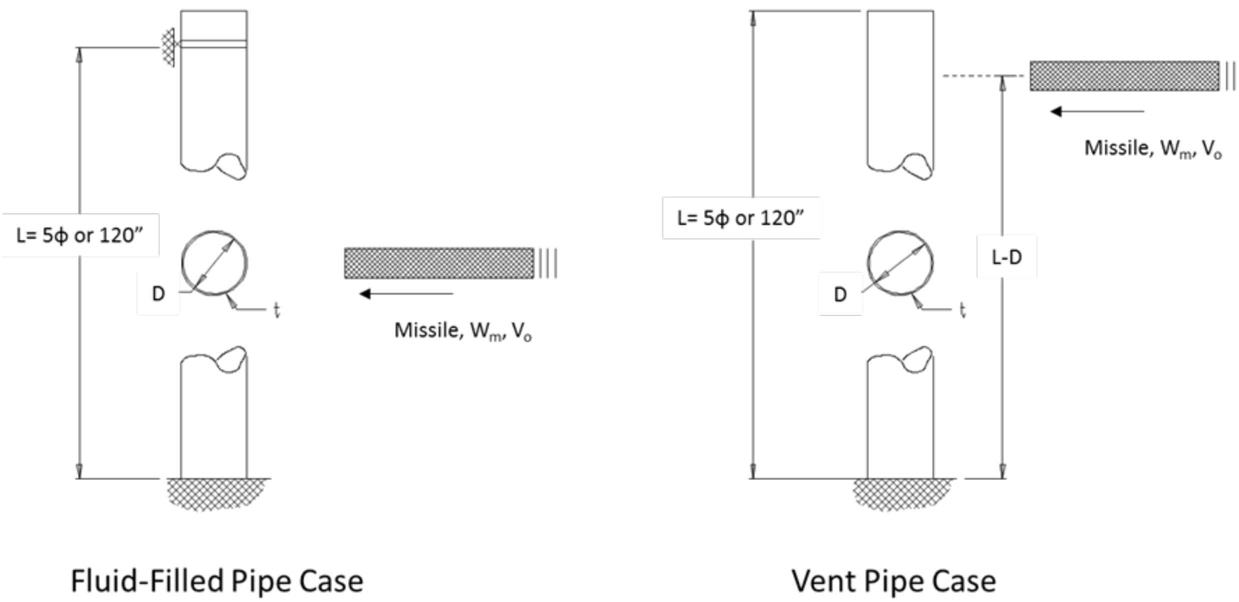
$$T = \frac{427}{\sqrt{f'_c}} \frac{W}{D_m^{\ 1.8}} \left(\frac{V_s}{1{,}000}\right)^{1.33}$$

T = thickness of concrete element to be just perforated (in)
W = weight of missile (lb)
D_m = diameter of missile (in)
V_s = striking velocity of missile $\left(\frac{ft}{s}\right)$
f'_c = compressive strength of concrete (psi)

C.3.2 Pipe Crushing and Crimping

All steel pipe sections where evaluated for local crushing and crimping effects. Fluid-filled pipes were assumed to be fixed at one end and simple supported on the opposite end (Figure C-4). Vent pipe cases assumed to have a cantilevered support condition (i.e., supported at base only). The pipe spans were assumed to be the maximum value of five pipe diameters or 120 inches. The 120-inch span corresponds to a realistic unsupported pipe length.

Figure C-4. Missile impact on a pipe target



Pipe Impact Model
When a missile impacts a target, significant forces are developed at the target interfaces. These forces decelerate the missile and accelerate the target. The impact scenarios considered in this evaluation and judged to result in plastic impact, where the missile remains in contact with the target.

A simplified pipe impact model was developed to evaluate the radial deflection of a thin-walled pipe subjected to a concentrated force. The model assumes linear elastic properties for the pipe and accounts for nonlinear behavior through the use of bi-linear force-deflection curve. Viscous damping was assumed to account for energy dissipation due to the large-strains and deformations involved. The method was benchmarked to two physical experiments (discussed below) and reasonable results were obtained. The model does not account for the resisting effects of membrane tension under larger deformations. This is judged to be a conservative bias.

The pipe target is represented as a single-degree-of-freedom model with a bilinear spring and viscous damper (Figure C-5). The bilinear resistance function represents the radial stiffness of the pipe and the plastic moment capacity of the pipe section. The derivation of the linear stiffness and plastic moment capacity is shown in Section C7.0. To account for strain rate effects, a dynamic increase factor was applied to yield stress of the steel pipe material.

The equation of motion of the pipe target is solved as an initial velocity problem and numerically integrated using a 4th-order Runge Kutta method [5]. The velocity of the combined system after the collision is derived from conservation of momentum.

$$M_m V_m = (M_m + M_t) V_o$$

$$V_o = \frac{M_m V_m}{M_m + M_t}$$

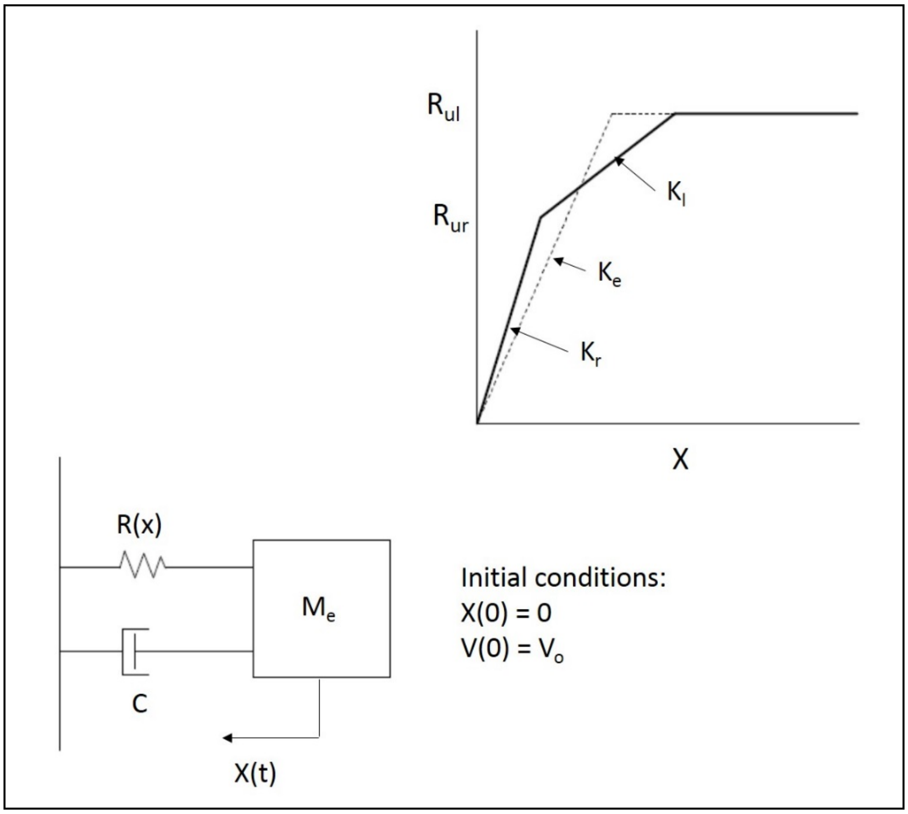
M_m = Missile mass
M_t = Target mass
V_m = Missile impact velocity
V_o = Target velocity

Impact velocities were assumed to be horizontal and the missile was assumed to impact normal to the target surface. For highly-deformable missiles (plywood, grating, siding, etc.), the weight was reduced to 30% of the total mass to account for energy absorbed to crushing, buckling, etc. (Table C-2). DOE guidance on aircraft impact [11] describes that for highly-deformable missiles (e.g., aircraft fuselage), a significant portion of impact energy is dissipated in deforming the missile. The effective mass will be significantly less than the total mass of the missile. DOE guidance limits the reduction to 30% of the total missile mass.

Table C-2 - Effective Mass Factor

Missile Characterization	Example Missiles	Effective Mass factor
Non-Deformable (essentially rigid)	rebar, gas cylinder, steel pipe, steel beam,	0.9
Deformable (higher rigidity, but susceptible to crushing)	toolbox, utility pole, cable reel, paver, concrete block, sawn lumber, small motor, concrete mixer, pallet rack, vehicle, concrete pipe	0.5
Highly-Deformable (low rigidity and crush strength)	Metal siding, plywood, 20’ tree, tank drum, steel grating	0.3

Figure C-5. Analytical model which utilizes a bi-linear resistance function



The pipe radial stiffness, K_r, and ultimate capacity, R_{ur}, is approximated below. Note that the details of their derivation are provided in Section C7.0.

$$K_r = \frac{9.28 \text{ E b t}^3}{D^3}$$

$$R_{ur} = \frac{4 \text{ b t}^2 \text{ F}_y}{D}$$

For the cantilevered pipe support conditions, the longitudinal stiffness, K_l, and longitudinal flexural capacity, R_{ul}, are derived using conventional beam relationships:

$$K_l = \frac{3 \text{ E I}}{(L - D)^3}$$

$$R_{ul} = \frac{2.4 \text{ F}_y \text{ I}}{\text{D} (L - D)}$$

Similarly, for fluid-filled pipe support conditions, the longitudinal stiffness, K_l, and longitudinal flexural capacity, R_{ul}, are derived using conventional beam relationships:

$$K_l = \frac{106\ E\ I}{L^3}$$

$$R_{ul} = \frac{14.4\ F_y\ I}{D\ L}$$

K_r = pipe radial stiffness $\left({}^{lb}/_{in}\right)$
K_l = pipe longitudinal stiffness $\left({}^{lb}/_{in}\right)$
R_{ur} = maximum radial crush resistance (lb)
R_{ul} = maximum longitudinal resistance (lb)
E = pipe material elastic modulus $\left(\frac{lb}{in^2}\right)$
F_y = pipe material yield stress $\left(\frac{lb}{in^2}\right)$
b = effective length of pipe (in); [comensurate with size of impacting missile]
t = pipe wall thickness (in)
D = mean pipe diameter (in)
I = pipe moment of inertia (in^4)
L = pipe span (in)

An equivalent pipe stiffness is derived by assuming the radial and longitudinal stiffnesses act in series:

$$\frac{1}{K_E} = \frac{1}{K_r} + \frac{1}{K_l}$$

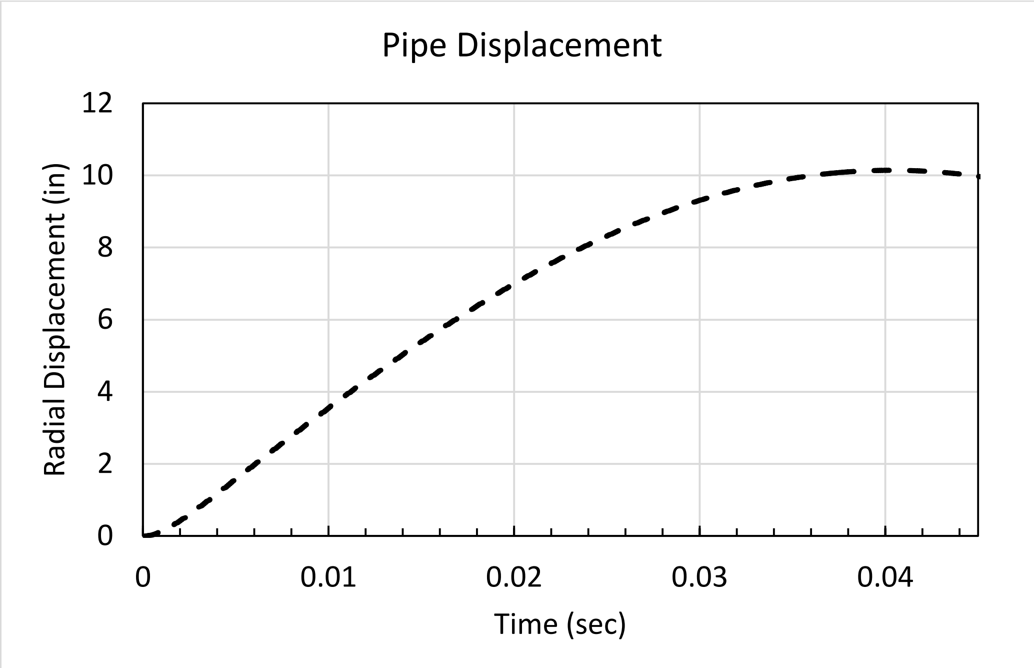
The equation-of-motion and initial conditions for the pipe system, shown in Figure C-5, is:

$$M_e\ddot{x} + C\dot{x} + R(x) = 0$$

$$x(0) = 0$$
$$\dot{x}(0) = V_t$$

The system is solved as an initial velocity problem using a Runge-Kutta numerical integration method [5]. The maximum displacement is estimated (Figure C-6.) and compared to an assumed limiting value. A displacement of more than 0.5 times the pipe diameter is considered failure of the pipe. A viscous damper was assumed in the model to represent the significant energy dissipation resulting from a highly nonlinear impact event. Critical damping values for both steel and concrete targets were assumed to be 15%, consistent with stress levels beyond yield and significant permanent deformation.

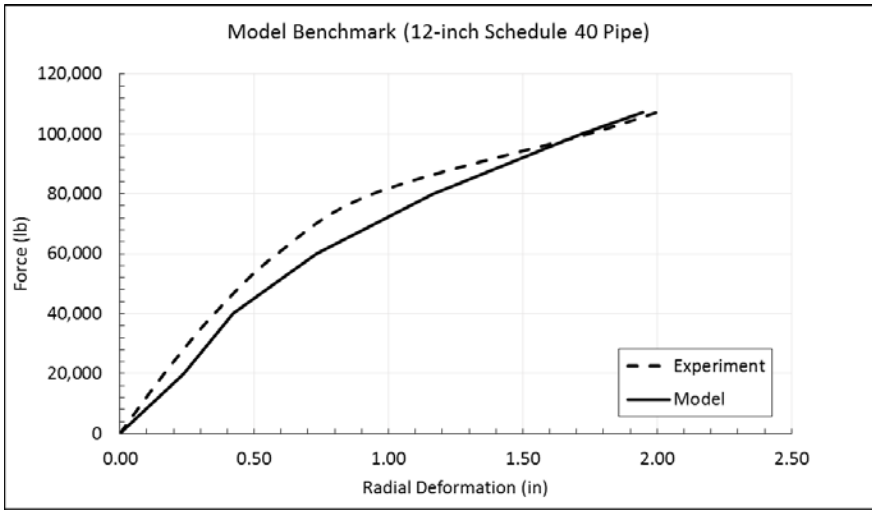
Figure C-6. Example model displacement response.



Benchmarking
To improve confidence in model predictions, comparisons of model results were made for two separate and relevant pipe impact experiments. The selected experiments involved the impact crush testing of thin steel tubes. The purpose of the experiments was to investigate offshore pipelines subjected to accidental loads, such as impacts from trawl gear or anchors. Due to the large radial deformations under impact conditions, it was judged that these experiments are relevant to problems involving wind-borne missile impacts on piping.

The first experiment involved drop testing of large weights (150 lbs) onto a 12-inch diameter steel pipe [14]. This test series involved the measurement of impact forces and pipe displacements for Grade 60 steel pipes. These measured forces and displacements where compared to those predicted using the simplified modeling approach. Model predictions agreed reasonably well with the test (Figure C-7). Based on a comparison of internal work (i.e., integral of the force-displacement curve), the model uncertainty is approximately 12%.

Figure C-7. Comparison of experiment and model results.



The second experiment involved pendulum impact tests on steel pipe sections [15] (Figures C-8 through C-10). The pipe sections were smaller in scale, but had thickness-to-diameter ratios comparable to exhaust pipes. The impactor was a heavy rigid steel anvil (weighing more than 3,000 lbs) attached to a trolley, which was capable of low impact speeds (less than 15 mph). Force and displacement transducers were used to measure impact force and pipe deformation, respectively. Some of the tested pipes had crush depths (or dents) greater than 50-percent of the pipe diameter. Six simplified analytical models were developed to represent each of the six test scenarios. Comparison of analytical model and experimental results is shown in Figure C-11. The estimated uncertainty in model results is approximately 25%, which is judged to be satisfactory, in light of the large pipe deformations involved.

Figure C-8. Pipe crimping experiment; impactor seen on the left side of the figure; source [15]

Figure C-9. Experimental setup; source [15]

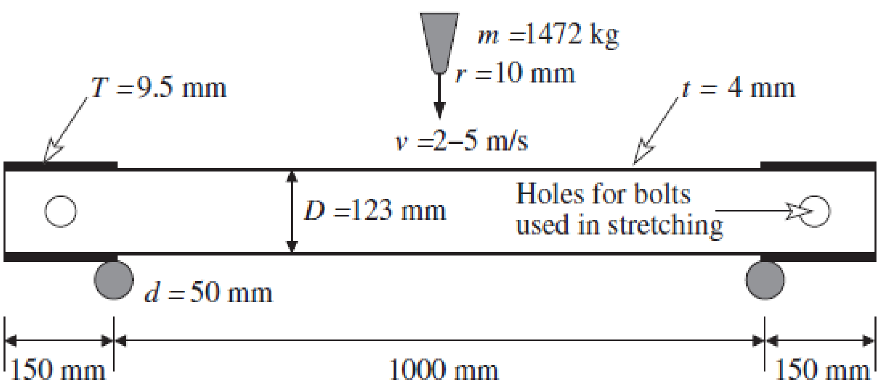


Figure C-10. Dynamic impact test showing pipe crimping; source [15]

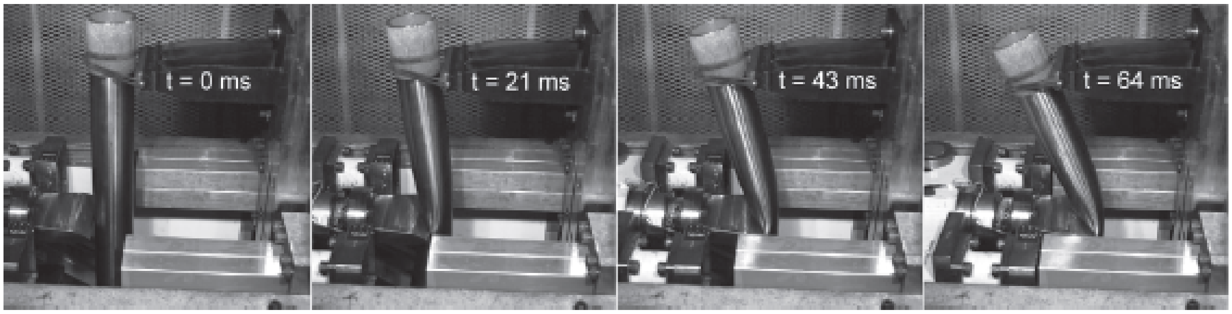
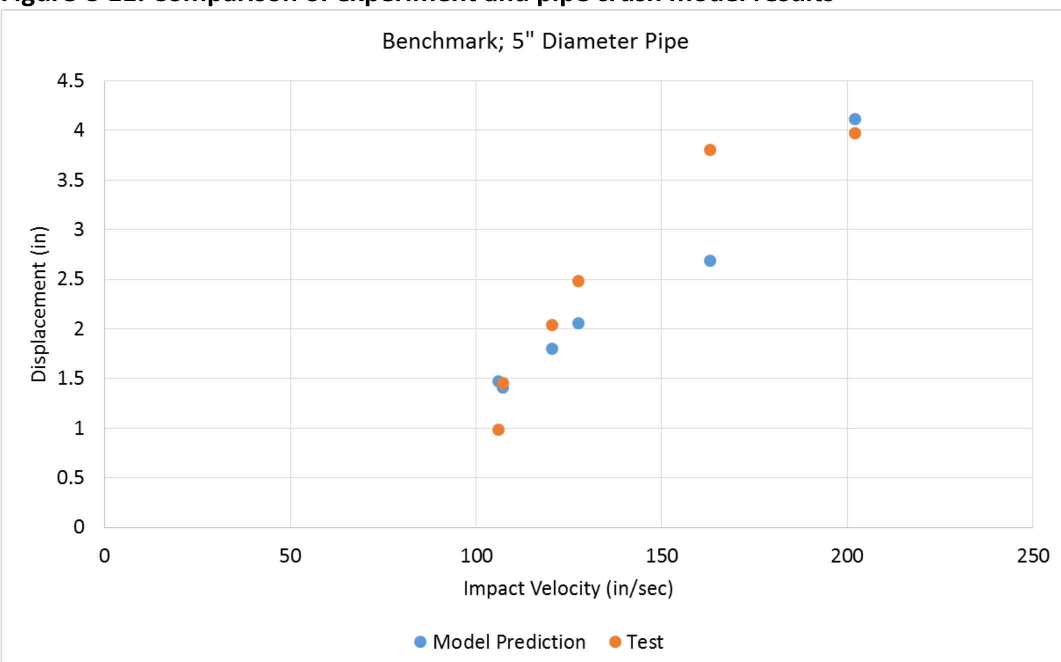


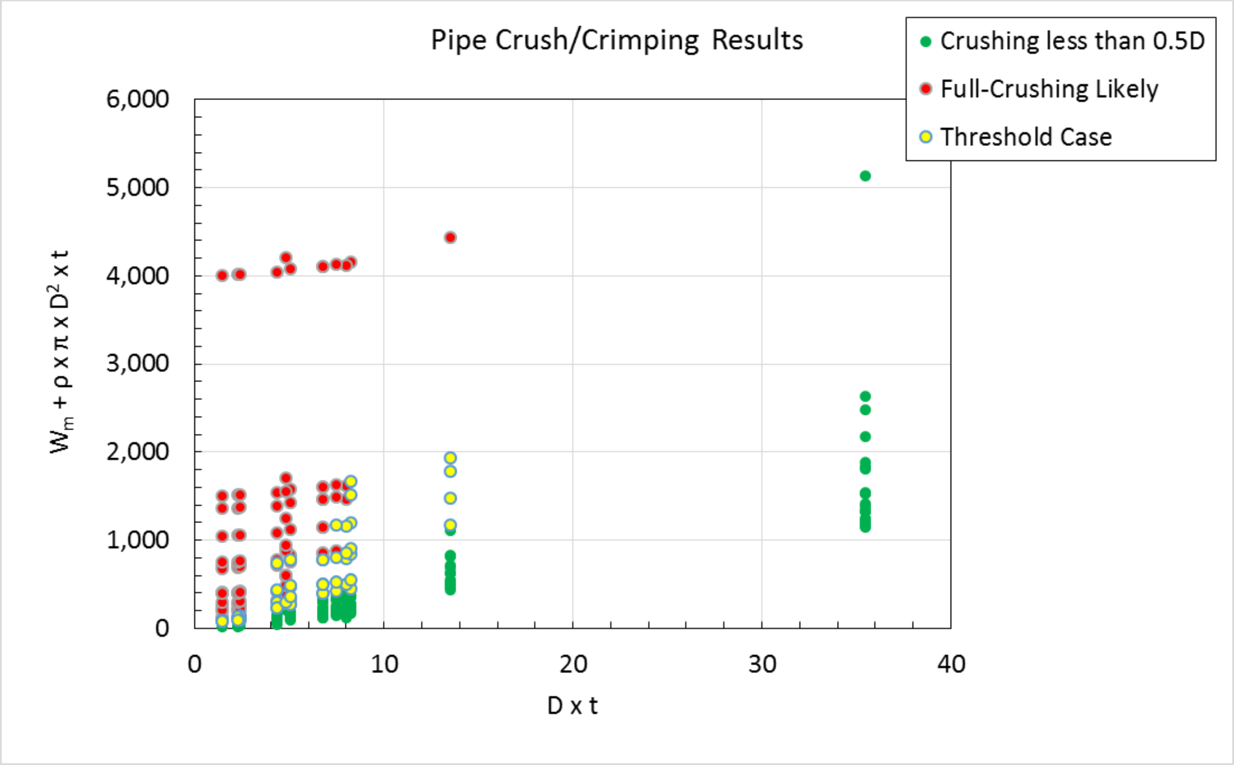
Figure C-11. Comparison of experiment and pipe crush model results



Model Results

Using the analytical model, various cases were run considering a wide range of missile types and pipes of various diameter and wall thicknesses. The results for the range of missile types and steel pipe targets considered in the TMRE are shown in Section C.8. In addition, the results are also shown in Figure C-12 below, which can be used to estimate pipe crush for wider range of impact scenarios. The green data points represent those cases that had pipe deformations less or equal to 0.5 times the pipe diameter. The yellow data points represent threshold cases were the pipe deformation was greater than 0.5 times the pipe diameter but less than full crimping. The red data points represent cases where the pipe is estimated to be completely crushed/crimped.

Figure C-12. Pipe impact evaluation results (6 in < D < 48 in) and (0.125 in < t < 0.98 in); Nominal impact velocity = 230 mph



C.3.3 Evaluation of Liquid-Filled Steel Tanks

Liquid-filled steel tanks were also evaluated for perforation and flexural failure of the shell in the vicinity of the missile impact (Table C-3). The added mass of the tank fluid (water) was considered in the dynamic model, but the stiffening effect (incompressible fluid) is conservatively neglected. The circular tank shells were modeled as ring structures and the additional stiffness contribution from the top enclosure and bottom foundation restraint were not considered. The exclusion of cylinder height in estimating tank stiffness is judged to be conservative.

Table C-3. Liquid-filled tank parameters

Tank Description	Tank Diameter (in)	Tank Shell Thickness (in)
CST	576	0.375
CST	576	0.250
Diesel Fuel Oil Tank	120	0.250
Diesel Fuel Oil Tank	120	0.145
Diesel Fuel Oil Tank	120	0.133

The evaluation of tanks was performed using the same analytical model as described in Section C3.2. The tank stiffness was approximated from the circumferential flexural shell frequency described by Den Hartog [8].

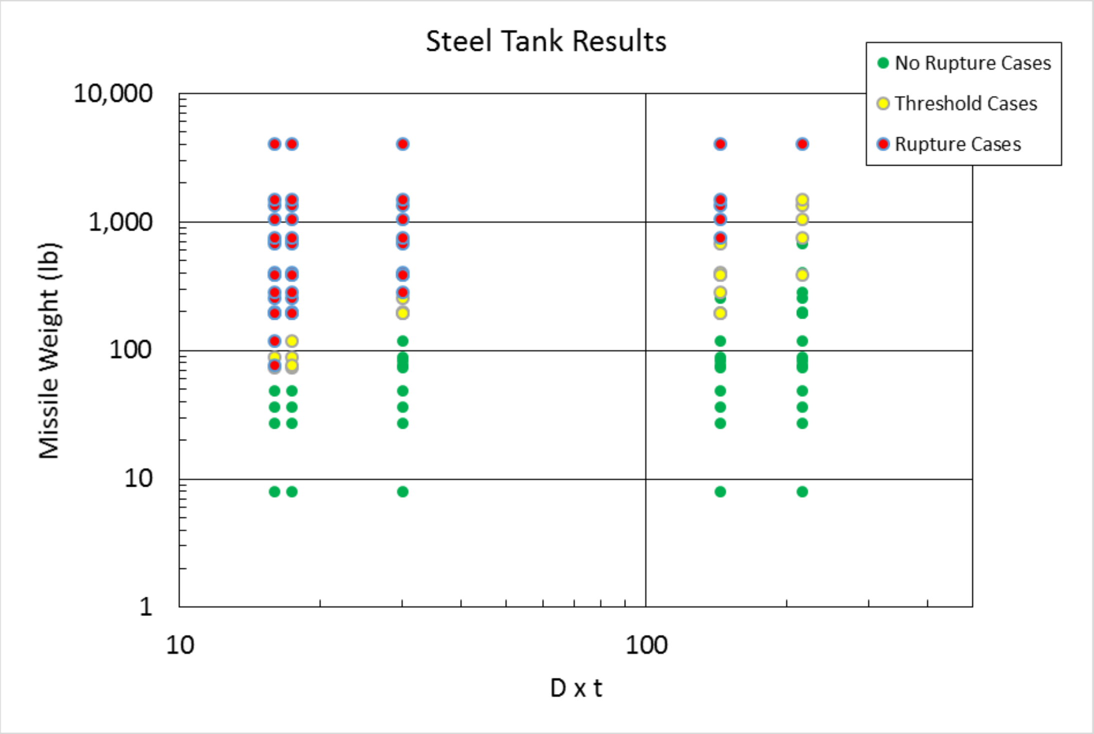
$$\omega_n = \frac{n(n^2 - 1)}{\sqrt{1 + n^2}} \sqrt{\frac{EI}{\gamma r^4}}$$

ω_n = natural tank shell frequency
n = number of full sine waves
E = material modulus
γ = mass per unit length
r = tank radius
The mass of water was accounted for by 'smearing' the water mass to the mass of the tank shell. The tank stiffness is estimated from:
$k_{tank} = m_{eff}{\omega_n}^2$
$m_{eff} = m_{tank\ shell} + m_{water}$
The ultimate capacity of the tank shell was assumed to be:
$R_{u\_tank} = 4\pi M_p$ [7] ;
where M_p is the plastic moment capacity of the tank shell

The effective mass of the tank was assumed to be ¼ shell area for large tanks and ½ shell area for smaller tanks. The maximum displacement for the tank shell was assumed to be 3 times the elastic displacement (ductility μ~3.0). This is judged to be conservative as ASCE standards allow for ductility ratios greater than 10.0 [13].

The results for the range of missile types and steel tank targets considered in the TMRE are shown in Section C.8. In addition, the results are also shown in Figure C-13 below, which can be used to estimate tank rupture for wider range of impact scenarios. The green data points represent cases where rupture is not likely (μ<1.0) and yellow data points represent threshold cases were rupture is not likely, but strain values are elevated (1.0<μ<3.0). The red data points represent cases were rupture may occur due to large displacements of the tank shell (μ>3.0).

Figure C-13. **Steel tank results: (120 in < D < 576 in) and (0.133 in < t < 0.375 in, Nominal impact velocity = 230 mph)**



C.3.4 Evaluation of Reinforced Concrete Roofs

An evaluation of reinforced concrete roofs was performed using the same dynamic modeling approach as was utilized for the evaluation of pipes and tanks. Roof slab stiffnesses and load capacities were evaluated for two roof thickness (4 and 8-inches). These thicknesses were selected based on common roof construction observed in NPP designs. The respective spans for the 4 and 8 inch roofs were 4 ft. and 20 ft., respectively. The 4-inch thick roof is assumed to be composite steel construction with steel bar joists spaced at 48-inches. The assumed roof design parameters are shown in Table 4 below. As missile impact was assumed to strike mid-span of the slab, the bar joists were not explicitly considered. The 8-inch thick roof is assumed to be ordinary reinforced concrete. The roof spans were assumed to be designed as one-way members and impact was also assumed to occur at the mid-span location. Empirical equations were used to evaluate perforation (Section C3.1). Scabbing (or spalling of concrete) was not evaluated, as most concrete roofs have metal decking on the underside of the slab. This decking confines the concrete cover over reinforcement and prevents the effects for scabbing.

Table C-4. Assumed reinforced concrete roof parameters

Parameter	4-inch RC Roof	8-inch RC Roof
Span (ft.)	4	20
Design Live Load (psf)	50	50
Concrete compressive strength (psi)	4,000	4,000
Steel reinforcement strength (psi)	40,000	40,000
Steel reinforcement ratio	0.002	0.008

Results

The results for the range of missile types and concrete roofs considered in the TMRE are shown in Table C-5, below. In addition, the results are also shown in Figure C-14 below, which can be used to estimate concrete roof damage for wider range of impact scenarios.

The green data points indicate cases where only moderate damage is expected (slight cracking) and the yellow data points indicate cases where heavy damage would be expected (significant cracking, but no structural failure. The red data points indicate cases where the roof slab is likely to fail structurally, resulting in hazardous debris into the space below.

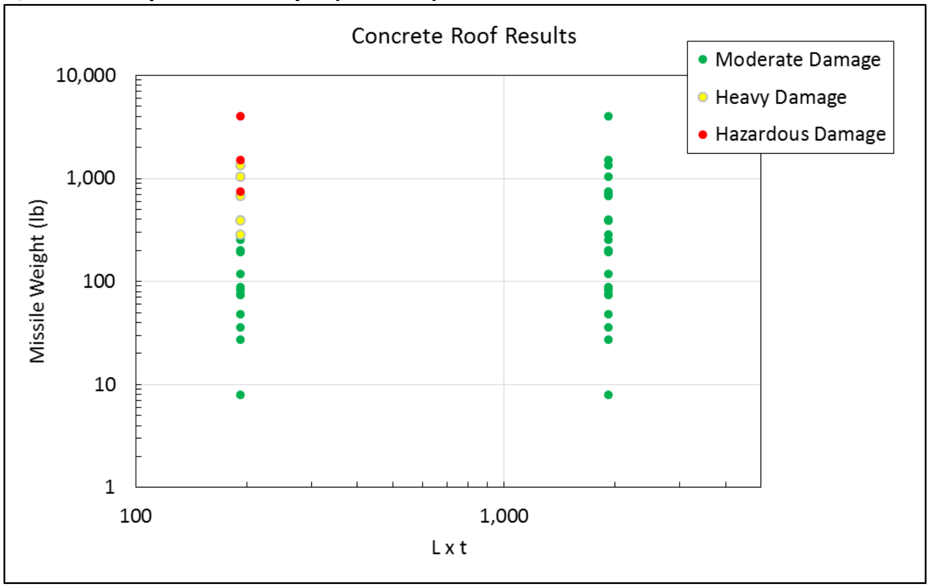
In some cases, mostly where missile weights are much greater than 500 lbs, the 4-inch thick concrete roof slab is susceptible to failure. However, the 8 inch thick concrete roof slab is not susceptible to overall failure from most of the missiles analyzed. Despite the longer span of the 8-inch roof slab (20 ft.), the mass of the roof contributes to a significant amount of inertia (keeping displacements small).

Table C-5. Results for reinforced concrete roof impacts

Missile	Minimum Perforation Thickness (in)	4" Roof Slab Edge rotation [2]	8" Roof Slab Edge rotation [3]	Evaluation
# 8 Rebar	6.1			Perforation failure of 4" slab
Gas Cyl (290 lb)	3.3			No failure of 4" or 8" slab
Tank Drum (500 lb)	1.6			No failure of 4" or 8" slab
Utility Pole (1500 lb)	7.7			Perforation failure of 4" slab; 8" slab OK as equation conservative for timber missiles
Cable Reel (253 lb)	0.3			No failure of 4" or 8" slab
3" pipe (76 lb)	6.0			Perforation failure of 4" slab not likely due to low stiffness of pipe (30% reduction not credited). Steel decking also not credited
6" pipe (284 lb)	6.8			Perforation failure of 4" slab
12" pipe (744 lb)	5.0			Panel (global) failure of 4" slab
Tool bx (675 lb)	0.5			Flexural failure of 4"; No failure 8" slab
Paver (88 lb)	1.6			No failure of 4" or 8" slab
Conc blk (36 lb)	0.5			No failure of 4" or 8" slab
4x12 timber (200 lb)	3.6			No failure of 4" or 8" slab
2x12 plank (27 lb)	0.9			No failure of 4" or 8" slab
Metal siding (125 lb)	1.2			No failure of 4" or 8" slab
7/8" plywood (84 lb)	1.7			No failure of 4" or 8" slab
W14x26 (390 lb)	4.8			Flexural failure of 4" slab; No failure of 8" slab
C6x13 (195 lb)	11.4			Irregular cross-section results in unrealistic result. Alternative Chang formula (DOE-STD-3014-96) indicates limiting thickness of 3.4"; assume no failure as steel decking not credited
small motor (388 lb)	0.5			No failure of 4" or 8" slab
conc mixer (1,350 lb)	0.8			Flexural failure of 4"; No failure 8" slab
steel grating (74 lb)	2.5			No failure of 4" or 8" slab
pallet rack (1,040 lb)	0.2			Flexural failure of 4"; No failure 8" slab
vehicle (4,000 lb)	0.4			Panel (global) failure of 4" slab; 8" also assumed to fail as a conservative measure
20' tree (700 lb)	11.0			Perforation failure of 4" slab not likely due to low stiffness of tree branches

*Green is max rotation < 0.210 radians [ASCE 59-11]
*Red is max rotation > 0.210 radians [ASCE 59-11]
[2] 4 ft span assumed for 4" slab
[3] 20 ft span assumed for 8" slab

Figure C-14. Concrete roof results (48 in < L < 240 in) and (4.0 in < t < 8.0 in); Nominal impact velocity = 2/3 x 230 mph or 153 mph (vertical)



C.4 DEBRIS FROM DAMAGED STRUCTURES

Wind pressures from tornadoes can be sufficiently high to cause structural damage to portions of building structures. Damage can range from localized (pieces of siding) to complete failure of the wall and roof systems. Debris from these damaged buildings can generate additional missile hazards. FEMA [16] has developed wind pressure fragility functions for various building types (wood framed, manufactured, pre-engineered, and engineered). For each building type, FEMA assessed the likelihood of damage for key structural components (roof and walls) for a range of wind speeds (typically 60-200 mph).

As these types of buildings are found on power plant sites, an estimation of number of available missiles for each building type was performed. The number of available missiles was estimated from typical construction practices (e.g., wood framing at 16-inch centers for wood buildings, and plywood sheets measuring 32 square feet). Based on a representative building for each construction type, the total number of building components was approximated. For example, the numbers of wall studs, roof rafters, and floor joists, were estimated for wood offices and warehouses (Figure C-15). In addition, the contents of buildings were considered depending on building function. The quantities of desks and furniture were estimated for office buildings, and quantities of pallets, drums, and shelving were estimated for warehouses. The results for potential tornado missiles per building type are shown in Tables C-9 through C-14, below. A walkdown of a warehouse at a nuclear power plant confirmed that the quantities shown below are generally representative of a typical warehouse.

To help clarify the approach used for estimating the total number of building components, an example evaluation of a pre-engineered metal warehouse building is provided below. The approach is similar for the other building types (wood-framed and manufactured).

<u>Pre-Engineered Metal Warehouse Building</u>

The metal warehouse building type is commonly found on nuclear power plant sites. The assumed building measures 80-ft x 40-ft in plan-view and has a height of 16-ft. The configuration of the building, including key structural elements, is shown on Figure C-16. The design and construction of the building was assumed to be consistent with that of typical metal building systems (Figure C-17). The key building dimensions and areas are shown in Table C-6 below.

Building Contents
The contents of the building were assumed to representative of construction equipment/supplies or items used in outages (tool bins, cable reels, lumber, generators, etc.). The quantities of stored items were based mainly on filling available shelf and floor area. Based on the warehouse general arrangement, the building is judged to be moderately stocked and not sparsely loaded. Table C-7 indicates the assumed building contents and quantities. Table C-8 provides a summary of potential missiles from both structural and stored contents and provides the missile count on a per 1,000 square foot building area.

Figure C-15. Typical wood building construction

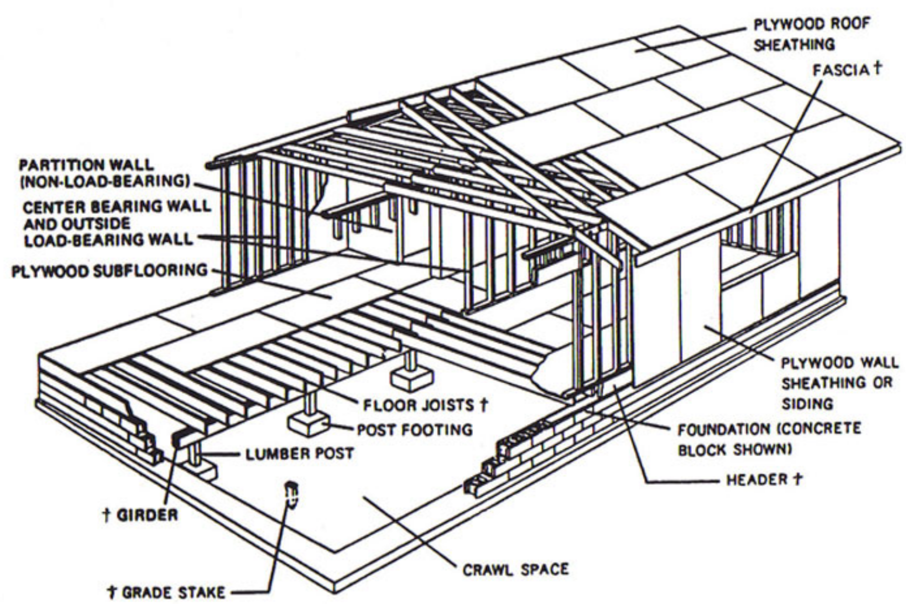


Figure C-16. Assumed layout of representative metal warehouse building

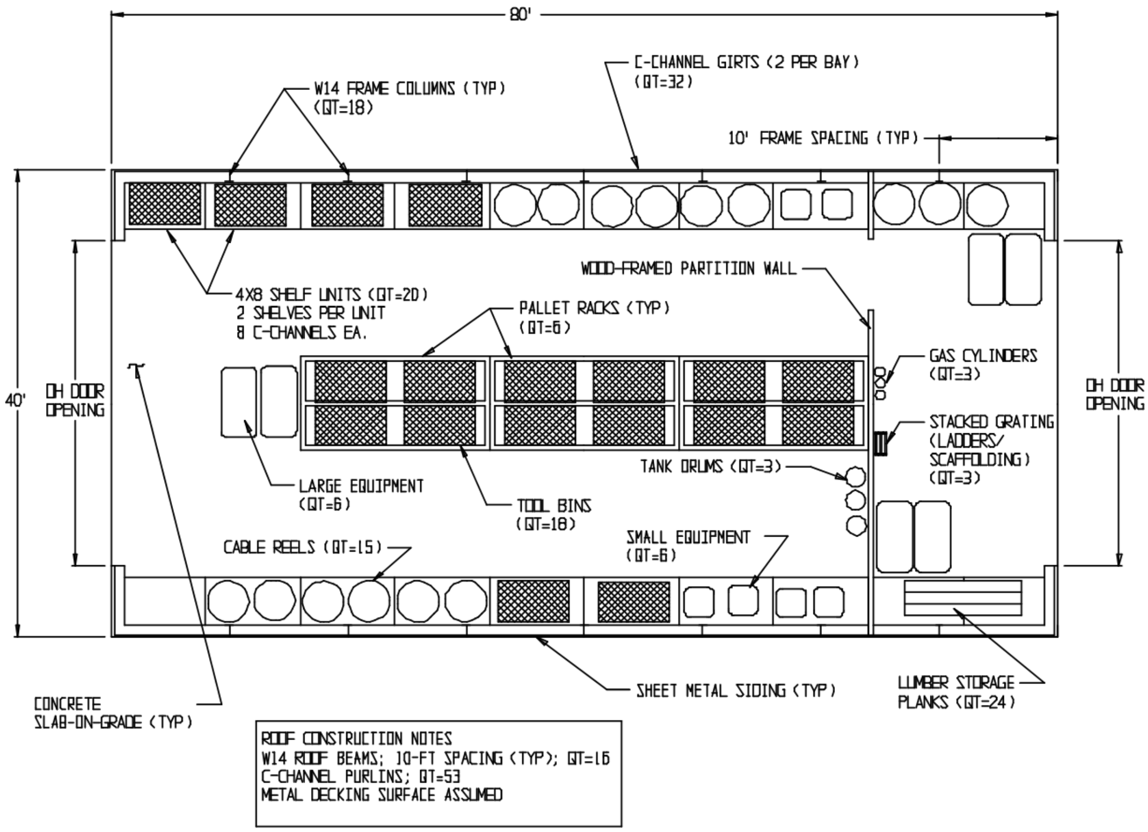


Figure C-17. Typical structural configuration for a metal building system

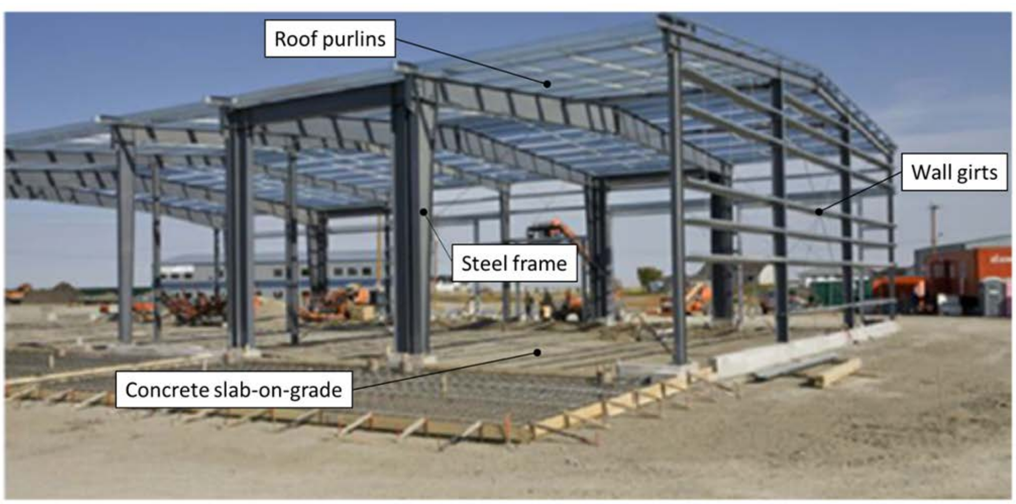


Table C-6. Key building parameters

Pre-Engineered/Engineered Building (Warehouse)	
Building length (ft)	80
Building width (ft)	40
Building height (ft)	16
Exterior wall length (ft)	240
Roof area (sf)	3,200
Exterior wall area (sf)	3,840
Floor area (sf)	3,200

Table C-7. Building Content Quantities

Building Contents	EPRI Missile No.	Assumed Quantity
Gas cylinder	2	3
Drum, tank	3	3
Cable Reel	5	15
Metal storage bin	9	18
Small equipment	18	6
Large equipment	19	6
Steel grating/ladders/scaffolding	20	3
Large steel frame	21	6
Wood planks	13	24

Table C-8. Summary of Building Missiles (per 1,000 ft^2)

EPRI Missile	Missile Description	Pre-Engineered/Engineered Building (Warehouse)		
		Missiles per 1,000 ft^2 Floor Area	Missiles per 1,000 ft^2 Roof Area	Missiles per 1,000 ft^2 Wall Area
1	Rebar	18	0	0
2	Gas Cylinder	1	0	0
3	Drum, tank	1	0	0
4	Utility pole	0	0	0
5	Cable reel	5	0	0
6	3" pipe	0	0	0
7	6" pipe	0	0	0
8	12" pipe	0	0	0
9	Metal storage bin	6	0	0
10	Concrete paver	0	0	0
11	Concrete masonry units	0	0	0
12	Wood beam (4x12)	0	0	0
13	Wood plank	16	0	0
14	Metal siding	0	25	25
15	7/8" plywood	12	0	0
16	Wide flange beam (W14x26)	0	5	4
17	Channel Section (C6x13)	5	16	8
18	Small Equip	2	1	0
19	Large Equip	2	1	0
20	Steel grating	1	0	0
21	Large steel frame	2	0	0
22	Vehicle	0	0	0
23	Tree	0	0	0
	Total	**71**	**48**	**37**

The release fraction, or number of missiles released, for a range of wind speeds was estimated for each building type. The release fractions were based on the FEMA damage probabilities for building components subjected to high winds. As the number of wind-driven missiles should increase as the probability of building damage increases, it was assumed that release fraction correlated to the probability of damage for the most severe building damage state (e.g., complete roof or wall failure). The estimated release fractions for wood framed, manufactured, and engineered building types are shown in Figures C-18 through C-20 below.

Table C-9. Potential Tornado Missile per Office Building, Wood-Framed

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	14	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	4	2	9
13	69	31	76
14	0	0	25
15	31	31	0
16	2	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**121**	**66**	**110**

Table C-10. Potential Tornado Missile per Office Building, Manufactured (Pre-fab)

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	16	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	2	0	0
10	0	0	0
11	0	0	0
12	13	3	23
13	183	20	56
14	0	0	24
15	31	25	0
16	2	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**248**	**50**	**103**

Table C-11. Potential Tornado Missile per Office Building, Engineered and Pre-Engineered

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	33	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	2	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	80	0	0
14	0	25	24
15	15	0	0
16	0	8	4
17	0	16	7
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**131**	**51**	**35**

Table C-12. Potential Tornado Missile per Office Building, Construction Trailer

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	0	0	0
2	1	0	0
3	2	0	0
4	0	0	0
5	4	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	4	0	0
10	0	0	0
11	0	0	0
12	12	6	14
13	151	12	96
14	0	25	24
15	31	0	0
16	0	0	0
17	0	0	0
18	1	1	0
19	0	1	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
Total	**206**	**45**	**134**

Table C-13. Potential Tornado Missile per Warehouse Building, Wood-Framed

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	27	0	0
2	1	0	0
3	1	0	0
4	0	0	0
5	5	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	6	0	0
10	0	0	0
11	0	0	0
12	6	2	4
13	30	20	78
14	0	31	24
15	20	0	0
16	0	0	0
17	0	0	0
18	2	1	0
19	2	1	0
20	1	0	0
21	2	0	0
22	0	0	0
23	0	0	0
Total	**103**	**55**	**106**

Table C-14. Potential Tornado Missiles per Warehouse Building, Engineered and Pre-Engineered

Missile Type	Per 1,000 ft^2 floor area	Per 1,000 ft^2 wall area	Per 1,000 ft^2 roof area
1	18	0	0
2	1	0	0
3	1	0	0
4	0	0	0
5	5	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	6	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	16	0	0
14	0	25	25
15	12	0	0
16	0	5	4
17	5	16	8
18	2	1	0
19	2	1	0
20	1	0	0
21	2	0	0
22	0	0	0
23	0	0	0
Total	**71**	**48**	**37**

Figure C-18. Missile release fractions for wooden buildings

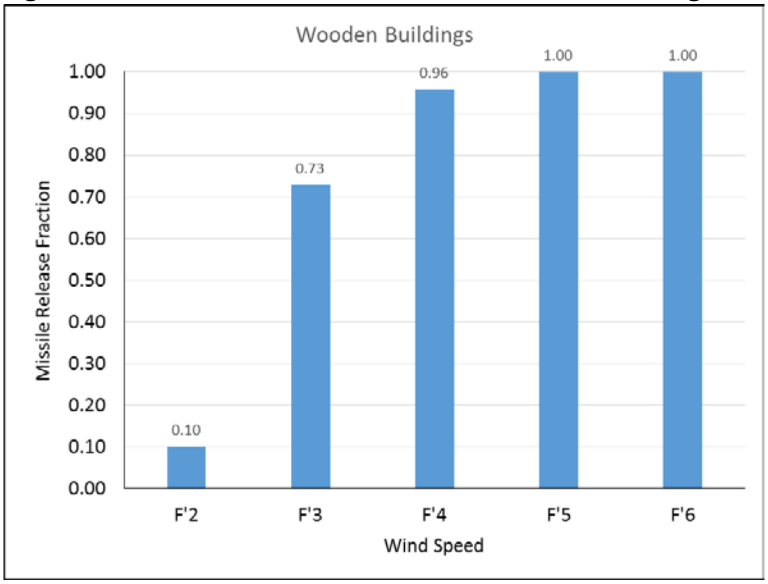


Figure C-19. Missile release fractions for trailers and manufactured buildings

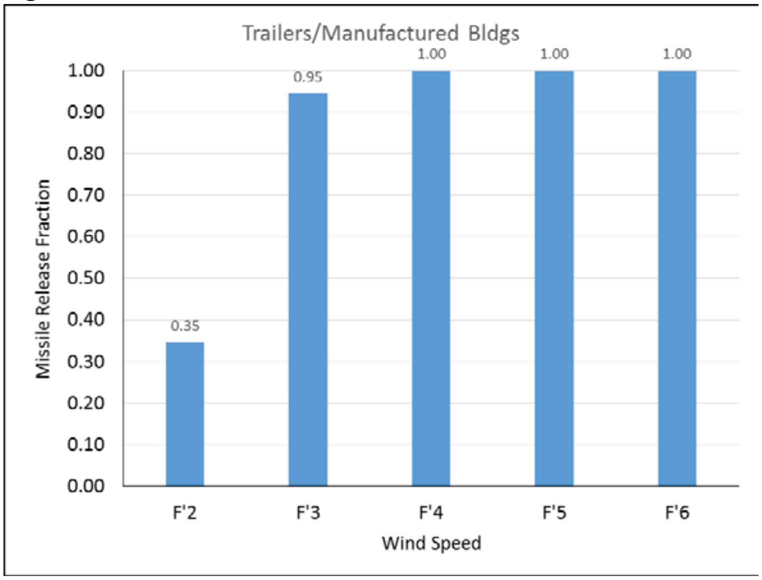
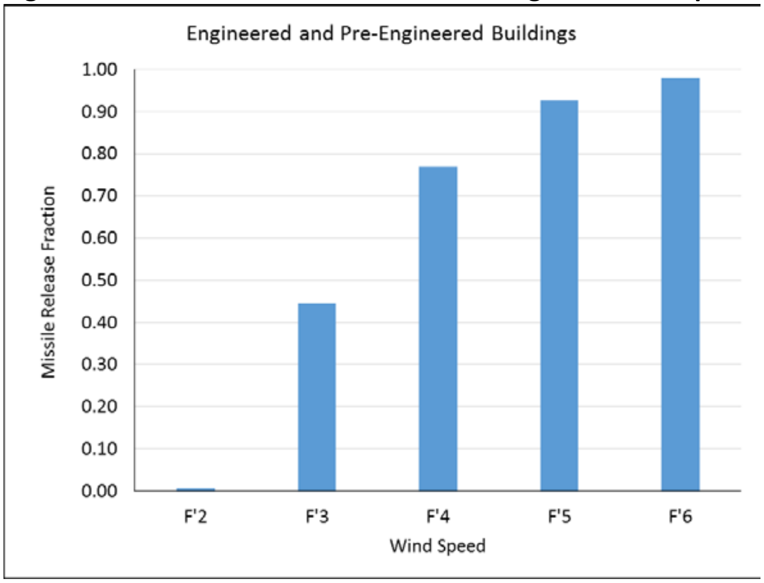


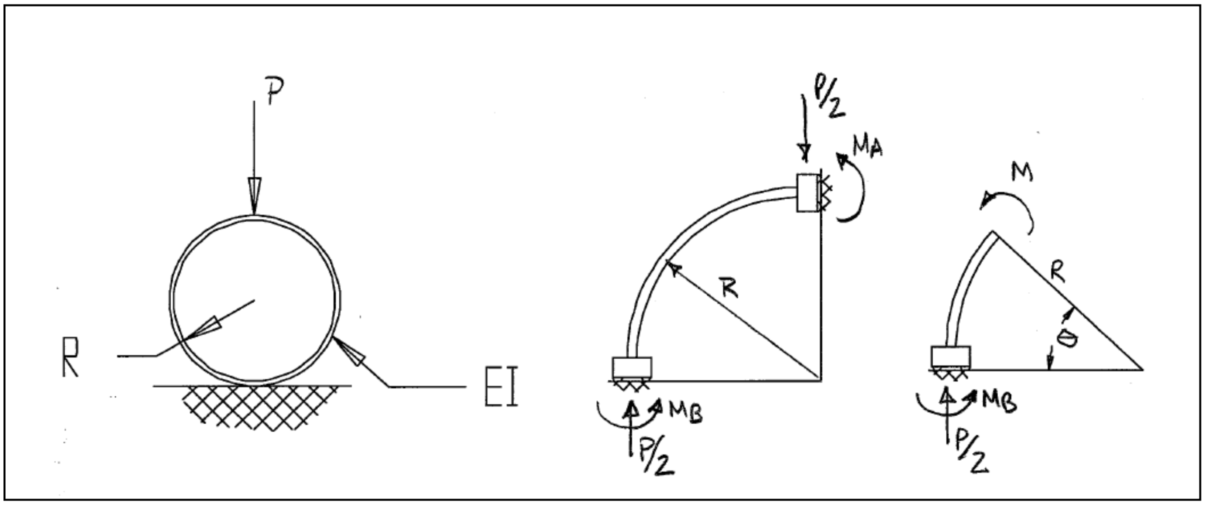
Figure C-20. Missile release fractions for engineered and pre-engineered buildings



C.5 DERIVATION OF PIPE RADIAL STIFFNESS AND ULTIMATE CAPACITY

An analytical model was developed to approximate the radial stiffness and capacity of a typical pipe segment (Figure C-21).

Figure C-21. Assumed pipe boundary condition and free-body diagram to obtain internal member actions



First step is to solve for radial displacement due to concentrated force, P

$$\frac{\partial U}{\partial P} = 2\int_0^{\pi/2} \frac{M}{EI}\frac{\partial M}{\partial P}\ R\,d\theta$$

Figure 15 (c) depicts the internal resisting moment in the pipe section. Solving for M:

$$M = \frac{PR}{2}(1-\cos\theta) - M_B$$

$$\frac{\partial M}{\partial P} = \frac{R}{2}\ (1-\cos\theta)$$

$$\frac{\partial U}{\partial P} = \frac{2}{EI}\int_0^{\pi/2}\left[\frac{PR}{2}(1-\cos\theta) - M_B\right]\left[\frac{R}{2}\ (1-\cos\theta)\right]\ R\,d\theta$$

$$\frac{\partial U}{\partial P} = \frac{2}{EI}\left[\frac{PR^3\theta}{4} - \frac{PR^3\sin\theta}{2} + \frac{PR^3}{4}\left(\frac{\theta}{2}+\frac{\sin 2\theta}{4}\right) - \frac{M_B R^2\theta}{2} + \frac{M_B R^2\sin\theta}{2}\ M_B\right] \Bigg| \begin{cases}\pi/2\\ 0\end{cases}$$

Evaluating integral at 0 and π/2, the radial displacement is:

$$\frac{\partial U}{\partial P} = \frac{2}{EI}\ [0.088PR^3\ - 0.285\ M_B R^2]$$

Solve for unknown reaction moment, M_B:

$$\frac{\partial M}{\partial M_B} = 0 = \int_0^{\pi/2}\frac{M}{EI}\frac{\partial M}{\partial M_B}\ R\,d\theta$$

$$M = \frac{PR}{2}(1-\cos\theta) - M_B$$

$$\frac{\partial M}{\partial M_B} = -1$$

$$\frac{\partial U}{\partial P} = 0 = \int_0^{\pi/2}\left[\frac{PR}{2}(1-\cos\theta) - M_B\right][-1]\ \ R\,d\theta$$

$$\frac{\partial U}{\partial P} = 0 = \left[\frac{-PR^2\theta}{2} - \frac{PR^2\sin\theta}{2} + M_B R\theta\right] \Bigg| \begin{cases}\pi/2\\ 0\end{cases}$$

Evaluating integral at 0 and π/2, the resisting moment, M_B, can be solved for:

$$0 = -0.285PR^2 + 1.57M_B R$$

$$M_B = 0.181PR$$

Substitute M_B into previous displacement equation:

$$\frac{\partial U}{\partial P} = \frac{2}{EI}\ [0.088PR^3\ - 0.285(0.181PR)\ R^2]$$

$$\frac{\partial U}{\partial P} = \frac{0.072PR^3}{EI}$$

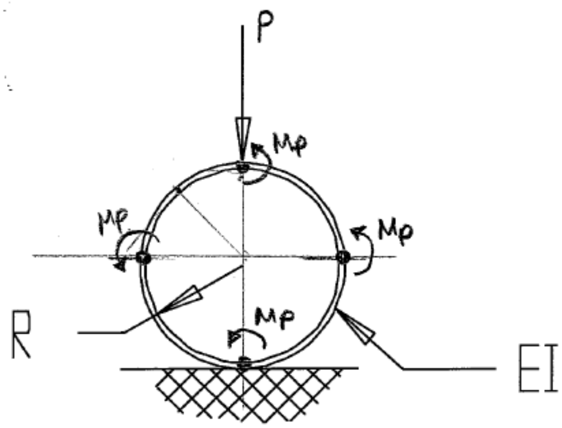
Substituting: $2R = D; I = \frac{1}{12}\ b\ t^3$

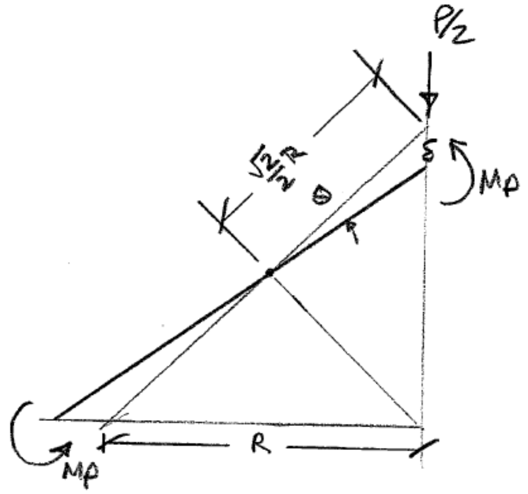
The radial stiffness, K_r, can be solved for:

$$K_r = \frac{9.28\ E\ b\ t^3}{D^3}$$

The principle of virtual work is used to estimate the plastic moment capacity of pipe section:

Figure C-22. Assumed locations of plastic moments and moment-virtual displacement relationship.





From virtual work, Figure 22(b):

$$\frac{P}{2}\,\delta = 4M_p\,\theta$$

$$\delta = \frac{\sqrt{2}}{2} R \text{ x } \sqrt{2}\,\theta$$

$$\delta = R\theta$$

$$PR\theta = 8M_p\theta$$

The critical concentrated pipe load is therefore:

$$P = \frac{16M_p}{D}$$

The plastic moment of the pipe segment is estimated to be:

$$M_p = \frac{bt^2}{4}\,F_y$$

The critical concentrated pipe demand is alternatively expressed as:

$$P = \frac{4bt^2}{D}\,F_y$$

C.6 TARGET DAMAGE APPROXIMATIONS

Description	Rebar	Gas Cylinder	Tank Drum	Utility Pole	Cable Reel	3" pipe (schedule 40)
Diesel Generator Exhaust Pipe						
SG Power Operated Relief Valve Tailpipe						
Turbine Driven Feedwater pump exhaust piping						
Steam Generator Power Operated RV Exh Pipe						
Diesel Generator Air intake (small)						
Diesel Generator Air intake (large)						
Diesel Generator Exh Silencer						
Condensate Storage Tank (t=0.25")						
Diesel Fuel Oil Tank (t=0.133")						
Diesel Fuel Oil Tank (t=0.145")						
Condensate Storage Tank (t=0.375")						
Well water piping (t=0.237")						
Condensate Piping (t=0.237")						
Main Steam Piping (t=0.985")						
Diesel Fuel Oil Storage Tank (t=0.25")						
Room Door (t=0.1")						
Service Water Piping (t=0.375")						
Aux Feedwater Piping (t=0.432")						
Concrete Roofs						
8" reinforced						
4" reinforced with steel decking						

Legend

Less than or equal to 50% crushing	
Greater than 50% crushing	
100% crushing	
Failure by perforation or crushing more than 50%	
Failure of concrete panels or steel grating	

Description	6" pipe (schedule 40)	12" pipe (schedule 40)	Storage Bin	Concrete Paver	Concrete block	4x12 timber
Diesel Generator Exhaust Pipe	Green	Yellow	Green	Green	Green	Green
SG Power Operated Relief Valve Tailpipe	Green	Red	Yellow	Green	Green	Green
Turbine Driven Feedwater pump exhaust piping	Yellow	Red	Yellow	Green	Green	Green
Steam Generator Power Operated RV Exh Pipe	Yellow	Red	Yellow	Green	Green	Green
Diesel Generator Air intake (small)	Red	Red	Red	Yellow	Green	Red
Diesel Generator Air intake (large)	Green	Red	Red	Green	Green	Yellow
Diesel Generator Exh Silencer	Green	Red	Green	Green	Green	Green
Condensate Storage Tank (t=0.25")	Dark blue	Dark blue	Dark blue	Green	Green	Green
Diesel Fuel Oil Tank (t=0.133")	Dark blue	Dark blue	Dark blue	Green	Green	Dark blue
Diesel Fuel Oil Tank (t=0.145")	Dark blue	Dark blue	Dark blue	Green	Green	Dark blue
Condensate Storage Tank (t=0.375")	Dark blue	Dark blue	Green	Green	Green	Green
Well water piping (t=0.237")	Dark blue	Dark blue	Dark blue	Green	Green	Dark blue
Condensate Piping (t=0.237")	Dark blue	Dark blue	Dark blue	Green	Green	Dark blue
Main Steam Piping (t=0.985")	Green	Green	Green	Green	Green	Green
Diesel Fuel Oil Storage Tank (t=0.25")	Dark blue	Dark blue	Dark blue	Green	Green	Green
Room Door (t=0.1")	Dark blue	Dark blue	Dark blue	Green	Green	Green
Service Water Piping (t=0.375")	Dark blue	Dark blue	Green	Green	Green	Green
Aux Feedwater Piping (t=0.432")	Dark blue	Dark blue	Green	Green	Green	Green
Concrete roofs						
8" reinforced	Green	Green	Green	Green	Green	Green
4" reinforced with steel decking	Light blue	Light blue	Light blue	Green	Green	Green

Legend

Less than or equal to 50% crushing	Green
Greater than 50% crushing	Yellow
100% crushing	Red
Failure by perforation or crushing more than 50%	Dark blue
Failure of concrete panels or steel grating	Light blue

Description	2x12	Metal siding	7/8" plywood	Wide Flange (WF 14x26	Channel Section C6x13	Small equipment
Diesel Generator Exhaust Pipe						
SG Power Operated Relief Valve Tailpipe						
Turbine Driven Feedwater pump exhaust piping						
Steam Generator Power Operated RV Exh Pipe						
Diesel Generator Air intake (small)						
Diesel Generator Air intake (large)						
Diesel Generator Exh Silencer						
Condensate Storage Tank (t=0.25")						
Diesel Fuel Oil Tank (t=0.133")						
Diesel Fuel Oil Tank (t=0.145")						
Condensate Storage Tank (t=0.375")						
Well water piping (t=0.237")						
Condensate Piping (t=0.237")						
Main Steam Piping (t=0.985")						
Diesel Fuel Oil Storage Tank (t=0.25")						
Room Door (t=0.1")						
Service Water Piping (t=0.375")						
Aux Feedwater Piping (t=0.432")						
Concrete roofs						
8" reinforced						
4" reinforced with steel decking						

Legend

Less than or equal to 50% crushing	
Greater than 50% crushing	
100% crushing	
Failure by perforation or crushing more than 50%	
Failure of concrete panels or steel grating	

Description	Large equipment	Frame/steel grating	Large steel frame	Vehicle	Tree
Diesel Generator Exhaust Pipe	Green	Green	Green	Green	Green
SG Power Operated Relief Valve Tailpipe	Red	Green	Red	Red	Green
Turbine Driven Feedwater pump exhaust piping	Yellow	Green	Yellow	Red	Green
Steam Generator Power Operated RV Exh Pipe	Red	Green	Red	Red	Green
Diesel Generator Air intake (small)	Red	Green	Red	Red	Red
Diesel Generator Air intake (large)	Red	Green	Red	Red	Red
Diesel Generator Exh Silencer	Yellow	Green	Yellow	Yellow	Green
Condensate Storage Tank (t=0.25")	Blue	Green	Blue	Blue	Green
Diesel Fuel Oil Tank (t=0.133")	Blue	Green	Blue	Blue	Blue
Diesel Fuel Oil Tank (t=0.145")	Blue	Green	Blue	Blue	Blue
Condensate Storage Tank (t=0.375")	Blue	Green	Green	Blue	Green
Well water piping (t=0.237")	Blue	Green	Blue	Blue	Blue
Condensate Piping (t=0.237")	Blue	Green	Blue	Blue	Blue
Main Steam Piping (t=0.985")	Green	Green	Green	Green	Green
Diesel Fuel Oil Storage Tank (t=0.25")	Blue	Green	Blue	Blue	Green
Room Door (t=0.1")	Blue	Green	Blue	Blue	Blue
Service Water Piping (t=0.375")	Blue	Green	Green	Blue	Green
Aux Feedwater Piping (t=0.432")	Blue	Green	Blue	Blue	Green
Concrete Roofs					
8" reinforced	Green	Green	Green	Light blue	Green
4" reinforced with steel decking	Light blue	Green	Light blue	Light blue	Green

Legend

Less than or equal to 50% crushing	Green
Greater than 50% crushing	Yellow
100% crushing	Red
Failure by perforation or crushing more than 50%	Blue
Failure of concrete panels or steel grating	Light blue

C.7 CONCLUSIONS

The impact of a missile onto a target is a complex dynamic problem. The phenomena typically involve nonlinear material behavior and high strain rates for both the missile and target. The problem of wind-driven missiles is further complicated, because these missiles are not engineered penetrators that are designed to penetrate a hardened target (i.e., remain rigid). In many cases, detailed finite element analysis are required to evaluate both missile and target response. However, such analyses are resource intensive and due to lack of experimental validation, these more detailed analysis may not significantly reduce uncertainty in results.

As the number of EPRI missile and target combinations to be analyzed was more than 400 (~23 missiles x 19 targets), a pragmatic approach was developed to evaluate target robustness. The approach relies on an analytical approach that is consistent with the NRC SRP Section 3.5.3 [1]. The approach makes accounts for missile characteristics such as impact speed, missile mass, and target characteristics such as stiffness, ultimate capacity, and mass. The analysis of pipe crimping was benchmarked to two relevant experiments.

While median material properties were assumed to develop a best-estimate of target response, the following conservative assumptions were made:

- The assumed maximum missile impact speed, of 230 mph, exceeds current SRP missile speeds. The highest horizontal missile impact speed cited in the most current NRC guidance is 92 mph (RG 1.76) for tornado winds and 209 mph (RG 1.221) for hurricane winds.

- For piping scenarios, it was assumed that missile impacts are normal to the target surface and that the axis of the missile is parallel to the line of flight. For impacts on pipes, the effectiveness of the missile impact degrades significantly as the strike location is offset from the centerline of the pipe.

- For impacts on liquid-filled steel tanks, the tank stiffness did not credit the added contribution of the tank end-closure and foundation restraint. The stiffening effect of the entrained liquid was also not credited.

- For impacts on thinner concrete roofs (4-inches), the effect of the steel decking was not credited. Steel decking tends to limit concrete spalling, increase confinement, thereby improving resistance to impact scenarios. Impact was also assumed to be normal to the roof surface, rather than the more realistic case of having an angle of incidence.

C.8 References

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APPENDIX D: TECHNICAL BASIS FOR TMRE METHODOLOGY

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
IE-A	*The initiating event analysis shall provide a reasonably complete identification of initiating events.*		
IE-A1	*Tornado initiating events will be consistent with the intervals defined in the TMRE process. TMRE considers all tornadoes will result in a LOOP. Tornado initiating event frequencies will be based on a hazard curve that uses site specific data provided in Table 6.1 of NUREG 4461 [IE-C1].*	TMRE process should ensure that the initiating events caused by extreme winds that give rise to significant accident sequences and accurately capture the additional risk of the unprotected SSCs (that should be protected per the CLB) are identified and used for this application.	4.3, 6.2
IE-A10	*For multi-unit sites with shared systems, INCLUDE multi-unit site initiators (e.g., multi-unit LOOP events or total loss of service water) that may impact the model.*		6.2
IE-B	*The initiating event analysis shall group the initiating events so that events in the same group have similar mitigation requirements (i.e., the requirements for most events in the group are less restrictive than the limiting mitigation requirements for the group) to facilitate an efficient but realistic estimation of CDF*		

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
IE-B5	*DO NOT SUBSUME multi-unit initiating events if they impact mitigation capability. Two unit sites should consider proximity of each unit to each other, the footprint of potential tornadoes for the region, and the systems shared between each unit.*		6.2
IE-C	*The initiating event analysis shall estimate the annual frequency of each initiating event or initiating event group.*	The tornado IEFs should be based on a hazard curve that uses site-specific data, such as found in NUREG-4461.	
IE-C1	*Tornado initiating event frequencies will be based on a hazard curve that uses site specific data provided in Table 6.1 of NUREG 4461*		4.1
IE-C3	*Do not credit recovery of offsite power.*	Same comment as AS-A10	6.1, Appendix A
IE-C15	*CHARACTERIZE the uncertainty in the tornado initiating event frequencies and PROVIDE mean values for use in the quantification of the PRA results. NUREG 4461, data includes uncertainty.*		4.3
AS-A	*Utilize the accident sequences (typically LOOP) provided in the internal events model and adjust as necessary to consider the consequences of a tornado event.*		
AS-A1	*Modify the internal events accident sequences in compliance with this SR*		6.1, 6.3, 6.4, 6.5

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
AS-A3	*Review the FPIE success criteria and modify the associated system models as necessary to account for the tornado event and its consequences.*		6.1, 6.3, 6.4, 6.5
AS-A4	*Review the FPIE success criteria and modify the associated operator actions as necessary to account for the tornado event and its consequences.*		6.4
AS-A5	*Modify the FPIE accident sequence model in a manner that is consistent with the plant-specific: system design, EOPs, abnormal procedures, and plant transient response. Account for system functions that, as a consequence of the tornado event, will not be operable or potentially degraded, and operator actions that will not be possible or impeded.*		6.1, 6.3, 6.4, 6.5

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
AS-A10	*Capability Category I. In modifying the accident sequence models, INCLUDE, for each tornado initiating event, INDIVIDUAL EVENTS IN THE ACCIDENT SEQUENCE SUFFICIENT TO BOUND SYSTEM OPERATION, TIMING, AND OPERATOR ACTIONS NECESSARY FOR KEY SAFETY FUNCTIONS.*	In constructing the accident sequence models, support system modeling, etc. realistic criteria or assumptions should be used, unless a conservative approach can be justified. Use of conservative assumptions in the base model can distort the results and may not be conservative for delta CDF/LERF calculation. While use of conservative or bounding assumptions in PRA models is acceptable, a qualitative or quantitative assessment may be needed to show that those assumptions do not underestimate delta CDF/LERF estimates.	6.3, 7.2.3, Appendix A
AS-B	*Dependencies that can impact the ability of the mitigating systems to operate and function shall be addressed.*		
AS-B1	*For each tornado event, IDENTIFY mitigating systems impacted by the occurrence of the initiator and the extent of the impact. INCLUDE the impact of initiating events on mitigating systems in the accident progression either in the accident sequence models or in the system models.*		6.1, 6.3, 6.5, 6.6

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
AS-B3	*IDENTIFY the phenomenological conditions created by the accident progression. Also high winds and rains after the tornado event could result in hazardous conditions (e.g. debris and structural instabilities) for actions outside the control room.*		5.6, 6.3, 6.4, 6.6
AS-B7	*Review FPIE time phased dependencies to identify model changes needed to address all the concurrent system functions failed by the tornado event; e.g. LOOP, instrument air, fire protection……etc. Do not model offsite recovery.*		6.1
SC-A	*The overall success criteria for the PRA and the system, structure, component, and human action success criteria used in the PRA shall be defined and referenced, and shall be consistent with the features, procedures, and operating philosophy of the plant.*		
SC-A4	*Consider impact on both units for the same tornado including the mitigating systems that are shared.*		6.1

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
SY-A	*The systems analysis shall provide a reasonably complete treatment of the causes of system failure and unavailability modes represented in the initiating events analysis and sequence definition*		
SY-A4	*Capability Category II. Walkdowns focusing on targets vulnerable to tornado missiles will be performed. Walkdown will include a missile inventory and a review of pathways available to the operators for ex-control room actions.*		*Section 3*
SY-A11	*New basic events will be added to address all the failure modes of the system targets exposed to tornado missiles; safety-related and non-safety related.* *The exclusions of SY-A15 do not apply for SSCs impacted by tornado missiles.*		6.3, 6.5, 6.6

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
SY-A12	*DO NOT INCLUDE in a system model component failures that would be beneficial to system operation, unless omission would distort the results. For example, do not assume a vent pipe will be sheered by a high energy missile verses crimped unless it can be shown this is true for all missiles at all speeds. Exceptions would be components that are intentionally designed to "fail" favorably when struck by a missile; e.g. a frangible plastic pipe used as a vent is designed to break off and not crimp when struck by a missile.*		*5.2*
SY-A13	*Consider the target's potential to cause a flow diversion when struck by a tornado missile.*		*6.5*
SY-A14	*Missile targets will be assessed for all failure modes - some new failure modes may be identified that are not in the FPIE model.* *The exclusions of SY-A15 do not apply for SSCs impacted by tornado missiles.*		*6.5*

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
SY-A15	*The failure of SSCs due to tornado missiles shall not use the exclusions of SY-A15.*	The failure by tornado missiles should be included in the model for all unprotected targets that are supposed to be protected according to the CLB and any unprotected targets that are not in the CLB but are in the PRA model. This is to facilitate sensitivity studies regarding possible correlation of tornado missile damage across systems. It is not expected that the number of basic events added to the model for this analysis will be so large that this screening is necessary.	6.5
SY-A17	*Certain post initiator HFEs will be modified to account for the tornado event.*		6.4
SY-B	*The thermal/hydraulic, structural, and other supporting engineering bases shall be capable of providing success criteria and event timing sufficient for quantification of CDF and LERF, determination of the relative impact of success criteria on SSC and human actions, and the impact of uncertainty on this determination.*		

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
SY-B7	*Capability Category I. BASE support system modeling on the use of CONSERVATIVE SUCCESS CRITERIA AND TIMING. Sensitivity studies will be performed to identify where conservative assumptions may be distorting risk and adjusted accordingly.*	Same comment as AS-A10	7.2.3
SY-B8	*Consider spatial relationships between components to identify correlated failures. Where the same missile can impact targets that are in close proximity to each other.*		5.6
SY-B14	*Statistical correlation of tornado missile damage between redundant and spatially separated components is NOT required.*	The industry indicated in earlier discussions that information is available to show that statistical correlation of tornado missile damage for specially separated components is insignificant. Until that information is reviewed and accepted by the staff, this SR should be met (spans all capability categories) and dependent failures of multiple SSCs should be considered.	Appendix B.4.4
SY-B15	*INCLUDE new operator interface dependencies across systems or trains related to the tornado event, if applicable.*		*6.4*

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
HR-E	*A systematic review of the relevant procedures shall be used to identify the set of operator responses required for each of the tornado accident sequences*		
HR-E3	*Operators will be interviewed (if necessary) to assess the need for changes to operator actions for the tornado initiating events.*		*6.4*
HR-E4	*Operators talk-throughs or simulator observations will be conducted (if necessary) to assess the need for changes to operator actions for the tornado initiating events.* *[Note: this applies to new sequences or failure combinations not accounted for in the internal events model. It is not intended that operator action timing needs be changed due to the tornado event alone]*		*6.4*
HR-G	*The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence.*		

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
HR-G5	*Operators will be interviewed and simulator observations conducted (if necessary) to assess the need for changes to operator action timing as a result of the tornado event.* *[Note: this applies to new sequences or failure combinations not accounted for in the internal events model. It is not intended that operator action timing needs be changed due to the tornado event alone]*		*6.4*
HR-G7	*For new operator action dependencies identified as part of QU-C1, ASSESS the degree of dependence, and calculate a joint human error probability that reflects the dependence.*		*6.4*
HR-H	*Recovery actions (at the cut set or scenario level) shall be modeled only if it has been demonstrated that the action is plausible and feasible for those scenarios to which they are applied. Estimates of probabilities of failure shall address dependency on prior human failures in the scenario.*		
HR-H1/H2	*Do not credit recovery actions to restore functions, systems, or components unless an explicit basis accounting for tornado impacts on the site and the SSCs of concern is provided.*		*6.4*

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
DA-A	*Each parameter shall be clearly defined in terms of the logic model, basic event boundary, and the model used to evaluate event probability.*		
DA-A1	*Develop new basic events for tornado missile targets (all failure modes) in accordance with this SR.*		6.3, 6.5, 6.6
QU-A	*The level 1 quantification shall quantify core damage frequency and shall support the quantification of LERF.*		
QU-A5	*Do not credit recovery actions to restore functions, systems, or components unless an explicit basis accounting for tornado impacts on the site and the SSCs of concern is provided.*		6.4
QU-C	*Model quantification shall determine that all identified dependencies are addressed appropriately.*		
QU-C1	*Identify new operator action dependencies created as a result of the changes to the internal events PRA model or failures associated with tornado events.*		6.4

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
QU-D	*The quantification results shall be reviewed, and significant contributors to CDF (and LERF), such as initiating events, accident sequences, and basic events (equipment unavailabilities and human failure events), shall be identified. The results shall be traceable to the inputs and assumptions made in the PRA.*		
QU-D5	*Review nonsignificant cut set or sequences to determine the sequences are valid*		*7.3*
QU-D7	*Review BE importance to make sure they make logical sense.*		*7.3*
QU-E	*Uncertainties in the PRA results shall be characterized. Sources of model uncertainty and related assumptions shall be identified, and their potential impact on the results understood.*		
QU-E1	*Identify sources of uncertainty related to MIP and missiles*		7.1 *Also see Appendices A and B for bases.*
QU-E2	*Identify assumptions made that are different than those in the internal events model*		Section 6
QU-E4	*Identify how the model uncertainty is affected by assumptions related to MIP and missiles*		7.1, Appendix A

TMRE - ASME PRA Standard Supporting Requirements Requiring Self-Assessment		NRC Comments (No comments if blank)	NEI 17-02 Section Addressing SR
LE-C	*The accident progression analysis shall include identification of those sequences that would result in a large early release.*		7.1, 7.3
LE-C3	*Do not credit recovery of offsite power. Do not credit recovery actions to restore functions, systems, or components unless an explicit basis accounting for tornado impacts on the site and the SSCs of concern is provided.*	Same comment as AS-A10	6.3, 7.2.3, Appendix A
Multiple SRs		Changes made for application of the PRA to tornado missile impact risk determination such as those to initiating event analysis, accident sequences, systems analysis, human reliability analysis, and parameter estimation should be documented, as described in various documentation SRs for each HLR. The documentation should be sufficient to understand basis and facilitate review. Examples of such SRs include IE-D1 through IE-D3, SY-C1 through SY-C3, and DA-E1 through DA-E3. It is recognized that the documentation of changes to the PRA and their basis will be captured in the change to the plant's licensing basis.	Section 8

APPENDIX E: TMRE METHODOLOGY SENSITVITY STUDIES

E.1 OBJECTIVES

The objective of this Appendix is to examine the sensitivity of MIP values to target size, target elevation, and the distribution of missiles inventory around the plant. The results are used to support the derivation of MIP values.

E.2 METHODOLOGY OVERVIEW

The sensitivity studies are performed using TORMIS code for two operating power plants.. Missile hit probabilities for selected targets are post processed and compared for the sake of understanding the effects of target sizes, target elevations and missile inventory distribution on the MIP.

The following points provide a high level overview of the methodology used:

1. Two existing nuclear power plants models (Plant A and Plant B) are selected for this study. Plants models were developed previously and permission has been obtained from plant owners for their use. Plant A is located in NRC region 1 and EPRI region A. Plant B is located in NRC region 1and border of EPRI regions A and B.

2. All sensitivity studies used the Enhanced Fujita Scale EF1 through EF5. This is consistent with RG. 1.76 revision 1 and is in alignment of industry practices in recent TORMIS analyses submitted to the NRC. For each EF scale two thousands randomly generated tornados are simulated. For each tornado, two thousands five hundred missiles are sampled. It is acknowledged that in recent years the number of simulations are in the order of ten millions. However, for this study, the number of simulation for each EF scale is judged to be adequate as relative values are of interest not the actual hit probabilities. .

3. Statistical convergence is attained by performing multiple analysis sets for each EF scale. That is, seven sets of analyses for the study of zonal vs uniform distribution of missiles, four sets of analyses for the studies of target elevation and target sizes. Consequently, the total number of simulations for the zonal vs uniform study is seven hundred millions for plants A and B combined and is two hundred millions each for the studies of target elevation and target sizes. Total number of simulation is calculated as follows (5,000,000 * 5(EFs) * 7(sets) * 2(uniform and zonal) * 2 (plants A and B) = 700,000,000.

4. Though a significant portion of Plants A and B missiles are restrained missiles, for simplification, this study assumes all missiles are free.

   The Missile types have been given a missile type that is consistent with TORMIS list of missiles. TORMIS missile sets (i.e. missile types defined in TORMIS code) are shown in Table 2-2 of Ref. (Np 768)

5. The results are based on TORMIS reported P (A) (i.e. single missile hit probability) for summation of events 2 and 7. Event 7 is "Auto" hit probability and Event 2 is hit probability for all other missiles.

E.3 Description of Plant Models

Plant A

Figure E-1 shows a 3D view of the TORMIS model for Plant A showing modeled power block structures. The Model includes 22 missile zones and encompass an area of 5000'X 5000'. Missile population from missile survey is in excess of 100,000 missiles. Missile population includes missiles that are located on top of the buildings in access of 4,340 missiles. The zonal area of Plant A is 19,771,450 ft^2.

Figure E-2 shows a plan view of missile zones along with number of missiles in each missile zone and missile building tops. The distribution of missiles in each zone is the actual distribution based on an actual plant walkdown.

Table E-1 lists missile description of plant A and the corresponding TORMIS missile types as designated by the walkdown personnel. Table E-2 list in a tabulated format the missile distribution shown in Figure E-2.

Figure E-1. 3D View of Plant A

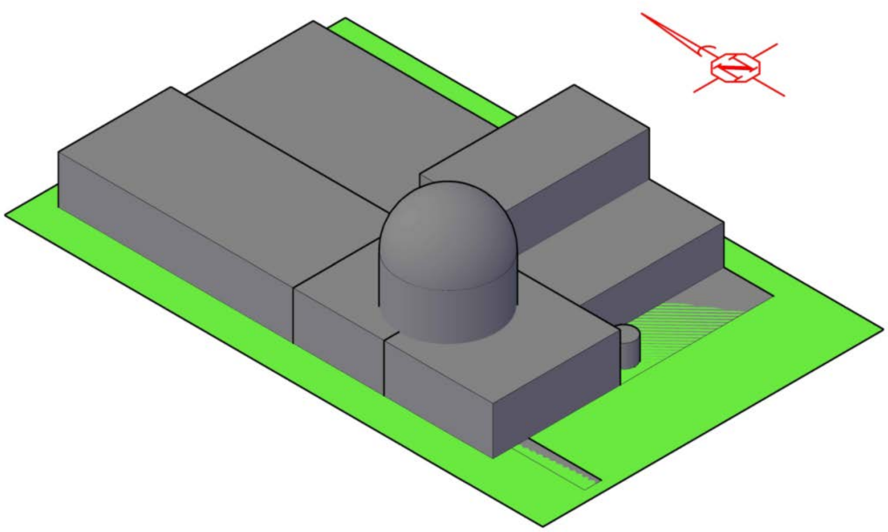
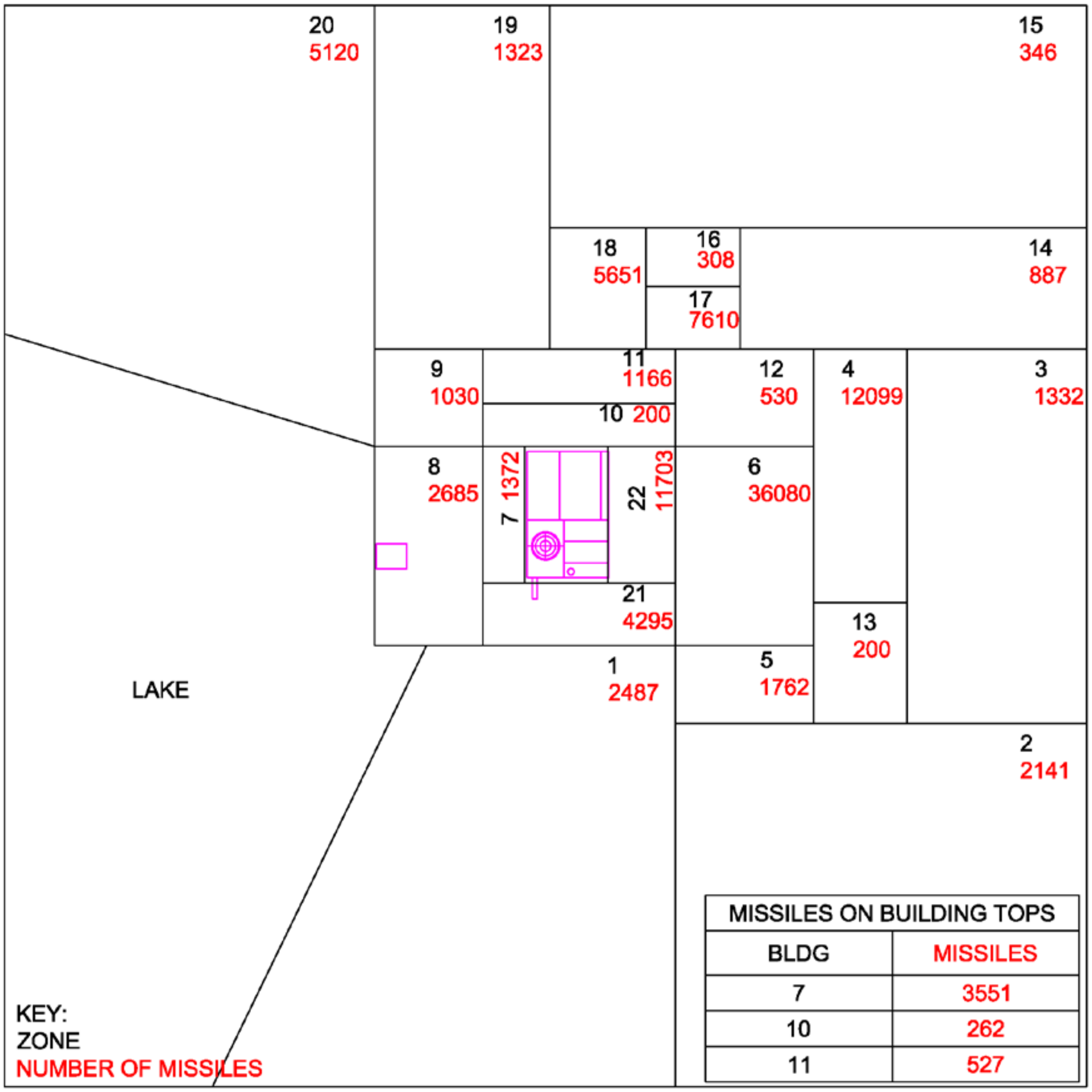


Figure E-2. Plant A missile zones and number of missiles in each zone



MISSILES ON BUILDING TOPS	
BLDG	MISSILES
7	3551
10	262
11	527

Table E-1. Missile description for Plant A

Type No.	Missile Description	TORMIS Missile Set No.
1	1"Φ steel rod L = 2' - 4'	1
2	1"Φ steel rod, L = 10' - 20'	1
3	8"Φ gas bottle, L = 5'	1
4	24"Φ drums, L = 3'	1
5	8"Φ wood post, L = 10' - 15'	2
6	14"Φ wood post, L = 30' - 40'	2
7	1"Φ steel pipe, L =10' - 20'	3
8	3"Φ steel pipe, L = 8' - 12'	3
9	6"Φ steel pipe, L = 10' - 20'	3
10	12"Φ steel pipe, L = 10' - 20'	3
11	4"x4" wood post, L = 8' - 12'	6
12	6"x1" wood plank, L = 4' - 8'	9
13	12"x4" wood plank, L = 8' - 16'	9
14	4'x1" steel plate, L = 4' - 8'	10
15	4'x1" wood plate, L = 4' - 8'	11
16	4' x 20 ga steel plate, L = 10' - 20'	12
17	W8x10 steel wide flange, L = 10' - 20'	14
18	2x2x1/4 steel angle, L = 10' - 20'	15
19	C8x11.5 steel channel, L = 15' - 25'	16
20	Automobile	25
21	Trees, d = 8", L = 10' - 40'	26

Table E-2. Missile Distribution for Plant A

		Missile Type Number																				
Zone Number	**Number of Missiles**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
1	2487	0	8	0	0		3	6	681	0	0	0	0	0	0	0	678	0	0	11	0	1100
2	2141	0	16	0	4	32	30	33	658	0	0	0	0	0	0	0	707	0	0	61	0	600
3	1332	0	16	0	25	1		28	506	0	0	0	0	0	0	0	554	0	0	52	0	150
4	12099	3840	64	0	0		3	324	2153	11	0	50	180	50	100	2170	2363	0	10	661	120	0
5	1762	0	32	0	0	3	0	46	531	43	0	0	320	20	1	0	613	0	0	103	0	50
6	36080	7139	366	424	310	17	0	1860	4635	168	78	85	1640	2780	329	3671	9094	19	180	3170	65	50
7	1372	150	32	0	0	0	0	32	224	4	0	0	0	0	0	150	323	0	400	57	0	0
8	2685	0	64	0	0	5	0	102	977	2	0	0	0	0	0	0	1201	0	0	234	0	100
9	1030	0	0	0	0	10	0	0	260		0	0	0	0	0	0	260	0	0	0	500	0
10	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200
11	1166	0	0	0	0	0	0	0	510	4	0	0	0	0	0	0	552	0	0	0	0	100
12	530	0	0	0	0	0	0	0	200		0	0	0	0	0	0	200	0	0	0	30	100
13	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200
14	887	18	0	0	0	0	2	0	321	1	0	0	0	0	0	7	330	0	100	8	0	100
15	346	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	25	0	0	300
16	308	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	200	100
17	7610	1600	16	0	10	0	0	240	1021	2	0	0	0	0	0	1600	2626	0	0	470	25	0
18	5651	0	0	0	0	6	0		520	325	0	0	0	0	0	0	500	200	4000	0	0	100
19	1323	44	32	0	0	4	0	16	204	2	0	0	0	0	0	45	247	0	600	29	0	100
20	5120	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	5100
21	4295	738	48	0	0	0	0	70	378	10	0	0	0	1450		693	776	0	0	132	0	0
22	11703	20	2048	20	20	20	20	2207	407	200	200	2000	200	200	20	200	2855	200	200	646	20	0

Plant B

Figure E-3 shows a 3D view of the TORMIS model for Plant B showing modeled power block structures. The Model includes 18 missile zones and encompasses an area of 5000'X5000'. Missile population from missile survey is 141,944 missiles. Missile population includes missiles that are located on top of the buildings in access of 11,766 missiles. The zonal area of Plant B is 19,771,450 ft^2.

Figure E-4 shows a plan view of missile zones along with number of missiles in each missile zone and missile building tops. The distribution of missiles in each zone is the actual distribution based on an actual plant walkdown.

Table E-3 lists missile description of plant B and the corresponding TORMIS missile type as designated by the walkdown personnel. Table E-3 lists in a tabulated format the missile distribution shown in Figure E-4.

Figure E-3. 3D View of Plant B

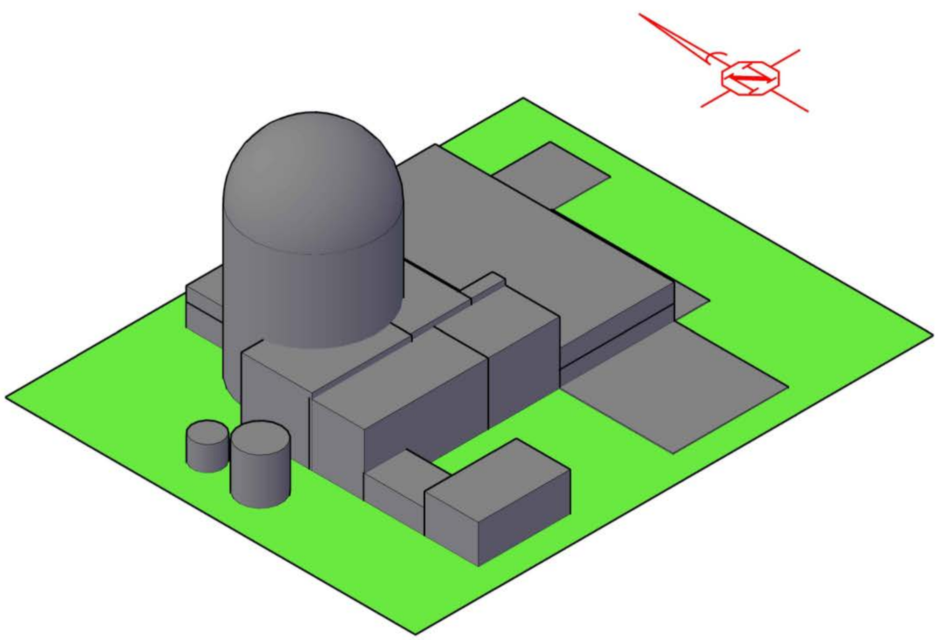
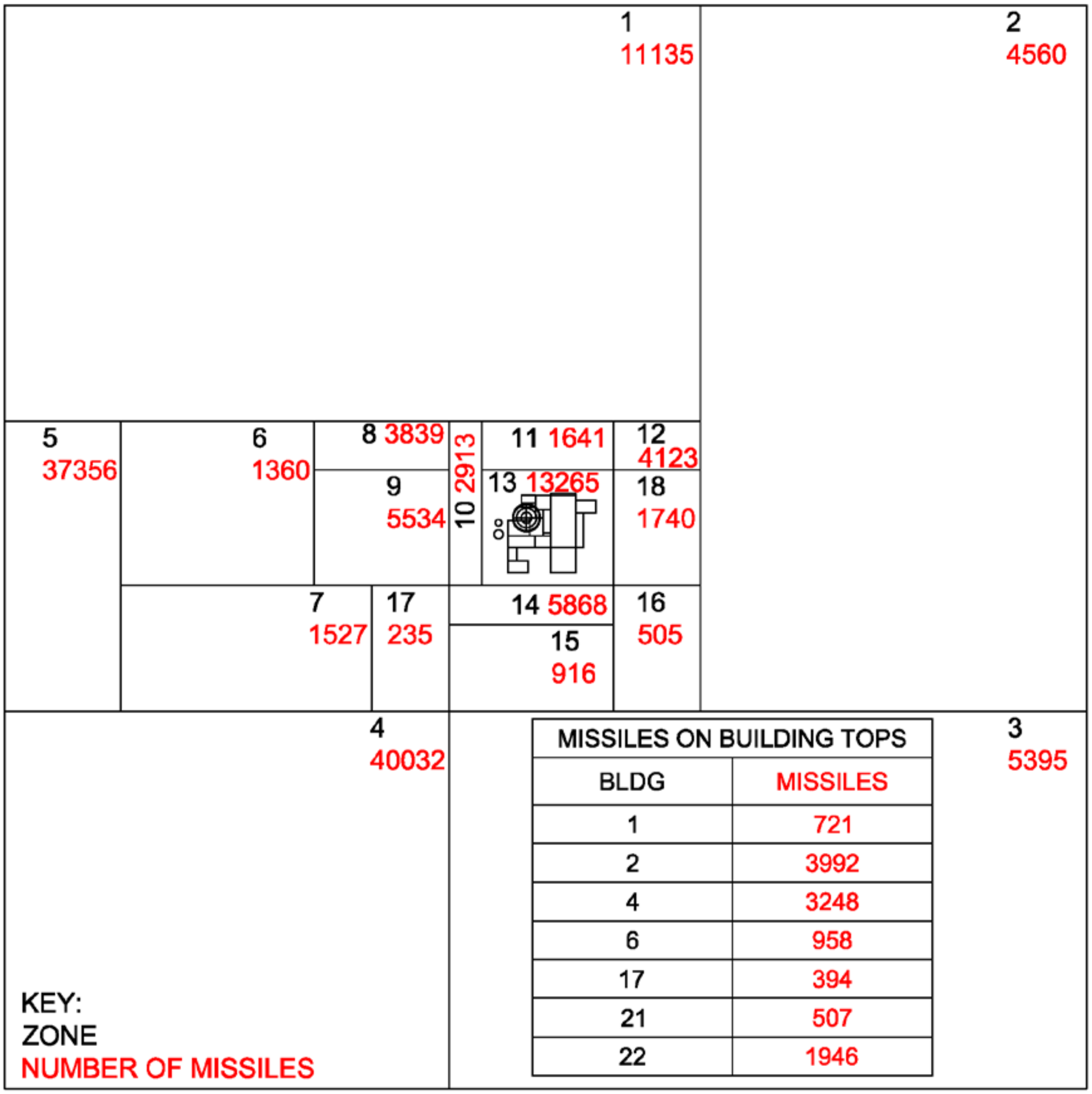


Figure E-4. Plant B missile zones and number of missiles in each zone



MISSILES ON BUILDING TOPS	
BLDG	MISSILES
1	721
2	3992
4	3248
6	958
17	394
21	507
22	1946

Table E-3. Missile description for Plant B

Type No.	Missile Description	TORMIS Missile Set No.
1	1"Φ steel rod L = 2' - 4'	1
2	1"Φ steel rod, L = 10' - 20'	1
3	8"Φ gas bottle, L = 5'	1
4	24"Φ drums, L = 3'	1
5	8"Φ wood post, L = 10' - 15'	2
6	14"Φ wood post, L = 30' - 40'	2
7	1"Φ steel pipe, L =10' - 20'	3
8	3"Φ steel pipe, L = 8' - 12'	3
9	6"Φ steel pipe, L = 10' - 20'	3
10	12"Φ steel pipe, L = 10' - 20'	3
11	4"x4" wood post, L = 8' - 12'	6
12	6"x1" wood plank, L = 4' - 8'	9
13	12"x4" wood plank, L = 8' - 16'	9
14	4'x1" steel plate, L = 4' - 8'	10
15	4'x1" wood plate, L = 4' - 8'	11
16	4' x 20 ga steel plate, L = 10' - 20'	12
17	W8x10 steel wide flange, L = 10' - 20'	14
18	2x2x1/4 steel angle, L = 10' - 20'	15
19	C8x11.5 steel channel, L = 15' - 25'	16
20	Gratting and ladders, L=15' - 25' 2"X1" thick	22
21	3"Φ PVC pipe, L = 8' - 12'	3
22	12"Φ 5 gallon plastic container, L = 18", W=32 lbs	2
23	1'-6" x 2" Concrete panels, L=2' - 3'	8
24	Automobile	25
25	Trees, d = 8", L = 10' - 40'	26

Table E-4. Missile distribution for Plant B

		Missile Type Number																								
Zone Number	**Number of Missiles**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1	11135	400	0	0	0	5	0	0	1266	20	0	0	0	0	0	0	824	273	378	0	129	0	0	0	0	7840
2	4560	0	0	0	0	10	0	0	400	0	0	0	0	0	0	0	400	0	0	0	0	0	0	0	0	3750
3	5395	0	32	0	0	3	0	184	283	160	0	0	750	70	0	120	302	100	0	72	101	0	0	0	0	3218
4	40032	6662	768	216	322	5	75	1170	3009	340	25	885	13160	55	110	2809	6206	67	1687	1331	105	25	600	100	250	50
5	37356	10984	48	0	0	20	50	464	3792	20	0	0	0	0	0	10984	8865	0	600	964	0	0	0	0	525	40
6	1360	50	0	0	0	10	0	0	150	100	50	0	0	0	0	0	0	0	900	0	0	0	0	0	0	100
7	1527	146	0	0	0	15	35	0	109	0	0	40	0	0	0	56	259	12	335	20	0	0	0	0	500	0
8	3839	0	16	15	82	0	21	566	720	0	0	200	575	50	100	100	304	0	0	590	0	110	0	240	150	0
9	5534	0	10	0	0	0	30	5	626	100	0	12	10	0	0	0	476	0	600	50	0	0	0	3600	15	0
10	2913	234	47	0	0	0	0	136	345	10	0	150	400	0	0	282	1040	10	0	259	0	0	0	0	0	0
11	1641	288	0	30	0	2	10	0	437	4	0	0	0	0	0	188	512	25	45	50	0	0	0	0	50	0
12	4123	606	73	30	11	0	4	592	439	0	0	0	30	5	0	296	1031	3	360	243	0	80	0	300	20	0
13	13265	3314	48	50	18	2	0	542	1232	450	0	55	2775	60	67	1634	1320	15	748	860	0	0	50	0	25	0
14	5868	276	74	100	15	0	1	189	740	91	40	0	2015	155	12	501	1191	25	140	251	2	0	50	0	0	0
15	916	110	62	8	0	0	0	67	65	2	0	20	105	0	40	20	185	4	3	59	0	6	0	0	160	0
16	505	0	0	0	0	5	0	0	190	0	0	0	0	0	0	0	190	0	0	0	0	0	0	0	0	120
17	235	0	0	0	0	5	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	220
18	1740	0	80	0	0	0	0	80	236	4	0	0	0	0	0	0	1007	0	0	233	0	0	0	0	0	100

Details of the Sensitivity Studies

Target Elevation Study

The objective of this study is to examine the impact of target elevation on targets hit probabilities. In this study both plants A and B models are used. The targets are created on an open wall with varied elevations without changing targets size.

For plant A four targets are considered on north, south, east and west walls of the plant, see Figure E-5. For plant B, three targets are considered, one on each of the north south and west walls. The east wall of plant B is blocked by turbine building. Missile inventory in Tables E-2 and E-4 for plants A and B are used. All missiles are assumed to be free missiles (i.e. not restrained). The total number of simulation for this study for both plants is two hundred millions. Table E-5 shows the size and location for the targets considered. All targets have a width of 20 feet and a height of 10 feet. Target elevations are considered to be the horizontal center line of the targets with respect to the ground. Figure E-5 and E-6 show the 3D view of the target locations for plant A. Figure E-7 and E-8 show the 3D view of the target locations for plant B.

As expected the sensitivity results show that in general as target elevation increases, hit probability is decreases.

Table E-5. Target sizes and location for target elevation study

Plant A	Size	Elev 1	Elev 2	Elev 3
East Wall	20'WX10'H	8'	38'	78'
West Wall	20'WX10'H	5'	25'	55'
North Wall	20'WX10'H	68'	78'	103'
South Wall	20'WX10'H	5'	20'	35'
Plant A	Size	Elev 1	Elev 2	Elev 3
East Wall	N/A	N/A	N/A	N/A
West Wall	20'WX10'H	8.5'	23.5'	53.5'
North Wall	20'WX10'H	6'	21'	41'
South Wall	20'WX10'H	6'	31'	64'

Figure 5. Plant A East and South Wall Targets

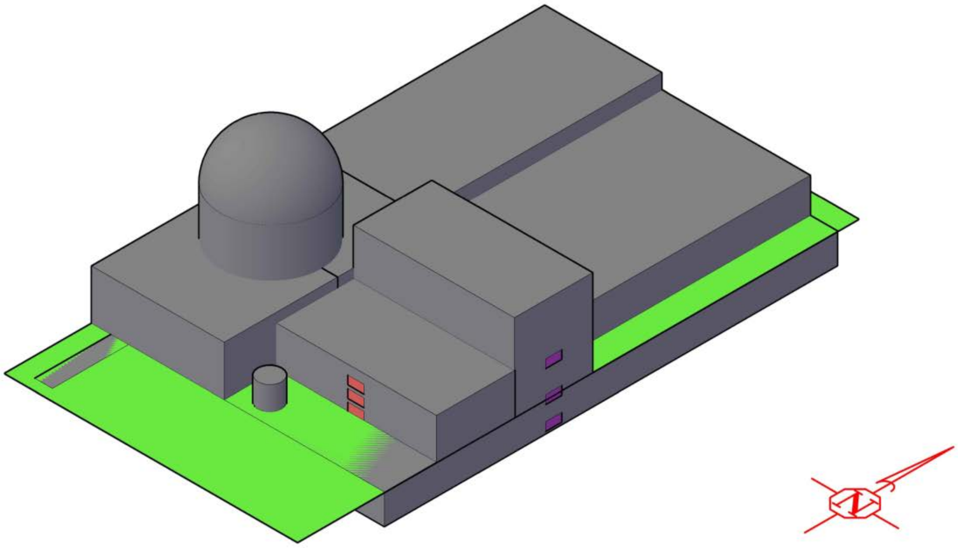


Figure 6. Plant A North and West Wall targets

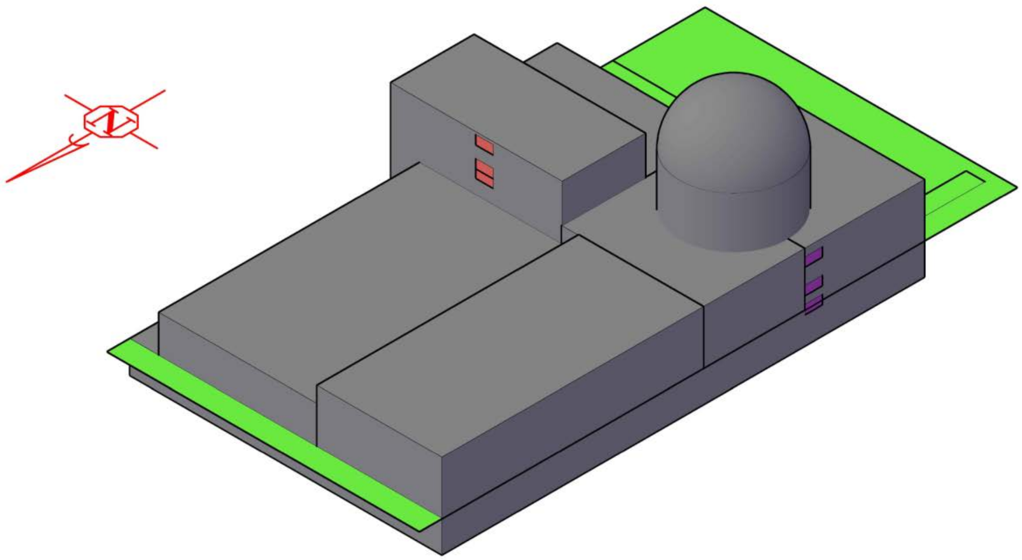


Figure 7. Plant B South Wall Targets

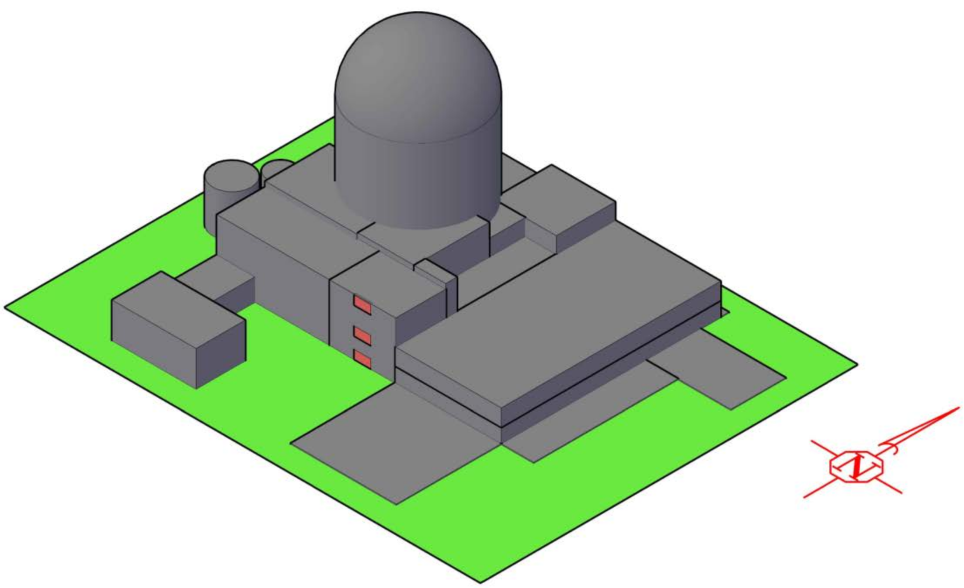


Figure 8. Plant B North and West Wall Targets

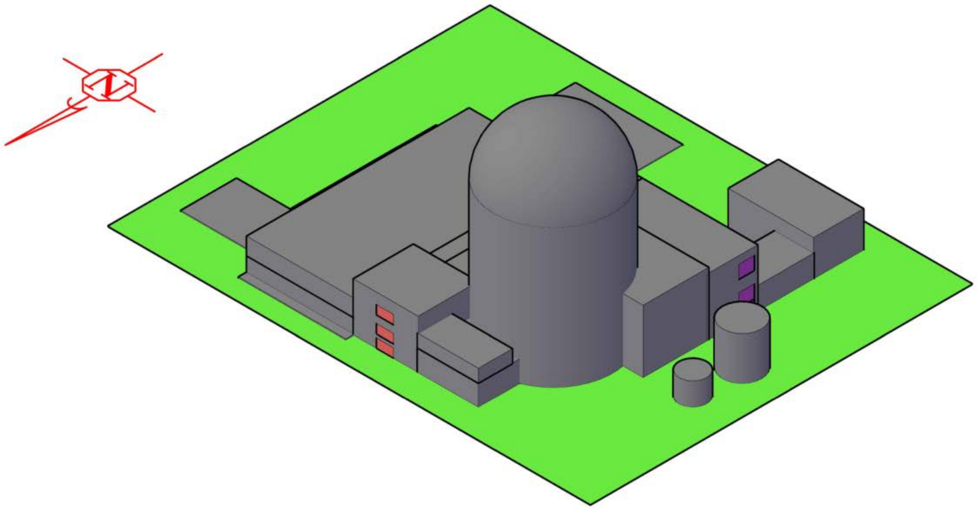


Figure 9. Plant A East Wall Hit Probability for all EFs

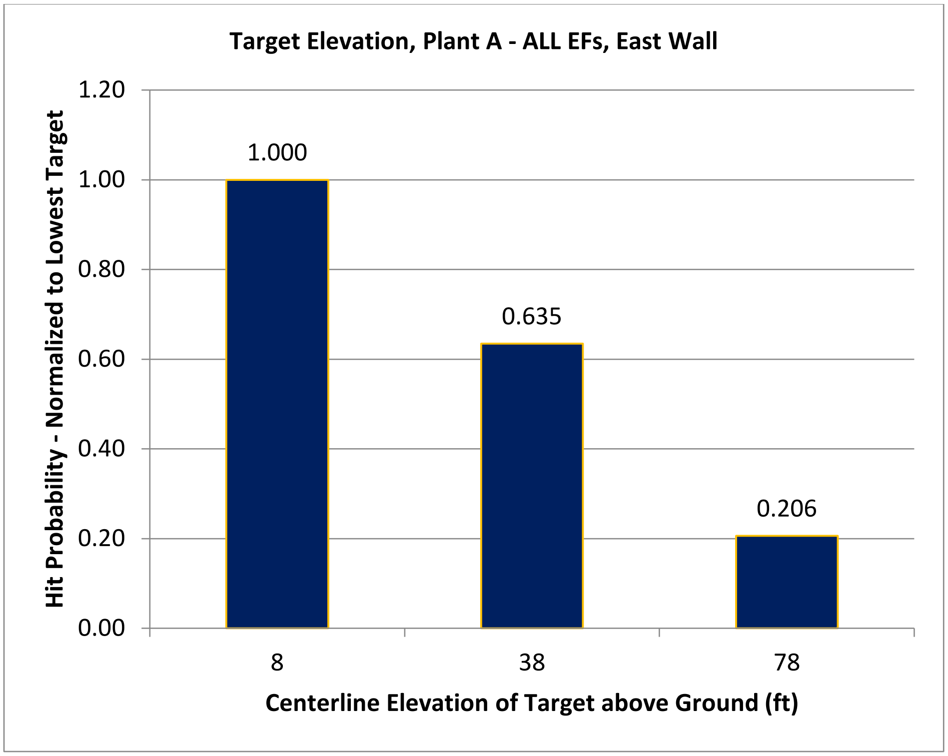


Figure 10. Plant A West Wall Hit Probability for all EFs

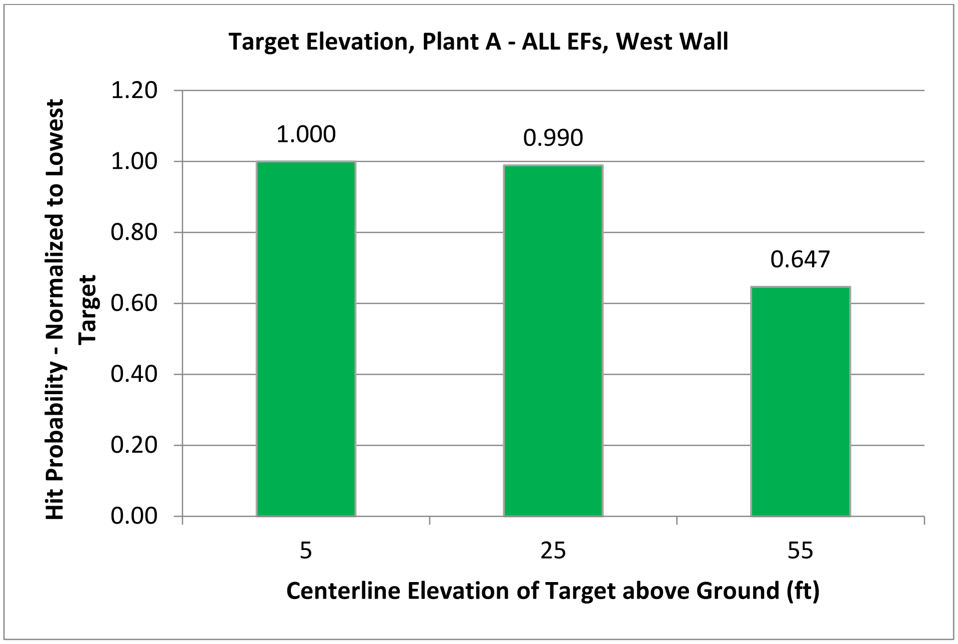


Figure 11. Plant A South Wall Hit Probability for all EFs

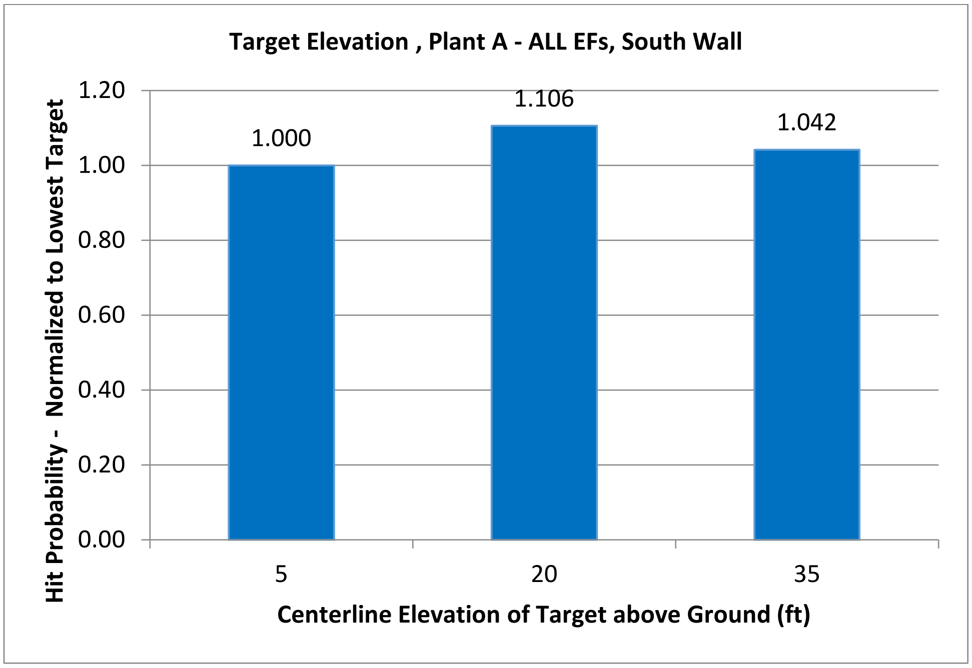


Figure 12. Plant A North Wall Hit Probability for all EFs

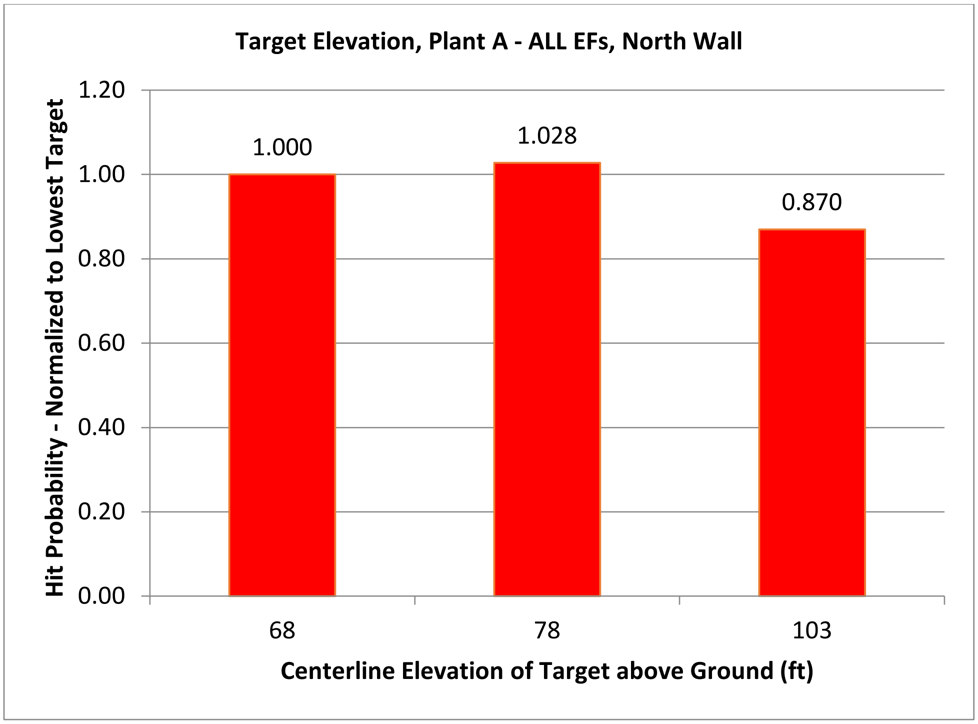


Figure 13. Plant B North Wall Hit Probability for all EFs

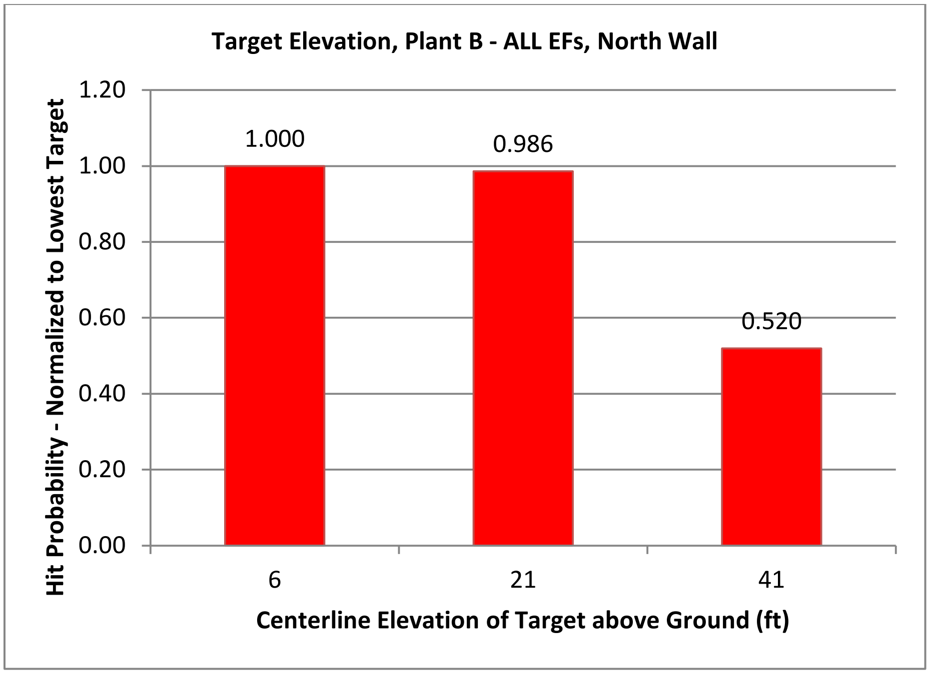


Figure 14. Plant B South Wall Hit Probability for all EFs

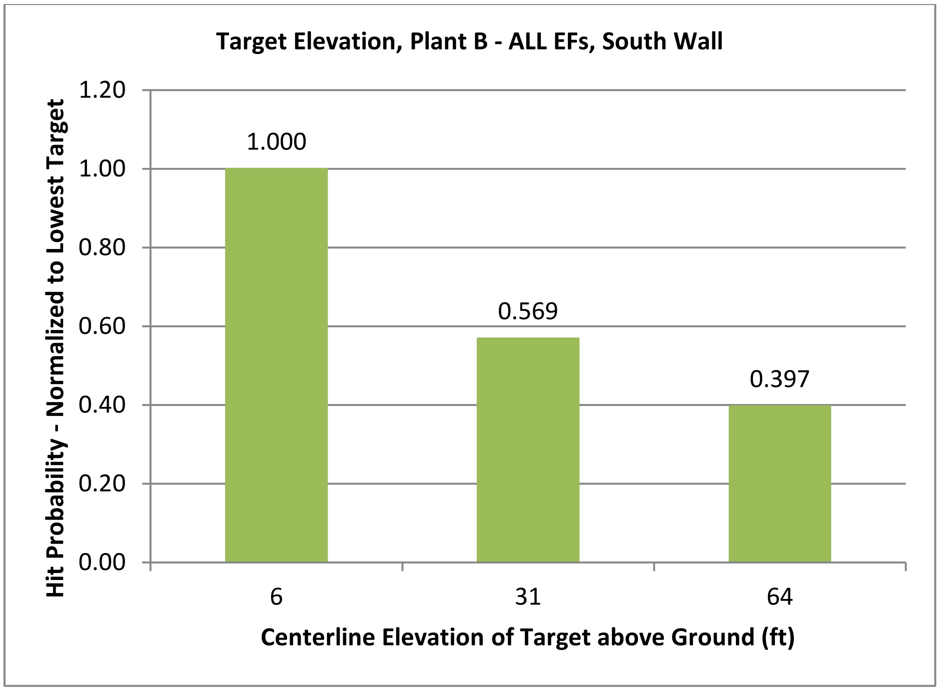
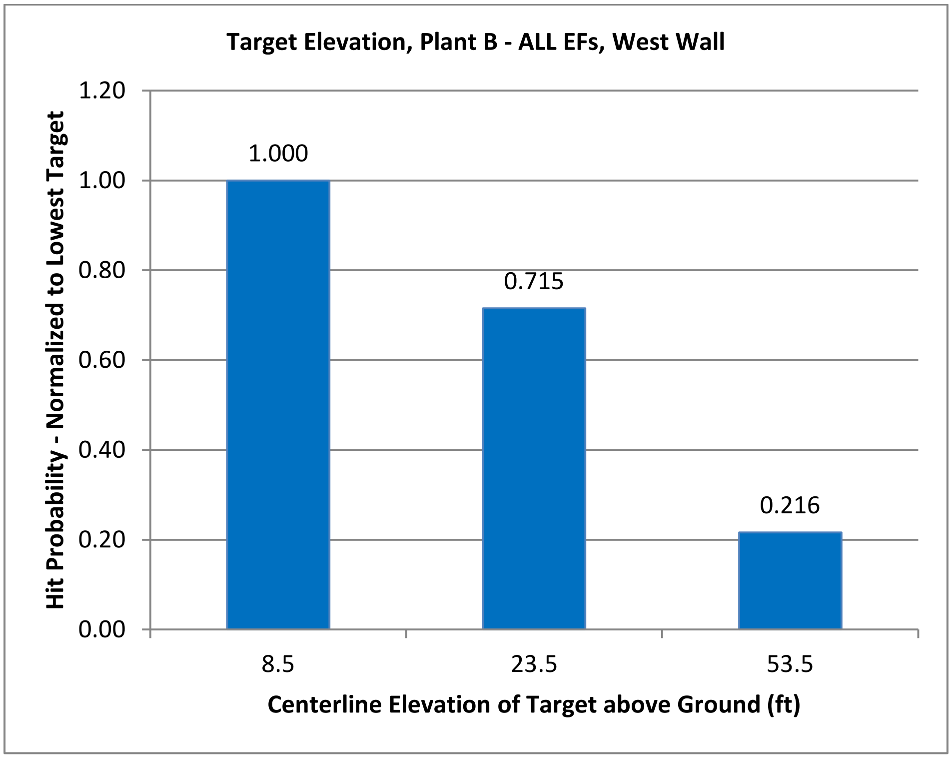


Figure 15. Plant B West Wall Hit Probability for all EFs



Target Size Study

The objective of this study is to examine the impact of target size on targets hit probabilities. In this study, both plants A and B models are used. Targets are created with varying widths and preserving target heights and elevations. Eight targets are created for each of the plant models. ,

Missile inventory in Tables E-2 and E-4 for plants A and B are used. All missiles are assumed to be free missiles (i.e. not restrained). The total number of simulations for this study for both plants is two hundred millions. South wall targets for plant A has a constant height of 20 ft. The width was varied to produce targets with 40, 100, 600, 2400 ft^2 respectively.

Targets on east wall for plant A has a constant height of 40 ft. The width was varied to produce targets with 60, 200, 2000, 4000 ft^2 respectively. Targets on North wall for plant B has a constant height of 40 ft. The width was varied to produce targets with 40, 120, 400, 2400 ft^2 respectively. Targets on west wall for plant B has a constant height of 30 ft. The width was varied to produce targets with the following areas 30, 90, 300, 1500 ft^2 respectively. Figures 16 and 17 show 3D view of targets for plant A. Figures 18 and 19 show 3D view of targets for plant B. Table 6 shows target sizes considered in this study. Results show that hit probability per unit area does not appreciably change with target size for targets with similar exposure, elevation, and height.

Table E-6. Target sizes and location for target elevation study

Plant A	**Height (ft)**	**Area 1 (ft^2)**	**Area 2 (ft^2)**	**Area 3 (ft^2)**	**Area 4 (ft^2)**
South Wall	20	40	100	600	2400
East Wall	40	60	200	2000	4000
Plant B					
North Wall	40	40	120	400	2400
West Wall	30	30	90	300	1500

Figure 16. Plant A Targets showing variations in size

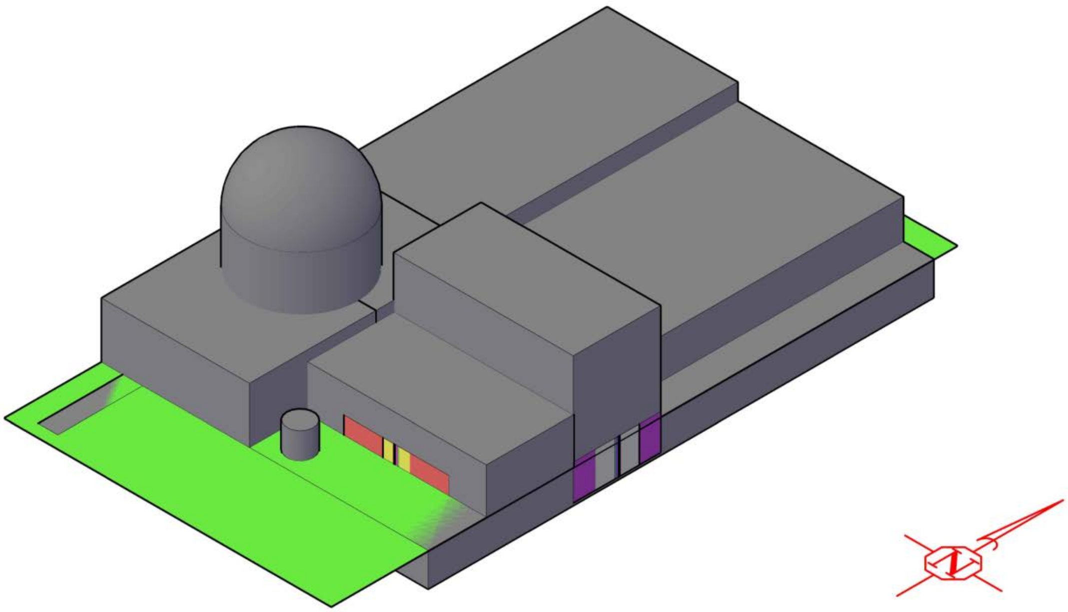


Figure 17. Close-up plant A targets showing variations in size

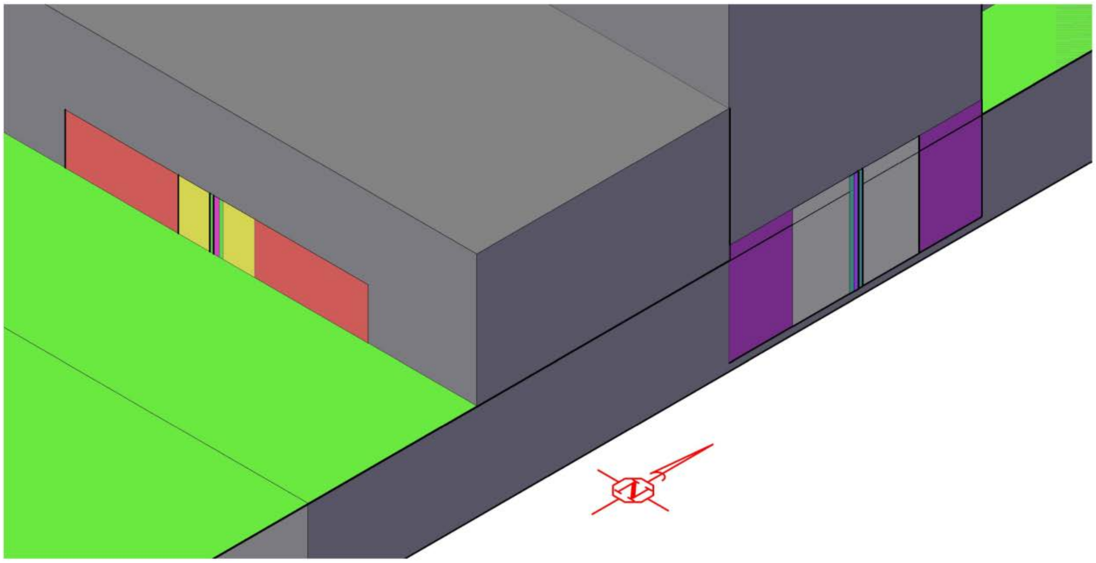


Figure 18. Plant B Targets showing variations in size

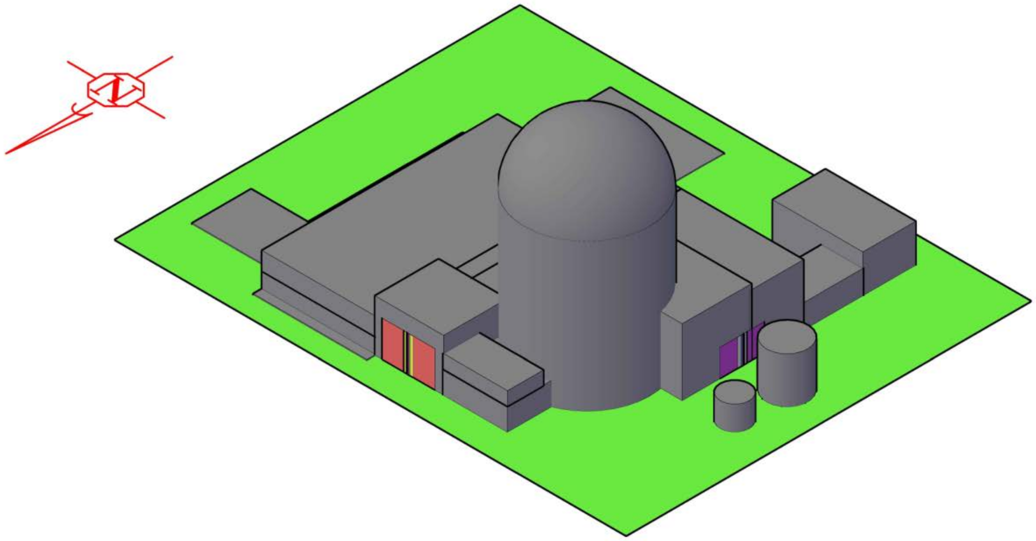


Figure 19. Close-up plant B targets showing variations in size

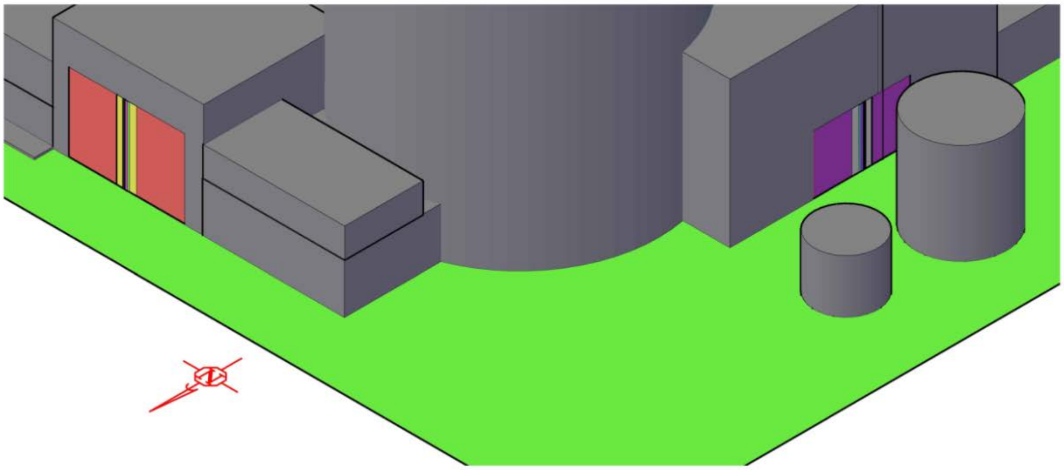


Figure 20. Normalized Plant A South Wall Hit Probability for all EFs

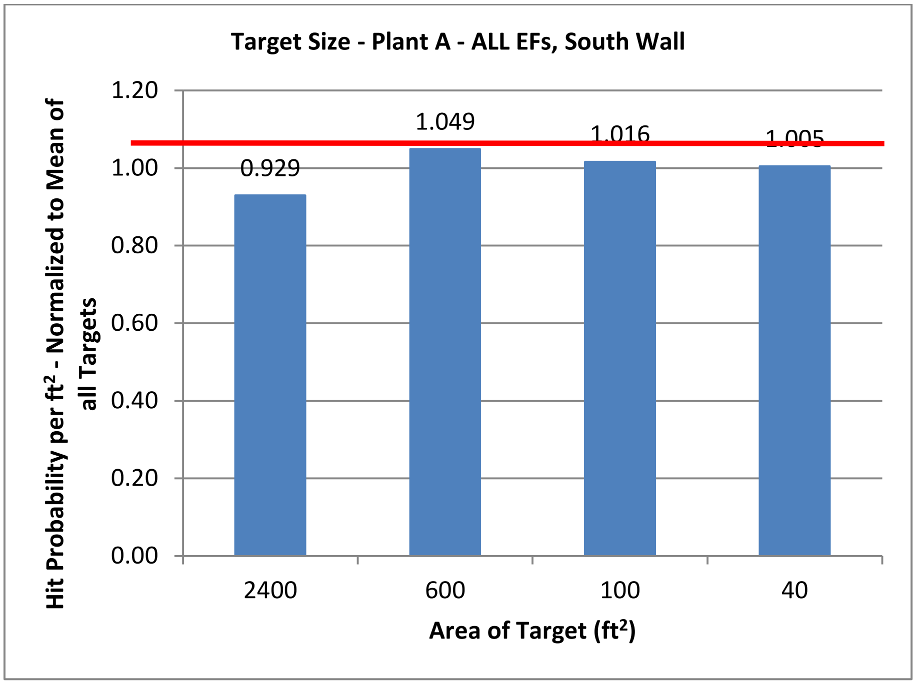


Figure 21. Normalized Plant A East Wall Hit Probability for all EFs

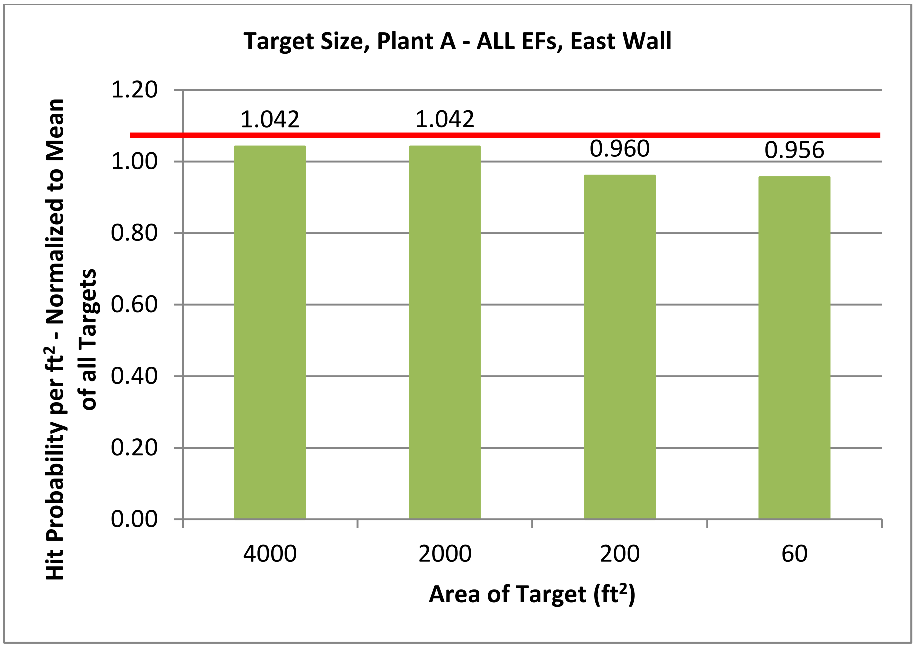


Figure 22. Normalized Plant B North Wall Hit Probability for all EFs

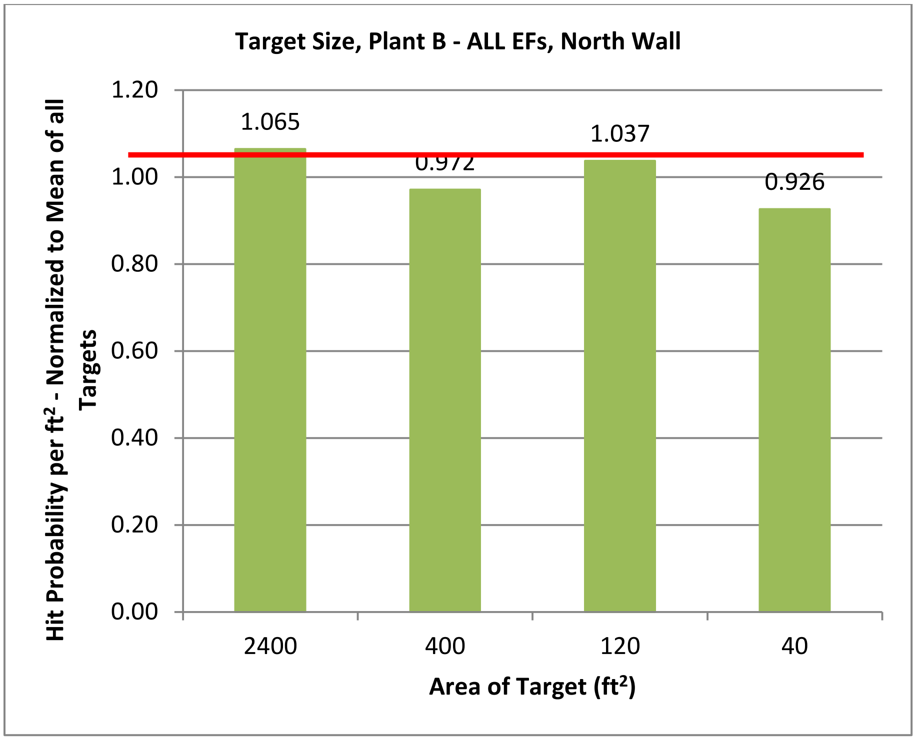
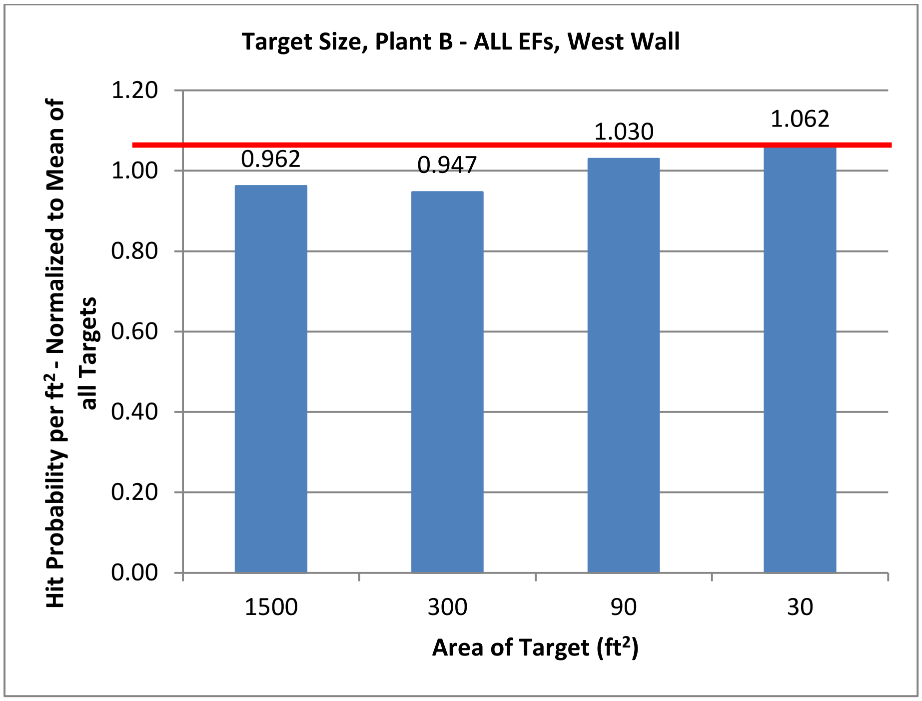


Figure 23. Normalized Plant B West Wall Hit Probability for all EFs



Missiles Distribution

The objective of this study is to examine target hit probabilities sensitivity to missile distribution. Two distribution schemes are examined zonal and uniform.

Uniform missile distribution, means that all zones have a constant missile density. On the other hand, for zonal missile distribution each zone has a different number of missiles and the missile density varies. For this study, no missile stratification is used since the use of stratification technique would negate the nature of uniform missile distribution. The zonal area of the plant A is 19,771,450 ft2 with a total of 100,327 missiles. The zonal area of the plant B is 31,360,000 ft2 with a total of 141,944 missiles. Missiles injected from top of buildings are excluded since uniform distribution of these missiles is unrealistic.

Zonal versus uniform missile and zones distribution for plants A and B are shown in Figures 24 and 25 respectively. Each zone has three designated numbers, the top number is the zone number, the middle number is the number of missiles in each zone (zonal distribution), and the bottom number is the number of missiles considering uniform distribution of missiles around the plant.

Results and conclusions of this study are discussed further in Appendix A.

Figure 24. Plant A zonal versus uniform missile distribution

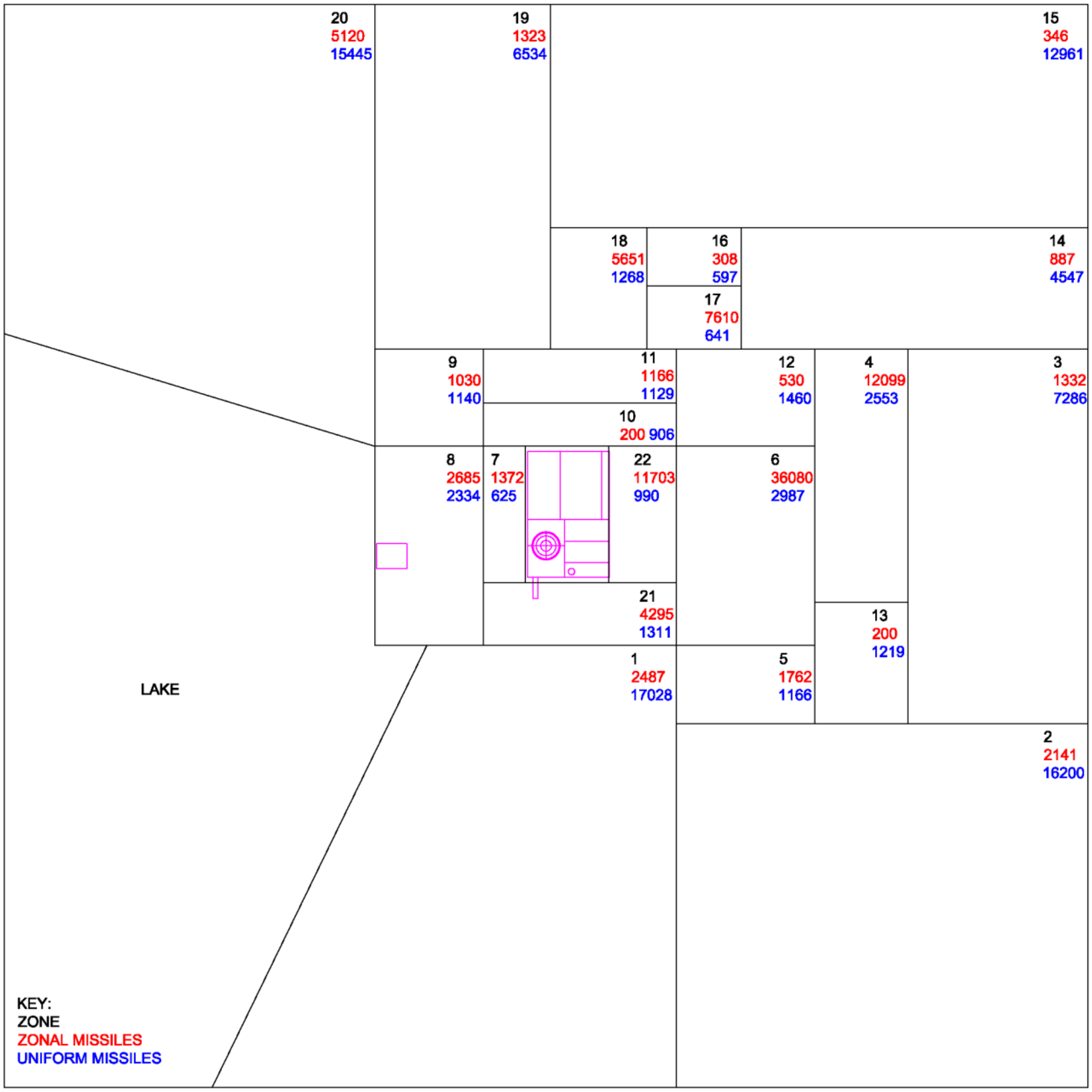
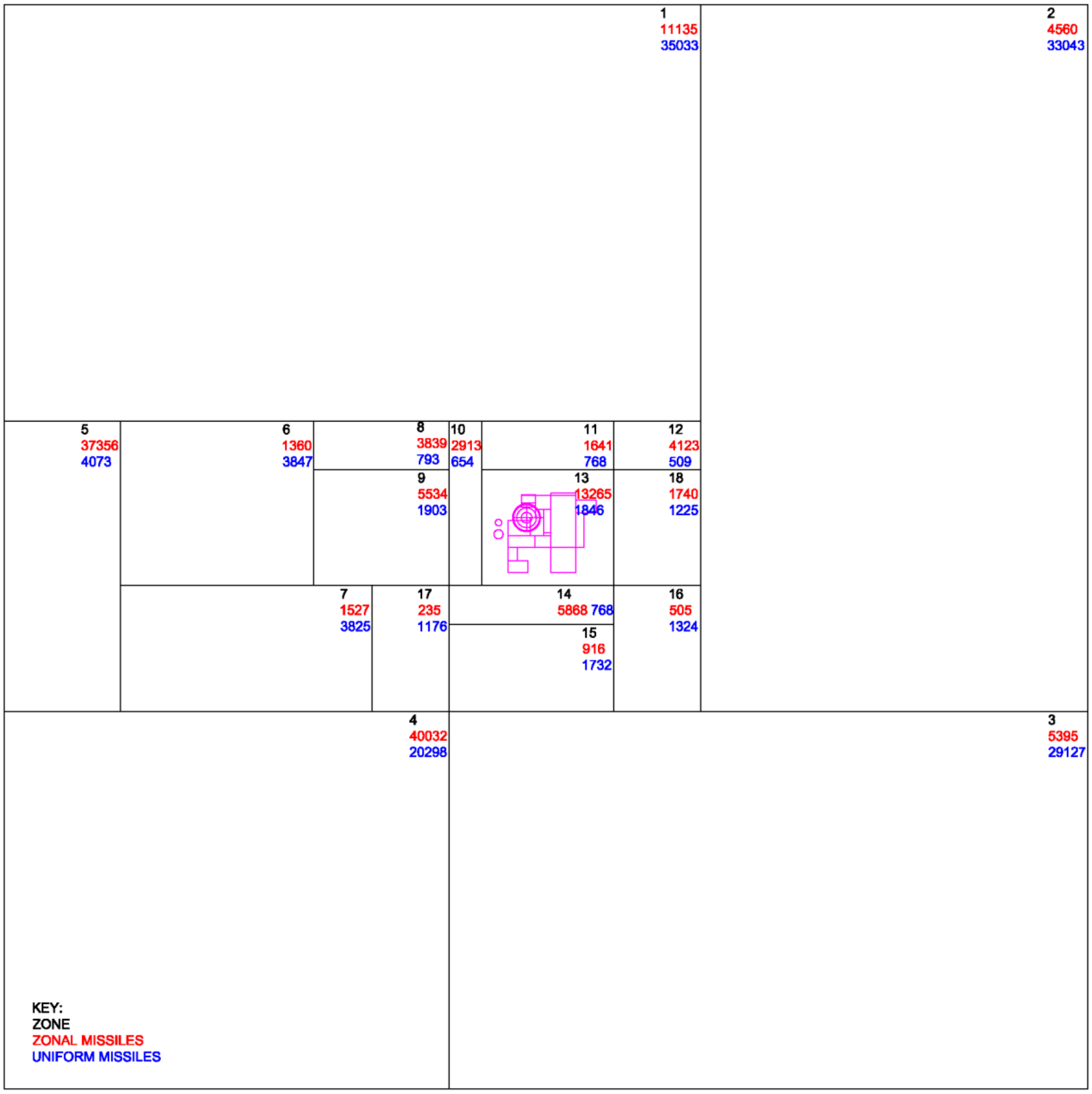


Figure 25. Plant B zonal versus uniform missile distribution



Serial: RA-18-0106

Shearon Harris Nuclear Power Plant, Unit 1
Docket No. 50-400 / Renewed License No. NPF-63

License Amendment Request to Incorporate Tornado Missile Risk Evaluator into Licensing Basis – Supplement and Request for Additional Information Response (EPID L-2017-LLA-0355)

Enclosure 4

Supplement to Address Additional Non-Conforming Conditions

Background

By letter dated October 19, 2017, as supplemented by letter dated January 11, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML17292B648 and ML18011A911, respectively), Duke Energy Progress, LLC (Duke Energy), submitted a license amendment request (LAR) regarding Shearon Harris Nuclear Power Plant, Unit 1 (HNP). The submittal incorporated by reference Nuclear Energy Institute (NEI) technical report NEI 17-02, Revision 1, "Tornado Missile Risk Evaluator (TMRE) Industry Guidance Document," September 2017, which contains the tornado missile risk evaluator methodology (ADAMS Accession No. ML17268A023). The proposed amendment would modify the licensing bases as described in the Updated Final Safety Analysis Report to include a new methodology for determining whether physical protection from tornado-generated missiles is warranted. The methodology can only be applied to discovered conditions where tornado missile protection is not currently provided, and cannot be used to revise the design basis to avoid providing tornado missile protection in the plant modification process.

Duke Energy identified additional conditions that are not in conformance to the HNP design and licensing bases for tornado missile protection for which treatment under TMRE is requested. The minor additional scope does not affect the conclusions of the original LAR and the No Significant Hazards Consideration Analysis of the original LAR remains valid.

Evaluation

The additional conditions that do not conform to the HNP current licensing bases for protection from tornado missiles are submerged under water, and located at either the main or auxiliary emergency service water intake structures. The current TMRE guidance does not provide an approach for treatment of submerged targets. The identified submerged targets were reviewed to determine if they can be qualitatively screened as having a negligible risk contribution.

The following qualitative insights apply to all identified submerged targets at HNP:

- Only a subset of all potential missiles have a shape needed to effectively travel through water and maintain forward momentum. The missile will also need to maintain sufficient structural integrity when entering the water.
- The potential subset of missiles that are shaped to travel effectively through water would also need to be aligned in a manner to penetrate the water and maintain substantial kinetic energy.
- The missiles penetrating the water must have minimal rotational momentum upon entry into the water. All missile energy would need to be in alignment with optimal water entry alignment.
- None of the identified targets are susceptible to direct vertical missiles with a relatively small horizontal component to the velocity.
- Missile water entry will be at an angle, that will result in a fraction of missiles skipping on water surface preventing significant penetration.
- Only missiles with sufficient air speed possess the necessary kinetic energy to travel through the water and damage submerged targets.
- Submerged targets at HNP are below grade and have limited exposure path to missiles; the missile trajectories needed to strike submerged targets are a very small subset of possible trajectories.

Each target was also reviewed individually to make a final assessment if screening is appropriate.

Main Reservoir 1SW-3 and 1SW-4

Damage Assessment:
1SW-3 and 1SW-4 are isolation valves that are used with 1SW-1 and 1SW-2 to align the emergency service water (ESW) pumps to the main or auxiliary reservoirs. Missiles would have to enter from the south side of the intake structure and enter the water below grade at an angle. The missile would need to penetrate the coarse screens and the traveling screens prior to impacting the valves of concern. Damage to 1SW-3 or 1SW-4 could prevent opening these valves to take suction from the main reservoir or fail isolation between the main and auxiliary reservoir. The ESW Main reservoir intake suction is not credited in the PRA model. The failure mode of concern is failure to isolate. If 1SW-3 or 1SW-4 were damaged preventing the valves from isolating, this would only impact one train of ESW, because the complementary valve in the auxiliary reservoir could be closed to maintain a water source to the unaffected train of ESW. Even if the redundant train of ESW was unavailable, there is the potential of the affected ESW pump to take suction from the main reservoir.

Qualitative Review:

- Target damage is recoverable based on damage assessment.
- The missile path to damage targets would have to penetrate the coarse screens and traveling screens.
- The normal water level will provide 47.7 feet of protection, the minimal water level for operation will provide 12.6 feet of protection but this limited level would only apply to a fraction of the operating exposure.
- Target exposure area is 78.2 square feet which is not significant.

Assessment:

These targets are expected to have a negligible impact on the total plant tornado missile risk assessment and are screened from the assessment.

Main Reservoir ESW Pumps (1SW-E005 and 1SW-E006)

Damage Assessment:

The ESW pump suction bells are potentially vulnerable to a missile strike. Missiles would have to enter from the south side of the intake structure and enter the water below grade at an angle. The missile would need to penetrate the coarse screens and the traveling screens prior to damaging the pump suction bell. The missiles would also have to pass through service water valves 1SW-3 or 1SW-4, these valves could be open or closed depending on plant configuration. A single missile cannot damage both trains of service water.

Negligible Screening Basis:

- The missile path to damage targets would have to penetrate the coarse screens and traveling screens.

- The normal water level will provide 64.3 feet of protection, the minimal water level for operation will provide 27.6 feet of protection but this limited level would only apply to a fraction of the operating exposure.
- Target exposure area is 7.8 square feet which is not significant, as supported by the attached sensitivity study.

Assessment:

These targets are expected to have a negligible impact on the total plant tornado missile risk assessment and are screened from the assessment.

<u>Auxiliary Reservoir Traveling Screens</u>

Damage Assessment:

The traveling screens supporting the emergency service water pump are potentially vulnerable to a missile strike. Missiles would have to enter from the west side of the screening structure and enter the water below grade at an angle. The missile would need to penetrate the coarse screens prior to damaging the traveling screen. Damage to the traveling screens does not result in certain failure of the associated ESW pump. A single missile cannot damage both trains of service water.

Negligible Screening Basis:

- The missile path to damage targets would have to penetrate the coarse screens.
- The normal water level will provide 35.6 feet of protection, the minimal water level for operation will provide 31.3 feet of protection but this limited level would only apply to a fraction of the operating exposure.
- Target exposure area is 107 square feet which is not significant, as supported by the attached sensitivity study.

Assessment:

These targets are expected to have a negligible impact on the total plant tornado missile risk assessment and are screened from the assessment.

<u>Auxiliary Reservoir 1SW-1 and 1SW-2</u>

Damage Assessment:

1SW-1 and 1SW-2 are isolation valves that are used with 1SW-3 and 1SW-4 to align the ESW pumps to the main or auxiliary reservoirs. Missiles would have to enter from the west side of the intake structure and enter the water below grade at an angle. The missile would need to penetrate the coarse screens and the traveling screens prior to impacting the valves of concern. Damage to 1SW-1 or 1SW-2 could prevent opening these valves to take suction from the auxiliary reservoir or fail isolation between the main and auxiliary reservoir. The PRA models 1SW-1 and 1SW-2 as normally open with ESW suction aligned to the auxiliary reservoir. Isolation from the main reservoir is model by 1SW-3 and 1SW-4 being aligned in the closed position. The ESW Main reservoir intake suction is not credited in the PRA model. It is very unlikely damage will occur preventing the valves from remaining open. If 1SW-1 or 1SW-2 was damaged preventing the valves from remaining open the ESW suction can be aligned to the main reservoir to maintain a water source to the affected train of ESW. A single missile cannot damage both trains of service water.

Negligible Screening Basis:

- Target damage is unlikely to impair PRA success criteria based on damage assessment.
- Target damage is recoverable based on damage assessment.
- The missile path to damage targets would have to penetrate the coarse screens and traveling screens.
- The normal water level will provide 57.5 feet of protection, the minimal water level for operation will provide 52.5 feet of protection but this limited level would only apply to a fraction of the operating exposure.
- Target exposure area is 4.9 square feet which is not significant.

Assessment:

These targets are expected to have a negligible impact on the total plant tornado missile risk assessment and are screened from the assessment.

Submerged Target Sensitivity

There currently is no guidance for addressing submerged targets in NEI 17-02, but a bounding approach can be applied. The submerged target sensitivity will assume no water or material shielding exist to protect components added in this study. This sensitivity study is highly conservative. Table 1 reviews each submerged target screened based on water shielding and identifies non-conformances directly impacting the PRA for inclusion in the sensitivity. Some of the non-conformances are related to components not modeled in the PRA and do not directly impact PRA functions. This sensitivity will add the auxiliary reservoir traveling screens for ESW and the ESW pump suction bells as targets in the degraded TMRE model and the impact on the delta core damage frequency (CDF) and large early release frequency (LERF) will provide bounding insight into the potential impact. Submerged targets EEFP are developed assuming the targets are not robust. Table 2 provides the EEFPs for the new targets added to the model.

Table 1. Submerged Target Review

Non-Conformance Description	Included in the Sensitivity	Notes
Main Reservoir 1SW-3 and 1SW-4	No	Only the auxiliary reservoir is modeled in the PRA. Damage to these valves could result in an auxiliary reservoir isolation failure from the main reservoir or unavailability of the main reservoir which is not credited in the PRA. Damage to these valves does not directly fail a function modeled in the PRA, and to impact the PRA would require a specific failure mode with additional failures. This non-conformance is not included in the sensitivity.
ESW Pumps (1SW-E005 and 1SW-E006)	Yes	The ESW Pumps are modeled in the PRA. This non-conformance is modeled as a direct impact on the associated ESW pump in the PRA model.
Aux Reservoir ESW Traveling Screens	Yes	The traveling screens in the auxiliary reservoir are modeled in the PRA. This non-conformance is modeled as a direct impact on the associated traveling screen in the PRA model.
Aux Reservoir ESW 1SW-1 and 1SW-2	No	Only the auxiliary reservoir is modeled in the PRA. Damage to these valves could result in an auxiliary reservoir isolation failure from the main reservoir or unavailability of the auxiliary reservoir which is recoverable with the main reservoir. The main reservoir is not modeled in the PRA. Damage to these valves does not directly fail a function modeled in the PRA, and to impact the PRA would require a specific failure mode with additional failures. This non-conformance is not included in the sensitivity.

Table 2. Submerged Target EEFPs

Target	AREA (ft^2)	Elev > 30'	Missile Count	F'-Scale	MIP	Probability of failure from Missile
Auxiliary Reservoir Traveling Screen Train A	107	N	155000	2	1.40E-10	2.32E-03
			155000	3	4.60E-10	7.63E-03
			205000	4	7.90E-10	1.73E-02
			240000	5	2.00E-09	5.14E-02
			240000	6	3.10E-09	7.96E-02
Auxiliary Reservoir Traveling Screen Train B	107	N	155000	2	1.40E-10	2.32E-03
			155000	3	4.60E-10	7.63E-03
			205000	4	7.90E-10	1.73E-02
			240000	5	2.00E-09	5.14E-02
			240000	6	3.10E-09	7.96E-02
ESW Pump Train A	7.8	N	155000	2	1.40E-10	1.69E-04
			155000	3	4.60E-10	5.56E-04
			205000	4	7.90E-10	1.26E-03
			240000	5	2.00E-09	3.74E-03
			240000	6	3.10E-09	5.80E-03
ESW Pump Train B	7.8	N	155000	2	1.40E-10	1.69E-04
			155000	3	4.60E-10	5.56E-04
			205000	4	7.90E-10	1.26E-03
			240000	5	2.00E-09	3.74E-03
			240000	6	3.10E-09	5.80E-03

The degraded model was re-quantified with the changes incorporated. The compliant case was not re-evaluated because all changes are non-conformances and would not impact the compliant model. The results of this sensitivity are presented in Table 3.

Table 3. Submerged Target Sensitivity Results

Result Type	CDF per Year	LERF per Year
Degraded	5.48E-7	5.81E-8
Compliant	5.23E-7	5.55E-8
Delta Risk	2.5E-8	2.6E-9

The delta risk for this sensitivity shows the risk of tornado missile non-conformances still meets the acceptance guidelines of RG 1.174 with significant margin. The sensitivity results are 2.5E-8 per year ΔCDF and 2.6E-9 per year ΔLERF. The tornado risk change for accepting non-conforming conditions still results in a very small risk increase (Region III) per RG 1.174 based on these sensitivity results.

Conclusions

The additional non-conforming conditions do not affect the technical justification, regulatory evaluation (including defense-in-depth and safety margins assessment), or no significant hazards consideration of the original LAR. A subjective analysis concluded the impact was negligible, and a very conservative sensitivity analysis supported that conclusion. The aggregate impact of the changes in the original LAR as supplemented by this analysis have been demonstrated to be of very low safety significance. Upon approval, the HNP UFSAR will be revised to reflect these additional conditions.