

A Graded Approach for Preliminary Design of Wind-Induced Missile Protection of Nuclear Power Plants

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OVERVIEW

- Introduction
- Proposed Methodology
- Application Example

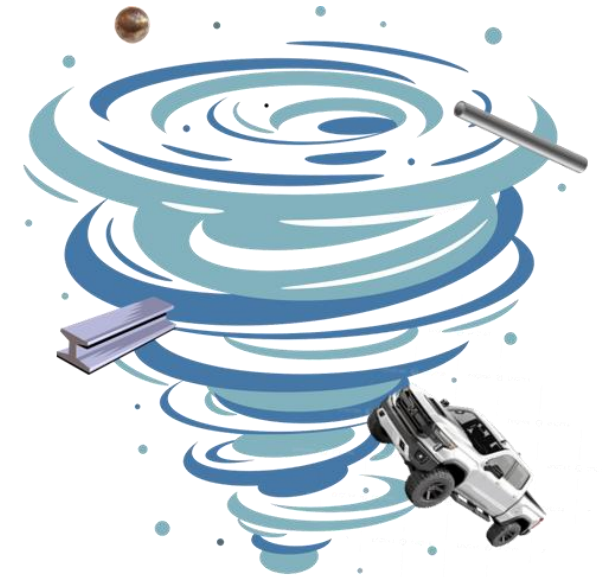
INTRODUCTION

PROPOSED METHODOLOGY

APPLICATION EXAMPLE

FEDERAL REGULATIONS

- Appendix A to 10 CFR Part 50, General Design Criteria:
 - Criterion 2: SSCs that are **important to safety** shall be designed to withstand effects of natural phenomena, including **tornadoes and hurricanes**, without loss of capability to perform their safety functions. Design basis shall reflect:
 - The **most severe events that have been historically reported** for site and surrounding area.
 - Appropriate combinations of effects of normal and accident conditions with effects of natural phenomena.
 - The **importance of safety functions** to be performed.
 - Criterion 4: SSCs that are important to safety shall be adequately protected against effects of **missiles** resulting from events and conditions outside plant.



RELEVANT NRC RGs & SRPs



U.S. NUCLEAR REGULATORY COMMISSION
October 2011

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.221
(New Regulatory Guide, Draft was issued as DG-1247, dated August 2010)

**DESIGN-BASIS HURRICANE AND HURRICANE MISSILES
FOR NUCLEAR POWER PLANTS**



U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH

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Technical Lead
Gordon Curran

REGULATORY GUIDE

REGULATORY GUIDE 1.117
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**PROTECTION AGAINST EXTREME WIND EVENTS AND
MISSILES FOR NUCLEAR POWER PLANTS**
(Previously titled, "TORNADO DESIGN CLASSIFICATION")



U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

NUREG-0800

3.5.3 BARRIER DESIGN PROCEDURES



U.S. NUCLEAR REGULATORY COMMISSION

March 2007
Revision 1

REGULATORY GUIDE

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REGULATORY GUIDE 1.76
(Draft was issued as DG-1143, dated January 2006)

**DESIGN-BASIS TORNADO AND TORNADO MISSILES
FOR NUCLEAR POWER PLANTS**

DESIGN-BASIS WIND-INDUCED MISSILE SPECTRUM

- NRC RG 1.76 & 1.221:



Automobile
(2,595/4,000 lb)
High Kinetic Energy



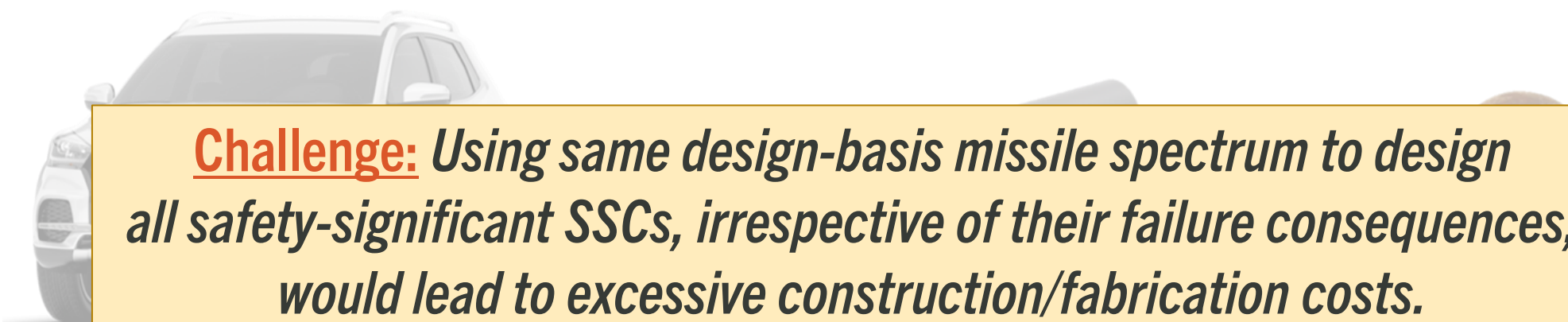
Schedule 40 Pipe
(6.625 in. dia., 15 ft long)
High Penetration Ability



Solid Steel Sphere
(1 in. dia.)
High Passing Ability

DESIGN-BASIS WIND-INDUCED MISSILE SPECTRUM

- NRC RG 1.76 & 1.221:



Challenge: *Using same design-basis missile spectrum to design all safety-significant SSCs, irrespective of their failure consequences, would lead to excessive construction/fabrication costs.*

Automobile
(2,595/4,000 lb)
High Kinetic Energy

Schedule 40 Pipe
(6.625 in. dia., 15 ft long)
High Penetration Ability

Solid Steel Sphere
(1 in. dia.)
High Passing Ability

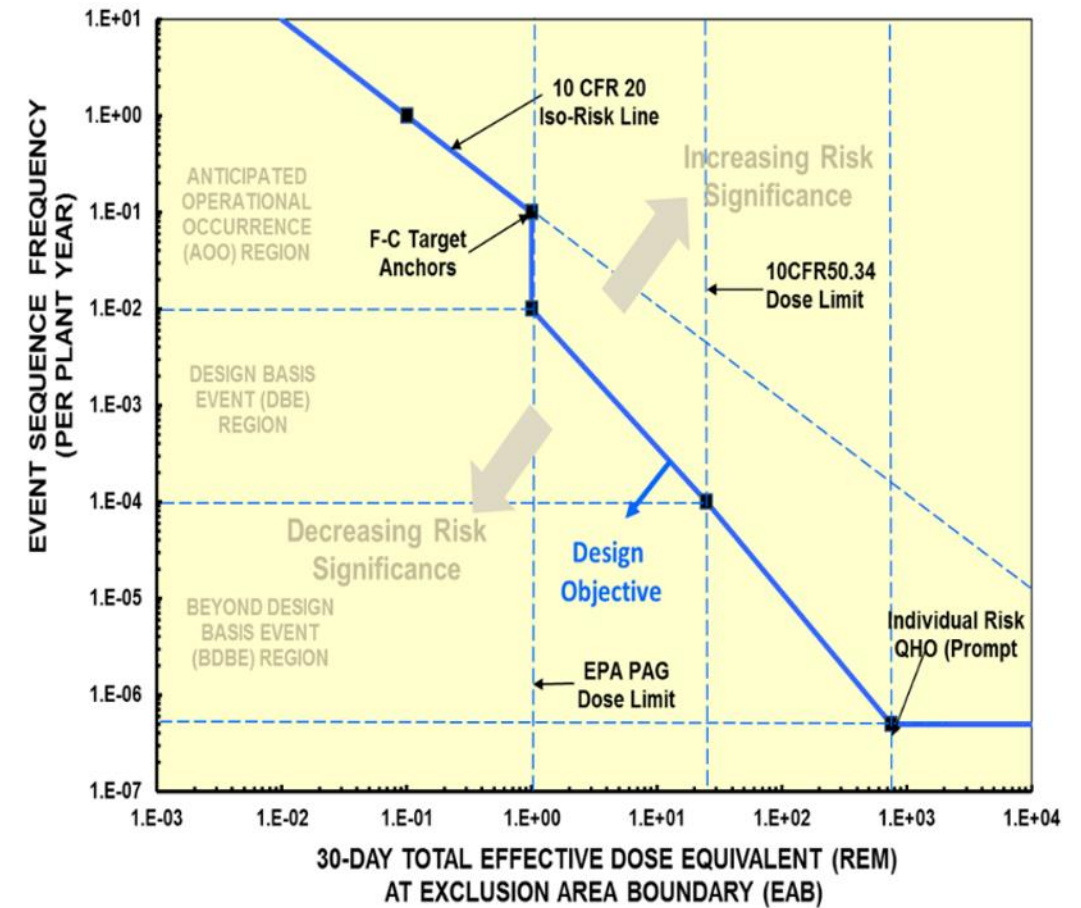
SOLUTION: GRADED APPROACH

- Use a graded approach to select/justify missile protection requirements of safety-significant SSCs, depending on their safety significance (failure consequences).
- Leverage technology-inclusive, risk-informed, and performance-based (TI-RIPB) process developed in Nuclear Energy Institute (NEI) 18-04 through Licensing Modernization Project (LMP).
 - Endorsed by NRC for non-light water reactors (non-LWRs) through RG 1.233.



LMP TI-RIPB PROCESS

- Compares event frequency-consequence ($F-C$) couples with an “ $F-C$ Target” to characterize relative safety significance of SSCs during various events.

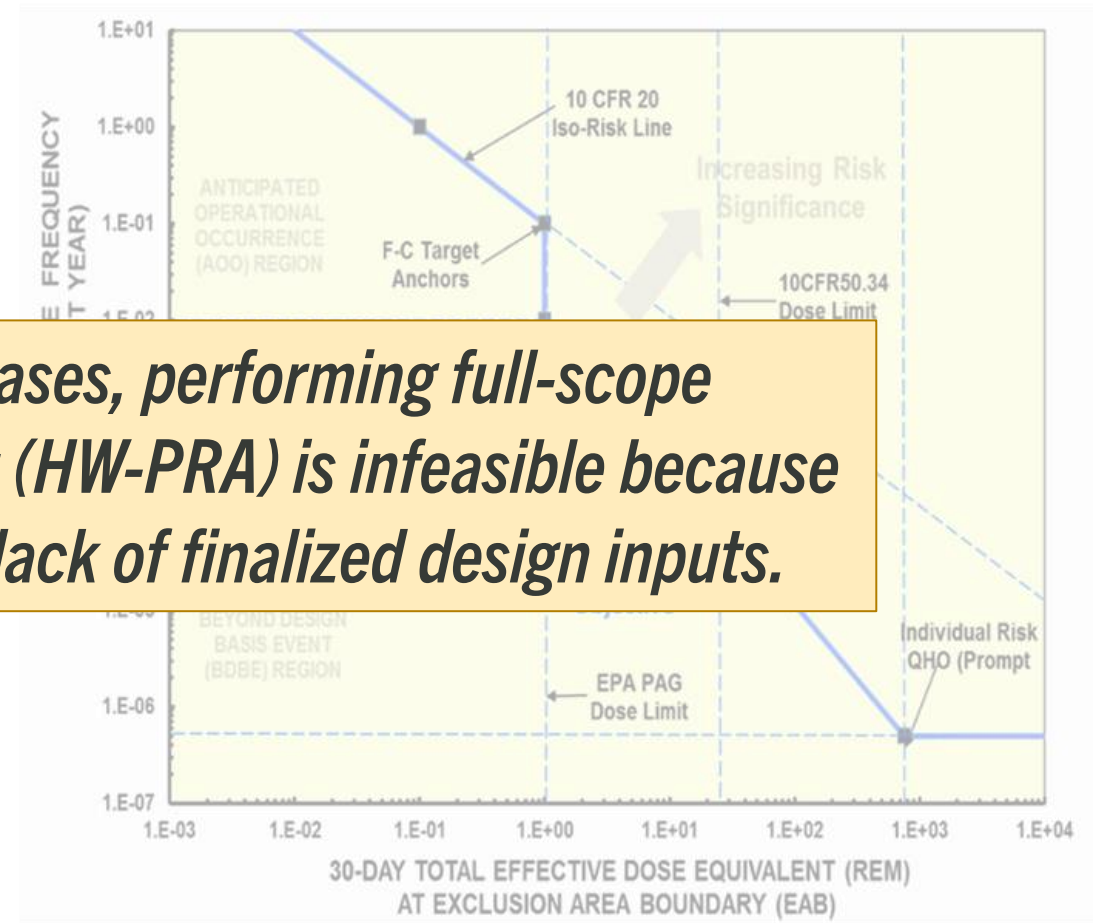


NEI 18-04 Rev. 1, Figure 3-4

LMP TI-RIPB PROCESS

- Compares event frequency-consequence ($F-C$) couples with an “ $F-C$ Target” to characterize relative safety significance of SSCs during various events.

Challenge: *During initial design phases, performing full-scope high-wind probabilistic risk assessment (HW-PRA) is infeasible because of its complexity, very high cost, and lack of finalized design inputs.*



NEI 18-04 Rev. 1, Figure 3-4

SOLUTION: TMRE ADAPTATION

- Calculate fragility functions based on the Tornado Missile Risk Evaluator (TMRE) framework of NEI 17-02.
 - Endorsed by NRC for evaluation of existing commercial nuclear power plants.
 - Allows deterministic calculation of so-called Exposed Equipment Failure Probability (EEFP) for five discrete tornado categories.

 TECHNICAL REPORT

18-04

TORNADO MISSILE RISK EVALUATOR (TMRE) INDUSTRY GUIDANCE DOCUMENT

Prepared by the Nuclear Energy Institute
September 2017

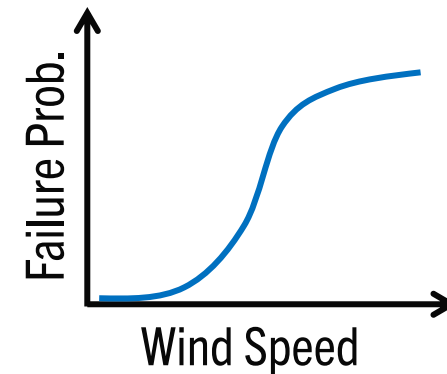
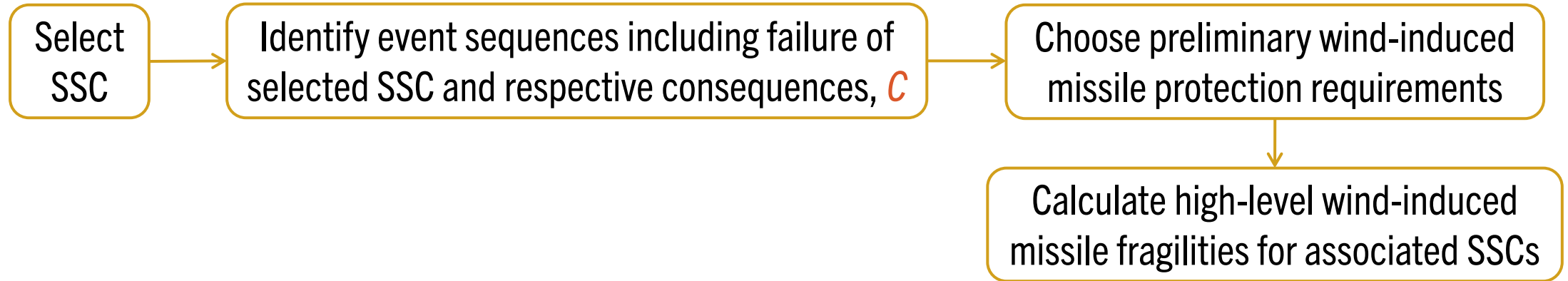
Executive Summary

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

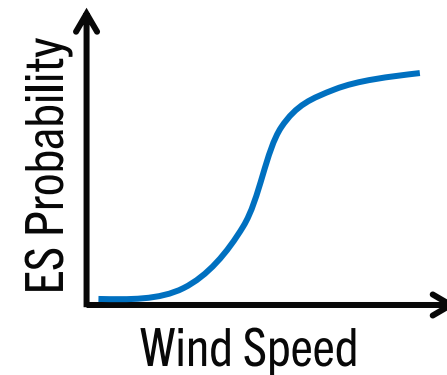
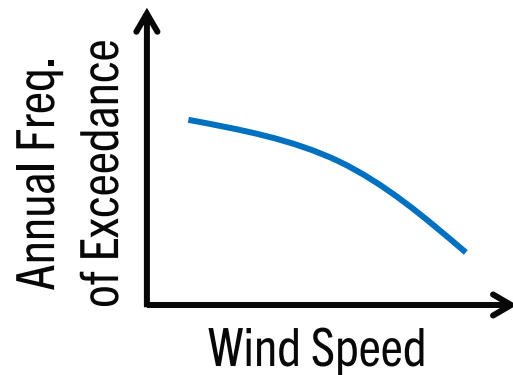
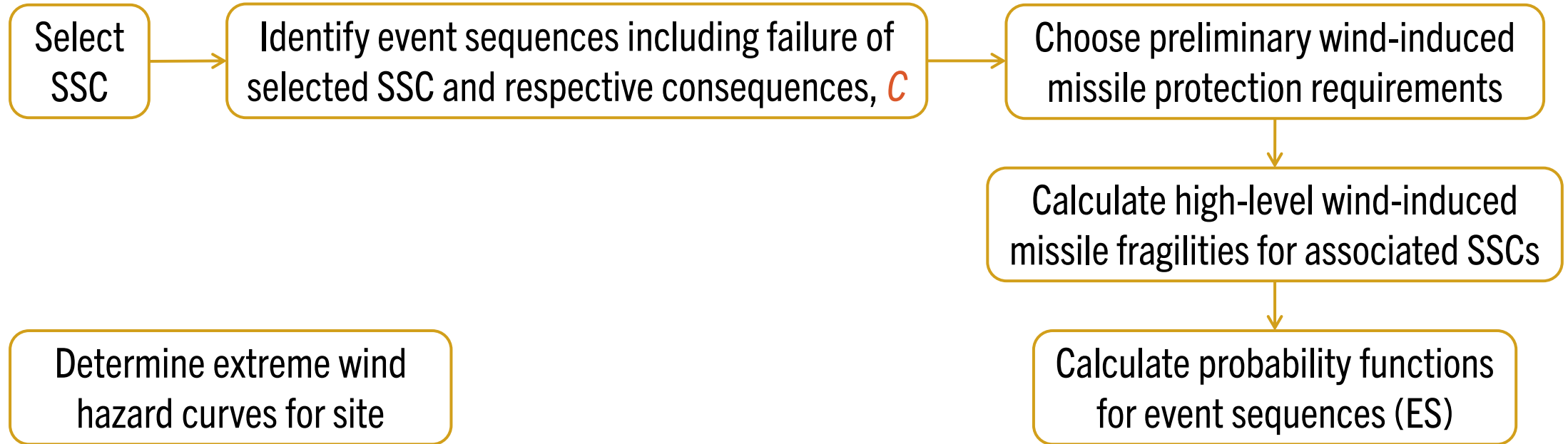
The Nuclear Energy Institute is the nuclear energy industry's policy organization.
This document and additional about nuclear energy are available at nei.org
1201 F Street, NW Washington, DC 20004

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PROPOSED METHODOLOGY
APPLICATION EXAMPLE

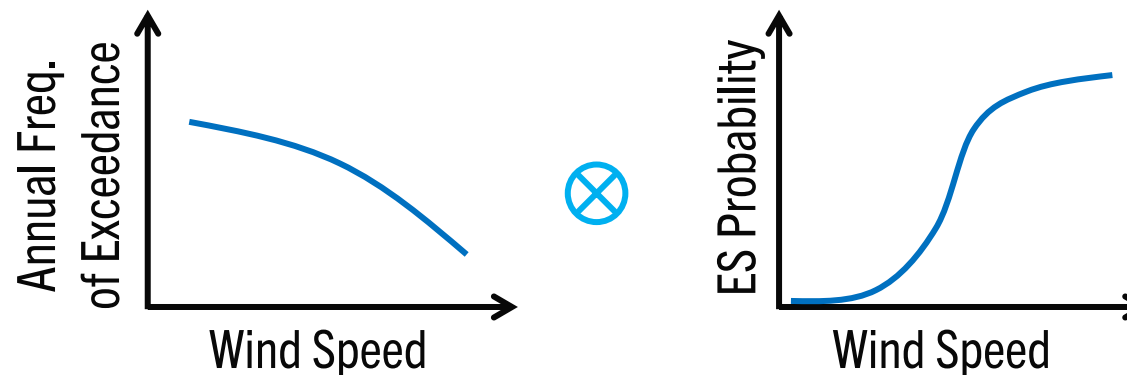
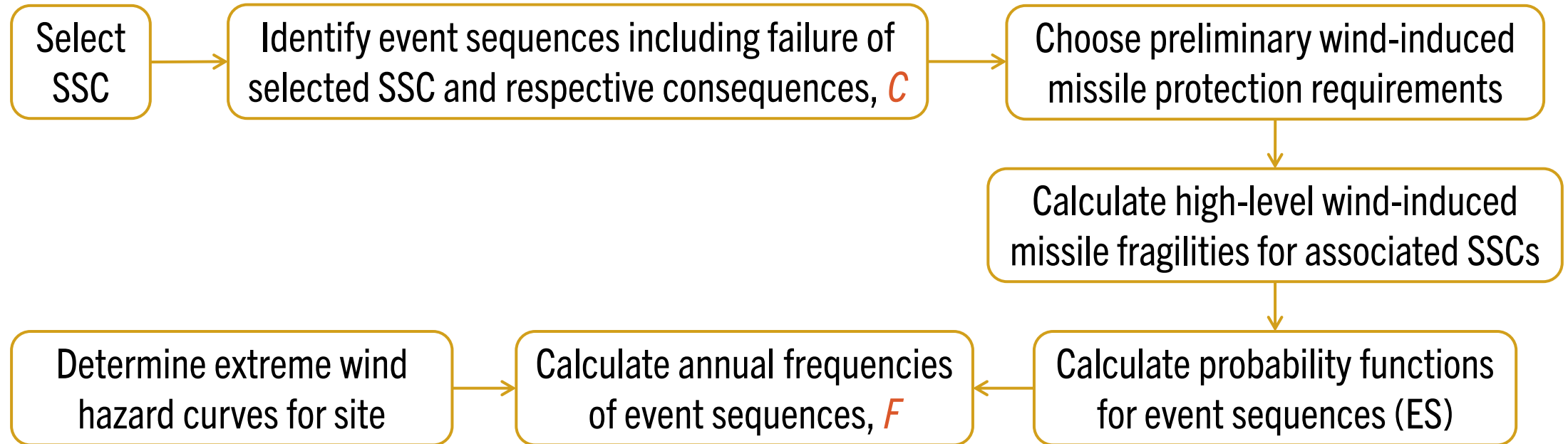
OVERALL METHODOLOGY



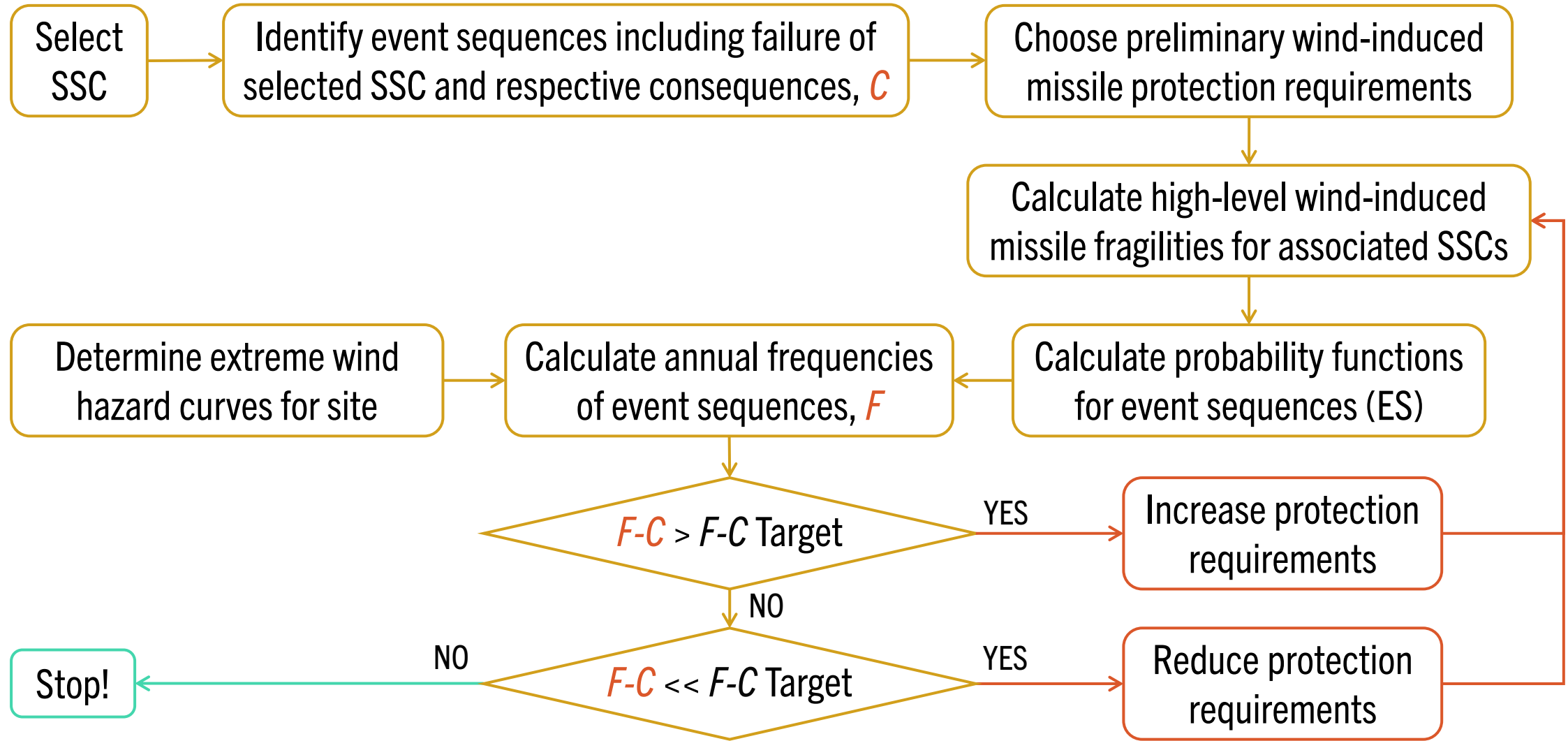
OVERALL METHODOLOGY



OVERALL METHODOLOGY

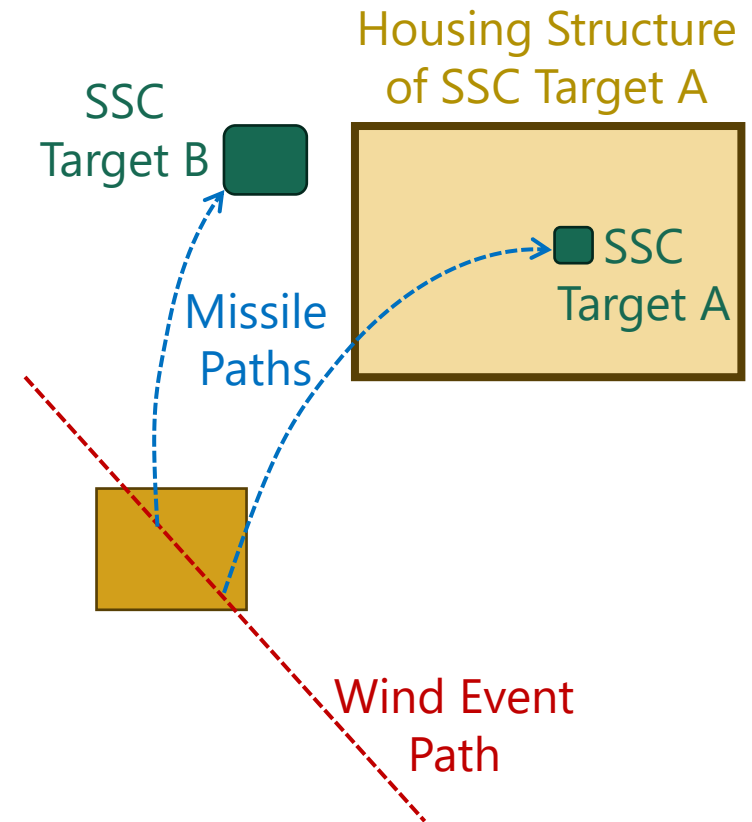


OVERALL METHODOLOGY



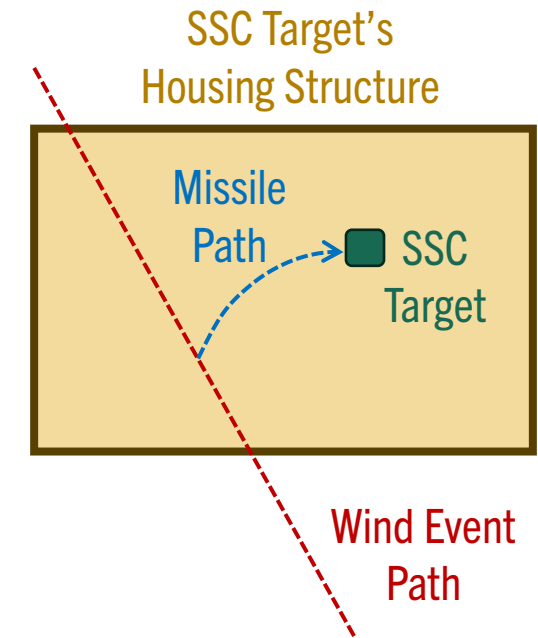
FAILURE CAUSES DUE TO WIND-INDUCED MISSILES

1. Direct impact of external missiles on target SSC



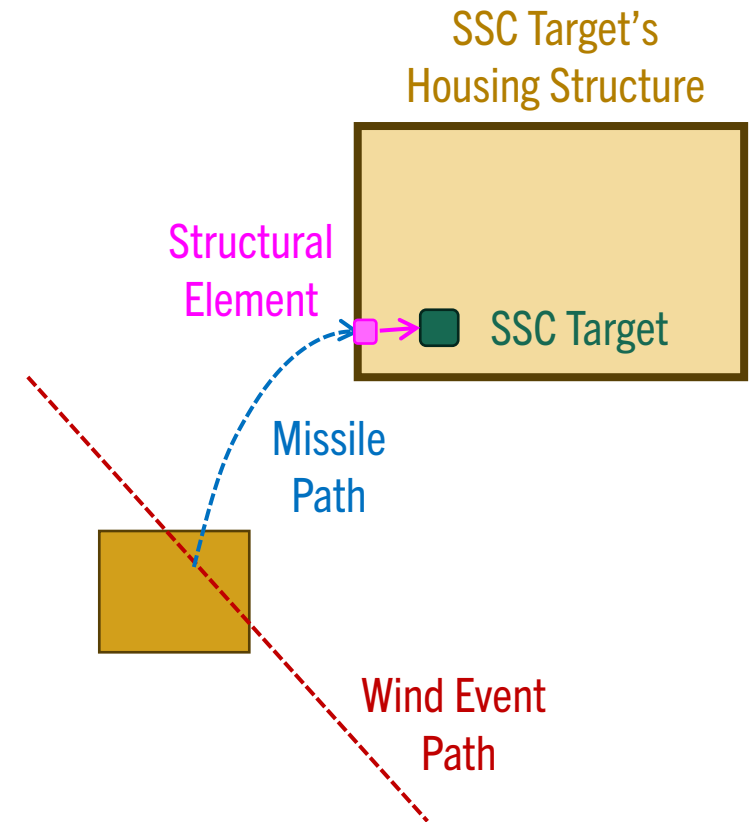
FAILURE CAUSES DUE TO WIND-INDUCED MISSILES

1. Direct impact of external missiles on target SSC
2. Direct impact of internal missiles produced by wind event striking SSC's housing structure on target SSC



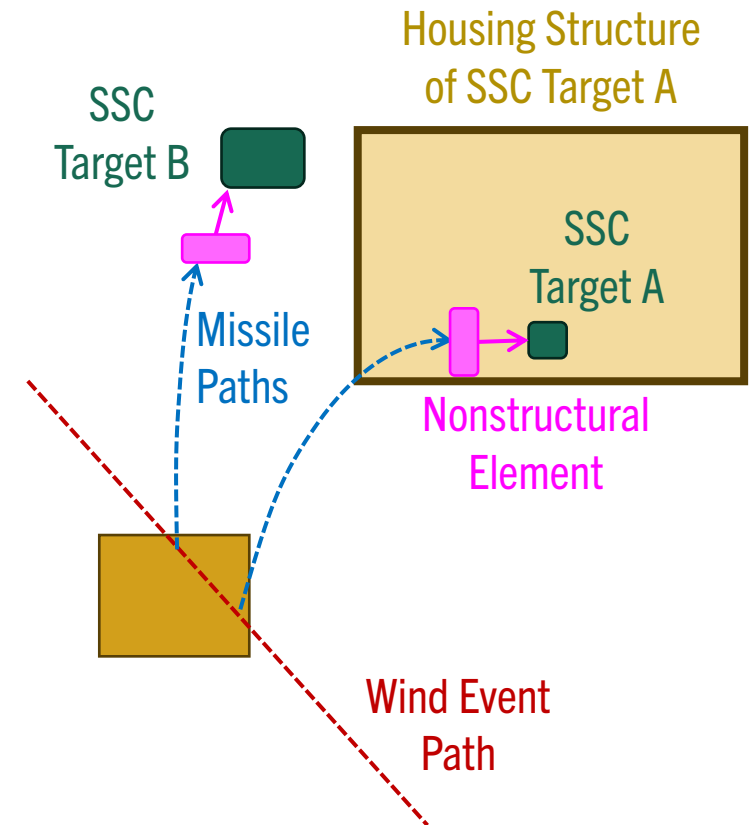
FAILURE CAUSES DUE TO WIND-INDUCED MISSILES

1. Direct impact of external missiles on target SSC
2. Direct impact of internal missiles produced by wind event striking SSC's housing structure on target SSC
3. Collapse of structural elements onto target SSC due to external missile impacts



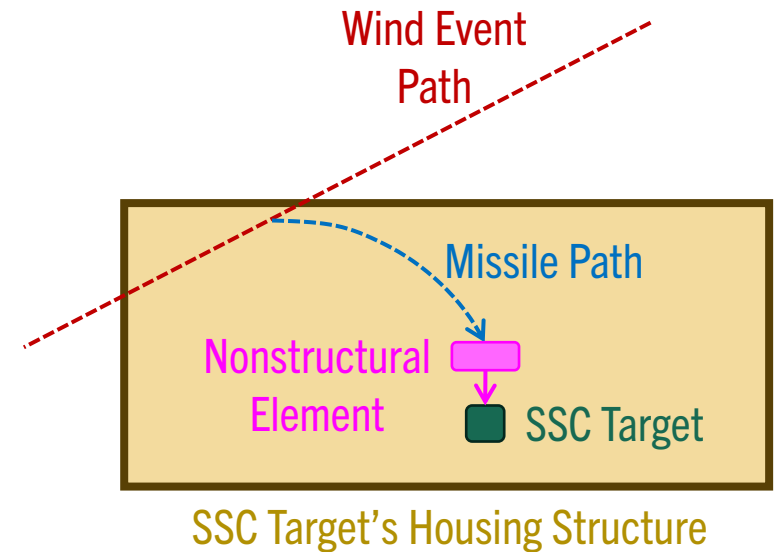
FAILURE CAUSES DUE TO WIND-INDUCED MISSILES

1. Direct impact of external missiles on target SSC
2. Direct impact of internal missiles produced by wind event striking SSC's housing structure on target SSC
3. Collapse of structural elements onto target SSC due to external missile impacts
4. Collapse of nonstructural elements onto target SSC due to external missile impacts



FAILURE CAUSES DUE TO WIND-INDUCED MISSILES

1. Direct impact of external missiles on target SSC
2. Direct impact of internal missiles produced by wind event striking SSC's housing structure on target SSC
3. Collapse of structural elements onto target SSC due to external missile impacts
4. Collapse of nonstructural elements onto target SSC due to external missile impacts
5. Impact/fall of a nonstructural element onto target SSC due to internal missile impact



TOTAL FRAGILITY CALCULATION

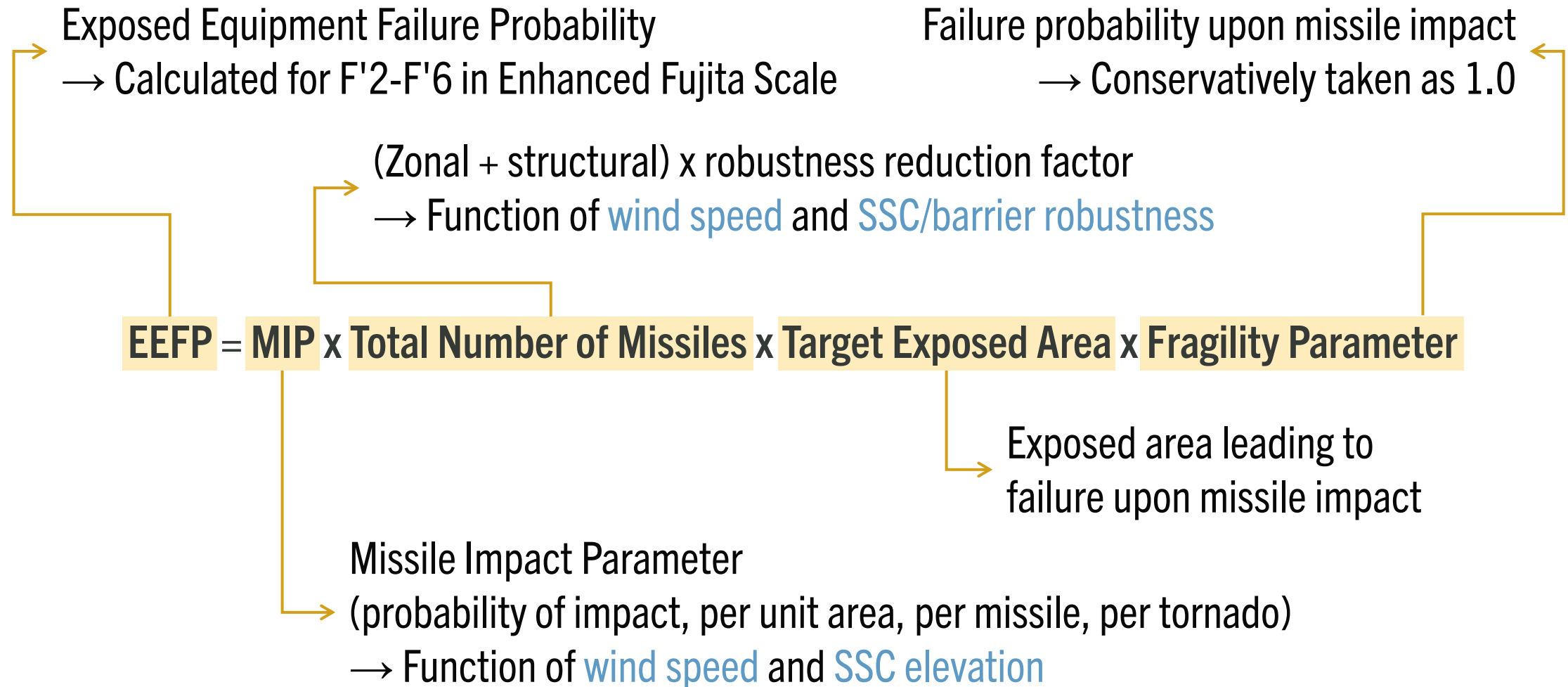
ID	Type	Failure Cause	Probability
D1	Direct	Direct impact of external missiles on target SSC	$P(D1)$
D2	Direct	Direct impact of missiles produced by housing structure on target SSC	$P(D2)$
ID1	Indirect	Fall of structural elements on SSC target due to external missile impacts	$P(ID1)$
ID2	Indirect	Fall of nonstructural elements on SSC target due to external missile impacts	$P(ID2)$
ID3	Indirect	Fall of nonstructural elements on SSC target due to internal missile impacts	$P(ID3)$

$$\begin{aligned}
 P_f = & P(\mathbf{D1} \vee \mathbf{D2} \vee \mathbf{ID1} \vee \mathbf{ID2} \vee \mathbf{ID3}) = P(D1) + P(D2) + \dots \\
 & - P(D1 \wedge D2) - P(D1 \wedge ID1) - \dots + P(D1 \wedge D2 \wedge ID1) + P(D1 \wedge D2 \wedge ID2) + \dots \\
 & - P(D1 \wedge D2 \wedge ID1 \wedge ID2) - P(D1 \wedge D2 \wedge ID1 \wedge ID3) - \dots \\
 & + P(D1 \wedge D2 \wedge ID1 \wedge ID2 \wedge ID3)
 \end{aligned}$$

- Considering individual event probabilities to be independent:

$$P(A_1 \wedge A_2 \wedge \dots \wedge A_n) = \prod_{i=1}^n P(A_i)$$

TORNADO MISSILE RISK EVALUATOR (TMRE)



REFINEMENT OF TMRE FORMULA

- Direct Causes:

$$P_f(S_w) = \sum_j \left(\left(A_{e,j} \text{MIP}_j(S_w) \right) P_{bf|bi,j}(S_w) \right) P_{tf|ti}(S_w)$$

Probability of barrier failure upon missile impact on barrier (points to $P_{bf|bi,j}(S_w)$)
 Probability of missile impact on barrier (points to $\text{MIP}_j(S_w)$)
 Probability of SSC failure upon missile impact on SSC (points to $P_{tf|ti}(S_w)$)

- Indirect Causes:

$$P_f(S_w) = \sum_k \left(\sum_j \left(\left(A_{e,j} \text{MIP}_j(S_w) \right) P_{bf|bi,j}(S_w) \right) P_{ef|ei,k} \right) P_{tf|ti}(S_w)$$

Probability of missile impact on barrier (points to $\text{MIP}_j(S_w)$)
 Probability of element fall upon missile impact on element (points to $P_{ef|ei,k}$)
 Probability of barrier failure upon missile impact on barrier (points to $P_{bf|bi,j}(S_w)$)
 Probability of SSC failure upon element fall on SSC (points to $P_{tf|ti}(S_w)$)

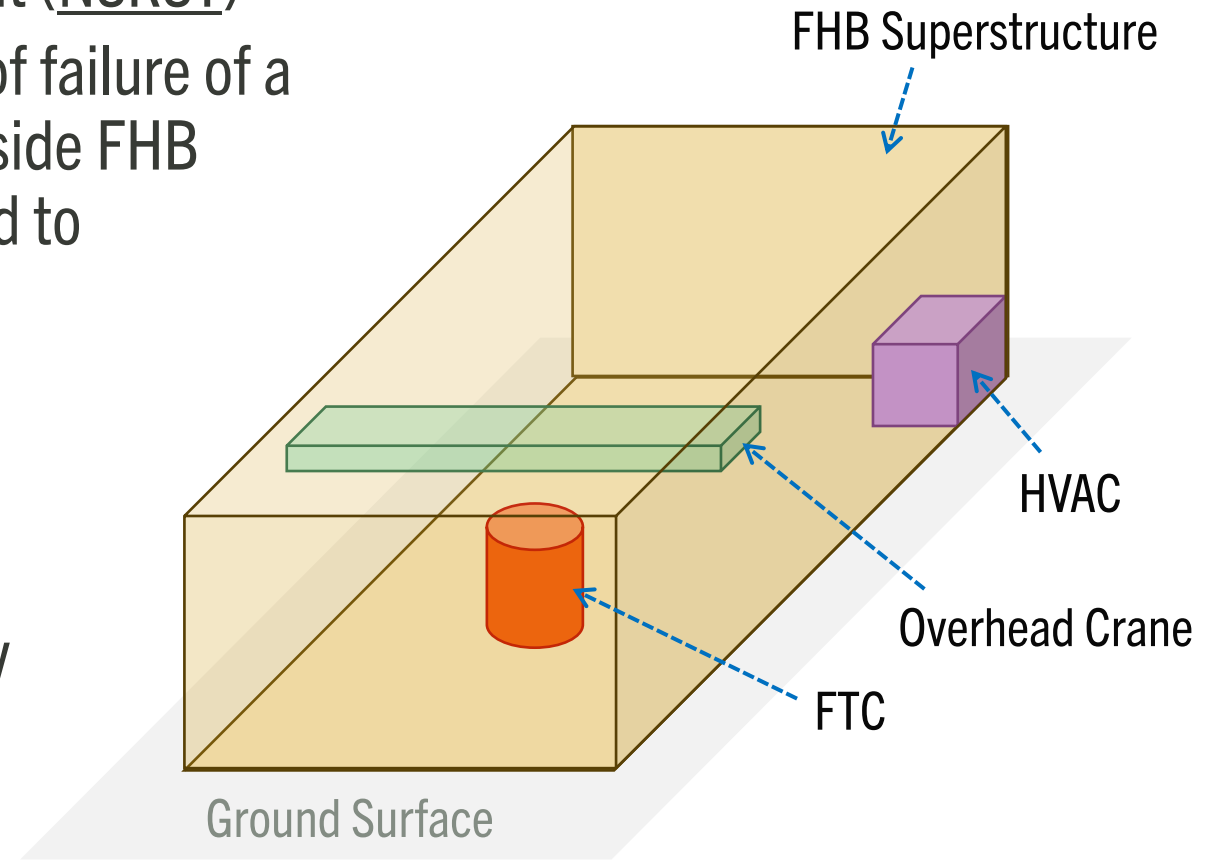
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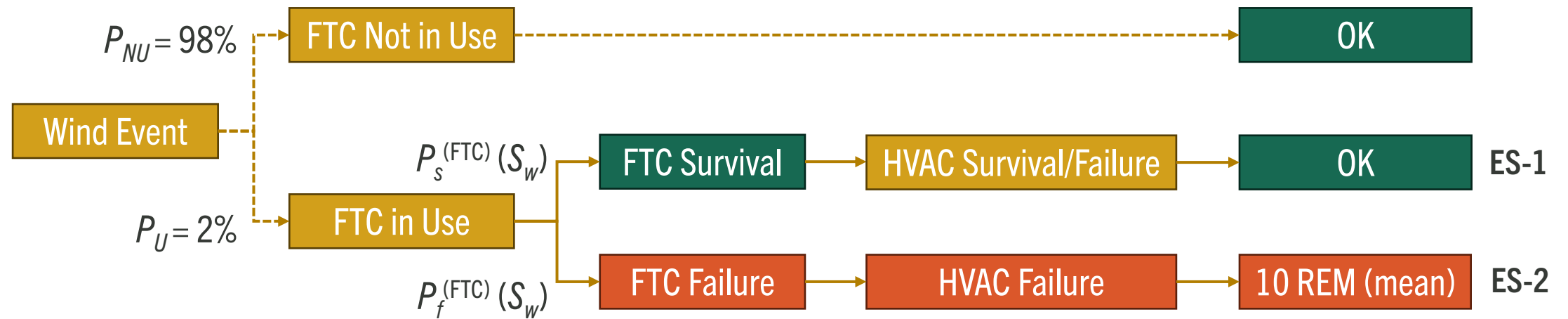
TARGET SSC

- HVAC system of a fuel handling building (FHB):
 - Non-safety-related with special treatment (NSRST)
 - Safety Function: Reduce consequences of failure of a fuel transfer cask (FTC) by filtering air inside FHB if fuel assembly carried by FTC is exposed to environment, provided FHB enclosure remains intact.
- FTC:
 - Safety-related (SR)
 - Safety Function: Carrying a fuel assembly and protecting it during this process.



EVENT TREE & SEQUENCES

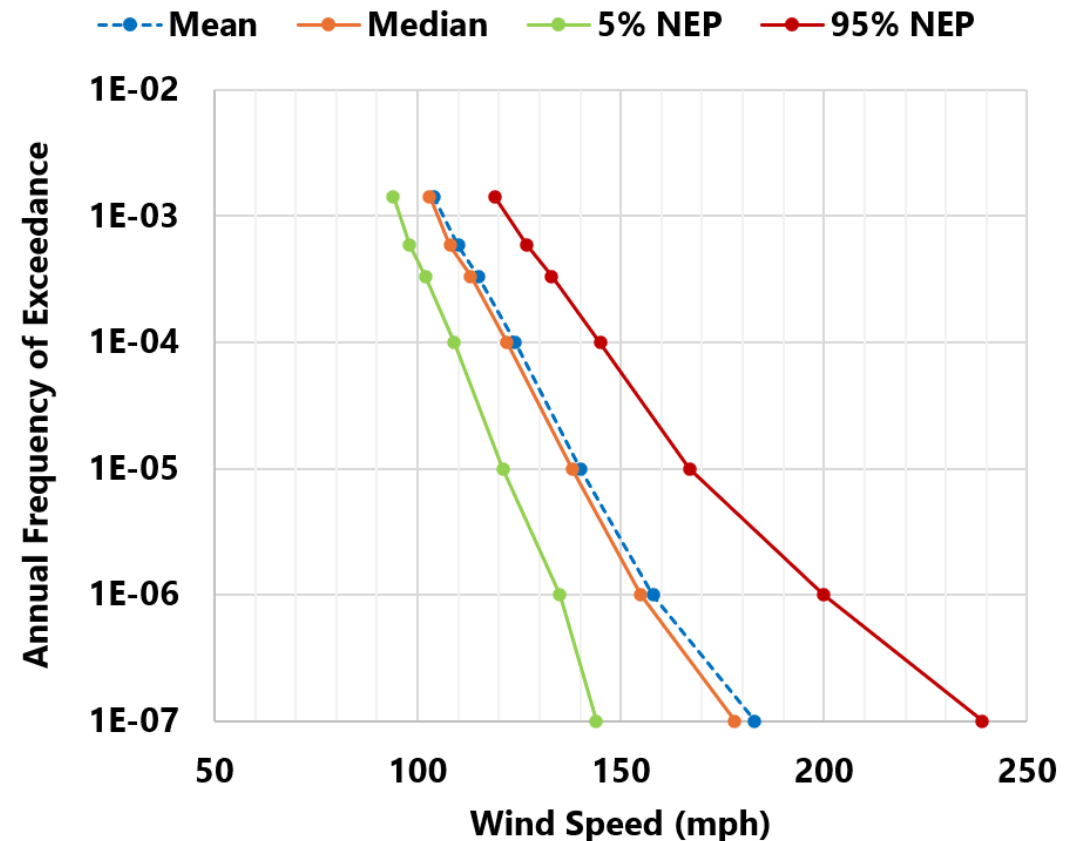
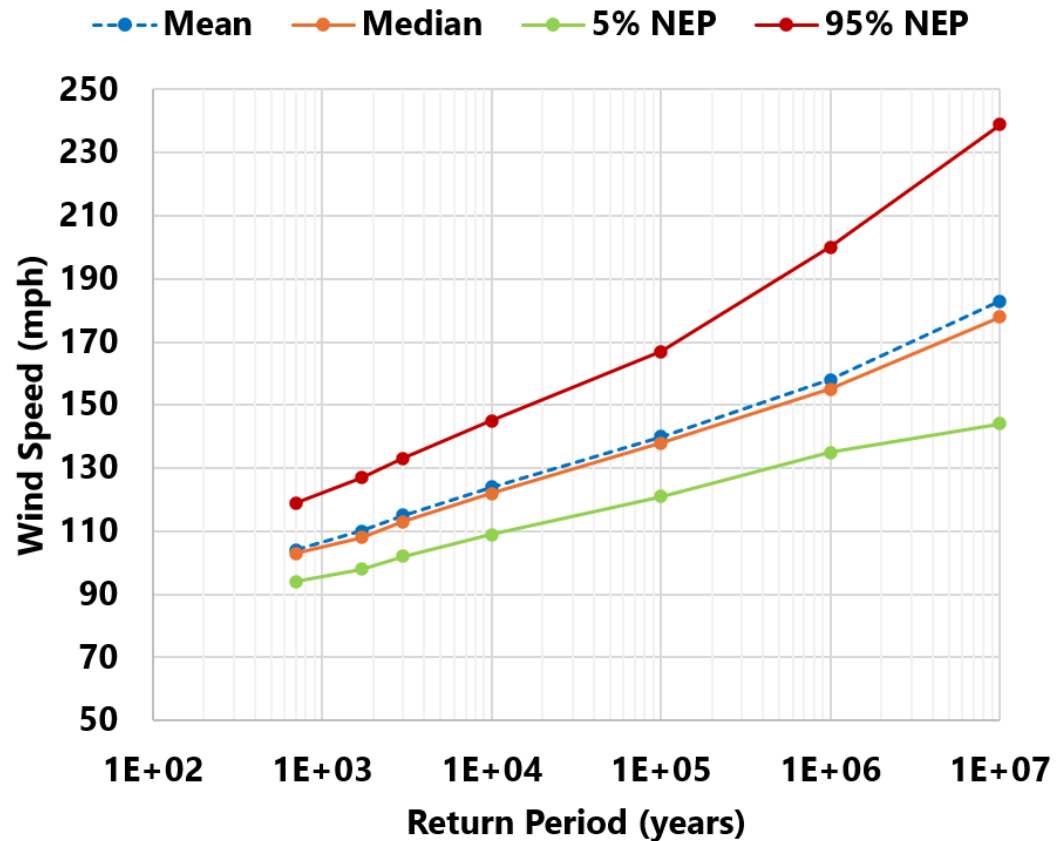
- Assume FHB's HVAC will lose its functionality upon wind-induced missile penetration into FHB



$$\begin{cases} P_{ES-1}(S_w) = P_U P_s^{(FTC)}(S_w) = P_U (1 - P_f^{(FTC)})(S_w) \\ P_{ES-2}(S_w) = P_U P_f^{(FTC)}(S_w) \end{cases}$$

WIND SPEED HAZARD CURVES

- Use envelope of ASCE 7-22 straight-line and tornado wind speed hazard curves

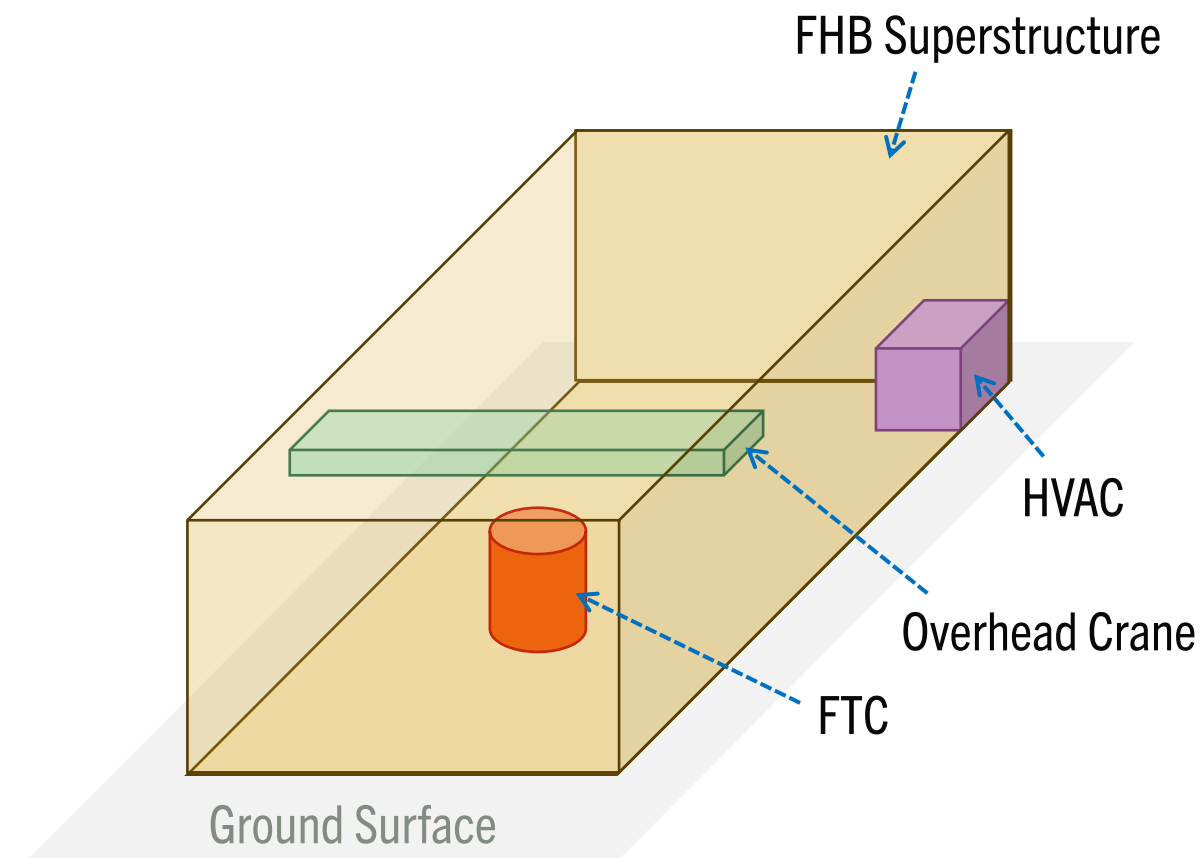


PRELIMINARY “ROBUSTNESS” ASSUMPTIONS

- FHB Enclosure:
 - Zero robustness against wind-induced missiles (conservative)
- FTC:
 - A large and sturdy equipment made of steel with radiation shielding
 - Against Wind-induced Missiles and Fall of Structural Elements: Consider robustness equivalent to TMRE category B (steel pipe with diameter ≥ 16 in. and $0.125 \text{ in.} \leq \text{thickness} < 3/8 \text{ in.}$) $\rightarrow$ 55% failure probability upon impact (conservative)
 - Against Overhead Crane Fall: Consider zero robustness (conservative)

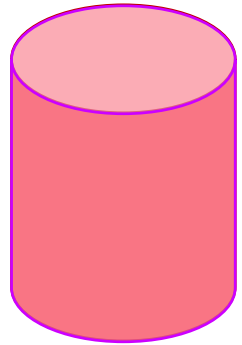
CREDIBLE FTC FAILURE CAUSES

	ID	Failure Cause
✓	D1	Direct impact of external missiles on FTC
✗	D2	Direct impact of missiles produced by FHB superstructure on FTC
✓	ID1	Fall of FHB structural elements on FTC due to external missile impacts
✓	ID2	Fall of FHB overhead crane on FTC due to external missile impacts
✗	ID3	Fall of FHB nonstructural elements on FTC due to internal missile impacts

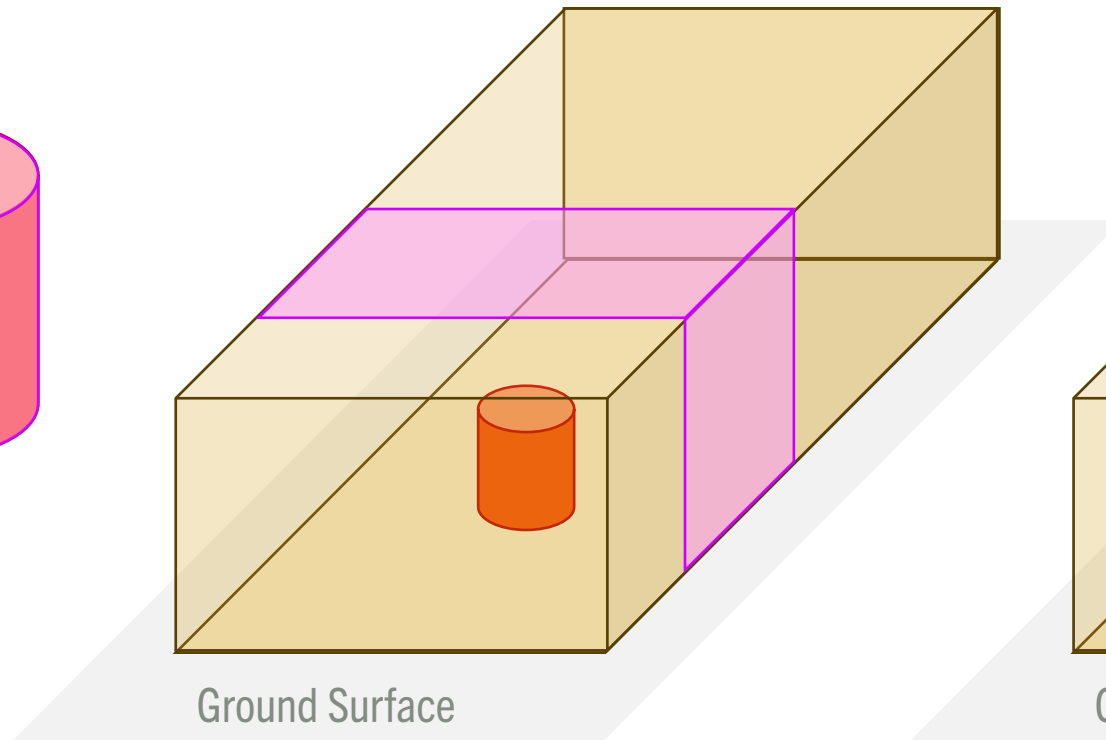


EXPOSED AREAS

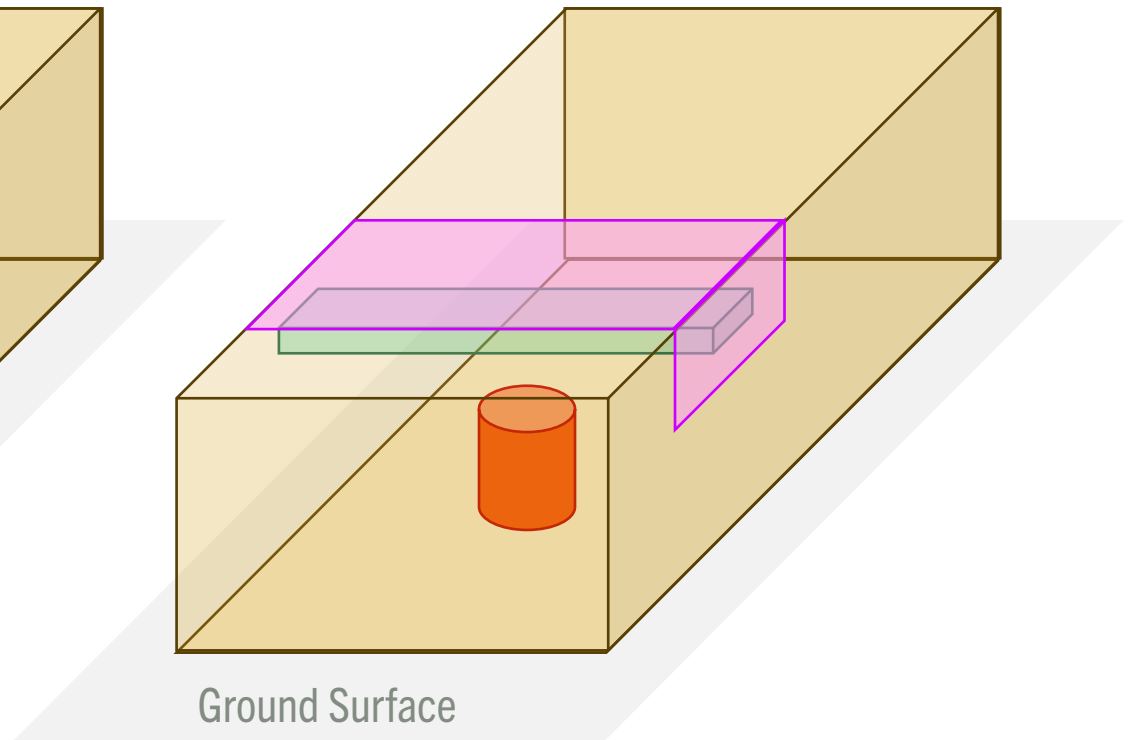
Cause D1



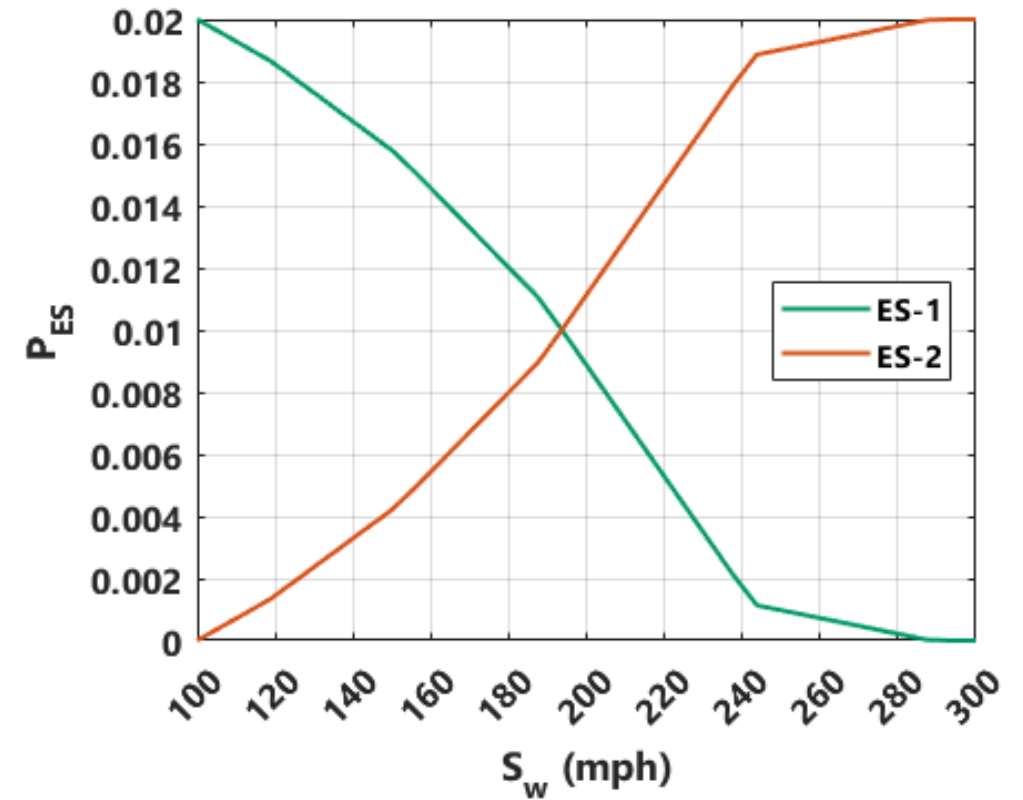
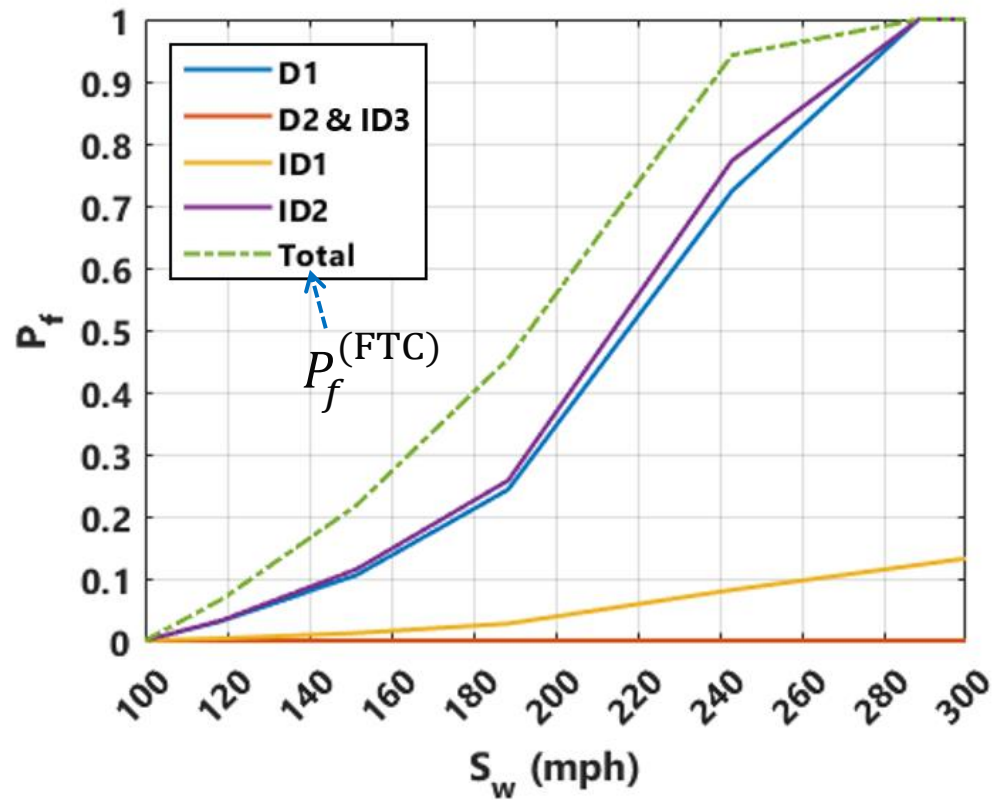
Cause ID1



Cause ID2

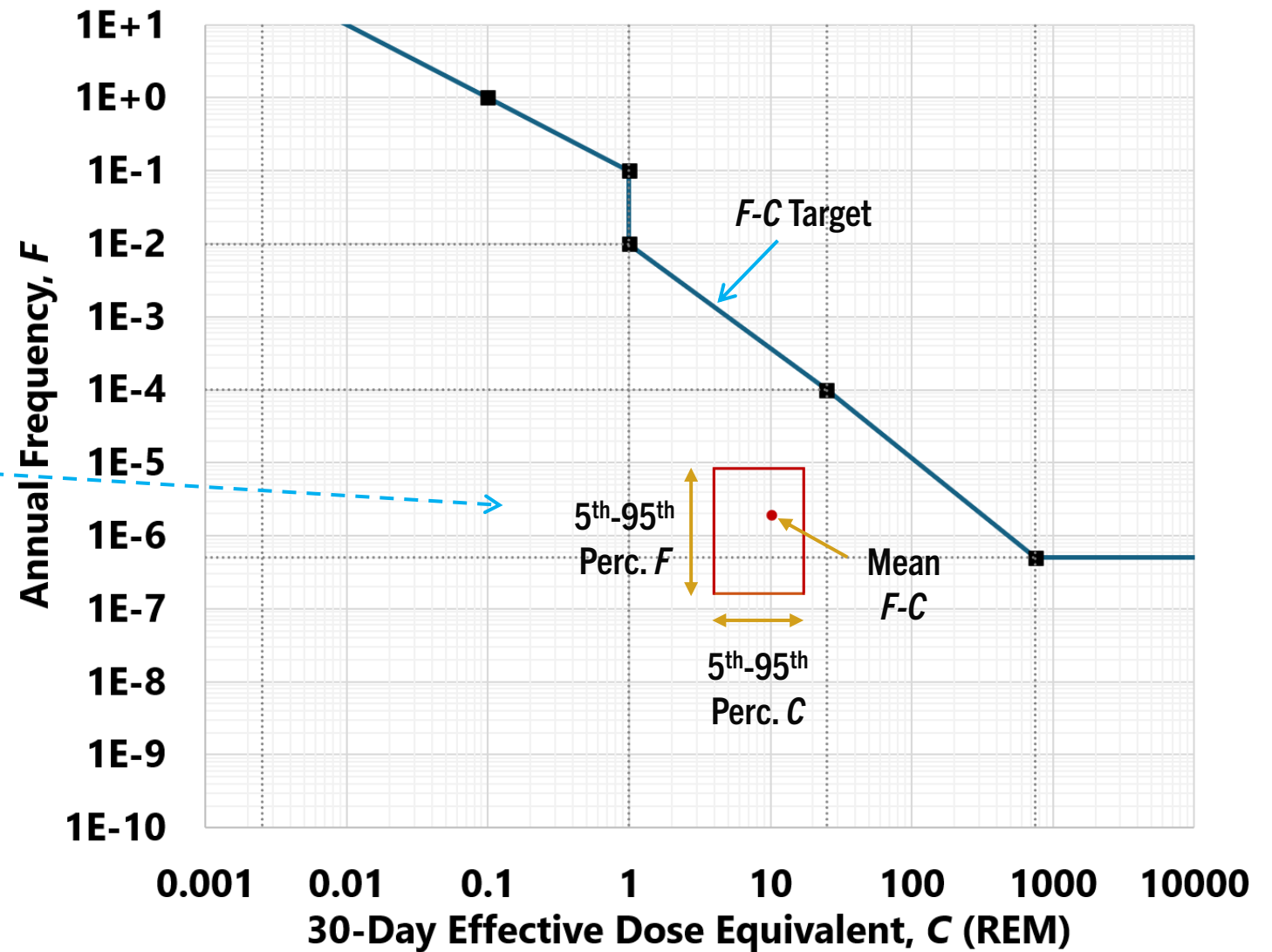


CALCULATED FRAGILITY & ES PROBABILITIES



F-C EVALUATION

Hazard	F (1/yr)	
	ES-1	ES-2
5 th Perc.	5.1E-6	1.6E-7
50 th Perc.	4.8E-5	1.9E-6
95 th Perc.	1.7E-4	8.4E-6



THANK YOU!

SGH

