NEI Tornado Missile Risk Evaluator (TMRE)

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Introduction

- Purpose
- Participants
- Methodology Overview
AGENDA

- Notional Plant Licensing Basis
- Tornado Missile Risk Evaluator (TMRE) Overview
- Tornado Climatology
- Safe Shutdown Targets
- Missile Population
- Plant Walkdown
- Exposed Equipment Failure Probability
- Tornado Missile Risk
- Acceptance Criterion
- TMRE Conservatisms
- TMRE Comparisons
- Conclusion
Notional Plant Licensing Basis

Containment
Seismic Class I Structures
Service Water (SW) Pumphouse
Diesel Generator Building
Containments/Seismic Class I Structures

Licensing Basis:

• “The containments and Seismic Class I portions of the Auxiliary Building, the turbine hall, the pumphouse, and the diesel generator building are designed to withstand the effects of a tornado.”

• “The design criteria of the containment and the Class I portions of the auxiliary and turbine buildings to withstand the effects of a tornado, including wind force, pressure differential, and missile impingement are described in Bechtel Topical Report B-TOP-3, ‘Design Criteria for Nuclear Power Plants Against Tornadoes.’”
Licensing Basis:

- “The pumphouse structure has been designed to remain intact under a tornado wind having a tangential velocity of 300 mph plus a forward progress of 60 mph.”

- “The structure is capable of remaining intact for a pressure drop of 1/2 psi. Before this pressure drop is realized, the building would be vented by the failure of the louvers and doors.”
Licensing Basis:

- “A lateral force caused by a funnel of tornado wind having a peripheral tangential velocity of 300 mph and a forward progress of 60 mph was applied to the building.”
External Missiles Considered

External missiles equivalent to:

• An airborne 4-in x 12-in x 12-ft plank traveling end on at 300 mph or

• A 4000-lb automobile flying through the air at 50 mph and at not more than 25 ft above the ground

Design Assumption

• Objects of low cross sectional density – such as boards, metal siding, and similar items – may be picked up and carried at the maximum wind velocity of 300 mph
External Missiles Considered

SW Pumphouse

Licensing Basis:

• “Interior missile shield walls and exterior walls protecting the service water pumps are constructed of reinforced concrete with a minimum thickness of 12”. The internal missile shield walls have been located to preclude the possibility of damage from a missile passing through a louver or door. Reinforced concrete walls of 12” thickness cannot be penetrated by the design tornado missiles...”
External Missiles Considered

• Vertical missiles not considered per Bechtel Topical Report B-TOP-3, “Design Criteria for Nuclear Power Plants Against Tornadoes”
Licensing Basis

• “The design basis for tornado missile protection of systems and components is that it is possible to shut the plant down and keep it in hot shutdown during and after the passage of a tornado.”
TMRE Overview

- Site Tornado Climatology
- Safe Shutdown Vulnerable Targets
- Missile Population
- Plant Walkdown
- Exposed Equipment Failure Probability (EEFP)
- Tornado Missile Risk (TMR)
Tornado Climatology
Data Sources Available for Calculating Tornado Strike Probability

- **NUREG/CR-4461, Rev 2, “Tornado Climatology of the Contiguous United States”**
  Provides nuclear plant site specific data to develop hazard curve

- **NOAA Storm Prediction Center**
  [http://www.spc.noaa.gov](http://www.spc.noaa.gov)
Tornado Climatology of the Contiguous United States

Table 6-1, *Tornado Wind Speed Estimates for United States Nuclear Power Plant Sites*

- Wind speeds for specific tornado frequencies
- Derived from plant-specific NOAA data

<table>
<thead>
<tr>
<th>Freq/Yr</th>
<th>Plant Q</th>
<th>Plant R</th>
<th>Plant S</th>
<th>Plant T</th>
<th>Plant U</th>
<th>Plant V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00E-05</td>
<td>177</td>
<td>209</td>
<td>147</td>
<td>143</td>
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<td>142</td>
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<tr>
<td>1.00E-06</td>
<td>232</td>
<td>260</td>
<td>205</td>
<td>203</td>
<td>191</td>
<td>203</td>
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<tr>
<td>1.00E-07</td>
<td>280</td>
<td>306</td>
<td>256</td>
<td>254</td>
<td>245</td>
<td>255</td>
</tr>
</tbody>
</table>
Tornado Frequencies

NUREG/CR-4461, Rev 2 - Tornado Climatology Data - FUJITA DATA

<table>
<thead>
<tr>
<th>Freq/Yr</th>
<th>Plant Q</th>
<th>Plant R</th>
<th>Plant S</th>
<th>Plant T</th>
<th>Plant U</th>
<th>Plant V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00E-05</td>
<td>177</td>
<td>209</td>
<td>147</td>
<td>143</td>
<td>128</td>
<td>142</td>
</tr>
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<td>232</td>
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<td>205</td>
<td>203</td>
<td>191</td>
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</tr>
<tr>
<td>1.00E-07</td>
<td>280</td>
<td>306</td>
<td>256</td>
<td>254</td>
<td>245</td>
<td>255</td>
</tr>
</tbody>
</table>
F’ Wind Scale

F’ is the wind scale used in NP-768 studies.

This wind scale was used to “back out” the missile impact parameter values that will be presented later.

<table>
<thead>
<tr>
<th>Tornado Intensity</th>
<th>Wind Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>F'0</td>
<td>40-73</td>
</tr>
<tr>
<td>F'1</td>
<td>73-103</td>
</tr>
<tr>
<td>F'2</td>
<td>103-135</td>
</tr>
<tr>
<td>F'3</td>
<td>135-168</td>
</tr>
<tr>
<td>F'4</td>
<td>168-209</td>
</tr>
<tr>
<td>F'5</td>
<td>209-277</td>
</tr>
<tr>
<td>F'6</td>
<td>277-300</td>
</tr>
</tbody>
</table>
Determination of Tornado Strike Frequency

Hazard curve equation was derived from the Fujita data in Table 6-1, NUREG/CR-4461, Rev. 2. F'2 through F'6 frequencies were calculated based on this equation.

<table>
<thead>
<tr>
<th>NOTIONAL PLANT</th>
<th>FREQ/YR</th>
</tr>
</thead>
<tbody>
<tr>
<td>FUJITA'</td>
<td></td>
</tr>
<tr>
<td>F'2</td>
<td>2.20E-04</td>
</tr>
<tr>
<td>F'3</td>
<td>5.02E-05</td>
</tr>
<tr>
<td>F'4</td>
<td>1.33E-05</td>
</tr>
<tr>
<td>F'5</td>
<td>2.40E-06</td>
</tr>
<tr>
<td>F'6</td>
<td>1.21E-07</td>
</tr>
</tbody>
</table>

HAZARD CURVE EQUATION

\[
\text{MPH} = -22.37\ln(\text{Frequency}) - 79.333
\]

\[
R^2 = 0.9985
\]
Selected Safe Shutdown Vulnerable Targets

Notional Plant
Targets Selected for Evaluation

• Identified based on design evaluation & walkthrough

• Selected for TMRE demonstration
  - Emergency Diesel Generator (EDG) Exhaust Stacks
  - Outside Cable Vault
  - Condensate Storage Tanks (CSTs)
  - Service Water (SW) Components
  - EDG & Auxiliaries
**Example Targets**

**EDG Stacks** are protected on one side by metal siding which is peeled off above F’2 scale winds.

**EDG stack support brackets** prevent stacks from collapsing during high winds, a significant issue above F’2 winds when siding begins to fail and act as a sail that increases wind pressure against the stacks.

**Cable vault** contains one division of safety related cables from diesels to safety related service water pumps.
Photos and diagram show two CSTs that are considered a single target due to proximity and vulnerable instrumentation located between tanks. CSTs were modeled as a single rectangular box containing the tanks, instrumentation and piping – see 3D view.
In addition to identifying and characterizing targets and their vulnerabilities, the walkdown identifies missiles and potentially simple remedies to minimizing missile risk.

Rollup Doors are made of light sheet metal and will allow missile entry into pumphouse containing service water pumps.

Access door and louvers allow missile entry.

Dumpsters filled with metal conduit fittings and pipe were relocated after identified during walkdown. Area was then made a missile-free zone.
Access door and louvers allow missile entry

“Missiles” (large heavy metal frames) with favorable aerodynamics stored in front of targets. Material was removed and area designated as a missile free zone.
Exposure Considerations – SW Pumphouse

Photo shows missile’s “view” of barriers protecting service water pumps and headers as seen from the rollup door. The large pump is circulating water pump.

Metal siding and grating that was previously installed to protect against missiles was not credited. View shown is just past the circulating water pump.
Potential missile paths to risk important targets can be evaluated by assessing missile tracks through vulnerable openings. Robust barriers blocking missile path to target should also be considered; circulating water pumps in this example.

Target exposure area would be assessed based on missile window size based on the direct path of a missile to the target.
Missile tracks are limited to paths that avoid the concrete building in the upper right of the plan view and travels through both the outside personnel and EDG room entry doors.
• Cladding and some structural members from cladded buildings will become missiles and need to be added to missile population.
• New targets exposed to tornado missiles when cladding is removed by high winds.
• Engineered buildings assumed to lose most cladding above F2 tornado.
Missile Population
Number of Missiles Onsite

- $N_m$ onsite may be estimated based on walkdowns
- Missile populations utilized in published analyses are shown below
  - Proximity to target
  - Missile energy & characteristics
  - Target fragility

<table>
<thead>
<tr>
<th>Site</th>
<th>Number of missiles</th>
<th>Reference</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermi</td>
<td>75,000</td>
<td>SER, NRC-2014-0109</td>
<td>Single-unit BWR adjacent to Lake Erie in Newport, MI. Considers missiles within 2500 feet, surveyed prior to refueling outage.</td>
</tr>
<tr>
<td>Seabrook</td>
<td>66,800</td>
<td>1984 Tornado Missile Risk Analysis</td>
<td>Single-unit PWR located on a salt marsh in Seabrook, NH.</td>
</tr>
</tbody>
</table>
Actual Missile Count Data

| Missile Origin Zone | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Total |
|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-------|
| 1                   | Rebar | 100 | 700 | 1,000 | 1,000 | 200 | 2,000 | 500 | 6,100 |
| 2                   | Gas Cylinder | 25 | 72 | 15 | 5 | 10 | 160 | 20 | 8 | 20 | 50 | 20 | 6 | 100 | 25 | 536 |
| 3                   | Drum, Tank | 20 | 5 | 10 | 40 | 20 | 20 | 50 | 10 | 10 | 30 | 15 | 22 | 1,010 | 120 | 1,417 |
| 4                   | Utility Pole | 10 | 10 | 1 | 10 | 10 | 10 | 8 | 10 | 10 | 68 |
| 5                   | Cable Reel | 10 | 10 | 400 | 50 | 20 | 5 | 485 |
| 6                   | 3-in Pipe | 25 | 100 | 300 | 27 | 200 | 500 | 10 | 4,100 | 1,600 | 6,862 |
| 7                   | 6-in Pipe | 100 | 500 | 150 | 800 | 20 | 1,570 |
| 8                   | 12-in Pipe | 10 | 50 | 20 | 100 | 50 | 14 | 400 | 38 | 712 |
| 9                   | Egpt., Bin | 1 | 3 | 10 | 28 | 44 | 11 | 36 | 54 | 4 | 16 | 10 | 320 | 22 | 559 |
| 10                  | Dumpster | 2 | 2 | 11 | 35 | 4 | 20 | 4 | 2 | 4 | 6 | 24 | 8 | 122 |
| 11                  | Wood Tie | 30 | 8 | 40 | 60 | 251 | 2,400 | 4,500 | 7,289 |
| 12                  | Wood Beam | 20 | 80 | 200 | 220 | 10 | 500 | 150 | 300 | 40 | 580 | 40 | 380 | 220 | 380 | 400 | 2,110 | 5,930 |
| 13                  | Wood Plank | 10 | 40 | 30 | 60 | 10 | 240 | 160 | 110 | 170 | 200 | 450 | 1,480 |
| 14                  | Metal Siding | 300 | 300 | 5 | 230 | 100 | 635 |
| 15                  | Plywood Sheet | 10 | 40 | 50 | 20 | 73 | 10 | 240 | 185 | 110 | 210 | 200 | 1,600 | 2,748 |
| 16                  | Wide Flange | 80 | 4 | 150 | 100 | 15 | 230 | 10 | 160 | 22 | 131 | 200 | 70 | 1,172 |
| 17                  | Angle Section | 100 | 150 | 200 | 80 | 8 | 5 | 6,000 | 3,000 | 9,543 |
| 18                  | Channel Section | 10 | 40 | 30 | 100 | 15 | 250 | 60 | 10 | 240 | 10 | 150 | 170 | 1,200 | 2,850 | 5,135 |
| 19                  | Small Eqpt. | 4 | 5 | 10 | 5 | 10 | 20 | 20 | 74 |
| 20                  | Large Eqpt. | 77 | 10 | 30 | 200 | 20 | 5,000 | 1 | 5,251 |
| 21                  | Pipe Frame | 6 | 100 | 8 | 16 | 320 | 450 |
| 22                  | Gating | 10 | 5 | 30 | 200 | 1,200 | 1,445 |
| 23                  | Rect. Frame | 10 | 100 | 1 | 1,000 | 1,111 |
| 24                  | Crane Sections | 5 | 1 | 3 | 2 | 5 | 10 | 5 | 2 | 1 | 1 | 1 | 10 | 10 | 200 | 35 | 2,514 | 90 | 183 | 3,080 |

Missile Population

Totals: 315 51 78 186 224 16 375 2,388 51 719 2,324 570 125 3,886 1,356 1,848 787 4,162 24,974 19,427 63,861
Damaging Missiles

• TMRE assumes any missile strike fails the target
  - 1.0 failure probability per missile strike

• Based on this assumption, missile population input to TMRE should be limited to missiles of sufficient energy to damage a specific target
  - Some targets may be very fragile, as such the population may include lower energy missiles (e.g., metal siding, branches, small pipe, etc.)
  - Some targets are relatively robust; the relevant population would include only high energy missiles (e.g., large pipe, automobiles, utility poles, etc.)
### Damaging Missiles - Actual Operating Site

**IPEEE Analysis**

<table>
<thead>
<tr>
<th>Missile Category</th>
<th>Counted Number of Missiles</th>
<th>Calculated Number of Missiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>55 Gallon Drum</td>
<td>135</td>
<td>405</td>
</tr>
<tr>
<td>Containers</td>
<td>18</td>
<td>900</td>
</tr>
<tr>
<td>Wood</td>
<td>170</td>
<td>510</td>
</tr>
<tr>
<td>Wood Structures</td>
<td>74</td>
<td>148</td>
</tr>
<tr>
<td>Structural Steel</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Gas Bottles</td>
<td>200</td>
<td>250</td>
</tr>
<tr>
<td>Scaffolding</td>
<td>400</td>
<td>600</td>
</tr>
<tr>
<td>Vehicles</td>
<td>255&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>319</td>
</tr>
<tr>
<td>Utility Poles</td>
<td>30&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>90</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1,309</strong></td>
<td><strong>3,249</strong></td>
</tr>
</tbody>
</table>

<sup>(1)</sup> Estimated values.
Damaging Missiles – NP-768 Study

• Plant A
  - Single unit
  - Uniform distribution of 6000 missiles

• Plant B1
  - 1 unit operational, 2nd under construction
  - Zone-based distribution of 5000 missiles

• Plant B2
  - 2-unit operational site
  - Zone-based distribution of 5000 missiles
TMRE Missile Population

- Assume conservative value of 10,000 damaging missiles for robust targets
- All missiles are within the damage proximity of each target
- Damaging missile count will be confirmed to be conservative during the plant walkdown – if not conservative the missile count will be adjusted.
Plant Walkdown
Plant Walkdown Process

• Develop walkdown plan

Identify:
  - Potential vulnerabilities
  - SSCs vulnerable to high winds

• Conduct walkdown

• Prepare walkdown documentation
PLANT WALKDOWN OBJECTIVES

CONFIRM:
- Validity of safe shutdown targets
- Damaging missile population is conservative
- Target correlation
- Adjustments to Internal Events PRA due to tornado effects

IDENTIFY:
- Specific tornado missile hazards that can be eliminated
- Additional vulnerabilities and targets that need to be considered
Typical Missiles Identified During Walkdowns Inside and Outside

Missiles Inside Metal Clad Building  Outside Missiles
Exposed Equipment Failure Probability (EEFP)

• Derive Missile Impact Parameter
• Set-up Plant Internal Events PRA
• Perform Risk Calculation Using EEFP
• Compare Results to Acceptance Criteria
Missile Impact Parameter (MIP) Derivation
MIP

Definition:
• Missile Impact Parameter (MIP)
  - Missile hit probability per missile per target exposed area (ft²) per tornado intensity (F’2 through F’6)

Use:
• MIP is used in calculating an exposed target failure probability for input into the adjusted Internal Events PRA:

Exposed Target Failure Probability = MIP x # of Missiles x Exposed Target Area x Fragility

MIP Derivation
**Definition of MIP**

- **MIP** is the probability of a wind-driven missile impact per unit area of the plant structures for each missile from the entire population of missiles for a specific tornado hazard frequency (F’2 – F’6).
- Using **MIP**, the conditional probability of a missile impact on a vulnerable target during a given tornado can be estimated if the **number of available missiles** and the **exposed surface area of the target** are known.
Missile Impact Parameter (MIP)

\[
MIP = \frac{H \text{ Value}}{\text{Tornado Frequency}} \div \text{Area of Plant Structures}
\]

Where Units are:

- **H-Value** \(\Rightarrow\) Missile Hit Probability \((\text{missile*year})^{-1}\)
- **Tornado Frequency** \(\Rightarrow\) year\(^{-1}\)
- **Area of Plant Structures** \(\Rightarrow\) ft\(^2\)

All data is from NP-768, Section 3. H-Value is the direct output from the analysis in NP-768.
Example MIP Calculation

Based on NP-768 Data

- Example MIP is based on Plant A tornado missile hit probability data (EPRI NP-768, Section 3).
- NP-768 does not calculate MIP directly.
- Derive example MIP from Plant A “H-Value,” tornado frequency, and total exposed area of plant structures from NP-768 data.

**MIP Derivation**

**“H-Value” (missile hit probability)**
Reference - EPRI NP-768, Table 3-15, page 3-22

<table>
<thead>
<tr>
<th>Tornado Intensity (F-Scale)</th>
<th>NRC Region</th>
<th>Lower Limit</th>
<th>Mean</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I</td>
<td>4.04x10^{-9}</td>
<td>1.62x10^{-8}</td>
<td>2.84x10^{-8}</td>
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<tr>
<td></td>
<td>II</td>
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<td></td>
<td>III</td>
<td>7.38x10^{-11}</td>
<td>2.96x10^{-10}</td>
<td>5.19x10^{-10}</td>
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<tr>
<td></td>
<td>I</td>
<td>8.16x10^{-9}</td>
<td>2.53x10^{-8}</td>
<td>4.23x10^{-8}</td>
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<tr>
<td></td>
<td>II</td>
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<td>1.94x10^{-9}</td>
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<td>III</td>
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<td>3.68x10^{-10}</td>
<td>6.18x10^{-10}</td>
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<tr>
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<td>I</td>
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<td>1.37x10^{-8}</td>
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<tr>
<td></td>
<td>II</td>
<td>3.02x10^{-10}</td>
<td>6.06x10^{-10}</td>
<td>9.11x10^{-10}</td>
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<tr>
<td></td>
<td>III</td>
<td>0.0</td>
<td>2.19x10^{-10}</td>
<td>4.40x10^{-10}</td>
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<tr>
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<td>I</td>
<td>3.60x10^{-9}</td>
<td>1.14x10^{-8}</td>
<td>1.93x10^{-8}</td>
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<tr>
<td></td>
<td>II</td>
<td>4.11x10^{-10}</td>
<td>7.49x10^{-10}</td>
<td>1.09x10^{-9}</td>
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<tr>
<td></td>
<td>I</td>
<td>8.68x10^{-10}</td>
<td>3.99x10^{-9}</td>
<td>7.11x10^{-9}</td>
</tr>
</tbody>
</table>

**Example MIP Calculation**

Plant A Mean H-Value Data

<table>
<thead>
<tr>
<th>F-Scale</th>
<th>1/(missile*year)</th>
<th>Tornado Mean Frequency</th>
<th>Area of Plant Structures</th>
<th>MIP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Table 3-15</td>
<td>Table 3-4</td>
<td>Table 3-1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
[H-Value] / [Tornado Frequency] / [Unit Area of Plant Structures] = MIP
\]
• MIP mean values for the three plants modeled in NP -768, (Plant A, B1, B2) are shown in the table below.
• A set of MIP values developed that bound all three sets of mean values.

<table>
<thead>
<tr>
<th></th>
<th>MEAN MIP Plant A</th>
<th>MEAN MIP Plant B1</th>
<th>MEAN MIP Plant B2</th>
<th>Bounding Mean MIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>F'2</td>
<td>5.81E-11</td>
<td>2.7E-11</td>
<td>1.1E-10</td>
<td><strong>1.1E-10</strong></td>
</tr>
<tr>
<td>F'3</td>
<td>1.97E-10</td>
<td>1.2E-10</td>
<td>5.2E-11</td>
<td><strong>2.5E-10</strong></td>
</tr>
<tr>
<td>F'4</td>
<td>2.27E-10</td>
<td>3.6E-10</td>
<td>2.2E-10</td>
<td><strong>5.0E-10</strong></td>
</tr>
<tr>
<td>F'5</td>
<td>8.66E-10</td>
<td>6.2E-10</td>
<td>4.1E-10</td>
<td><strong>9.0E-10</strong></td>
</tr>
<tr>
<td>F'6</td>
<td>1.33E-09</td>
<td>5.7E-10</td>
<td>1.0E-09</td>
<td><strong>1.7E-09</strong></td>
</tr>
</tbody>
</table>
MEAN MIP VALUES

Mean MIP Curve

Bounding Mean Equation:
\[ y = -1E-16x^3 + 9E-14x^2 - 1E-11x + 5E-10 \]
\[ R^2 = 1 \]

MIP Derivation
Upper limit MIP values for the three NP-768 plants are provided in the table below. A set of MIP values were developed that bound all three sets of upper limit values. The set of MIP values that will be used in the TMRE is based on the bounding upper limit MIP values increased by a factor of 1.25.

<table>
<thead>
<tr>
<th></th>
<th>Bounding Mean MIP</th>
<th>Upper Limit MIP Plant A</th>
<th>Upper Limit MIP Plant B1</th>
<th>Upper Limit MIP Plant B2</th>
<th>Bounding Upper Limit MIP</th>
<th>TMRE MIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F'2$</td>
<td>$1.1E-10$</td>
<td>1.0E-10</td>
<td>4.9E-11</td>
<td>1.9E-10</td>
<td>1.9E-10</td>
<td>2.4E-10</td>
</tr>
<tr>
<td>$F'3$</td>
<td>$2.5E-10$</td>
<td>3.3E-10</td>
<td>2.2E-10</td>
<td>8.4E-11</td>
<td>4.1E-10</td>
<td>5.1E-10</td>
</tr>
<tr>
<td>$F'4$</td>
<td>$5.0E-10$</td>
<td>3.4E-10</td>
<td>6.3E-10</td>
<td>3.2E-10</td>
<td>8.0E-10</td>
<td>1.0E-09</td>
</tr>
<tr>
<td>$F'5$</td>
<td>$9.0E-10$</td>
<td>1.5E-09</td>
<td>9.1E-10</td>
<td>6.3E-10</td>
<td>1.5E-09</td>
<td>1.9E-09</td>
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<td>$F'6$</td>
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<td>8.8E-10</td>
<td>1.6E-09</td>
<td>3.0E-09</td>
<td>3.8E-09</td>
</tr>
</tbody>
</table>
MIP Derivation
Target Characteristics

- Surface Area
- Exposure
- Correlation
Target Surface Area

- EDG Exhaust Stacks
- Outside Cable Vault
- CSTs
- SW Components
Definition of Correlation

- Exposed targets are correlated if the targets can be struck by the same tornado missile, considering the set of missiles defined in the licensing basis.
EDG Exhaust Stacks

• Two separate targets, not correlated
• Exposed cylindrical surface (870 ft² each)
Outside Cable Vault

- Two targets, one vault for each division that are not correlated – separated by ~ 120ft.
- Area of concrete pad vault cover (58 ft²)
Condensate Storage Tanks

- Two tanks, correlated, representing one target
- Exposed area calculated from exposed five-sided rectangular box (3200 ft²)
Service Water Components

- Two targets per unit — service water header isolation valve, not correlated
- Only rollup door provides a path to target. However target is shielded by circ water pumps which a robust barrier to missile progress. **Target screened out.**
Missile tracks are limited to paths that avoid the concrete building in the upper right of the plan view and travels through both the outside personnel and EDG room entry doors. Target Screened Out.
Calculating Tornado Missile Risk (TMR)

• Exposed Equipment Failure Probability
• PRA Model Modifications
• Risk Calculation
• Comparison to Acceptance Criterion
Exposed Equipment Failure Probability
CST Example

<table>
<thead>
<tr>
<th>Target</th>
<th>F'-Scale</th>
<th>MIP</th>
<th># of Missiles</th>
<th>Target Area</th>
<th>Conditional Probability (Fragility)</th>
<th>Probability of Failure from Missile Strike</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSTs</td>
<td>2</td>
<td>2.41E-10</td>
<td>10000</td>
<td></td>
<td>1.0E+00</td>
<td>7.7E-03</td>
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<tr>
<td></td>
<td>3</td>
<td>5.13E-10</td>
<td>10000</td>
<td></td>
<td>1.0E+00</td>
<td>1.6E-02</td>
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<tr>
<td></td>
<td>4</td>
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<td>10000</td>
<td>3200</td>
<td>1.0E+00</td>
<td>3.2E-02</td>
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<td>10000</td>
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<td>1.0E+00</td>
<td>1.2E-01</td>
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</table>

Calculating Tornado Missile Risk
PRA Model Modifications - Overview

PRA logic modeling of TMRE discussed per ASME/ANS PRA Standard Technical Elements:

- Initiating Event/Hazard Analysis (IE)
- Accident Sequence Analysis (AS)
- Success Criteria (SC)
- Systems Analysis (SY)
- Human Reliability Analysis (HR)
- Data Analysis (DA)
- Quantification (QU)
PRA Model Modifications – IE

- Site tornado hazard (e.g., based on NUREG/CR-4461, Rev. 2)
- Hazard implemented in PRA as separate initiating event per F’-Scale hazard interval
  - F’0 and F’1 non-significant risk contributors, not specifically modeled
  - F’2, F’3, F’4, F’5 and F’6 hazard intervals specifically modeled
- Hazard interval frequency = [Hazard Exceedance Frequency at Beginning of Interval] - [Hazard Exceedance Frequency at End of Interval]
Logic Model Implementation - AS

- Loss of Offsite Power Accident (LOOP) accident sequence model used
- LOOP initiators replaced by F’2 thru F’6 tornado hazard interval initiating events
PRA Model Modifications - SC

- No changes to systemic or thermal hydraulic success criteria bases
- Tornado events do not change these bases
System fault tree logic supporting LOOP accident sequence logic maintained, but modified for tornado as described below:

- Tornado hazard interval initiators inserted in system logic in same locations the LOOP initiators exist
- Equipment/Functions in logic models assumed directly failed (set to TRUE in flag file, or tornado hazard interval initiating events inserted directly under these functions to fail them):
  - Gas Turbine
  - Fire Pumps
  - Instrument Air
- Tornado missile impact failure probabilities for each target modeled with AND gate as shown
- Target fragility assumed 1.0 given damaging missile hit
Logic Model Implementation - HR

- **Pre-Initiator Human Error Probabilities:** no changes
  - Tornado events do not change the probabilities of latent errors

- **Post-Initiator Human Error Probabilities (HEPs)**
  - In Main Control Room (MCR) actions
    - HEPs for LOOP scenarios used
  - Outside MCR actions
    - In safety-related buildings: used HEPs for LOOP scenarios
    - Actions exposed to wind effects:
      - HEPs set to 1.0 for actions required at $t \leq 60$ minutes
      - HEPs for LOOP scenarios used for action required at $t > 60$ minutes

- **Recovery Actions**
  - No recovery credit for wind-induced failures, including loss of offsite power (i.e., offsite AC recovery probabilities set to 1.0 or deleted from logic)

Calculating Tornado Missile Risk
Logic Model Implementation - DA

- No changes to random failure probabilities, common cause failure (CCF) probabilities, or maintenance unavailabilities.
- Tornado events do not change these probabilities (refer to previous slides regarding implementation of wind-induced failures in the system fault tree logic and human reliability analysis).
Logic Model Implementation - QU

- Model quantified in the same manner as base PRA
- Risk metric quantified: Core Damage Frequency (CDF)
Relevance of Notional Plant F&Os

- Reviewed and determined to have no impact on RG 1.200 Internal Events PRA use for TMRE methodology
- Licensee will cover F&Os in addition to defense-in-depth and safety margin in LAR submittal
Acceptance Criterion

- SRP 3.5.1.4, Revision 4 (March 2015)

Section II, SRP Acceptance Criterion 3:

“The method of identifying appropriate design-basis missiles generated by natural phenomena should be consistent with the acceptance criteria defined for the evaluation of potential accidents from external sources in **SRP Section 2.2.3**, ‘Evaluation of Potential Accidents.’ A licensee or applicant may justify the acceptability of the use of another methodology.”
Acceptance Criterion

- SRP 2.2.3, Revision 3 (March 2007)

Section II, SRP Acceptance Criterion 2:

“If data are not available to make an accurate estimate of the event probability (see Technical Rationale 2), an expected rate of occurrence of potential exposures resulting radiological dose in excess of the 10 CFR 50.34(a)(1) as relates to the requirements of 10 CFR Part 100, by an order of magnitude of $10^{-6}$ per year is acceptable if, when combined with reasonable qualitative arguments, the realistic probability can be shown to be lower.”
Technical Rationale 2

- SRP 2.2.3, Revision 3 (March 2007)
  
  Section II, Technical Rationale 2:
  
  “Data are often not available to enable the accurate calculation of probabilities because of the low probabilities associated with the events under consideration. Accordingly, the expected rate of occurrence of potential exposures in excess of the 10 CFR 50.34 (a)(1) requirements as they relate to the requirements of 10 CFR Part 100 guidelines by an order of magnitude of 10^{-6} per year is acceptable if, when combined with reasonable qualitative arguments, the realistic probability can be shown to be lower.”
EPRI NP-768 conservatisms (basis for MIP values):

**Plant Model Orientation**
- Oriented in compass direction that maximizes missile impact probabilities on modeled targets

** Missile Injection**
- Methodologies conservative to favor missile injection and transport

Examples:
- Each missile positioned to wind to maximize lift probability
- Each missile sample is independent of other missiles; thus, each missile transport not hindered by possible collision with other missiles
TMRE Conservatisms

• MIP
  - Upper limit
  - Additional 25% added for conservatism

• Target Hit Probability
  - Target elevation
    ▪ High & low targets have same probability of being hit

• Target Failure Given Hit (Fragility)
  - Base approach directly fails target function with 1.0 failure probability given a missile hit
TMRE Conservatisms

PRA Model

• No Recoveries

  - No recoveries of wind-induced failures (including offsite AC) during the PRA mission time.
TMRE COMPARISON TO RG 1.200

- TMRE CDF: 2.32E-07
- RG 1.200 CDF: 1.76E-07
### TMRE MISSILE SENSITIVITY

<table>
<thead>
<tr>
<th>F'-Scale</th>
<th>10,000 MISSILES</th>
<th>20,000 MISSILES</th>
<th>50,000 MISSILES</th>
<th>100,000 MISSILES</th>
</tr>
</thead>
<tbody>
<tr>
<td>F'6 (&gt;277 mph)</td>
<td>6.27E-10</td>
<td>1.66E-09</td>
<td>7.10E-09</td>
<td>2.58E-08</td>
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<tr>
<td>F'5 (209-277 mph)</td>
<td>6.77E-09</td>
<td>1.48E-08</td>
<td>4.98E-08</td>
<td>1.47E-07</td>
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<tr>
<td>F'4 (168-209)</td>
<td>2.21E-08</td>
<td>4.27E-08</td>
<td>1.22E-07</td>
<td>3.08E-07</td>
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<tr>
<td>F'3 (135-168 mph)</td>
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<td>8.84E-08</td>
<td>2.13E-07</td>
<td>4.65E-07</td>
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<tr>
<td>F'2 (103-135 mph)</td>
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<td>4.49E-07</td>
<td>8.86E-07</td>
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<tr>
<td>TOTAL</td>
<td>2.32E-07</td>
<td>3.68E-07</td>
<td>8.40E-07</td>
<td>1.83E-06</td>
</tr>
</tbody>
</table>

- The sensitivities all assume uniform distribution of missiles across the site; this is conservative since missiles are typically concentrated away from targets.
- Missile count will be verified during the plant walkthrough – if 10,000 is not conservative the missile count will be adjusted.
The NEI Tornado Missile Risk Evaluator provides a simple and demonstrably conservative tool that can be broadly used by nuclear power plant licensees to assess the need to provide additional physical protection for plant components.