Tornado Missile Protection and the Tornado Missile Risk Evaluator

Bruce Montgomery
Technical Advisor
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Meeting Objectives

- Provide an overview of the industry's Tornado Missile Risk Evaluator (TMRE)
- Update NRC on TMRE model development activities and validation results
- Describe industry's plan for TMRE deployment including pilot applications and submittal of NEI TMRE guidance to NRC for endorsement
- Obtain NRC feedback

Background Discussion

- Issuance of NRC RIS 2015-06 and companion enforcement discretion memorandum
- Industry actions in response to RIS
- TMRE "Tabletop" public meeting March 23, 2016
- Public meetings May 11 and June 29, 2016
- TMRE refinements and validation activities completed October 31, 2016

Agenda

• TMRE Process Overview	Jack Grobe
• TMRE Model Development	Alex Gilbreath
• TMRE Benchmarking/Sensitivity	Leo Shanley
• TMRE Missile/Target Characteristics	Leo Shanley
• TMRE Conservatisms/Uncertainties	Leo Shanley
• TMRE Guidance Document	Bruce Montgomery
• License Amendment Requests	Ken Lowery
• Overview of NRC Review Plan	NRC
• TMRE Deployment	Bruce Montgomery
• Additional Topics	Jack Grobe
• Wrap-up and Closure	Bruce Montgomery

TMRE Process Overview

Jack Grobe
Exelon

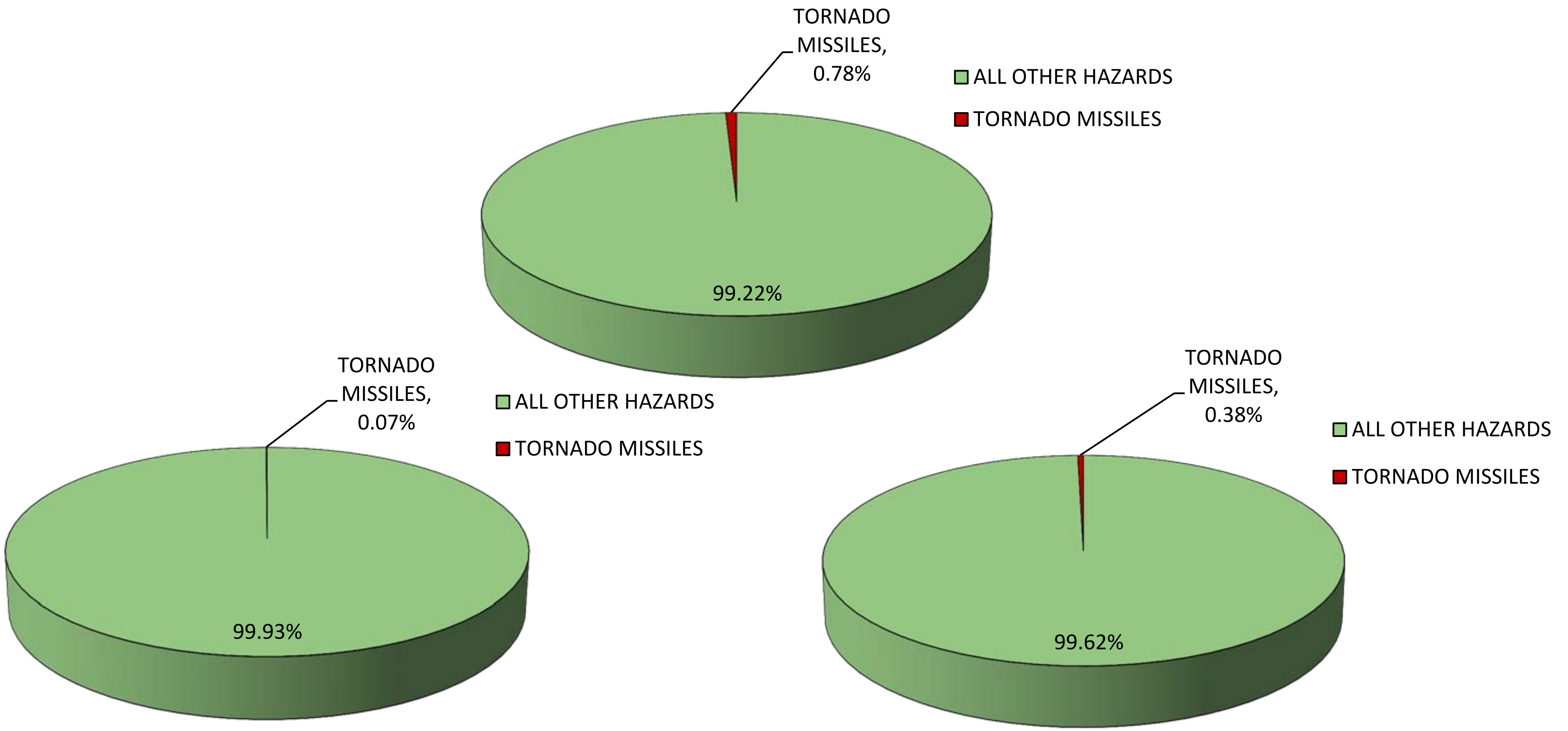
Industry Approach to Resolve TMP Issues

- Facilities are performing licensing, design and structural evaluations identifying Tornado Missile Protection (TMP) vulnerabilities and nonconforming conditions
- TMP nonconforming conditions are not a significant safety concern
  - Nonconforming conditions involve limited exposure to tornado missiles
  - Frequency of a damaging tornado is very low
- Cost of modifications to resolve nonconforming conditions can be high
- Legacy TMP nonconforming conditions are ideal candidates for resolution through a risk informed license amendment request (LAR)

Tornado Missile Risk Profile

Core Damage Frequency Fraction from Tornado Missiles

(Three Operating Facilities with RG1.200 Peer-Reviewed High Winds PRAs)



Tornado Missile Risk Evaluator (TMRE)

- NEI facilitating development of the TMRE beginning in September 2015
  - Duke, Entergy, Exelon, NextEra, Southern, TVA and Xcel supported by EPRI and JENSEN HUGHES
  - Extensive engagement with NRC
- Goals of TMRE model development - Cost-effective, risk-informed simplified approach that can be …
  - Effectively run by utility staff
  - Efficiently reviewed by NRC staff
  - Applied across the operating fleet

Discovery Activities

- In response to the operating experience contained in the NRC Regulatory Issue Summary, licensees are evaluating tornado missile protection
- Typical discovery activities involve five steps:
  - Assembly of licensing basis (PSAR, Q&A, CP, FSAR, Q&A, OL, LARs, SEP, IPEEE)
  - Assembly of design documentation
  - Screening the tornado protective features for equipment required to be protected using design drawings to identify potential vulnerabilities
  - Performing physical walkdowns to evaluate potential vulnerabilities
  - Identification of nonconforming conditions

TMRE Fundamentals

- TMP nonconforming conditions and other vulnerabilities are known
- Modify the facility Internal Events PRA (IE PRA)
  - Establish the Base Case PRA model
    - Address the tornado initiating event – Loss of offsite power (LOOP)
      - LOOP initiating frequency adjusted for site specific F’2 through F’6 tornado hazard intervals
    - Make unavailable those SSCs not protected from the effects of tornados
    - Adjust human error probabilities for actions in areas exposed to tornados
  - Establish the Degraded Case PRA model
    - **Incorporate exposed equipment failure probability (EEFP) for SSCs with TMP nonconforming conditions and vulnerabilities**
- Determine change in core damage frequency associated with the SSCs having nonconforming TMP - Compare to the RG 1.174 acceptance criteria
- Submit RG 1.174 LAR

Consideration of F'0 and F'1 Tornados

Characterization of Tornado Damage

National Science Engineering Center and The Weather Channel

EF0 and EF1 tornados are not considered in the TMRE since they do not generate damaging missiles

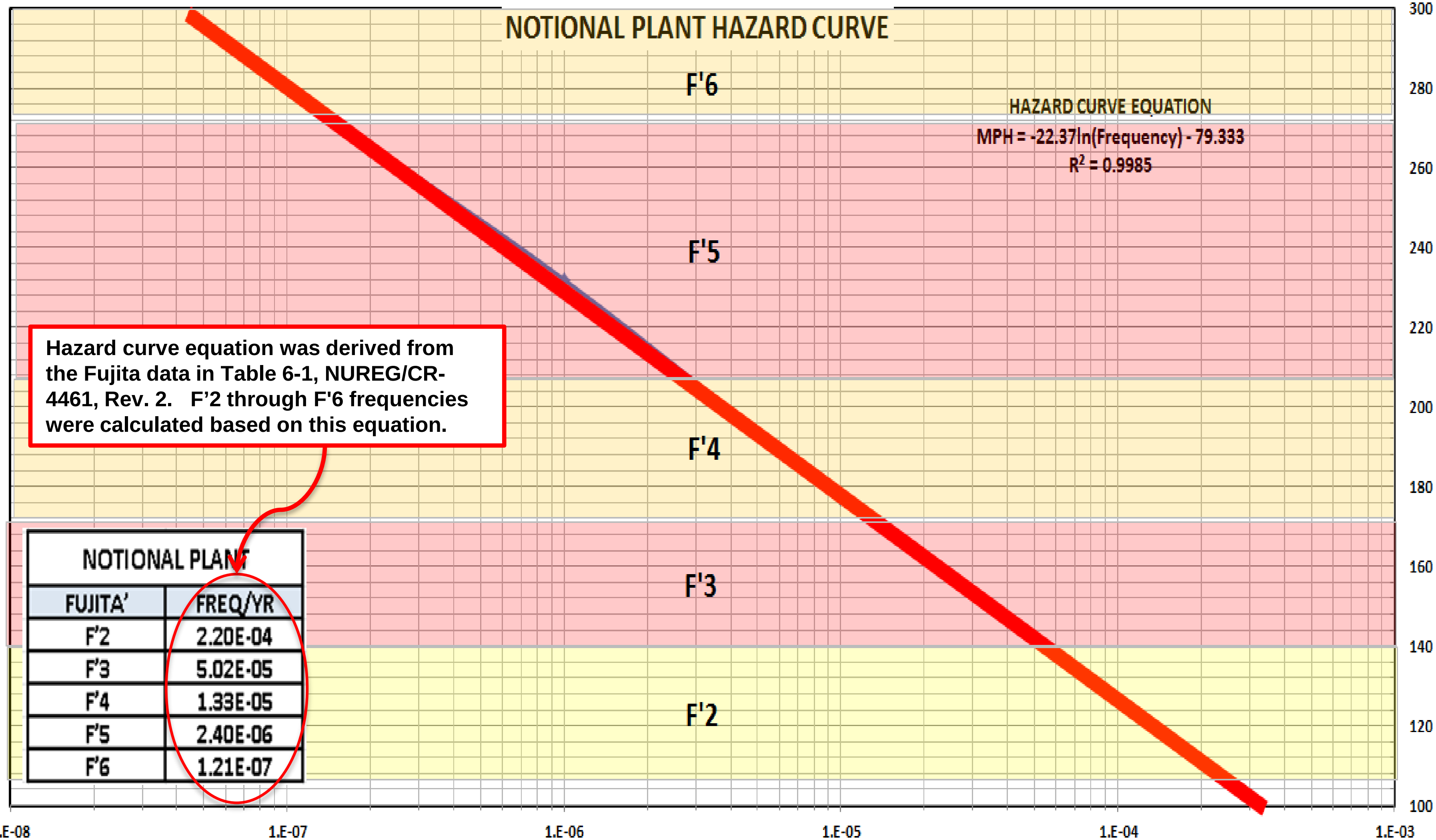
- EF0 - Light damage. Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over.
- EF1 - Moderate damage. Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.
- EF2 - Considerable damage. Roofs torn off well-constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
- EF3, EF4, EF5 and EF6: More significant damage.

Tornado Strike Frequency

NUREG/CR-4461, Revision 2, Table 6-1: Tornado Wind Speed Estimates for United States Nuclear Power Plant Sites derived from plant-specific NOAA data

NUREG/CR-4461, Rev 2 - Tornado Climatology Data - FUJITA DATA						
Freq/Yr	MPH					
	Plant Q	Plant R	Plant S	Plant T	Plant U	Plant V
1.00E-05	177	209	147	143	128	142
1.00E-06	232	260	205	203	191	203
1.00E-07	280	306	256	254	245	255

Notional Plant Tornado Strike Frequency



NOTIONAL PLANT	
FUJITA'	FREQ/YR
F'2	2.20E-04
F'3	5.02E-05
F'4	1.33E-05
F'5	2.40E-06
F'6	1.21E-07

Exposed Equipment Failure Probability

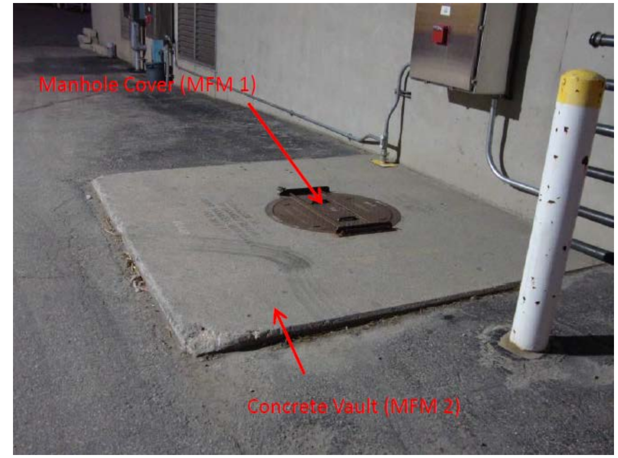
EEFP = (MIP) x (# of Missiles) x (Target Exposed Area) x (Fragility)

- Missile Impact Parameter (MIP) – <u>generic factor</u>
  - Missile hit probability per missile per exposed target area for each tornado intensity and exposed target height
- Number of damaging missiles for robust and less robust exposed targets – <u>generic factor</u>
- Conditional failure probability or fragility – <u>generic factor</u>
- TMP nonconformance characteristics – <u>**only site specific factor**</u>
  - Exposed area
  - Robustness of target
  - Physical correlation between redundant targets

Examples of Exposed Targets

EDG Exhaust Stacks

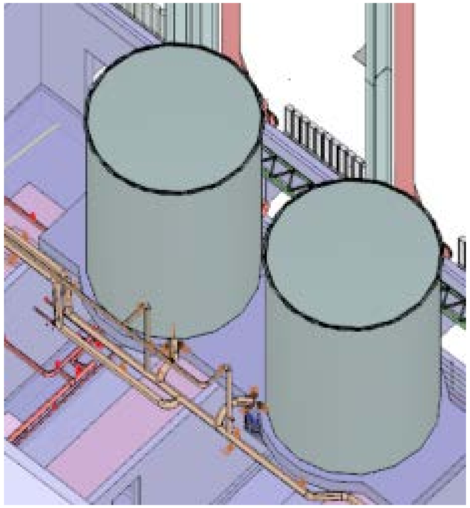
EDG Exhaust Stack Support Bracket

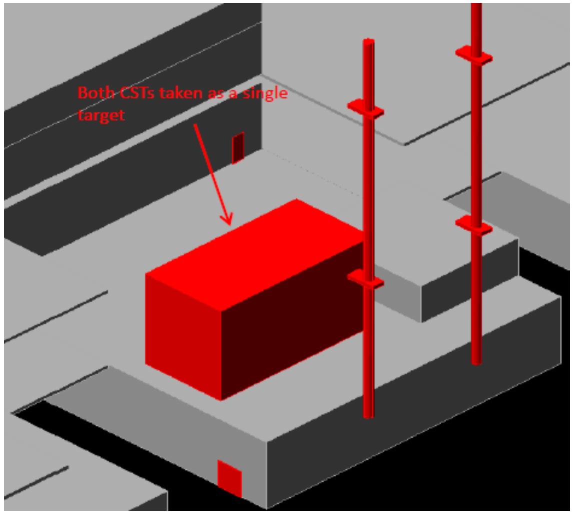


Cable Vault

- Each EDG exhaust stack is a separate non-correlated three dimensional cylindrical target with exposed area of 870 sq.ft.
- Each cable vault is a separate non-correlated two dimensional rectangular target with exposed area of 58 sq.ft.

Examples of Exposed Targets





The two CSTs and associated instrumentation are considered as one three dimensional physically correlated rectangular box target with exposed area of 3,200 sq.ft. (five sides)

Service Water Pumphouse

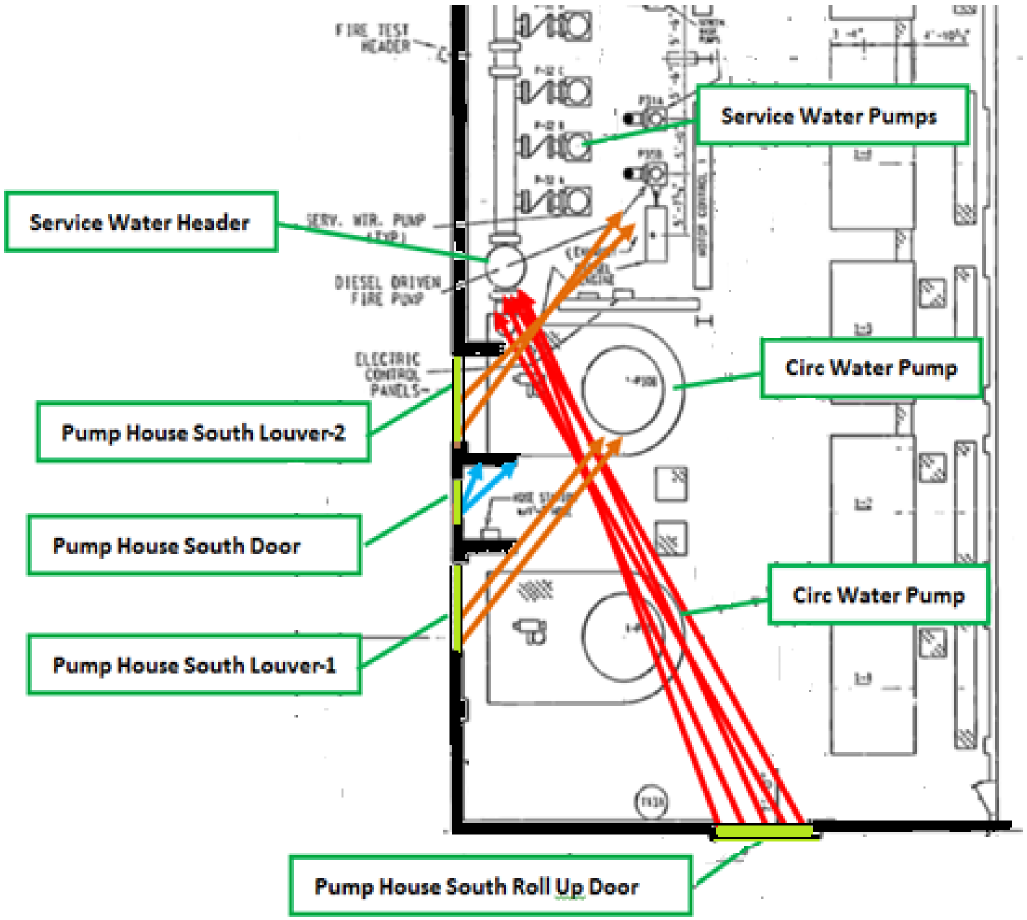
Access door and louvers unprotected from tornado missiles.

Sheet metal rollup door unprotected from tornado missiles.

Dumpsters filled with metal conduit fittings and pipe were relocated after walkdown.

The walkdown identified an unnecessary concentration of potential missiles near TMP nonconforming conditions

Service Water Pumphouse



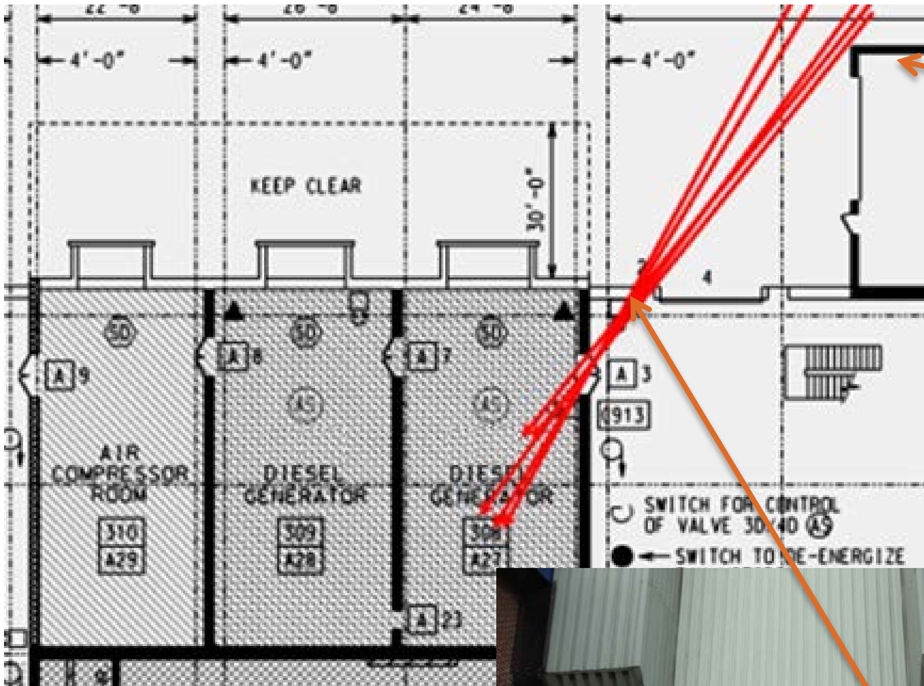
Pumphouse Missile Path Through Louvers, Doors, and Roll-Up Doors

Potential missile paths and exposure area evaluated by assessing missile tracks through vulnerable openings

Only the rollup door provides a direct path to an exposed target - intervening equipment reduces exposure area

Small exposure window through rollup door

EDG & Auxiliaries

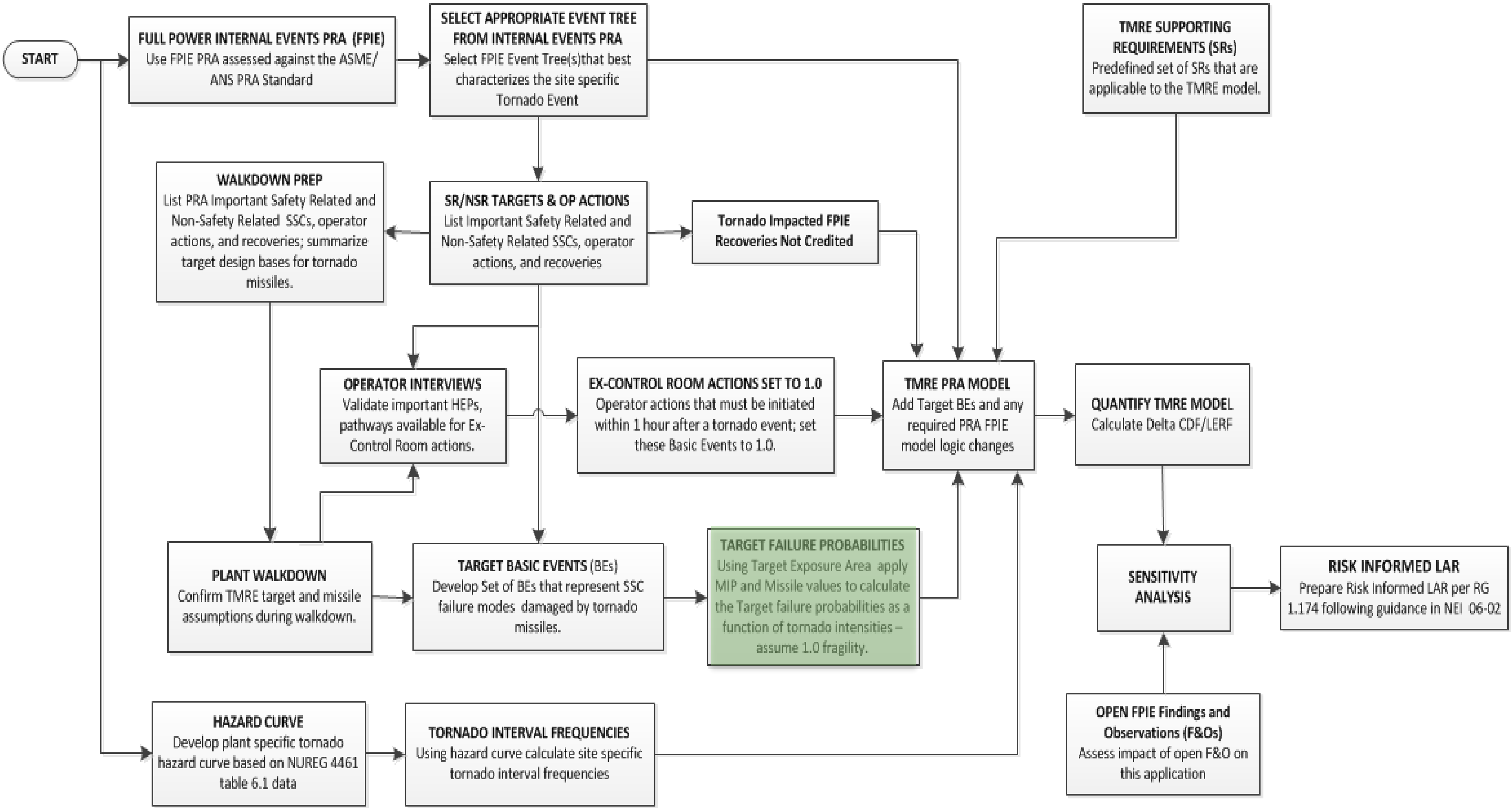


Extremely small exposure window

TMRE Model Development

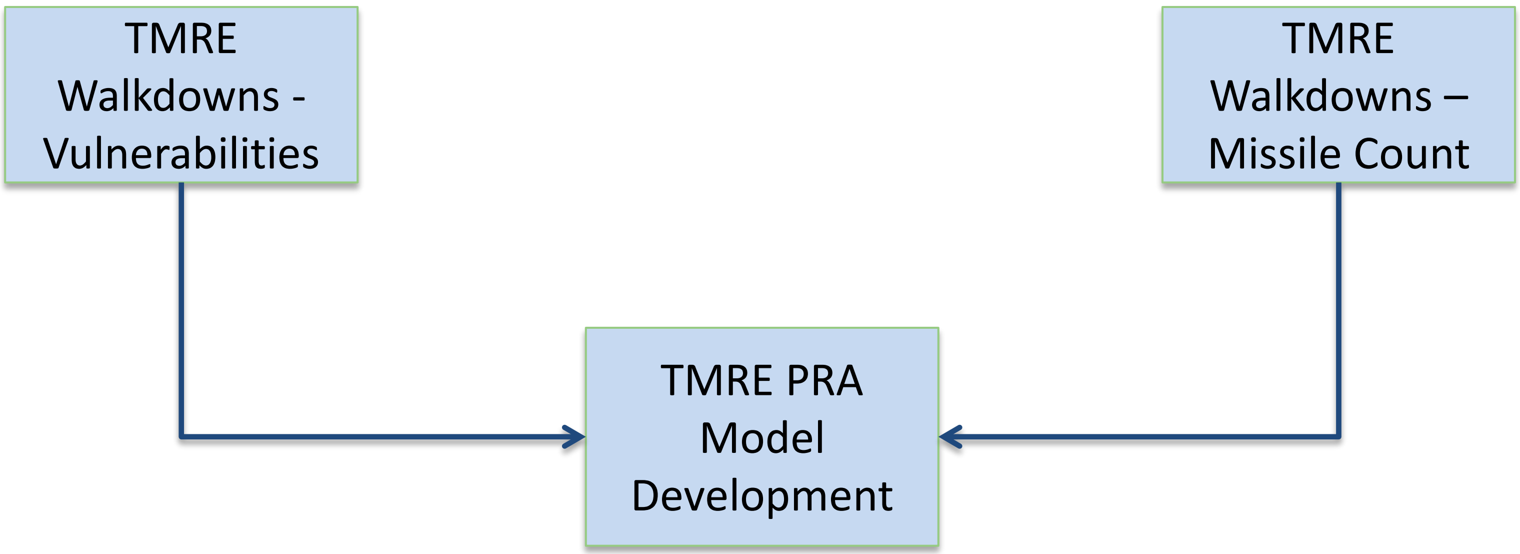
Alex Gilbreath
Southern Nuclear

TMRE Model

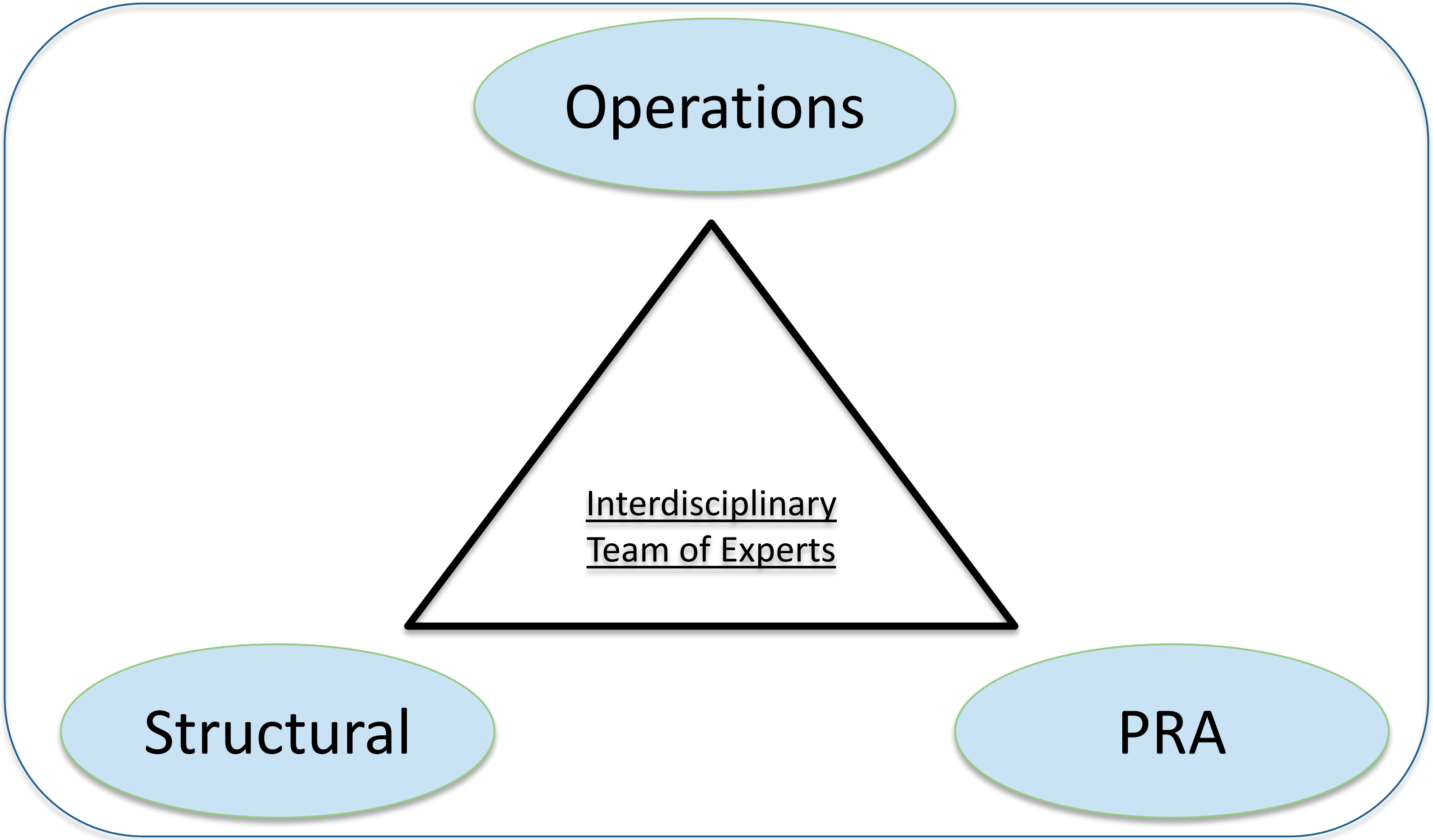

START
FULL POWER INTERNAL EVENTS PRA (FPIE) Use FPIE PRA assessed against the ASME/ ANS PRA Standard
SELECT APPROPRIATE EVENT TREE FROM INTERNAL EVENTS PRA Select FPIE Event Tree(s)that best characterizes the site specific Tornado Event
TMRE SUPPORTING REQUIREMENTS (SRs) Predefined set of SRs that are applicable to the TMRE model.
WALKDOWN PREP List PRA Important Safety Related and Non-Safety Related SSCs, operator actions, and recoveries; summarize target design bases for tornado missiles.
SR/NSR TARGETS & OP ACTIONS List Important Safety Related and Non-Safety Related SSCs, operator actions, and recoveries
Tornado Impacted FPIE Recoveries Not Credited
OPERATOR INTERVIEWS Validate important HEPs, pathways available for Ex-Control Room actions.
EX-CONTROL ROOM ACTIONS SET TO 1.0 Operator actions that must be initiated within 1 hour after a tornado event; set these Basic Events to 1.0.
TMRE PRA MODEL Add Target BEs and any required PRA FPIE model logic changes
QUANTIFY TMRE MODEL Calculate Delta CDF/LERF
PLANT WALKDOWN Confirm TMRE target and missile assumptions during walkdown.
TARGET BASIC EVENTS (BEs) Develop Set of BEs that represent SSC failure modes damaged by tornado missiles.
TARGET FAILURE PROBABILITIES Using Target Exposure Area apply MIP and Missile values to calculate the Target failure probabilities as a function of tornado intensities – assume 1.0 fragility.
SENSITIVITY ANALYSIS
RISK INFORMED LAR Prepare Risk Informed LAR per RG 1.174 following guidance in NEI 06-02
HAZARD CURVE Develop plant specific tornado hazard curve based on NUREG 4461 table 6.1 data
TORNADO INTERVAL FREQUENCIES Using hazard curve calculate site specific tornado interval frequencies
OPEN FPIE Findings and Observations (F&Os) Assess impact of open F&O on this application

TMRE Walkdowns

- The purpose of the TMRE walkdowns is to inform the TMRE PRA model development.



Walkdown Team



Vulnerability Confirmation

- Review each nonconformance to verify missile vulnerability and affected SSCs
- Document details of targets:
  - Dimensions, robustness, and correlation
  - Dimensions of exposed SSCs, whose exposure may be limited by openings
    - Example: an SSC that is exposed to tornado missiles due to an opening in a Class I structure.
  - Include SSC support systems or piece-parts
    - Example: MOV –valve operator, cabling, local controller
- Identify and document additional vulnerabilities
- Determine necessary adjustments to internal events PRA

Vulnerability Confirmation

- Identify and document additional SSCs that are vulnerable to wind or missile failures
  - The TMRE needs to consider impact of tornado winds and missiles on all SSCs credited in the PRA
    - Example: Non-safety related SSC (diesel fire pump)
  - Walkdown may identify other SSCs not identified through documentation review
- Vertical Missiles
  - Plants that do not include vertical missiles in their licensing basis must still consider vertical missiles damaging SSCs as part of the TMRE
  - Looking for SSCs credited in PRA that have inadequate protection against vertical missiles

Vulnerability Confirmation

- SSC dimensions and dimensions of openings that expose SSC to tornado missiles (e.g., louvers or doors in Class 1 buildings)
  - Note location of SSC relative to openings; is the missile path to the SSC limited by geometry/layout?
- Associated piping, cabling, and controllers
- Walls or shielding surrounding the SSC
- Proximity of SSCs to non-Class I structures or other components
  - Can the failure of an SSC result in the failure of a credited SSC (e.g., water tank falls onto building)?

PRA Considerations and Inputs

- The walkdowns provide key inputs to the PRA model
  - Non-conformances and other vulnerabilities have new basic event failure modes created.
  - Measurements provide a component of the EEFP, including the effects of physical correlation.
  - While a bounding missile count will be established, TMRE walkdowns are conducted to ensure the viability of the number for a given plant.
  - Operator Actions are identified and adjusted.

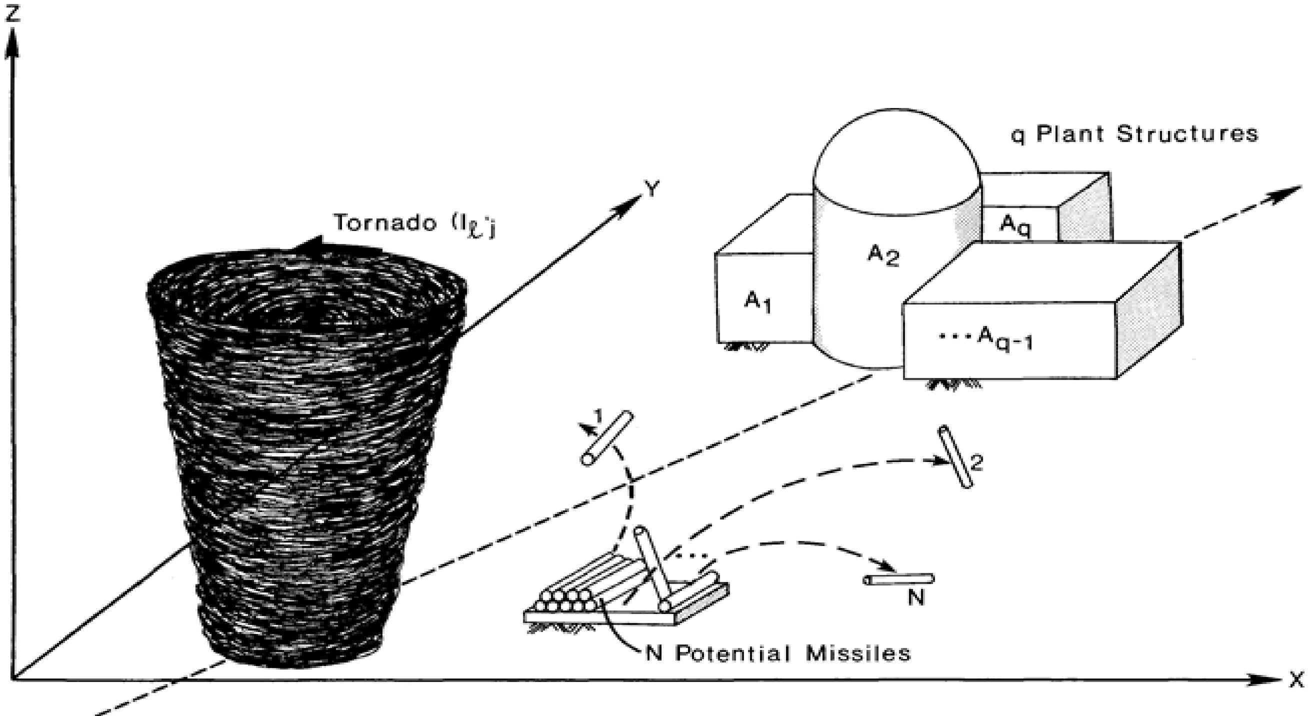
TMRE Methodology - EEFP

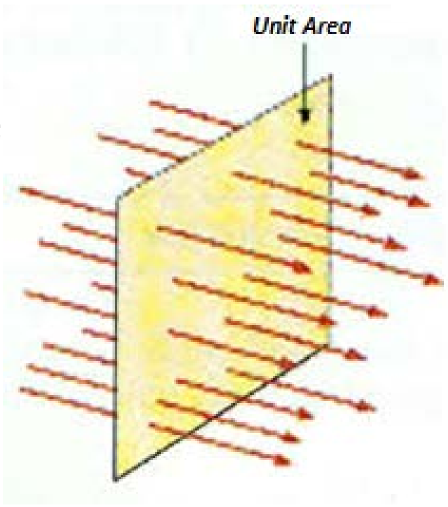
- One of the key inputs to the TMRE is the Exposed Equipment Failure Probability, or EEFP.
- In practice, the EEFP serves as the basic event failure probability for the tornado missile strike failure mode of exposed equipment (or targets)
- The EEFP depends on missile impact parameter (MIP), the surface area (SA) and fragility of the targets, and the number of damaging missiles.
- EEFP is defined by the following linear equation:

$$EEFP_i = (MIP_i) \times (SA) \times (\#\ of\ Missiles) \times (Fragility)$$

Where i is the tornado missile intensity, # of missiles is a bounding value, and the fragility is set to unity.

MIP Definition





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). The MIP also depends on the exposed target elevation.

MIP Derivation

MIP = H Value / Tornado Frequency /Area of Plant Structures

Where Units are:

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

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

NP-768 Plant A Target MIP Calculations

	Target 1	*Target 2*	*Target 3*	*Target 4*	*Target 5*	*Target 6*	*Target 7*	*3/23 Proposed MIP*
F'2	2.6E-12	1.7E-11	7.4E-11	2.9E-10	5.8E-11	2.7E-10	5.6E-11	**2.4E-10**
F'3	1.5E-11	1.8E-10	1.7E-10	8.9E-10	3.7E-11	1.8E-09	2.9E-10	**5.1E-10**
F'4	1.8E-11	1.4E-10	2.9E-10	1.0E-09	1.1E-09	2.9E-10	6.1E-10	**1.0E-9**
F'5	1.6E-11	1.1E-09	1.2E-09	1.8E-09	7.3E-10	1.3E-09	1.4E-09	**1.9E-9**
F'6	5.4E-11	9.9E-10	1.9E-09	3.0E-09	1.6E-09	1.4E-09	2.7E-09	**3.8E-9**

- This table was presented to NRC in 6/29 meeting
- All target MIPs calculated with all *exposed* areas (walls and roof)
  - See next slide for Plant A target buildings and layout
- Target 4 MIP values generally bound the original proposed MIP
- Industry recalculated Target 4 MIPs using only wall area, excluding the roof (smaller area results in higher MIP)

Plant A Layout (EPRI NP-768)

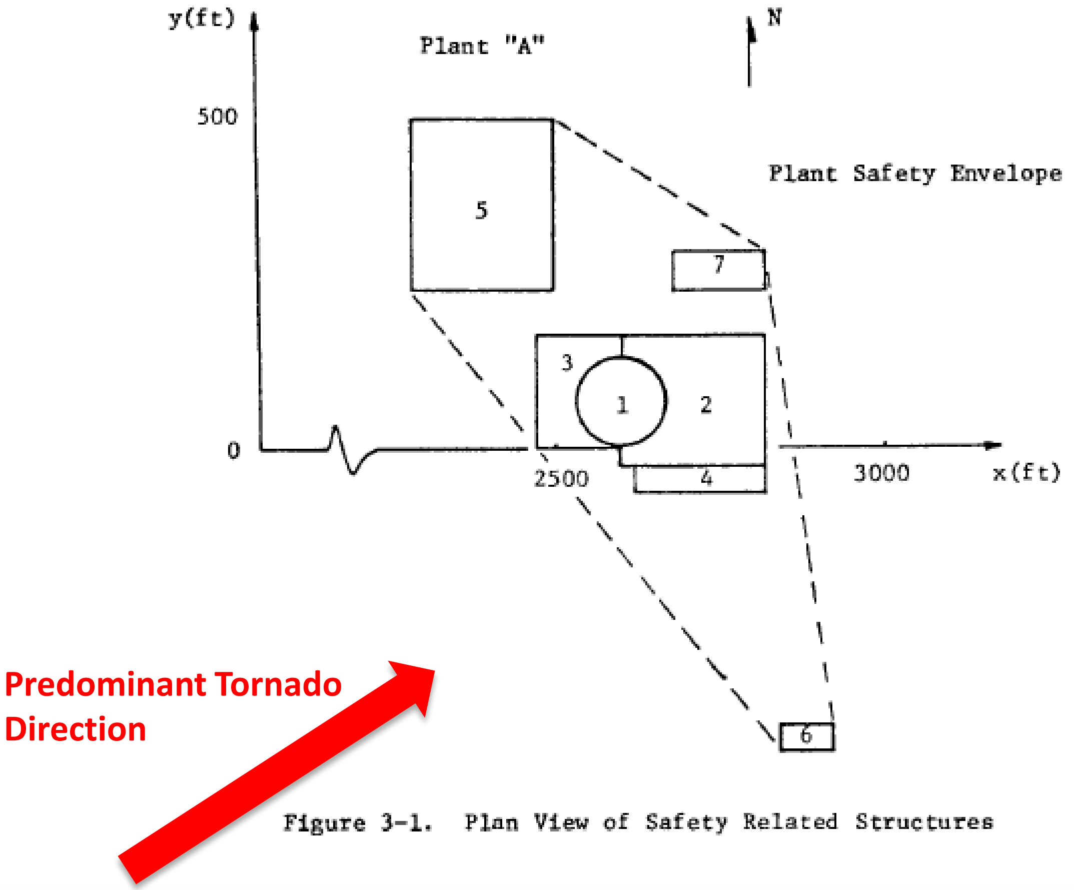


Figure 3-1. Plan View of Safety Related Structures

Lower Elevation MIP

	Final MIP Target 4 (no roof)	*Updated MIP Target 4 (6/29)*	*Original MIP (3/23)*
F'2	4.5E-10	2.9E-10	**2.4E-10**
F'3	1.4E-09	8.9E-10	**5.1E-10**
F'4	1.6E-09	1.0E-09	**1.0E-9**
F'5	2.9E-09	1.8E-09	**1.9E-9**
F'6	4.7E-09	3.0E-09	**3.8E-9**

- Recalculated Target 4 MIP using only exposed wall area
- Final Target 4 MIP bounds all previously presented values
- Use these MIP values for targets ≤30 feet elevation

Elevated Target MIP

	Elevated Target MIP
F'2	1.9E-10
F'3	6.0E-10
F'4	6.2E-10
F'5	2.7E-09
F'6	4.4E-09

- MIPs for elevated targets based on total plant missile hits on all surfaces
  - ✓ Roof surface areas excluded but roof hits included
- Use for targets greater than 30’ above grade

Final TMRE MIP Values

	Targets >30’ above grade	*Targets ≤30’ above grade*
F'2	1.9E-10	4.5E-10
F'3	6.0E-10	1.4E-09
F'4	6.2E-10	1.6E-09
F'5	2.7E-09	2.9E-09
F'6	4.4E-09	4.7E-09

Treatment of Horizontal Targets

- The TMRE will assess the risk of vulnerable horizontal targets to vertical missiles
- Final MIP values (ground-level and elevated) will be used for these targets
- This will over-estimate hit probability for horizontal surfaces

Example Calculation of Exposed Equipment Failure Probability, EEFP

(Ground level, Robust Target)

Target	F'-Scale	MIP	# of Missiles	Target Area (ft^2)	Fragility	EEFP
Tank	2	4.5E-10	10,000	1600	1.0	7.20E-3
	3	1.4E-09	10,000		1.0	2.24E-2
	4	1.6E-09	10,000		1.0	2.56E-2
	5	2.9E-09	10,000		1.0	4.64E-2
	6	4.7E-09	10,000		1.0	7.52E-2

Example Calculation of Exposed Equipment Failure Probability, EEFP

(Elevated, Non-robust Target)

Target	F'-Scale	MIP	# of Missiles	Target Area (ft^2)	Fragility	EEFP
AOV	2	1.9E-10	50,000	12	1.0	1.14E-4
	3	6.0E-10	50,000		1.0	3.60E-4
	4	6.2E-10	50,000		1.0	3.72E-4
	5	2.7E-09	50,000		1.0	1.62E-3
	6	4.4E-09	50,000		1.0	2.64E-3

TMRE Quantification: Base Case vs. Degraded Case

Type of SSC	Failure Probability – Base Case	Failure Probability – Degraded Case
• Switchyard • Exposed NSR SSC • Operator Actions outside CR	1.0 with no recovery	1.0 with no recovery
Non-Conformances	No new failure	EEFP
Other Vulnerabilities (SR)	No new failure	EEFP

- It is reasonable to assume complete, non-recoverable failure of exposed SSCs for F2 and above tornadoes.
- Non-conforming SSCs as well as other safety-related vulnerabilities, including horizontal targets, will result in a conservative delta CDF due to the initial assumption of complete protection in the base case.

TMRE Benchmarking

Leo Shanley
JENSEN HUGHES

PLANT X
TMRE VS RG1.200 SEQUENCE COMPARISON

SEQUENCE CDF COMPARISON *[w/o RG 1.200 HEP adjustment]* [ORDERED BY TMRE RANK]							
TMRE Sequences				**RG 1.200 Sequences**			**TMRE/ RG 1.200**
RANK	**Description**	**CDF (per yr)**		**RANK**	**Description**	**CDF (per yr)**	
1	**T1-003_SEQ** *Loss of Aux Feed and F&B Success*	2.9E-07		2	**T1-003_SEQ** *Loss of Aux Feed and F&B Success*	1.4E-08	20
2	**T1-004_SEQ** *LOOP Loss of Aux Feed and F&B*	2.6E-07		1	**T1-004_SEQ** *LOOP Loss of Aux Feed and F&B*	1.2E-07	2.1
3	**SBO-098_SEQ** *TD Aux Feed and Gas Turb fail along with Recovery Failure*	7.7E-08		4	**SBO-098_SEQ** *TD Aux Feed and Gas Turb fail along with Recovery Failure*	6.4E-09	12
4	**LIFTWAY FAIL**	3.8E-08		3	**LIFTWAY FAIL**	1.7E-08	2.2
5	**S2-022_SEQ** *LOOP, RCP seal cooling fail, failure of RCP seals or PORV, or pressurizer SV to reclose [Small LOCA]. HHSI fails and Aux Feed fails*	1.2E-08		6	**S2-022_SEQ** *LOOP, RCP seal cooling fail, failure of RCP seals or PORV, or pressurizer SV to reclose [Small LOCA]. HHSI fails and Aux Feed fails*	8.2E-10	15
TOTAL CDF	*Top 5 Sequences*	**6.8E-07**		**TOTAL CDF**	*Sequences listed*	**1.6E-07**	**4.2**
	All Sequences	**6.8E-07**			*All Sequences*	**1.8E-07**	**3.8**

Plant Y
TMRE VS RG 1.200 Sequence Comparison

Sequence	Sequence Description	TMRE CDF (yr^{-1})	RG 1.200 CDF (yr^{-1})	TMRE/ RG1.200
TBU	Transient with a loss of SSHR and injection fails	7.8E-06	1.9E-06	4.1
TQU	Transient LOCA with a failure of Injection	1.9E-07	9.1E-08	2.1
TBX	Transient with a loss of SSHR and recirculation fails	1.1E-08	6.9E-10	16.4
TQX	Transient LOCA with a failure of recirculation	1.0E-08	6.9E-09	1.5
ATWS	ATWS Sequence	NA	5.4E-11	Not in TMRE
	Total CDF	**8.0E-06**	**2.0E-06**	

- Ranking of sequences is similar
- TMRE sequence CDFs are higher, except for ATWS.

PLANT Y
TMRE VS RG1.200 TARGET COMPARISON

Target #	Target Desc	TMRE CDF (yr^{-1})	RG 1.200 CDF (yr^{-1})	TMRE/ RG1.200
MSLINE	Main steam lines near EDG air intake	5.8E-06	2.3E-08	252.4
FWLINE	Main Feedwater lines near EDG air intake	2.0E-06	1.8E-06	1.1
RWST	Refueling water Storage Tank	8.3E-08	1.4E-09	61.3
SS	Shutdown support Structure Steel building construction 1.0 failure	8.1E-08	1.0E-08	7.9
BSW	Backup service water supply outdoor valve in a valve pit	9.5E-09	5.2E-11	180.5
IA DC	Failure of Backup IA header	5.4E-09	1.4E-09	3.9
EDG A	Emergency Diesel Generator Train A	2.6E-09	4.6E-10	5.7
EDG B	Emergency Diesel Generator Train B	2.2E-09	4.4E-10	5.0
TDPEX	Turbine Driven Pump Steam Exhaust Line	2.1E-10	NA	Not in 1.200

Plant Y Target Failure Probabilities – TMRE vs. RG 1.200

Target	Target Desc	Tornado Category	TRME Failure Probability	RG 1.200 Failure Probability	TRME/ RG 1.200
EDG A	Emergency Diesel Generator Train A	F'2	6.5E-04	1.1E-04	5.9
		F'3	2.0E-03	1.0E-03	2.0
		F'4	2.3E-03	1.8E-03	1.3
		F'5	4.2E-03	3.8E-03	1.1
		F'6	6.8E-03	6.2E-03	1.1
EDG B	Emergency Diesel Generator Train B	F'2	6.5E-04	1.1E-04	6.2
		F'3	2.0E-03	1.1E-03	1.9
		F'4	2.3E-03	1.9E-03	1.2
		F'5	4.2E-03	3.5E-03	1.2
		F'6	6.8E-03	6.2E-03	1.1
TDPEX	Turbine Driven Pump Steam Exhaust Line	F'2	4.2E-04	0.0E+00	NA
		F'3	1.3E-03	1.2E-05	107
		F'4	1.4E-03	3.3E-05	42
		F'5	5.9E-03	1.8E-04	34
		F'6	9.7E-03	3.3E-04	29
FWLINE	Main Feedwater lines near EDG air intake	F'2	1.3E-02	7.7E-06	1659
		F'3	4.0E-02	2.9E-04	137
		F'4	4.5E-02	6.1E-04	74
		F'5	8.2E-02	1.8E-03	45
		F'6	1.3E-01	4.3E-03	31
MSLINE	Main steam lines near EDG air intake	F'2	3.7E-02	1.3E-05	2856
		F'3	1.1E-01	1.2E-03	98
		F'4	1.3E-01	1.9E-03	69
		F'5	2.4E-01	4.9E-03	49
		F'6	3.9E-01	1.2E-02	32

Plant Y Target Failure Probabilities – TMRE vs. RG 1.200 (cont.)

Target	Target Desc	Tornado Category	TRME Failure Probability	RG 1.200 Failure Probability	TRME/ RG 1.200
SS	Shutdown Support Structure (Steel Building Construction - 1.0 Failure)	F'2	1.0E+00	1.1E-02	95
		F'3	1.0E+00	3.6E-02	28
		F'4	1.0E+00	3.5E-02	29
		F'5	1.0E+00	6.1E-02	16
		F'6	1.0E+00	9.6E-02	10
IA DC	Failure of Backup IA header	F'2	2.8E-02	3.5E-03	8.1
		F'3	8.7E-02	2.7E-02	3.3
		F'4	1.0E-01	4.2E-02	2.4
		F'5	1.8E-01	7.8E-02	2.3
		F'6	2.9E-01	1.2E-01	2.5
RWST	Refueling water Storage Tank	F'2	1.1E-01	1.7E-03	65
		F'3	3.5E-01	1.4E-02	26
		F'4	4.0E-01	2.5E-02	16
		F'5	7.3E-01	5.7E-02	13
		F'6	1.0E+00	9.8E-02	10
BSW	Backup Service Water Supply Valve (outdoors in a valve pit)	F'2	7.9E-04	2.3E-06	349
		F'3	2.5E-03	3.5E-05	70
		F'4	2.8E-03	8.7E-05	32
		F'5	5.1E-03	1.6E-04	32
		F'6	8.2E-03	1.7E-04	49

Tornado
Sensitivity Analysis

Leo Shanley

November 15, 2016

Introduction - General

- Sargent & Lundy (S&L) was contracted by EPRI to perform sensitivity Analyses
  - Used two TORMIS models for two separate plants, Plants A and B
    - Plant A is located in NRC Tornado Zone 1 and EPRI Tornado Zone A
    - Plant B is located in NRC Tornado Zone 1 and Border of EPRI Tornado Zones A and B
  - Existing TORMIS models of Plants A and B were prepared under S&L QA Program
  - Existing models were modified as required for the sensitivity analyses
  - Sensitivity Analyses includes 3 cases:
    - Case 1: Target Size
    - Case 2: Target Elevation
    - Case 3: Uniform vs. Zonal Missile Distribution

Introduction – General, NRC Tornado Regions, 1974

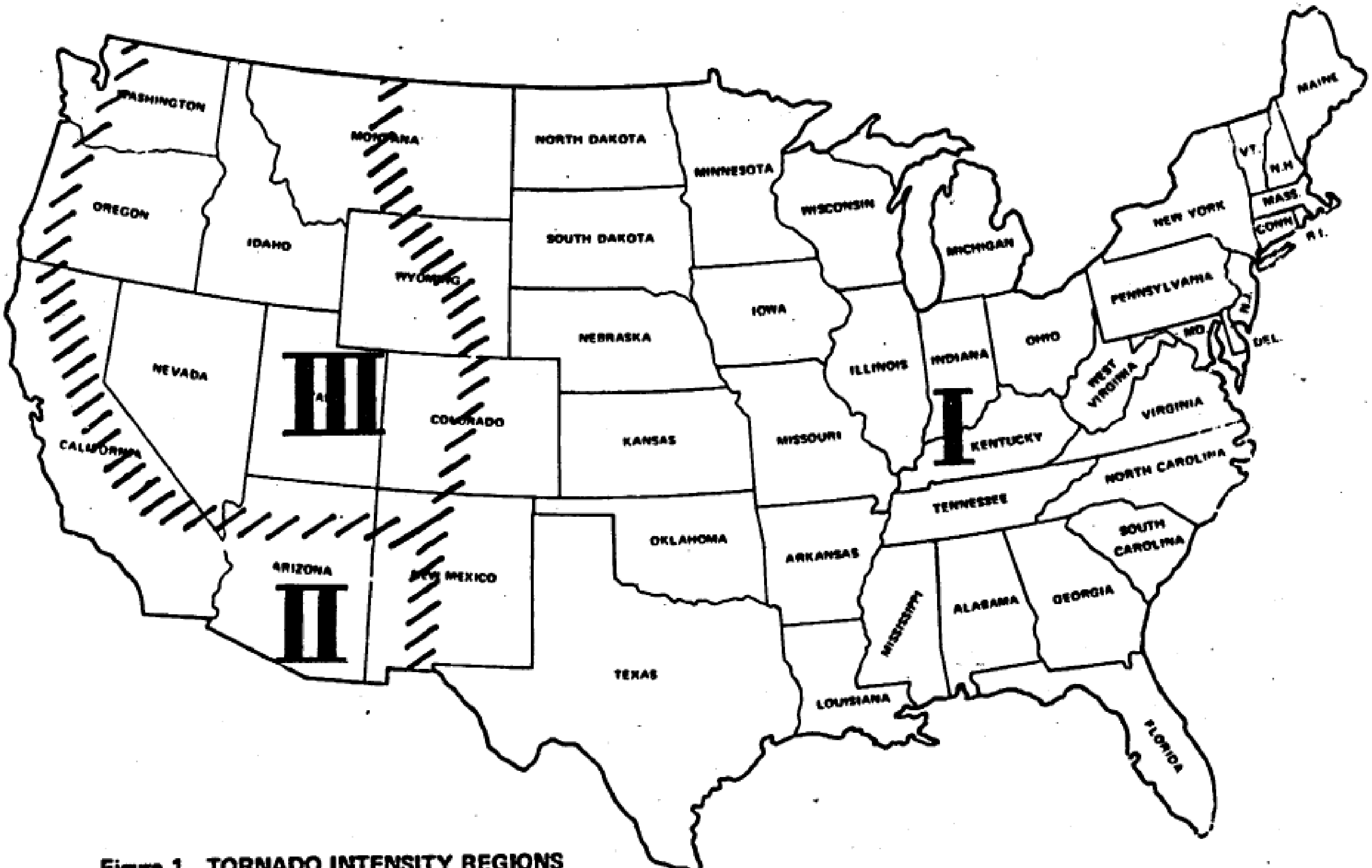
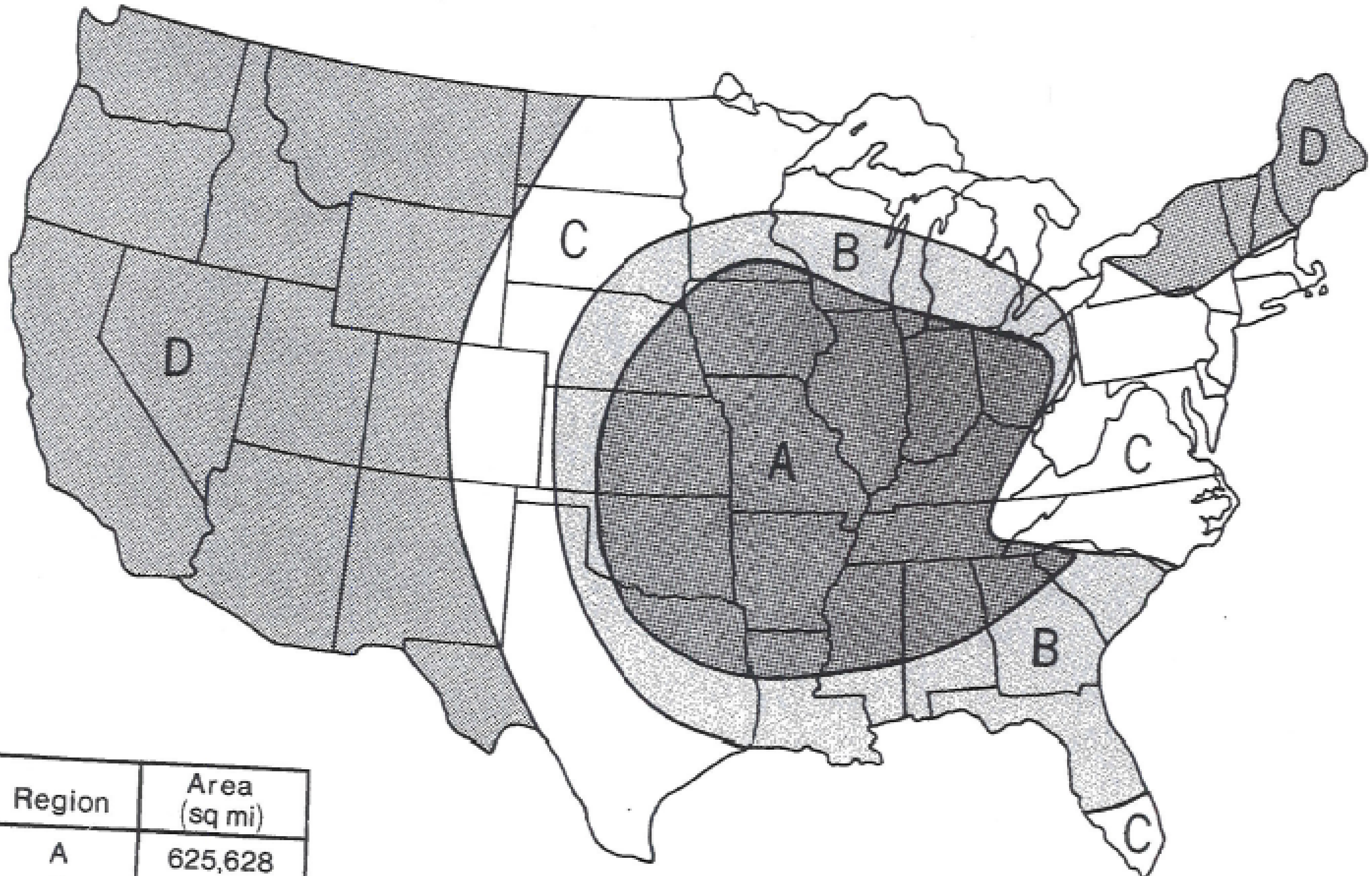


Figure 1. TORNADO INTENSITY REGIONS

Introduction – General, EPRI Tornado Regions



Region	Area (sq mi)
A	625,628
B	365,180
C	775,569
D	1,205,117

Introduction – General, TORMIS Basic Missile Sets

Basic Aerodynamic Shape Set	General Description	Cross-Section b/d Variation	Impact Material	Final Set Number
Cylinder	Rod	d	Steel	1
			Wood	2
	Pipe	d	Steel	3
			Concrete	4
Rectangle	Box, Beam	d, b=d	Steel	5
			Wood	6
		d, b=d/4	Steel	7
			Concrete	8
			Wood	9
	Plate	d, b=d/10	Steel	10
			Wood	11
		d, b=d/50	Steel	12
			Wood	13
I-Shape	Wide Flange	d	Steel	14
Angle	Angle	d	Steel	15
Channel	Channel	d	Steel	16
			Concrete	17
Frame, Truss	Pipe Frame	d, d	Steel	18
	Rect. Frame		Steel	19
	Rect. Frame		Wood	20
	Pipe Frame	d, d/4	Steel	21
	Rect. Frame		Steel	22
	Rect. Frame		Wood	23
Sphere	Sphere	d	Steel	24
Vehicle	Auto, Trailer	d, d	Steel	25
Tree	Tree	d	Wood	26

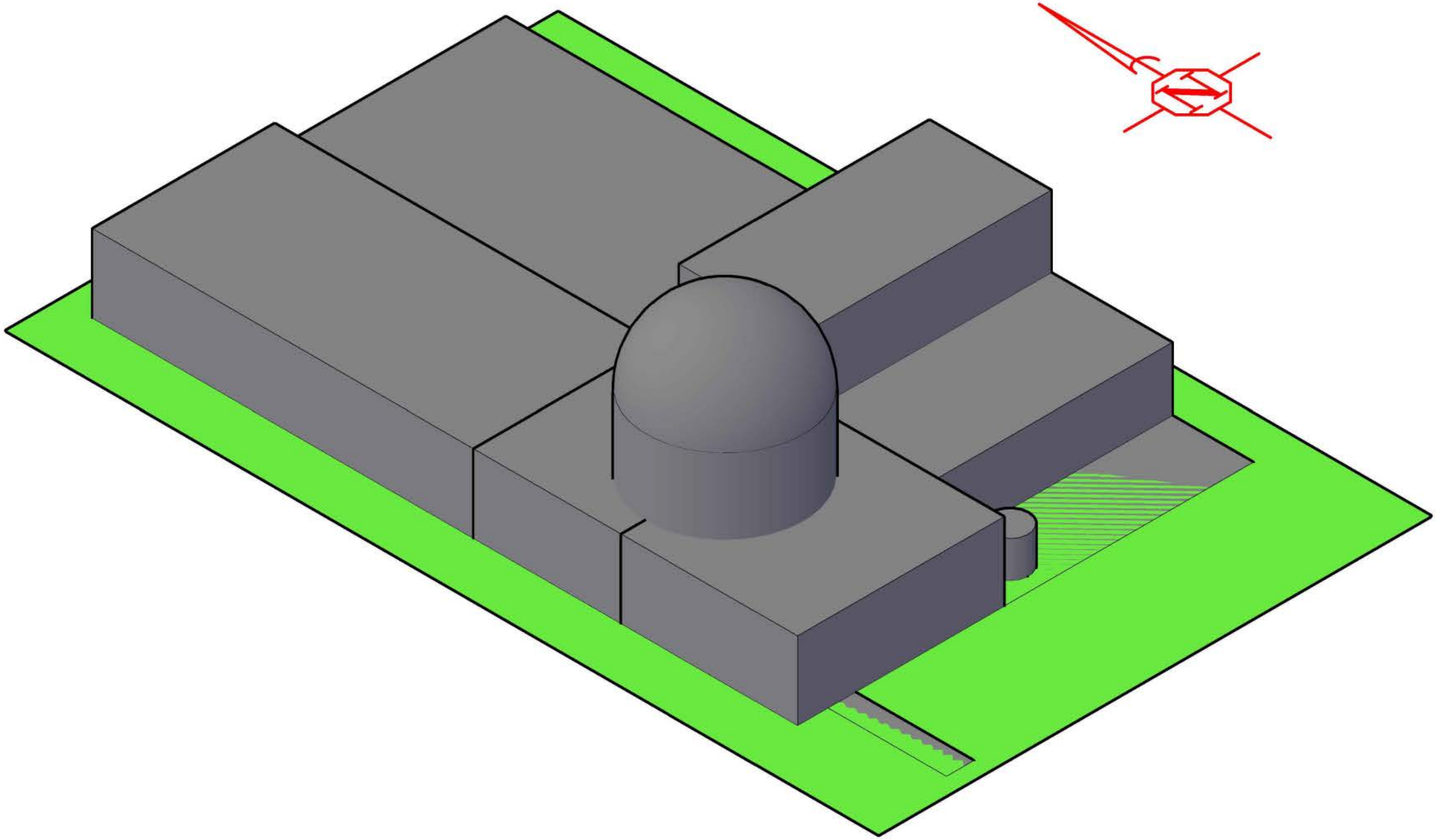
General Setup/Boundary Conditions

- All sensitivity analyses use Enhanced Fujita Scale EF1 thru EF5
  - EF scale is close to F' scale used for MIPs
  - In agreement with RG 1.76 Rev. 1
  - Recent TORMIS submittals to NRC have used EF scale
- For each EF scale, 5,000,000 simulations (i.e. 2,000 tornados with 2,500 missile/tornado) are used. This is judged to be adequate
  - This is a sensitivity study, actual probabilities are not being determined. This is far above the number of simulations used in EPRI NP-768 (source for MIPs)
- To account for effect of seed numbers for random generation:
  - 4 sets of analyses are performed for cases 1 and 2, mean of 4 sets is used
    - Case 1 analyses results are based on a total of 200,000,000 simulations
    - Case 2 analyses results are based on a total of 200,000,000 simulations
  - 7 sets of analyses are performed for case 3, mean of 7 sets is used
    - Case 3 analyses results are based on a total of 700,000,000 simulations

General Setup/Boundary Conditions

- Plant B is located at borderline of EPRI Tornado Zones A and B. EPRI Tornado Zone B is selected for Plant B analyses so that the sensitivity analyses cover both EPRI Tornado Zones A and B
- Though a significant portion of Plants A and B missiles are restrained missiles, sensitivity analyses are performed assuming all missiles are free
- All analysis results are based on TORMIS reported P(A) (i.e. single missile hit probability) for summation of all missile events.

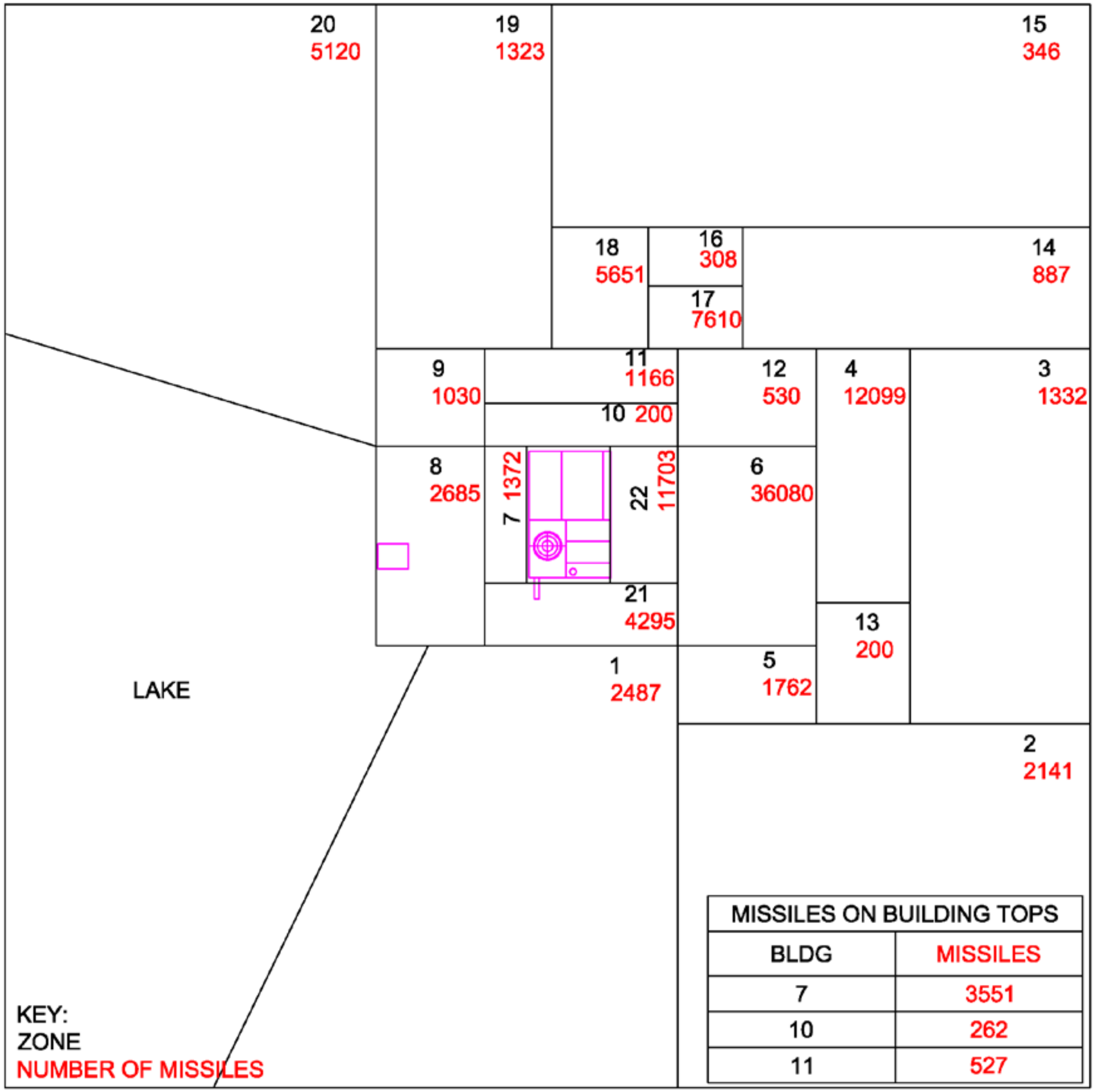
Plant A - Model



Introduction – Plant A

- Plant A
  - Located in NRC Tornado Zone 1 and EPRI Tornado Zone A
  - Model includes 22 Missile Zones, see next slide
  - Missile zones encompass a 5000' x 5000' area
  - Missile population is in excess of 100,000
  - Missile population includes free and restrained missiles, about 65% restrained
  - Missile population includes missiles coming off of buildings
  - The total area of Plant A missile zones is 19,771,450 ft^2, with a total of 100,327 missiles. Additional 4,340 missiles are located on building tops
  - Missile set for Plant A includes 13 of 26 TORMIS missile sets (1, 2, 3, 6, 9, 10, 11, 12, 14, 15, 16, 25, and 26).

Plant A - # of Missiles and Missile Zones



MISSILES ON BUILDING TOPS	
BLDG	MISSILES
7	3551
10	262
11	527

Plant A – Missile Population

	Number of Missiles	EPRI Basic Missile Set No.																				
		1				2		3				6	9		10	11	12	14	15	16	25	26
		Missile Type No.																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Zone 1	2487		8				3	6	681								678			11		1100
Zone 2	2141		16		4	32	30	33	658								707			61		600
Zone 3	1332		16		25	1		28	506								554			52		150
Zone 4	12099	3840	64				3	324	2153	11		50	180	50	100	2170	2363		10	661	120	
Zone 5	1762		32			3		46	531	43			320	20	1		613			103		50
Zone 6	36080	7139	366	424	310	17		1860	4635	168	78	85	1640	2780	329	3671	9094	19	180	3170	65	50
Zone 7	1372	150	32					32	224	4						150	323		400	57		
Zone 8	2685		64			5		102	977	2							1201			234		100
Zone 9	1030					10			260								260				500	
Zone 10	200																					200
Zone 11	1166								510	4							552					100
Zone 12	530								200								200				30	100
Zone 13	200																					200
Zone 14	887	18					2		321	1						7	330		100	8		100
Zone 15	346						21												25			300
Zone 16	308						8														200	100
Zone 17	7610	1600	16		10			240	1021	2						1600	2626			470	25	
Zone 18	5651					6			520	325							500	200	4000			100
Zone 19	1323	44	32			4		16	204	2						45	247		600	29		100
Zone 20	5120					12													8			5100
Zone 21	4295	738	48					70	378	10				1450		693	776			132		
Zone 22	11703	20	2048	20	20	20	20	2207	407	200	200	2000	200	200	20	200	2855	200	200	646	20	
Bldg. 7	3551	442	395					225									1781			708		
Bldg. 10	262	50						15									147			50		
Bldg. 11	527	14	60					48									291			114		
	104667	14055	3197	444	369	110	87	5252	14186	772	278	2135	2340	4500	450	8536	26098	419	5523	6506	960	8450

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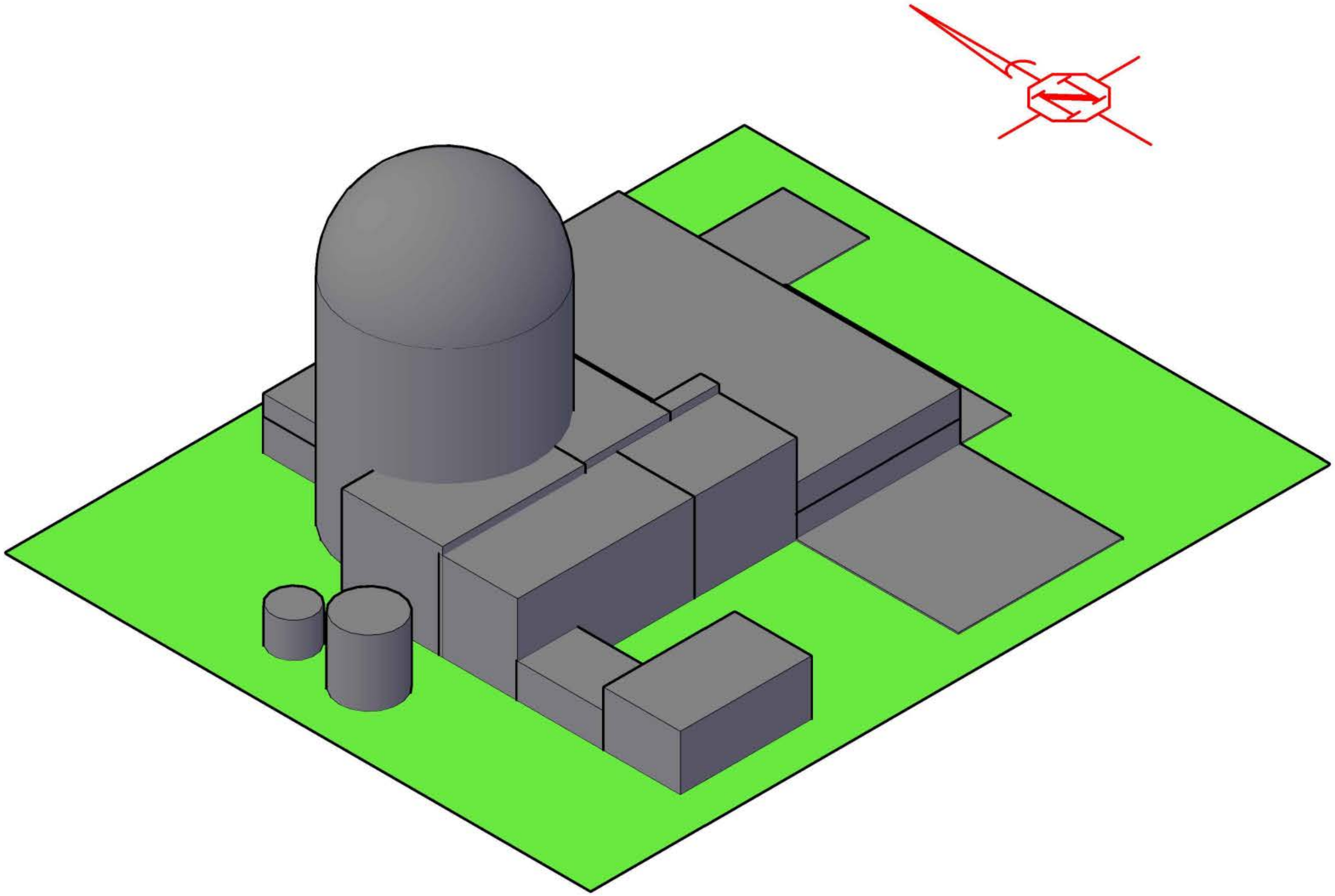
Plant A: Missile Types

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

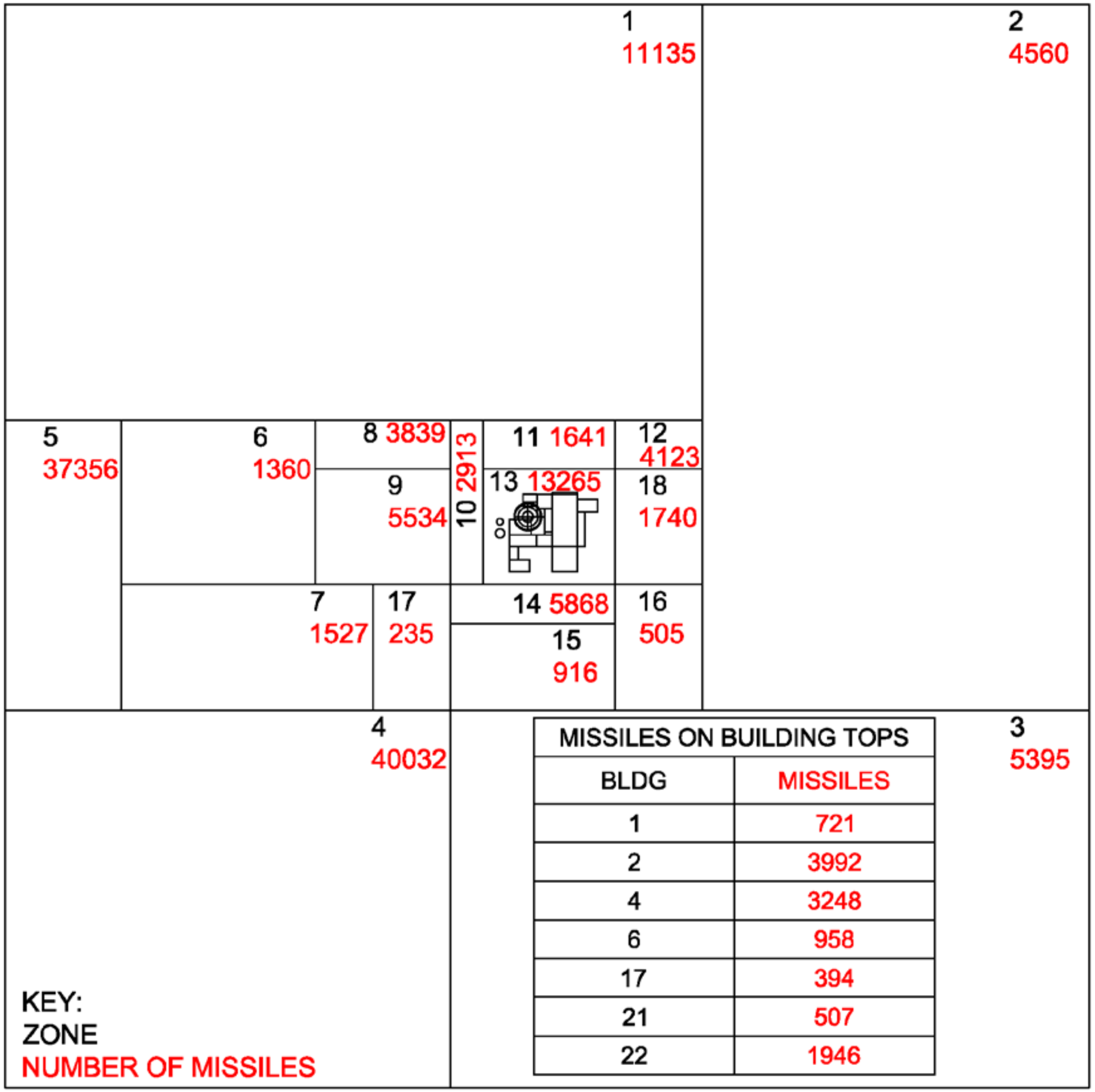
Introduction – Plant B



Introduction – Plant B

- Plant B
  - Located in NRC Tornado Zone I and at border of EPRI Tornado Zones A & B
  - Model includes 18 Missile Zones, see next slide
  - Missile zones encompass a 5000’ x 5000’ area
  - Missile population is in excess of 150,000
  - Missile population includes free and restrained missiles, about 50% restrained
  - Missile population includes missiles coming off of buildings
  - The total area of Plant B missile zones is 31,360,000 ft^2, with a total of 141,944 missiles. Additional 11,766 missiles are located on building tops
  - Missile population includes 15 of 26 TORMIS missile sets (1, 2, 3, 6, 8, 9, 10, 11, 12, 14, 15, 16, 22, 25, and 26)

Plant B Missile Zones



MISSILES ON BUILDING TOPS

BLDG	MISSILES
1	721
2	3992
4	3248
6	958
17	394
21	507
22	1946

Plant B – Missile Population

	Number of Missiles	EPRI Basic Missile Set No.																								
		1				2		3				6	9		10	11	12	14	15	16	22	3	2	8	25	26
		Missile Type No.																								
		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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Zone 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
Bldg. 1	721		48					46	46								462			119						
Bldg. 2	3992	912	80					58	315							912	1520			195						
Bldg. 4	3248		80					208	208								2190			562						
Bldg.6	958		80					40	40								660			138						
Bldg. 17	394		32					28	28								242			64						
Bldg. 21	507		48					26	26								333			74						
Bldg. 22	1946		80					96	96								1392			282						
	152456	23070	1706	449	448	82	226	4497	14798	1311	115	1362	19820	395	329	17560	30911	534	5796	6416	337	221	700	4240	1695	15438

Plant B: Missile Types

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	13.5"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

Case 1 Setup: Target Size

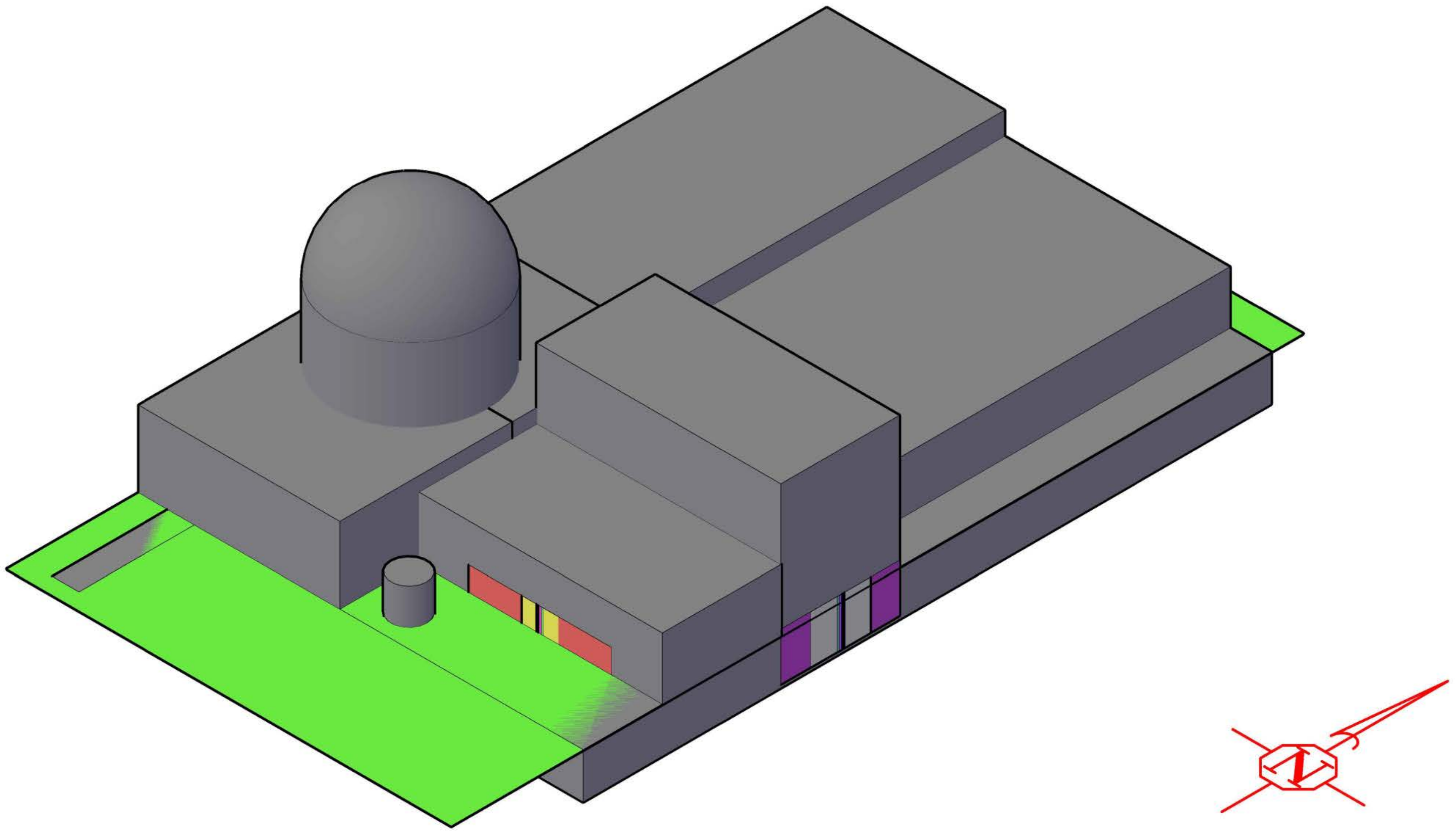
- Objective is to examine impact of target size on target hit probabilities
- Both Plants A and B are used
- Created one target on an open wall and varied target width without changing target height and center location. Picked middle of wall horizontally, where possible
- Plant A: 8 targets (4 targets with same center location and height but different widths on each of the South and East walls)
- Plant B: 8 targets (4 targets with same center location and height but different widths on each of the North and West walls)
- Missile population for case 2 studies were same as the existing models with the following adjustment:
  - The entire population of restrained and free missiles is considered as free missiles

Case 1 Setup: Target Size

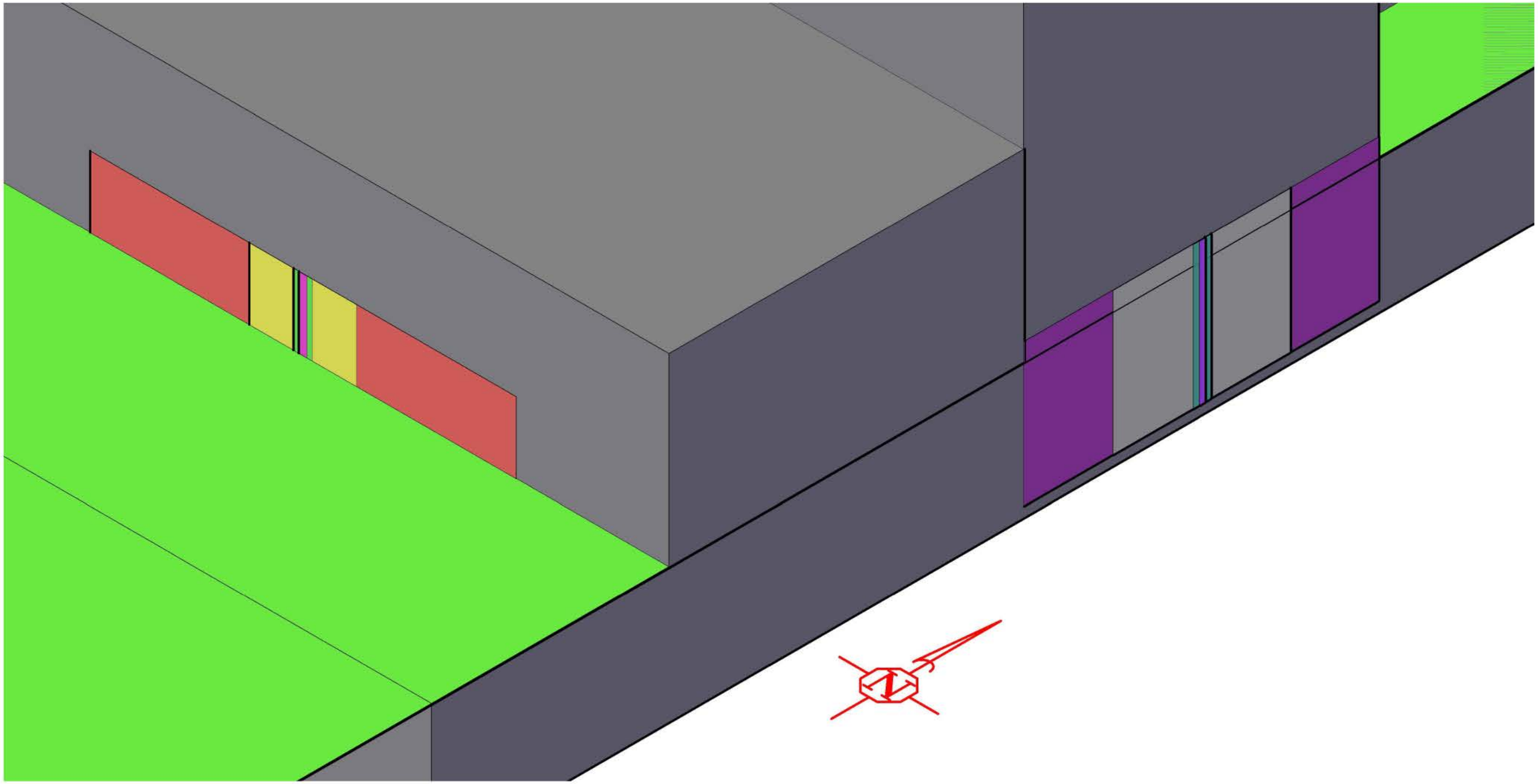
- Target sizes are as follows:
  - Plant A, South Wall: 40 ft^2, 100 ft^2, 600 ft^2, and 2400 ft^2 (all targets are 20 ft high)
  - Plant A, East Wall: 60 ft^2, 200 ft^2, 2000 ft^2, and 4000 ft^2 (all targets are 40 ft high)

  - Plant B, North Wall: 40 ft^2, 120 ft^2, 400 ft^2, and 2400 ft^2 (all targets are 40 ft high)
  - Plant B, West Wall: 30 ft^2, 90 ft^2, 300 ft^2, and 1500 ft^2 (all targets are 30 ft high)

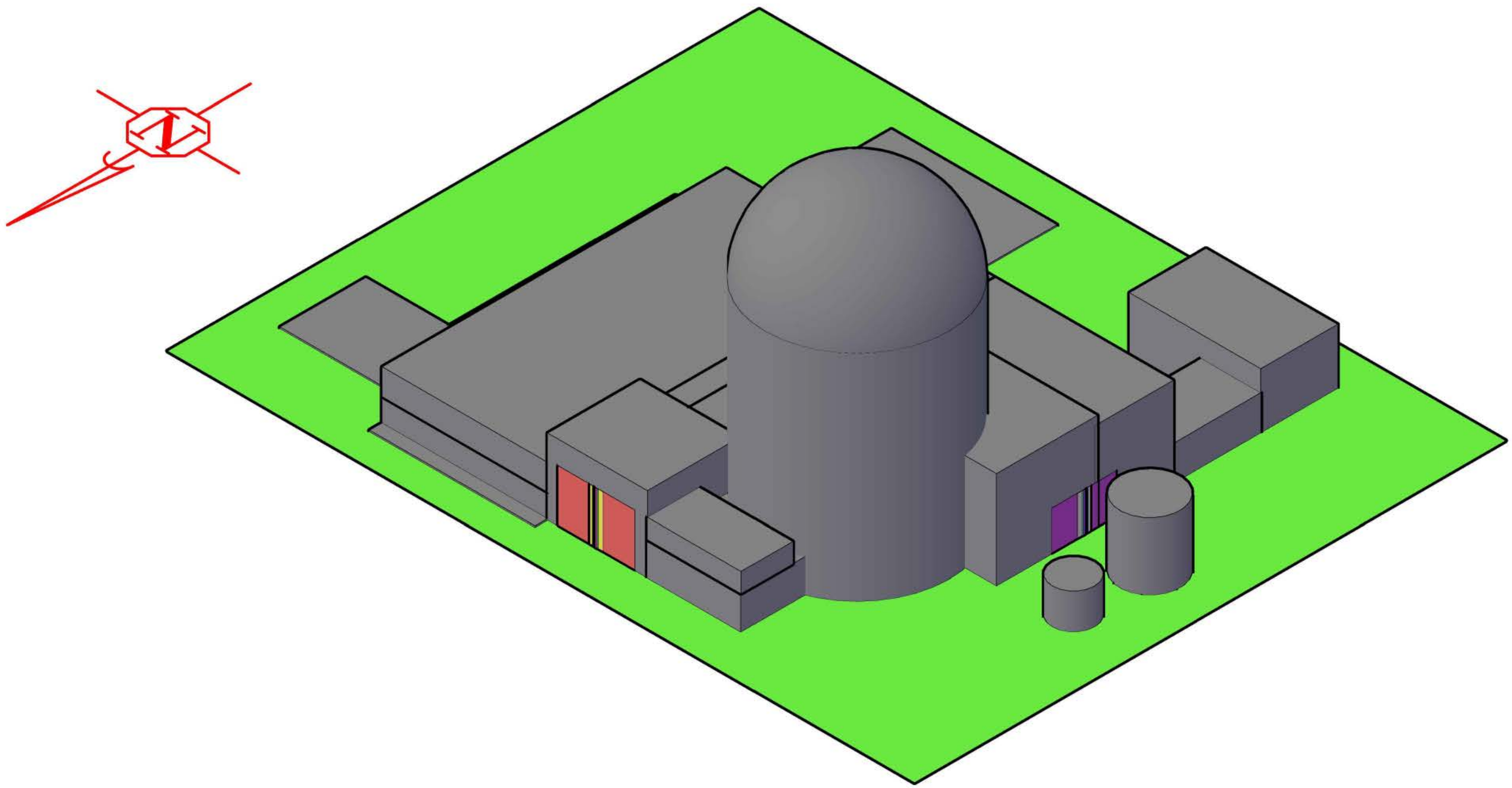
Case 1: Target Size – Plant A Target Locations



Case 1 – Plant A Target Locations



Case 1: Target Size – Plant B Target Locations



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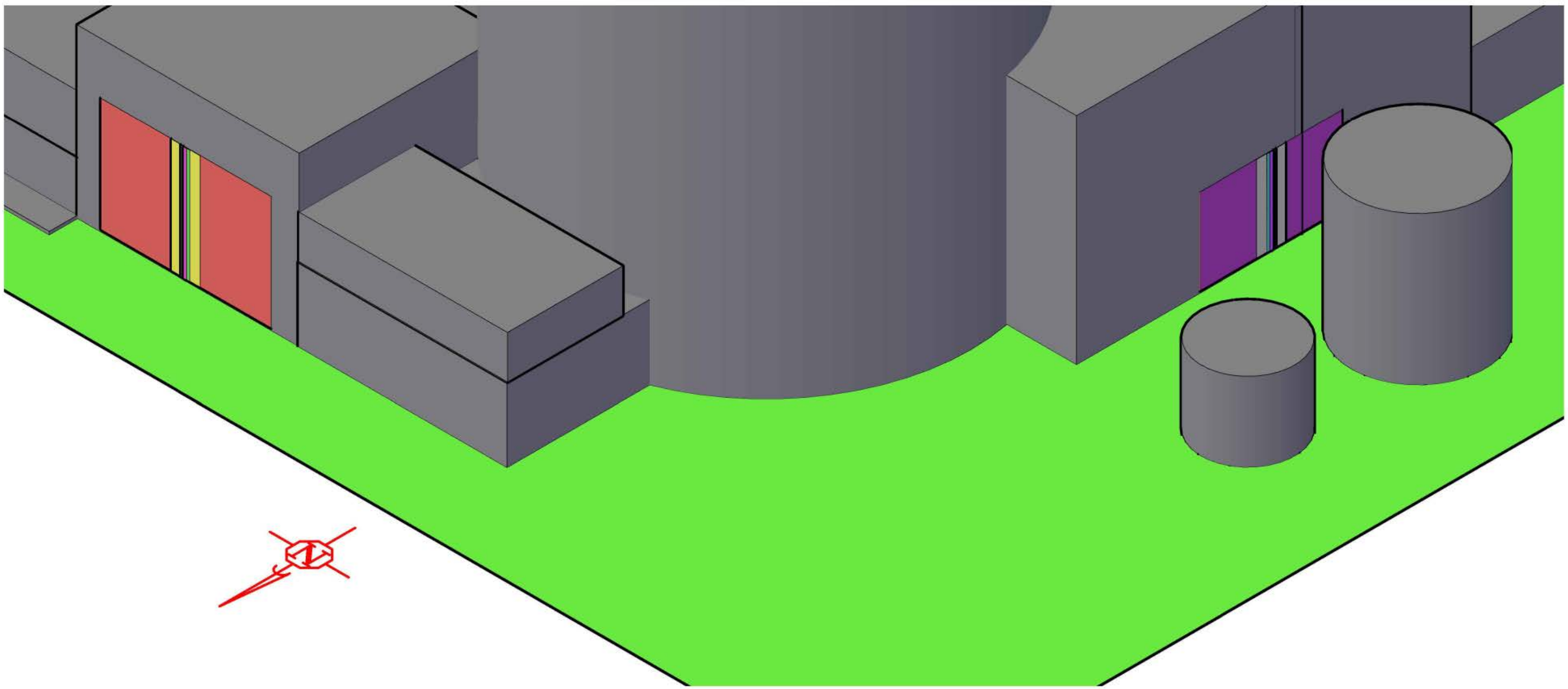
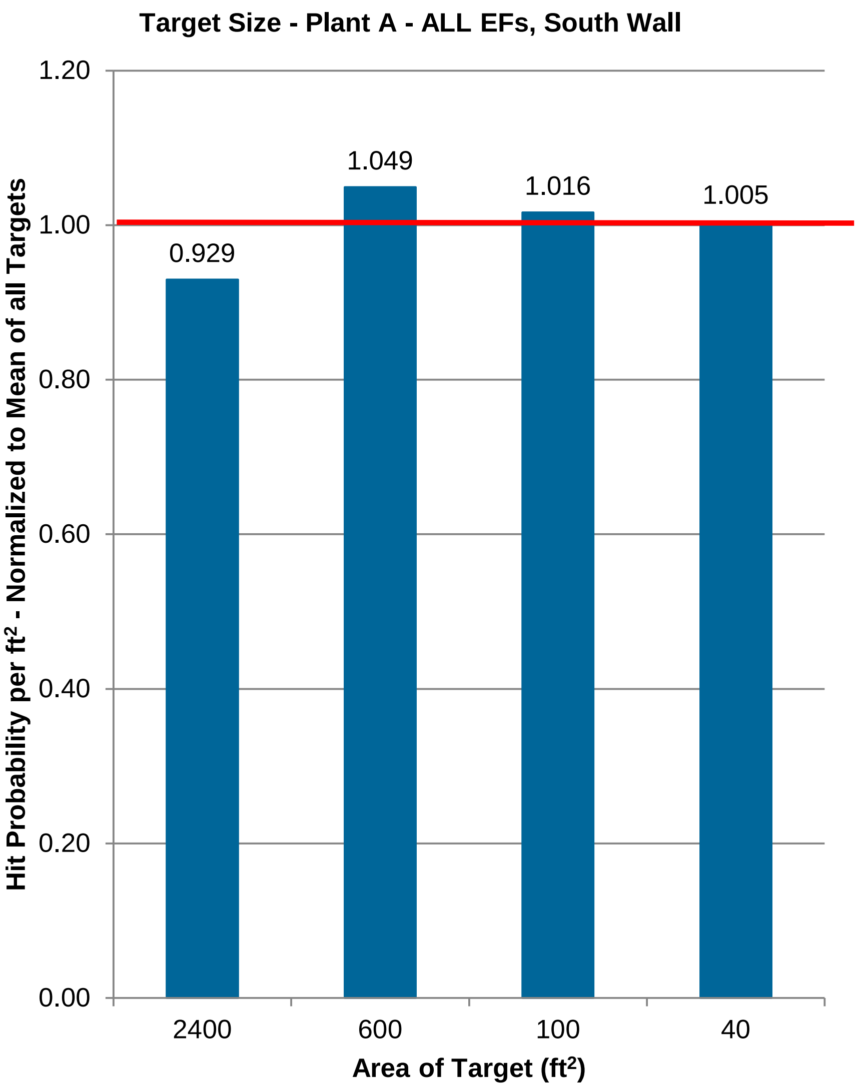
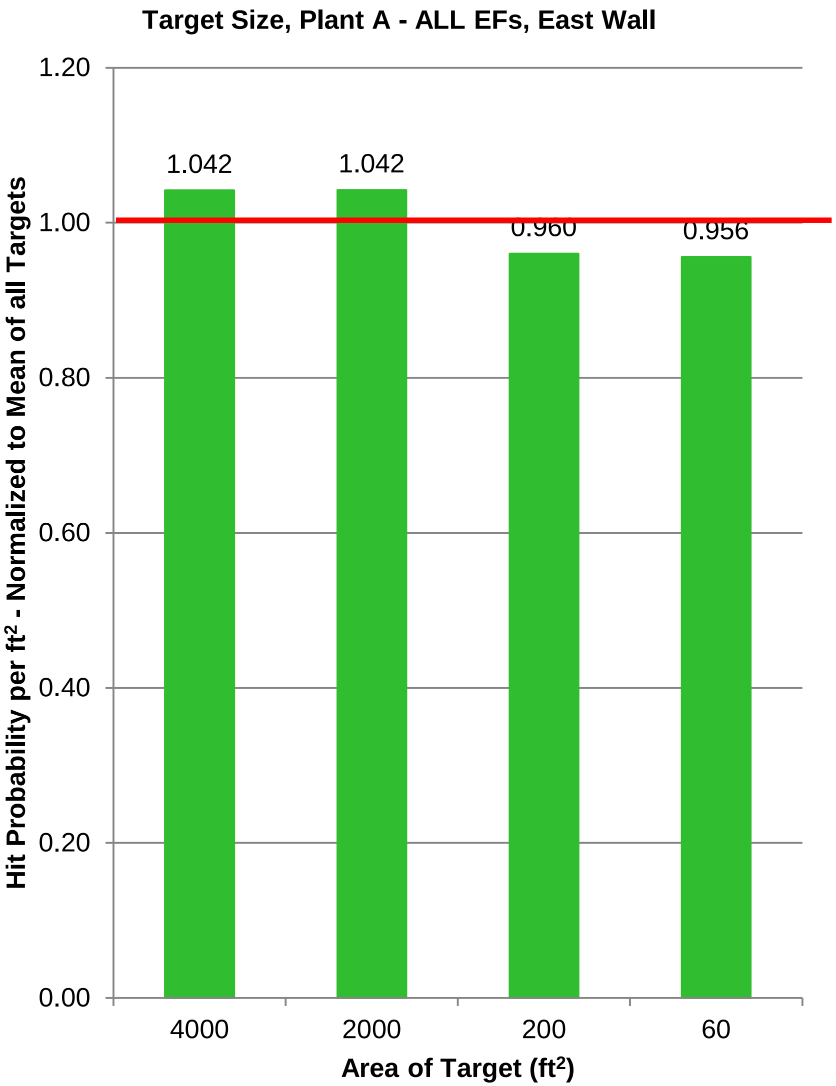
Case 1: Target Size – Plant B Target Locations

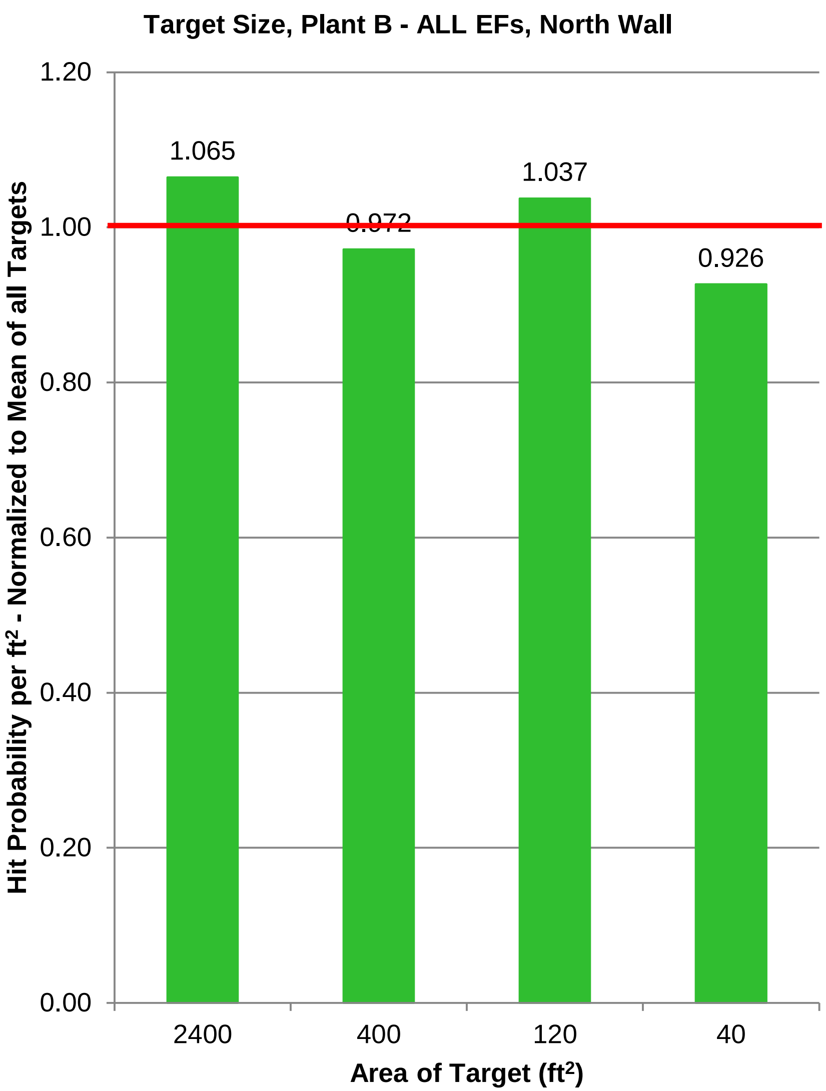


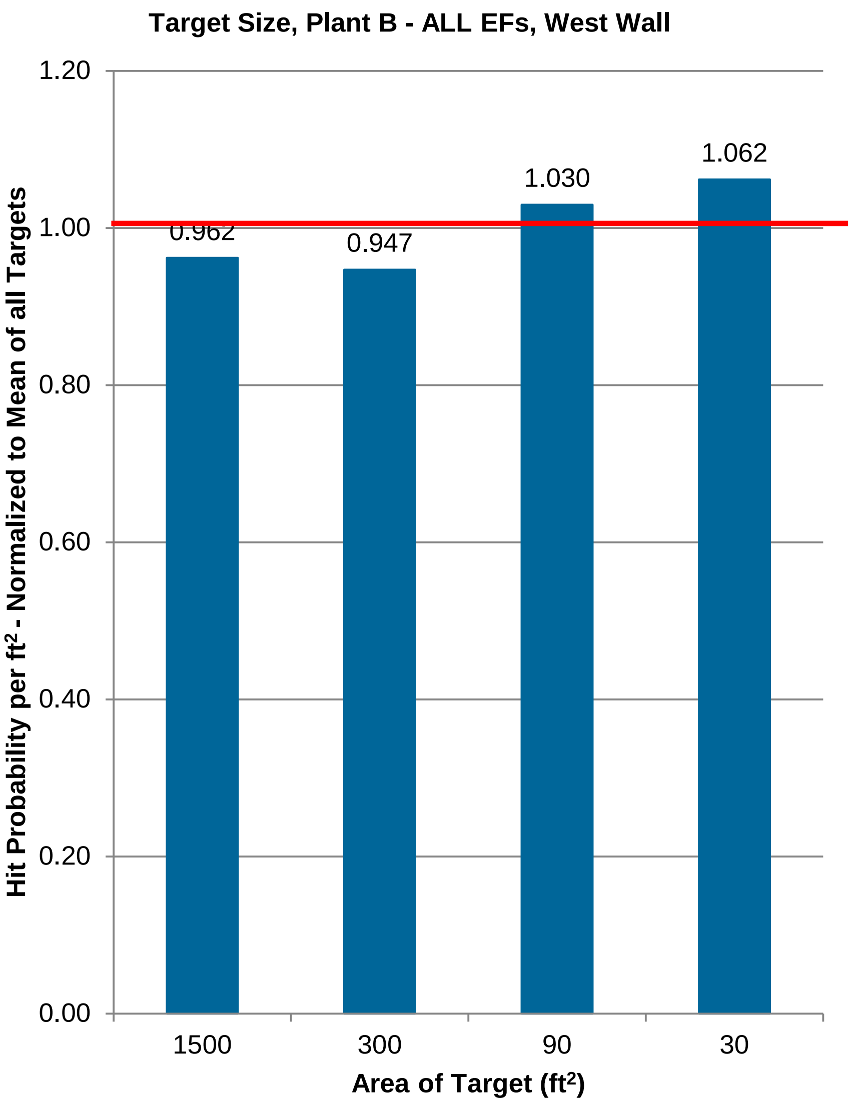
Case 1: Target Size Results – Plant A





Case 1: Target Size Results – Plant B





Conclusions – Target Size Sensitivity

- Missile Impact Parameter (MIP) is based on hit probability from NP-768 building walls
  - Relatively large targets
  - We are applying MIP to targets of varying sizes
- Sensitivity case was performed to determine if normalized (per area) hit probability changes significantly with size
- Sensitivity results shows that target size does not appreciably change the normalized (per area) hit probability
  - Normalized hit probabilities varied less than ~10% from the mean
  - Target sizes as large as 4000 ft^2 and as small as 30 ft^2
  - Each individual target area changed by a factor of 50 – 60
- **Conclusion: MIP developed for TMRE can be applied to all targets, regardless of size**

Case 2 Setup: Target Elevation

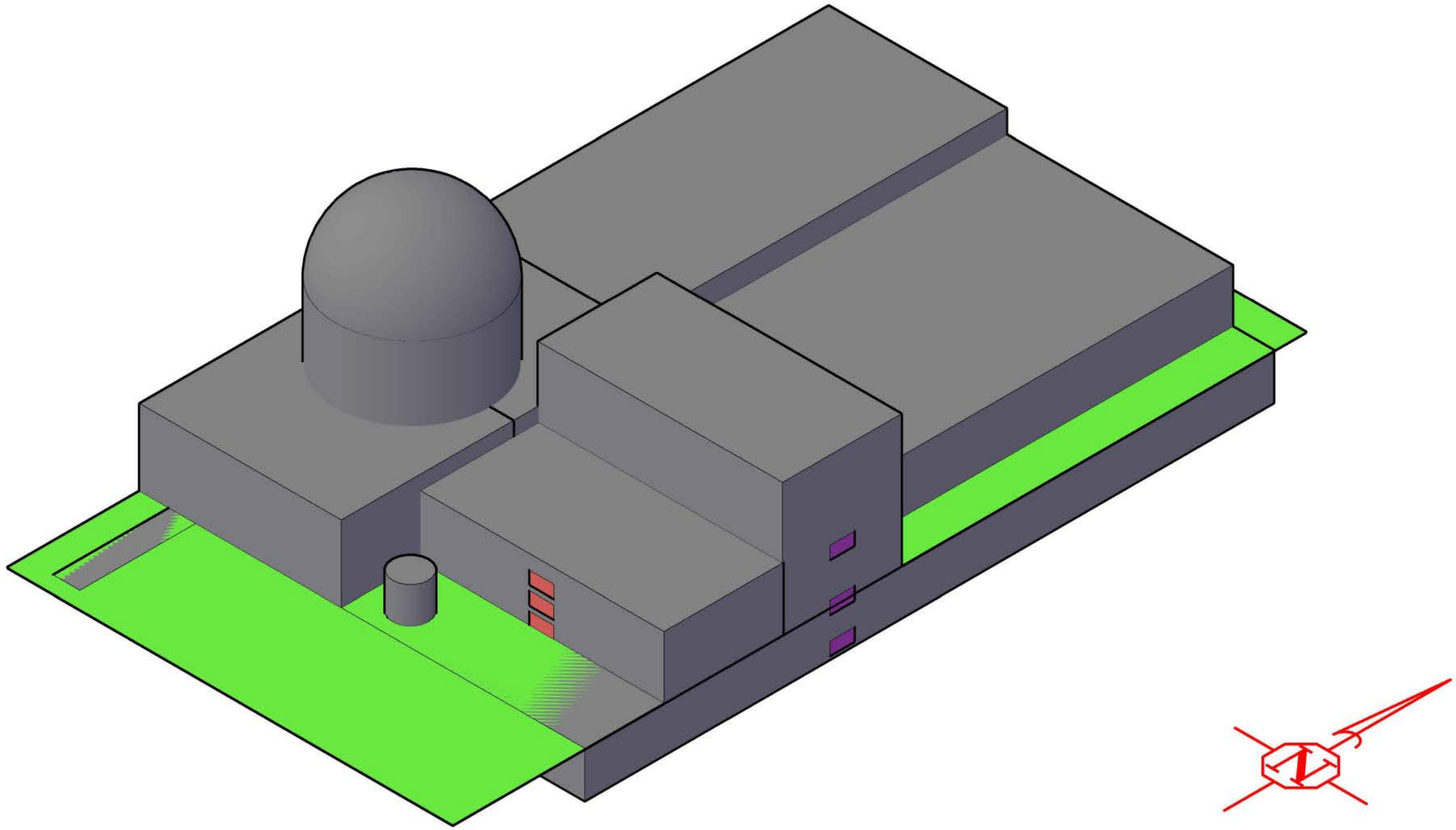
- Objective is to examine impact of target elevation on target hit probabilities
- Both Plants A and B are used
- Created one target on an open wall and varied target elevation without changing target size and plan location. Picked middle of wall horizontally, where possible
- Plant A: 4 targets, one on N, S, E, and W walls
- Plant B: 3 targets, one on N, S, and W walls (E wall blocked by Turbine Building)
- Missile population for case 2 studies were same as the existing models with the following adjustment:
  - The entire population of restrained and free missiles is considered as free missiles

Case 2 Setup: Target Elevation

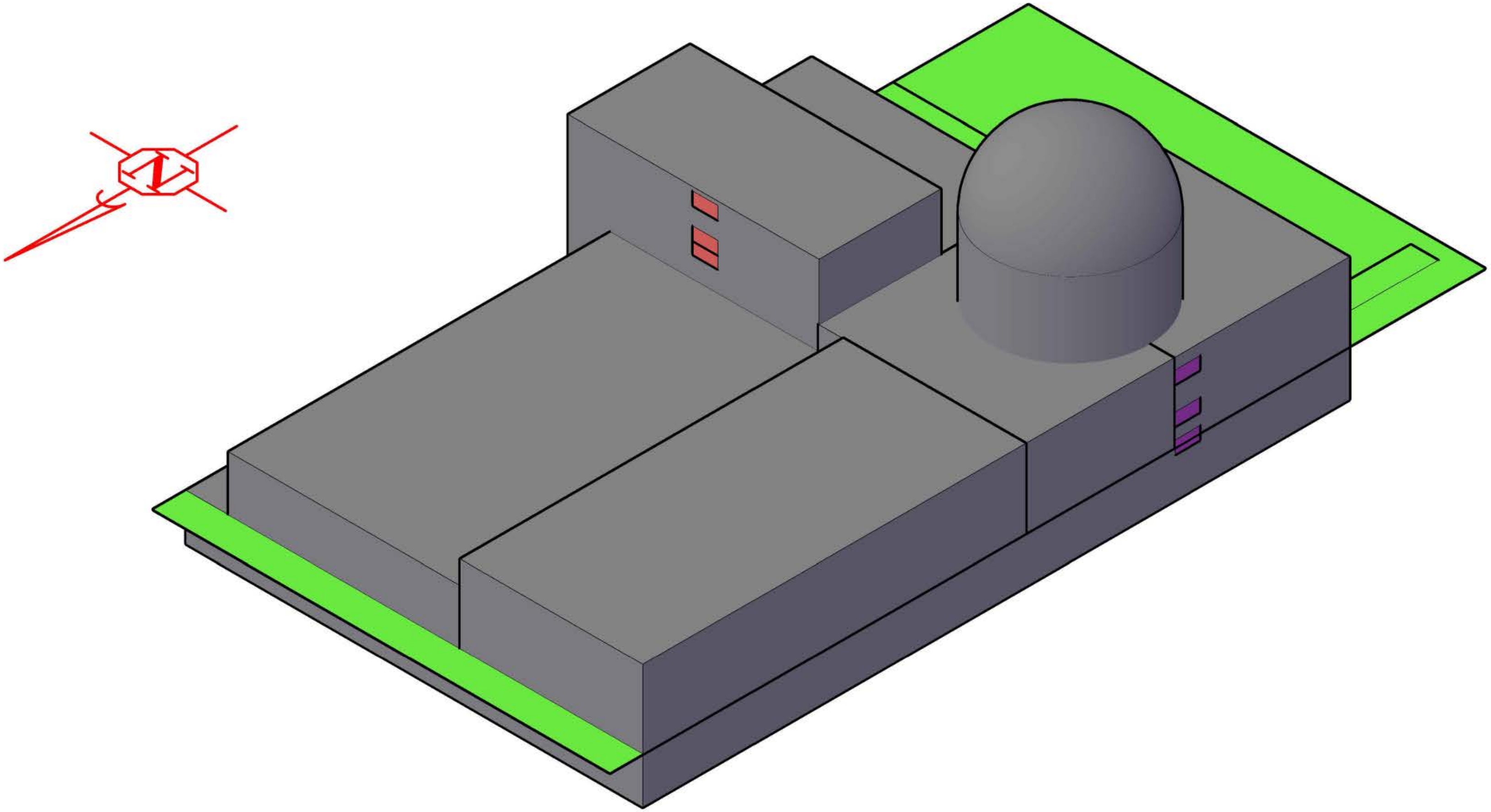
- Target sizes are as follows:
  - Plant A, East Wall: 20’ wide X 10’ high targets with target center at 8’, 38’, and 78’ above ground
  - Plant A, West Wall: 20’ wide X 10’ high targets with target center at 5’, 25’, and 55’ above ground
  - Plant A, North Wall: 20’ wide X 10’ high targets with target center at 68’, 78’, and 103’ above ground
  - Plant A, South Wall: 20’ wide X 10’ high targets with target center at 5’, 20’, and 35’ above ground

  - Plant B, North Wall: 20’ wide X 10’ high targets with target center at 6’, 21’, and 41’ above ground
  - Plant B, South Wall: 20’ wide X 10’ high targets with target center at 6’, 31’, and 64’ above ground
  - Plant B, West Wall: 18’ wide X 15’ high targets with target center at 8.5’, 23.5’, and 53.5’ above ground

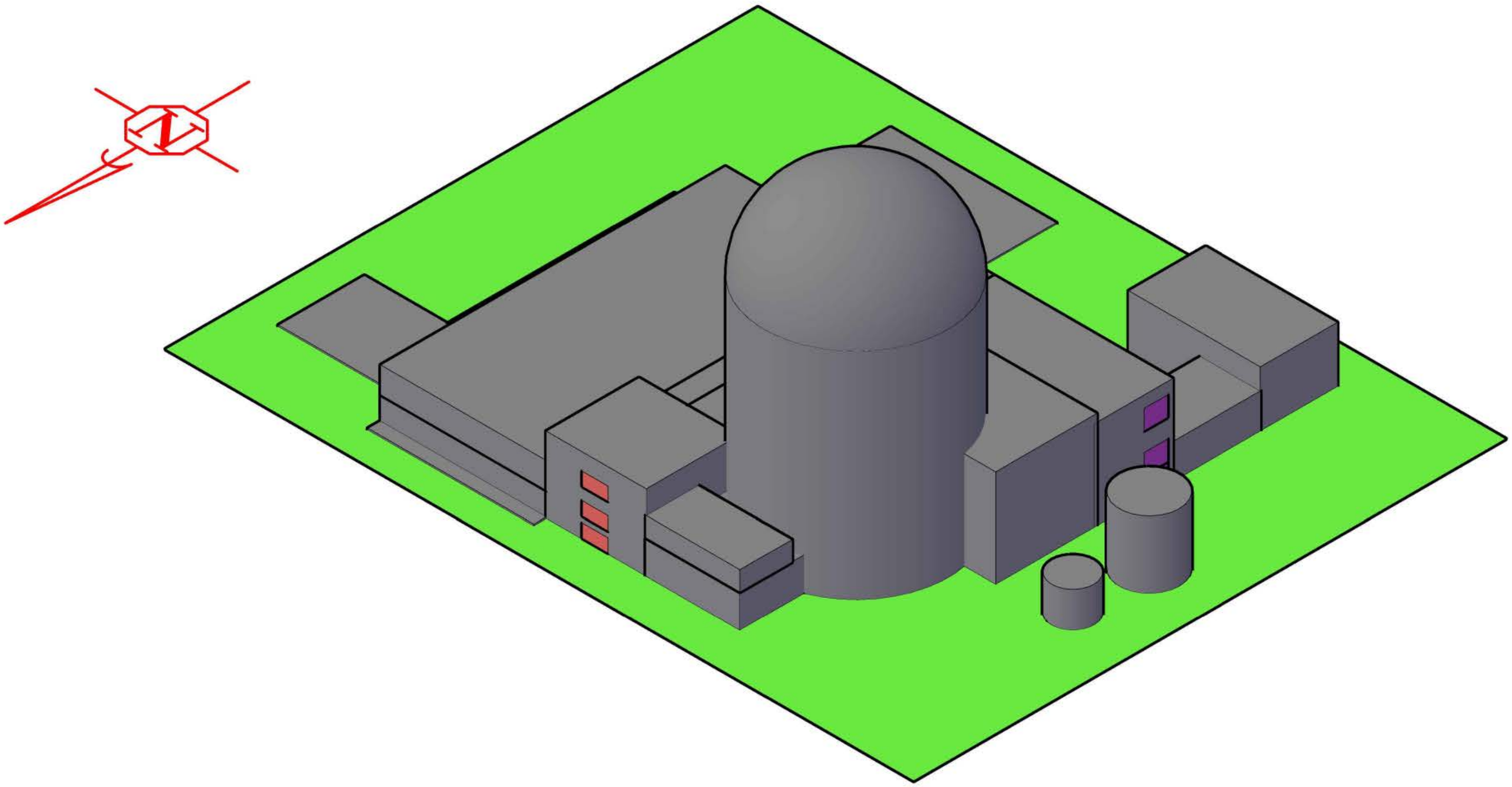
Case 2: Target Elevation Plant A – East and South Wall



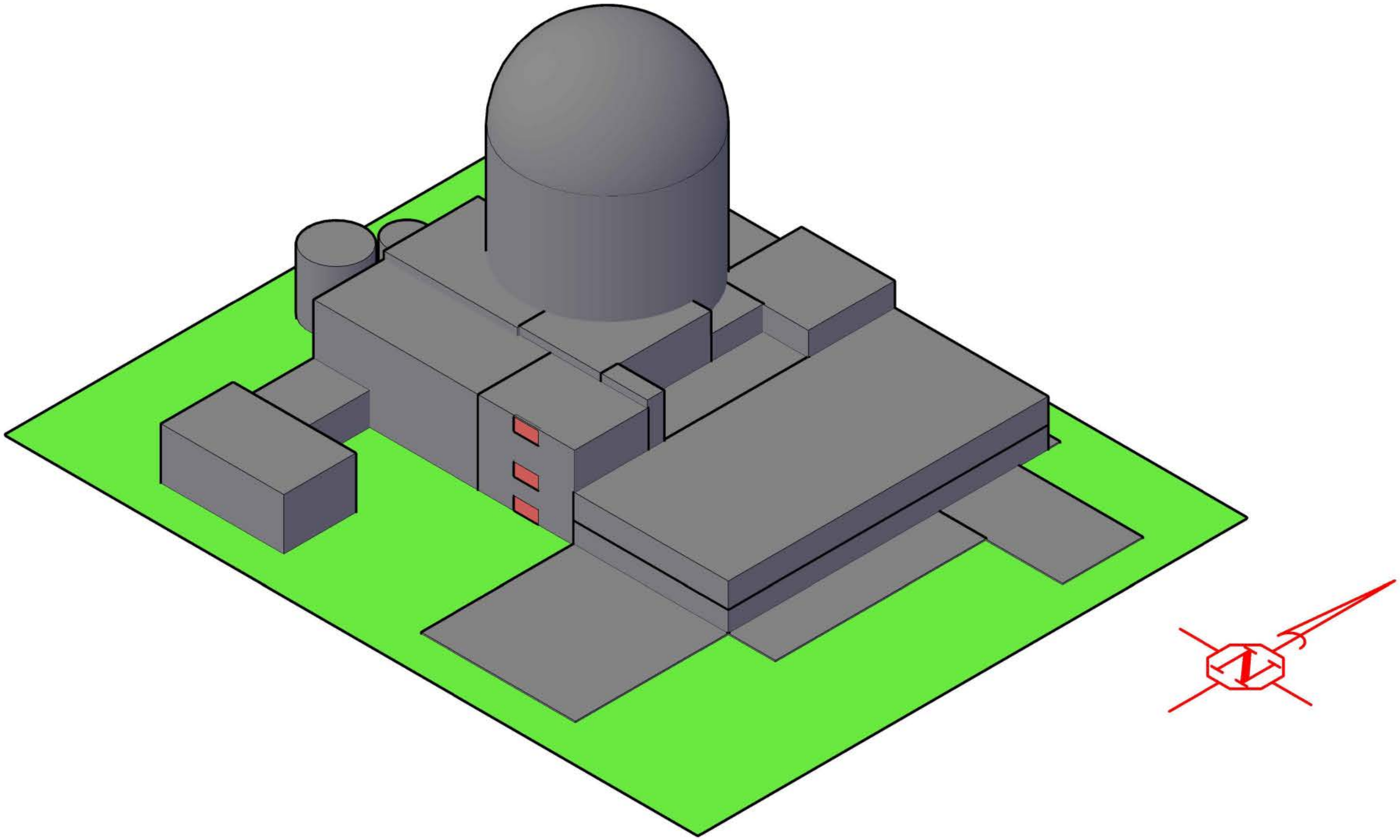
Case 2: Target Elevation Plant A – North and West Wall



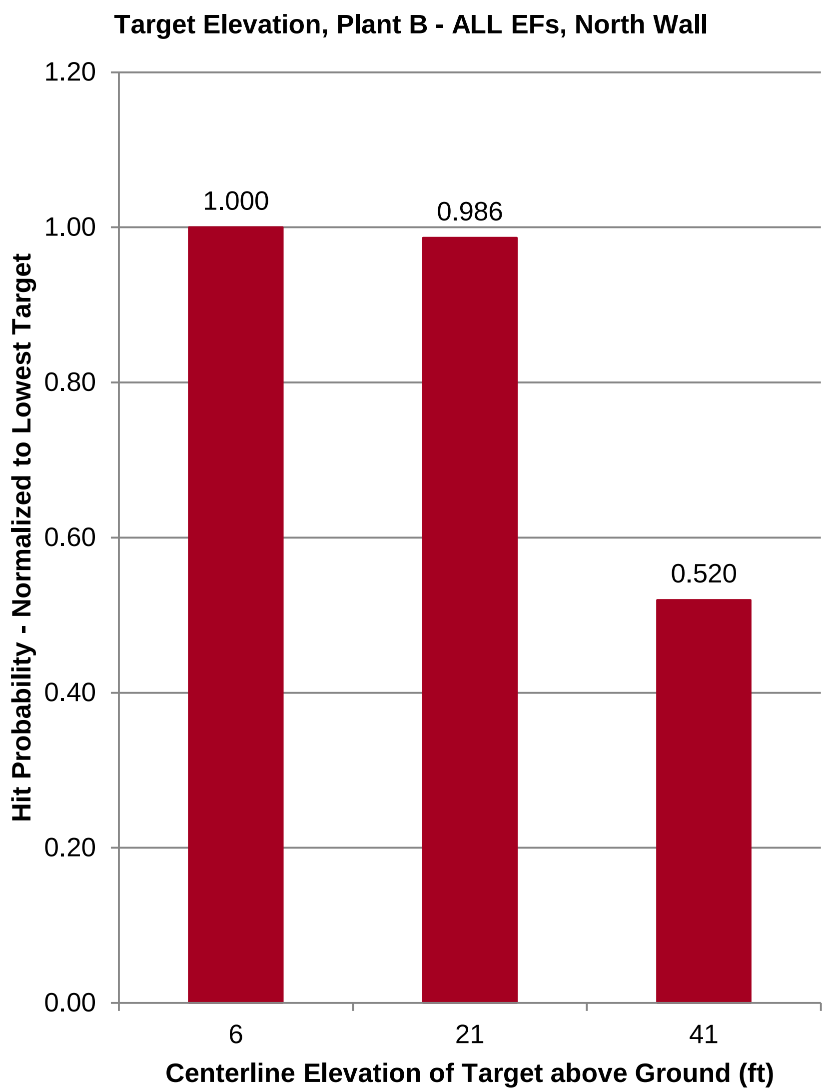
Case 2: Target Elevation Plant B – North and West Wall

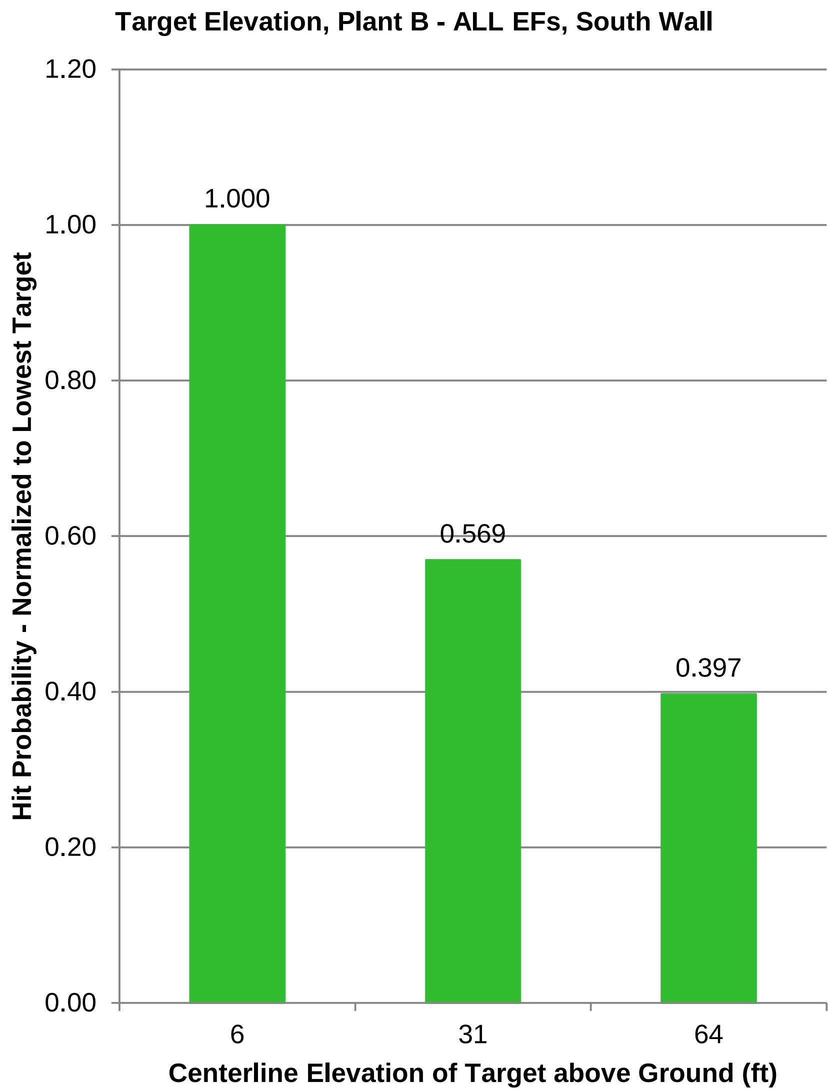


Case 2: Target Elevation Plant B – South Wall

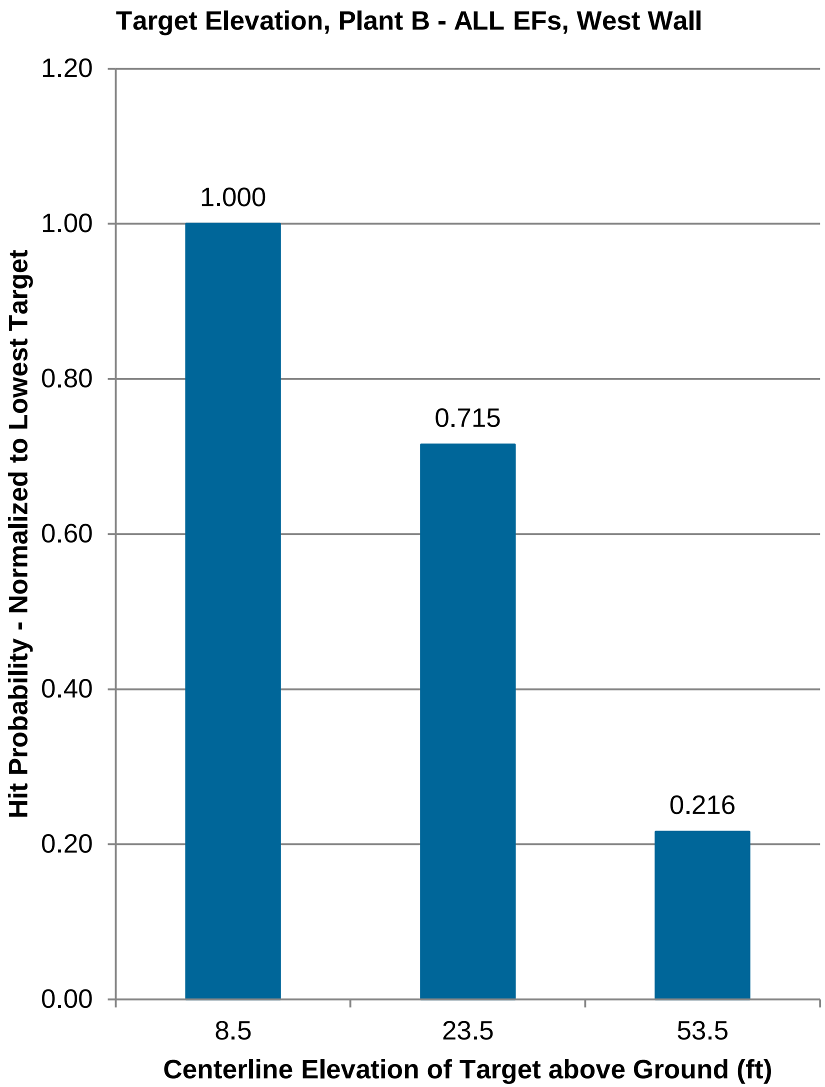


Case 2 Results – Plant B

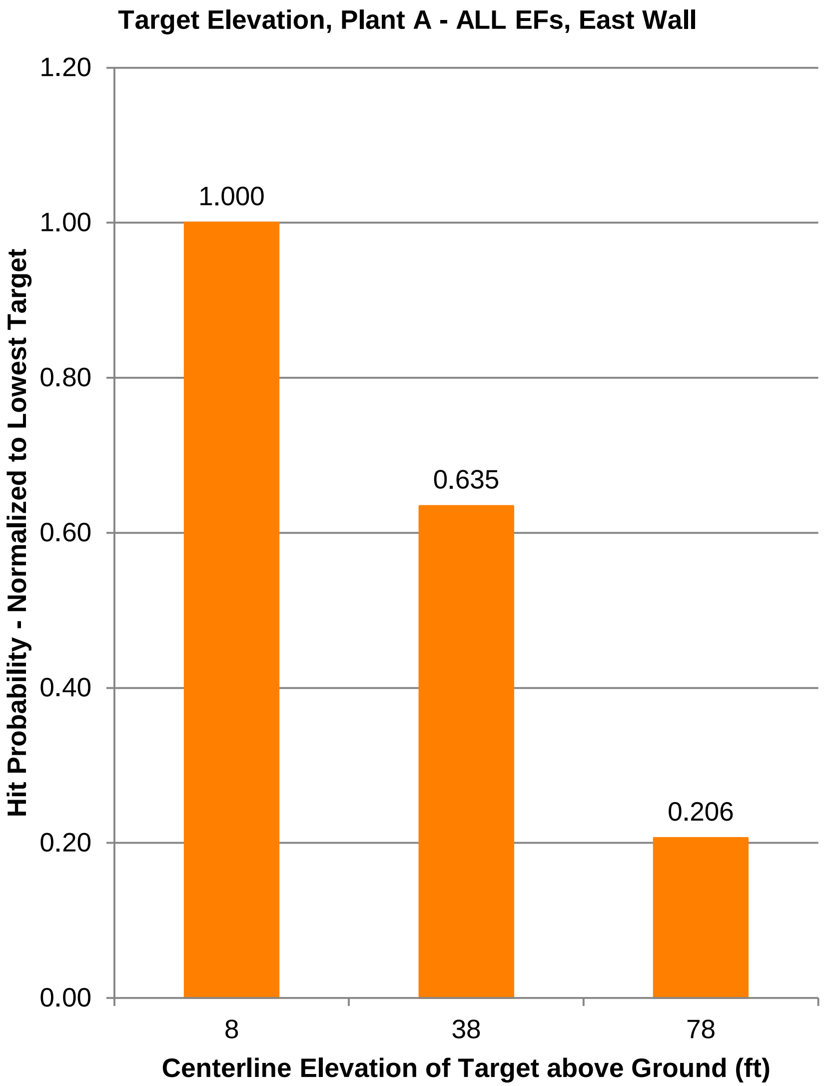


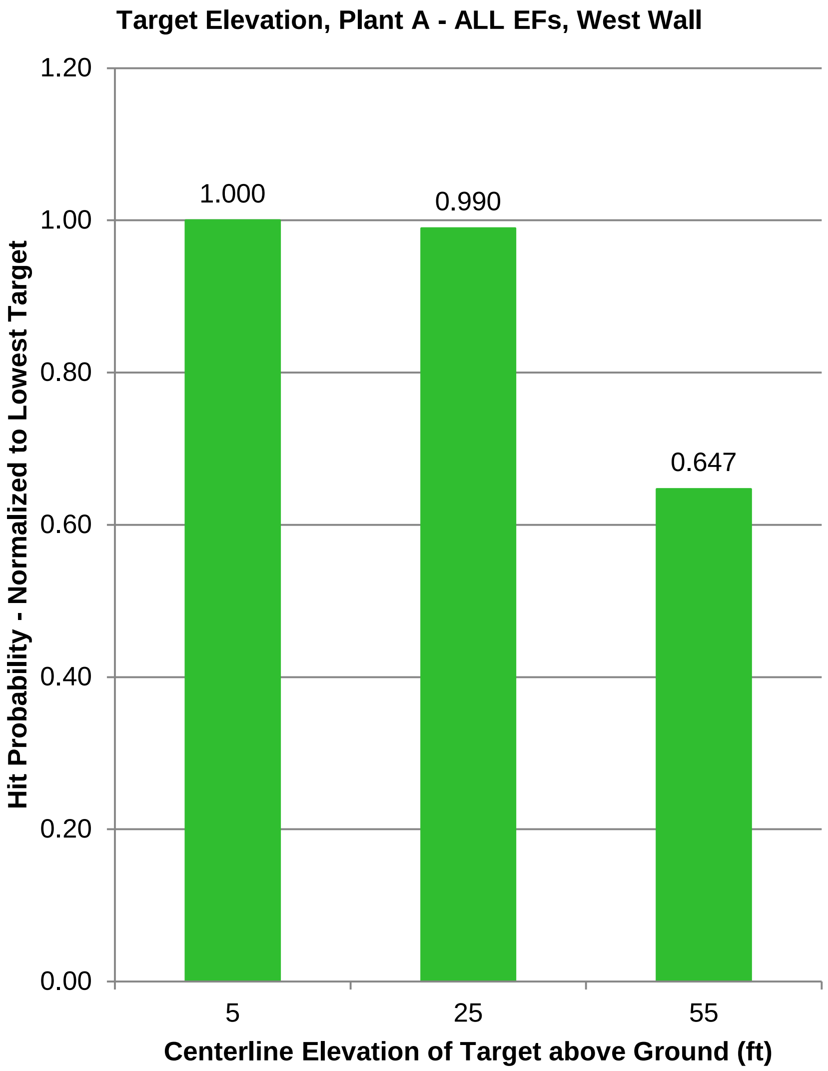


Case 2 Results: Target Elevation – Plant B

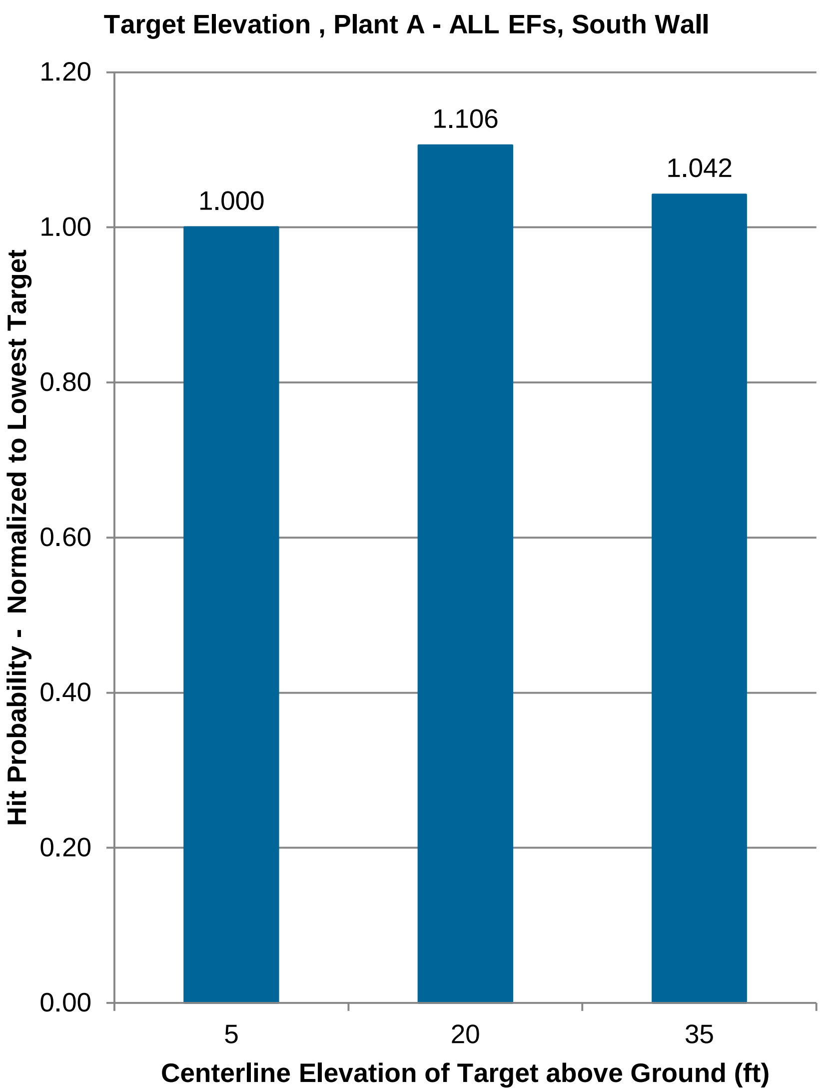


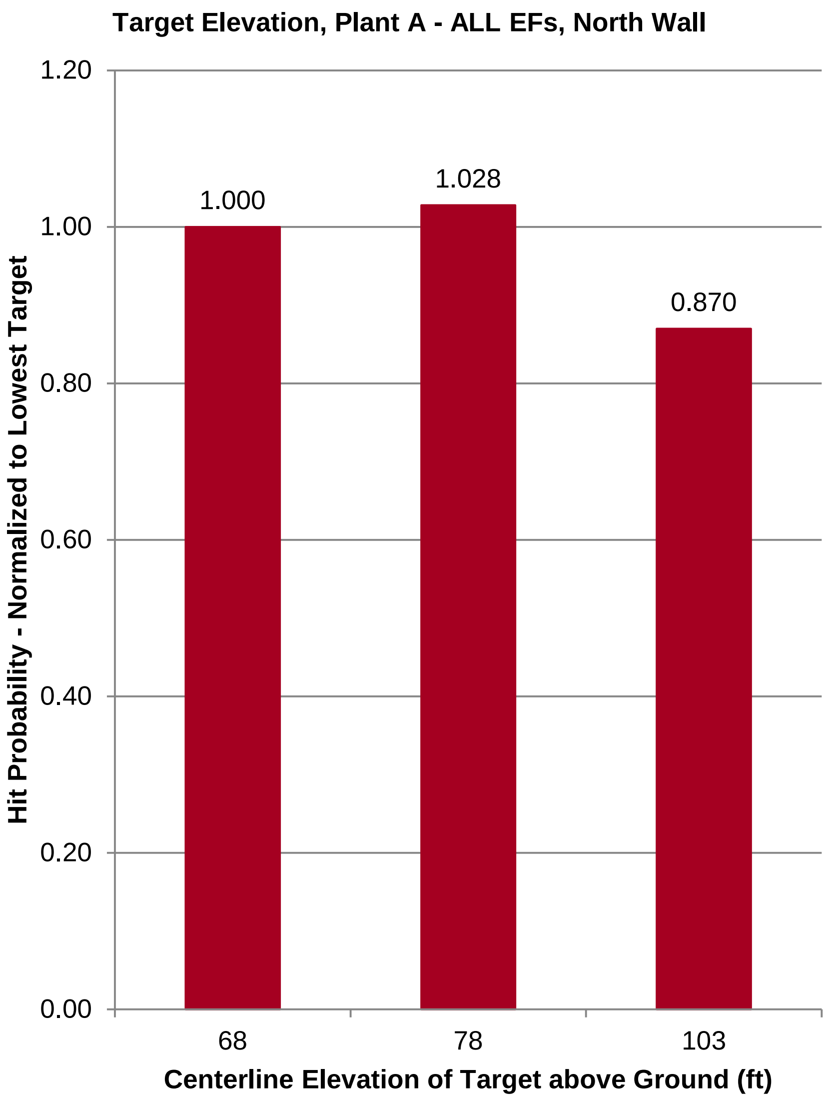
Case 2 Results: Target Elevation – Plant A





Case 2 Results: Target Elevation – Plant A





Conclusions: Target Elevation Sensitivity

- TMRE method provides lower Missile Impact Parameter (MIP) for elevated targets compared to ground level targets
- Sensitivity case investigated how the hit probability changes with target elevation
- Sensitivity results shows that elevated targets are hit less frequently than ground level targets
  - This is the expected behavior
  - Most cases showed substantial reduction in hit probability
- **Conclusion: Use of lower MIP for elevated targets is appropriate**

TMRE Missile and Target Characteristics

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TMRE Missile Counts

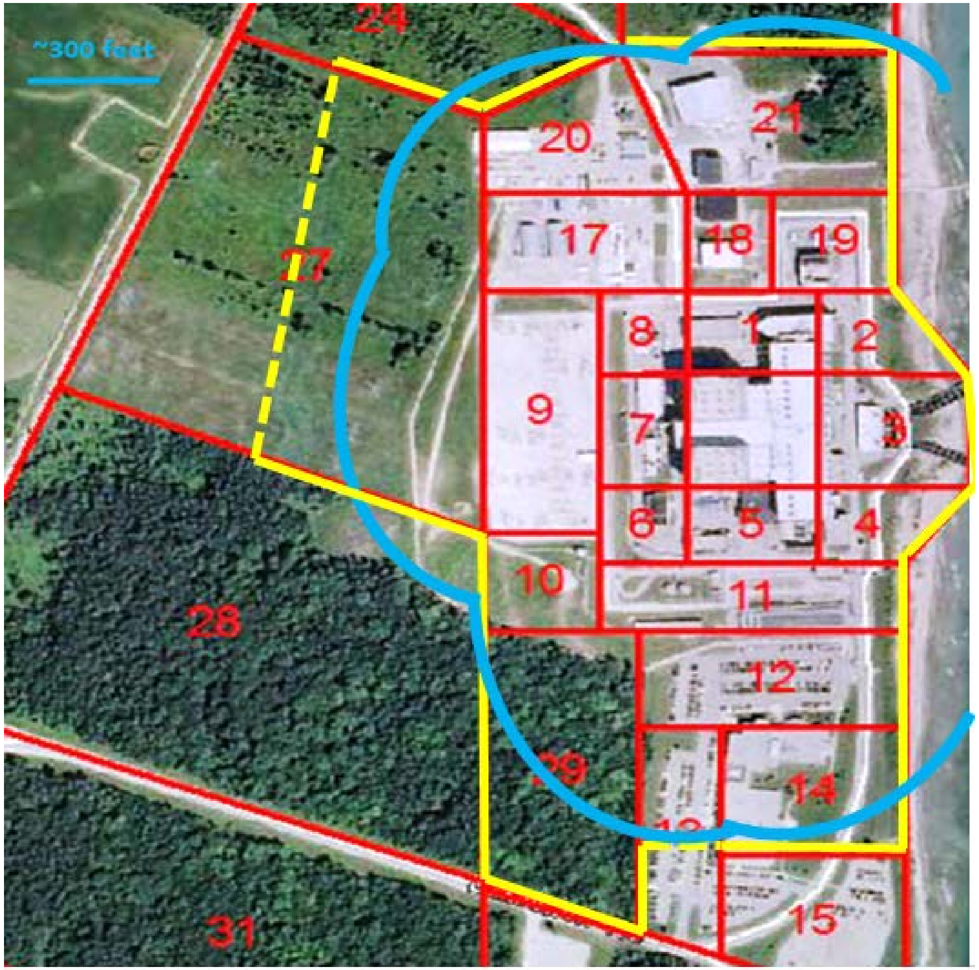
- Recall: **EEFP = (MIP) x (# of Missiles) x (Target Exposed Area) x (Fragility)**
- From a high level perspective, every target EEFP calculation could use the entire site missile population for **(# of Missiles)**
- Determine generic missile population for use in the TMRE
  - Expect total to be in the 50K – 60K range

TMRE Missile Counts

- Reviewing TORMIS models and HW PRAs for missile counts
  - 3 or 4 TORMIS models, 4 or 5 HW PRAs
- Typical TORMIS analysis has missiles within 2500' radius circle from center of plant (usually Containment or Reactor Building)
  - Missiles are counted by zone
- Evidence from previous TORMIS analyses
  - Missiles within 300 feet have most impact on hit probability
  - Missiles outside 600 feet have very little impact

TMRE Missile Counts

- Example missile zones
- 600' from edge of powerblock shown in blue
- Include missile zones within ~600 feet of power block
  - Outlined in Yellow
    - 1 - 14
    - 17 – 21
    - 27 and 29
- Analysis in progress



TMRE Missile Types

- **EEFP = (MIP) x (# of Missiles) x (Target Exposed Area) x (Fragility)**
- Although every target could use the entire site missile population for (**# of Missiles)**, this is too conservative for 'robust targets'
  - Exhaust pipes, system piping, tanks
- Determine which missiles can damage robust targets, and only include those in EEFP calculation
  - Crimping/Crushing and Penetration failure modes may have a different set of damaging missiles
  - Individual component types vs. individual missile types

Missile Types

- Need missile type inventory for parsing missile population for robust and non-robust targets
  - 26 different missile types, based on TORMIS categories
  - Missile counts from TORMIS models will be used to develop generic percentages of missiles

Description	Thickness (inches)	Pipe Diameter (inches)	# 8 Rebar	Gas Cyl (193 lb)	Tank Drum (300 lb)	Utility Pole (1500 lb)	Cable Reel (253 lb)	3" pipe (76 lb)	6" pipe (284 lb)	12" pipe (744 lb)	Tool bx (675 lb)	Paver (88 lb)	Conc blk (36 lb)	4x12 timber (200 lb)	2x12 plank (27 lb)	Metal siding	7/8" plywood	W14x26 (390 lb)	C6x13 (195 lb)	small motor (388 lb)	Conc mixer (1,350 lb)	Steel grating (74 lb)	Pallet rack (1,040 lb)	Vehicle (4,000 lb)	20' tree (700 lb)
Diesel Generator Air intake	0.1	48	0.1	0.9	0.6	1.0	0.8	0.3	1.0	1.0	0.6	1.0	0.4	0.1	0.1	0.1	0.1	0.5	0.1	0.6	1.0	0.1	1.0	1.0	0.2
Main Steam Relief Valve	0.28	18	0.0	1.0	0.9	1.0	1.0	0.5	1.0	1.0	1.0	1.0	0.5	0.1	0.0	0.1	0.0	0.7	0.0	0.9	1.0	0.0	1.0	1.0	0.3
Steam Generator Power Operated RV Exh Pipe	0.375	18	0.0	0.3	0.2	0.4	0.3	0.1	0.5	1.0	0.2	0.4	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.2	1.0	0.0	0.4	1.0	0.1
Turbine Driven Feedwater pump exhaust piping (vert)	0.375	20	0.0	0.4	0.2	0.5	0.3	0.1	0.6	1.0	0.3	0.4	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.2	1.0	0.0	0.5	1.0	0.1
Diesel Generator Exh Silencer	0.375	22	0.0	0.4	0.3	0.5	0.4	0.2	0.6	1.0	0.3	0.5	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.3	1.0	0.0	0.5	1.0	0.1
Diesel Generator Exhaust Pipe (vert)	0.375	36	0.1	0.7	0.4	0.9	0.6	0.3	1.0	1.0	0.5	0.8	0.3	0.1	0.1	0.1	0.1	0.3	0.1	0.4	1.0	0.1	0.9	1.0	0.2
SG Power Operated Relief Valve Tailpipe	0.5	16	0.0	0.1	0.1	0.1	0.1	0.0	0.1	1.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	0.0	0.1	1.0	0.0

Crushing/Crimping

Penetration

Description of Target	Thickness (inches)	# 8 Rebar	Gas Cyl (193 lb)	Tank Drum (300 lb)	Utility Pole (1500 lb)	Cable Reel (253 lb)	3" pipe (76 lb)	6" pipe (284 lb)	12" pipe (744 lb)	Tool bx (675 lb)	Paver (88 lb)	Conc blk (36 lb)	4x12 timber (200 lb)	2x12 plank (27 lb)	Metal siding	7/8" plywood	W14x26 (390 lb)	C6x13 (195 lb)	Small motor (388 lb)	Conc mixer (1,350 lb)	Steel grating (74 lb)	Pallet rack (1,040 lb)	Vehicle (4,000 lb)	20' tree (700 lb)	Concrete pipe (400 lb)
Tank (e.g., CST, DFO, RWT)	>= 0.25																								
Tank (e.g., CST, DFO, RWT)	< 0.25																								
Piping (e.g, Main Steam, Service Water, Condensate)	>= 0.5																								
Piping (e.g., Steam, Service Water, Condensate)	>= 0.375																								
Piping (e.g., Steam, Service Water, Condensate)	0.25 - 0.375																								
Concrete roof slab on steel decking	>= 4																								
Concrete roof slab	>= 8																								

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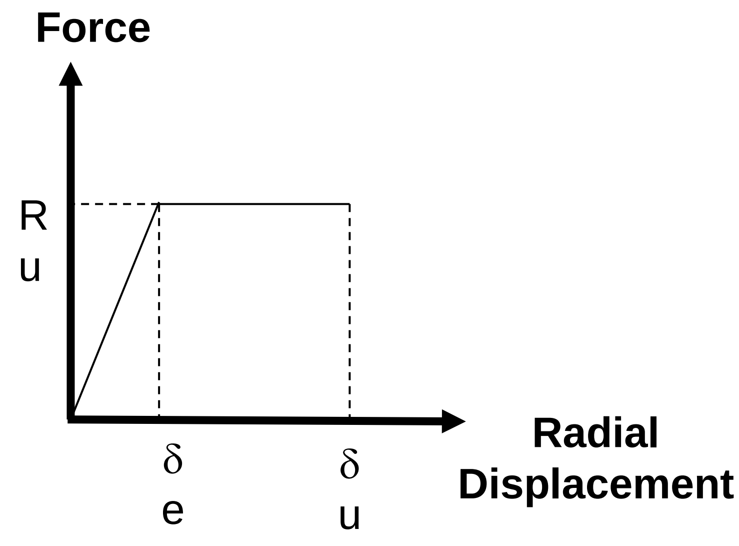
Robust Targets (Crushing and Crimping)

- Simplified model was used to evaluate the radial deformation of a thin walled pipe to an impact force
- Model assumes elastic then perfectly plastic deformation
- Approach is commonly used in dynamic analysis
  – Typically applied to beams or frames



Robust Targets (Crushing and Crimping)

- The impact force is calculated as the minimum of the following
  - Missile buckling force
  - Missile crushing force
  - Target plastic resistance force
- Pipe deformation based on equilibrium of missile kinetic energy and strain energy of target

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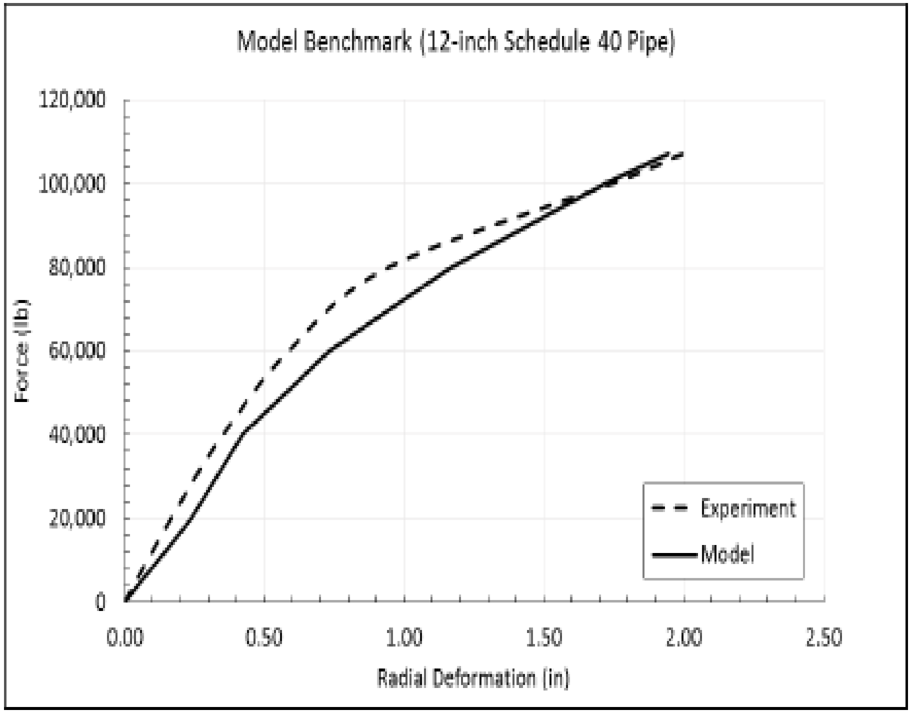
Robust Targets (Crushing and Crimping)

- Calculation Inputs – Missiles
  - Missile weights per TORMIS missile inventory
  - Missile speed is based on SRP 3.5.1.4 "No Tumbling"
    - SRP includes pipes, rods, wood plank, utility pole and vehicle
    - Interpolated/estimated speeds for non-SRP missiles
- Calculation Inputs – Targets
  - Assumed steel pipes with 30 ksi yield-strength
  - Pipe diameter
  - Pipe wall thickness
  - Acceptable flow area reduction is plant-specific

Robust Targets (Crushing and Crimping)

- The method was benchmarked to a physical experiment and reasonable results were obtained.
- The results compare reasonably well with the expert judgment
- Energy-based method currently being confirmed using transient analysis



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Preliminary Robust Targets (Crushing and Crimping)

Description	Thickness (inches)	Pipe Diameter (inches)	# 8 Rebar	Gas Cyl (193 lb)	Tank Drum (300 lb)	Utility Pole (1500 lb)	3" pipe (76 lb)	6" pipe (284 lb)	12" pipe (744 lb)	Tool bx (675 lb)	Paver (88 lb)	Conc blk (36 lb)	4x12 timber (200 lb)	2x12 plank (27 lb)	Metal siding	7/8" plywood	W14x26 (390 lb)	small motor (388 lb)	conc mixer (1,350 lb)	steel grating (74 lb)	pallet rack (1,040 lb)	vehicle (4,000 lb)	20' tree (700 lb)
Diesel Generator Air intake	0.1	48	Green	Red	Red	Red	Yellow	Red	Red	Red	Red	Yellow	Green	Green	Green	Green	Red	Red	Red	Green	Red	Red	Green
Main Steam Relief Valve Exhaust Pipe	0.28	18	Green	Red	Red	Red	Red	Red	Red	Red	Red	Red	Green	Green	Green	Green	Red	Red	Red	Green	Red	Red	Yellow
Steam Generator PORV Exhaust Pipe	0.375	18	Green	Yellow	Green	Yellow	Green	Red	Red	Green	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green	Yellow	Red	Green
Turbine Driven Feedwater Pump Exh	0.375	20	Green	Yellow	Green	Red	Green	Red	Red	Yellow	Yellow	Green	Green	Green	Green	Green	Green	Green	Red	Green	Red	Red	Green
Diesel Generator Exh Silencer	0.375	22	Green	Yellow	Yellow	Red	Green	Red	Red	Yellow	Red	Green	Green	Green	Green	Green	Green	Yellow	Red	Green	Red	Red	Green
Diesel Generator Exhaust Pipe	0.375	36	Green	Red	Yellow	Red	Yellow	Red	Red	Red	Red	Yellow	Green	Green	Green	Green	Yellow	Yellow	Red	Green	Red	Red	Green
Main Steam Pipe	0.5	16	Green	Green	Green	Green	Green	Green	Red	Green	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green	Green	Red	Green

All Targets are Steel with 30ksi Yield Strength

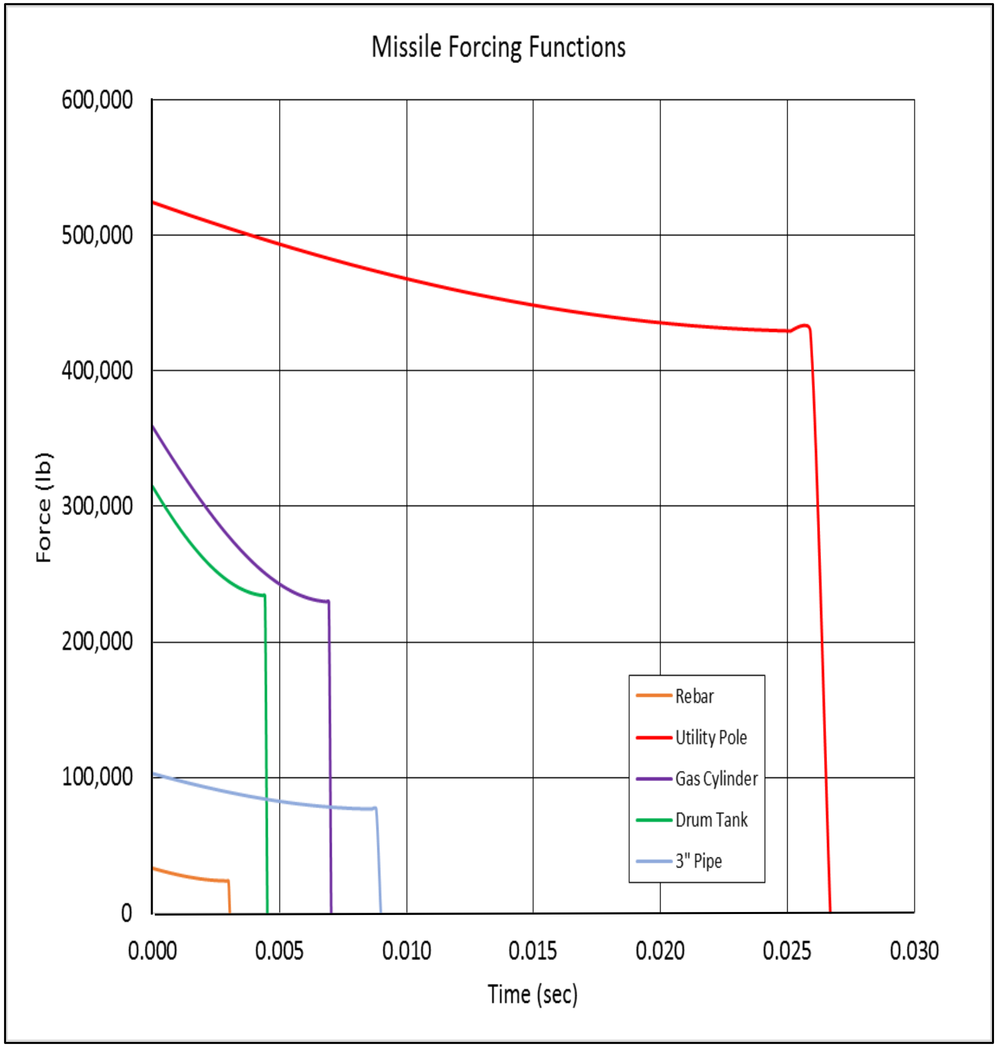
<20% (Green)	Less than 20% reduction in flow area
20-50% (Yellow)	Between 20%-50% reduction in flow area
> 50% (Red)	Greater than 50% reduction in flow area

Robust Targets (Perforation)

- Empirical equations exist for evaluating steel and concrete targets; typically representative of hard/rigid projectiles
  - Ballistic Research Lab (BRL) typically used
- Most wind-driven missiles are deformable (not hard/rigid)
  - Susceptible to crushing (wood) and buckling (steel), which significantly reduces impact force
- While empirical equations can be conservatively utilized, a more realistic method is being develop to account for deformable missiles
- Factors provided for deformable missile impacting concrete targets
  - Developing factors for steel targets

Robust Targets (Perforation)

- In evaluating impacts of deformable missiles (susceptible to crushing, buckling), use of empirical perforation equations may be overly-conservative.
- Transient analysis is more realistic and can account for both missile and target deformation (dynamic interaction).
- Benchmark to relevant experiments
- Target response (deformation, strain, etc.) compared to code limits



Sample force-time functions used in transient analysis

Preliminary Robust Targets (Penetration)

Description of Robust Target	Thickness (inches)	# 8 Rebar	Gas Cyl (193 lb)	Tank Drum (300 lb)	Utility Pole (1500 lb)	3" pipe (76 lb)	6" pipe (284 lb)	12" pipe (744 lb)	Toolbox (675 lb)	Paver (88 lb)	Concrete block (36 lb)	4x12 timber (200 lb)	2x12 plank (27 lb)	Metal siding	7/8" plywood	W14x26 (390 lb)	Small motor (388 lb)	Conc mixer (1,350 lb)	Steel grating (74 lb)	Pallet rack (1,040 lb)	Vehicle (4,000 lb)	20' tree (700 lb)
Tank (e.g., CST, DFO, RWT)	>= 0.25	Red	Red	Red	Red	Red	Red	Red	Red	Green	Green	Green	Green	Green	Green	Red	Red	Red	Green	Red	Red	Green
Tank (e.g., CST, DFO, RWT)	< 0.25	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Green	Red	Red	Red	Red	Red	Red	Red	Red
Piping (e.g, Main Steam, Service Water, Cond)	>= 0.5	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green	Red	Red	Green
Piping (e.g., Steam, Service Water, Cond)	>= 0.375	Green	Green	Green	Red	Green	Red	Red	Green	Green	Green	Green	Green	Green	Green	Red	Red	Red	Green	Red	Red	Green
Piping (e.g., Steam, Service Water, Cond)	0.25 - 0.375	Green	Red	Green	Red	Red	Red	Red	Green	Green	Green	Green	Green	Green	Green	Red	Red	Red	Green	Red	Red	Green
Concrete roof slab on steel decking	>= 4	Green	Green	Green	Red	Green	Red	Red	Red	Green	Green	Green	Green	Green	Green	Red	Red	Red	Green	Red	Red	Red
Concrete roof slab	>= 8	Green	Green	Green	Red	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green	Red	Red	Red

Green - Target not failed by this missile type

Red - Target failed by this missile type

Final Results

- Reviewing results and comparing with experimental data
- Initial Missile/Target Matrix was based on engineering judgment.
  - Using empirical relationships to help refine judgments
- Final result will be a mix of analytical model results and consensus judgment
  - Bases will be documented in NEI guidance document

TMRE
Conservatism and Uncertainty

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Conservatism in TMRE Method

- ALL damaging missiles are included in the EEFP starting with F'2 tornadoes
  - F'2 wind speeds are from 103 – 135 mph
  - Few high energy missiles created at these speeds
  - F'2 will typically be the highest frequency tornado in the TMRE

- Assume a 1.0 for SSC fragility
  - If SSC is hit with a tornado missile, the SSC is assumed to fail
  - Conservatism most evident at lower tornado wind speeds (e.g., F'2 and F'3), which have higher frequencies

Conservatism in TMRE Method

- TMRE RG 1.174 LAR Acceptance Criterion is $\Delta CDF < 10^{-6}$/yr
  - SRP risk-informed acceptance criterion for TMP is to maintain probability of exceeding 10 CFR Part 100 exposure guidelines less than 10^{-6} per year
  - RG 1.174 acceptance criterion is an order of magnitude more restrictive than SRP acceptance criterion.

Key Assumptions in TMRE Method

- Missile Impact Parameter (MIP) Values
  - Values based on generic TORMIS studies from NP-768
  - Chose target with highest hit probabilities as basis for near-ground target MIP
  - Used Plant A average hit probabilities as basis for elevated target MIP
  - Excluded roof areas from MIP derivation, while retaining roof hits – results in a lower MIP
  - Plant A TORMIS runs assumed a uniform missile distribution

- Missile Count
  - Missile inventory on site can vary temporally by location and type
  - Many missiles unable to damage safety related SSCs
  - Generic inventory based on review of previous TORMIS models
  - Entire missile inventory assumed available to hit all targets

Benchmarking Studies

- Compare peer reviewed HW PRA against TMRE model developed for that site
  - 2 separate plants
- Review Results (CDF, ΔCDF) at:
  - Plant level
  - Sequence level
  - Target level
- **Results of TMRE models are conservative as compared to HW PRA results**

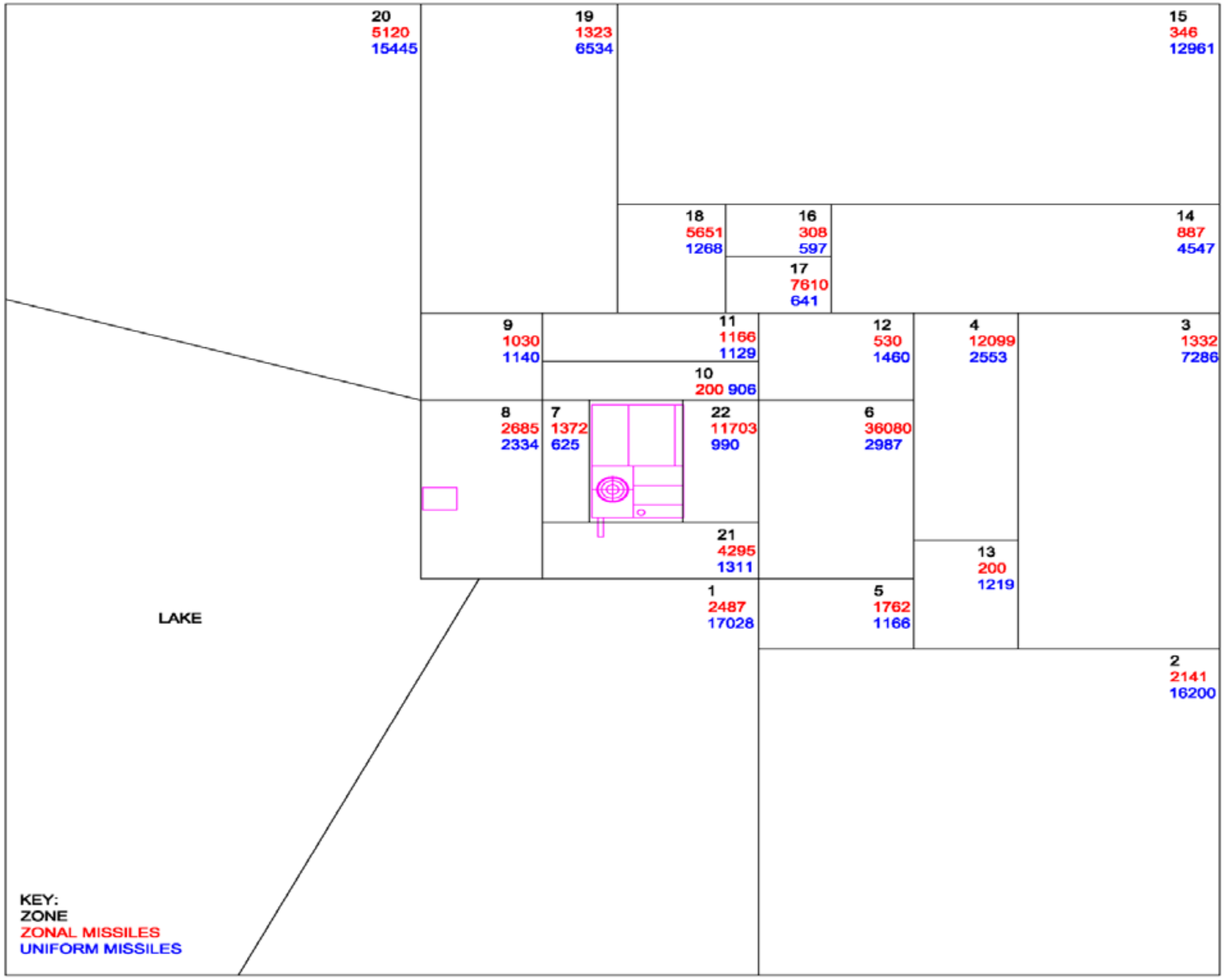
Case 3 Setup: Missile Distribution Sensitivity

- The total area of the Plant A missile zones is 19,771,450 ft^2, with a total of 100,327 missiles.
- Missile set for Plant A includes 13 of 26 TORMIS missile types (1, 2, 3, 6, 9, 10, 11, 12, 14, 15, 16, 25, and 26).
- The total area of the Plant B missile zones is 31,360,000 ft^2, with a total of 141,944 missiles.
- Missile set for Plant B includes 15 of 26 TORMIS missile types (1, 2, 3, 6, 8, 9, 10, 11, 12, 14, 15, 16, 22, 25, and 26).

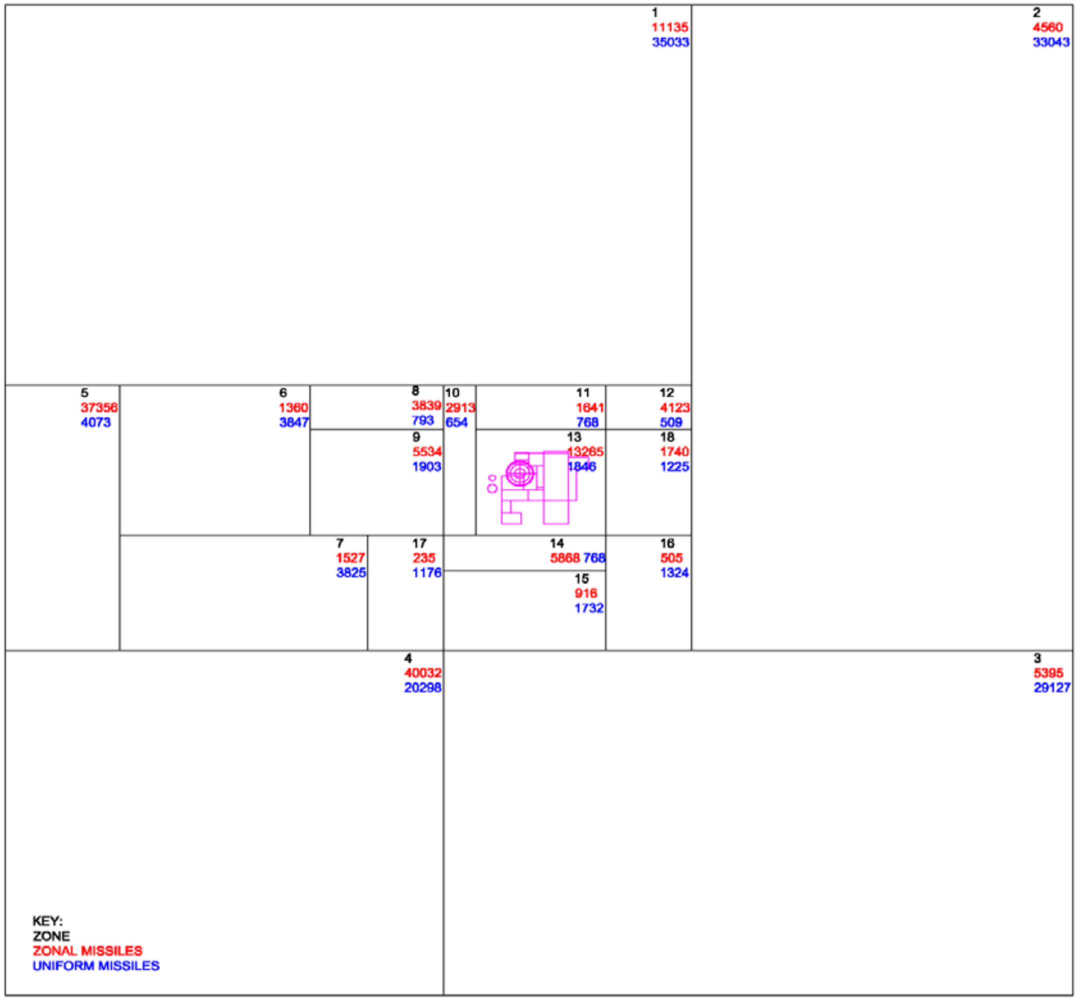
Case 3 Setup: Missile Distribution Sensitivity

- Objective was to examine impact of Zonal and Uniform missile distribution on target hit probabilities
- Both Plants A and B were used
- Model vulnerable targets were unchanged
- Only missiles in missile zones were considered.
  - Missiles injected from top of buildings are excluded since uniform distribution of such missiles is unrealistic
- For Zonal missile distribution, sum of restrained and free missiles for a given zone were considered applicable to the zone as free missiles
- For Uniform missile distribution, the total number of Zonal missiles were distributed amongst the missile zones in proportion to the zone areas as free missiles

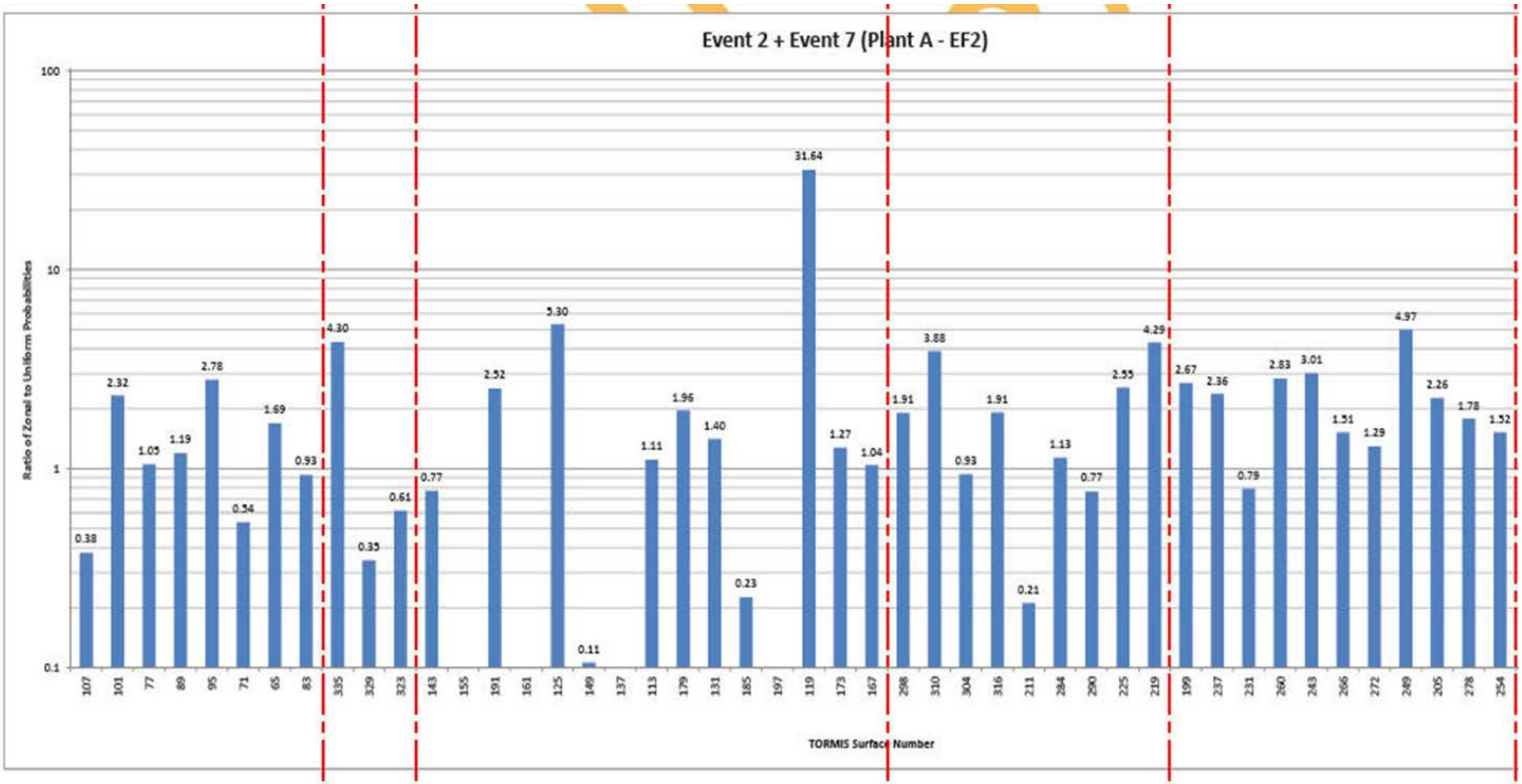
Case 3: Plant A – Zonal vs. Uniform Missile Distribution



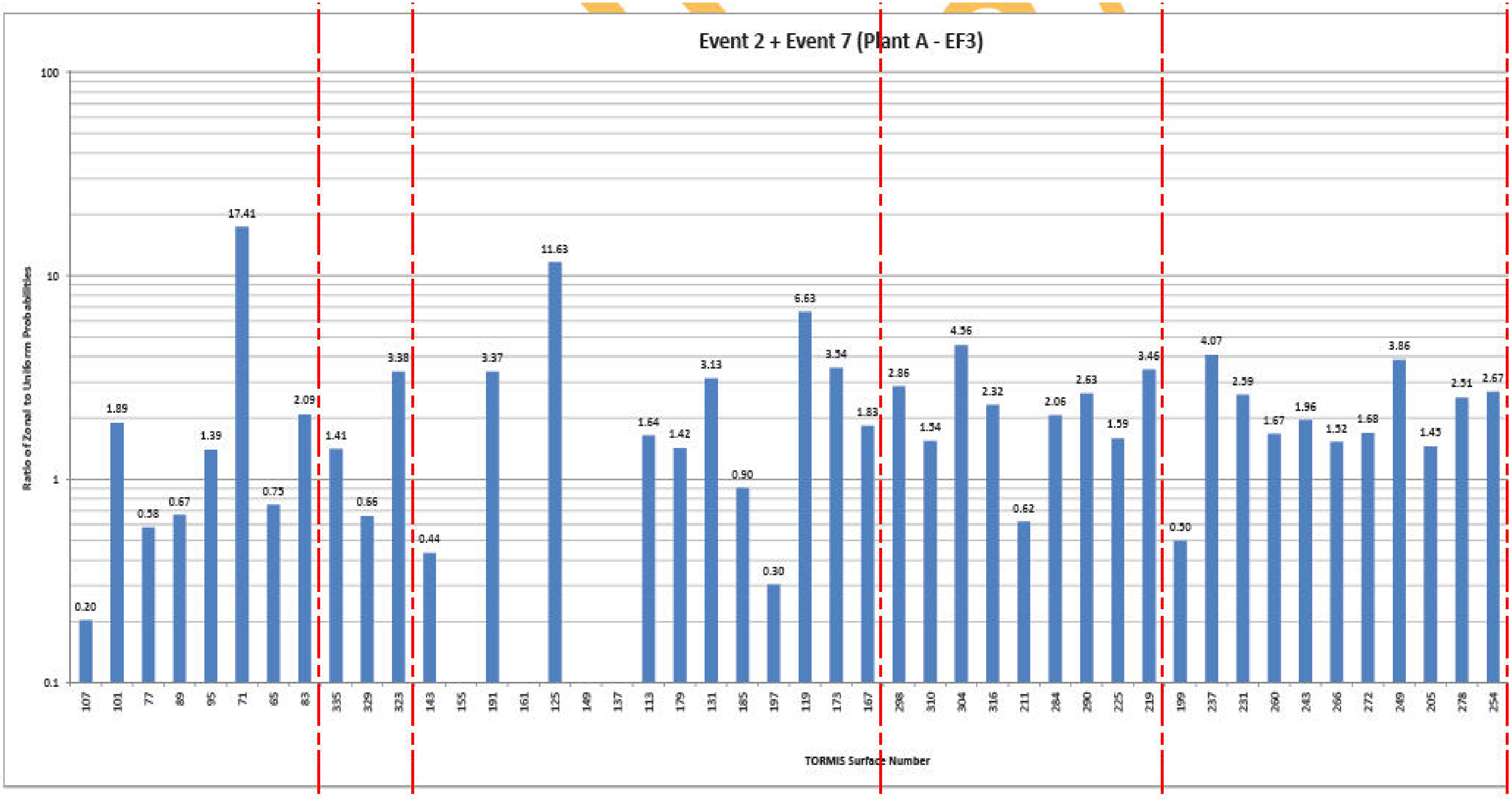
Case 3: Plant B – Zonal vs. Uniform Missile Distribution



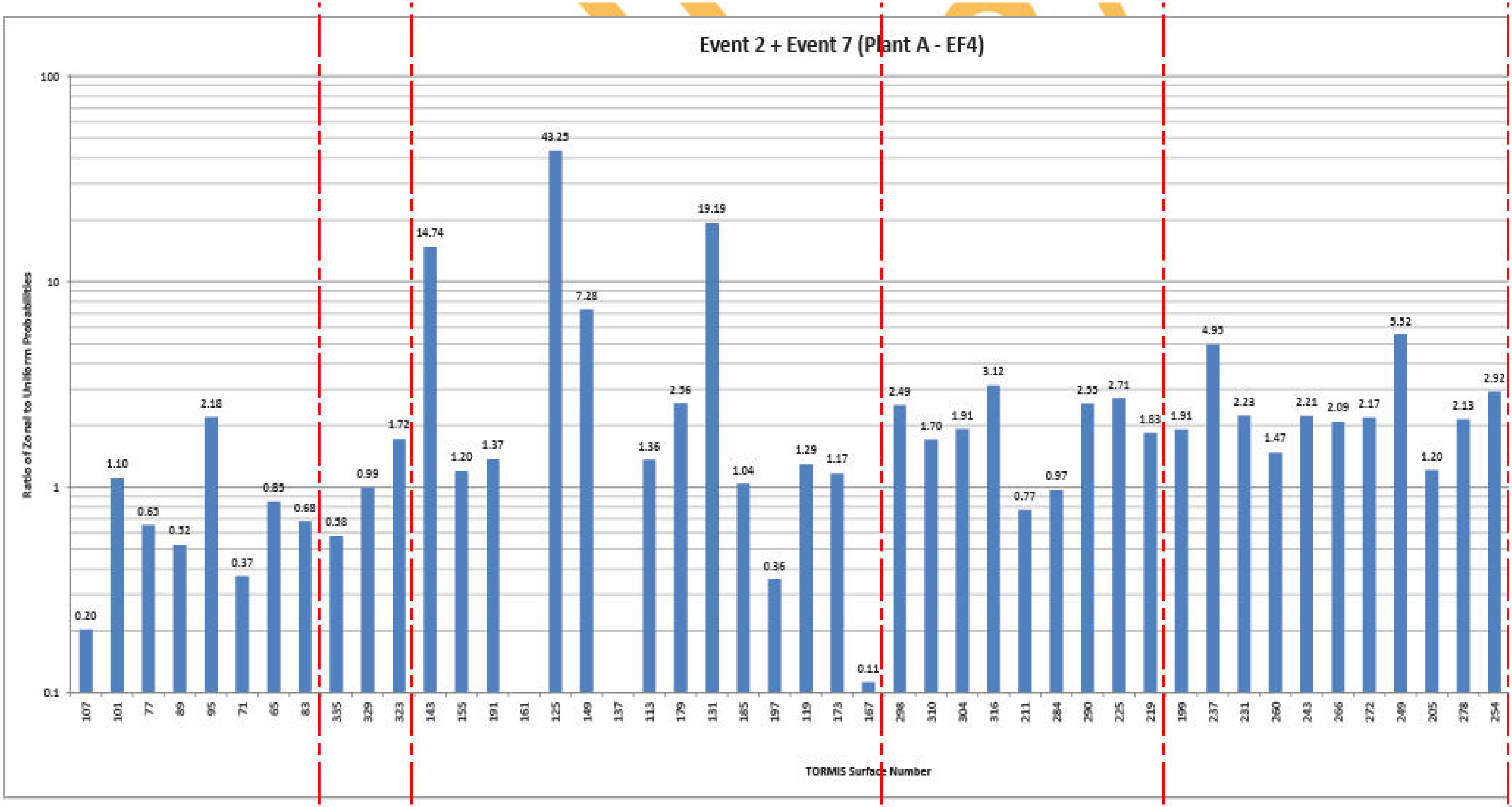
Case 3 Results – Plant A (EF2)



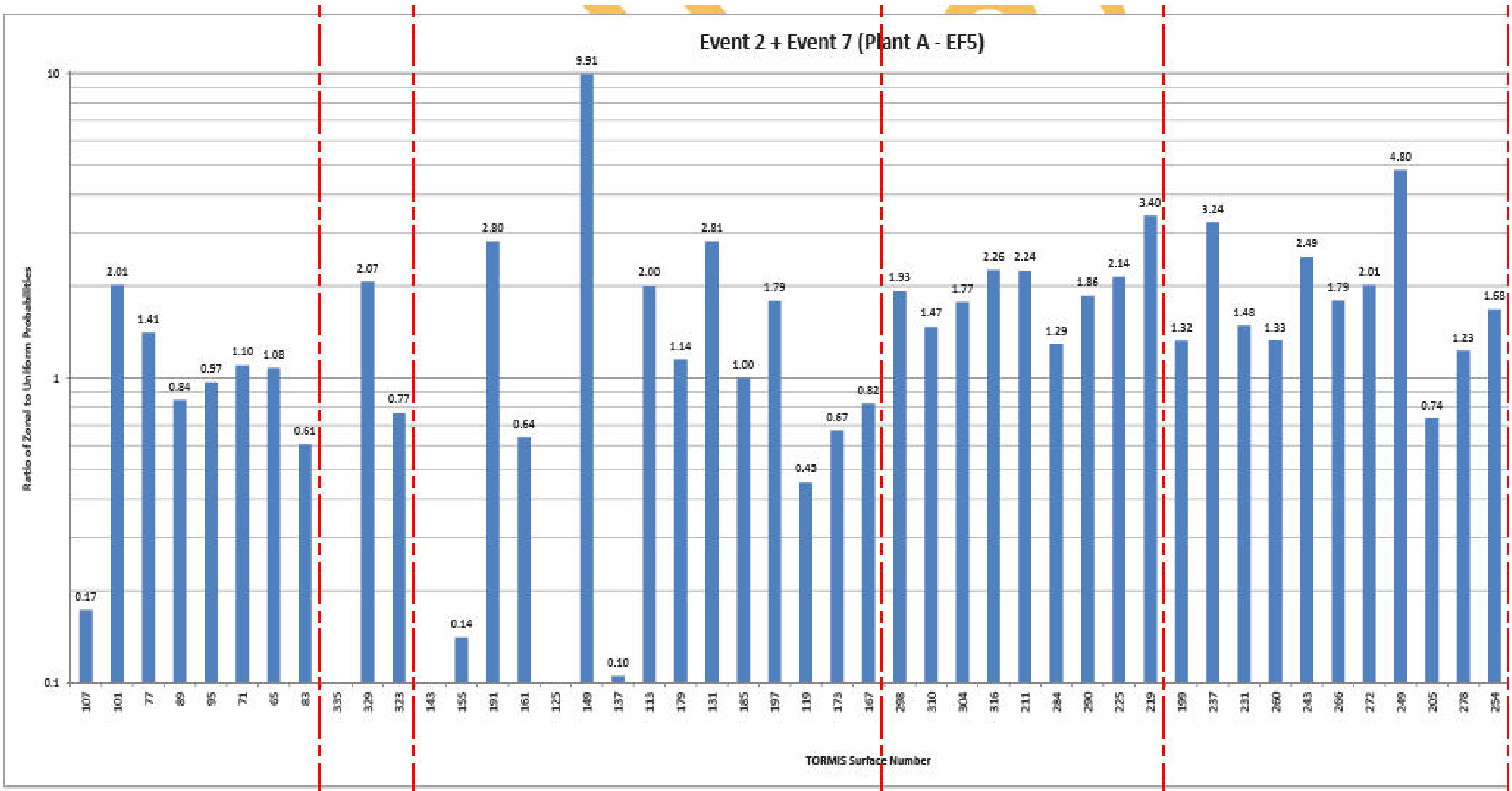
Case 3 Results – Plant A (EF3)



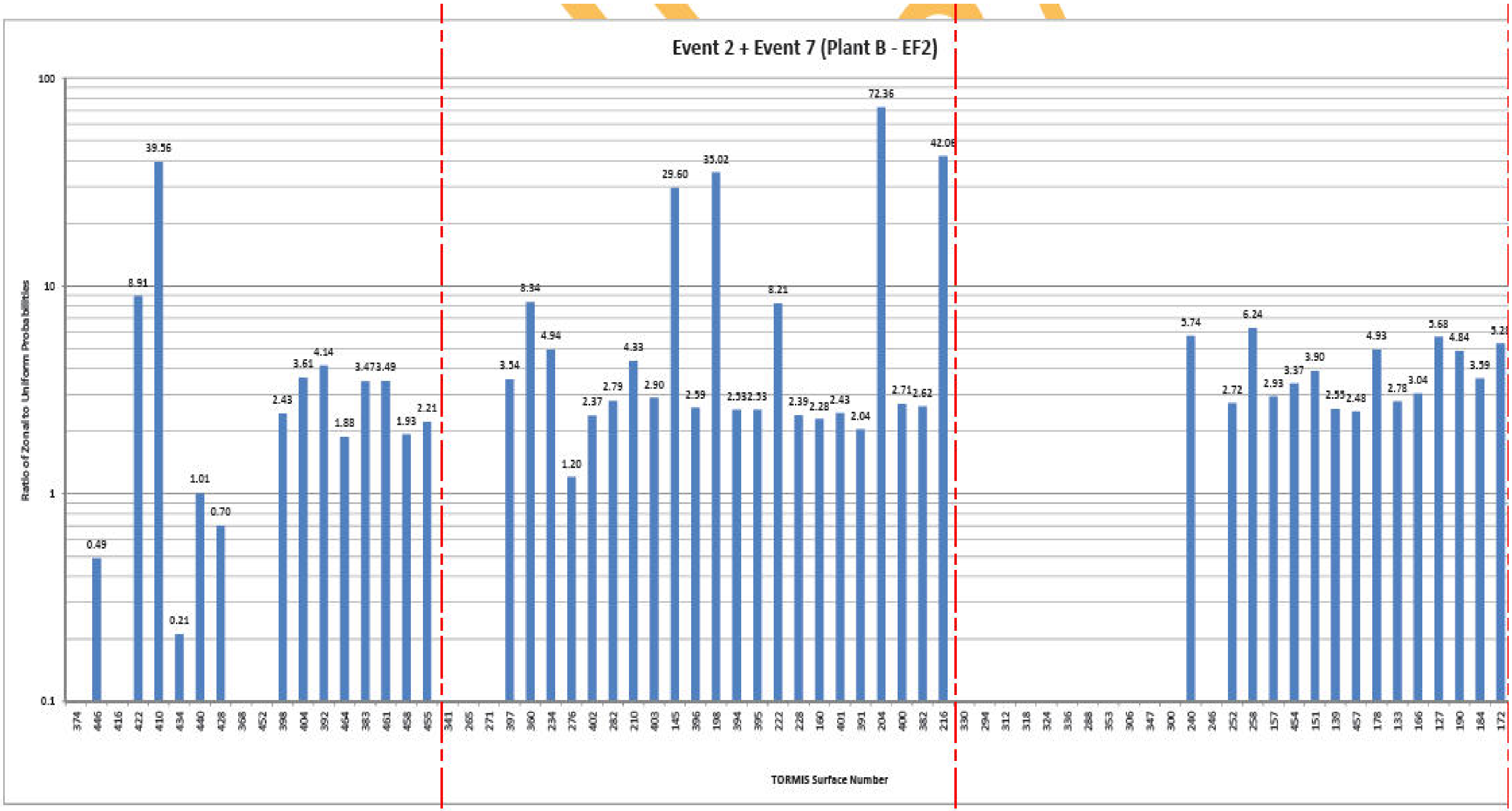
Case 3 Results – Plant A (EF4)



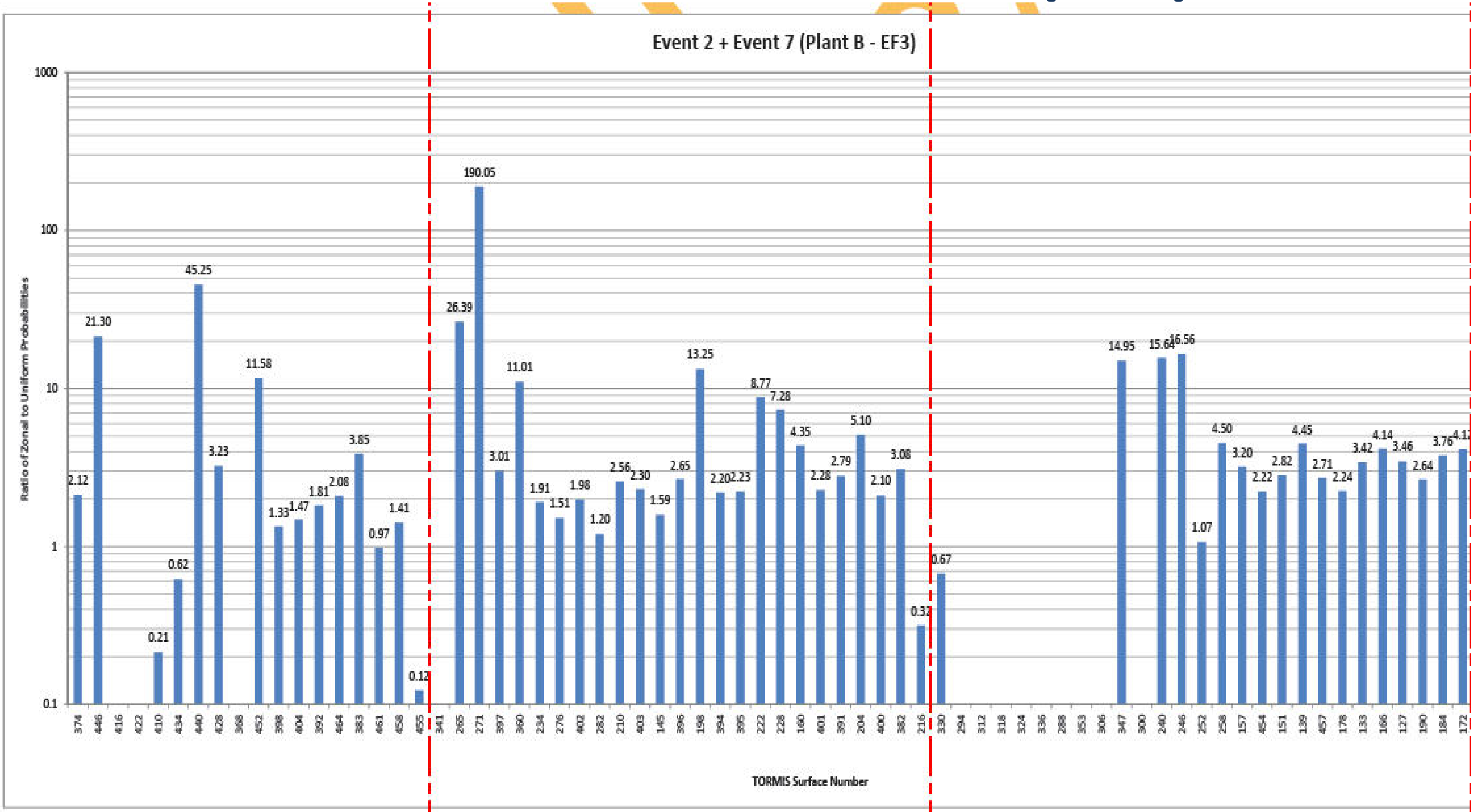
Case 3 Results – Plant A (EF5)



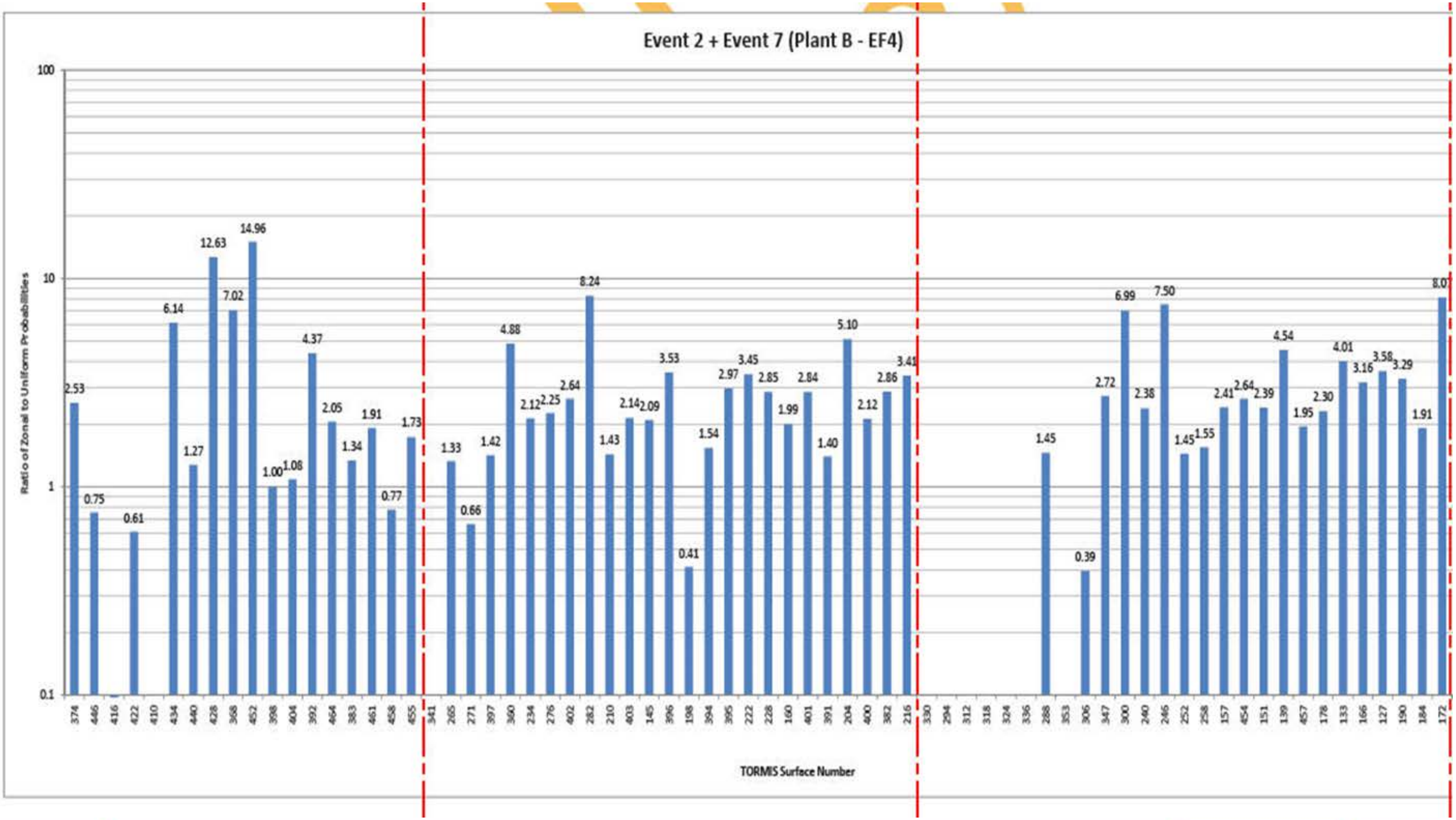
Case 3 Results – Plant B (EF2)



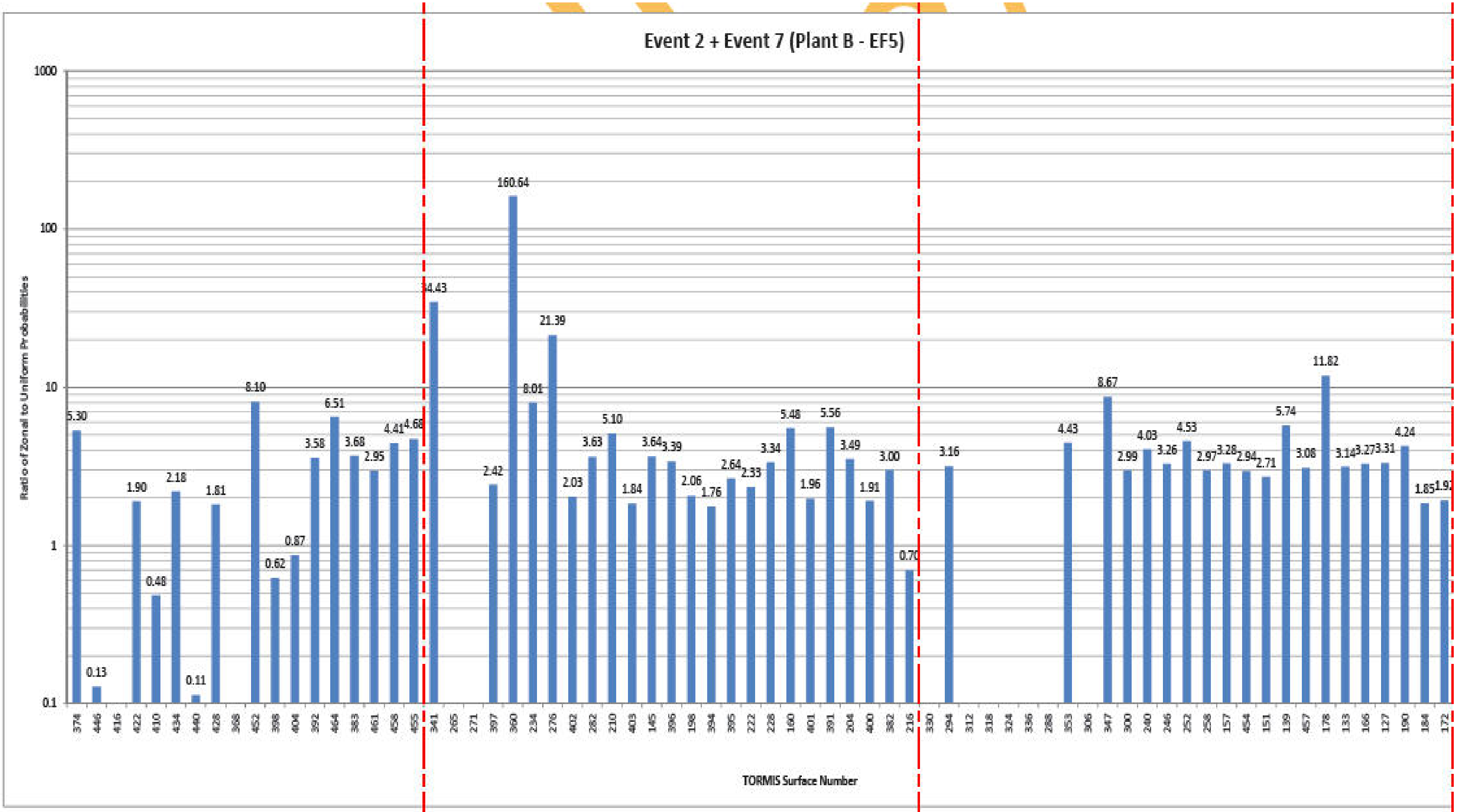
Case 3 Results – Plant B (EF3)



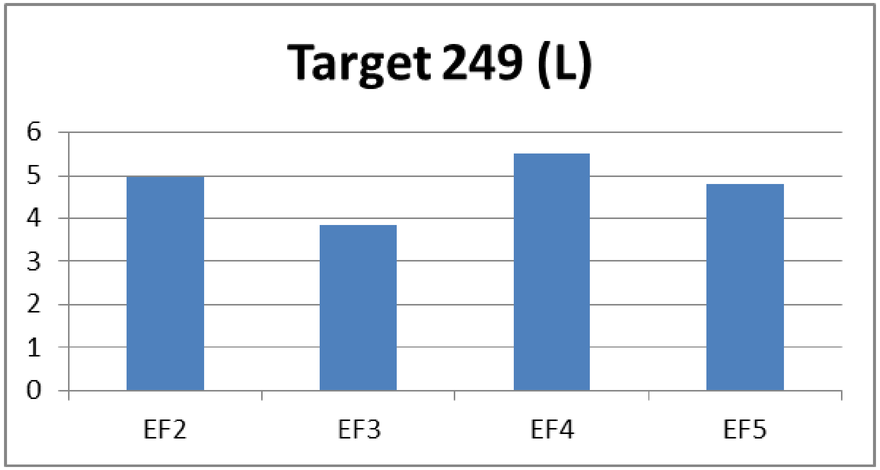
Case 3 Results – Plant B

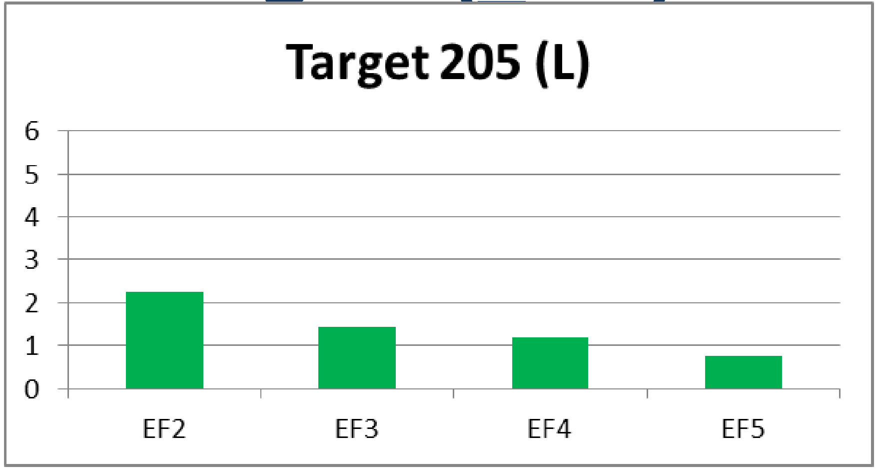


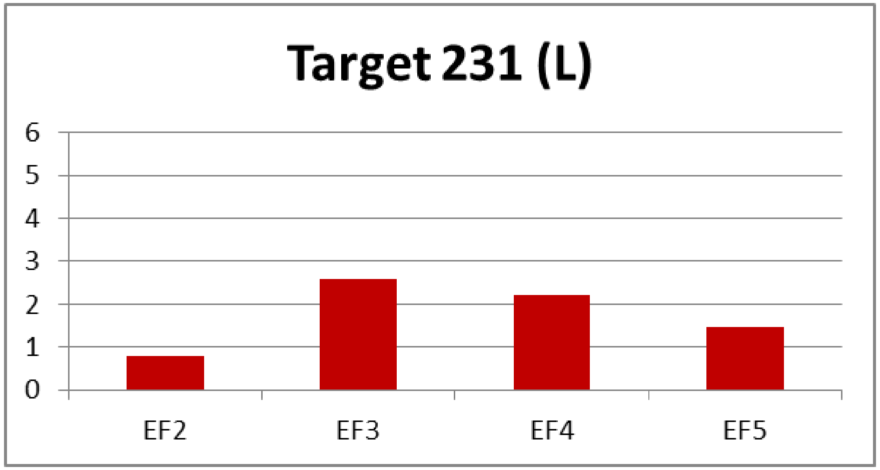
Case 3 Results – Plant B



Case 3 – Plant A – Low Targets (<30')

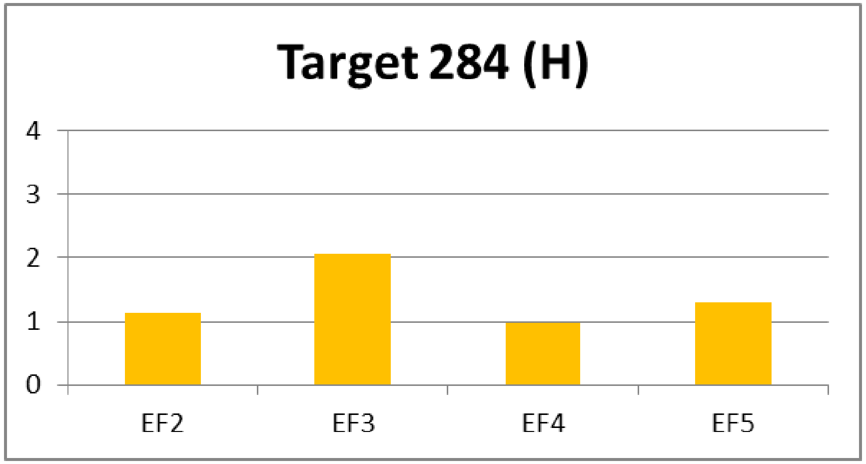


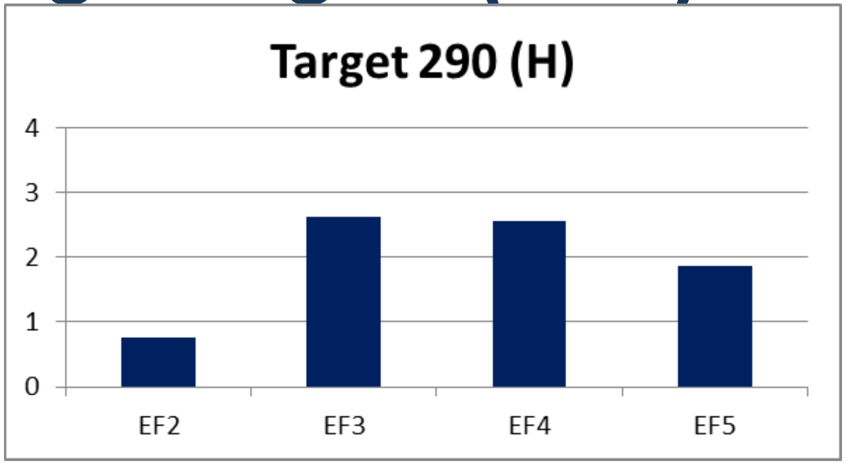


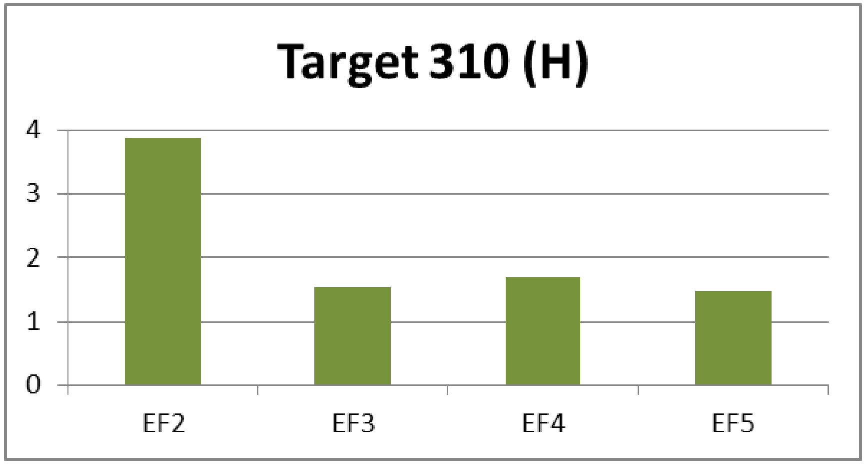


Note: All charts are same scale

Case 3 – Plant A – High Targets (>30')

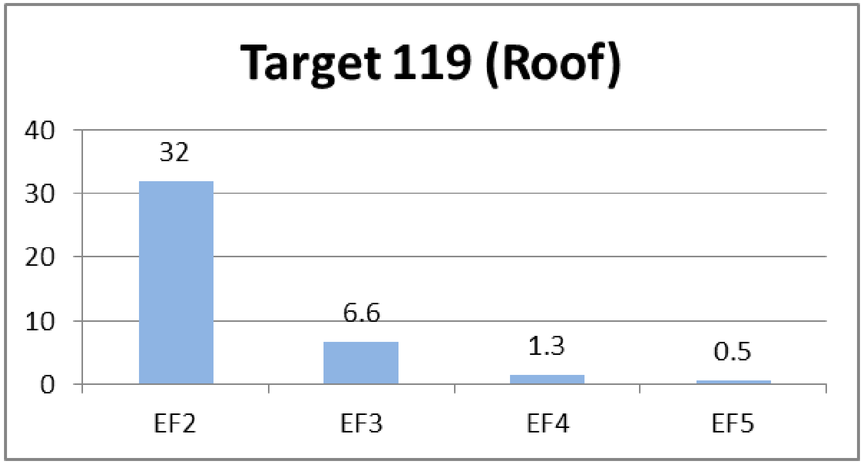


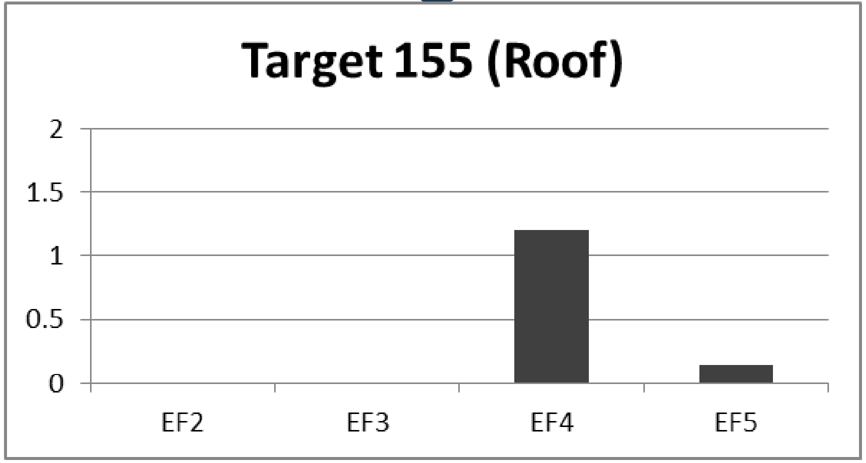


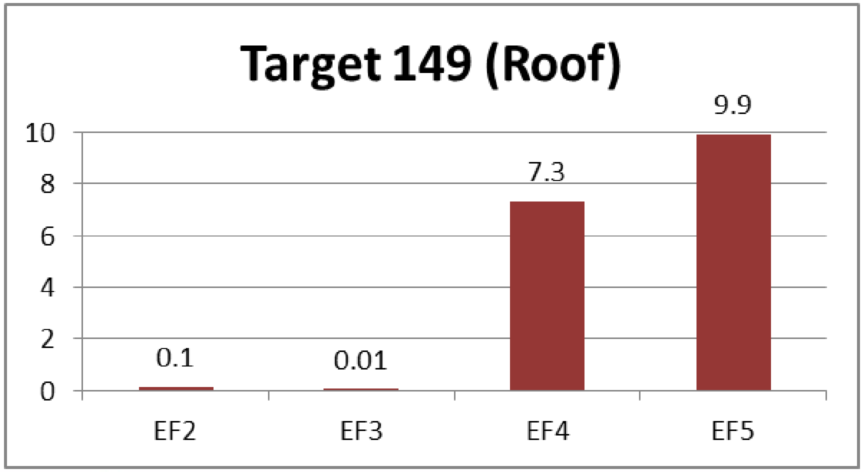


Note: All charts are same scale

Case 3 – Plant A – Roof Targets



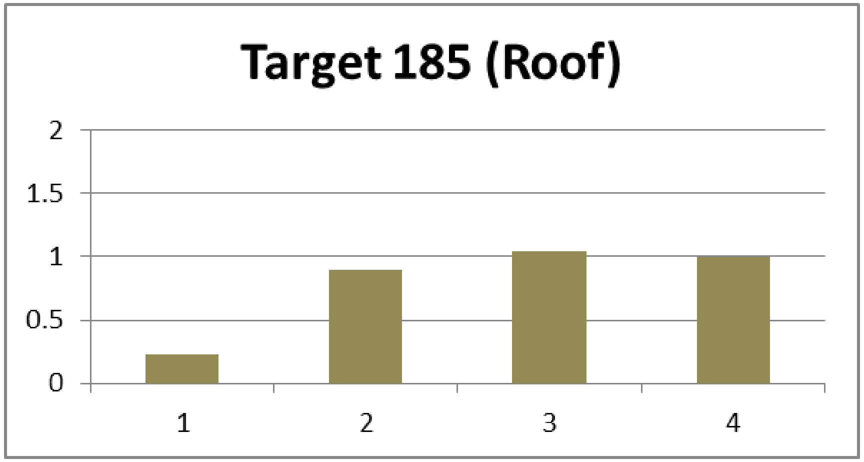


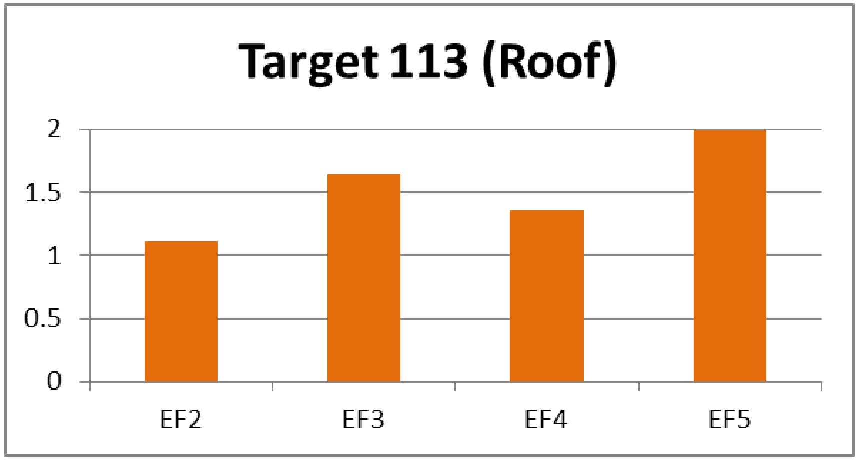


Notes:

- Charts are different scales
- 0 indicates no hits in either Zonal and/or Uniform cases

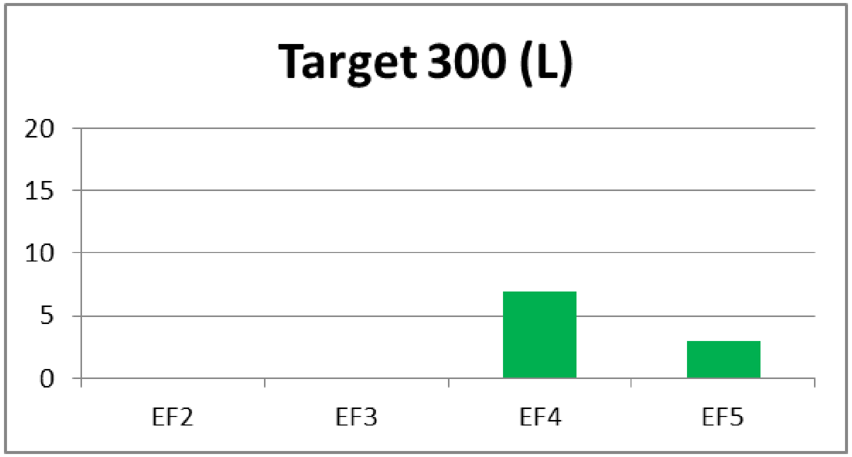
Case 3 – Plant A – Roof Targets (continued)

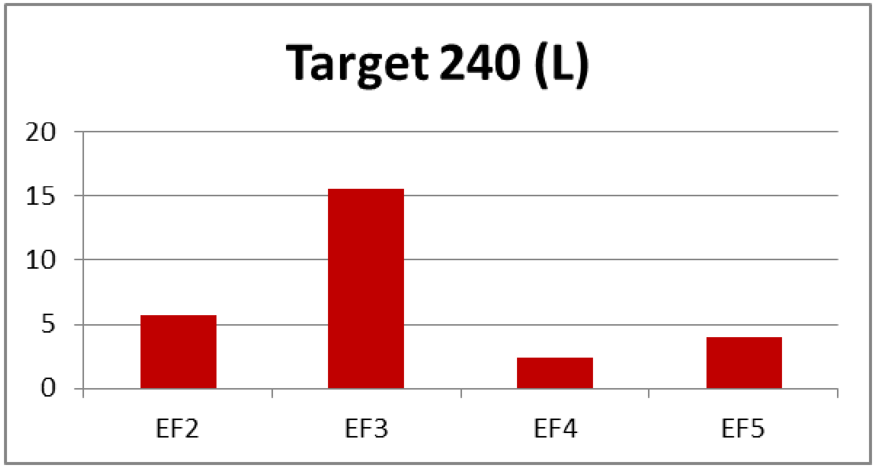


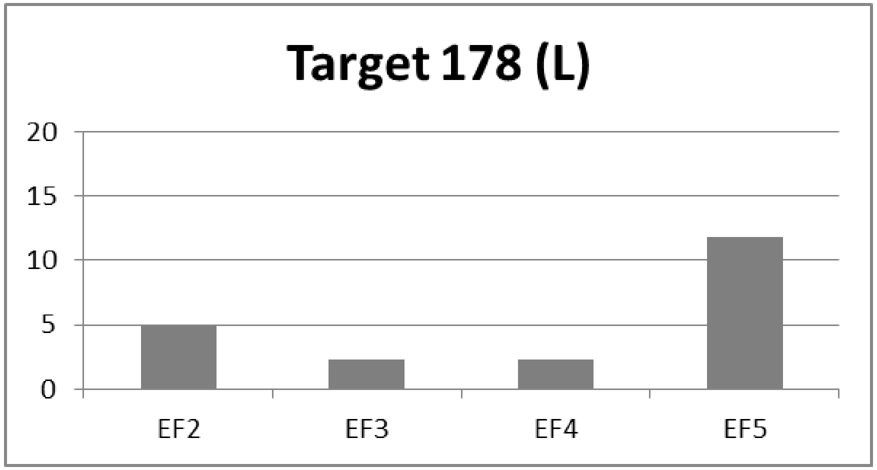


Note: Both charts are same scale

Case 3 – Plant B – Low Targets (≤30')

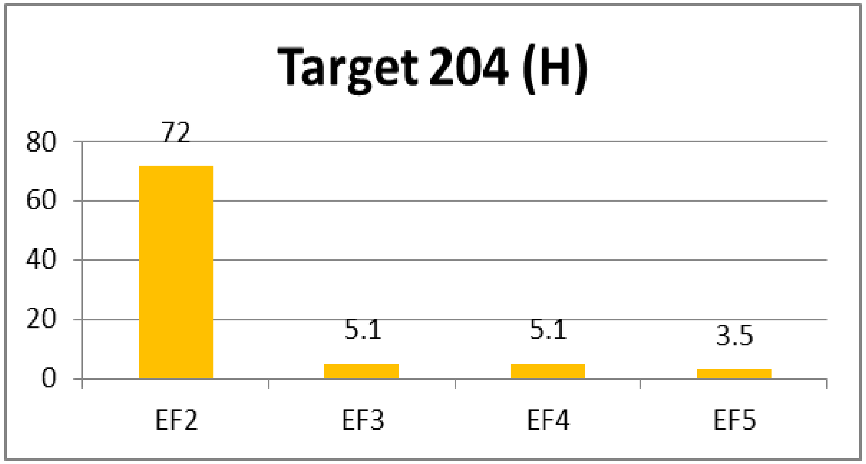


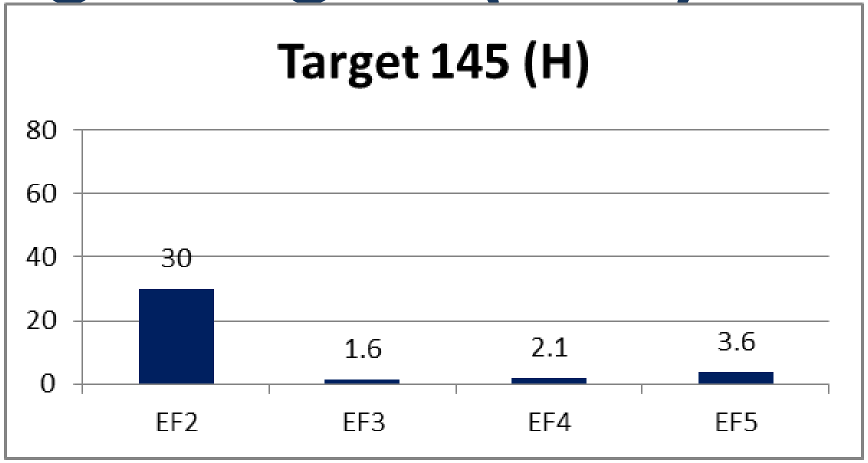


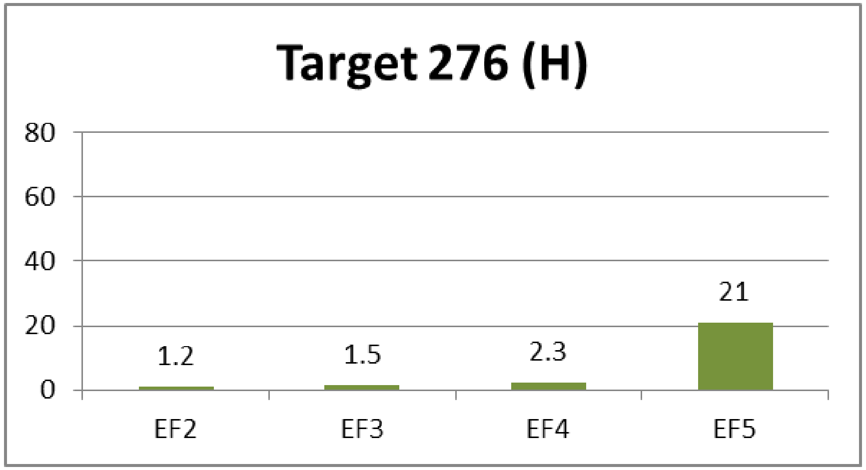


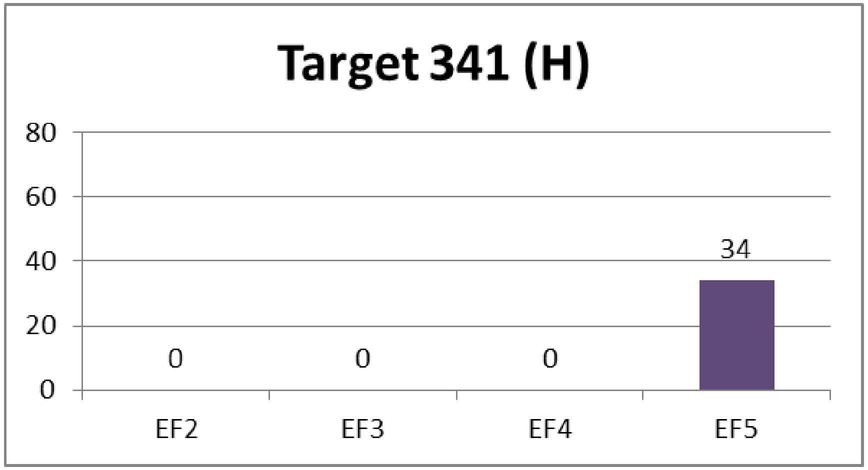
Notes:
- All charts are same scale
- 0 indicates no hits in either Zonal and/or Uniform cases

Case 3 – Plant A – High Targets (>30')



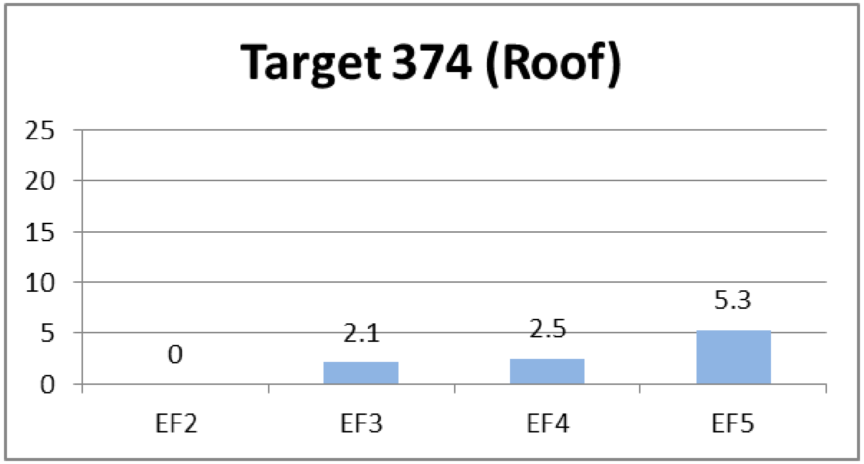


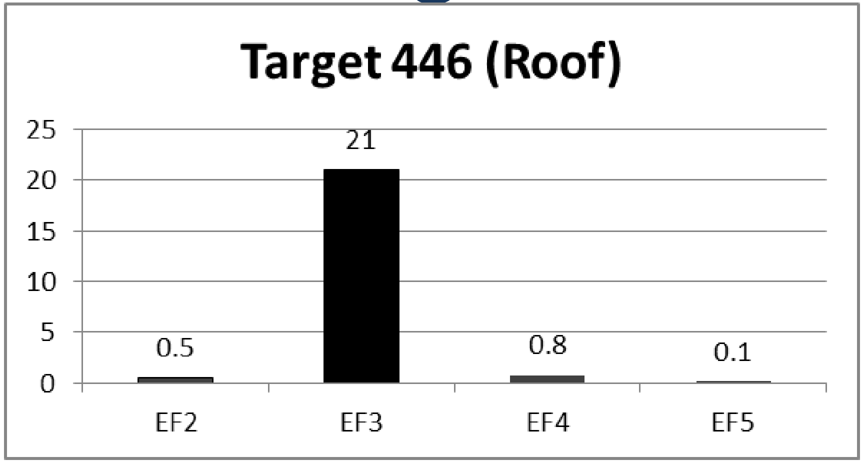


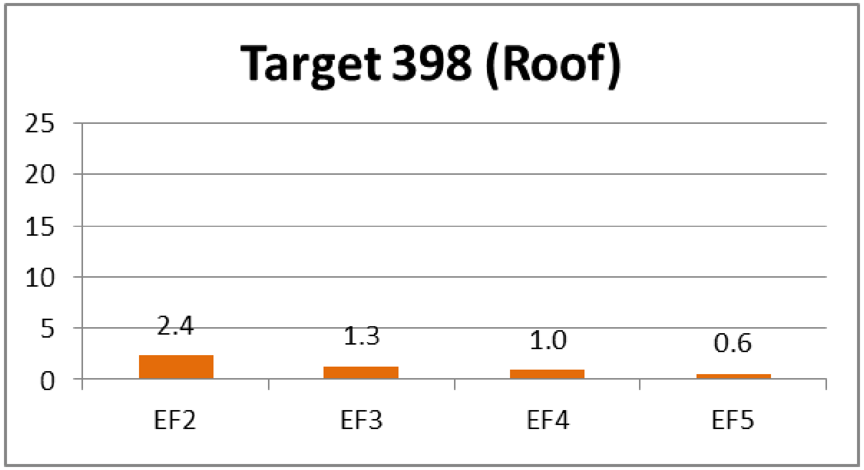


Note: All charts are same scale

Case 3 – Plant A – Roof Targets







Note: All charts are the same scale

Conclusions: Missile Distribution Sensitivity

- Sensitivity study did not effectively characterize how the changes in missile distribution affect the hit probability
- Results do not provide a correlation of the impact of missile distribution on the MIP values or EEFP
- Benchmarking demonstrated that TMRE is conservative when evaluating:
  - Total CDF
  - Sequence level CDF
  - Target hit probability

TMRE Guidance Document (NEI 17-xx)

Bruce Montgomery

NEI

TMRE Guidance Document

- Compliance with Tornado-Generated Missile Design and Licensing Basis
- Overview of Tornado Missile Risk Evaluator (TMRE) Methodology
- Identify Nonconforming SSCs
- Perform Plant TMRE Walkdown
- Determine Site Tornado Hazard Frequency
- Evaluate Target and Missile Characteristics
- Develop TMRE PRA Model
- Quantify Risk, Perform Sensitivity Analyses, and Compare to Thresholds
- License Amendment Request
- Post-LAR Configuration Changes

TMRE License Amendment Request

Ken Lowery
Southern Nuclear

TMRE License Amendment Request

- Pre-submittal Meeting
- LAR Submittal
  - Summary Description
  - Detailed Description
  - Technical Evaluation
  - Regulatory Evaluation
  - Environmental Considerations
  - UFSAR markups
- NRC Review

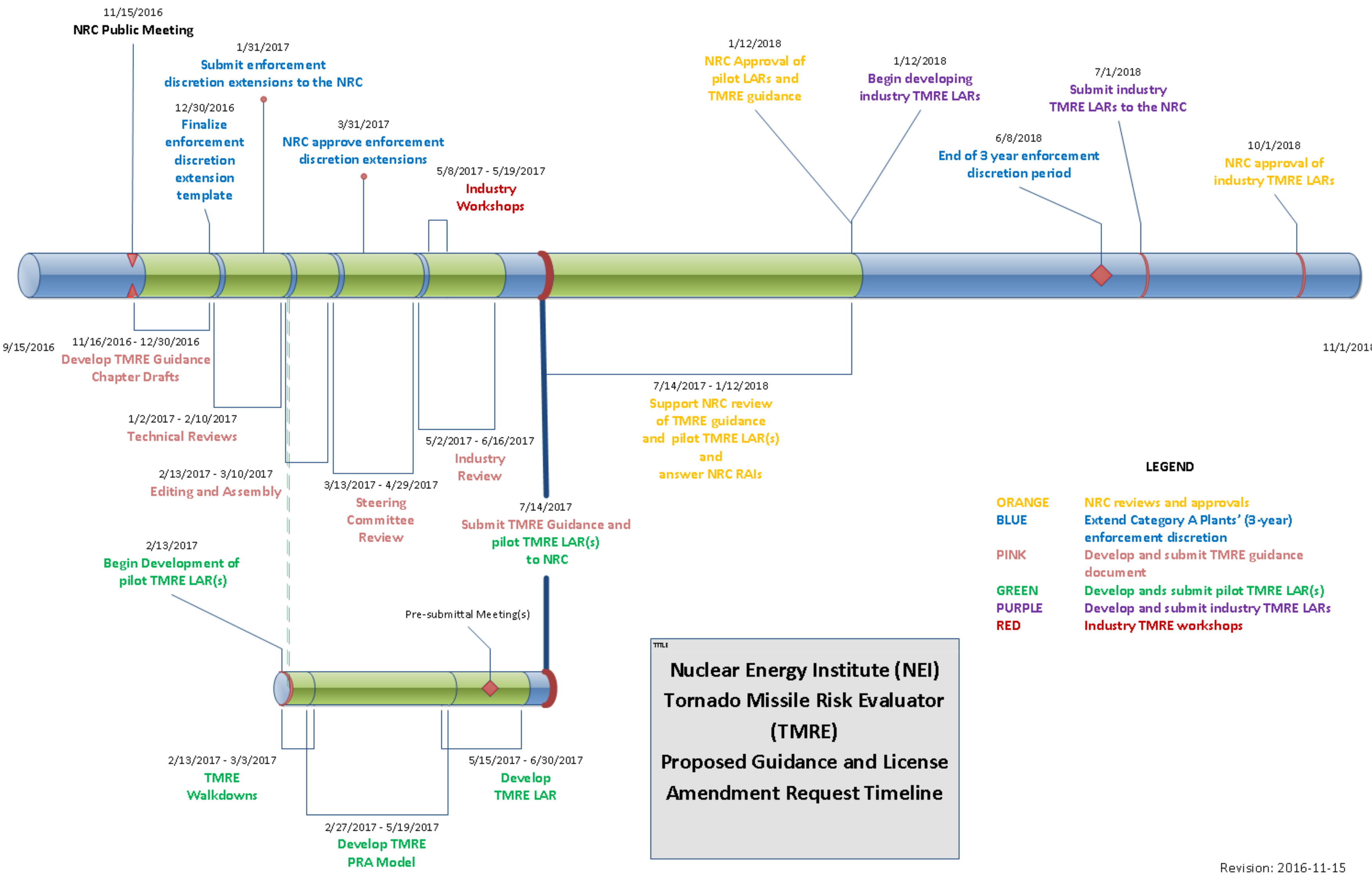
Overview of NRC Review Plan

NRC Staff

TMRE Deployment

Bruce Montgomery

NEI



11/15/2016
NRC Public Meeting
1/31/2017
Submit enforcement discretion extensions to the NRC
12/30/2016
Finalize enforcement discretion extension template
3/31/2017
NRC approve enforcement discretion extensions
5/8/2017 - 5/19/2017
Industry Workshops
1/12/2018
NRC Approval of pilot LARs and TMRE guidance
1/12/2018
Begin developing industry TMRE LARs
7/1/2018
Submit industry TMRE LARs to the NRC
6/8/2018
End of 3 year enforcement discretion period
10/1/2018
NRC approval of industry TMRE LARs
9/15/2016
11/16/2016 - 12/30/2016
Develop TMRE Guidance Chapter Drafts
11/1/2018
1/2/2017 - 2/10/2017
Technical Reviews
7/14/2017 - 1/12/2018
Support NRC review of TMRE guidance and pilot TMRE LAR(s) and answer NRC RAIs
2/13/2017 - 3/10/2017
Editing and Assembly
5/2/2017 - 6/16/2017
Industry Review
3/13/2017 - 4/29/2017
Steering Committee Review
7/14/2017
Submit TMRE Guidance and pilot TMRE LAR(s) to NRC
2/13/2017
Begin Development of pilot TMRE LAR(s)
Pre-submittal Meeting(s)
2/13/2017 - 3/3/2017
TMRE Walkdowns
5/15/2017 - 6/30/2017
Develop TMRE LAR
2/27/2017 - 5/19/2017
Develop TMRE PRA Model
LEGEND
ORANGE NRC reviews and approvals
BLUE Extend Category A Plants' (3-year) enforcement discretion
PINK Develop and submit TMRE guidance document
GREEN Develop ands submit pilot TMRE LAR(s)
PURPLE Develop and submit industry TMRE LARs
RED Industry TMRE workshops
TITLE
Nuclear Energy Institute (NEI) Tornado Missile Risk Evaluator (TMRE) Proposed Guidance and License Amendment Request Timeline
Revision: 2016-11-15

Additional Topics

Jack Grobe

Exelon

Tornado Missile Protection Enforcement Discretion

- Enforcement Discretion Memorandum (EGM) issued June 2015
  - Group A (NRC Tornado Region 1)
    - Enforcement discretion provided for 3 years
    - Expires June 2018
  - Group B (Tornado Regions 2 and 3)
    - Enforcement discretion provided for 5 years
    - Expires June 2020

Enforcement Discretion Considerations

- Outage planning requires outage modification scope/design "lock-down" 12 months ahead of outage
  - Fall 2017 outage "lock-down" – now
  - Spring 2018 outage "lock-down" – in several months
- Preferred TMP resolution method is TMRE risk-informed LAR
  - TMRE schedule with no margin/float does not support Group A enforcement discretion expiration date
- Need additional time for clarity of options and decision making

TMRE Completion Milestones

- November 2016 - Complete TMRE conceptual development
- February 2017 - Draft and technical review of guidance document – Begin development of pilot TMRE LARs
- July 2017 - Completion and submission of final guidance document and pilot LARs
- January 2018 – Completion of NRC review and approval of guidance document and pilot LARs – Begin development of industry TMRE LARs
- **June 2018 - Expiration of Group A enforcement discretion**
- July 2018 – Completion and submission of industry TMRE LARs

Enforcement Discretion Extension Process

- Only applies to Group A plants described in the EGM
- Necessary to support utility TMRE decision
- Request letter to NRR Licensing Project Manager
- Elements of request letter – Describe:
  - Nonconforming conditions where EGM exercised
  - Prompt compensatory actions in place and reports made
  - Long-term compensatory actions in place or planned
  - Basis for need of additional time – decision making
  - When issues will be addressed – within Group B timeline

TMP Reporting Considerations

- June 10, 2015 EGM 15-002 provides enforcement discretion for NRC- or licensee-identified TMP noncompliance on one or multiple systems for three to five years
- During the enforcement discretion period the equipment is considered operable provided compensatory measures are maintained and the nonconforming condition is entered into the corrective action program
- The February 2016 ISG-DSS-2016-01 provides guidance on implementing EGM 15-002 and indicates that the resident inspector be notified of application of EGM 15-002

10CFR50.72 – Immediate Notification Requirements

- 10CFR50.72(b) specifies one-hour, four-hour and eight-hour reporting requirements for non-emergency events
- Prompt notification requirements focus on loss of safety function, seriously degraded safety barriers or unanalyzed conditions that significantly degraded plant safety
- One prompt notification will be made for the first nonconforming condition that meets the reporting requirements of 10CFR50.72
- Further prompt reports will not be required

10 CFR 50.73 - Licensee Event Report Requirements

- 60 day Licensee Event Report (LER) reporting requirements focus on loss of safety function, seriously degraded safety barriers or unanalyzed conditions that significantly degraded plant safety
- One LER will be submitted within 60 days of identification of the first nonconforming condition that meets the reporting requirements of 10CFR50.73
- Should additional nonconforming conditions be identified through the discovery process, that initial LER will be supplemented at the completion of the discovery process

Reactor Oversight Process (ROP) Considerations

- The ROP includes performance indicators (PIs) for safety system functional failures (SSFF) – NRC endorsed guidance for implementation of the ROP SSFF PI is contained in NEI 99-02 Revision 7

- NEI 99-02 indicates that a single event or condition that affects multiple systems counts as as only one failure for consideration of the ROP SSFF PI

Reactor Oversight Process (ROP) Considerations

- Only for consideration of TMP issues addressed under the EGM:
  - Single event is considered the potential occurrence of a tornado
  - Single condition is considered the engineering work performed many decades ago that resulted in latent engineering based nonconforming conditions
- Consequently, only one SSFF is required to be reported under the ROP SSFF PI for TMP nonconforming conditions (ROP FAQ 16-03)

Conclusion

- TMRE provides a reasonable treatment of the risk posed by tornado missile vulnerabilities for use in risk informed license amendment requests (RG 1.174)

Review Actions

ADJOURN