External Events Risk Analysis
P-204

April 2009

United States
Nuclear Regulatory Commission

Idaho National Laboratory

External Events Risk Analysis (P-204)

April 2009 – Bethesda, MD

Instructors

William J. Galyean
phone: (208) 526-0627
email: William.Galyean@inl.gov

Dana L. Kelly
phone: (208) 360-0538
email: Dana.Kelly@inl.gov

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Course Objectives

- **Familiarize students with terminology and approaches used to assess external event risk.**

- **Enable students to effectively review external event analysis submittals from licensees**

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Course Scope

- **Focus on Seismic Analysis and Fire (PRA and SDP)**
- **Includes Internal Floods and HFO (High winds, external Floods, and Other)**
- **Survey and overview of methods used**
  - **Basic principles and simple examples**
  - **Reference list included for further study**
- **Individual Plant Examination for External Events (IPEEE)**
  - **Reason every plant has some type of EE analysis**
- **PRA Standards**
  - **ASME RA-Sa-2009 (Internal Events PRA, includes internal floods)**
  - **ANS/ANSI-58.21-2007 (External Events PRA)**
  - **ANSI/ANS-58.23-2007 (Fire PRA Methodology)**

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Outline of Course

- **Background**
  - **IPE/IPEEE**
  - **PRA/PRA-EE standards**
- **Internal Flood**
  - **Included in IPE not IPEEE**
- **Other External Events**
  - **High winds, external Flood, and Others (HFO)**
- **Seismic Analysis**
- **Fire Analysis**
  - **Fire PRA**
  - **Fire SDP**

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What are External Events?

- **Initiating-events external to typical plant system operations**
  - **Includes fires, floods, earthquakes, etc.**
    - **Fires and floods inside and outside of the plant**
- **Separated from "internal-events" analysis because:**
  - **Unique and specialized methods of analysis**
  - **Common cause or wide-area effects**

Example External Events

- Seismic
- Internal Fires
- High Winds and Tornadoes
- External Floods
- Transportation and Nearby Facility Accidents
- Internal Floods

- Lightning
- Extreme Temperatures
- External Fires
- Extraterrestrial Activities
- Volcanic Activity

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External Events Found to be Risk Important

- 1979 - Oyster Creek (first seismic PRA)

- 1979 - HTGR (first fire PRA)

- 1981 - Big Rock Point

- 1982 - Zion/Indian Point

- 1988 - GL 88-20 (IPEs to include internal floods)

- 1989 - NUREG-1150 (fire and seismic)

- 1991 - GL-88-20, Supplement 4 (IPEEE)

  - Revised in 1995 with supplement 5, which modified seismic requirements

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Purposes of IPEs/IPEEEs

- **Systematically examine plant design, operation, and emergency operation**

- **Identify plant-specific vulnerabilities to severe accidents and possible scenarios**

- **Develop understanding of what could possibly go wrong in a plant**

- **Identify and evaluate means for improving plant and containment performance with respect to severe accidents**

- **Decide which of these improvements to implement and when**

- **Perform this examination for selected external events (IPEEE)**

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Brief History of GL 88-20

- **1988-Nov: GL 88-20 issued requesting IPEs**
- **1989-Aug: GL 88-20 Supplement 1**
  - **Availability of NUREG-1335 – IPE Submittal Guidance**
- **1990-April: GL 88-20 Supplement 2**
  - **List of severe accident management strategies to consider in IPE (NUREG/CR-5474)**
- **1990-July: GL 88-20 Supplement 3**
  - **Announced complete of NRC Containment Performance Improvement (CPI) program**
- **1991-June: GL 88-20 Supplement 4**
  - **IPE for External Events (IPEEE)**
- **1995-Sept: GL 88-20 Supplement 5**
  - **Modified recommended scope of seismic analysis to include revised seismic hazard curves (NUREG/CR-1488, LLNL)**

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GL 88-20 did not Require a PRA

- **All utilities chose to perform a PRA to address GL 88-20**
  - PRAs not performed to specified standards
    - No requirements specified for data or models
- **Not all utilities used PRAs to analyze external events**
  - Earthquakes and fires can be analyzed via margins approach
- **IPE submittal typically not a full PRA (level of detail varies widely, only full-power operation considered)**
- **IPEs not performed to support risk-informed, performance-based regulation**

External Events Included in Both IPE and IPEEE

- **IPE included consideration of internal flood**

  - **Guidance in NUREG-1335 (1989)**

  - **Results and insights in NUREG-1560 (1997)**

  - **Note that internal flood is now part of internal events PRA standard**

- **IPEEE included all other external events**

  - **Guidance in NUREG-1407 (1991)**

  - **Results and insights in NUREG-1742 (2002)**

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IPEEE Explicitly Addressed

- **Seismic Events**

- **Internal Fires**

- **High Winds and Tornadoes**

- **External Floods**

- **Transportation and Nearby Facility Accidents**

- **Any other plant-specific hazards know to the licensee**

Remember that the IPE explicitly included internal flooding

IPEEE Methods Employed

- **Seismic**
  - **Seismic Margins**
  - **Seismic PRA**
- **Fire**
  - **FIVE (Fire-Induced Vulnerability Evaluation)**
  - **Fire PRA**
- **Other**
  - **Graded Approach**

IPE Results (Internal Flood)

- **Internal Floods are a small risk contributor for most plants**
  - Typically <10% of CDF
- **Important for some because of plant-specific designs**
  - Water system ruptures that cause failure of multiple systems (directly or through flooding)
    - Drains not large enough to prevent buildup or backflow through drains
  - Plant-layout – Separation and compartmentalization of system components
    - E.g., direction doors swing open

IPEEE Results

- **Seismic**
  - **Offsite power and on-site electrical equipment dominate risk**
  - **Building and structural failures also important**
- **Fire**
  - **Switchgear areas and main control rooms (abandonment) important**
- **High Winds, External Floods, and Other EEs**
  - **Most HFOs screened-out via qualitative analysis**
  - **Some quantitative analyses done on: high winds and tornadoes, external floods, transportation and nearby facilities, lightning (1), snow and ice (1), chemical release(1)**

PRA Standards Include External Events

- **Standards are NOT procedure guides**
  - **Focus is on risk-informed application issues**
- **ASME standard on PRA includes internal flood (IF) events**
  - **ASME RA-Sa-2009 (February 2009)**
    - **This is fourth revision of original (RA-S-2002, April 2002)**
- **ANS standard ANSI/ANS 58.21 addresses all other external events (except internal fires)**
  - **Original approved March-2003, published Dec-2003**
- **Internal fire standard developed (ANS)**
    - **ANSI/ANS-58.23-2007 approved November 20, 2007**

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Internal Flooding (ASME PRA Std.)

Objectives:

- **Internal floods (IF) as either an initiator or mitigating system failure are evaluated such that:**

    a) Flood sources within plant are identified

    b) Flood scenarios/sequences that contribute to CDF and LERF are identified and quantified

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IF Std. – High Level Requirements

Designator	Requirement (abbreviated)
HLR-IF-A	Flood areas of the plant SHALL be identified
HLR-IF-B	Flood sources and mechanisms SHALL be identified
HLR-IF-C	Scenarios for each source SHALL be developed (i.e. propagation path and affected SSC)
HLR-IF-D	Flooding-induced IEs SHALL be identified and frequencies estimated
HLR-IF-E	Flood-induced accident sequences SHALL be quantified
HLR-IF-F	Analysis SHALL be documented to support upgrades and peer review

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Supporting Requirements

- **Each High Level Requirement delineated in terms of more detailed supporting requirements (SR)**
  - **Each SR described in terms of action statements**
    - **E.g., DEFINE, IDENTIFY, USE, CONDUCT**
  - **Each SR linked to one or more of the three Capability Categories, which are defined by the standard in terms of:**
    - **Scope and level of detail**
    - **Plant-Specificity**
    - **Realism**

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ANS PRA External Events Standard

- **Original ANSI/ANS 58.21-2003**

- **Updated ANSI/ANS 58.21-2007**

- **All EE except internal flood (included in ASME Std.) and internal fire (under development by ANS as a separate std.)**

  - **While plant is at nominal full power**

  - **Includes both seismic PRA and seismic margins assessment (SMA)**

ANS PRA External Events Std.

- **Objective:**

   Requirements for EE PRA used to support risk-informed decisions for commercial NPP

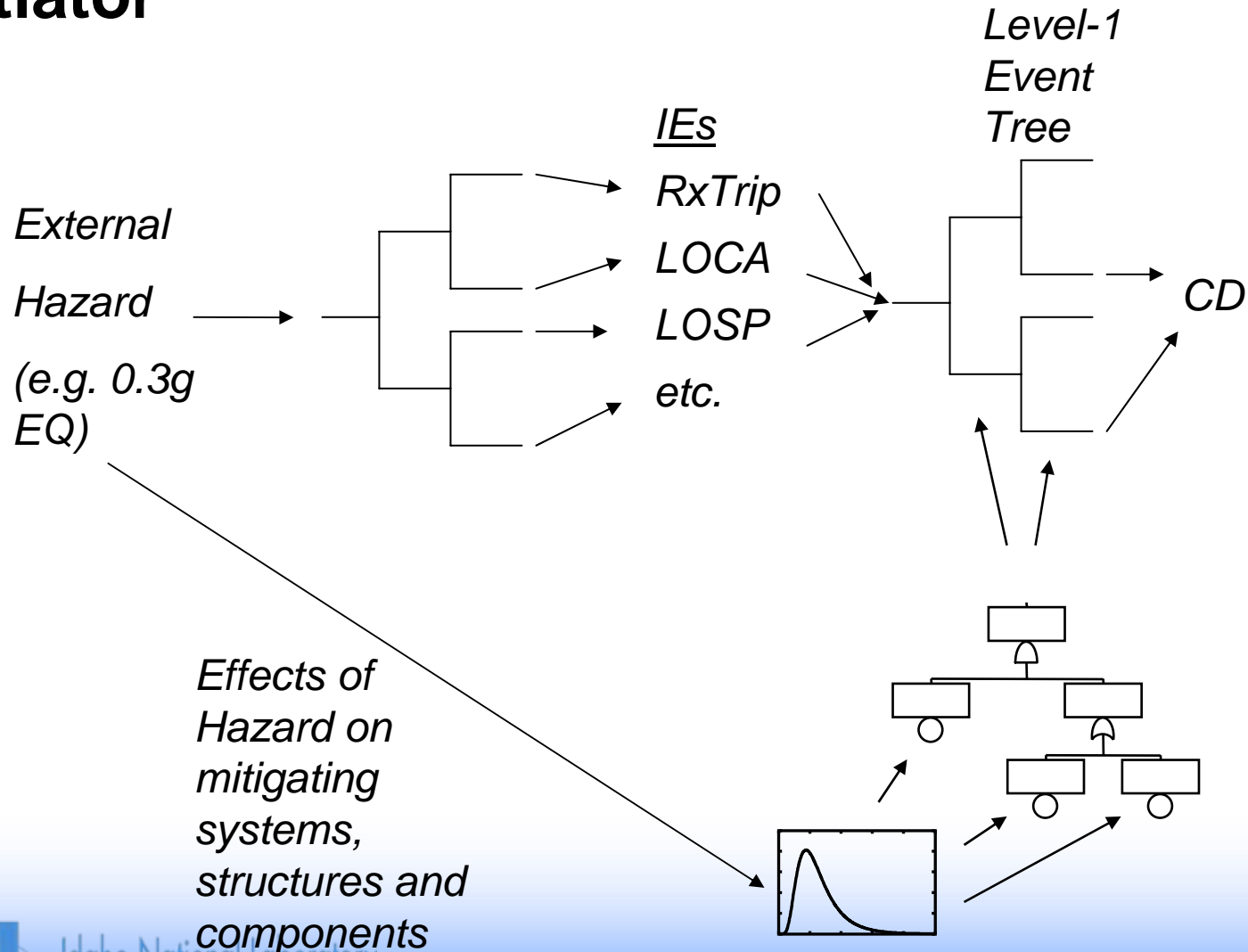- **Intended to be coordinated with ASME-RA-Sa-2009**

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ANS PRA EE Std High-Level Req.

Designator	Requirement (abbreviated)
HLR-EXT-A	All potential EE that may affect the site SHALL be subject to screening, bounding or detailed analysis
HLR-EXT-B	Preliminary screening analysis, if used, SHALL be performed using a defined set of screening criteria
HLR-EXT-C	Bounding analysis, if used, SHALL be performed using a defined set of quantitative screening criteria
HLR-EXT-D	The basis for screening-out of an EE SHALL be confirmed through a walkdown
HLR-EXT-E	The screening-out of an EE SHALL be documented in a manner that facilitates applying and update the PRA and that enables peer review

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Internal Events PRA Models are Basic Framework for External Events Analyses

- **Typical approach in External Event PRA**
  - **Characterize hazard (EQ, fire, flood, etc.)**
    - **Frequency and damage to plant (varies by hazard scenario)**
  - **Calculate conditional core damage probability (CCDP) given occurrence of hazard**
    - **E.g., using internal event PRA, set damage equipment to "failed" and calculate conditional core damage probability**
  - **Combine hazard frequency with each CCDP**
    - **For each hazard scenario**
    - **Sum over all hazard scenarios**

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Hazard is New IE – Induces Internal Events Initiator

External

Hazard

(e.g. 0.3g EQ)

IEs

RxTrip

LOCA

LOSP

etc.

Level-1 Event Tree

CD

Effects of Hazard on mitigating systems, structures and components

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Internal Flooding

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Objectives

- **To become familiar with:**

  - **History of internal flooding analyses and the current approaches being used**

  - **References available on typical internal flooding analysis methods**

  - **Resources for data used in typical internal flooding analyses**

Flood Risk Historically Ignored

- **Reactor Safety Study (WASH-1400, 1975) qualitatively judged flood risk negligible**
  - **Plants designed to withstand probable maximum flood (PMF) – External Floods**
  - **Internal flooding was not considered**
- **Internal Flooding identified as a risk issue ~1980's**
  - **Service water system and condenser ruptures**
  - **Zion (1982) and Indian Point (1983) PRAs**

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Sample of Turbine Bldg Flooding Events

Date	Plant	Notes	Result
June 1972	Quad Cities 1	Condenser Circulating water valve closed inadvertently causing water hammer rupture of expansion joint	Rapid flooding of room containing pumps in several system
April 1977	TMI-1	Condenser circulating water pump casing split	Rapid flooding of room containing six pumps
Oct. 1976	Oconee	Condenser circulating water isolation valve opened during maintenance	Lake water spilled into turbine bldg flooding emergency FW pumps
Oct. 1979	Dresden 2	Fire-water leak	Diesel-generator control cabinet sprayed

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Internal Flood Included in IPE

- **Heightened concern about internal flooding resulted in increased scrutiny**

- **Internal flood risk incorporated in IPE scope (not IPEEE)**

  - **Other EE analyses delayed to allow NRC/Industry time to finalize scope and methods**

    - **IPEEE trailed IPE by about 2 years**

(This has generated inconsistency over the years about whether internal flooding is treated in *internal* or *external* events analysis.)

Internal Flooding Analysis

- **Successive Screening Approach**
  - **Typical of an external event analysis**
- **Qualitative Screening Analysis**
- **Quantitative Screening Analysis**
- **Detailed Analysis**

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Initialization of Flood Analysis

- **Identify areas of concern**
  - **Both susceptible to flooding AND contain equipment modeled in PRA**
- **Plant divided into unique flood locations**
  - **Including areas that can be affected by water spray or steam**
  - **Water retention and flood propagation potential**
  - **Not necessarily separated by water-tight barriers**
- **Flood sources for each location identified**
  - **Water spray, steam and flood**

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Typical Assumptions/Boundary Conditions

- Only single rupture/flood considered at a time
- Some events already treated by internal events analysis
    - LOCAs inside and outside containment
- Temporary potential flooding sources typically ignored
    - Short time of exposure, plant staff in local area
- Floods are initiator, not subsequent to others IEs
- Spurious actuation of fire-suppression included
- Flood barriers (e.g., walls) assumed to be effective
    - Capacity of drains and doors need to be assessed

Initial Screening of Locations

- **Screening of locations assuming maximum damage**
  - **Given flooding occurs, all equipment in source location and propagation locations fails**
  - **What alternate equipment (success paths) are available?**
- **Flood sources for each location identified**
- **Flood scenarios identified**
  - **Flood source and affected location(s)**

Qualitative Screening

- **Identify independent flood areas/zones**
  - **Independent if flood outside area cannot enter area (without the failure of a barrier)**
- **Identify flooding sources in each flood area**
  - **Including water capacity and maximum flow rate**
  - **Typical flooding sources are pipes**
    - **Need pipe routing information (can be accomplished via local inspection)**
- **Identify equipment in each flood area**
  - **Only equipment needed for safe shutdown (i.e., modeled in PRA) or if damaged, would lead to a reactor trip, is counted**
    - **Includes electrical, control, and instrumentation equipment**

Qualitative Screening (cont.)

- **Flood area screened-out if:**
  - **Area does not contain any safe shutdown equipment, nor any equipment such that if damaged could lead to reactor trip**
    - **However, typically if flood only causes reactor trip with no damage to mitigating equipment, area is screened out**
      - **This scenario is bounded by internal events analysis**
  - **Flooding sources do not have enough capacity to damage equipment**

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Qualitative Screening Refined

- For those flood areas not screened out a more detailed screening can be done
    - Determine the critical height of vital equipment
    - Determine the maximum height of potential flooding in that area
        - Assume worst case flood sources
        - Account for drainage out of flood area
    - Identify effects other than submergence that might damage critical equipment (e.g., spraying)
    - Assess impact of flood propagation out of area (i.e., might this area be important as a flood initiator for another area)
- If max flood height is less than critical height of equipment, if other effects do not impact equipment, and if flood propagating to adjacent areas is not a concern, then can screen out

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Quantitative Screening Analysis

- **Four steps**
  - **Bounding estimate of flooding frequency**
    - **0.1 or 0.01**
  - **Bounding estimate for flood propagation probability**
    - **Human errors and mechanical failures**
  - **For each flood scenario calculate conditional core damage probability**
  - **Screen CDF for each flood scenario against screening criteria**
    - **E.g., 1E-7/yr (flood CDF small compared to internal events)**

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Detailed Internal Flooding

- **Flood scenarios that survive screening**
  - **Unique flood areas/locations/zones identified**
    - **SSC's within each area listed**
  - **Flood sources within each area**
- **Flood frequency within each area estimated**
- **More realistic estimate of flood damage and damage propagation**
- **Potential for recovery or mitigation assessed**
- **Additional (random) failures accounted for**
- **Core damage frequency calculated**

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Flood IE Frequency Estimates

- **Itemized list of potential sources**
  - **Pipe (length)**
  - **Generic pipe rupture rates**
    - **E.g., 4E-10/pipe-section-hour (EPRI TR-100380)**
- **Sum total flood IE frequency for each location**
  - **Possibly perform further screening based on IE frequency**
  - **Each flood scenario assigned IE frequency**

Flood Frequency Estimates

- **Pipe failure frequency from WASH-1400**
  - **Pipe > 3 in. diameter**
    - **8.8E-7/seg-yr (median), 2.6E-5/seg-yr (95%)**
  - **Pipe < 3 in. diameter**
    - **8.8E-6/seg-yr (median), 2.6E-4/seg-yr (95%)**
- **Expansion joint failure from Oconee PRA**
  - **2.5E-4/yr**
- **Tank rupture from IAEA TECDOC-478 (reliability database, 1988)**
  - **2.3E-4/yr**

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Flood Flow Rate

- **Rate of flooding determines time available for recovery actions**

- **Flooding rate dependent on**
  - **Pumping capacity, size of pipe, presence of restricting orifices**

- **Flood rate allocation method presented in Oconee PRA (NSAC-60, 1984)**
  - **Large, medium, and small**

Flood Rate Allocation

Oconee PRA (NSAC-60, 1984)

- **Total flood frequency allocated to:**
  - **Large flood (10%)**
  - **Medium flood (30%)**
  - **Small flood (60%)**
- **Flood Rate**
  - **Large flood = maximum rate**
  - **Medium flood = (max rate)/3**
  - **Small flood = (max rate)/6**

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More Recent Estimates from EPRI

- **Pipe Rupture Frequencies for Internal Flooding PRAs, Revision 1. EPRI, Palo Alto, CA: 2006. (EPRI-1013141)**

- **Rates per Reactor Operating Year**
  - **By Plant system, pipe diameter, and flood mode**
    - **Spray (<100 gpm)**
    - **Flood (100 gpm to 2,000 gpm)**
    - **Major Flood (>2,000 gpm)**

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Flood Scenarios Defined

- **Flood scenarios depend on:**
  - **Flood source**
  - **Area layout**
  - **Flood growth and propagation**
    - **Flood rate, drainage, free area for flooding, critical height of flood (time to fill volume)**
    - **Different equipment targets can produce different critical heights**
    - **Spray and splashing should also be considered**
  - **Time available for recovery**

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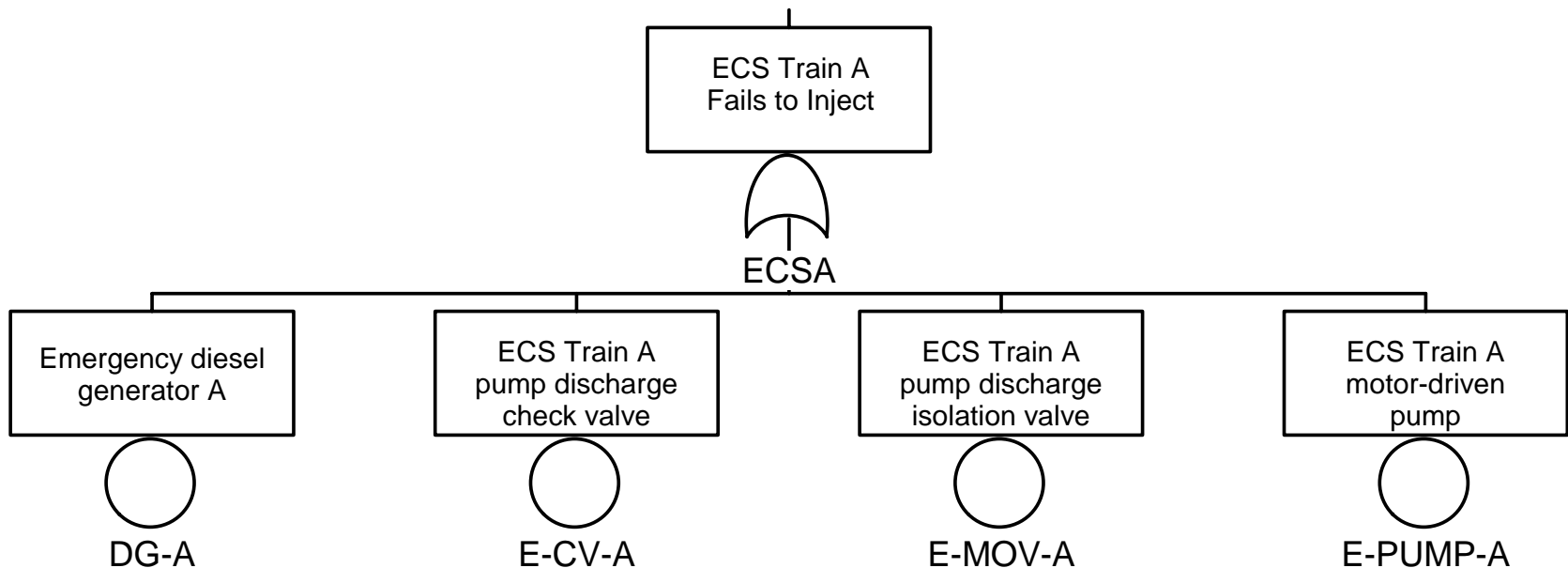# Quantifying Flood Core Damage Freq.

- **For each flood scenario:**
  - **Flood frequency**
  - **Fail to recover probability**
  - **Flood propagation probability**
    - **Failure of any flood barriers**
  - **Set of equipment failed by flood**
    - **Internal events PRA model modified to calculate conditional core damage probability**
  - **Flood scenario frequency (first 3 items) combined with CCDP to calculate flood core damage frequency**

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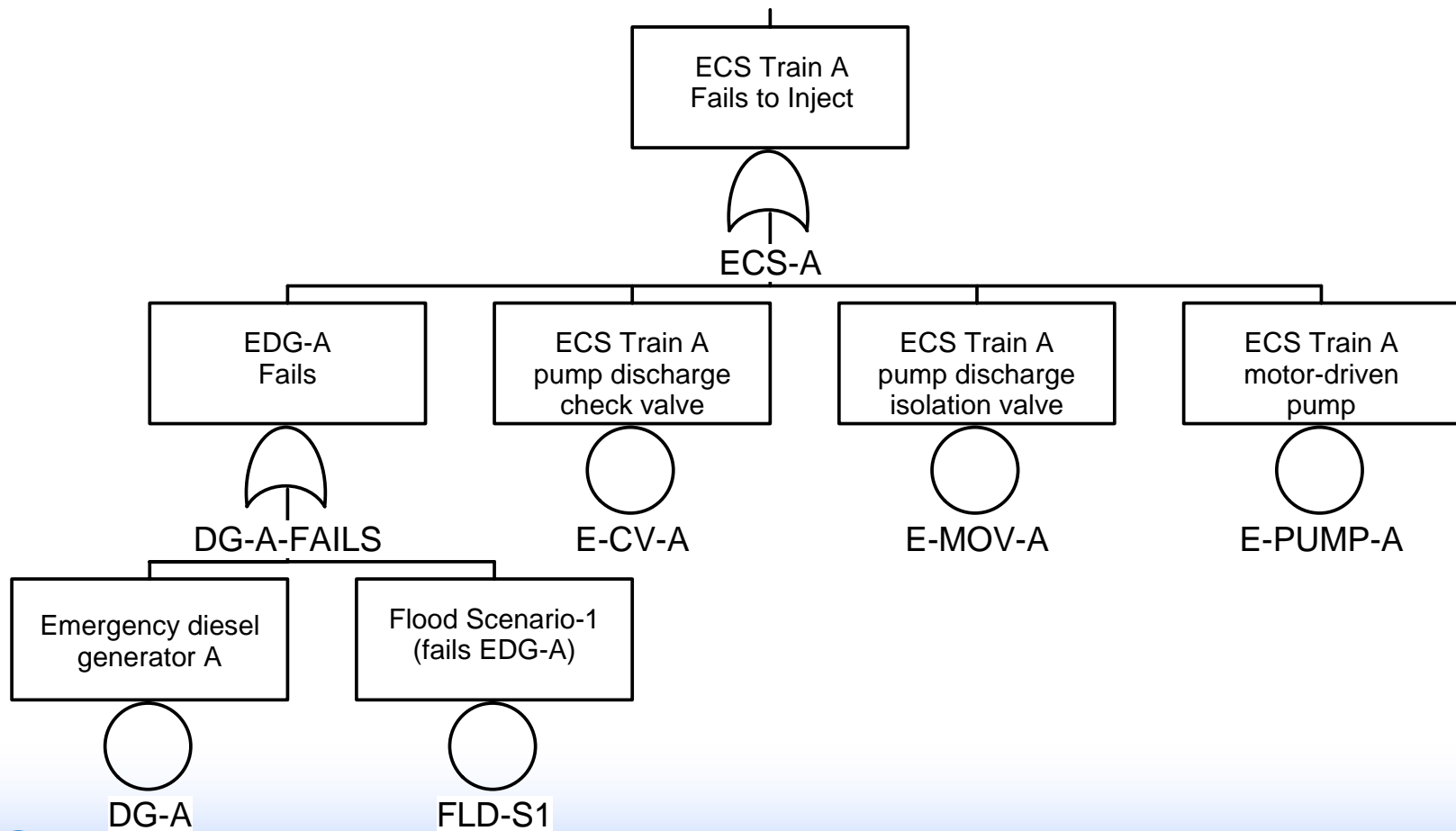# Flood Scenarios can also be added to PRA Model

- **Internal Events PRA model expanded to include flood scenarios**

- **Equipment (basic events) transformation to flood scenarios**

  - **E.g., DG-A = DG-A + FLD-Z1**

Original Fault Tree for ECS Train A
Transform DG-A basic event to include failure caused by flood in zone-1

ECS Train A
Fails to Inject

ECSA

| Emergency diesel generator A | ECS Train A pump discharge check valve | ECS Train A pump discharge isolation valve | ECS Train A motor-driven pump |

DG-A   E-CV-A   E-MOV-A   E-PUMP-A

DG-A Transformed to Include failure caused by Flood Scenario-1

Flood Scenario Frequency Refined

- **For each Flood Scenario:**
  - **Recovery (isolation of rupture) probability**
  - **More realistic estimates of**
    - **Flood propagation (from one location to another)**
    - **Equipment fragility**
- **Continue refining until**
  - **Scenario no longer significant contributor to risk, or**
  - **Realistic estimate of risk contribution**

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Few Plants Identified Internal Flooding Vulnerabilities via IPE

- **Propagation of flood to adjacent areas (doors swing outward) fails safeguards equipment**

- **Failure of circulating water expansion joints**

- **Rupture of service water or circulating water systems result in flooding of turbine building**

- **Rupture of demineralized water line results in flood of relay and switchgear rooms**

- **However, 17 plants identified internal flood related plant improvements**

High Winds, External Flood, and Other (HFO)

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Learning Objectives

- **After studying this section you should know:**

  - **Steps in the progressive screening approach for other external events**

    - **Comparison to Standard Review Plan (SRP)**

  - **Examples of nonconformance to SRP criteria for high winds, external floods, transportation accidents, and nearby facility accidents, and the analysis method(s) used to address these external hazards.**

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Overview

- **HFO events considered in the IPEEE:**
  - **High Winds**
  - **External Floods**
  - **Transportation Accident**
  - **Nearby Facility Accident**
  - **"Other" External Events**
- **Progressive screening approach summarized in Figure 5.1 of NUREG-1407**
- **Does NOT include Internal Flood, Internal Fire or Seismic, which were addressed specifically**

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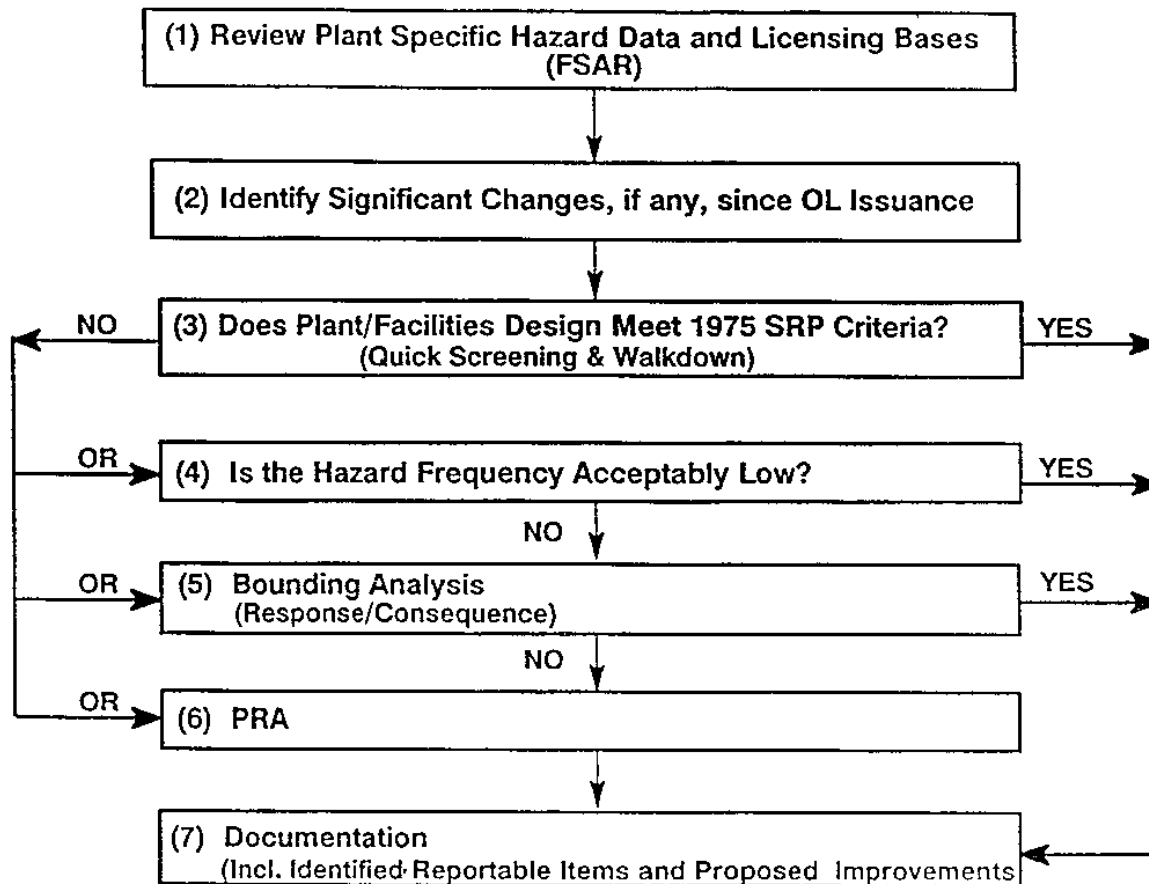# Recommended IPEEE Approach for Winds, Floods, and Others

Figure 5.1 Recommended IPEEE Approach for Winds, Floods, and Others

Procedure for Progressive Screening of Other External Events

Series of analyses in increasing level of detail, effort, and resolution.

1. Review plant design hazard, the licensing bases, and the resolution of each hazard event (FSAR and SER).

2. Identify significant changes at the site and surrounding, if any, since the issuance of OL, with respect to:

   - Military and industrial facilities within 5 miles of the site.

   - Onsite storage or other activities involving hazardous materials.

   - Transportation.

   - Development that could affect the original design conditions.

2. Perform a confirmatory walkdown of the plant.

3. Determine if the plant and facilities design meet the SRP criteria (if yes, then no further analysis is necessary)

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Procedure for Progressive Screening of Other External Events (continued)

- **If plant and facilities design do not meet SRP criteria for an external hazard, optional steps include:**

  4. **Determine if the hazard frequency is acceptably low (less than 1E-5 per year).**

  5. **Perform a bounding analysis.**

  6. **Perform a PRA.**

- **Bounding analysis criteria:**

  – **Hazard would not result in core damage.**

  – **CDF (conservatively estimated) is below 1E-6 per year.**

- **PRA criterion:**

  – **CDF is below 1E-6 per year.**

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Potential External Events to be Considered

- Aircraft Impact

- Avalanche

- Biological Events

- Coastal Erosion

- Dam Failure

- Drought

- External Flooding

- Extreme Winds and Tornadoes

- Fog

- Forest Fire

- Frost

- Hail

- High Tide, High Lake level or High River Stage

- High Summer Temperature

- Hurricane

- Ice Cover

- Industrial or Military Facility Accident

- Intense Precipitation

- Internal Flooding

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Potential External Events to be Considered

- Landslide
- Lightning
- Low Lake or River Stage
- Low Winter Temperature
- Meteorite
- Release of Chemicals from On-site Storage
- River Diversion
- Sand Storm
- Seiche

- Seismic Event
- Snow
- Soil Shrink/Swell
- Storm Surge
- Transportation Accidents
- Tsunami
- Toxic Gas
- Turbine Generated Missiles
- Volcanic Activity
- Waves

Initial Screening of Events

From NUREG/CR-2300, Section 10.3.1

1. The event is of equal or lesser damage potential than the events for which the plant has been designed.

2. The event has a significantly lower mean frequency of occurrence than other events with similar uncertainties and could not result in worse consequences than those events

3. The event cannot occur close enough to the plant to affect it.

4. The event is included in the definition of other event

5. The event is slow in developing and there is sufficient time to eliminate the source of the threat or to provide an adequate response.

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Example Initial Screening

Event	Screening Criteria	Remarks
Aircraft Impact	----	Bounding analysis
Dam Failure	4	Included in external flooding analysis
Forest Fire	3	There are no forests in the vicinity; site is cleared
Lightning	1	All buildings protected
Meteorite	2	Small frequency
Sand Storm	3	Not relevant for the region

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Typical Events for Bounding Analysis

- **Aircraft Impact**
- **External Flooding**
- **Extreme Winds and Tornadoes**
- **Industrial or Military Facility Accidents**
- **Release of Chemicals from On-site Storage**
- **Transportation Accidents**
- **Turbine Generated Missiles**

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High Winds/Tornadoes

- **NRC Regulatory Requirements:**
  - 10 CFR Part 50 Appendix A Criterion 2 and Criterion 4, 10 CFR Part 100.10

- **Other Related Documents:**
  - Regulatory Guide 1.13 (Spent Fuel Pool), 1.76, 1.117
  - SRP (1975) No. 3.3.1, 3.3.2, 3.5.1.4, 3.5.1.5, 3.5.2, 3.5.3
  - ASCE Paper 3269, "Wind Forces on Structures," Transactions of the American Society of Civil Engineers, Vol. 126, Part II, 1961
  - ANSI A58.1 Building Code Requirements for Minimum Design Loads in Buildings and Other Structures, American National Standards Institute Committee A58.1-1972

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Examples of Nonconformance to SRP Criteria

- **Maximum wind speed considered in plant design was less than the design basis tornado specified in Regulatory Guide 1.76.**

- **Design basis tornado missile spectrum differs from that specified in SRP.**

- **Structure not designed to withstand tornado wind or missile impact.**

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Wind Hazard Frequency

- **Wind loading due to tornado is limiting.**

- **Tornado wind annual exceedence frequency:**

    $$\phi_v = \phi_t \bullet \phi_{v|t}$$

    where

    ϕ_v **= annual frequency of a tornado striking the plant with a wind speed > v.**

    ϕ_t **= the annual frequency of a tornado striking the plant.**

    $\phi_{v|t}$ **= the conditional probability of tornado intensity or fraction of tornadoes with peak wind speed > v.**

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Fujita Tornado F Scale Wind Speeds

Intensity	Description	Orig. F-Scale (Fastest ¼ mile, mph)	Fujita Scale (3-s gust, mph)	Operational Enhanced Fujita Scale (3-s gust, mph)
F0	Light Damage	40 – 72	45 – 78	65 – 85
F1	Moderate Damage	73 - 112	79 – 117	86 – 110
F2	Considerable Damage	113 - 157	118 – 161	111 – 135
F3	Severe Damage	158 – 206	162 – 209	136 – 165
F4	Devastating Damage	207 - 260	210 – 261	166 – 200
F5	Incredible Damage	261 - 318	262 - 317	>200

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Tornado Intensity Distribution

Intensity	F0	F1	F2	F3	F4	F5
Number	17554	16076	9145	2903	1005	130
Ave. Length (mi)	1.14	3.376	6.633	10.495	13.442	14.945
Ave. Width (ft)	119.9	241.3	442.4	872.6	1426.8	1581.0
Ave. Area (mi²)	0.0458	0.2220	0.7366	2.1059	3.7797	4.6410

Data is from NUREG/CR-4461, Rev. 2, Tornado Climatology of the Contiguous United States, February 2007, is for contiguous United States (3,020,000 mi²), and spans beginning of 1950 to the end of August 2003 (53.67 years)

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Frequency of Tornado Striking the Plant (ϕ_t)

- **Two models for estimating the tornado strike frequency:**
  - **Point Target Model**
  - **Large (aka Aerial) Target Model**

- **Point target model is used if there are no vulnerable structures at the site with dimensions on the order of tornado damage width dimensions.**

- **Point target model tornado strike frequency:**
  - $\phi_t = n \bullet (A_{tp}/A)$
  - **n = the mean number of tornado occurrences per year in the reference area.**
  - A_{tp} **= the mean path area of tornado.**
  - **A = the reference area where the plant is located and over which tornado data are accumulated.**

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# Frequency of Tornado Striking the Plant, ϕ_t (continued)

- **Large target model tornado strike frequency:**
  - $\phi_t = n \bullet (A_t / A)$
    - A_t calculated considering footprint of plant, damage area of a typical tornado (width and travel length), and angle of tornado approach
    - See next slide
  - Alternate method (NUREG/CR-4461, Rev. 2)
    - $A_t = w_{target} \times L_{tornado}$
      Where:
      w_{target} = dimension of target
      $L_{tornado}$ = path length of tornado

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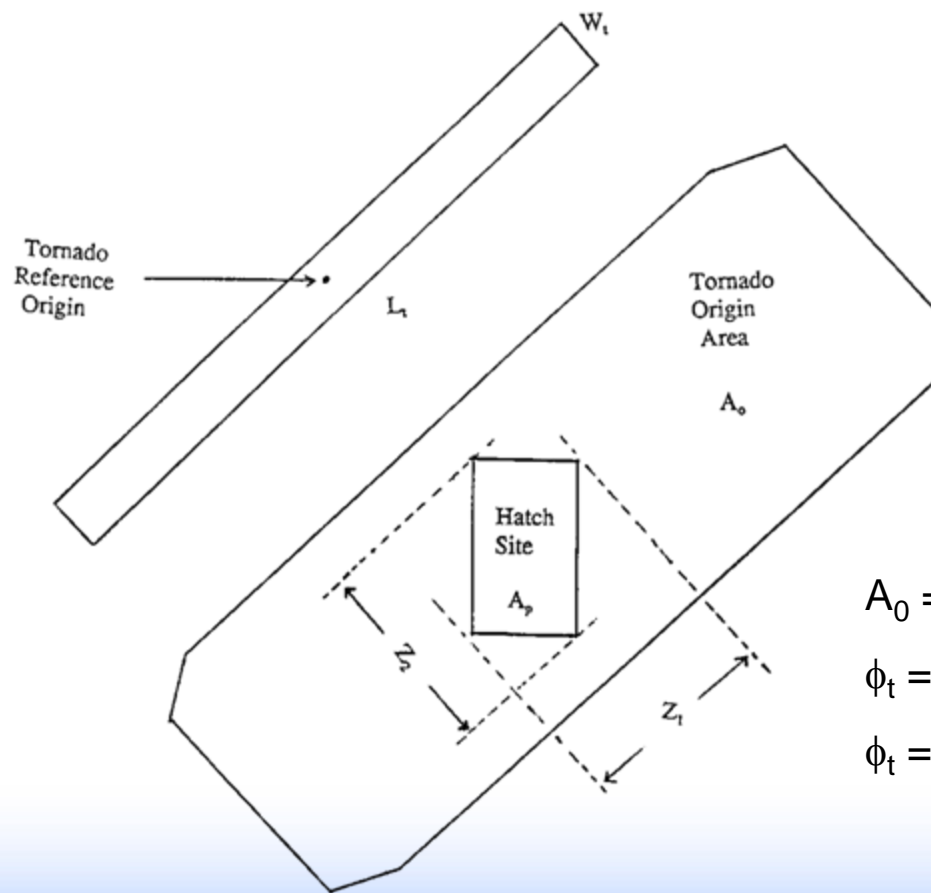
Tornado Strike Area Calculation

Structure
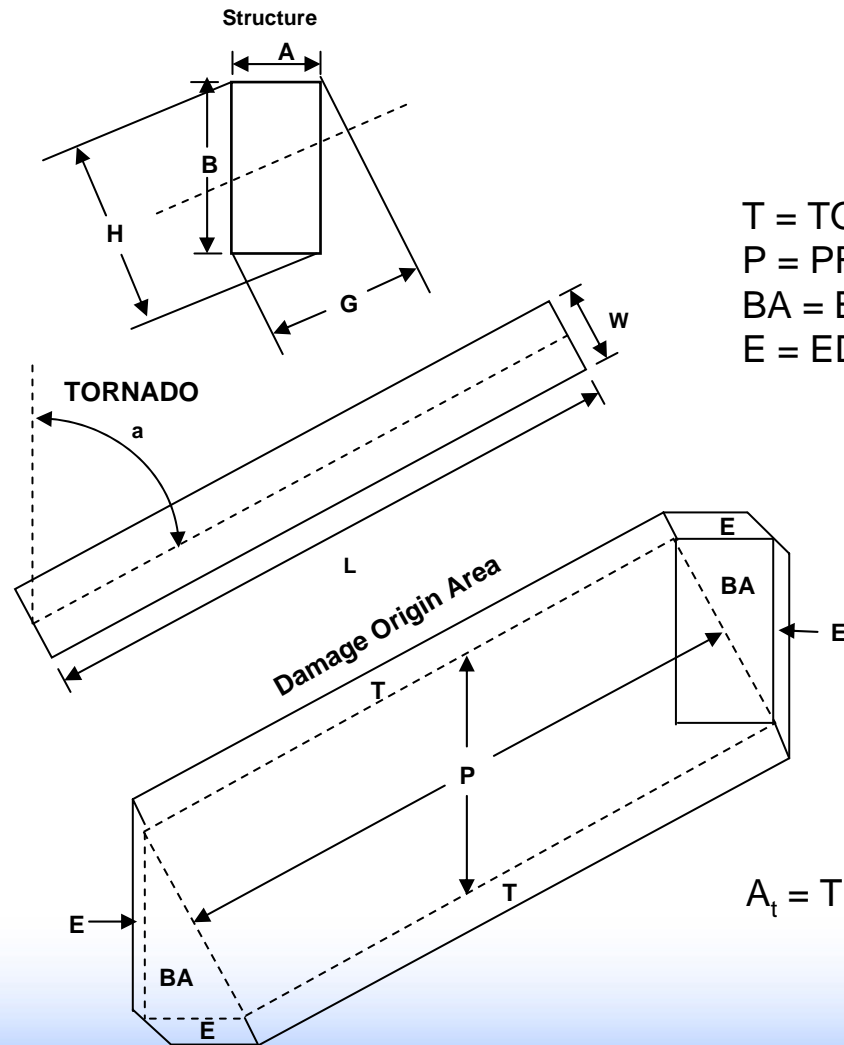
T = TORNADO AREA = WL
P = PROJECTED AREA = HL
BA = BUILDING AREA = AB
E = EDGE AREA = WG

$A_t = T + P + BA + E.$

Examples from the Hatch and Oconee IPEEEs

Tornado Origin Area ($A_0 = A_t$) for the Hatch Site

Tornado Reference Origin

W_t

N

Tornado Origin Area

A_o

L_t

Hatch Site

A_p

Z_2

Z_1

$A_0 = W_tL_t + W_tZ_1 + L_tZ_2 + A_p$

$\phi_t = n \bullet (A_0 \, / \, A)$

$\phi_t = n \bullet [(W_tL_t + W_tZ_1 + L_tZ_2 + A_p) \, / \, A]$

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Tornado Model Comparions

- **For Hatch IPEEE (1996):**
  - Site is represented by a rectangular area of length, 2000 ft in the N-S direction, and width, 1100 ft. For this analysis, it is conservatively assumed that the projections on the tornado length (Z_1) and width (Z_2) has the maximum possible value of 2280 ft.
  - Tornado data from National Severe Storm Forecast: 55 tornados occurred in 38 years (Aug. 1954 – Jan. 1993) in a 36-mi radius of the Hatch.
  - Ave. path length is 2.17 miles, ave. path width is 0.051 miles, and the reference area (within 36-mile radius) = 4070 sq. mi.
  - Tornado strike frequency = 4.09E-4/year
- **Calculate strike frequency using Point Target and NUREG/CR-4461, Rev. 2 models**

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Diagram of Tornado Origins ($A_s = A_{tp}$)

Tornado Damage Path Length (L)

Target

Target of Diameter (D)

Path Width (W)

Direction

Touchdown Zone

Area of origins that cross the target

Area of origins that terminate inside the target area
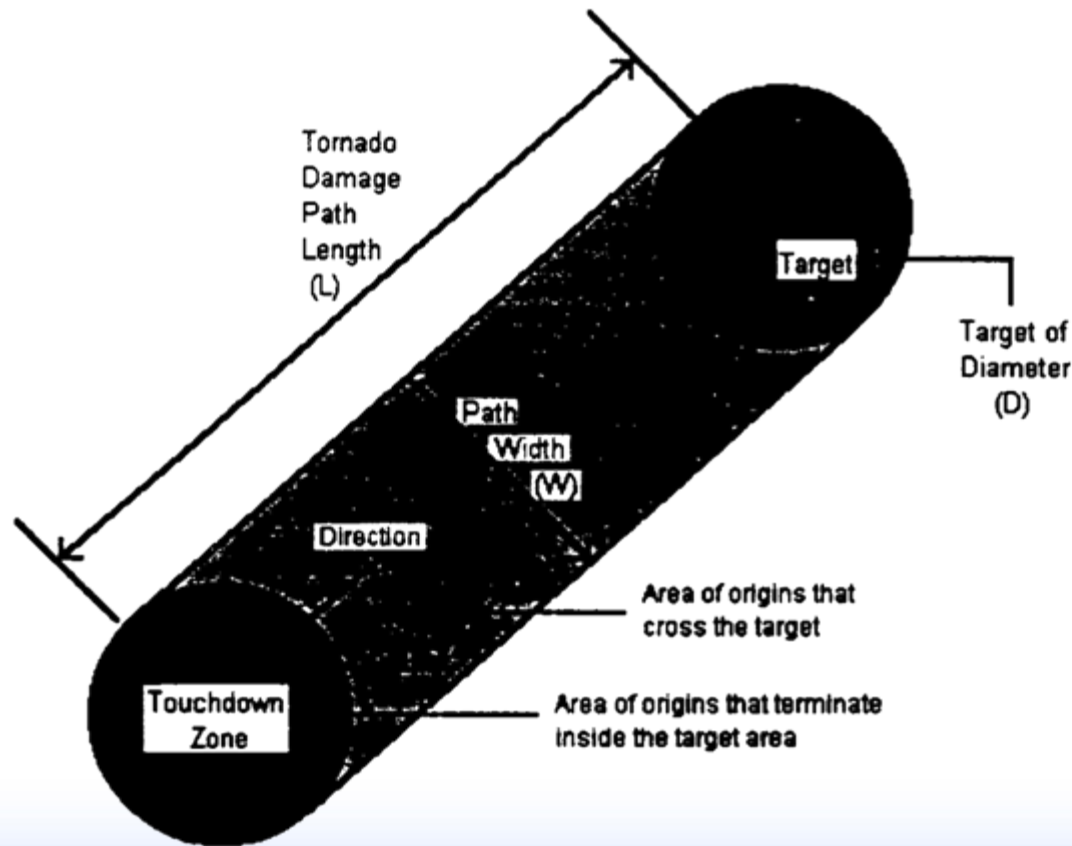
$$A_s = (L)(D + W) + \pi \left(\frac{D + W}{2} \right)^2$$

L = mean damage length

W = mean damage width

D = target diameter

Example taken from Oconee IPEEE

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Frequency of Tornado Striking the Plant, ϕ_t (continued)

- **Number of tornado occurrences per year at the site from SeverePlot by the Storm Prediction Center, National Weather Service**
  http://www.spc.noaa.gov/software/svrplot2/

  – **Historical tornado data for continental U.S.**

  – **Location specific (longitude and latitude)**

  – **Magnitude specific**

- **Previous analyses used TORPLOT for tornado frequency**

  (no longer available)

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Oconee Tornado Data and Frequency

F-Scale	Wind Speed Range (mph)	Number Reported (1950-93)	Estimated Number of Unreported Tornados [2]	Occurrence Frequency (#/yr-sq mi)	Mean Path Length (mi)	Mean Path Width (mi)	Impact Frequency (# / year)
F-0	40-72	99	17.4	4.07E-05	1.2	0.05	5.58E-06
F-1	73-112	290	26.3	1.11E-04	2.99	0.05	3.63E-05
F-2	113-157	159	13.3	6.02E-05	5.56	0.1	5.37E-05
F-3	158-206	34	3.9	1.33E-05	11.45	0.21	4.12E-05
F-4	207-260	14	1.0	5.24E-06	21.33	0.26	3.59E-05
F-5	261+	0.23 (1)	0.1	1.15E-07	33.00 (1)	0.39 (1)	1.71E-06

Note 1: No F-5 tornados were recorded during the entire 44 year period of data for the Oconee Plant. A Chi-Squared method was used to calculate an equivalent number of reported tornados. The mean path length and width for F-5 tornados are assumed values based on data for the eastern U.S. provided in NUREG/CR-4461 (Table 6, p. 40).

Note 2: The estimated number of unreported tornados is approximated from NUREG/CR-3058 Section 4.6.

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Keowee Conditional Failure Probabilities given Tornado Impact

		Keowee Damage Probability		
	F-scale (J)	Conditional Hit Probability	Conditional Damage Probability	Total Damage Probability
Tornado Rating (I)	F-2	0.124	0.500	0.062
	F-3	0.232	0.670	0.155
	F-4	0.299	0.750	0.224
	F-5	0.389	0.800	0.312

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Tornado Missile Impact Frequency

- Dependent on tornado strike frequency ϕt and probability of tornado-generated missile hitting a plant structure.

- Methods of estimating tornado missile impact frequency:
  - TORMIS computer code.
  - Generic results from TORMIS calculations for hypothetical plants [EPRI NP-768, -769].
  - Other computer programs; e.g., SPRPND by Bechtel used in the Palo Verde IPEEE.

- Study approach postulates a spectrum of available missiles and evaluates potential damage to plant structures.

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Example of Tornado Missile Analysis Using TORMIS from the Oconee IPEEE

TORMIS Analysis Plant Site Model
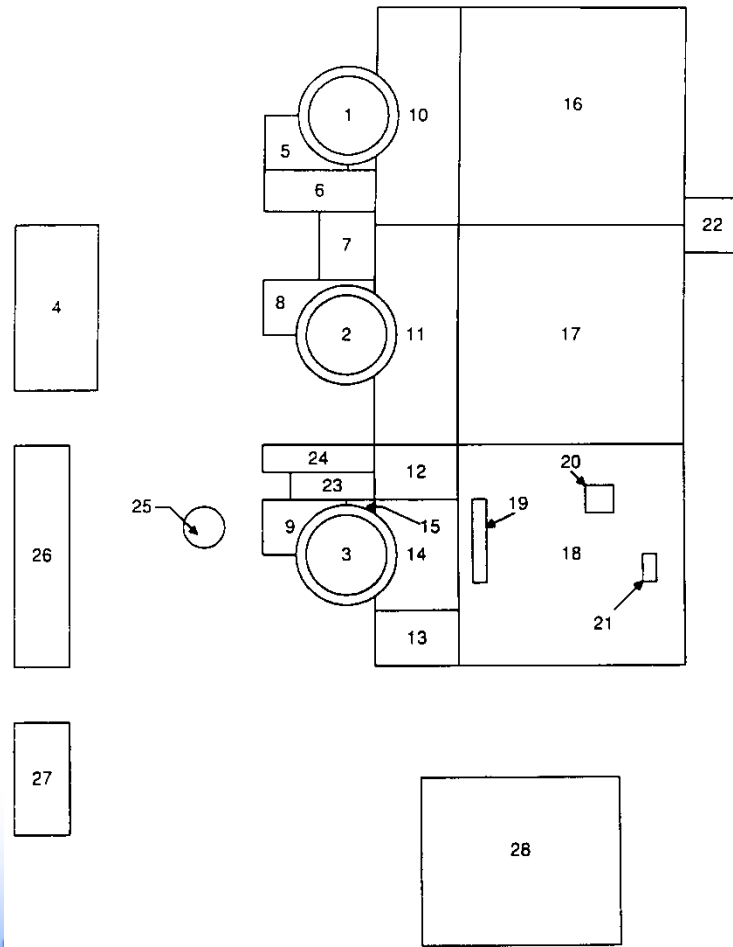
TORMIS Analysis Plant Site Model (continued)

Target Number	Target Structure
1.	Unit 1 Reactor Building
2.	Unit 2 Reactor Building
3.	Unit 3 Reactor Building
4.	SSF
5.	Unit 1 West Penetration Room
6.	Units 1 and 2 Fuel Handling Structure
7.	Units 1 and 2 Fuel Pool
8.	Unit 2 West Penetration Room
9.	Unit 3 West Penetration Room
10.	Unit 1 Auxiliary Building
11.	Unit 2 Auxiliary Building
12.	Unit 3 Auxiliary Building (Control Room Region)
13.	Unit 3 Auxiliary Building (Volume beneath U3 East Pen.Room)
14.	Unit 3 East Penetration Room

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TORMIS Analysis Plant Site Model (continued)

Target Number	Target Structure
15.	Unit 3 Auxiliary Building (between Control Room and U3 Rx. Bldg.)
16.	Unit 1 Turbine Building
17.	Unit 2 Turbine Building
18.	Unit 3 Turbine Building
19.	Unit 3 Upper Surge Tanks
20.	Region above Unit 3 EFW motor-driven pumps
21.	Region above Unit 3 EFW turbine-driven pump
22.	CT-4 Transformer Enclosure
23.	Unit 3 Fuel Pool
24.	Unit 3 Fuel Handling Structure
25.	Unit 3 Borated Water Storage Tank
26.	Warehouse
27.	Interim Radwaste Facility
28.	Radwaste Facility

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Oconee Nuclear Station Missile Origination Zones
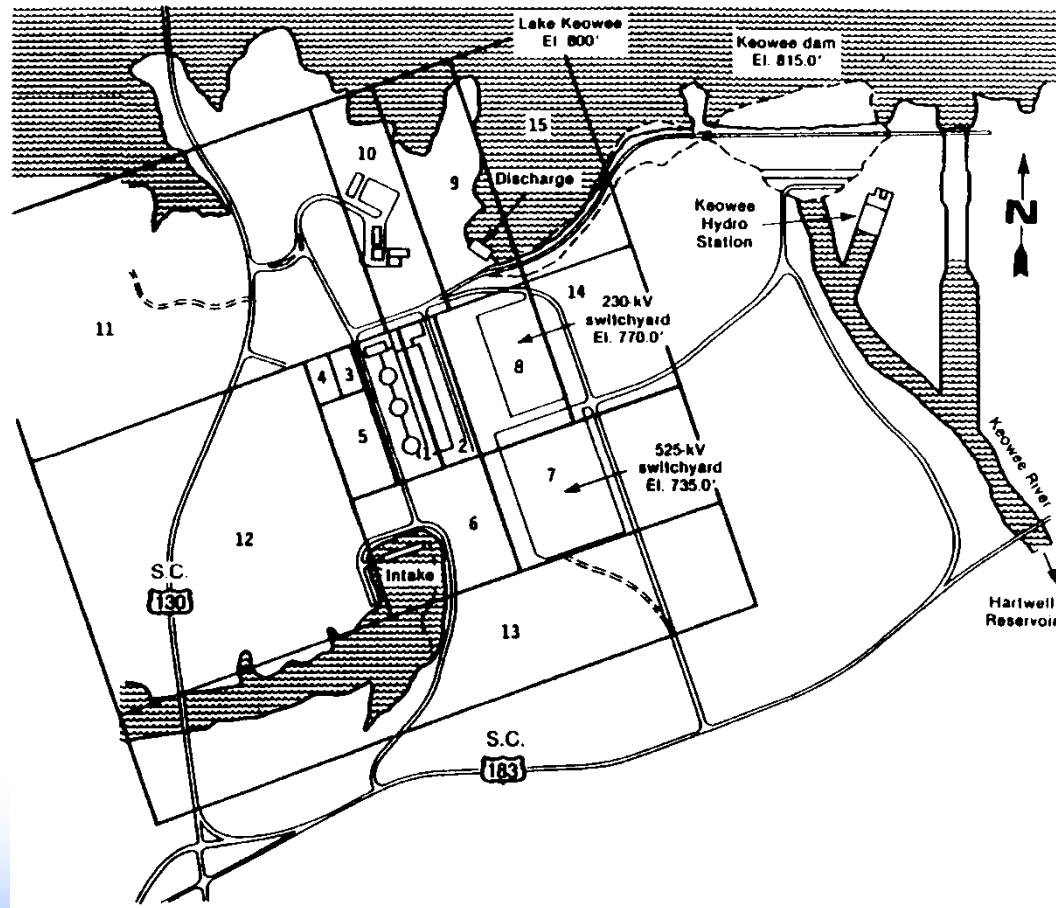
Oconee Nuclear Station Missile Distribution

Missiles	Missile Zones														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cars	6	24	72	0	490	30	30	15	0	292	100	390	0	25	0
Trucks	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Trailers	9	9	3	0	6	12	0	0	0	0	0	0	0	0	0
Utility Poles	9	7	0	0	20	0	67	71	0	26	0	0	0	7	0
Barrels	5	0	0	0	0	0	0	250	0	0	0	0	0	0	0
1" Rods	0	0	0	0	25	0	0	10	0	0	0	0	400	400	0
Concrete Slabs	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small Trees	0	0	0	1600	400	0	0	0	100	130	0	4000	800	13000	0
Large Trees	0	0	0	80	0	0	0	0	0	0	0	100	350	520	0
Wire Reels	0	0	0	0	0	0	0	6	0	0	0	0	10	300	0
I-Beam 4"	0	70	0	0	0	0	0	0	00	0	0	0	500	365	0
8'	0	0	0	0	0	0	0	50	0	100	150	0	500	350	0
12"	0	10	0	0	50	0	0	0	0	0	0	0	200	1061	0

Example of Tornado Missile Analysis Based on the Results of EPRI NP-768, NP-769 from the Farley IPEEE

TORMIS Results for Hypothetical Plants

- **Typical result for an operating two-unit plant in NRC Region I, with tornado frequency of 2.29E-03 per year:**

  - Frequency that any tornado-generated missile hits the plant structures(P^N) is 7.09E-05 per year.

  - Frequency that a missile impacts with sufficient force to cause back scabbing if all of the plant structures had 6-in. concrete walls (P_L) is 3.45E-05 per year.

  - Frequency that a missile impacts with sufficient force to cause back scabbing if all of the plant structures had a 18-in. concrete walls (P_U) is 3.33E-06 per year.

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Tornado Strike Frequency at the Farley Site

- Based on 94 tornadoes during a 42-year history (1950-1992) within 36 miles of site.

- Average tornado path length is 4.24 miles and average tornado path width is 0.066 mile.

- Reference area is 4,070 square miles.

- Tornado strike frequency at the site is 8.57E-04 per year.

Tornado Impact and Damage Frequencies for Farley

- **Scaling down the impact and damage frequencies from EPRI NP-768 with the ratio of the site-specific tornado strike frequency to the NRC Region 1 tornado occurrence frequency:**

  - P^N = 2.65E-05 per year - Frequency that any tornado-generated missile will hit plant

  - P_L = 1.29E-05 per year - Frequency of back-scabbing caused by missile impacting a 6-inch thick wall

  - P_U = 1.25E-06 per year - Frequency of back-scabbing caused by missile impacting a 18-inch thick wall

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Factors Affecting the Tornado Risk for Farley

- Farley's safety-related buildings are constructed of at least 24-inch-thick concrete walls.

- Frequency of a tornado missile hitting a particular target at the site is less than the strike frequency at the site.

- Missiles that cause back scabbing at a concrete wall do not necessarily cause structural failure, nor do they necessarily cause sufficient damage to components located near the wall so as to lead to their failure.

- Therefore, tornado-generated missile contribution to core-damage frequency is judged to be much less than 1E-6 per year and is an insignificant contributor to plant risk

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Indian Point 2 High Wind PSA

Overview of Methods and Results

- **IP2 design for high winds does not meet the 1975 standard Review Plan; many key structures are steel buildings with light metal siding.**

- **The event (high wind) could not be screened out at the hazard frequency level.**

- **PSA performed in several "phases" starting with very conservative assumptions and providing refinement where of value.**

Overview of Methods and Results (continued)

- **Wind hazard and fragility analyses of IPPSS* were reviewed and updated. A new event tree based approach was used to define a set of unique wind induced plant states and their frequencies were evaluated.**

- **The core damage frequency resulting from each wind induced damage state was then quantified by modifying the internal event plant logic.**

* Indian Point Probabilistic Safety Study (1983) used as the basis of the IP2 IPEEE

Overview of Methods and Results (continued)

- The mean core damage frequency from tornadoes, hurricanes, and extratropical cyclones was estimated to be 3.03×10^{-5} per year.

  - Mean CDF from internal events = 3.13×10^{-5} per year

- No vulnerability was identified.

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Wind Hazard Analysis

- Detailed wind hazard analysis was performed for IPPSS. The methods and data used in the IPPSS have not changed over the years. Therefore, the hazard results from IPPSS were deemed applicable for IPEEE of IP2.

- Wind speed exceedance frequency curves for four principal directions (north, south, east and west) were provided in the IPPSS for each of the high wind events (tornadoes, hurricanes and extratropical cyclones).

- Uncertainty in the wind hazard is represented by means of a family of five hazard curves (lower, mid-lower, median, mid-upper and upper confidence curves).

Combined Wind Speed Exceedance Frequencies - Plant West Direction

Vi* Fastest Mile mph (m/s)	Hazard Curve	Windspeed Exceedance Frequencies Per Year			
		Hurricane	Extratropical Cyclone	Tornado	Combined Extratropical Cyclone and Tornado
60 (27)	Lower	5E-4	4E-7	-	4.0E-7
	Median	6E-3	2E-3	-	2.0E-3
	Upper	3E-2	4E-2	-	4.0E-2
80 (36)	Lower	2E-5	-	8E-7	8.0E-7
	Median	3E-4	4E-5	9E-5	1.3E-4
	Upper	1E-3	4E-3	5E-4	4.5E-3
100 (45)	Lower	2E-7	-	4E-7	4.0E-7
	Median	4E-6	1E-6	7E-6	8.0E-6
	Upper	2E-5	5E-4	2E-4	7.0E-4
125 (56)	Lower	-	-	1E-7	1.0E-7
	Median	-	-	3E-6	3.0E-6
	Upper	1E-7	2E-5	7E-5	9.0E-5
150 (67)	Lower	-	-	5E-8	5.0E-8
	Median	-	-	2E-6	2.0E-6
	Upper	-	2E-6	3E-5	3.2E-5
200 (90)	Lower	-	-	-	-
	Median	-	-	3E-7	3.0E-7
	Upper	-	-	2E-6	2.0E-6

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Wind Fragilities

- **Wind fragilities for key structures were calculated by reviewing building design drawings and wind design calculations, and the information obtained from the metal siding manufacturer.**

- **Various modes of failure of these structures were assessed for extreme wind loadings in each of the four principal wind directions.**

- **Analysis considered building shape factors, roofing and siding failures from impinging winds and negative pressures, and building frame and anchor failures.**

- **Funneling and shielding effects of these buildings were also considered.**

Wind Speed Fragility Curves
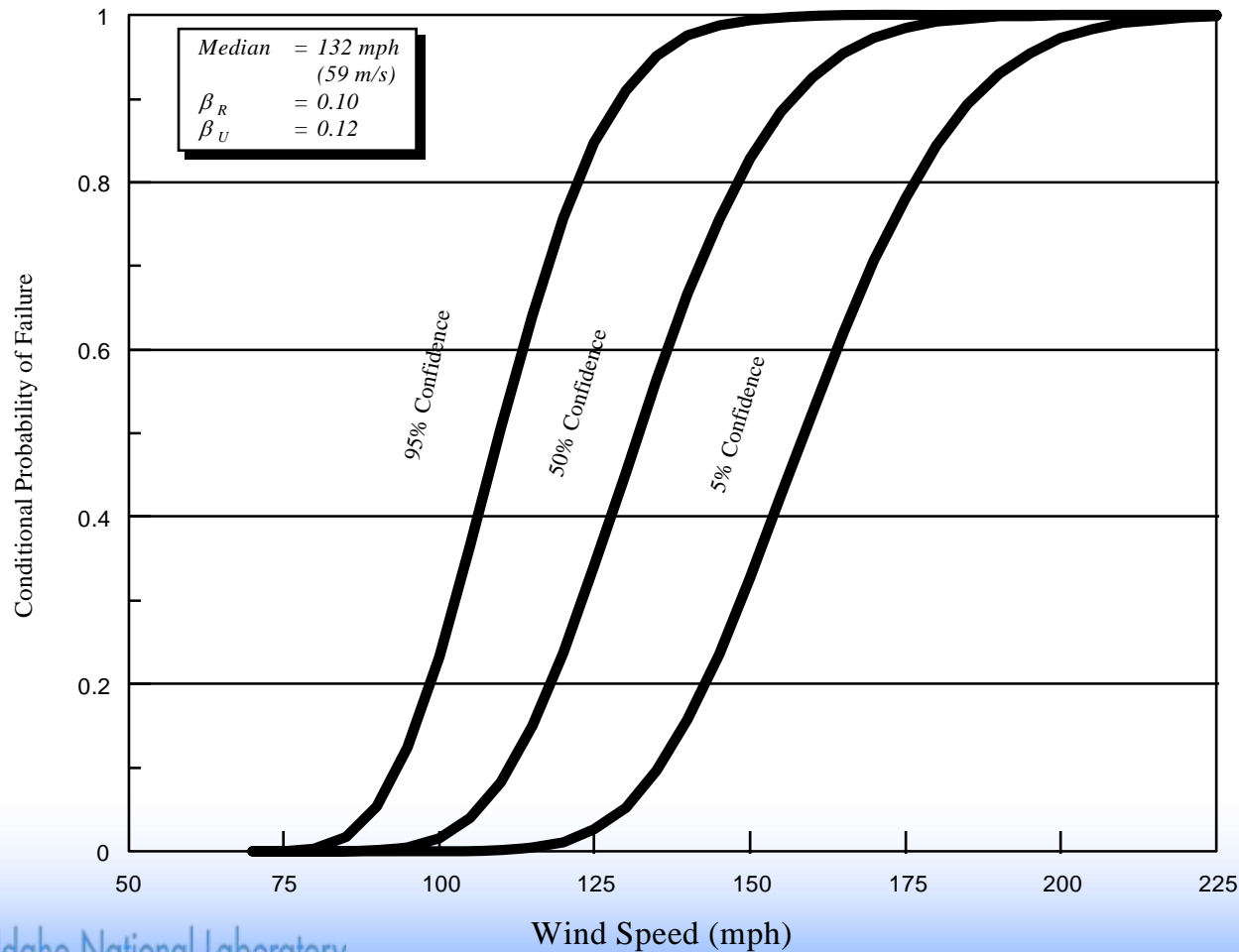
Wind Fragilities of Key Structures For West Direction

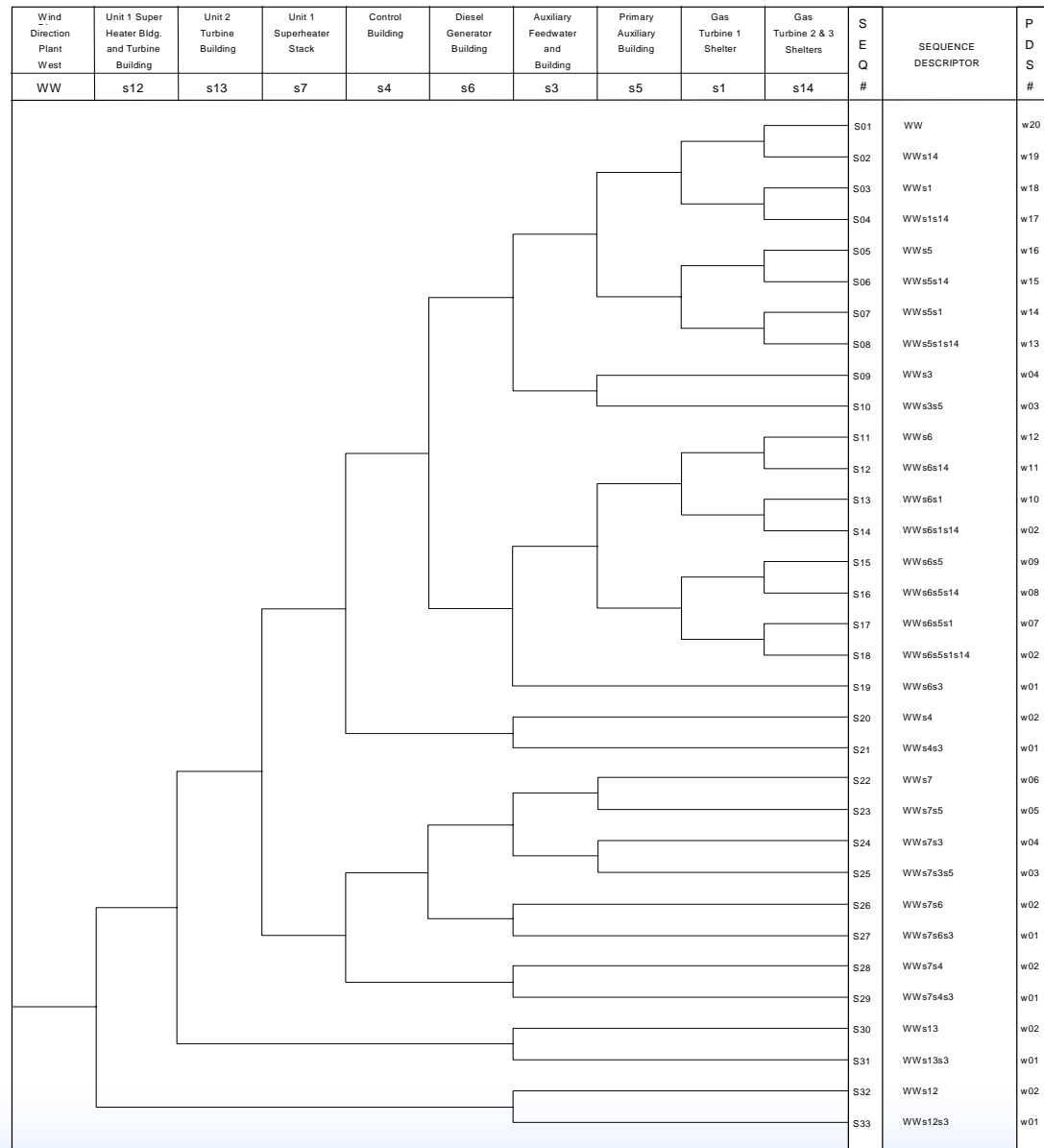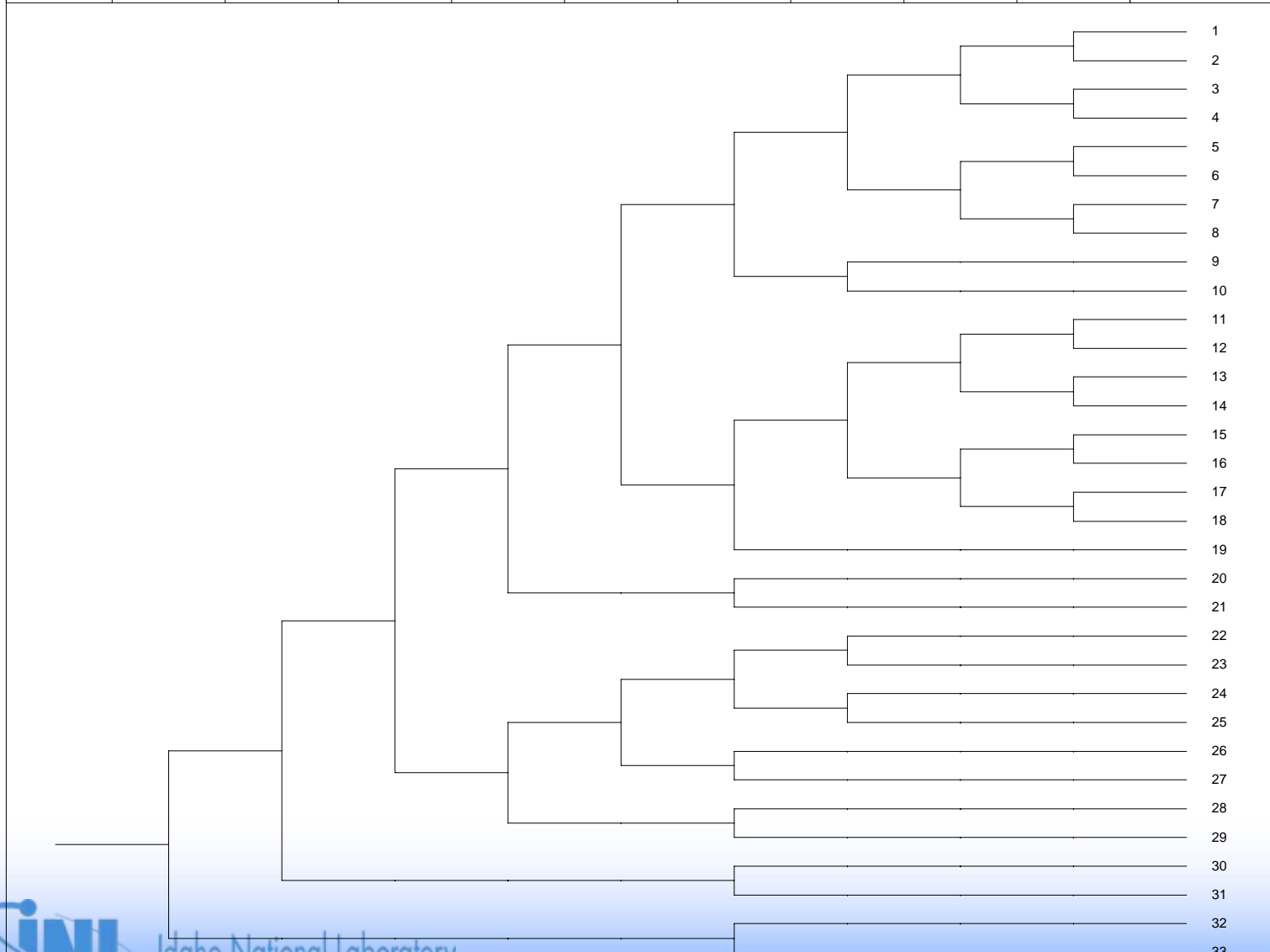| Structure	Median Capacity mph (m/s)	β_R	β_U
S1 - Gas Turbine 1 Shelter	83 (37)	0.15	0.20
S3 - Aux. Feed Pump Bldg.	222 (99)	0.10	0.16
S4 - Control Bldg.	167 (75)	0.10	0.10
S5 - PAB (metal portion)	174 (78)	0.10	0.05
S6 - Diesel Gen. Bldg.	132 (59)	0.10	0.12
S7 - Stack	360 (161)	0.10	0.12
S12 - Unit 1 Turbine Bldg.	200 (89)	0.07	0.07
S13 - Unit 2 Turbine Bldg	170 (75))	0.10	0.07
S14 - Gas Turbine 3 Shelter	83 (37)	0.15	0.20

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Wind Damage Event Tree

- **Wind induced failures were evaluated separately from random equipment failures using an event tree logic approach with the objective of identifying and quantifying a unique set of wind damage states.**

- **Components not susceptible to wind damage, but only susceptible to tornado missile damage (e.g. RWST) were excluded; tornado missile damage probability was separately estimated.**

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Wind Damage Event Tree (continued)

- **Consequential effect of a structural failure on loss of function of equipment located in another structure was considered:**

    - **One building collapsing on to another**

    - **Loss of supporting equipment in the damaged structure rendering the loss of equipment function in another**

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Wind Damage Event Tree for IP2 IPEEE (Dec. 1995)

Wind Direction Plant West	Unit 1 Super Heater Bldg. and Turbine Building	Unit 2 Turbine Building	Unit 1 Superheater Stack	Control Building	Diesel Generator Building	Auxiliary Feedwater and Building	Primary Auxiliary Building	Gas Turbine 1 Shelter	Gas Turbine 2 & 3 Shelters	S E Q #	SEQUENCE DESCRIPTOR	P D S #
WW	s12	s13	s7	s4	s6	s3	s5	s1	s14			
										S01	WW	w20
										S02	WWs14	w19
										S03	WWs1	w18
										S04	WWs1s14	w17
										S05	WWs5	w16
										S06	WWs5s14	w15
										S07	WWs5s1	w14
										S08	WWs5s1s14	w13
										S09	WWs3	w04
										S10	WWs3s5	w03
										S11	WWs6	w12
										S12	WWs6s14	w11
										S13	WWs6s1	w10
										S14	WWs6s1s14	w02
										S15	WWs6s5	w09
										S16	WWs6s5s14	w08
										S17	WWs6s5s1	w07
										S18	WWs6s5s1s14	w02
										S19	WWs6s3	w01
										S20	WWs4	w02
										S21	WWs4s3	w01
										S22	WWs7	w06
										S23	WWs7s5	w05
										S24	WWs7s3	w04
										S25	WWs7s3s5	w03
										S26	WWs7s6	w02
										S27	WWs7s6s3	w01
										S28	WWs7s4	w02
										S29	WWs7s4s3	w01
										S30	WWs13	w02
										S31	WWs13s3	w01
										S32	WWs12	w02
										S33	WWs12s3	w01

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Wind Direction Plant West	Unit 1 Super Heater Bldg and Turbine Bldg	Unit 2 Turbine Building	Unit 1 Superheater Stack	Control Building	Diesel Generator Building	Auxiliary Feedwater and Building	Primary Auxiliary Building	Gas Turbine 1 Shelter	Gas Turbine 2&3 Shelters		#	SEQ-DESC	PDS-#
WW	S12	S13	S7	S4	S6	S3	S5	S1	S14				
											1	WW	W20
											2	WWS14	W19
											3	WWS1	W18
											4	WWS1S14	W17
											5	WWS5	W16
											6	WWS5E14	W15
											7	WWS5E1	W14
											8	WWS5S1S14	W13
											9	WWS3	W04
											10	WWS3E5	W03
											11	WWS6	W12
											12	WWS6S14	W11
											13	WWS6S2	W10
											14	WWS6S1S14	W02
											15	WWS6S5	W09
											16	WWS6S5S14	W08
											17	WWS6S5S1	W07
											18	WWS6S5S1S14	W02
											19	WWS6S3	W01
											20	WWS4	W02
											21	WWS4S3	W01
											22	WWS7	W06
											23	WWS7S5	W05
											24	WWS7S3	W04
											25	WWS7S3S5	W03
											26	WWS7S6	W02
											27	WWS7S6S3	W01
											28	WWS7S4	W02
											29	WWS7S4S3	W01
											30	WWS13	W02
											31	WWS13S3	W01
											32	WWS12	W02
											33	WWS12S13	W01

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Wind Plant Damage States

PDS	Description
W01	EDG power and control failed, GTs failed, AFW failed
W02	EDG power and control failed, GTs failed, AFW success
W03	AFW failed, PAB failed, GTs failed, EDG pwr & ctl success
W04	AFW failed, GTs failed, EDG power and control success
W05	PAB failed, GTs failed, EDG pwr & ctl success, AFW success
W06	GTs failed, PAB success, EDG pwr&ctl success, AFW success
W07	GT1 failed, PAB failed, EDG pwr failed, GT2&3 and AFW success
Etc.	

W01 and W02 lead directly to CD, others need additional failures

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Mean Annual Frequencies of Wind Damage State from Phase 1 Quantification (Tornado and Extratropical Storms)

Plant Damage States	WIND DIRECTION			
	North	East	South	West
w01	9.51E-7	5.74E-7	5.27E-7	8.60E-7
w02	1.08E-5	1.16E-5	8.37E-6	3.21E-5
w10	1.27E-6	1.09E-6	7.69E-7	1.25E-6
w11	1.27E-6	1.09E-6	7.69E-7	1.25E-6
w12	7.30E-7	3.73E-7	3.30E-7	4.33E-7
w17	8.15E-5	3.75E-5	3.34E-5	3.66E-4
w18	1.68E-4	6.14E-5	7.69E-7	4.32E-4
w19	1.68E-4	6.14E-5	5.29E-5	4.32E-4
w20	5.63E-4	1.81E-4	1.60E-4	7.58E-4

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Mean Annual Frequencies of Wind Damage State from Phase 1 Quantification (Hurricanes)

Plant Damage States	WIND DIRECTION			
	North	East	South	West
w01	3.44E-8	7.00E-11	4.10E-13	2.83E-9
w02	1.49E-6	1.96E-9	9.43E-9	2.23E-6
w10	1.02E-6	7.43E-10	8.94E-9	3.10E-7
w11	1.02E-6	7.43E-10	8.93E-9	3.10E-7
w12	1.13E-6	5.99E-10	1.37E-8	1.97E-7
w17	2.28E-4	3.43E-7	4.52E-6	2.77E-4
w18	6.57E-4	1.10E-6	8.94E-9	4.25E-4
w19	6.57E-4	1.10E-6	1.70E-5	4.25E-4
w20	2.55E-3	4.52E-6	7.94E-5	8.22E-4

Refinement of Fragilities and Sequence Modeling

- **Sensitivity studies on Phase 1 results showed that the failures of Unit 2 turbine building and the diesel generator building dominate the contribution to core damage frequency.**

- **The wind capacity of the Unit 2 turbine building was refined by accounting for the likelihood that part of the siding will blow away at lower wind speeds thereby reducing the wind loading on the structure. When this was done, it was found that the contribution of the Unit 2 turbine building failure to the core damage frequency was substantially reduced.**

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Refinement of Fragilities and Sequence Modeling (continued)

- **Diesel generator building roof failure was judged to lead to total failure of DG in 70% of the time.**

- **Consider the distances between the EDG building and Gas Turbines 2 and 3, the probability of a tornado simultaneously striking and damaging the EDG building and the three gas turbines was estimated to be 0.14 (not 1.0 as assumed in Phase 1 quantification).**

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Wind Induced CD Calculated

- **Wind damage states propagated through internal events event trees**

  - **Internal events event trees modified to account for dependencies associated with each wind damage state, e.g.:**

    - **Offsite power assumed to always be lost**

    - **EDG assumed failed for w01, w02, w10, w11, and w12**

    - **EDG mission times increased from 6 hours to 24 hours**

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Final Core Damage Frequency From Wind Damage States

CORE DAMAGE FREQUENCY FROM WIND DAMAGE STATES	
Wind Damage State	**Mean Core Damage Frequency / yr**
Tornadoes IE Name: w01TT IE Name: w02TT IE Name: w10TT IE Name: w11TT IE Name: w12TT IE Name: w17TT IE Name: w18TT IE Name: w19TT IE Name: w20TT	Total: 2.4900E-06 Total: 1.0599E-05 Total: 7.4718E-07 Total: 8.6480E-08 Total: 1.6725E-07 Total: 2.9930E-07 Total: 1.0864E-06 Total: 7.7233E-07 Total: 5.8171E-07 **Total from Tornadoes 1.683E-5**
Hurricanes IE Name: w01HT IE Name: w02HT IE Name: w10HT IE Name: w11HT IE Name: w12HT IE Name: w17HT IE Name: w18HT IE Name: w19HT IE Name: w20HT	Total: 3.3498E-08 Total: 1.7810E-07 Total: 2.0632E-08 Total: 3.6022E-08 Total: 1.1050E-08 total: 4.7359E-07 Total: 3.3732E-07 Total: 4.6580E-07 Total: 8.7974E-07 **Total from Hurricanes 2.4E-06**
Extratropical Cyclone IE Name: w01CT IE Name: w02CT IE Name: w10CT IE Name: w11CT IE Name: w12CT IE Name: w17CT IE Name: w18CT IE Name: w19CT IE Name: w20CT	Total: 1.0800E-08 Total: 7.5592E-06 Total: 4.3293E-07 Total: 7.0093E-07 Total: 1.4437E-07 Total: 9.3848E-07 Total: 3.7638E-07 Total: 2.6967E-07 total: 6.8021E-07 **Total from Extratropical Cyclones 1.1E-05**
Total Contribution to CDF From High Winds	**3.03E-05**

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Summary of Major Contributors

- **Tornadoes and extratropical cyclones are the major contributors to total core damage frequency (28%).**

- **The dominant accident scenarios occur due to wind damage state WO2, which represents loss of normal and emergency power with auxiliary feed available.**

- **Dominant structural failures are: the Emergency Diesel Generator Building and the Gas Turbine shelters, with lower contributions from the IP2 Turbine Building and Control Building.**

- **There exists no single (or a small set of) structure or component especially vulnerable to high winds at IP2. No upgrade of the plant structures was identified which would cost effectively reduce the wind induced risk contribution.**

External Floods

External Floods

- **NRC Regulatory Requirements:**
  - **10 CFR Part 50 Appendix A Criterion 2, 10 CFR Part 100, 10 CFR Part 100 Appendix A**

- **Other Related Documents**
  - **Regulatory Guide 1.27, 1.59, 1.102**
  - **SRP No. 2.4.2, 2.4.3, 2.4.4, 3.4.1**

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Flooding Phenomena

- **Flooding due to intense local precipitation and runoff effects.**

- **Stream or river flooding.**

- **Dam failures.**

- **Coastal and estuarine flooding.**

- **Tsunami flooding.**

- **High water level, wave effects, surges.**

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Flooding Reviewed in FSAR or SER

- **Example of nonconformance to SRP criteria: estimation of the probable maximum precipitation (PMP) at the site was based on earlier or other information sources; e.g., HMR-33 (1956).**

- **New PMP criteria developed by the National Weather Service, presented in Generic Letter No. 89-22.**

  - **Reanalysis of potential flooding impacts based on more recent HMRs; e.g., HMR-51 and HMR-52.**

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Example from the Beaver Valley Unit 1 IPEEE

- Some of the calculations of the PMF due to runoffs were based on the PMP data from HMR-33.

- Maximum flood water level below door sills of safety-related buildings.

- Using data from HMR-51 and HMR-52, flood water would rise above the door sills of three safety-related buildings.

- Internal flood depths calculated were shown to be below the location of safety-related equipment in the buildings.

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Major Elements of External Flooding PRA

- **Flooding hazard analysis**

- **Evaluation of flooding pathways, water level, and damage to SSCs**

- **Plant and system response analysis including quantification**

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Transportation Accidents

Transportation Accidents

- **NRC Regulatory Requirements:**
  - **10 CFR Part 50.34, 10 CFR Part 100, 10 CFR Part 100.10**
- **Other Related Documents**
  - **Regulatory Guide 1.78, 1.91, 1.95**
  - **SRP No. 2.2.1, 2.2.2, 2.2.3, 3.5.1.5, 3.5.1.6**
- **NRC regulatory guides are deterministic in nature; for example:**
  - **Shipment of hazardous material of certain weight, below certain frequency.**
  - **Peak positive incident overpressure below 1 psi from an explosion on transportation route.**
  - **Plant is at least 2 statute miles beyond the nearest edge of a federal airway, holding pattern, or approach pattern.**

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Transportation Accidents (continued)

- **Modes of Transportation**

    - **Air Traffic (commercial, general, military)**

    - **Ground Traffic (on roads and railways)**

    - **Water Traffic (ship and barge)**

    - **Pipeline (gas and oil)**

- **Transportation accidents were evaluated at the time of OL issuance and are documented in the FSAR and SER.**

- **Plants designed against NRC's current criteria should have no significant vulnerability to severe accidents from transportation accident events.**

- **Updated analysis may be required due to changes since the original design.**

- **Older plants may not meet NRC's current criteria.**

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Aircraft Hazards

- **If acceptance criteria for siting with respect to aircraft hazards are no longer true, then detailed review of aircraft hazards must be performed.**

- **Procedure for estimating the frequency of aircraft crashing into the plant P_{FA} is provided in the SRP No. 3.5.1.6:**

  - **For airways: $P_{FA} = C \bullet N \bullet A/w$**

  - **C = inflight crash rate per mile for aircraft using airway.**

  - **N = number of flights per year along airway.**

  - **A = effective area of plant in square miles.**

  - **w = width of airway in miles (plus twice the distance from the airway edge to the site when site is outside the airway).**

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Aircraft Hazards (continued)

- **Source of aviation accident data is the NTSB, and source of information on airport activity and flights is the FAA.**

- **Aircraft hazard analysis must be updated using current data: number of operations/flights and aircraft crash rates.**

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Example from PVNGS

Annual Operations at Airports Near PVNGS

Airport	Closest Distance and Orientation between the Airport and PVNGS (mi)	1978 Estimated No. of Annual Operations	1993 Estimated No. of Annual Operations	Regulatory Guide 1.70 Allowable Number of Operations[a]
Buckeye Municipal Airport	10.8	6,000	100,000	116,000
Pierce Airport	15.5 E	23,586	23,586	240,250
LAFB	32.8 ENE	100,000	300,000	1,075,840
Empire Machinery Airstrip	5.3 NNW	8,600	< 100	14,045
APS Helipad	Onsite	1,000[b]	< 50	na

Notes to Table 5.3-4: (a). 500 d^2 for airports located between 5 and 10 miles; 1000 d^2 for airports located more than 10 miles. d is distance from plant in miles. (b). Estimated annual activity after PVNGS becomes operational.

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Aircraft Impact Evaluation (1978)

Airway	Distance to Nearest Safety Related Structure (mi)	Type of Operation	Number of Flights per year	Crash Rate (mi⁻¹)	Effective Impact Area (mi²)	Lateral Crash Density (mi⁻¹)	Impact Probability
V-16	4.5	Air Carrier	27,740	5.9×10^{-10}	0.05	6×10^{-4}	5×10^{-10}
		Military	5,110	1.2×10^{-8}	0.04	5.6×10^{-3}	1.4×10^{-8}
		General Aviation	107,300	9.8×10^{-8}	0.01	1.2×10^{-4}	1.3×10^{-8}
V-461	3.2	General Aviation	100	9.8×10^{-8}	0.01	1.7×10^{-3}	2×10^{-10}
J-65	4.5	Air Carrier	37,230	5.9×10^{-10}	0.05	6.0×10^{-4}	7×10^{-10}
J-4	2.9	Air Carrier	37,230	5.9×10^{-10}	0.05	7.7×10^{-3}	8.5×10^{-9}
LAFB	12.5	Military	54,800	1.2×10^{-8}	0.04	1.9×10^{-6}	$<1 \times 10^{-10}$
IR218	12.6	Military	180	1.2×10^{-8}	0.04	1.7×10^{-6}	$<1 \times 10^{-10}$
IR272	12.4	Military	500	1.2×10^{-8}	0.04	2.1×10^{-6}	$<1 \times 10^{-10}$
PVNGS[a]	0.13	Helicopter	1,000	4.9×10^{-7} [a]	----------	7.5×10^{-5} [a]	3.7×10^{-8}
TOTAL							7.4×10^{-8}

Notes to Table 5.3-2: (a) PVNGS data refers to helicopter traffic at the PVNGS helipad. For this airway only the crash rate is given in crashes per takeoff or landing operation (rather than per mile), and the value listed in the lateral crash density column represents the conditional probability of striking a safety related structure.

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Aircraft Impact Evaluation (1993)

Airway	Distance to Nearest Safety Related Structure (mi)	Type of Operation	Number of Flights per year	Crash Rate (mi^{-1})	Effective Impact Area (mi^2)	Lateral Crash Density (mi^{-1})	Impact Probability
V-16	4.5	Air Carrier	33,116	1.18×10^{-9}	0.05	6×10^{-4}	1.2×10^{-9}
		Military	0	2.36×10^{-8}	0.04	5.6×10^{-3}	0
		General Aviation	18,148	1.41×10^{-7}	0.01	1.2×10^{-4}	3.1×10^{-9}
V - 461	3.2	General Aviation	100	1.41×10^{-7}	0.01	1.7×10^{-3}	2.4×10^{-10}
J - 65	4.5	Air Carrier	44,480	1.18×10^{-9}	0.05	6.0×10^{-4}	1.6×10^{-9}
J- 4	2.9	Air Carrier	44,480	1.18×10^{-9}	0.05	7.7×10^{-3}	2.0×10^{-8}
LAFB	12.5	Military	42,800	2.36×10^{-8}	0.04	1.9×10^{-6}	8×10^{-11}
IR218	12.6	Military	180	2.36×10^{-8}	0.04	1.7×10^{-6}	$< 1 \times 10^{-10}$
IR272	12.4	Military	0	2.36×10^{-8}	0.04	2.1×10^{-6}	0
PVNGS[a]	0.13	Helicopter	100	4.9×10^{-7} [a]	---------	7.5×10^{-5} [a]	3.7×10^{-9}
TOTAL							3.0×10^{-8}

Notes to Table 5.3-3: (a) PVNGS data refers to helicopter traffic at the PVNGS helipad. For this airway only the crash rate is given in crashes per takeoff or landing operation (rather than per mile), and the value listed in the lateral crash density column represents the conditional probability of striking a safety related structure.

Ground Transportation Accidents (Road, Railroad, and Waterway)

- **Transportation accident resulting in an explosion, missiles generated by an explosion and/or release of hazardous materials.**

- **Hazards associated with transportation accidents (on roads, railroads, and waterways) must be reviewed and reevaluated using current data: types of hazardous materials, number of shipments of hazardous materials, vehicle accident rates, etc.**

- **Method for evaluating transportation risk is provided in Appendix 6.A.1 of NUREG/CR-5042.**

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Elements of Transportation Risk Evaluation due to Releases

- Frequency of transportation accident within 5 miles of plant is dependent on:
  - Vehicle hazard distance, L, which is distance traveled by vehicle within 5 miles of plant.
  - Number of vehicles travel on road/railroad/waterway per year.
  - Vehicle accident rate (per vehicle-mile).
- Proportion of the vehicles carrying hazardous materials involved in accidents that results in releases.
- Probability of diffusion of hazardous materials from accident site towards the plant.
- Probability of control room not isolated from the hazardous materials released from the accident site.

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Calculation of Hazard Distance (L)

Nuclear power plant site

Offset distance, D

Radius R = 5 miles

Vehicle hazard distance, L
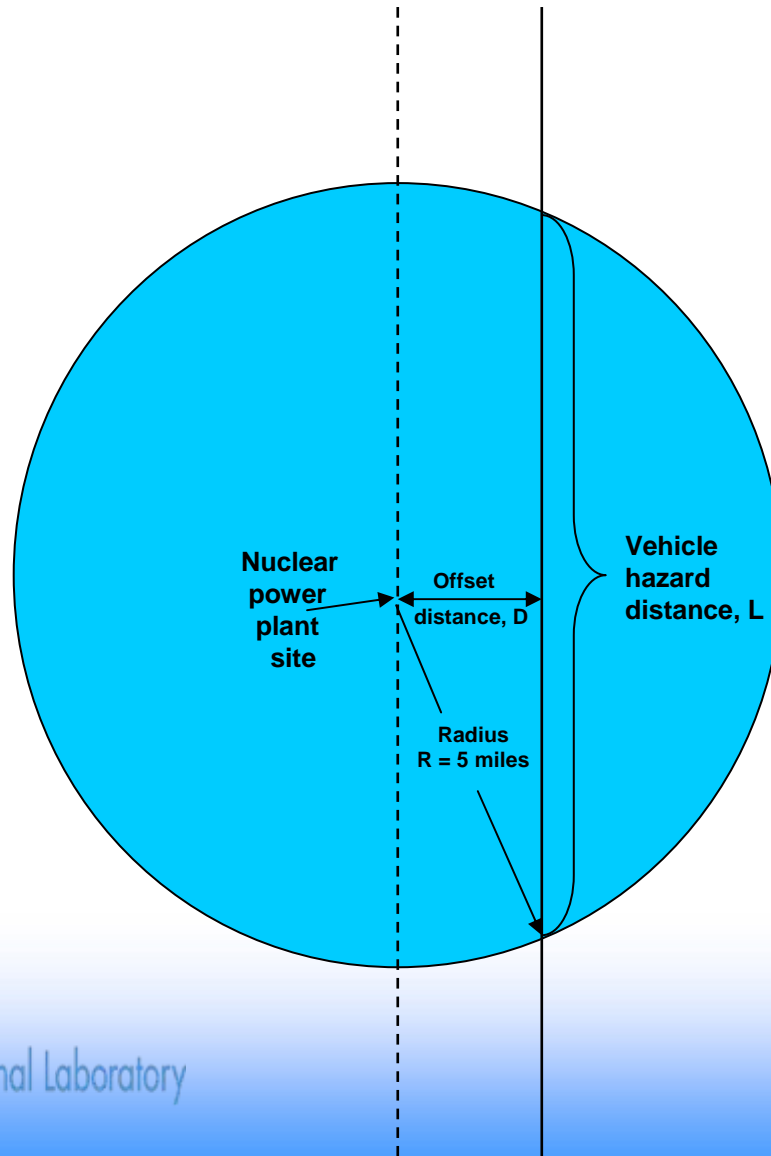
$$R^2 = \left[\frac{L}{2}\right]^2 + D^2$$

$$25 = \frac{L^2}{4} + D^2$$

$$L = (100 - 4D^2)^{1/2}$$

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Other Transportation Accident Modes

- **Vehicle hitting a plant structure or offsite structure.**

  - **Truck traffic movement within the plant boundaries is controlled and infrequent.**

- **Ship or barge colliding with intake structure.**

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Pipeline (Oil and Gas) Accidents

- **Hazards associated with pipeline accidents:**
    - **Release of hazardous materials towards the plant.**
    - **Pressure waves from explosion cause damage to plant.**
    - **Debris or missile generated from explosion cause damage to plant.**
- **Only high pressure pipelines going through or near the plant exclusion area pose a threat to the plant.**

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Nearby Industrial/Military Facilities Accidents

- Examples of accidents are:
  - Chemical plant fires and/or explosions.
  - Munitions plant explosions and/or fire.
- Effect of accidents on power plants similar to that of transportation accident.
  - Explosion overpressure causing damage to the plant.
  - Debris and missiles causing damage to the plant.
  - Hazardous materials release towards plant.
- For plants located near industrial sites, industrial accidents were considered in the licensing of the plant.
- Evaluate the impact of new industries (built since the issuance of OL) in the vicinity of plant.

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Examples of Plants Located near Industrial/Military Sites

- Waterford 3 near oil refineries and chemical plants.

- Vogtle near the DOE Savannah River facility.

- Columbia at the DOE Hanford site.

- San Onofre near the U.S. Marine Corps Camp Pendleton Base.

- Turkey Point 3 & 4 near fossil-fueled Units 1 & 2

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On-Site Storage of Hazardous and Explosive Materials

- Examples of hazardous and explosive materials at the site:
  - Chlorine, hydrazine, etc.
  - Hydrogen tanks, propane tanks, etc.
- Release of hazardous materials affect control room habitability.
- Explosion may cause damage to safety-related structure, equipment, etc.
- Evaluation required for issuance of operating license.
- Changes since the issuance of OL must be evaluated.

Other External Events

- **Lightning**
  - **Primary impact of lightning is loss of offsite power.**
  - **May affect safety-related equipment and cause reactor trip.**
  - **Unlikely to affect onsite power and other safety system.**
  - **Impact may be bounded by loss of offsite power or reactor trip events.**
  - **Need to review site-specific lightning events to confirm impact of lightning.**

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Other External Events (continued)

- **Severe Temperature Transients (Extreme Heat, Extreme Cold)**
  - May impact the capacity of UHS and offsite power supply.
  - May also freeze instrument lines.
  - NUREG-1407 concluded that events need not be addressed in IPEEE.
  - Need to review site specific events and impact.
- **Severe Weather Storm (Ice Storms, Hail Storms, Snow Storms, Dust/Sand Storms)**
  - May cause loss of offsite power.
  - NUREG-1407 concluded events need not be addressed in IPEEE.
  - Need to review site specific events and impact.

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Other External Events (continued)

- **Example of Evaluation of Dust and Sand Storm for PVNGS**

  - **Performed dust concentration evaluation.**

  - **Dust buildup on switchyard insulators reduced by insulator configuration in transmission lines. Little contribution to line outage frequency from dust storm.**

  - **Design of diesel generator and control room ventilation and diesel generator intake and exhaust system adequate in protecting dust and sandstorms.**

  - **The UHS is adequately designed against dust and sandstorm.**

  - **Essential HVAC and control room HVAC systems are adequately designed against dust and sand storm.**

Other External Events (continued)

- **External Fires (Forest Fires, Grass Fires)**
  - **Fires occurring outside the plant site boundary.**
  - **May cause loss of offsite power and forced plant ventilation isolation.**
  - **Unlikely to spread onsite.**
  - **NUREG-1407 concluded that events need not be addressed in IPEEE.**

- **Extraterrestrial Activity (Meteorite Strikes, Satellite Falls)**
  - **Probability of a meteorite strike is insignificant.**
  - **NUREG-1407 concluded that events need not be addressed in IPEEE based on its low initiating event frequency.**

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Other External Events (continued)

- **Volcanic Activity**

    - **Active volcanoes in the continental U.S. are located in the Cascade mountain range.**

    - **Trojan and Columbia could be affected by volcanic activity.**

    - **Potential impacts include forced plant ventilation isolation, debris in the UHS, and ash fall accumulation on roof top.**

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Other External Events (continued)

- **Example of Volcanic Activity Evaluation for Columbia**

  - **Columbia is located 165 km from Mt. Adams and 220 km from Mt. St. Helens.**

  - **Major threat from volcanic eruption is from the ash fall.**

  - **A review of the plant design was conducted after the eruption of Mt. St. Helens in 1980; Columbia was under construction.**

  - **Procedures were written for implementation in the event of volcanic eruption.**

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Columbia Design Basis Ash Fall Parameters

Design Basis Ash Fall Parameters

Parameter [Units]	Mt. St. Helens 1980	FSAR	SER
Maximum Ash fall [in] uncompacted	2.75	5.00	7.4
Maximum Ash fall [in] compacted	1.65	3.00	3.00
Ash fall Duration [hrs.]	20	20	20
Ash fall Rate [in/hr] Average	0.14	0.25	0.35
Ash fall Rate [in/hr] Maximum	0.21	0.35	0.44
Average Grain Size [μm]	75	75	75
Density [lb/ft^3] compacted	96	96	96
Compaction [%]	40	40	60
Air Concentration [μgm/m^3] Average	69,795	124,634	174,488
Air Concentration [μgm/m^3] Maximum	104,693	155,793	219,536

Concluding Observations

Concluding Remarks on Other External Events

- **Newer plant and facilities design meets the 1975 SRP criteria.**

- **Older plant design must be evaluated to determine if it meets the 1975 SRP criteria.**

- **Identify and evaluate significant changes at the site, if any, since OL issuance that affect original design conditions.**

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Insights from HFO IPEEE Review

- Level of analysis varied widely from plant to plant (from simplistic screening methods to PRA/bounding analysis).

- Most of the HFO IPEEE studies used qualitative screening method.

- None of the submittals identified a vulnerability.

- CDF from high winds/tornadoes varies from 6E-5 to 2E-7/yr. CDF from external flooding varies from 7E-6 to 2E-8/yr.

- Many submittals just used the IPE CCDP, given LOSP and loss of service water without modeling the specific significant impacts of high winds or floods. CDF may be underestimated.

- Risk associated with high winds and external floods for those plants located in coastal areas or along rivers is of concern for a few plants.

- Potential failures of upstream dams leading to flooding of the plant site were considered in a few submittals.

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Insights from HFO IPEEE Review (continued)

- Given the large uncertainties in the site specific hazard curves for external floods, screening may have been premature in some cases. A flood level just a few inches (or less) below the failure-incipient level might have a frequency of one or two orders of magnitude greater than the hazard for the failure-incipient level.

- High winds and external floods have motivated improvements at certain plant sites. External floods accounted for about 50% of the plant improvements.

- Some licensees implemented plant modifications/procedural changes (flood protection at entry pathways, door seals, sandbagging, etc.).

- Accidents related to transportation and nearby facilities have been screened out in all of the IPEEE submittals.

- Plant-unique hazards such as lightning (8E-6/yr) and snow/ice loads (7E-6/yr) were reported in one submittal to result in non-negligible risk. Chemical release from a nearby facility (8E-6/yr) was reported in another submittal.

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Key Background Documents for Other External Events

- NUREG-75/087, "Standard Review Plan for the Review of Safety Analysis Report for Nuclear Power Plants," December 1975 (Updated SRP NUREG-0800, July 1981).

- NUREG/CR-2300, "PRA Procedures Guide," January 1983

- NUREG/CR-4839, "Methods for External Event Screening Quantification: Risk Methods Integration and Evaluation Program (RMIEP) Methods Development," March 1992.

- NUREG/CR-5042, "Evaluation of External Hazards to Nuclear Power Plants in the United States," December 1987.

- NUREG/CR-5042, Supplement 2, "Evaluation of External hazards to Nuclear Power Plants in the United States, Other External Events," February 1989.

- NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities," Final Report, June 1991.

- NUREG-1742, "Perspectives Gained from the Individual Plant Examination of External Events (IPEEE) Program," April 2002

- ANSI/ANS-58.21-2007, "External Events PRA Methodology Standard," March 1, 2007.

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Seismic Risk Assessment

P-204

April 2009

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Learning Objectives

- **After studying this section you should be able to:**

  - **Describe fundamental differences between the seismic PRA and seismic margin approaches.**

  - **Define key terms such as hazard curve, fragility curve, and HCLPF.**

  - **Understand how seismic PRA and seismic margin methodology and procedures can be used in risk informed applications.**

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Outline of Seismic Analysis Presentation

- **Seismic Analysis Methods Overview**
  – **Terminology**
- **Seismic Margin Approach**
- **Seismic Hazard Evaluation**
- **Seismic Fragility Evaluation**
- **Plant System and Sequence Analysis**
- **Example Results**

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Seismic Analysis Approach

INITIATOR FREQUENCIES

CORE MELT/ RELEASE FREQUENCIES

HAZARD FREQUENCIES

EVENT TREES

FRAGILITIES

DATA

AFW

TANK

PUMP 1

PUMP 2

PUMP 3

FAULT TREES

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April-2009 Seismic-4
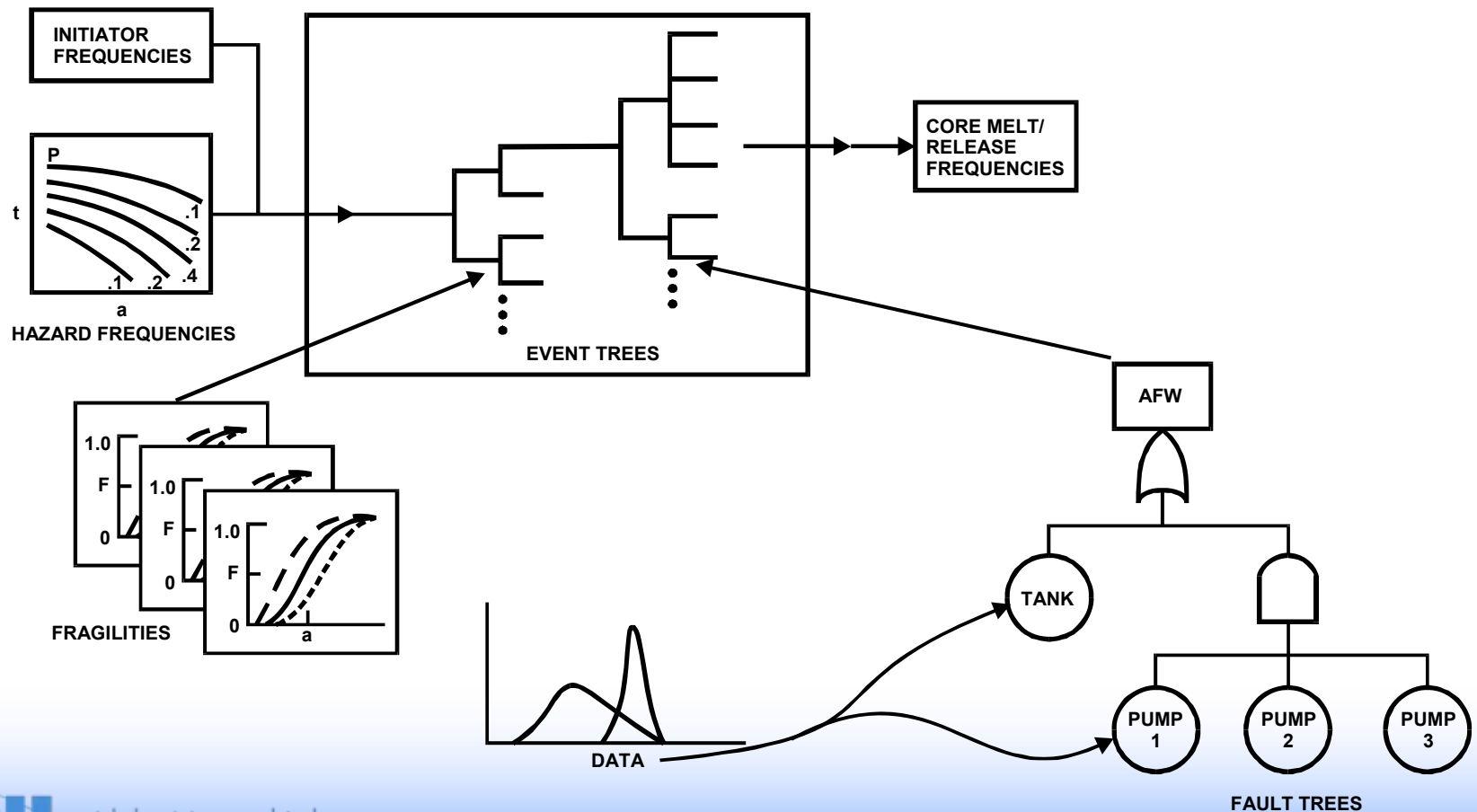
Terminology

- **Hazard Curve**
  - A monotonically decreasing curve indicating the frequency per unit time of an external event of a specified severity or greater occurring at a specific site; most often used for earthquakes and high winds; only one parameter is used to describe the event severity.

- **Hazard Curve Family**
  - A discrete set of hazard curves that represents the uncertainty in the assessed hazard, each curve is assigned a probability of being the true representation of the hazard; the sum of the assigned weights add to 1; usually 10 or fewer curves in the set.

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Seismic Hazard Curves

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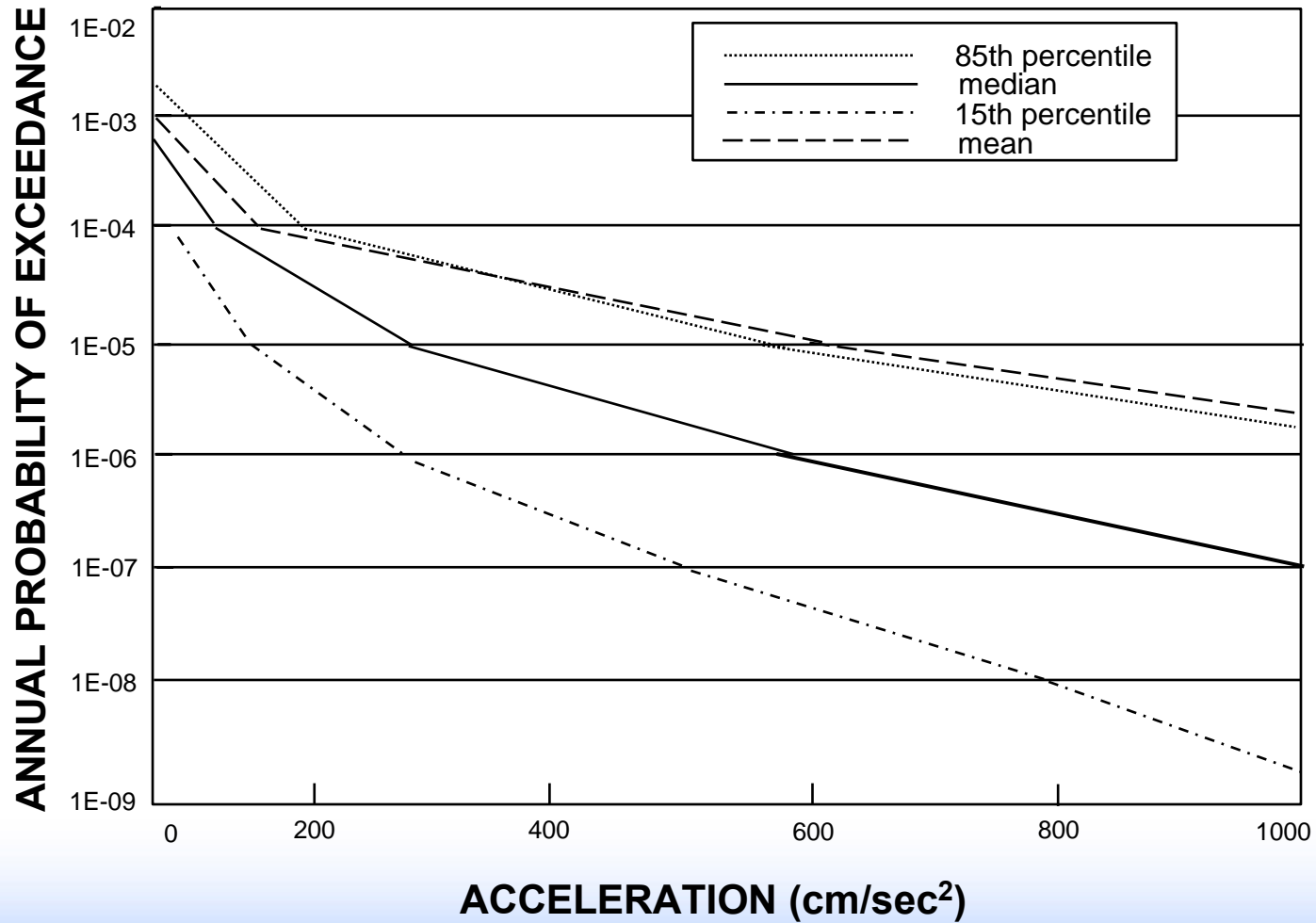
Seismic Hazard Curves
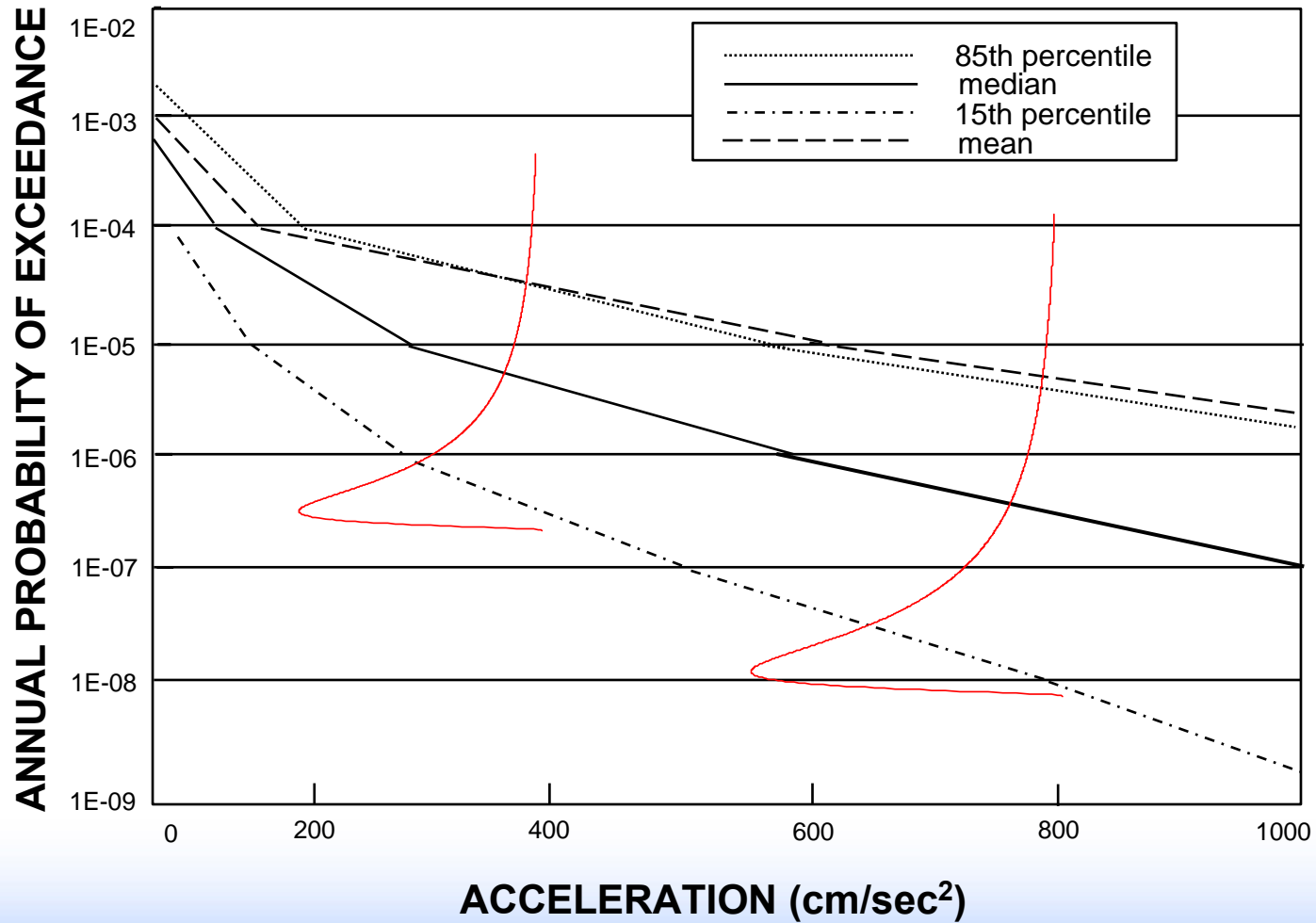
Terminology (Continued)

- **Response Spectrum**

    – **A plot of natural (harmonic) frequency vs. spectral acceleration, velocity or displacement signifying the response of a single degree of freedom system to the earthquake ground motion.**

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Response Spectrum and Model

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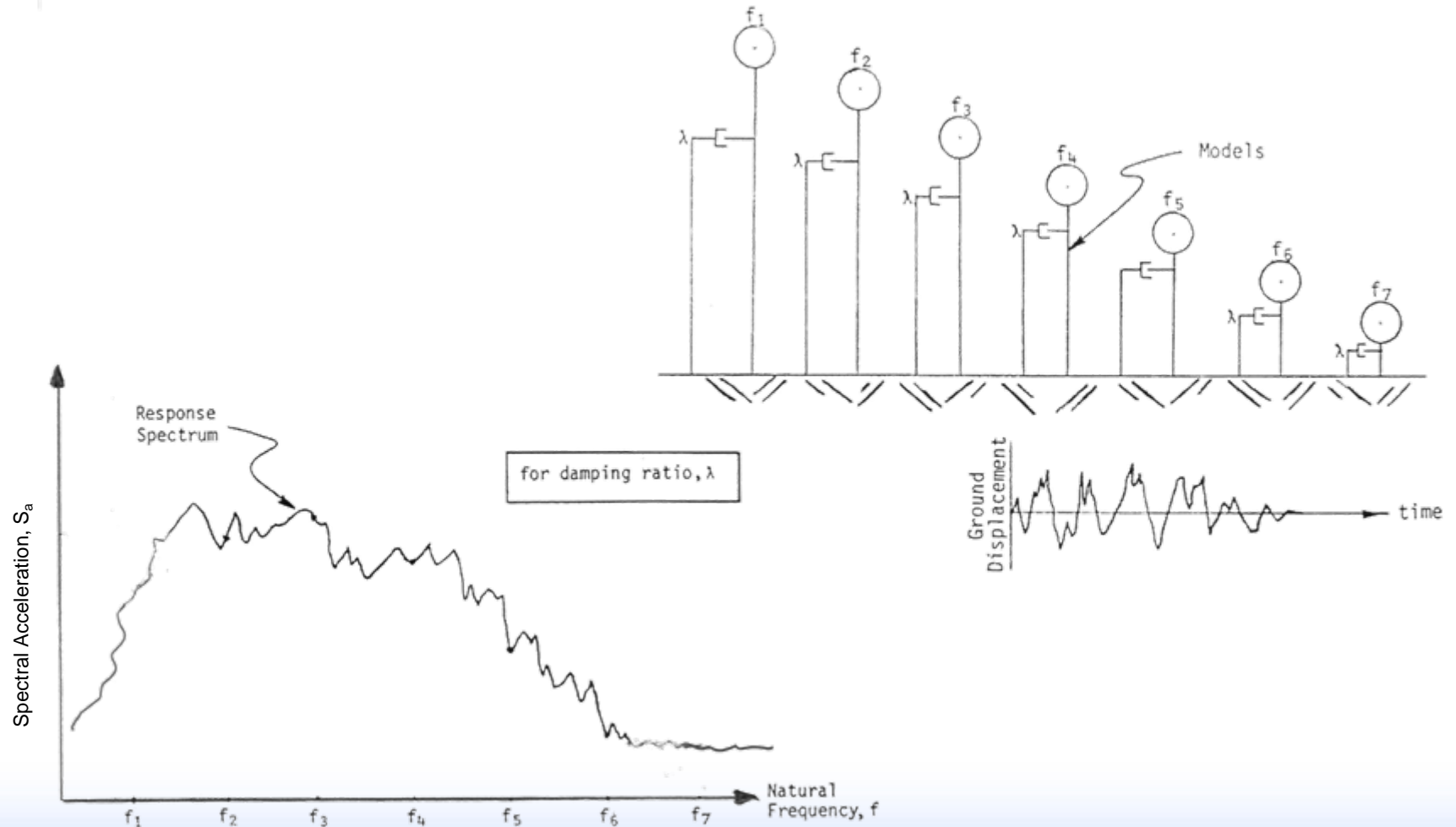
Response Spectra Assessment

- **Considers soil-structure interactions**

- **Reflects the damping and/or amplification effects**

- **Used to produce the Hazard Spectrum**

  - **Not only magnitude of motion, but also harmonic-frequency of motion**

  - **Spectra (harmonic-frequency) can be an important consideration when estimating SSC fragilities**

Both Stress and Strength Info Needed

- **Hazard curves represent stress on the plant**

- **Strength of plant systems, structures and components is also needed**

- **Strength of SSC described as *Fragility***
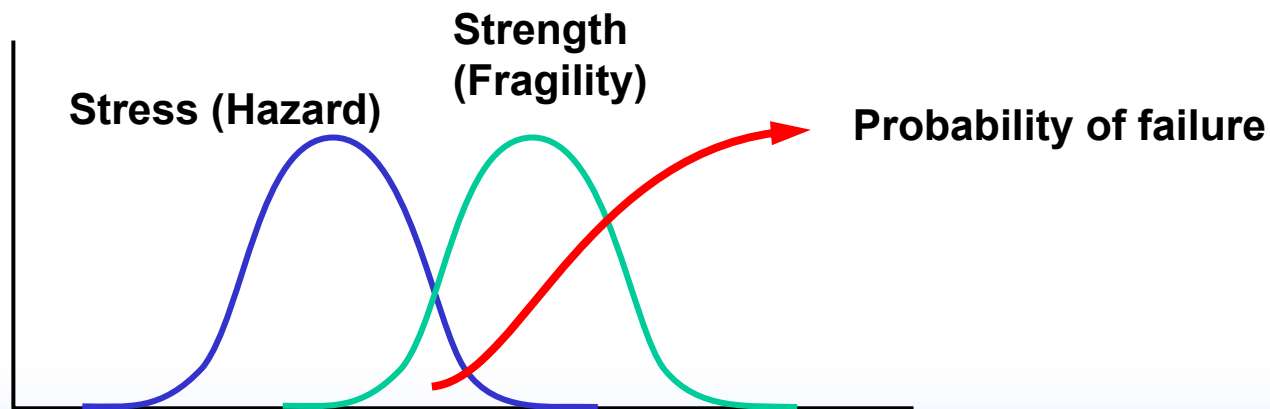
Terminology (Continued)

- **Fragility Curve**

  - **A monotonically increasing curve indicating the chances of failure of a single structure or component as a function of external event severity; most often used for earthquakes and high winds, event severity is represented by the same parameter used to develop the hazard curve.**

- **Fragility Curve Family**

  - **A continuum of fragility curves that describe the uncertainty in the assessed structure or component fragility; the curves are identified by the cumulative probability of being the correct or at least a conservative curve; e.g., 95% curve.**

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Component Fragility Curves

Fragility Parameters

$A_m = 0.87$

$\beta_r = 0.25$

$\beta_u = 0.35$

Conditional Frequency of Failure

Peak Ground Acceleration (g)

0.324

0.05

Median
95% confidence
5% confidence
mean

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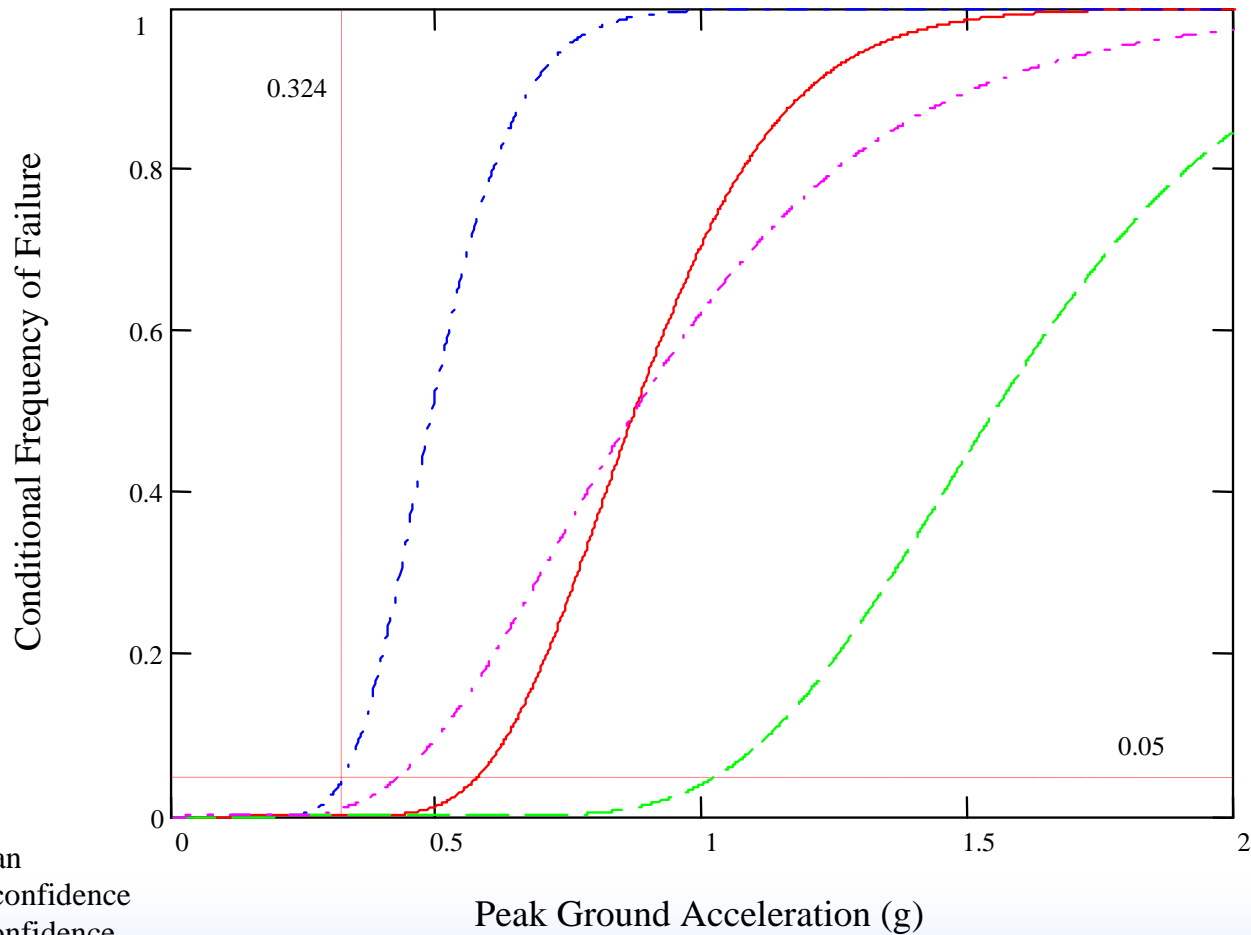
Failure Probability Calculation

- *Median* fragility function (curve) evaluated at a specific g-level to estimate the conditional probability of failure given an earthquake of a specific magnitude

$$\text{Prob}(\text{fail} \mid a) = \Phi(\ln(a / A_m) / \beta_r)$$

- **Where:**

    Φ (phi) is the cumulative standard normal or Gaussian distribution

    a = earthquake magnitude

    A_m = median fragility

    β_r = uncertainty parameter (randomness)

Standard Normal (Gaussian) Distribution

- **Useful function in many statistics and probability problems**

- **Normal distribution with mean = 0,**

    and standard deviation = 1.0

- **Tables for standard normal distribution available in almost every probability and statistics text**

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Terminology (Continued)

- **HCLPF (High Confidence of Low Probability of Failure)**

  - **The earthquake acceleration level at which the analysts' have a 95% confidence that the chance of a specific structure or component failure is less than 5%, when the structure or component is subjected to an earthquake of that magnitude.**

  - **HCLPF value should be higher than design basis earthquake if all structures and components were designed to regulatory accepted criteria.**

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HCLPF Calculation

- **Earthquake magnitude at which the SSC is predicted with 95% confidence to have a 5% failure probability**

$$\text{HCLPF} = (A_m)\exp[-1.645(\beta_r + \beta_u)]$$

- **Where:**

    A_m = median fragility

    β_r = randomness parameter

    β_u = uncertainty parameter

Component Fragility Curves

$A_m = 0.87$

$\beta_r = 0.25$

$\beta_u = 0.35$

Median
95% confidence
5% confidence
mean

Conditional Frequency of Failure

Peak Ground Acceleration (g)

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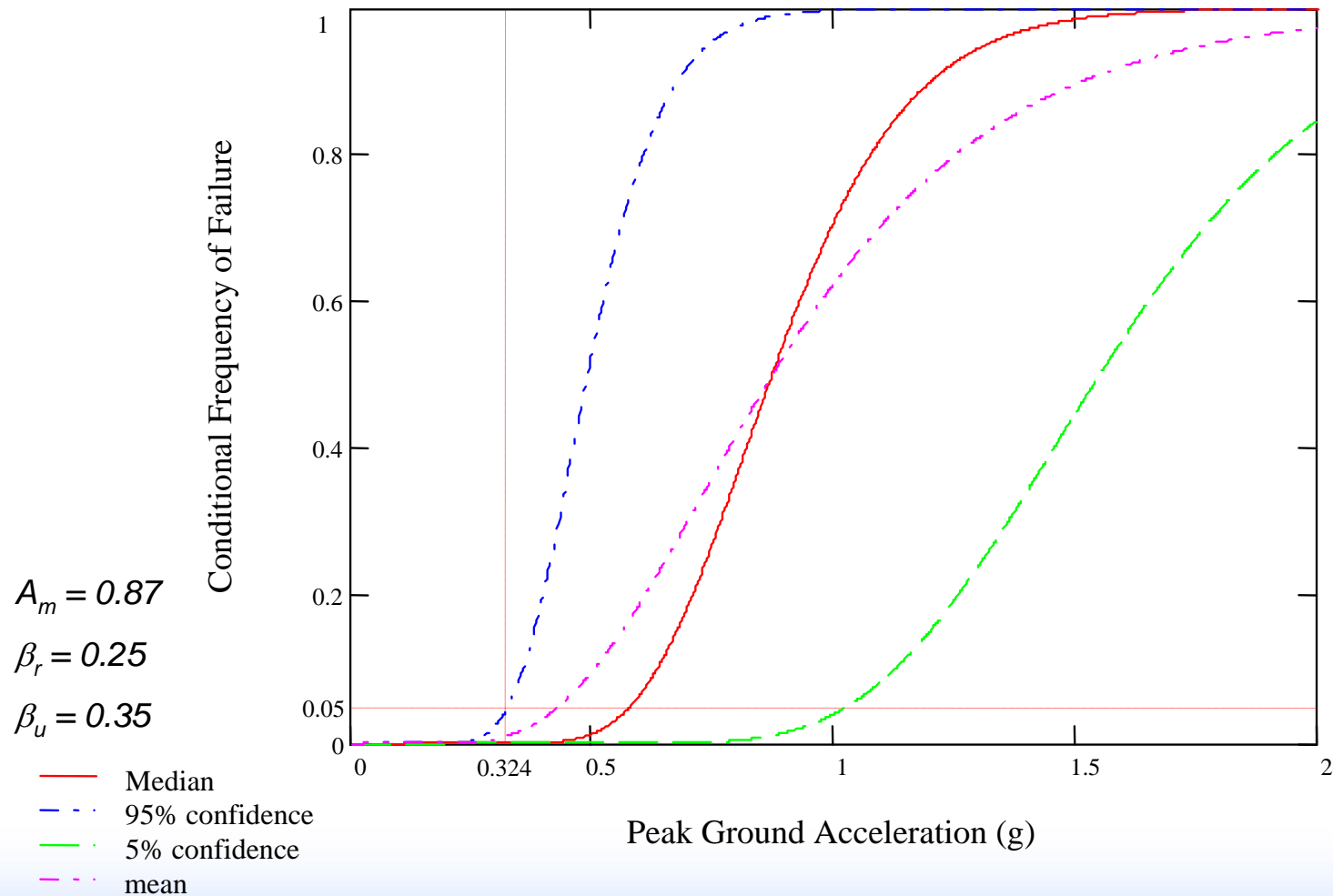
Seismic Analysis Methods Overview

- **Two approaches:**

  - **Seismic Margins Analysis (SMA)**

    - **Postulate an earthquake of a specific magnitude, then judge effect on the plant**

  - **Seismic PRA**

    - **Assess earthquake hazard (freq vs magnitude), evaluate strength of plant SSCs (fragility), then combine the two to calculate risk**

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Seismic Evaluations Options for IPEEE

- **Seismic Margins Analysis**

  - **U.S. Nuclear Regulatory Commission/LLNL Approach (failure scenarios)**

  - **Electric Power Research Institute Approach (safe shutdown path)**

- **Probabilistic Risk Assessment (Level 1 plus containment performance analysis, LERF)**

- **Any other systematic examination if reviewed and found acceptable by the staff.**

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Seismic Margins Method

- **Different scope levels depending on plant location**
  - **i.e., based on estimated seismic hazard**
  - **NUREG-1407 provides a list including specification of the review level earthquake (RLE)**
    - **0.3g or 0.5g**
- **Reduced Scope (uses Safe Shutdown Earthquake as RLE)**
- **0.3g Focused Scope**
- **0.3g Full Scope**
- **0.5g (required for Western U.S. plants)**
- **Diablo Canyon and San Onofre – Seismic PRA Required**

NRC Seismic Margins Method

- **Vital plant functions examined (e.g., reactor sub-criticality and early core cooling)**

- **Screening using generic seismic capacities**

  – **Walkdown to ensure no weaknesses exist**

- **Event/fault trees used to delineate accident sequences**

  – **Typically assume transients and small LOCA**

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EPRI Seismic Margins Method

- **Guidance provided in EPRI NP-6041, supplemented by NUREG-1407**

- **Success paths identified**

  - **For safe shutdown, given seismically induced transient or small LOCA**

  - **Preferred path and alternate path**

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Steps in a Seismic PRA

- **Seismic hazard analysis – frequency vs. magnitude of ground motion**

- **Response spectra analysis – translates ground motion into local (ground, floor, or component) motion**

- **Plant walkdown – identifies typical and atypical SSCs**

- **Fragility analysis – assesses the "strength" of SSCs**

- **Systems analysis – generates seismic core damage cutsets**

- **Containment response and offsite consequences**

Major Differences between Seismic Margins and SPRA Options

- Seismic hazard and uncertainties (probabilistic) versus review level earthquake (deterministic).

- Accident scenarios versus limited success/failure paths.

- Risk quantification versus pass/fail.

- Quantitative ranking of component significance versus no indication of relative importance to risk.

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Seismic Margin Approach

Learning Objectives

- **After studying this section, you should be able to:**
    - **Understand seismic screening techniques**
    - **Understand how a plant HCLPF is computed in a seismic margin assessment**
    - **Describe key differences between the EPRI and NRC seismic margin methods**

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Two SMA Methodologies

- **NRC and EPRI methods**

- **Utilize Review Level Earthquake (RLE)**

  - **0.3g and 0.5g Peak Ground Acceleration (PGA)**

  - **RLE for each plant assigned by NRC in IPEEE guidance (NUREG-1407)**

- **Three scope levels**

  - **Reduced scope, focused scope, and full scope**

  - **Scope level for each plant assigned by NRC in IPEEE guidance (NUREG-1407)**

Two SMA Methods Differ

- **NRC Methodology (NUREG/CR-4334, NUREG/CR-4482)**
  - **Fault Tree Approach**
  - **Abbreviated PRA**
- **EPRI Methodology (EPRI NP-6041, EPRI NP-6041SL)**
  - **Success Path Approach**
  - **Screening method**
- **Bases for Methodologies**
  - **System analysis experience from prior PRAs.**
  - **Fragility information from earthquake experience data, test data, and prior PRAs.**

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EPRI SMA Method

- **Success path approach**
  - **Two success paths must be identified**
    - **One must address small LOCA**
  - **Each success path capable of bringing plant to a safe state (hot or cold shutdown) after an EQ larger than DBE, and maintain it for for 72 hours**
  - **Set of SSCs for each success path become focus of analysis**
    - **Seismic capacity of each SSC in each path is evaluated**
    - **Seismic capacity of success path is that of the weakest SSC**
    - **Seismic capacity of plant is that of the strongest success path**

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IPEEE Specified Four Enhancements to EPRI SMA

- **Initial screening needs to start with more than just two success paths**
  - **Exclusion of some paths might mask HCLPF and defense-in-depth insights**
- **Non-seismic failure and human actions need to be included in success path analyses**
- **Containment performance needs to be address**
  - **Both containment structure and containment systems**
- **Relay chatter needs to be considered**

EPRI SMA Comprises 7 Steps

1. Selection of the seismic margin earthquake

2. Selection of assessment team

3. Preparatory work prior to walkdown

4. Systems and elements selection ("success path") walkdown

5. Seismic capability walkdown

6. Seismic margin assessment

7. Documentation

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Selection of SME

- **NRC has specified the SME (also referred to as RLE) for every plant in the U.S.**

  - **Tables 3.1 (CEUS) and 3.2 (WUS) of NUREG-1407**

  - **Reduced Scope plants could use the SSE ground response spectra from FSAR (i.e., design basis)**

  - **Other plants use the response spectra from NUREG/CR-0098 anchored at 0.3g or 0.5g PGA**

CEUS – Central and Eastern U.S. (east of Rocky Mountains)

WUS – Western U.S. (west of Rocky Mountains)

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Selection of Success Paths

- **Identify reasonably complete set of paths considering transients and small LOCAs.**

- **Select preferred path for transient and SBLOCA case.**

- **Alternate path (should involve operational sequences, systems, piping runs, and components different from preferred path).**

- **Nonseismic failures and human actions in selected paths show low failure probabilities (< .01).**

- **Include containment performance in SMA (isolation, cooling, bypass).**

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Example Success Path Logic Diagram - PWR, Intact Reactor Coolant System Pressure Boundary

SEISMIC MARGIN EARTHQUAKE

SUPPORT SYSTEMS:
AC POWER
DC POWER
SERVICE WATER
COMPONENT
COOLING WATER

CONTROL ROD INSERTION

EMERGENCY BORATION

AUXILIARY FEEDWATER

STEAM GENERATOR PORVs

LONG-TERM FEEDWATER SOURCE

RHR PUMPS (LOOP RECIRCULATION)

RHR HEAT EXCHANGERS

PRESSURIZER PORVs

CHARGING PUMPS

SAFETY INJECTION PUMPS

RHR PUMPS (SUMP RECIRCULATION)

RHR HEAT EXCHANGERS

LONG-TERM SAFE SHUTDOWN

*Support system requirements must be determined for specific plant.

**Emergency boration not recommended for success path.

BWR/6 Example Success Path

Safety Function	Required System
All	Support Systems
Reactivity Control	Reactor Protection System
Pressure Control	Main Steam Isolation
	Safety Relief Valves
Core Cooling and Inventory Control	High Pressure Injection
Decay Heat Removal	Residual Heat Removal

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Two Walkdowns Are Performed

Initial Screening Walkdown

- **Objective is to identify those success paths that are easiest to demonstrate a high seismic margin**

  - **Seismically weak SSCs are screened-out**

  - **Identify any evaluation problems**

    - **Missing anchorages or spatial interactions**

Seismic Capacity Walkdown

- **Identify those SSCs in the success path whose seismic margin (w.r.t. the RLE) is in question**

  - **Seismically strong SSCs are screened-out**

  - **Develop list of SSCs that require more detailed assessment**

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Success Path HCLPF

- **HCLPF – g-level at which there is a High Confidence (95%) of Low Probability (5%) of Failure**

- **Lowest HCLPF in a success path is the HCLPF for that success path**

- **Highest HCLPF of the two success paths is the plant HCLPF**

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EPRI SMA Summary

- **EPRI Seismic Margins**
  - **Similar to SQUG program for A-46**
  - **Deterministic (but includes some probabilistic aspects)**
  - **Safe shutdown paths and associated equipment**
  - **Use of EQ experience and judgement for screening**
  - **Walkdowns (vital part of approach) and screening**
  - **Selected calculations**
  - **HCLPF defined for weak link in shutdown paths**

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NRC SMA Summary

- **NRC Seismic Margins**
  - **Similar to PRA without use of seismic hazard**
  - **Plant systems models and seismic fragility curves**
  - **Use of PRA and EQ experience for screening**
  - **Walkdown and screening**
  - **Dominant accident sequences and plant level HCLPF derived from fragility curves and systems models**
  - **Core damage frequency not computed (since no IE/hazard frequency)**

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Seismic Hazard Analysis

Seismic Analysis Approach

INITIATOR FREQUENCIES

P

t

.1
.2
.4

.1 .2 .4

a

HAZARD FREQUENCIES

CORE MELT/ RELEASE FREQUENCIES

EVENT TREES

1.0

F

0

1.0

F

0

1.0

F

0

a

FRAGILITIES

DATA

AFW

TANK

PUMP 1

PUMP 2

PUMP 3

FAULT TREES
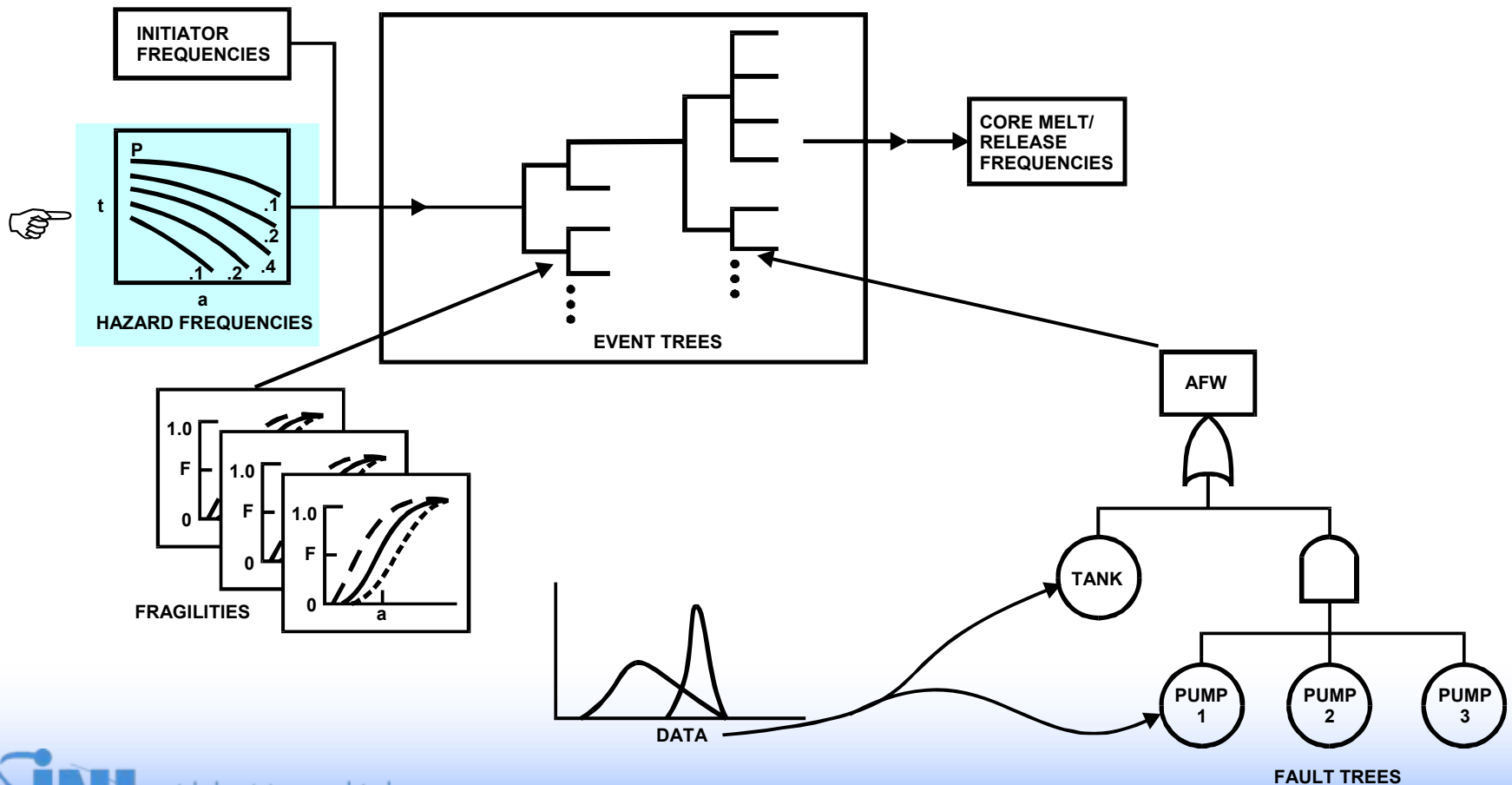
Estimating Seismic Hazard

- **Historical Methods**

  - **Recreate ground motions at the site over historical times.**

  - **Translate recreated observations into annual probabilities of exceedance.**

  - **Extrapolate probabilities to high amplitude of ground shaking.**

  - **Shortcomings — large uncertainties not fully quantified.**

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Seismic Hazard Analysis (cont.)

- **Deductive Methods**
  - **Earthquake occurrence model deduced from:**
    - **Tectonic Theories**
    - **Geologic Evidence**
    - **Analogies with Other Regions**
    - **Historical Seismicity**
  - **Typical method for PRA**

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Seismic Hazard for IPEEE

- **Extensive Research by USNRC and EPRI Hazard Quantified for Eastern U.S. sites**
  - **NUREG/CR-5250 (1989)**
  - **NUREG-1488   (1994)**
  - **EPRI NP-6395-D (1989)**
- **Western Sites Required (by IPEEE) Independent Site Specific Studies for PRA**
  - **San Onofre**
  - **Diablo Canyon**
  - **Columbia* (WNP-2)**
  - **Palo Verde***
  - **Rancho Seco* (shutdown)**
  - **Trojan* (shutdown)**

* 0.5g Seismic Margins Evaluations or Optional PRA

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Site-Specific Seismic Hazard Estimation

- Develop the probability/year of exceeding a given estimator of ground motion, such as *peak ground acceleration* or *pseudo-relative velocity*.[a]

    a. A computational approximation to the response spectrum

- At a given probability/year, develop the equally-weighted spectral shape known as a *uniform hazard spectrum*.

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Four Basic Steps to the Methodology

- **Step 1 - Identify seismic sources (or source zones)**

- **Step 2 - For each source, develop a model describing the expected frequency as a function of magnitude.**

- **Step 3 - For each source, develop a model describing the expected value of a ground-motion parameter as a function of (M, D) = (magnitude, distance from the source).**

- **Step 4 - Integrate among the sources to form a seismic hazard curve.**

Seismic Hazard Development
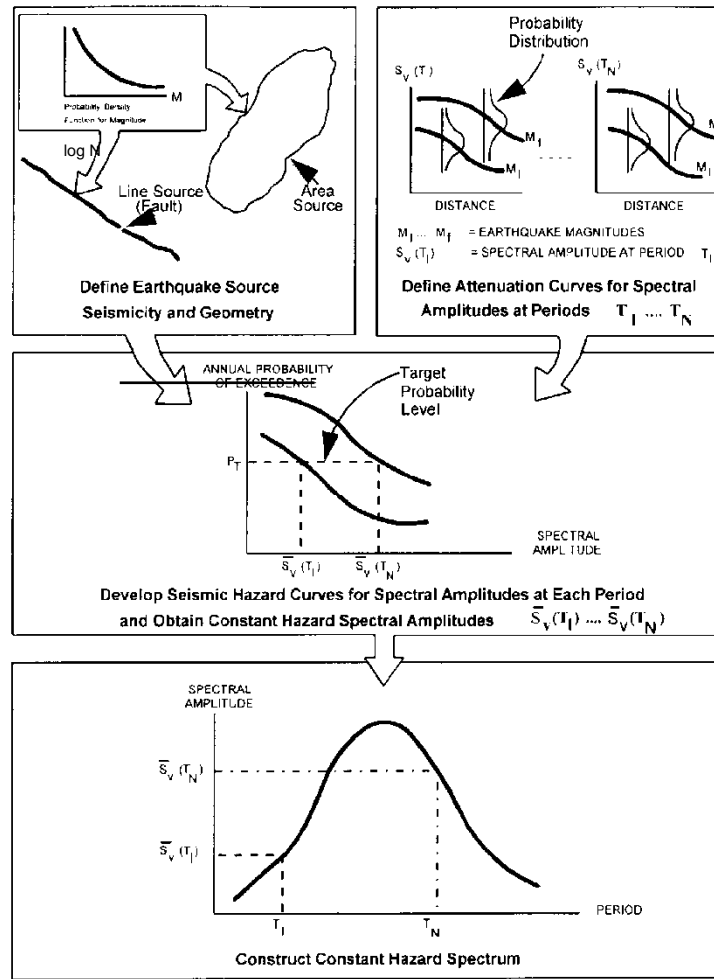
10000-year Return Period
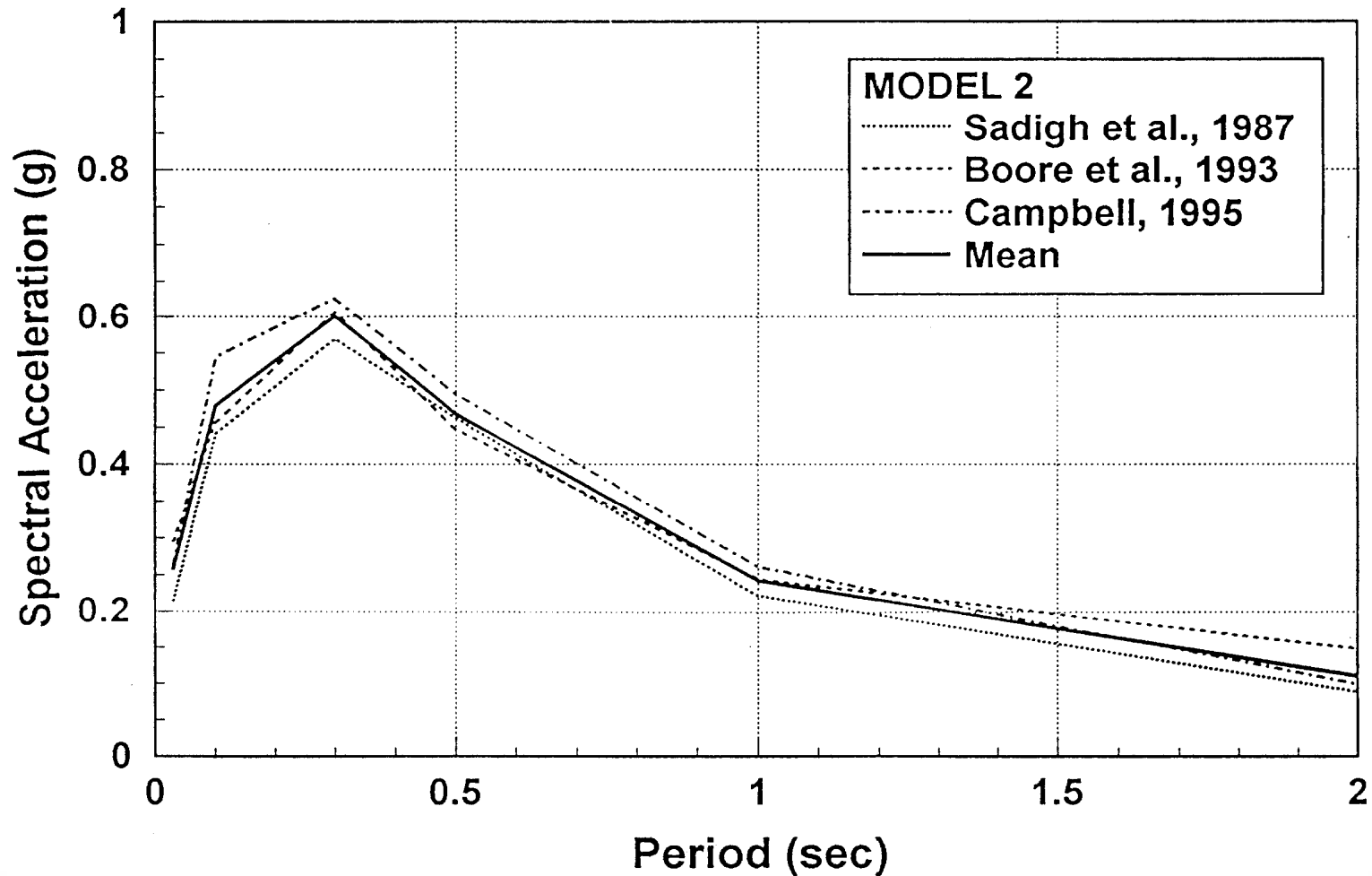
Calculated 5%-damped acceleration response spectra with a return period of 10,000-years for Earthquake Source Zonation Module 2.

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Ground Motion Estimation

- **Attenuation generally based on propagation through rock.**

- **Hazard is specified at free surface.**

- **For non-rock sites, a site-specific soil amplification analysis, considering uncertainties, must be conducted.**

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Ground Motion Estimation (Continued)

- **Ground Motion Parameters**
  - **Peak Ground Acceleration (PGA)**
  - **Spectral Acceleration (SA)**
- **Pros and cons of using spectral acceleration:**
  - **Better indicator of damaging potential of earthquake.**
  - **Reduced uncertainty in spectral amplitudes.**
  - **Ground motion estimates have to be done at several frequencies.**
  - **Additional effort.**
- **Need to be consistent with what is used in fragility evaluation.**

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Seismic Hazard Curve Determination

- **Integrates the contribution of all possible earthquakes and calculates the probabilities that selected ground motion parameter will be exceeded.**

$$P\big[A > a\big]year = \Sigma v \int P\big[A > a\,|\,m,d\big]f(m)f(d)dddm$$

- **Seismic hazard curves — annual frequency of exceedance versus specified ground motion parameter.**

Uncertainty in Seismic Hazard

- **Two types of uncertainty:**
  - **Aleatory (Randomness)**
    - **Inherent, irreducible, random nature of events.**
    - **Yields annual probabilities of exceedance for various ground motion levels.**
  - **Epistemic (Uncertainty)**
    - **Modeling uncertainty, reducible.**
    - **Seismic hazard curves with different confidence levels.**
- **Sources of uncertainty**
  - **Randomness and uncertainty in all three elements of seismic hazard.**
    - **Time, location and size**

Seismic Hazard Described 3 Ways

- **Peak Ground Acceleration (PGA)**

- **Spectral Acceleration (SA)**

- **Uniform Hazard Spectra (UHS)**

Annual Probability of Exceeding a Peak Ground Acceleration
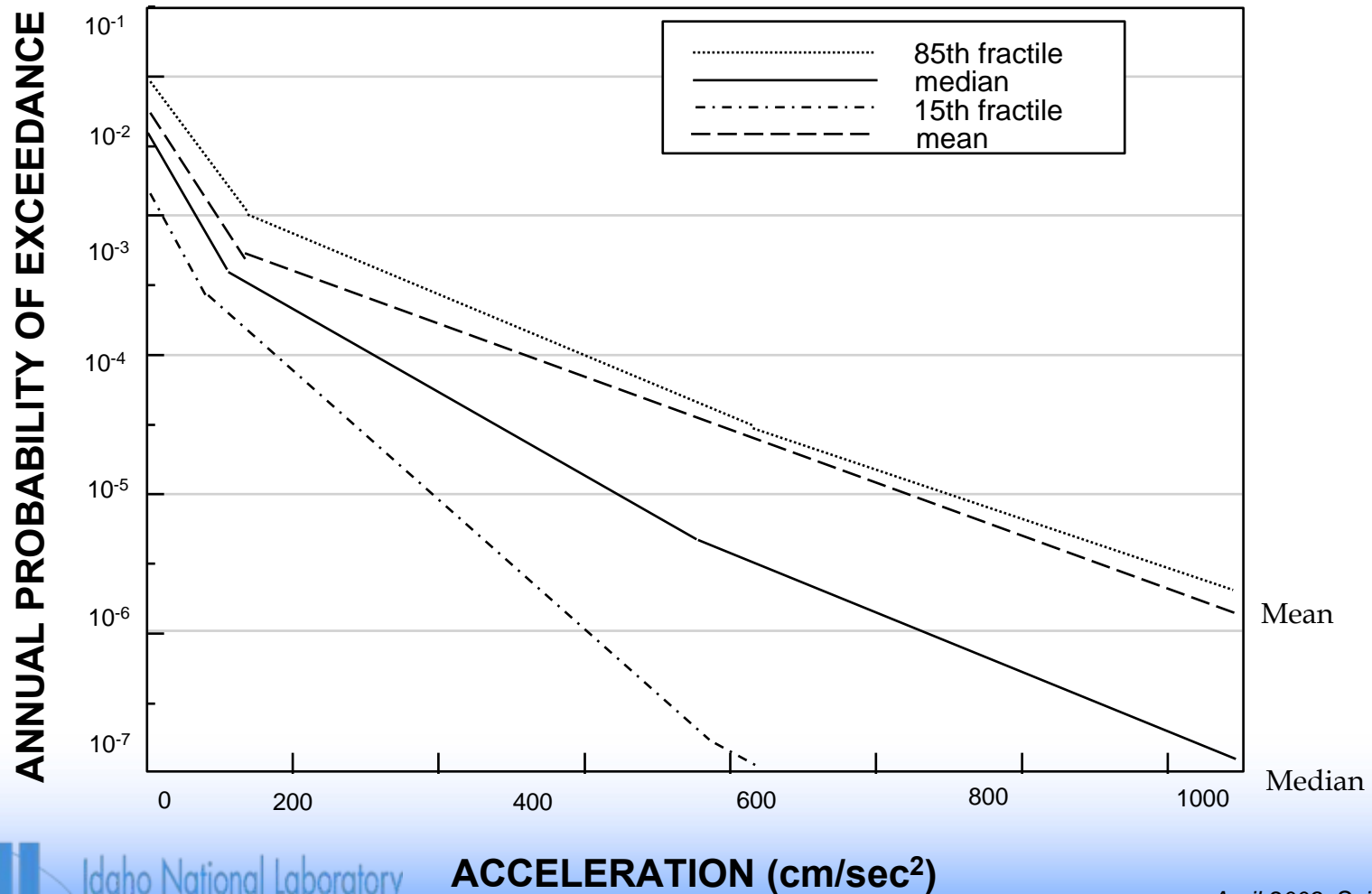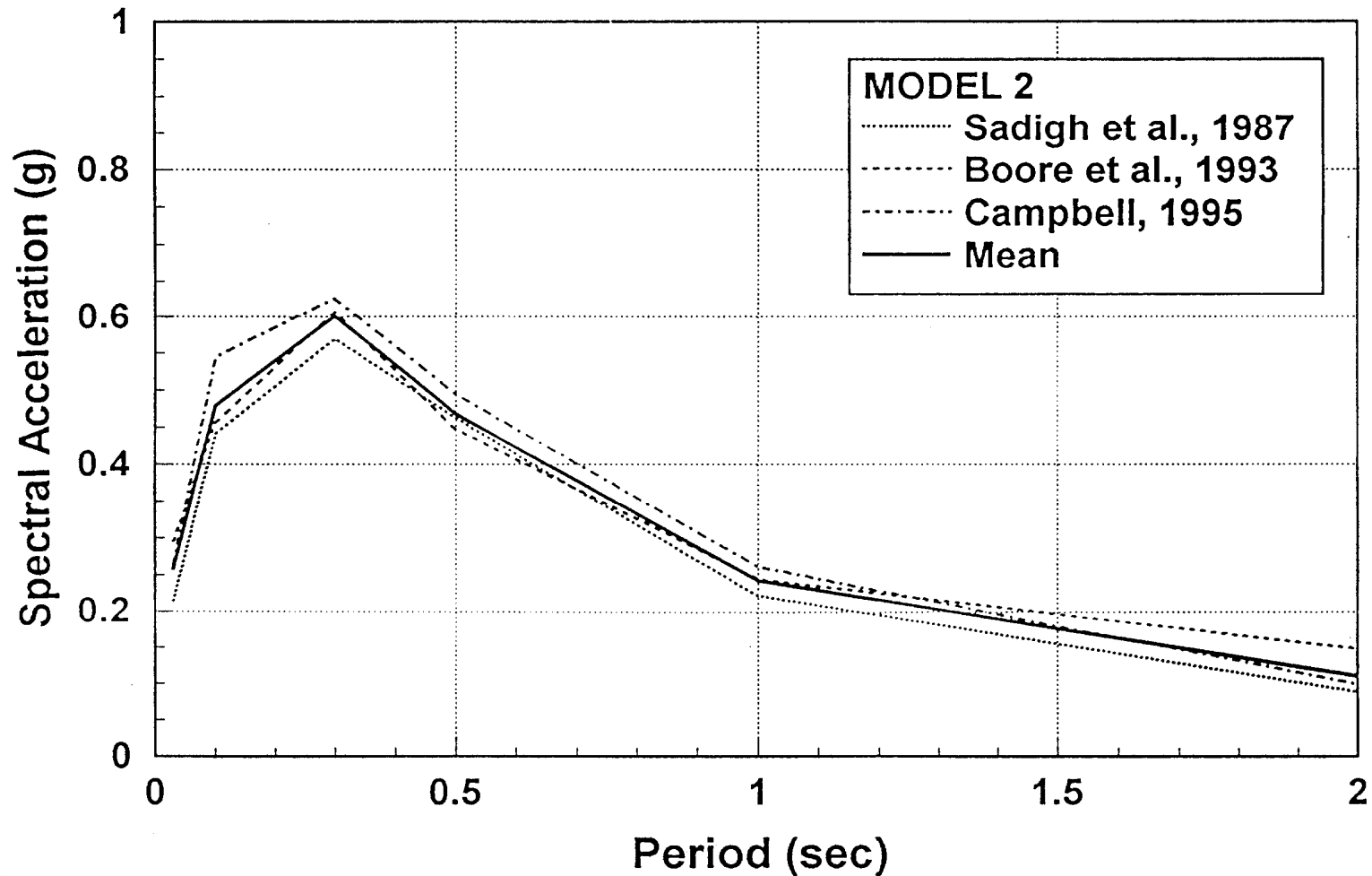
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ACCELERATION (cm/sec²)

April-2009 Seismic-55

10000-year Return Period

Calculated 5%-damped acceleration response spectra with a return period of 10,000-years for Earthquake Source Zonation Module 2.

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NUREG/CR-0098 Median Spectra Anchored to 0.3g and 0.5g PGA Soil Site vs. EPRI Screening Levels
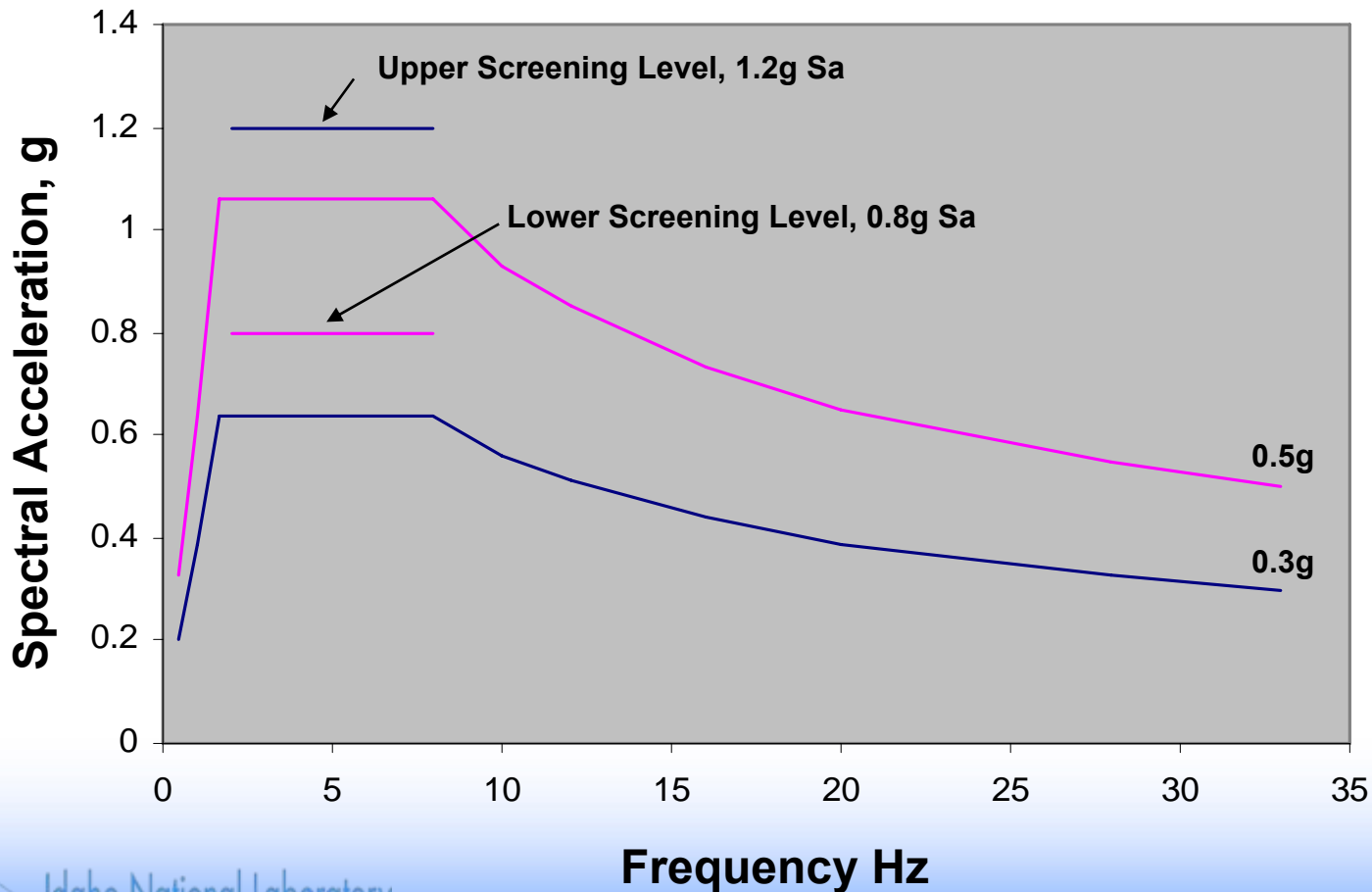
Uniform Hazard Spectra For the 10^{-4} Annual Probability of Exceedance

Spectra shown for three percentiles: 15th, 50th, and 85th.
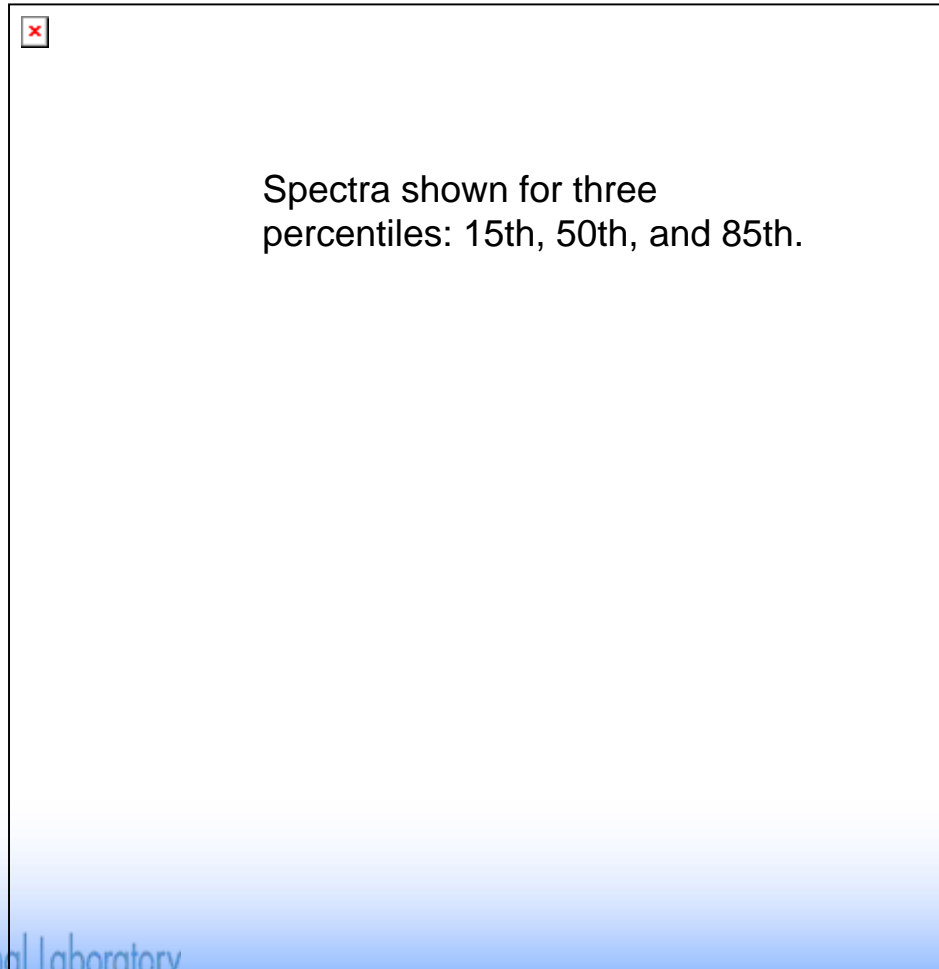
Seismic Fragility Evaluation

Seismic Analysis Approach
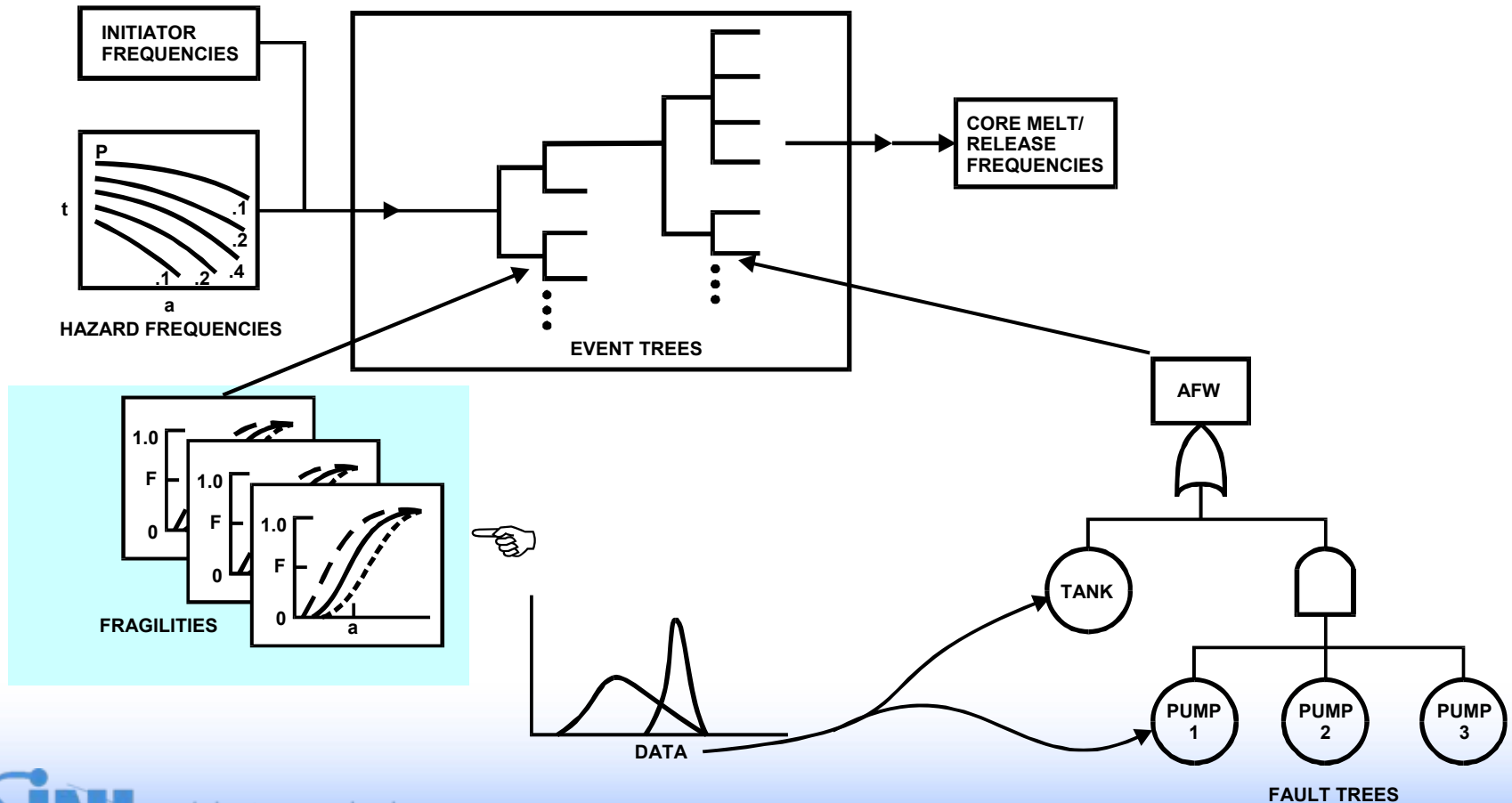
Learning Objectives

- **After studying this section, you should be able to understand the concept of fragility curves sufficiently to:**

    (1) Understand the difference between a single fragility curve and a family of fragility curves.

    (2) Understand the lognormal representation of fragility curves

    (3) Understand the definition and significance of a HCLPF.

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Component Fragilities

- **Conditional probability of failure for a given response value, or earthquake level**
- **Requires clear definition of failure and its consequences**
  - **Several failure modes may be of interest.**
  - **Generally component loses functional capability before pressure boundary fails**
- **Screening used to limit required number of fragility curves**

Stress (Hazard)

Strength (Fragility)

Probability of failure

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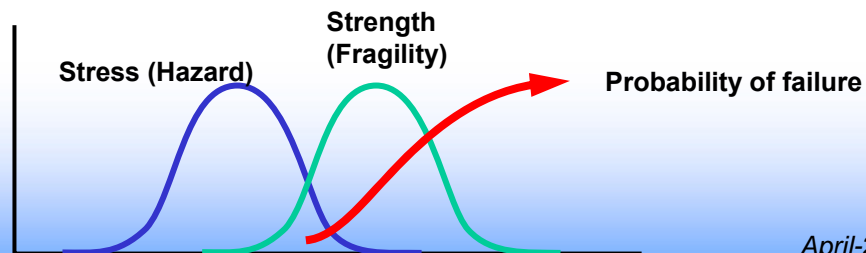
Fragility Evaluation for Equipment

Variables Considered:

- – **Strength**
- – **Inelastic energy absorption**
- – **Spectral shape**
- – **Damping**
- – **Modeling**
- – **Method of analysis/testing**
- – **Combination of modes**
- – **Combination of earthquake components**
- – **Structural response**
- – **Soil-structure interaction**
- – **Ground Motion Incoherence**

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Fragility Model

- **Log normal model (all properties of variables have log normal distribution).**

- **Entire fragility curve (A) and its uncertainty expressed by three parameters (A_M, β_R, β_U).**

$$A = A_m \, \varepsilon_R \, \varepsilon_U$$

where

$$A \;=\; \text{ground acceleration corresponding to any given frequency of failure.}$$

$$A_m \;=\; \text{median ground acceleration capacity.}$$

$$\varepsilon_R, \varepsilon_U \;=\; \text{random variables with unit median and logarithmic standard deviation } \beta_R, \beta_U.$$

$\varepsilon_R, \varepsilon_U$ represent inherent randomness about the median and uncertainty in the median value, respectively.

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Fragility Derivation

- **Usually, fragility is extrapolated from design information by quantifying factors of conservatism and variability**

  $$A_m = F_C \, F_{RE} \, F_{RS} \, A_{SSE}$$

  Where:

  F_C = capacity factor (strength and ductility)

  F_{RE} = response factor for equipment

  F_{RS} = response factor for structure

  A_{SSE} = safe shutdown earthquake acceleration

Equations Used to Generate Fragility Curves

- **Median curve: Prob(fail|g) = $\Phi[\ln(g/A_m)/\beta_r]$**

- **Mean curve: Prob(fail|g) = $\Phi[\ln(g/A_m)/\beta_c]$**

    $\beta_c = \mathrm{sqrt}(\beta_r^2 + \beta_u^2)$

- **95% confidence curve:**

$$\mathrm{Prob}(\mathrm{fail}\mid g) = \Phi\left(\frac{\ln\left[\left(\dfrac{g}{A_m} \right) e^{\left(\beta u [\Phi^{-1}(0.95)] \right)} \right]}{\beta_r} \right)$$

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Cumulative probabilities for POSITIVE z-values									
z	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0.5	0.504	0.508	0.512	0.516	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.591	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.648	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.67	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.695	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.719	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.758	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.791	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.834	0.8365	0.8389
1	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.877	0.879	0.881	0.883
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.898	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.937	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.975	0.9756	0.9761	0.9767
2	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.983	0.9834	0.9838	0.9842	0.9846	0.985	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.989
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916

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HCLPF Calculation

- **Earthquake magnitude at which the SSC is predicted with 95% confidence to have a 5% failure probability**
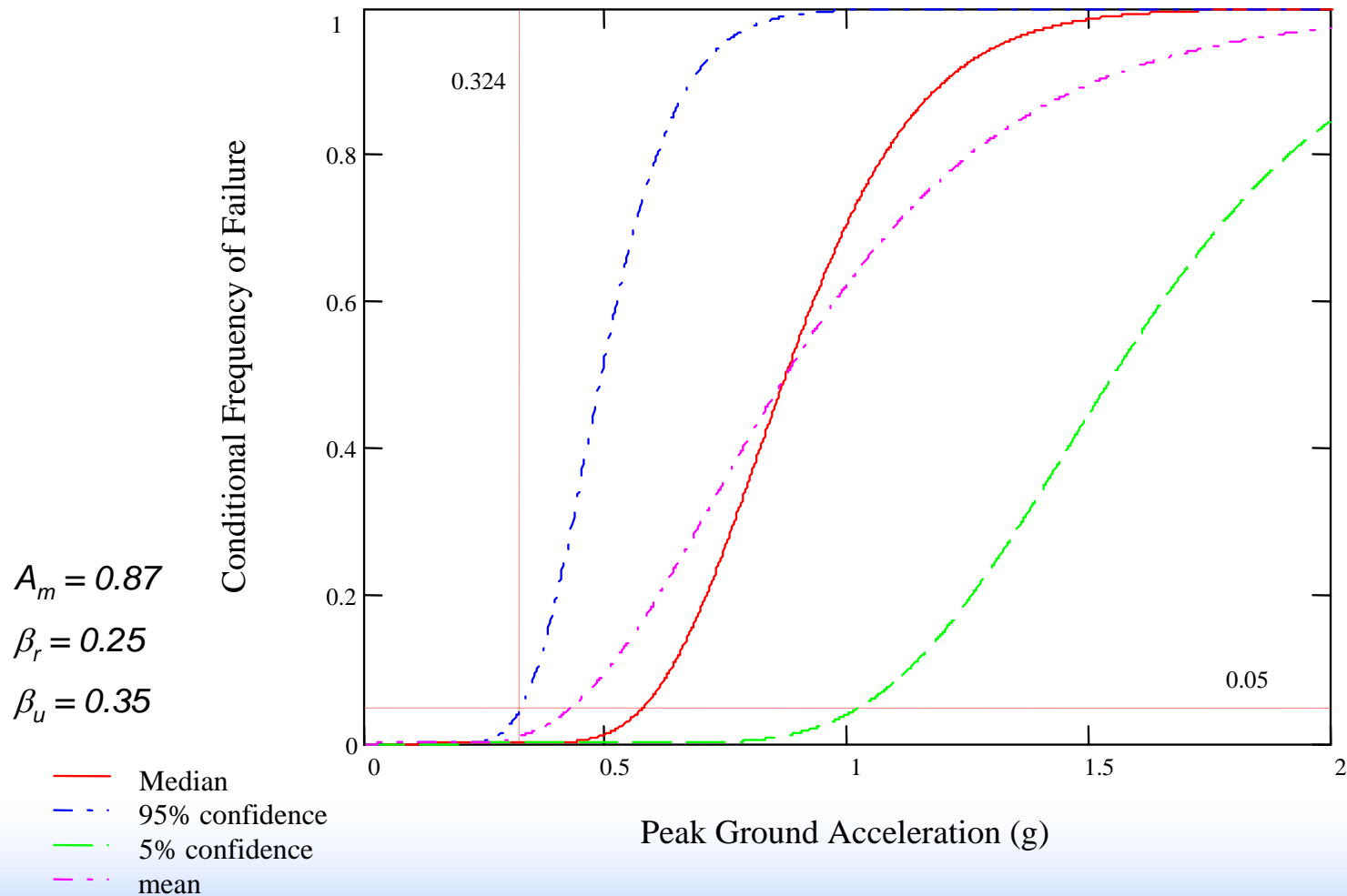
$$\mathrm{HCLPF} = (A_m)\exp[-1.645(\beta_r + \beta_u)]$$

- **Where:**

  A_m =median fragility

  β_r = randomness parameter

  β_u = uncertainty parameter

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Component Fragility Curves

$A_m = 0.87$

$\beta_r = 0.25$

$\beta_u = 0.35$

0.324

0.05

Conditional Frequency of Failure

Peak Ground Acceleration (g)

— Median
-·- 95% confidence
-·- 5% confidence
-·- mean

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Fragility Methodology and Examples

- **Methodology**
  - **EPRI TR-103959 (1994)**
  - **EPRI TR-1002988 (2003)**
- **Examples**
  - **NUREG/CR-5270 (1989)**
    - **Conclusion was that there was more variation in analysts than in methods.**
  - **NUREG-1150 (1990)**
  - **Published SPRA's**

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Fragilities Calculated Different Ways

- **Response factor can be included in fragility or hazard (spectral acceleration)**

  - **Need to be consistent between the two, don't over-count or under-count response factor**

- **Fragility stated for a SSC might not be for the SSC itself**

  - **Building collapse or anchor failure might dominate**

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Components Typically Needing Capacity Evaluations

- **Bad actor relays.**

- **Unreinforced or lightly reinforced masonry and block walls that may impact safety components.**

- **Flat bottom tanks; e.g., RWST, CST.**

- **Electrical cabinets.**

- **Large heat exchangers and vessels.**

- **Long column pumps.**

- **Most fragilities developed from existing plant documentation.**

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Workshop on Fragility Calculations

A_m = 0.87

β_r = 0.25

β_u = 0.35

Calculate stated failure probability given:

95% confidence for 0.5g

Mean for 1.0g

Median for 1.5g

Calculate HCLPF

Significance of Contact Chatter

- **Could impact the availability of components required to maintain the reactor in a safe shutdown condition.**

- **Could cause operator confusion because of unusual equipment operating configurations as well as inconsistent and erroneous indications on control panels.**

- **Could induce interfacing systems LOCA.**

- **Could lock out containment isolation.**

Relay Chatter Evaluation Steps

- **Includes electric relays, contactors, and switches prone to chatter.**

- **Determine types of relays installed in risk-related circuits.**

- **Screen out relays known to be not sensitive to high frequency vibration (High Ruggedness Relays).**

- **Review circuit diagrams to screen out relays whose chatter would not matter.**

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Relay Chatter Evaluation Steps (Continued)

- **Screen out relays if recovery actions can be reasonably assured. (HRA must consider stress from earthquake.)**

- **Develop fragilities for remaining relays, add to seismic event tree, and determine if they affect important scenarios.**

- **For relays in dominant scenarios, consider replacement or testing to show insensitivity to high frequencies.**

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Relay Chatter Evaluation (Continued)

- **Fragility calculations for relays should address these issues:**

  - **Relay Capacity (GERS, Test Data, BNL Data)**

  - **Single-Axis Sensitivity**

  - **Cabinet Amplification**

  - **Clipping of Demand**

  - **State of Operation (open, closed, energized, unenergized)**

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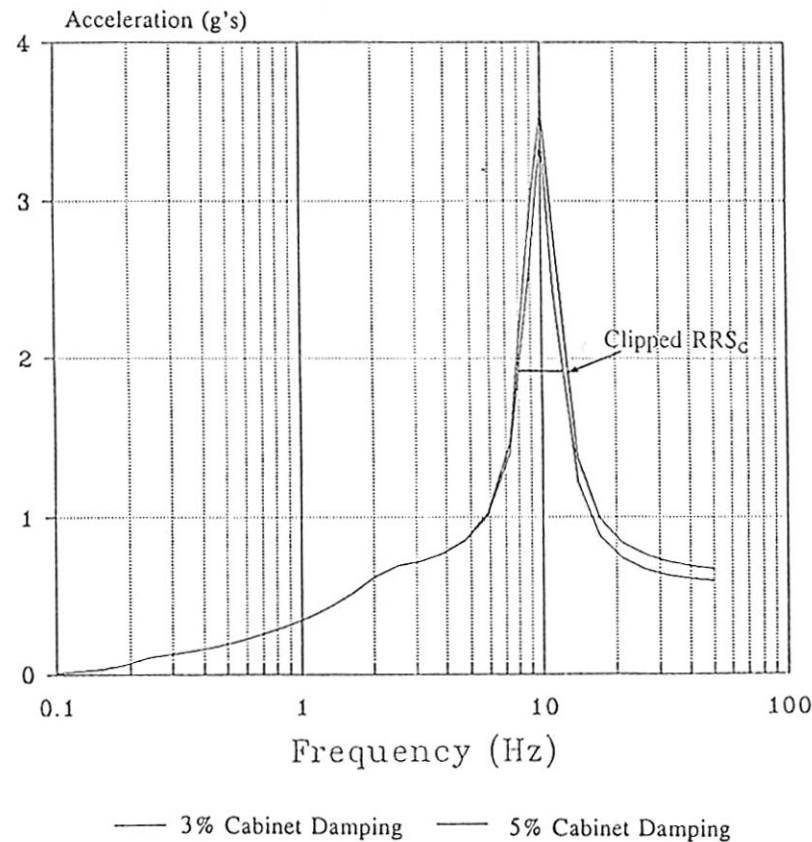
Clipping of Demand

In-cabinet response spectra for cabinet with single
10 Hz frequency panel mode.

Clipping of Demand (Continued)
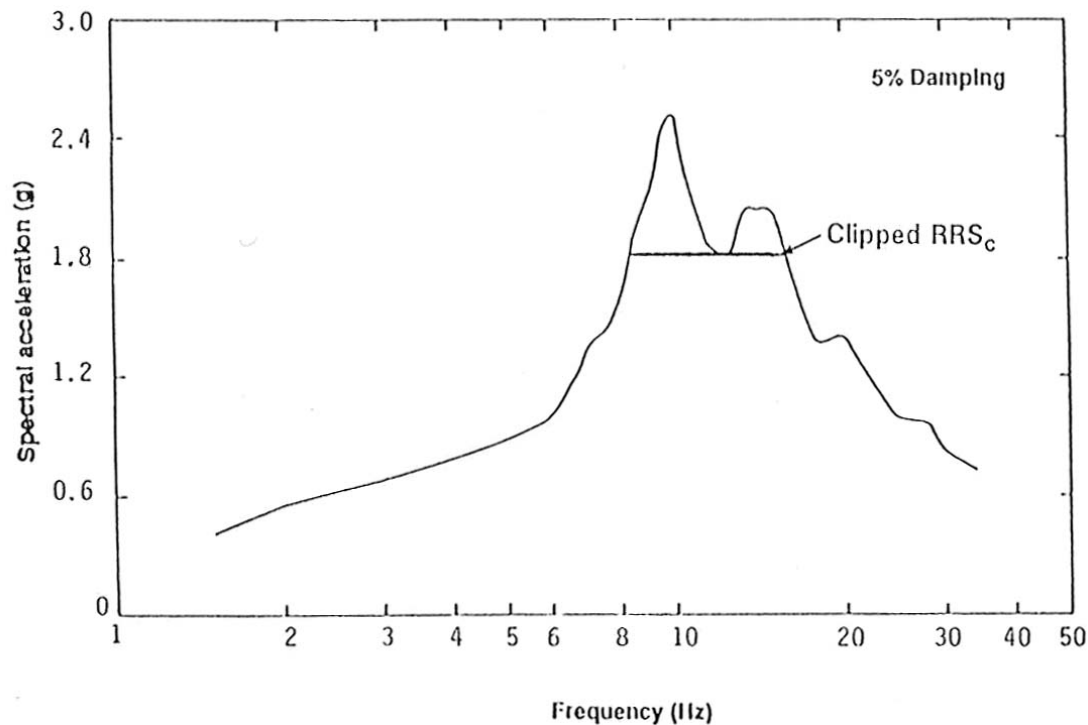
In-cabinet response spectrum for multiple cabinet modes.

Plant System and Sequence Analysis

External Event Analysis Approach

INITIATOR FREQUENCIES

HAZARD FREQUENCIES

EVENT TREES

CORE MELT/ RELEASE FREQUENCIES

FRAGILITIES

DATA

AFW

TANK

PUMP 1

PUMP 2

PUMP 3

FAULT TREES

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April-2009 Seismic-81
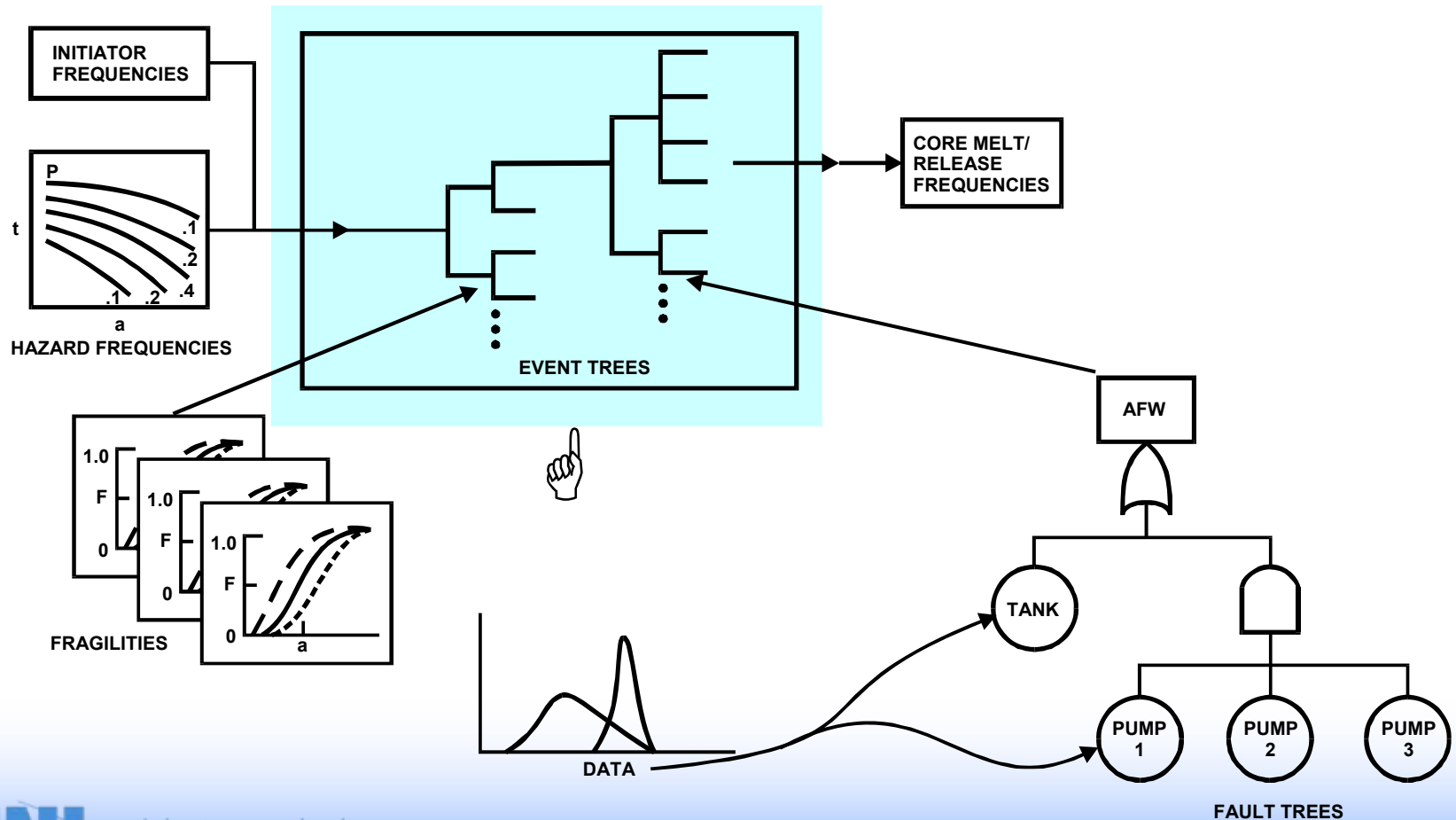
Learning Objectives

- **After studying this section, you should be able:**

    (1) To explain how seismic-induced failures can be incorporated into an accident sequence model.

    (2) List key issues related to seismic-initiated event sequence modeling.

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Plant System and Sequence Analysis

- Identify earthquake-induced initiating events.

- Account for increased likelihood of multiple safety system failures.

- Account for correlation and increased dependencies between component failures.

- Combine random and seismic-induced failures.

- Two general approaches: fault tree linking and event tree with boundary conditions.

Identify Initiators

- **Use component fragilities to rank components, including structural failures.**

- **Review applicability of nonseismic initiators.**

- **Initiator frequencies obtained by multiplying hazard frequencies at different earthquake acceleration levels with component fragilities.**

- **Multiple initiators may have significant frequency.**

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Earthquake Sequence Modeling

- **Fault Tree Linking Approach**
  - Adapt nonseismic event trees to account for earthquake-induced initiators and consequential failures.
  - Revise modeling approximations made for internal events if failure frequencies have significantly changed.
  - System fault trees are modified to include basic events attributed to earthquake-induced failure modes.

- **Alternate Fault Tree Linking Approach**
  - A core damage fault tree may be developed for all earthquake sequences.
  - Quantification of minimal cutsets must not employ the rare-event approximation.

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Oconee Seismic Analysis

- **Seismic event tree used to develop sequence logic**
- **Sequence logic quantified using single fault trees**
  - **Support Systems**
  - **Relay Chatter**

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Oconee Seismic Event Tree

Seismic event affects Oconee site	RPS trips reactor	RCS Overpressure Prevented	Unisolable ISLOCA does not occur	Large-break LOCA does not occur	Medium-break LOCA does not occur	Secondary-side heat removal maintained	RCS relief valve reseats after opening	RCP seal integrity maintained	Safety Injection established	Long-term cooling established		#	Class
C	K	E/TT	ISLOCA	L	M	B	Q(R)	Q(S)	U	X			
												1	NCM
												2	NCM
												3	CQSX
												4	CQSU
												5	NCM
												6	CQRX
												7	NCM
												8	CBX
												9	CBU
												10	NCM
												11	CBQSX
												12	CBQXU
												13	NCM
												14	CBQRX
												15	CBQRU
												16	NCM
												17	CMX
												18	CMU
												19	NCM
												20	CLX
												21	CLU
												22	CISLOCA
												23	NCM
												24	CKU
												25	CKB
												26	CKETT

April-2009 Seismic-87

Seismic Sequence Fault Tree Logic

Seismic Sequence Fault Tree Logic (Continued)
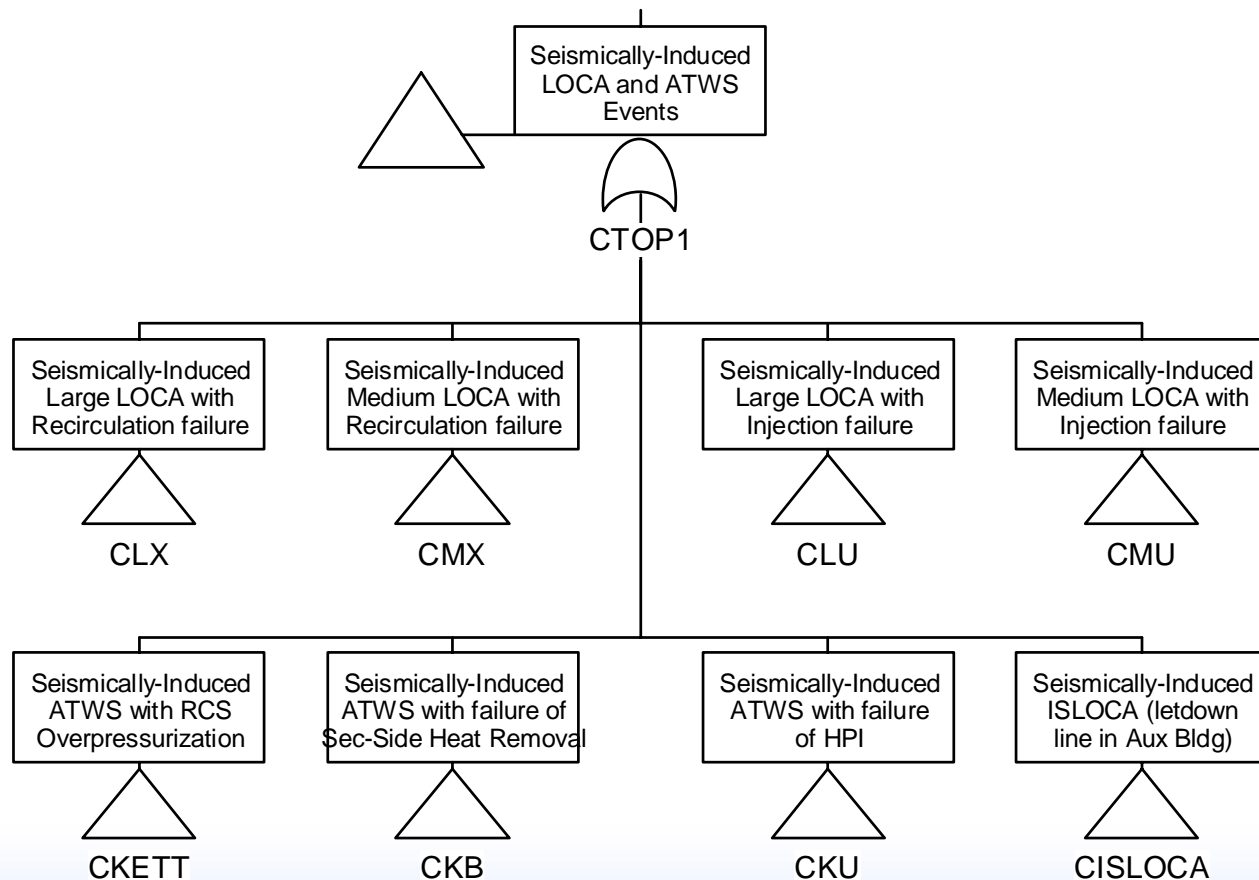
Seismic Sequence Fault Tree Logic (Continued)
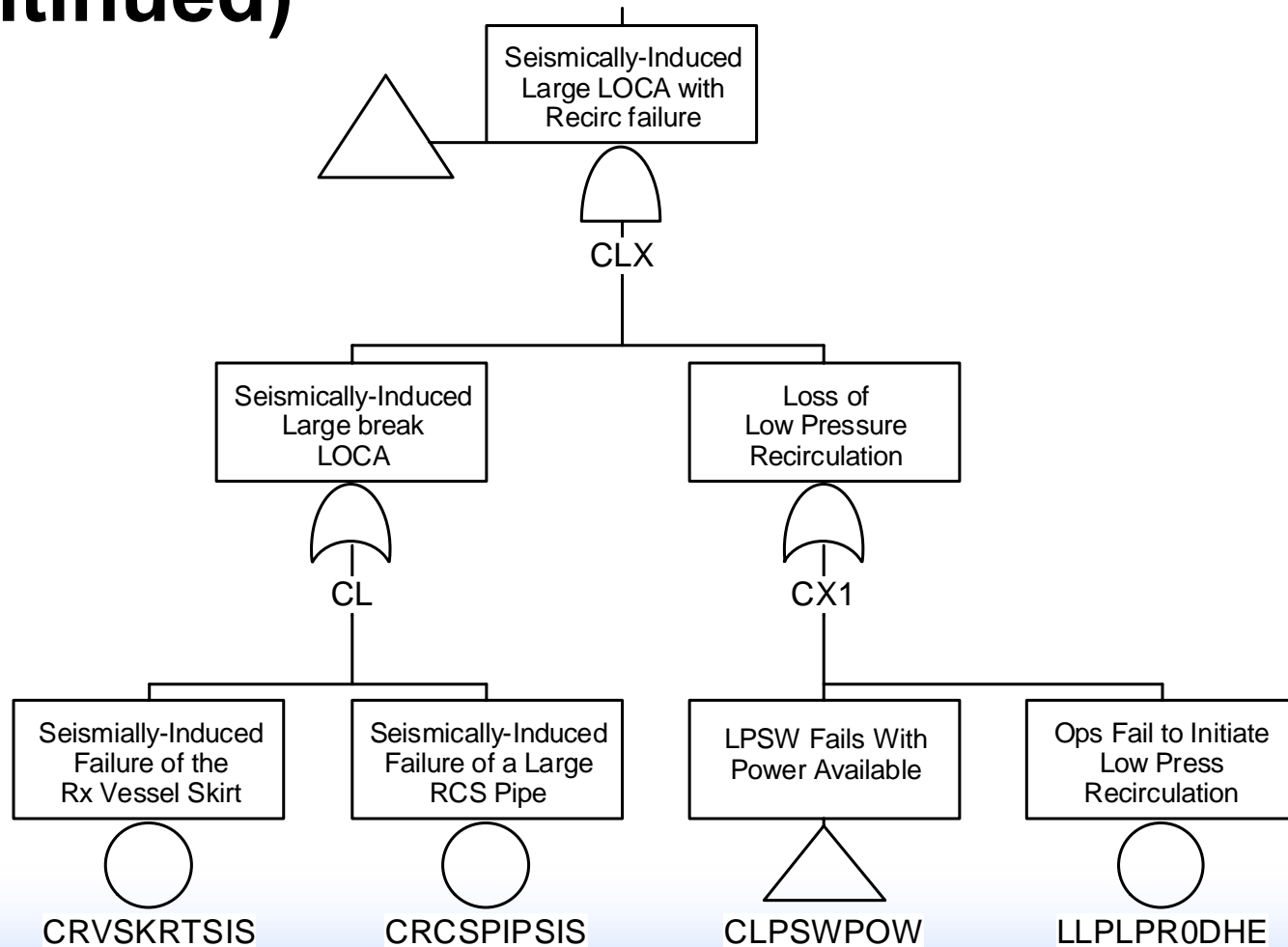
Seismic Sequence Fault Tree Logic (Continued)
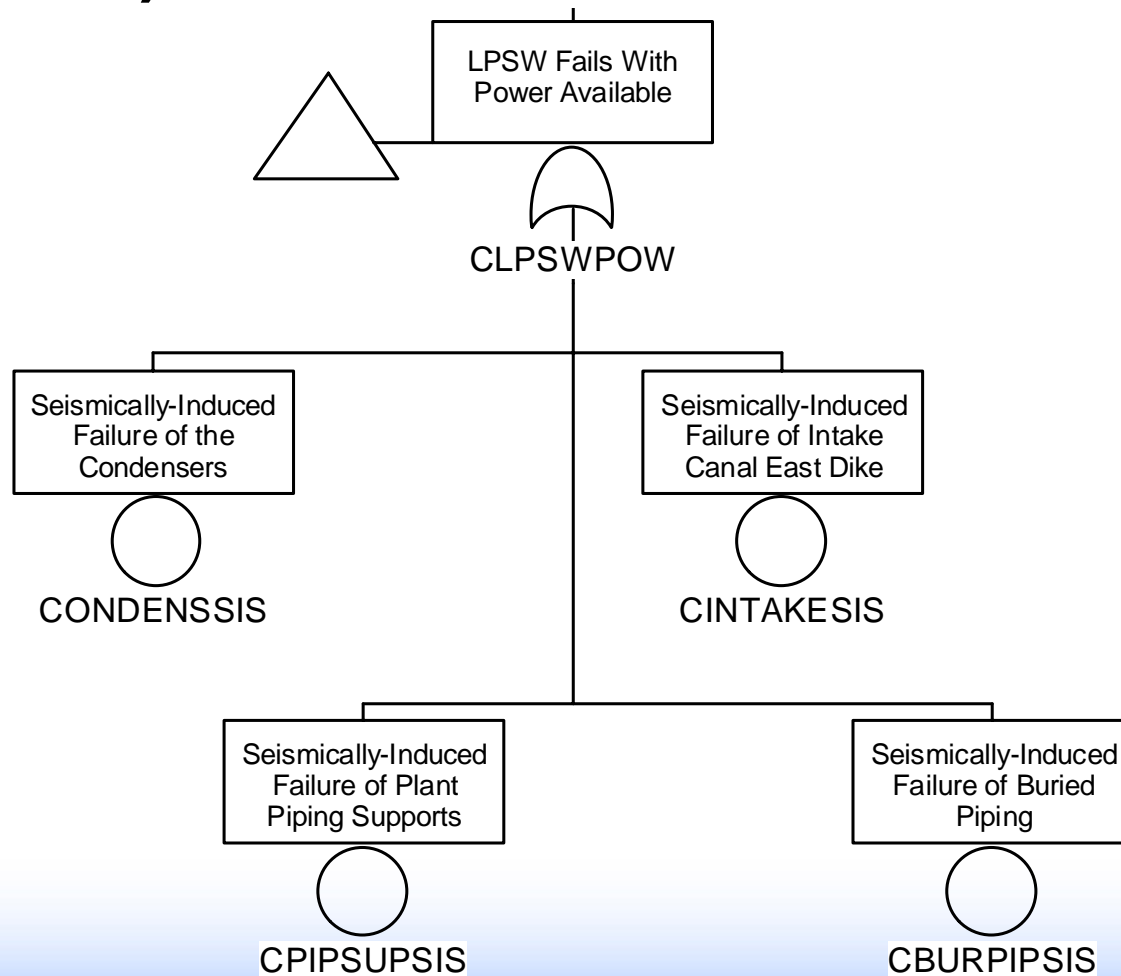
Earthquake Sequence Modeling Event Tree Linking Approach

- Earthquakes for different ranges of acceleration are defined as initiators.

- All seismic failures represented by a new single seismic event tree.

- Group components into seismic failure top events.

- Use same support event trees as for internal events.

- Use same general transient or other frontline event trees, depending on seismic failure initiator.

Earthquake Sequence Modeling Event Tree Linking Approach

- **Define new top events on existing trees for seismic unique impacts; e.g., relay chatter and excessive LOCAs.**

- **Account for dependencies between earthquake failures and system responses.**

- **Quantify event trees for each range of earthquakes.**

- **Plant damage state assignment similar to non-seismic.**

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Seismic Initiating Events for Diablo Canyon

SEISMIC INITIATING EVENT DESIGNATOR	SPECTRAL* ACCELERATION LEVEL (g)	FREQUENCY (PER YEAR)
SEIS1	0.0 to 1.25	1.41E-02
SEIS2	1.25 to 1.75	8.00E-04
SEIS3	1.75 to 2.0	1.47E-04
SEIS4	2.0 to 2.5	1.17E-04
SEIS5	2.5 to 3.0	2.82E-05
SEIS6	3.0 to 4.0	7.43E-06
TOTAL SEISMIC INITIATING EVENT FREQUENCY		1.52E-02

* Average 5% damped spectral acceleration over the 3-8.5 Hz frequency range

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Diablo Canyon Seismic PRA Component Groupings for Top Events

Seismic Top Event	Components/Structures
SOP - OFFSITE POWER	OFFSITE POWER, 230 KV
SDC - 125V DC POWER	AUXILIARY BUILDING BATTERIES DC SWITCHGEAR/BREAKER PANEL
STRUT - TURBINE BUILDING STRUT	STRUT FOR TURBINE BUILDING
SACSS - ALL 4KV VITAL AC POWER/STRUT SUCCESS	TURBINE BUILDING SHEAR WALL 4 KV SWITCHGEAR SAFEGUARD RELAY PANEL BATTERY CHARGERS 4KV/480V TRANSFORMERS BUS F POTENTIAL TRANSFORM BLOCK WALLS
SACSF - ALL 4KV VITAL AC POWER/STRUT FAILURE	TURBINE BUILDING SHEAR WALL BATTERY CHARGERS 4KV/480V TRANSFORMERS SWITCHGEAR/STRUT FAILURE SAFEGUARD RELAY PANEL/STR BUS F POTENTIAL TRANSFORM BLOCK WALLS

Diablo Canyon Seismic PRA Component Groupings for Top Events (Continued)

Seismic Top Event	Components/Structures
SDG - ALL SIX DIESEL GENERATORS	DIESEL GENERATORS DG RADIATOR/WATER PUMPS DG EXCITATION CUBICAL DG CONTROL PANEL
SFO - FUEL OIL TRANSFER	DG FUEL OIL PUMPS/FILTERS BOP PIPING AND SUPPORTS
SVI - ALL FOUR VITAL INSTRUMENT CHANNELS	INVERTERS PROCESS CONTROL AND PROTECTION PRESSURE AND DP TRANSMITTERS
SRT - REACTOR TRIP	REACTOR INTERNALS
SPT - PARTIAL REACTOR TRIP	REACTOR TRIP SWITCHGEAR
SCV - CONTROL ROOM VENTILATION	CONTROL ROOM SUPPLY FANS HVAC DUCTING AND SUPPORTS
SCC - COMPONENT COOLING WATER	RHR HEAT EXCHANGERS CCW PUMPS CCW HEAT EXCHANGERS CCW SURGE TANK BOP PIPING AND SUPPORTS

Seismic and Non-Seismic Event Tree Calculation

SEISMIC PRE TREE   SUPPORT SYSTEM TREE   FRONTLINE SYSTEM TREE
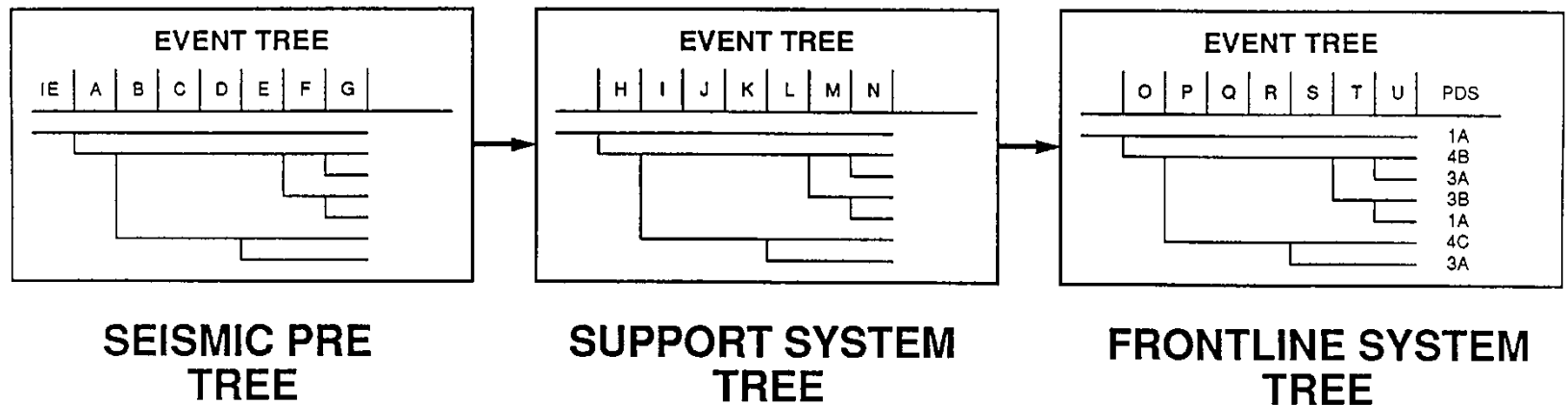
Containment Response

- **Sequences binned into plant damage states.**

- **Seismic-induced containment failure modes different from IPE.**

  - **Mechanisms leading to containment bypass; e.g., steam generator failure.**

  - **Structural failure of the containment.**

  - **Containment safeguards — failure of containment fan coolers creating path to CCW system outside containment.**

  - **Containment isolation valves/signals.**

- **Review Level 2 containment event tree to determine if applicable to seismic core damage sequence types.**

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Seismic Human Action Considerations

- Applicability of procedures.

- Error probabilities may increase with earthquake size.

- Offsite power recovery changes for earthquakes.

- Pathways to critical areas.

- Competing requirements for actions.

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Approximate Relationships between Intensity and Acceleration (1 of 2)

Modified Mercalli Intensity Scale	Richter Mag.	Max. Accel. (g)	Description of Effects
III	3	0.003 to 0.007	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV	4	0.007 to 0.015	Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frames creak.
V	4	0.015 to 0.03	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI	5	0.03 to 0.09	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken, knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and some masonry cracked. Small bells ring (church, school). Trees, bushes shaken (visible, or heard to rustle).
VII	5-6	0.07 to 0.22	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to some masonry, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

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Approximate Relationships between Intensity and Acceleration (2 of 2)

Modified Mercalli Intensity Scale	Richter Mag.	Max. Accel. (g)	Description of Effects
VIII	6	0.15 to 0.3	Steering of motor cars affected. Damage to some masonry; partial collapse. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX	7	0.3 to 0.7	General panic. Some masonry destroyed; other masonry seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.
X	7-8	0.45 to 1.5	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks to canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI	8+	0.5 to 3	Rails bent greatly. Underground pipelines completely out of service.
XII	8+	0.5 to 7	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

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Diablo Canyon IPEEE Seismic Human Action Values

Human Action Identifier	Human Action Description	Point Estimate Values Used for Internal Events Analysis	Multiplication Factors Used for Seismic Initiating Events		
			SEIS1 SEIS2	SEIS3 SEIS4	SEIS5 SEIS6
ZHEAC1	Failure to Recover from common cause Startup Breaker Failure on Demand	2.30E-03	30	30	30
ZHEAS1	Failure to remotely crosstie U1 & U2 ASW-Both U1 Pumps Failure	7.10E-03	30	30	30
ZHEAS2	Failure to Locally crosstie U1 & U2 ASW or Fail to Open	5.90E-03	1	5	30
ZHECC1	Failure to Reduce CCW heat Loads with One CCW Pump	8.20E-03	1	5	30
ZHECT1	Failure to Restore AC Power - Relay Chatter	1.20E-02	1	5	30
ZHECT2	Failure to Restore AC Power - Relay Chatter, SLOCA, No AFW	1.30E-02	1	5	30
ZHECT3	Failure to Restore AC Power - Relay Chatter and No AFW	1.10E-02	1	5	30

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Diablo Canyon IPEEE Seismic Human Action Values (Continued)

Human Action Identifier	Human Action Description	Point Estimate Values Used for Internal Events Analysis	Multiplication Factors Used for Seismic Initiating Events		
			SEIS1 SEIS2	SEIS3 SEIS4	SEIS5 SEIS6
ZHECT4	Failure to Restore AC Power-Relay Chatter, SLOCA, No AFW	1.40E-02	1	5	30
ZHEF04	Failure to Realign Fuel transfer pump Power Source to Opposite unit	1.00E-02	1	5	30
ZHEF05	Failure to Realign Fuel Oil transfer pump Given 1 pump loss of Power	1.50E-02	1	5	30
ZHEF06	Failure to Align a Dedicate, Portable Fuel Oil Transfer pump	1.70E-02	30	30	30
ZHELA1	Failure to Trip RHR if RCS Pressure is High, for Feed & Bleed	1.90E-03	1	5	30
ZHELA2	Failure to Trip RHR if RCS Pressure is High, for Small LOCA	1.90E-03	1	5	30

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Diablo Canyon IPEEE Seismic Human Action Values (Continued)

Human Action Identifier	Human Action Description	Point Estimate Values Used for Internal Events Analysis	Multiplication Factors Used for Seismic Initiating Events		
			SEIS1 SEIS2	SEIS3 SEIS4	SEIS5 SEIS6
ZHEPR4	Failure to Isolate Stuck Open PORV W/O Reactor Trip	2.10E-03	30	30	30
ZHERF1	Failure to Switch to Recirculation from Injection Mode SLOCA w/spray	1.10E-03	30	30	30
ZHERF2	Failure to Switch to Recirculation from Injection Mode (ECCS) MLOCA/LLOCA	1.30E-03	30	30	30
ZHERF3	Failure to Switch to Recirculation from Injection Mode After core damage	4.51E-03	30	30	30
ZHERF5	Failure to Switch to Recirculation from Injection Mode SLOCA w/spray	1.20E-03	30	30	30
ZHERP1	Failure to Trip RCPS Given CCW Fails	1.50E-03	30	30	30

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Key Diablo Canyon Seismic Human Actions

- **Offsite power recovery.**

- **Recovery from relay chatter-induced blackout.**

- **Align fire water cooling to charging pumps.**

- **Crosstie service water between units.**

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Human Factor Error Rates Used for SONGS

- **Rates are a function of timing and access.**

Seismic IPEEE Performance Shaping Factors	short time period (t < 20 min)	medium time period (20 m < t < 60 m)	long time period (1 hr < t < 24 hr)
In control room action	10	5	1
Ex-control room action	30	10	5

Human Error Rates Used for Kewaunee Seismic PRA

- **Rates are a function of seismic level**

    - **< 0.12g (SSE); no change.**

    - **0.12g - .36g; linear increase to factor of 10 at 3*SSE.**

    - **> .36g; failure probability = 1.0.**

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SPRA Documentation

- **Level of SPRA documentation should follow new ANS Standard for External Event PRA.**

- **SPRA documentation should include:**

  - **Description of methodology and key assumptions.**

  - **Hazard curves used in analysis.**

  - **Walkdown team, procedures and findings.**

  - **Systems information (including non-seismic failures human actions modeling of screened out components, correlations and dependencies).**

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SPRA Documentation (Continued)

- **SPRA documentation should include (continued):**
  - List of fragility parameter values.
  - Core damage fragility curve.
  - Mean core damage frequency and ranking of contributors.
  - Containment failures and performance insights.
  - Results of evaluation and insights gained.
  - Documentation regarding other seismic issues.
    - Decay heat removal.
    - Seismic/fire interaction.
    - Inadvertent actuations of fire protection systems.

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Example Results

Learning Objectives

- **After studying this section you should be able to:**

  (1) **Interpret and understand the different presentation of results in a seismic PRA.**

  (2) **Judge the reasonableness of sequence contributors given the list of detailed fragilities.**

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Example Results

- **Insights From Submittals**

- **Relative Importance to CDF**

- **Key Plant Damage States**

- **Key Sequence Groups**

- **Seismic Basic Event Importance**

Seismic Core Damage Frequencies

| Plant	Unit (34)	A-46	Reactor Type	Seismic IPEEE Approach	RLE	Mean Seismic CDF Per Year	Ratio of Seismic CDF to Internal CDF	Seismic Hazard Used for Base Case
No. 03	1	📰	W-PWR	PRA	0.3g Focused	9.07E-06	7.75%	EPRI
No. 04	2		W-PWR	PRA	0.3g Focused	5.33E-06	8.90%	EPRI
No. 10	1	📰	C-E - PWR	PRA	0.3g Focused	1.30E-05	5.40%	Revised LLNL
No. 11	2	📰	C-E - PWR	PRA	0.3g Focused	1.50E-05	6.25%	Revised LLNL
No. 12	1 & 2		W-PWR	PRA	0.3g Focused	1.60E-05	36.36%	EPRI
No. 15	1 & 2	📰	W-PWR	PRA	0.3g Focused	1.83E-05	29.23%	Site-Specific
No. 19	1 & 2		W-PWR	PRA	PRA	4.00E-05	45.45%	Site-Specific
* No. 29		📰	W-PWR	PRA	0.3g Focused	2.26E-04		EPRI
No. 30			GE-BWR	PRA	0.3g Focused	1.00E-06	2.16%	EPRI
No. 31	2	📰	W-PWR	PRA	0.3g Full	1.10E-05	35.14%	EPRI
No. 32	3	📰	W-PWR	PRA	0.3g Full	5.30E-05	120.45%	EPRI
No. 33		📰	W-PWR	PRA	0.3g Focused	1.10E-05	16.54%	EPRI
No. 37	1 & 2		W-PWR	PRA	0.3g Focused	1.10E-05	27.50%	EPRI
No. 42	1	📰	GE-BWR	Margin & PRA	0.3g Focused	1.10E-06	20.00%	EPRI
No. 43	2		GE-BWR	Margin & PRA	0.3g Focused	2.50E-07	0.81%	EPRI
No. 46	1,2 & 3	📰	B&W - PWR	PRA	0.3g full	3.60E-05	156.52%	EPRI
No. 47		📰	GE-BWR	PRA	0.3g Focused	3.60E-06	97.56%	EPRI
No. 48		📰	C-E - PWR	PRA	0.3g Focused	8.88E-06	17.20%	Revised LLNL
No. 52		📰	GE-BWR	PRA	0.3g Full	5.82E-05	100.34%	EPRI
No. 53	1 & 2	📰	W-PWR	PRA	0.3g Focused	1.31E-05	12.17%	Revised LLNL
No. 59/No. 60	1 & 2	📰	W-PWR	PRA	0.3g Full	4.70E-06	7.52%	EPRI
No. 61	2 & 3	📰	C-E - PWR	PRA	PRA	1.70E-05	56.67%	Site-Specific
No. 62			W-PWR	PRA	Full	1.20E-05	17.91%	Site-Specific
No. 71	1	📰	B&W - PWR	PRA	0.3g Focused	3.21E-05	71.49%	EPRI
No. 77	2		GE-BWR	PRA	0.5g	2.00E-05	114.29%	Site-Specific

* Decommissioned

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Mean Seismic CDF (EPRI, LLNL, Site Specific Hazard)
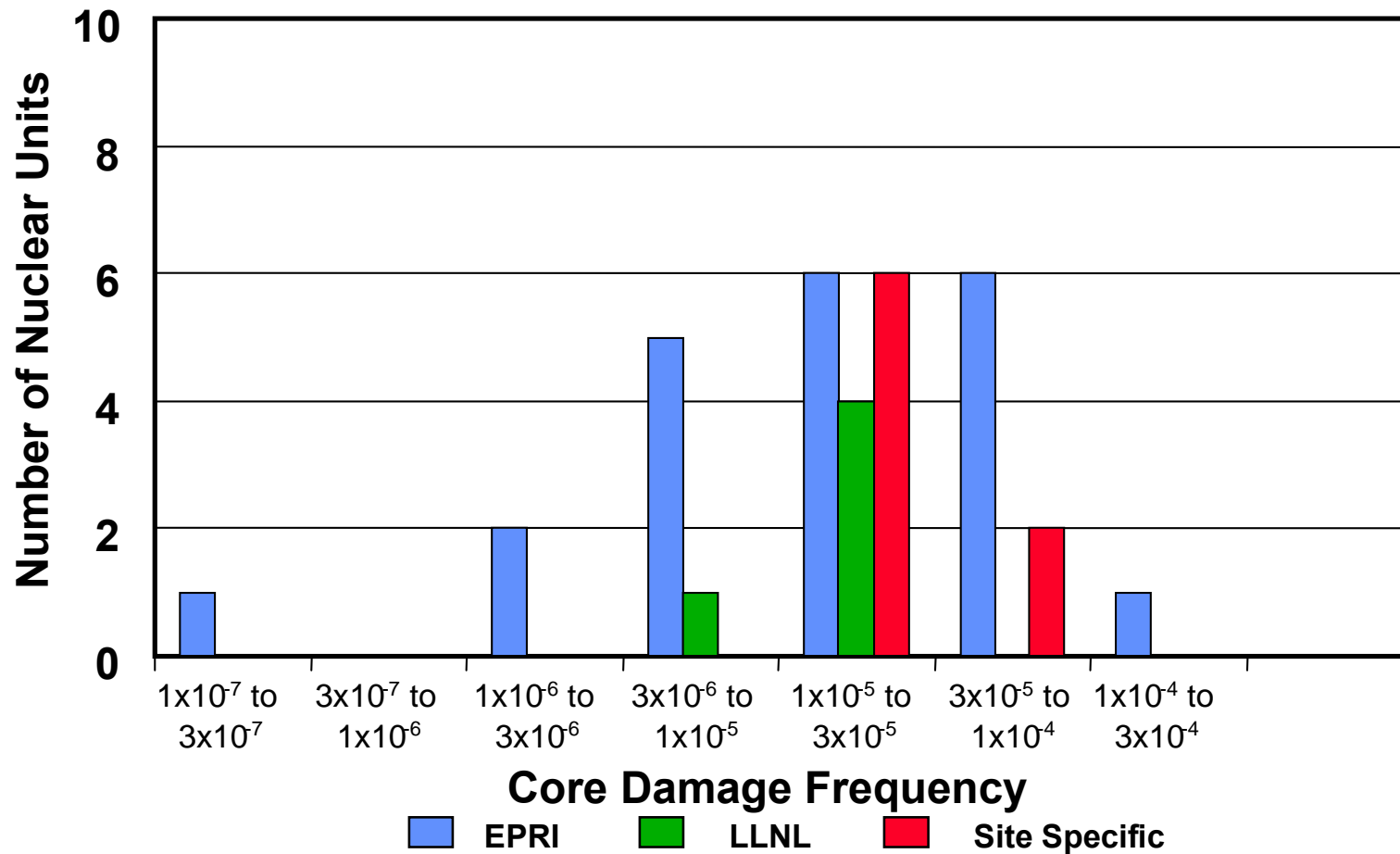
Seismic/Internal Event CDF's
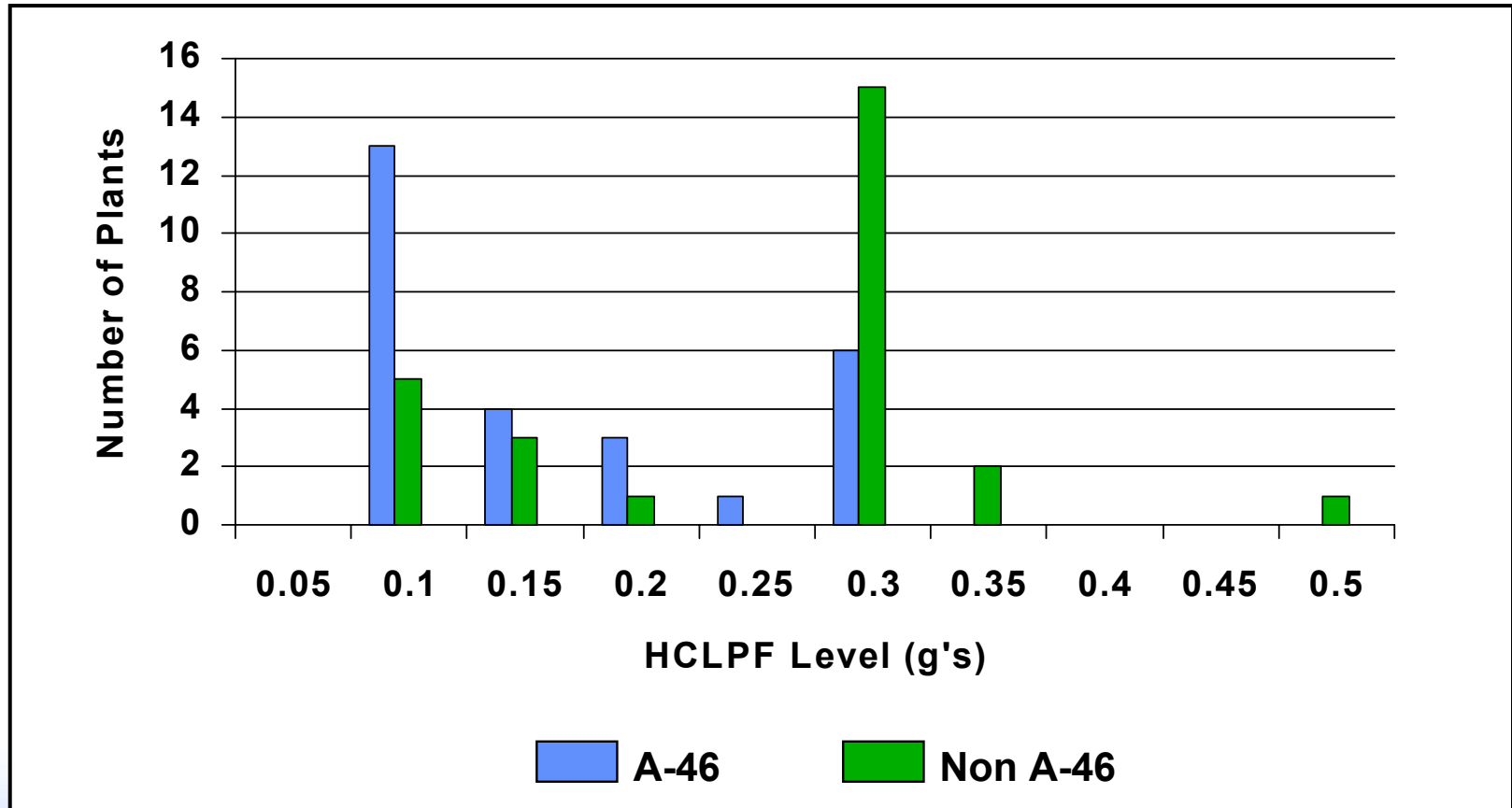

33 Plants

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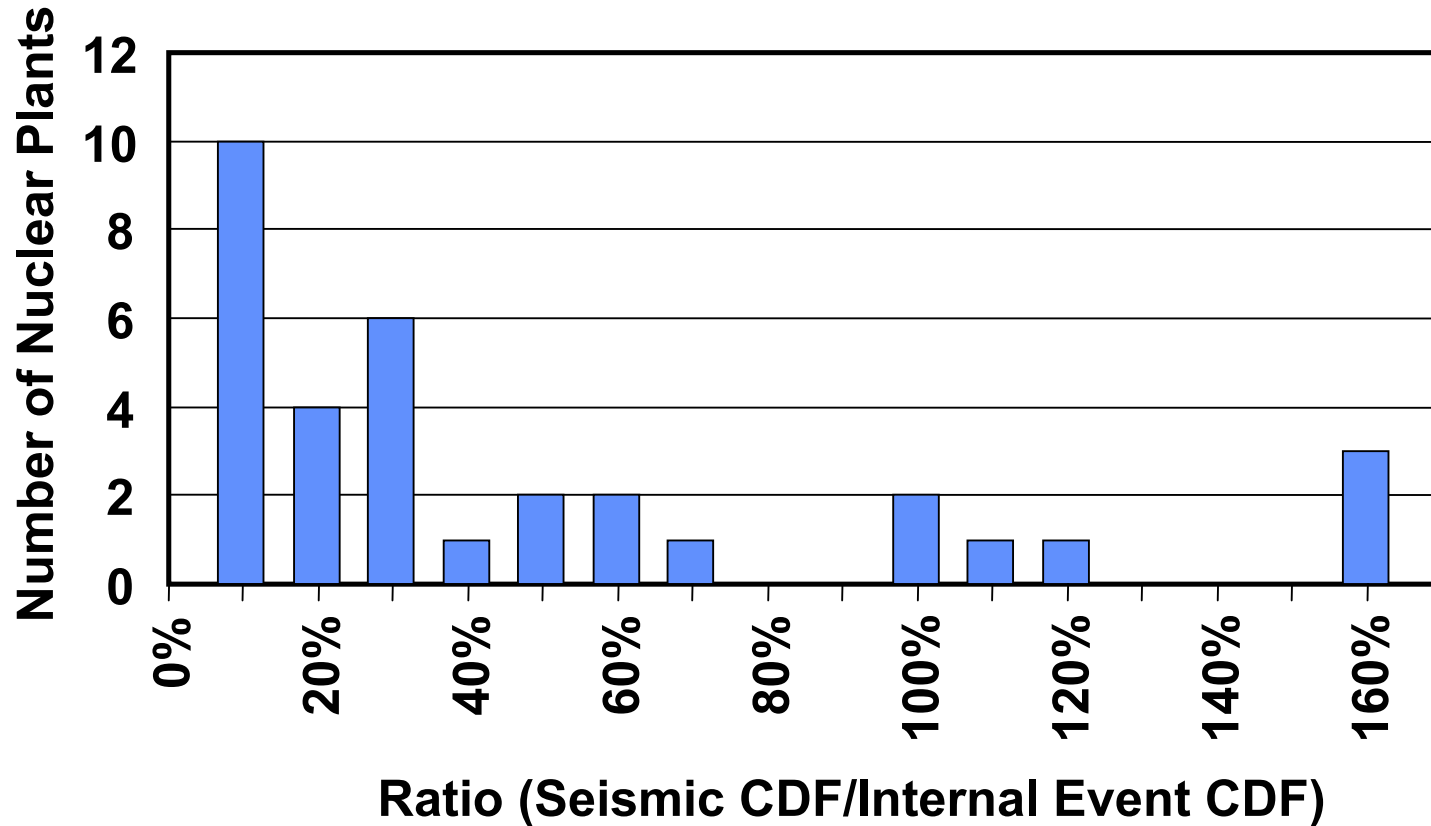
CDF Comparison: Plant Vintage
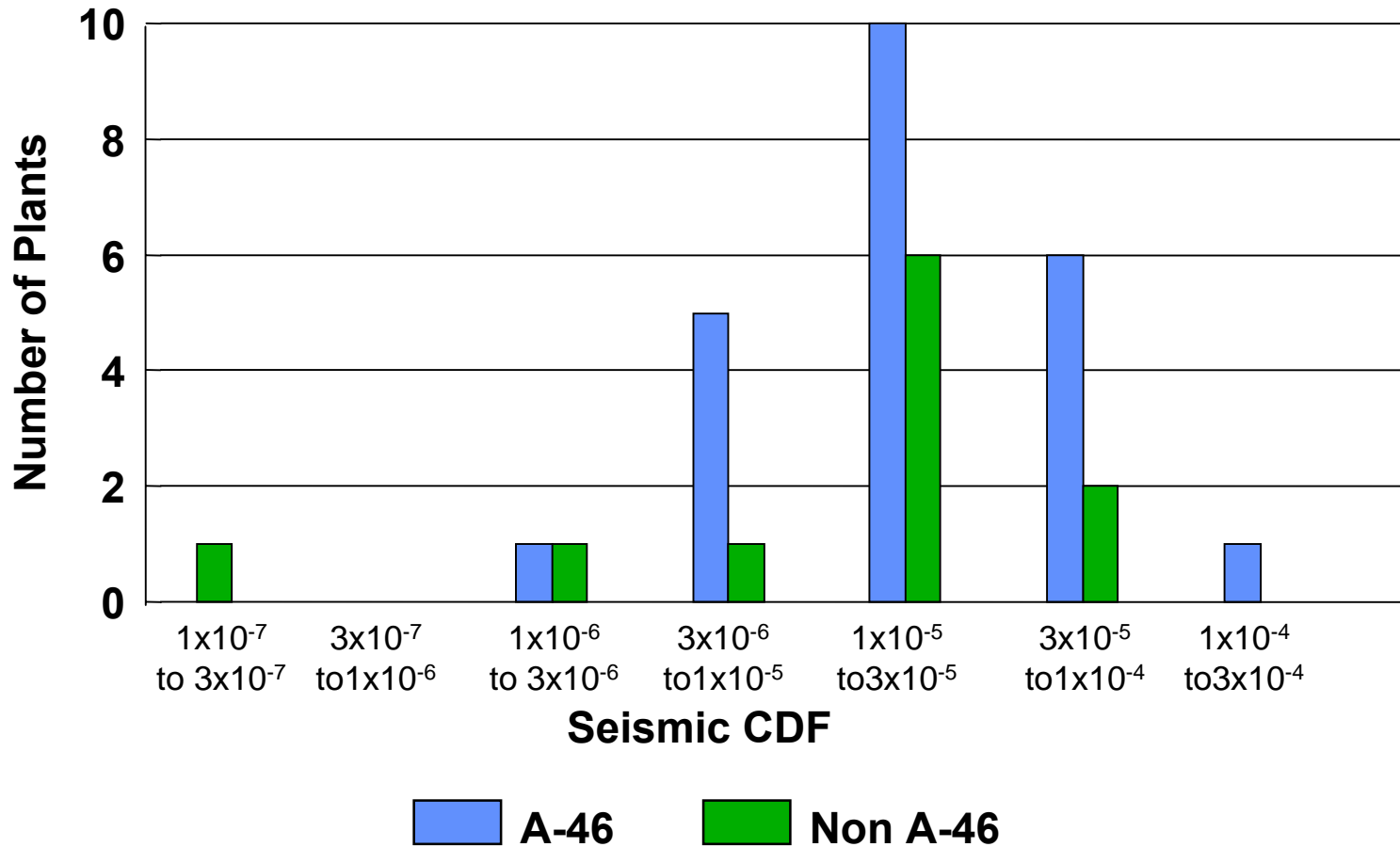
Plant HCLPF Capacities: Plant Vintage

IPEEE Seismic PRA Results
Dominant Risk Contributors: Plant Systems

Unit Code	Off Site Power	Diesel Generators System	AC Power System (Non-Diesel)	Auxiliary/Emergency Feedwater	Service Water System	Main Steam System	Main Feedwater System	Component Cooling Water	DC Power System	Site Unique Sequence/System	Residual/Decay Heat Removal	NSSS
3	X	X							X			
4	X	X										
15/16	X				X							
17/18	X	X										
22/23	X				X	X	X					
27/28	X											
40*	X	X		X			X					
41			X							X		
42			X					X				
43	X	X	X								X	
44			X		X							X
45/46	X											
50/51	X	X										
54	X	X									X	
56	X	X										
57	X	X										
60/61/62	X		X							X[2]		
63	X	X	X	X								
64	X	X				X				X[1]		
71[3]												
72/73	X	X	X	X								
81/82	X				X				X			
83/84	X		X									
85	X	X	X									
89/90	X	X										
94/95	X									X[4]		
98	X	X	X									
107	X	X	X									
Total Units = 41	37	20	15	4	7	3	3	1	4	6	2	1

* Decommissioned
[1] Fire Protection System Used As Makeup for CST
[2] Refers to a Hydro Plant and a Safe Shutdown Facility for Emergency Power
[3] Dominant Risk Contributors not defined in the submittal
[4] Seismic-induced damage to turbine building which leads to loss of cooling of emergency switchgear room, changing pump, RHR heat exchanger, and recirculation spray.

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IPEEE Seismic PRA Results
Dominant Risk Contributors: Component Types

Unit Code	Tanks	Relays	Piping	Cable Trays	Valves	Diesel Generators	Electrical Cabinets	Pumps	Batteries/Chargers	Heat Exchangers	Transformers	Buildings	Seismic Interaction	Block Walls	Chillers/HVAC	Fans	Surrogate	NSSS Components
3														X				
4						X					X	X	X					
15/16	X						X								X		X	
17/18	X						X		X									
22/23	X										X	X						
27/28		X					X				X	X						
40*		X									X					X	X	
41							X											
42	X											X	X					
43	X						X	X										
44																	X	
45/46																		
50/51	X						X		X									
54	X					X						X						X
56	X					X											X	
57	X					X											X	
60/61/62													X				X	
63	X					X							X					
64	X				X		X	X										
71	X						X	X				X	X	X				X
72/73			X				X				X						X	
81/82									X			X				X		
83/84							X				X	X					X	
85	X						X	X										
89/90	X	X					X	X										
94/95	X											X	X					
98	X					X				X		X						X
107						X											X	
Total Units = 41	22	4	1	2	1	9	20	3	7	1	9	13	11	2	3	3	13	3

* Decommissioned

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Insights from Seismic IPEEE Submittals

- **Need for sensitivity study of operator error rates.**

- **Fire sources often not clearly located.**

- **Degradation of fire suppression capability needs greater attention.**

- **Component screening criteria in a SPRA may not always be chosen sufficiently high. (Surrogate elements are significant contributors or are not included to represent screened out components.)**

- **Relay chatter effects not quantified for focused scope plants that conducted SPRA.**

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Insights from Seismic IPEEE Submittals (Continued)

- **CDFs range from 2.5×10^{-7} to 2.3×10^{-4}/year.**

- **Eastern site HCLPFs range from 0.09g to 0.50g.***

- **Bad actor relays have often been found.**

- **Soil failures might be of concern (often screened out at lower level than component screening).**

- **Key failures frequently repeated.**

  - **Seismic — Offsite Power, Electrical Panels, Block Walls, Tanks, Interactions, Structures**

  - **Random — Diesel Generators**

  *after some modifications

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Diablo Canyon PRA Core Damage Frequency by Initiating Event
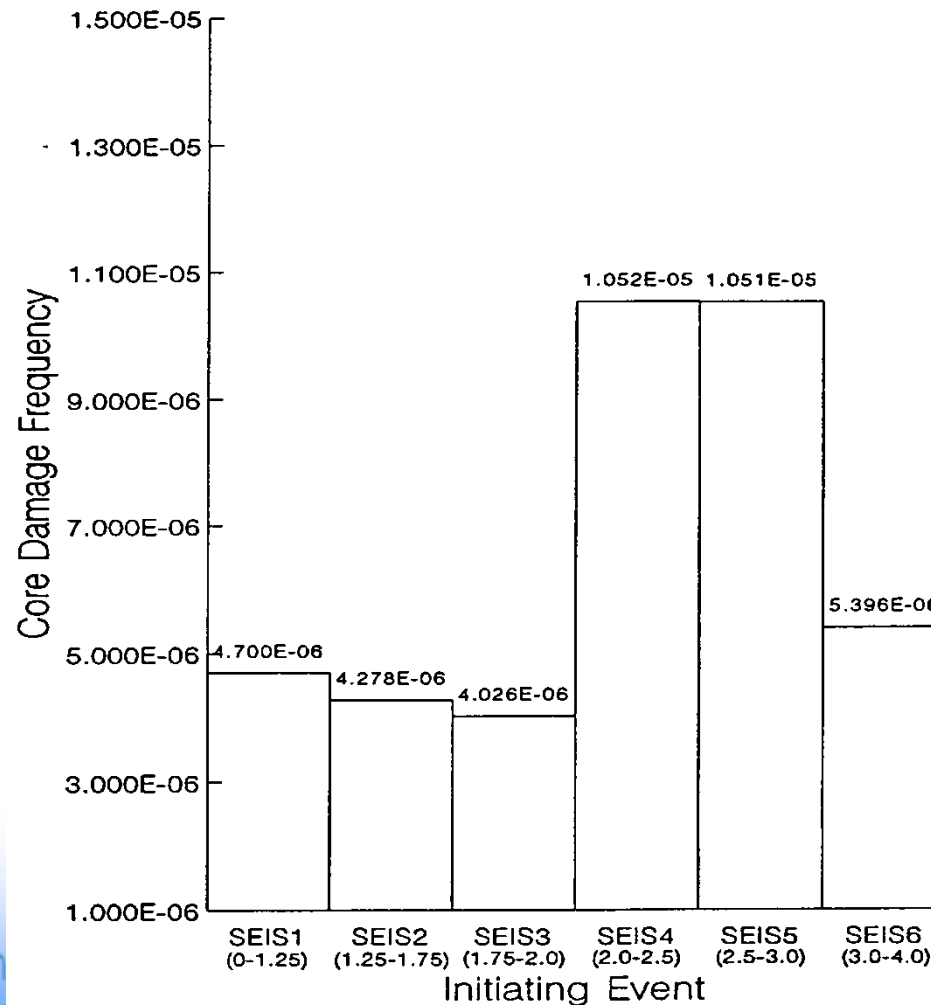
DCPRA Plant Fragility Including Seismic Failure and Random Failure Modes for Seismic Initiators
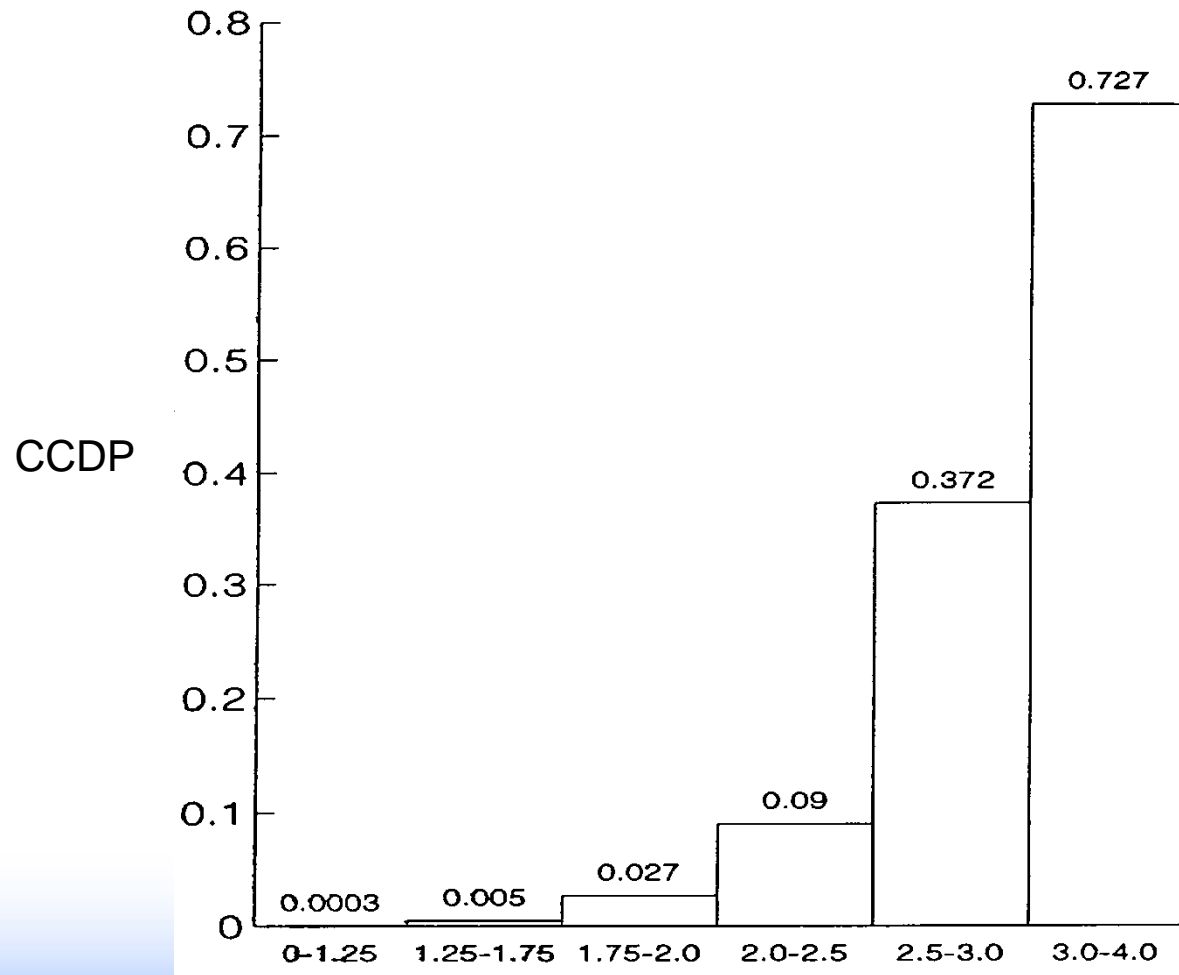
Groups of Seismic Failures Contributing to Core Damage in Original DCPRA

Sequences Evaluated	Failure Frequency (per year)
Total Seismic Core Damage	3.7×10^{-5}
All 4.16-kV Vital AC Switchgear Fail	1.7×10^{-5}
Loss of Offsite Power	1.2×10^{-5}
Excessive LOCAs	7.8×10^{-6}
All Vital 125V DC Fails	5.6×10^{-6}
All 120V Vital Instrumentation Fails	1.4×10^{-6}
Relay Chatter with Failure To Recover	1.2×10^{-6}
Control Room Boards and Hot Shutdown Panel Fail	9.7×10^{-7}

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Uncertainty Results of the DCPRA
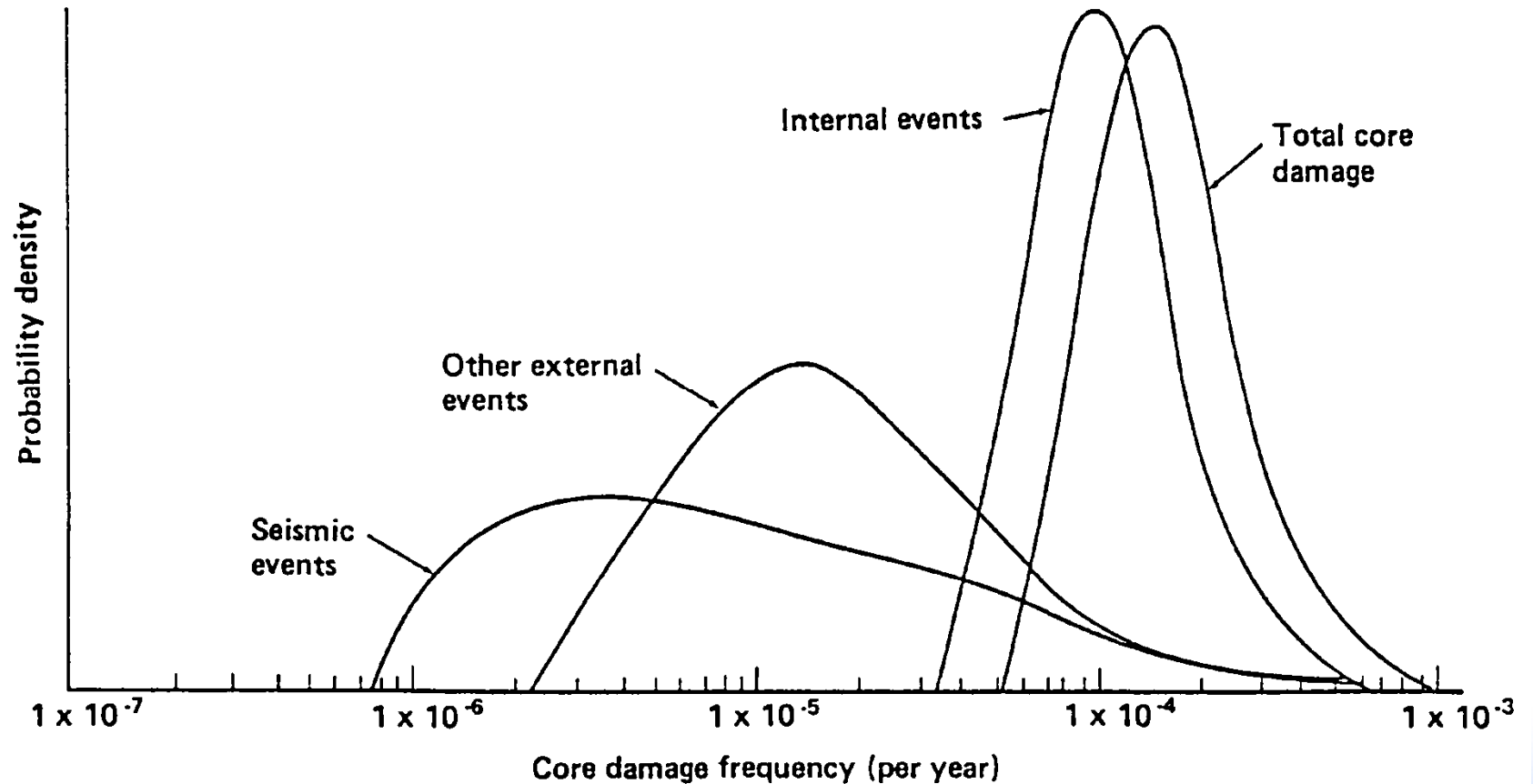
Insights From Seismic IPEEEs

- **Utility personnel received seismic IPEEE training and generally had a significant participation in the seismic walkdown and evaluation process.**

- **Seismic walkdown performed for each plant was useful in identifying vulnerabilities.**

- **Where needed, potential adverse effects of relay chatter have been corrected.**

- **Containment safeguard equipment have generally been found to be rugged.**

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Insights From Seismic IPEEEs (Continued)

- Simplifications in systems analysis and fragility analysis have limited insights to a qualitative nature.

- Risk reduction from plant improvements often not reported.

- The differences in hazard curves from different studies (LLNL and EPRI) generally do not change dominant contributor ranking (for some cases examined, the choice of hazard could make a significant difference).

- Different ground motion spectra used for PRA and margins, thus HCLPFs not comparable.

- Seismic-induced fires and floods have been addressed in all the plants to varying levels of detail.

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Example Issues Identified in Seismic IPEEEs

- Failure of toxic and flammable gas storage tanks.

- Collapse of nearby tall chimney or stack.

- Spatial interactions with columns or grating.

- Incorrectly supported piping between buildings.

- Amplification of ground motion at shallow soil sites.

- Unanchored equipment, such as DG day tanks and DG jacket water expansion tanks, don't meet design basis.

- Banging of unattached adjacent cabinets, causing potential relay chatter.

- Poor battery racks and poorly anchored cabinets.

- Non safety related structures can dominate CDF and LERF results.

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Summary

- **Seismic PRA and seismic margin are useful tools to analyze beyond-design-basis events.**

- **At many plants (including new plants), seismic reviews have identified some design, construction, and maintenance errors.**

- **Seismic reviews have also identified items with low seismic margin above the design basis earthquake, and identified cost-effective upgrades to improve plant seismic safety.**

- **Methodology and knowledge gained can be used for future risk informed decisions.**

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Summary (Continued)

- **Seismic reviews have been used to develop training and simulator scenarios, and also to identify changes to operating procedures to improve plant seismic safety.**

- **In addition to prioritizing seismic plant modifications, PRAs have been used to quantify the risk versus return and the cost effectiveness of modifications.**

- **IPEEE models and information can potentially be used for future risk-informed plant modifications or regulatory activities.**

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Summary (Continued)

- **ANS Standard for External Event PRA focused on risk informed decisions.**

- **IPEEE requirements focused on identifying vulnerabilities.**

- **IPEEE SPRA models will likely require enhancement for future risk informed applications.**

- **IPEEE SMA studies will require recasting into a quantitative risk model**

  - **Develop fragilities from HCLPF calculations.**

  - **Develop risk models from internal event PRA models.**

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Fire Risk Analysis Introduction

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April 2009

What is a "Fire"?

- **Fire occurs within the plant**
- **Fire results in plant trip**
- **Fire causes systems needed for safe shutdown to become unavailable**
  - **Increases likelihood of core damage**
- **Sometimes referred to as:**
  - **External Event**
  - **Internal Fire**
  - **Fires external to the plant boundary have generally been judged to be not risk significant.**

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Questions Commonly Asked in Fire Risk Analysis

- **Where and how much:**

  - **Ignition Sources**

  - **Combustible Loading**

  - **Critical Components**

- **Are there any room features that affect fire growth?**

- **Can a fire grow to a size that can damage the critical components in its vicinity?**

- **If a fire can potentially damage critical components in its vicinity, when will it happen?**

  - **Fire is a horse race between damage and suppression**

Fire Area vs. Fire compartment

- **Fire area – portion of building that is separated from other areas by a rated fire barrier (per Reg Guide 1.189)**

- **Fire compartment – enclosed room where a fire would be expected to be substantially confined**

  - **Defined to support a fire PRA**

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Compartment Fires

- Compartment fires are enclosure fires that are confined (at least initially) to a single compartment or space (i.e. room or hall way) within a structure.

- The course of the compartment fire and the conditions that result depend on the following major variables (others also exist):

  - Fire growth time

  - Heat release rate (HRR) of combustibles

  - Enclosure size

  - Enclosure design and construction

  - Enclosure ventilation

  - Suppression systems

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Compartment Fires

- **Ventilation is achieved through open doors and windows and HVAC systems**
  - **In some ventilated situations, ventilation is stopped automatically under fire conditions either through termination of HVAC system operation or shutting or closing of fire doors and dampers**

  - **However, in other situations, ventilation may continue or unprotected opening may remain open**
    - **These fires typically progress through 4 stages (or phases) as a function of time**

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Stages of Compartment Fires

Stage 1: Fire Plume/Ceiling Jet Stage
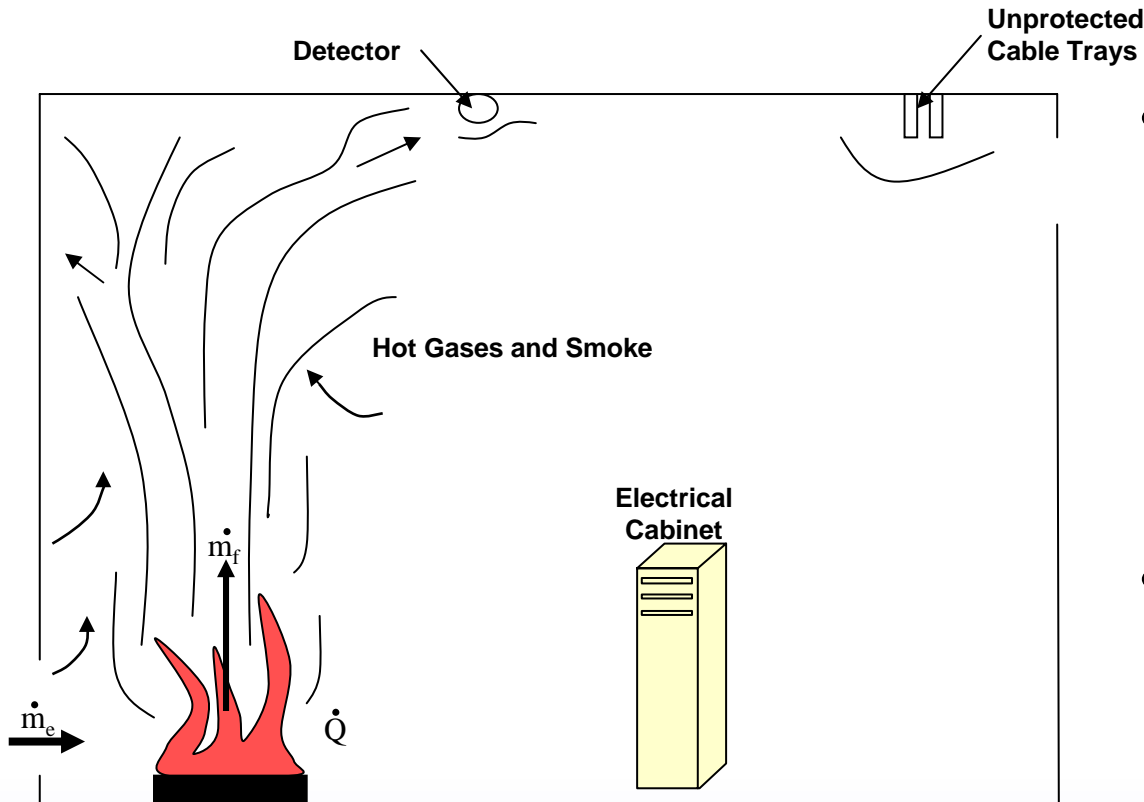
- Hot gases rise to ceiling and entrain cool air
  - Decrease in plume temperature
  - Increase in smoke volume
- Plume gases form a ceiling jet and continues to extend until confined by enclosure boundaries

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Stages of Compartment Fires

Stage 2: Unvented Smoke Filing Stage

Detector

Unprotected
Cable Trays

Hot Gases and Smoke

Electrical
Cabinet

$\dot{Q}$
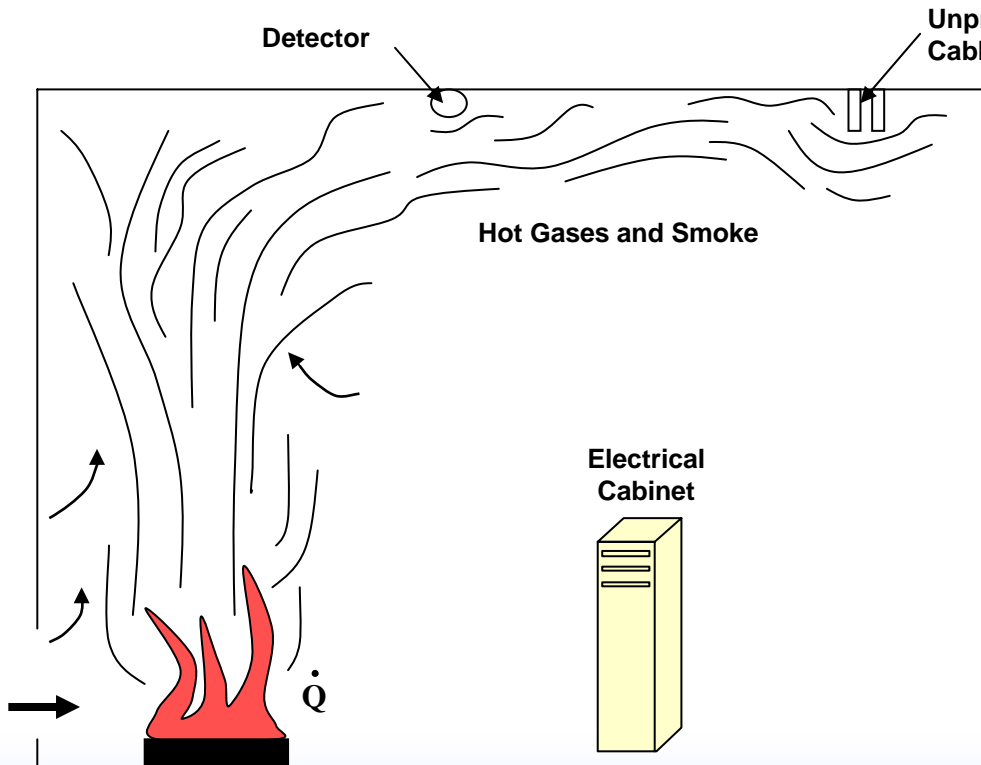
- Ceiling jet spreads to the full extent of compartment

- Smoke descends due to gas expansion

- Heat addition increase smoke layer temperature

- Continuing entrainment of cool air slows temperature increase

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Stages of Compartment Fires

Stage 3: Pre-flashover Vented Stage
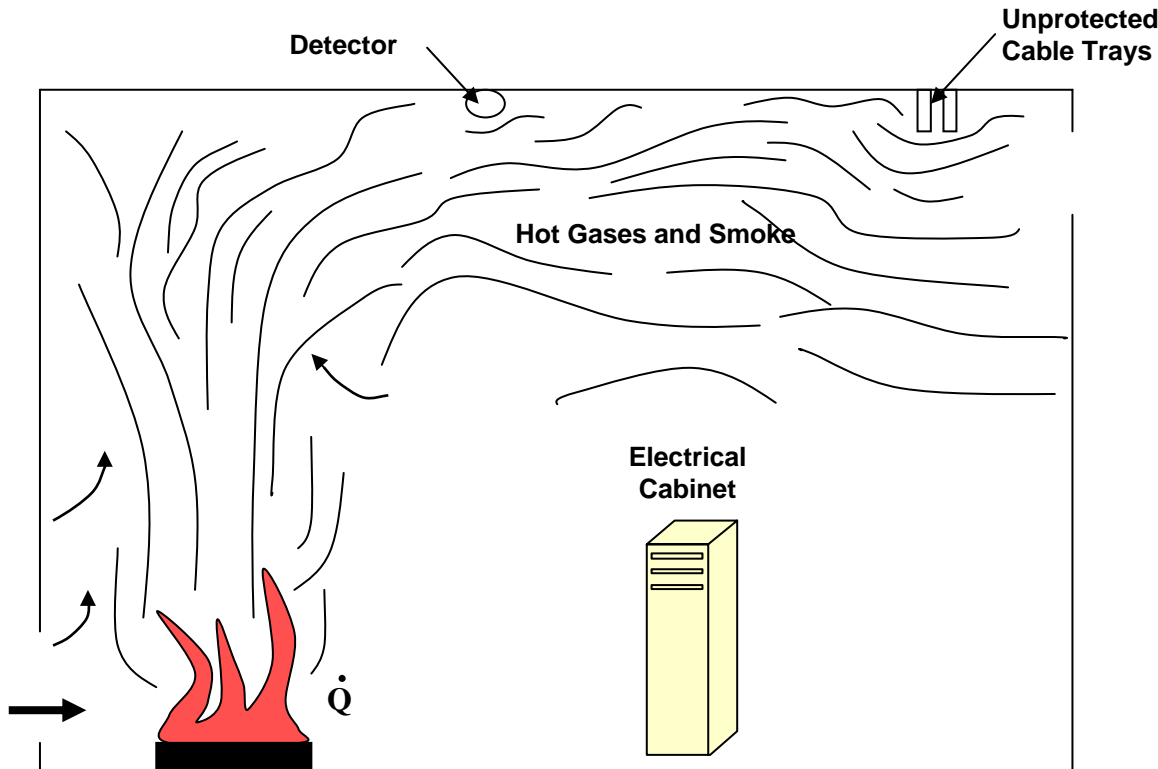
- Smoke begins to flow from the compartment

- Ventilation may occur naturally through openings (doorways)

- Ventilation may be forced by HVAC systems

- Smoke layer may continue to expand and descend

Stages of Compartment Fires

Stage 4: Post-flashover Vented Stage
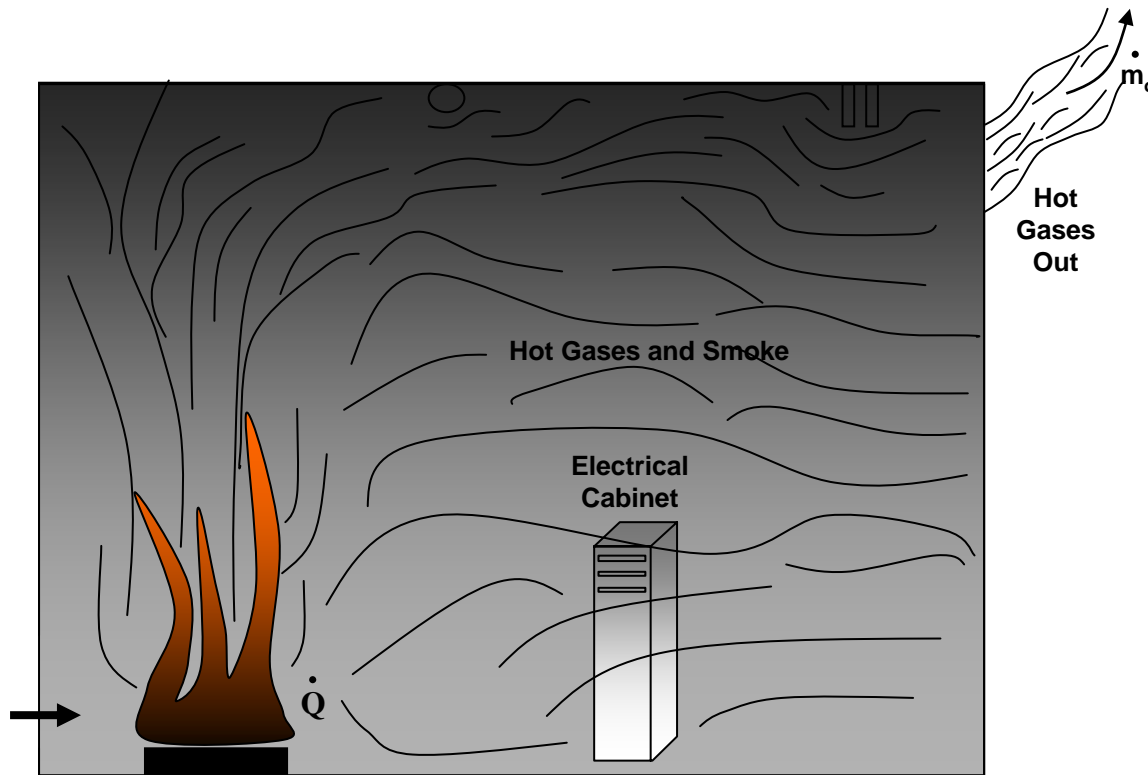
- Most significant hazard

- Thermal conditions have reached a point where all exposed combustibles ignite

- With adequate ventilation, flames may fill the enclosed volume

- Flashover causes fire to reach fully developed state where all fuel within the compartment becomes involved

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Typical Features in a Compartment Fire
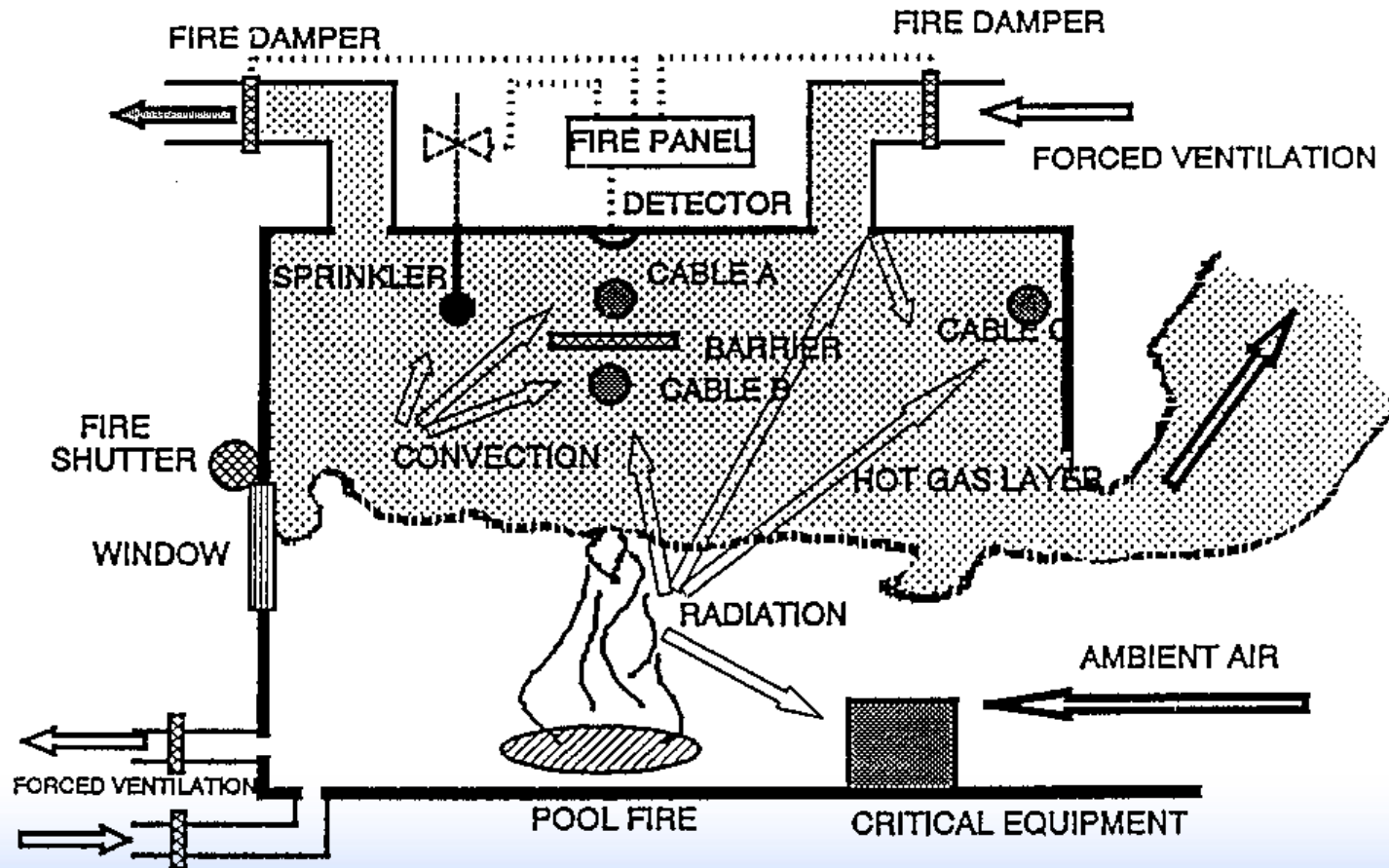
Latest (Jointly Accepted) Guidance on Fire PRA

- **NUREG/CR-6850, Vol. 1 & 2, September 2005**

- **Joint effort between NRC and EPRI**

  - **Report also identified as EPRI 1011989**

  - **Includes advances in the state-of-the-art on Fire PRA**

- **Talk about this in more detail later**

- **EPRI has recently published new interim guidance on several issues arising from pilot applications of NUREG/CR-6850**

  - **NRC has not accepted these updates**

- **Joint work ongoing in Fire HRA**

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Acceptable Methods for Performing Internal Fire PRA

- **The analysis should contain or involve the following:**
  - **Identification of plant areas/locations in which a fire could impact safety-related equipment.**
  - **Calculate a fire initiating event frequency in each area.**
  - **Estimation of the likelihood of equipment damage by a fire in the area.**
  - **Calculate the fire-induced core damage frequency for each area.**
  - **Determine impact of fire on containment performance.**

Major Steps of Fire Risk Analysis

- **Qualitative Analysis of Spatial Interactions**
  - **Information gathering, data collection, and plant walkthrough.**
  - **Plant fire locations definitions.**
  - **Development of fire location characteristics tables.**
  - **Development of location-based fire scenarios.**
- **Scenario Screening Analysis**
  - **Qualitative screening.**
  - **Quantitative screening.**

Major Steps of Fire Risk Analysis (continued)

- **Detailed Scenario Analysis**

  - **Information review and plant walkthrough**

  - **For each compartment/scenario not screened**

    - **Evaluation of scenario frequency refinement factors.**

    - **Analysis of plant response.**

  - **Risk quantification and sensitivity/uncertainty analysis.**

Internal Fire PRA - Two-Phase Approach
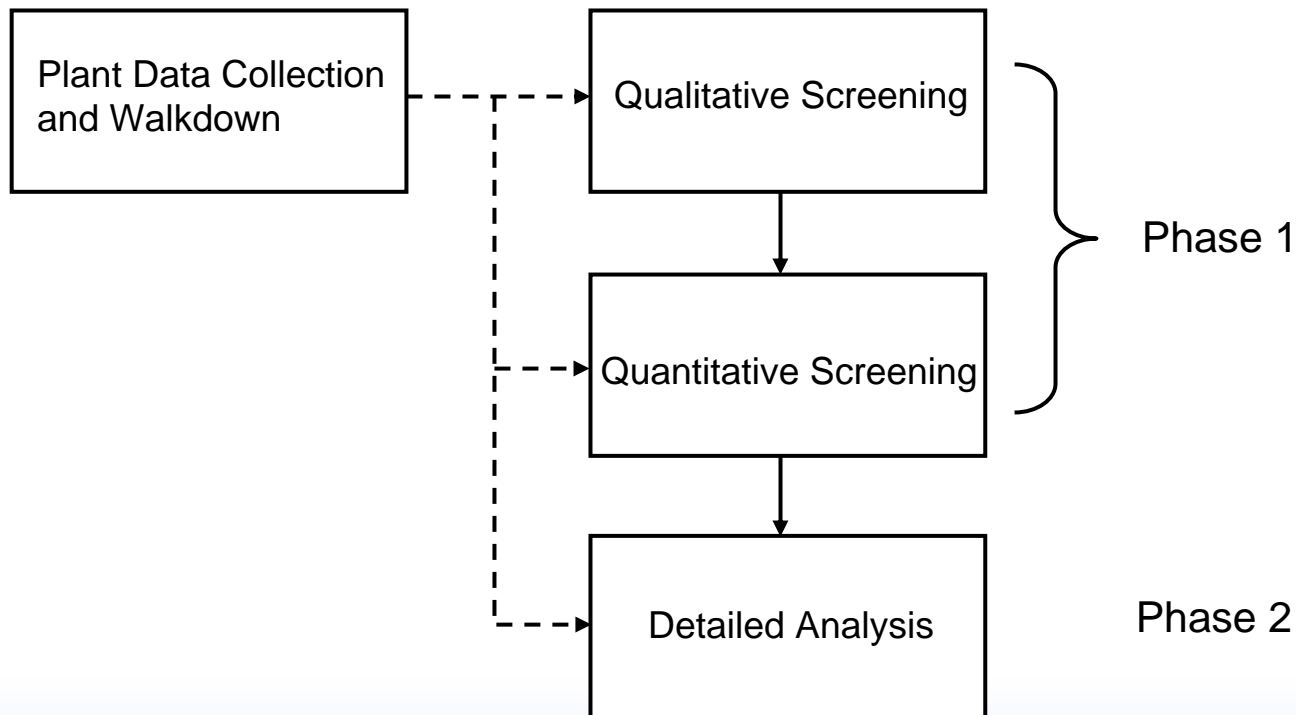
Internal Fire PRA - Key Aspects

- **Phase 1 - Screening Analysis to Identify Important Fire Locations**

  - **Screen out areas not risk significant.**

- **Phase 2 - Detailed Analysis of the Important Fire Scenarios**

  - **Involves analysis of fire frequencies and performance evaluation of fire scenarios (propagation, damage, and suppression).**

  - **Phenomenological models (COMPBRN, CFDs, etc.) for fire growth.**

  - **Reliability and/or state-transition models for suppression.**

  - **Uses logic models developed for Internal Events PRAs.**

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Overview of an Internal Fire PRA Approach

Information Collection and Processing

Fire Scenario Definition and Screening Analysis

Detailed Fire Scenario Analysis

Fire Risk Quantification

- Information Collection and Data-Base Setup
- Fire Area, Zone, Scenario Definition
- Qualitative Screening
- Estimate Conditional CDP
- Quantitative Screening
- Fire Area, Zones, Scenarios Unimportant to Risk
- Fire Area, Zones, Scenarios Important to Risk
- Fire Occurrence Frequency Assessment
- Fire Growth and Propagation Analysis
- Equipment Damage Evaluation
- Fire Detection and Suppression Modeling
- Fire Risk Quantification

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Fire Risk Quantification

LOCATION FIRE SCENARIOS

DETAILED FIRE SCENARIOS

EVENT TREES

CORE MELT/ RELEASE FREQUENCIES

AFW

TANK

DATA

PUMP 1

PUMP 2

PUMP 3

FAULT TREES

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Detailed Fire Scenarios

Example types of fire scenarios (fire source and fire targets):

- Equipment fire affecting other equipment

- Equipment fire affecting raceways

- Raceway fire affecting other raceways
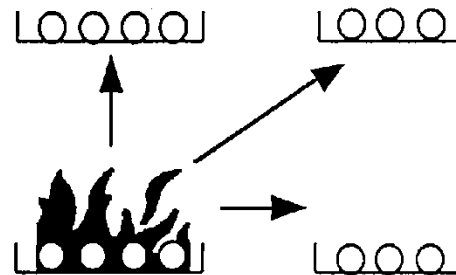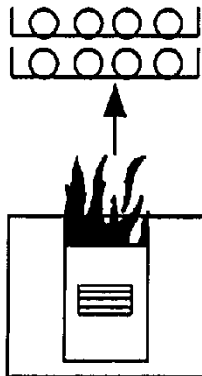
- Transient fire affecting equipment and/or raceways
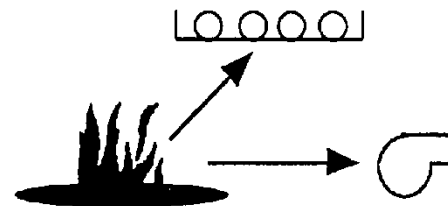
Fire Occurrence Frequency Assessment

- Determine the fire frequency for each fire location/scenario; fire initiating event frequency.

- Two approaches in fire occurrence frequency assessment:

  - Location based: auxiliary building, turbine building, diesel generator building, etc.

  - Component based: Battery, pumps, cable, transformer, motors, etc.

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Fire Occurrence Frequency Assessment (continued)

- **Two kinds of information needed:**

  - **Number of fire events.**

  - **Corresponding number of years of operating experience.**

- **Two steps involved in fire frequency determination for the plant fire locations/scenarios:**

  - **Calculate the fire occurrence frequencies for the plant buildings/components.**

  - **Apportion the fire frequencies to the fire locations/scenarios.**

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Location-Based Fire Occurrence Frequency Assessment

- **Used in earlier fire PRAs.**

- **Fire events are categorized according to the location of occurrences regardless of fire source.**

- **The generic fire occurrence frequencies are updated (Bayesian) with plant specific experience.**

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Location-Based Fire Occurrence Frequency Assessment (continued)

- **Fire occurrence frequency for a building is then apportioned to all the fire areas/zones in the building based on the characteristics of the fire areas/zones:**

  - **Amount of ignition sources.**

  - **Amount of combustibles.**

  - **The size of the fire area/zone.**

  - **Activity level in the fire area/zone.**

  - **Whether the fire area/zone is controlled.**

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Examples of Building/Room Fire Occurrence Frequencies

Statistical Evidence of Fires in LWRs (NUREG/CR-6850)

Table 6-1
Fire Frequency Bins and Generic Frequencies (Continued)

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
25	Plant-Wide Components	Transients	Power	9.9E-03	0	0	1.0	0	0	0
26	Plant-Wide Components	Ventilation Subsystems	All	7.4E-03	0.95	0.05	0	0	0	0
27	Transformer Yard	Transformer – Catastrophic[2]	Power	6.0E-03	1.0[3]		0	0	0	0
28	Transformer Yard	Transformer - Non Catastrophic[2]	Power	1.2E-02	1.0[3]		0	0	0	0
29	Transformer Yard	Yard transformers (Others)	Power	2.2E-03	1.0	0	0	0	0	0
30	Turbine Building	Boiler	All	1.1E-03	0	1.0	0	0	0	0
31	Turbine Building	Cable fires caused by welding and cutting	Power	1.6E-03	0	0	0	1.0	0	0
32	Turbine Building	Main Feedwater Pumps	Power	1.3E-02	0.11	0.89	0	0	0	0
33	Turbine Building	Turbine Generator Excitor	Power	3.9E-03	1.0	0	0	0	0	0
34	Turbine Building	Turbine Generator Hydrogen	Power	6.5E-03	0	0	0	0	1.0	0
35	Turbine Building	Turbine Generator Oil	Power	9.5E-03	0	1.0	0	0	0	0
36	Turbine Building	Transient fires caused by welding and cutting	Power	8.2E-03	0	0	0	1.0	0	0
37	Turbine Building	Transients	Power	8.5E-03	0	0	1.0	0	0	0

1. See Appendix M for a description of high-energy arcing fault (HEAF) fires.

2. See Section 6.5.6 below for a definition.

3. The event should be considered either as an electrical or oil fire, whichever yields the worst consequences.

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Surry Fire Initiating Event Frequencies (/yr)*

Fire Area	Mean	5th Percentile	50th Percentile	95th Percentile
Control Room	1.8E-3	1.2E-6	9.6E-4	7.4E-3
Cable Vault/Tunnel	7.5E-3	3.0E-6	1.8E-3	1.6E-2
Electrical Switchgear Room	8.0E-3	2.0E-5	2.4E-3	1.7E-2
Auxiliary Building	6.6E-2	2.7E-2	5.9E-2	1.6E-1
Pump Room	3.7E-3	(Lognormal EF = 3)		

*[NUREG/CR-4550, Vol. 3, Part 3]

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Component-Based Fire Occurrence Frequency Assessment

- Fire frequency in a compartment is proportional to the number of potential ignition sources.

- Used in more recent fire PRAs.

- Fire events are categorized according to the component types.

- The generic fire occurrence frequencies are updated (Bayesian) with plant-specific experience.

- Fire occurrence frequency for a fire area/zone in the plant is based on the amount and type of fire ignition sources in that fire area/zone.

Example of Component-Based Fire Occurrence Frequencies from NUREG/CR-6144

Surry-Specific Fire Frequency from Bayesian Updating for Selected Component Categories[+]

Type of fire (fire area)	5%	50%	Mean	95%
MCC Small	1.5-3	4.2-3	4.9-3	1.1-2
MCC large	4.8-5	2.9-4	5.2-4	1.8-3
Bus small	1.8-3	4.8-3	5.5-3	1.2-2
Bus large	2.2-4	9.5-4	1.3-3	4.0-3
Bus small, shutdown only	1.3-4	7.8-4	1.1-3	3.5-3
Transformer small	4.4-4	1.6-3	2.1-3	6.0-3
Transformer large	2.2-4	9.5-4	1.3-3	4.0-3
Pump small	2.2-4	9.5-4	1.3-3	4.0-3
Pump small, shutdown only	4.5-4	2.7-3	3.9-3	1.3-2
UPS, shutdown only	1.30-4	7.8-4	1.1-3	3.5-3

+ NOTE: All fire frequencies are per plant year, not per panel year or cabinet year, similarly for pumps.

Fire Growth and Propagation Analysis

- Model more realistic impact of fire on the equipment in that location.

- Consider relative location of fire source and safety-related equipment (target).

- Consider heat release rate of fire source and duration of fire exposure.

- Fire growth rate and size depend on amount/type of combustible and ventilation.

- Use computer code:
  - To predict time to damage of cable trays.
  - To determine critical distance of fire source from target.

- Computer codes: COMPBRN IIIe, CFAST, FASTLITE, FPETOOL, FLAMME-S, MAGIC, CFD models, etc.

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Example of COMPBRN IIIe Analysis Results from NUREG/CR-6144

Cable Damage Time for Oil Fires in ESGR Room J (Time in Minutes)

Cable Elevation ft.	Fire Source Distance from Cable, Ft.									
	Small Fire		Medium Fire		Large Fire					
	1	2	2	3	0	2	3	4	4.5	5
7	2	-	2	-	1	2	3	5	10	-
9	3	-	3	-	1	2	3	7	-	-
10	3	-	5	-	1	2	4	-	-	-
11	3	-	8	-	1	2	5	-	-	-
11.5	-	-	-	-	1	2	5	-	-	-
12.5	-	-	-	-	-	4	9	-	-	-
13.5	-	-	-	-	3	4	-	-	-	-

Note: 1.   Cable at 7 ft. is non-critical

2.   - No damage predicted

3.   Cable ignition is predicted for large fires at 0 and 2 ft. from the cable tray.

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Component Fragilities and Failure Modes Evaluation

- Assess equipment response and determine the likelihood and mode of equipment failure.

- Fire in a fire zone assumed to damage equipment, e.g.,

  - Cable assumed damaged if surface temperature greater than damage temperature;

  - Some other components may be assumed damaged if incident heat flux exceeds a critical value.

- Evaluate equipment failure mode; fire damage may not disable fail-safe equipment.

- Impact of fire on control cables and circuits; loss of function, spurious actuation.

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Fire-Induced Cable Failures

- **Fire-induced failures of electrical cables**
  - **Electrical insulation capability of the insulation material degrades as the cables are heated by fire.**
  - **All cable insulation and jacket materials support combustion.**
  - **One of the most important contributors to fire risk.**
- **Risk-important areas in the plant**
  - **Presence of significant fire ignition sources in the compartments.**
  - **Compartments through which critical electrical cables are routed.**
    - **Cost of tracing cables can be significant fraction of overall fire PRA cost**

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Cable Insulation Materials

- **Two broad categories: Thermoset and thermoplastic**
- **Thermoplastic**
  - **Easy to manufacture and economical to use**
  - **Generally NOT qualified (IEEE 383), more prone to fail (melting and burning)**
  - **Polyethylene (PE), Polyvinyl chloride (PVC), polyurethane, polypropylene (PPE), nylon, Teflon, etc.**
- **Thermoset**
  - **Generally qualified**
  - **Ethylene propylene rubber (EPR), crosslinked polyethylene (XLPE), DuPont's Hypalon, neoprene, silicone rubber, etc.**

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Cable Damage Mechanisms
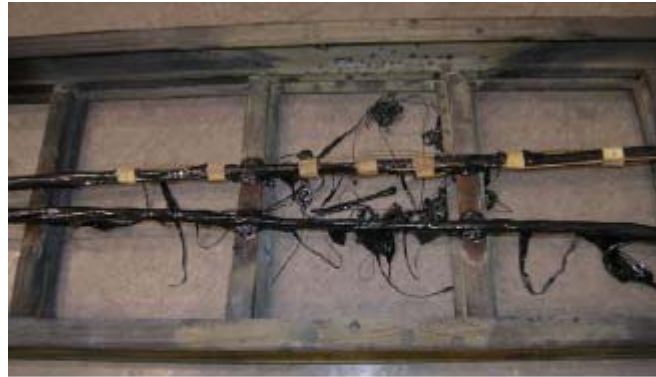
Thermoplastic

Thermoset

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Insights from Latest Research on Cable Fire Behavior (CAROLFIRE)

- Inter-cable shorting of Thermoset cable is plausible, but less likely than intra-cable failure

- Inter-cable shorting between Thermoset and thermoplastic cables is plausible, but less likely than intra-cable failure

- Configurations requiring failure of $\geq$ 3 cables plausible

  - No *a priori* limit on number of cables

    - Scenario-dependent

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Insights from Latest Research on Cable Fire Behavior (CAROLFIRE)

- **Multiple spurious operations in control circuits with properly sized current-power transformers:**

  - **Inconclusive results, do not coincide with earlier NEI/EPRI results**

- **Fire-induced hot shorts lasting > 20 minutes unlikely**

- **Spurious actuation of cold shutdown circuits not investigated by CAROLFIRE**

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Overview of the EPRI Fire-Induced Vulnerability Evaluation (FIVE) Methodology[1]

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1. EPRI TR-100370, *Fire-Induced Vulnerability Evaluation (FIVE) Methodology Plant Screening Guide,* Professional Loss Control, April 1992.

April 2009

Learning Objectives

- **After studying this section you should be able to:**

  – **List the three phases of the FIVE method.**

  – **Outline the steps involved in each of the three phases of the FIVE method.**

  – **Estimate the fire ignition frequency of a fire compartment.**

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FIVE Methodology

- **Developed to satisfy GL 88-20 requirements**
  - **Oriented toward uncovering plant fire vulnerabilities.**
- **Uses the progressive screening approach at various stages.**
- **Provides guidelines to assess potential for fire propagation across compartments due to failure of barriers and penetration seals**
- **Provides tables, worksheets, and various equations for fire growth and spread analyses.**
- **Provides tables for estimating the availability of automatic detection and suppression systems**

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FIVE Methodology is Performed in Three Phases

- **Phase I: Fire Area Screening (Qualitative Analysis)**

- **Phase II: Fire Compartment Screening (Quantitative Analysis)**

- **Phase III: Plant Walk-Through and Verification**

FIVE Overview

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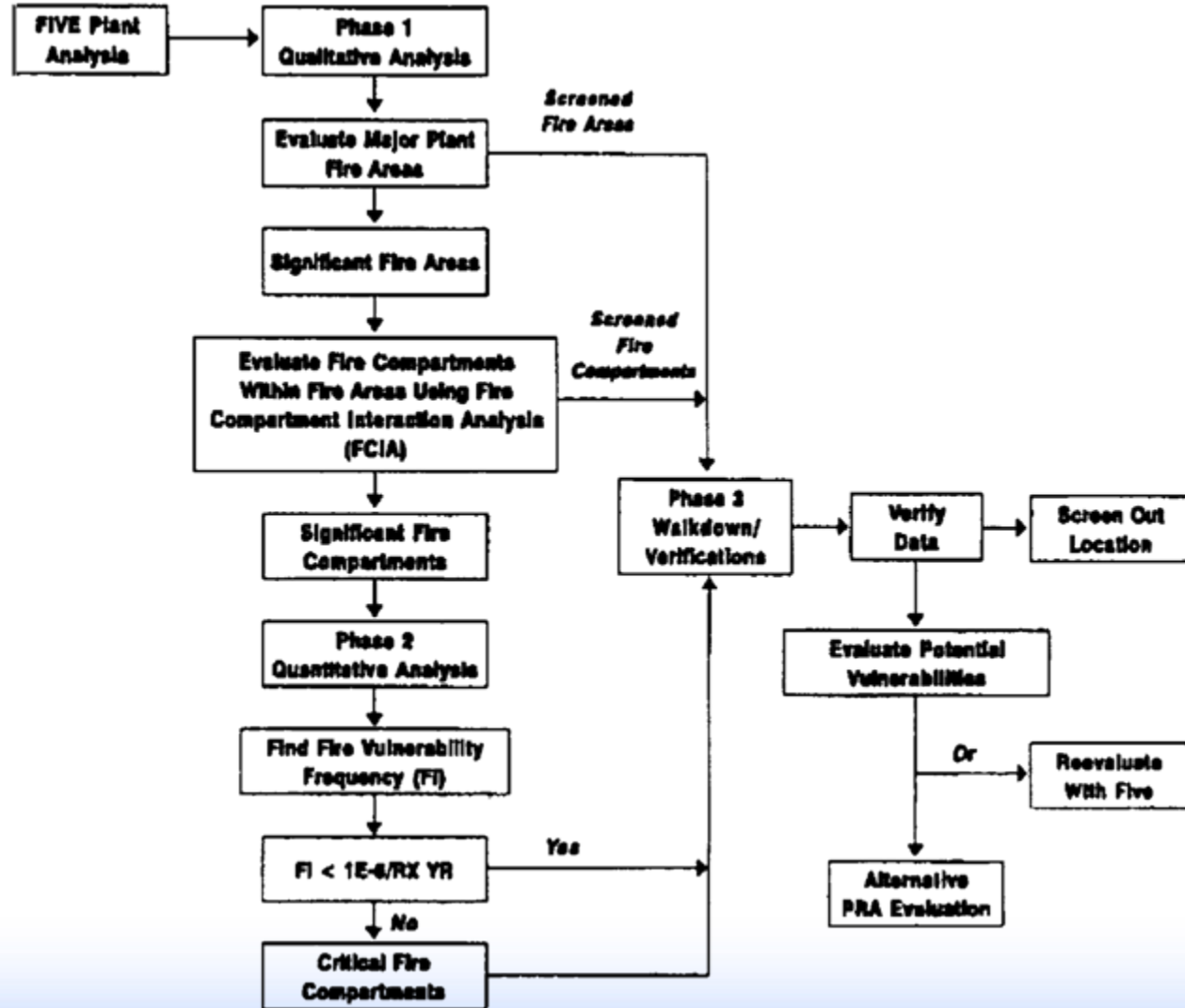
Phase I Fire Area Screening Involves the Following Steps

1. Identify plant safe shutdown systems.

2. Identify fire areas and associated compartments.

3. Identify safe shutdown equipment in each fire compartment.

4. For each fire area, perform qualitative screening analysis.

5. For the unscreened fire compartments, perform the fire compartment interaction analysis.

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Identify Plant Safe Shutdown Systems

- **Safe shutdown systems credited in Appendix R analysis.**

- **FIVE provides table format for documenting information.**

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Identify Fire Areas and Associated Compartments

- **Identify fire areas in the plant**

- **Use plant general arrangement drawings and Appendix R information**

- **Consider barriers that are included in the plant's inspection, testing, and maintenance program**

- **Define fire compartments within fire areas**

- **FIVE provides table format for documenting information**

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Identify Safe Shutdown Equipment in Each Fire Compartment

- **Use Appendix R safe shutdown equipment list.**

- **FIVE provides Safe Shutdown Equipment Detail Worksheet for documentation.**

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Qualitative Screening Criteria

- **A fire area can not be screened from further evaluation if:**

  - There are safe shutdown equipment, cables, or components in the area.

    OR

  - Following a fire in the area, there is a demand for safe-shutdown functions because the plant can not maintain normal plant operation.

- **Fire is assumed to damage everything within the fire area boundaries.**

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Fire Compartment Interactions Analysis

- Screened fire areas include all associated fire compartments.

- Unscreened fire areas may contain compartment(s) that are not important with respect to plant risk.

- Identify and screen unimportant fire compartments based on the potential for fire propagation
  - Barrier rating
  - Combustible loading
  - Fire suppression features

Fire Compartment Interactions Analysis (continued)

- **Screening criteria for compartment boundaries:**
    - Boundaries between two compartments, neither of which contain safe shutdown components nor plant trip initiators.
    - Boundaries that consist of a 2-hour or 3-hour rated fire barrier.
    - Boundaries that consist of a 1-hour rated fire barrier with combustible loading in the exposing compartment < 80,000 Btu per ft2.
    - Boundaries in which the exposing compartment has a very low combustible loading < 20,000 Btu per ft2 and automatic fire detection.
    - Boundaries in which both the exposing and exposed compartment have a very low combustible loading < 20,000 Btu per ft2.
    - Boundaries in which automatic fire suppression is installed over combustibles in the exposing compartment.

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Fire Compartment Interactions Analysis (continued)

- **Compartment is screened if:**

  - **All boundaries (adjacent compartments) of the compartment are screened out.**

    AND

  - **{Compartment contains no safe shutdown equipment} OR {Following a fire, there is no demand for safe shutdown functions}.**

- **Combine adjacent compartments with unscreened boundaries into a single compartment.**

Phase II Fire Compartment Screening Involves the Following

- **Calculate compartment fire initiation frequency (FC).**

- **If FC is less than 1E-6 per reactor year, compartment is screened from further analysis.**

- **Calculate unavailability of redundant/alternate shutdown path (PRA).**

- **For unscreened compartment, if FC•PRA is less than 1E-6 per reactor year, screen compartment from further analysis.**

- **If not screened-out, then perform fire hazard analysis and combustible material evaluation.**

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Compartment Fire initiation Frequency (FC)

- **Based on the type and amount of fire source equipment in location.**

- **Use fire ignition source frequencies, FI, from the EPRI Generic Fire Events Database.**

- **Determine weighting factor for the location (WFL).**

- **Determine weighting factor for each type of ignition source (WFIS).**

- **Compartment fire initiation frequency:**

  - $$FC = \Sigma \; FI \cdot WFL \cdot WFIS$$

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Determination of Location Weighting Factor, WFL

Weighting Factors for adjusting generic location fire frequencies to plant-specific locations	
Plant Location	**Weighting Factors (WFL)**
Auxiliary Building (PWR)	The number of units per site divided by the number of buildings.
Reactor Building (BWR) [Does not include containment]	The number of units per site divided by the number of buildings.
Cable Spreading Room	The number of units per site divided by the number of rooms per site.
Plant-Wide Components	The number of units per site.

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Determination of Ignition Source Weighting Factor, WFIS

Fire Ignition Sources and Frequencies by plant location			
Plant Location	**Ignition/Fuel Source**	**Fire Frequency (per year)**	**Method for Calculating WFIS**
Auxiliary Building (PWR)	Electrical Cabinets, Pumps	1.9×10^{-2} 1.9×10^{-2}	Divide the number of ignition sources in the fire compartment by the number in the location.
Reactor Building (BWR)	Electrical Cabinets, Pumps	5.0×10^{-2} 2.5×10^{-2}	Divide the number of ignition sources in the fire compartment by the number in the location.
Cable Spreading Room	Electrical Cabinets	3.2×10^{-2}	No ignition source weighting factor is necessary

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Fire Area/Compartment Ignition Source Data Sheet (ISDS) Auxiliary Building

Fire Compartment Boundaries: Compartment 17-1, Unit 1 Charging Pump Cubicle 1

Inside Fire Area: 17, Auxiliary Building

AREA/COMPARTMENT FIRE IGNITION FREQUENCY

FIVE STEP 1.1 Selected Plant Location (Ref. FIVE Table 1.1)	Auxiliary Building
FIVE STEP 1.2 Location Weighting Factor (WF_L) (Ref. FIVE Table 1.1)	2 Units/1 Building = 2.0

FIVE STEP 1.3   IGNITION SOURCE FREQUENCY (F_{1f})[1]

AREA/COMPARTMENT IGNITION SOURCES	(A)	(B)	WF_{IS}=A/B	F_f (Table 1.2)	F_{1f}
1. Electrical Cabinets	0	100%	0	1.9E-2	0
2. Pumps	1	36	2.78E-2	1.9E-2	1.1E-3

| Plant Wide Components Weighting Factors (WF_L) per Five Table 1.1 | WF_L = 2 2 Units | | | | |

PLANT WIDE IGNITION SOURCES	(A)	(C)	WF_{IS}=A/C	F_f (Table 1.2)	
1. Transients (0 + 4 + 0 + 0 + 2 + 0)	6	1*/69	8.70E-2	1.3E-3	2.3E-4
2. Welding/Ordinary Combustibles	1	1*/69	1.45E-2	3.1E-2	9.0E-4
3. Welding/Cables	1	1*/69	1.45E-2	5.1E-3	1.5E-4
4. Transformers	0	93	0	7.9E-3	
5. Ventilation Systems	0	195	0	9.5E-3	
6. Fire Protection Panels	0	30	0	2.4E-3	
7. Air Compressors	0	25	0	4.7E-3	

| FIVE STEP 1.4   AREA/COMPARTMENT FIRE FREQUENCY (F_1)[2] | | | | | 2.38E-3 |

WFL

WFL

FC

WFIS   FI

Fire Hazard and Combustible Material Analysis/Fire Growth and Propagation

- A process for evaluating the probability of critical combustible loading for the compartment.

- Fixed and transient combustibles are considered.

- Fire suppression prior to target equipment damage is considered.

- FIVE provides the algorithm, worksheets, and look-up tables for analysis.

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Fire Hazard and Combustible Material Analysis (continued)

- **Evaluate fixed and transient combustible exposures.**
    - **Identify fire sources.**
    - **Identify target component.**
    - **Develop fire scenarios.**
    - **Determine critical combustible loading.**
- **Use FIVE evaluation worksheets.**
- **Determine fire suppression (automatic and/or manual) unavailability.**
- **Determine critical combustible (transient) loading probability.**

Critical Combustible (Transient) Loading Probability

- **The CCL probability is dependent on the following factors:**
  - **Probability of combustibles located within a critical range of target, P_r.**
  - **Probability of combustibles being exposed, P_e.**
  - **Frequency of combustible present in the compartment.**
  - **Frequency of combustible material inspection.**
- **Probability of critical transient combustible loading is given by:**

    $$P_r \bullet P_e \bullet P_p$$

    where P_p is the probability of critical amount of transient combustibles being present between inspections.

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Compartment Critical Combustible Loading Probability and Fire Damage Frequency

- **Probability of compartment critical combustible loading fire is given by:**

$$P_{CL} = P_{fx} + P_r \bullet P_e \bullet P_p$$

  where P_{fx} is for a fixed source in the compartment, and is evaluated first.

- **Transient source not considered if fixed source has impact on target (P_{fx} = 1).**

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Compartment Critical Combustible Loading Probability and Fire Damage Frequency (continued)

- **Overall fire damage frequency for compartment is given by:**

$$F_{FD} = F_C \bullet P_{RA} \bullet P_{CL} \bullet U_{FS}$$

    F_C is the compartment fire frequency

    P_{RA} is the unreliability of redundant/alternate shutdown path

    U_{FS} is the unreliability of fire suppression

- **Compartment is screened from further analysis if F_{FD} is less than 1E-06 per reactor year.**

- **Compartments not screened are significant fire compartments.**

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Evaluate Potential Fire Vulnerabilities

- **For the unscreened compartments:**

    – **Accept the results.**

    – **Implement administrative and/or hardware changes.**

    – **Refine the analysis for the unscreened compartments.**

- **Use PRA models to determine risk significance of unscreened compartments.**

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Phase III Plant Walk-Through and Verification Involves the Following Steps

- Performed before or after Phase I/II.

- Collect data and confirm information gathered for analysis.

- Verify assumptions and calculations.

- Plant walkdown guide/checklist provided.

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Examples from IPEEE Submittals

- **Boiling Water Reactor (Duane Arnold Energy Center)**

- **Pressurized Water Reactor (Wolf Creek Generating Electric Station)**

DAEC Summary of FIVE Phase I Screening

Building	Total Number of Fire Zones	FIVE Phase I Screening
Reactor Building	33	15 fire zones can be screened out on the basis that a postulated fire does not propagate into adjacent fire zones <u>and</u> 1 fire zone does not impact safe shutdown equipment. (The drywell is dismissed due to the N2 atmosphere - consistent with FIVE.) Total of 16 zones screen out.
Turbine Building	20	8 fire zones can be screened out as described above.
Control Building	9	2 fire zones can be screened out as described above.
Radwaste/Offgas Building	9	Entire building screens out.

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DAEC Summary of FIVE Phase I Screening (continued)

Building	Total Number of Fire Zones	FIVE Phase I Screening
Pump House/Intake Structure	10	3 fire zones can be screened out as described above.
Security Center/ Technical Support Center/DAC	9	Entire building screens out.
Administration Building	3	Entire building screens out.
Low Level Radwaste Processing and Storage Facility	21	Entire building screens out.
TOTAL	114	71 fire zones screen out - 43 left unscreened.

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DAEC FIVE Phase I Screening

NO.	FIRE AREA	COMP ID	COMPARTMENT DESCRIPTION	SSE	FIE	PHASE I STEP #4 SCREEN	PHASE I STEP #5 SCREEN	PFS	PHASE I STEP #6 SCREEN
47	TB	8-G	Diesel Generator Day Tank Room - Division II	Y	Y	N	N	N	N
48	TB	8-N	Emergency Diesel Generator Room - Division I	Y	Y	N	N	N	N
49	TB	8-J	Diesel Generator Day Tank Room - Division I	Y	Y	N	N	N	N
50	TB	8-K	Demineralizer Pump and Tank Cells	N	Y	N	N	N	Y
51	TB	9-A	Turbine Operating Floor (North End)	N	Y	N	N	N	Y
52	TB	9-B	Turbine Operating Floor (Area Between the Shield Walls)	N	Y	N	N	Y	N
53	TB	9-C	Turbine Operating Floor (South End)	N	Y	N	N	N	Y
54	CB	10-A	Corridor Control Building	N	Y	N	N	N	Y
55	CB	10-B	Battery Room Division II	Y	Y	N	N	N	N
56	CB	10-C	Battery Room Nonessential	N	Y	N	N	N	Y
57	CB	10-D	Battery Room Division I	Y	Y	N	N	N	Y
58	CB	10-E	Essential Switchgear Room Division II	Y	Y	N	N	N	N
59	CB	10-F	Essential Switchgear Room Division I	Y	Y	N	N	N	N
60	CB	11-A	Cable Spreading Room	Y	Y	N	N	N	N
61	CB	12-A	Control Room Complex	Y	Y	N	N	N	N
62	CB	12-B	Control Building HVAC Room	Y	Y	N	N	N	N
63	Rad/Offgas Bldg	13-A	Radwaste Drumming and Shipping	N	Y	N	N	N	Y
64	Rad/Offgas Bldg	13-B	Radwaste Treatment and Access Area	N	Y	N	N	N	Y
65	Rad/Offgas Bldg	13-C	Radwaste Precoat and Access Area	N	Y	N	N	N	Y
66	Rad/Offgas Bldg	13-D	Radwaste Control Room	N	Y	N	N	N	Y
67	Rad/Offgas Bldg	14-A	Machine Shop	N	Y	N	N	N	Y
68	Rad/Offgas Bldg	15-A	Offgas Charcoal Adsorber Vault	N	Y	N	N	N	Y
69	Rad/Offgas Bldg	15-B	Offgas Control and Glycol Area	N	Y	N	N	N	Y
70	Rad/Offgas Bldg	15-C	Offgas Prefilter and Condenser Area	N	Y	N	N	N	Y
71	Rad/Offgas Bldg	OGS	Offgas Stack	N	Y	N	N	N	Y
72	Pumphouse/Intake	16-A	Pumphouse RHR and ESW Pump Area Division II	Y	Y	N	N	N	N
73	Pumphouse/Intake	16-B	Pumphouse RHR and ESW Pump Area Division I	Y	Y	N	N	N	N
74	Pumphouse/Intake	16-C	Pumphouse Main Pump Room	N	Y	N	N	N	Y
75	Pumphouse/Intake	16-D	Pumphouse Diesel Fire Pump	N	Y	N	N	N	Y
76	Pumphouse/Intake	16-E	Pumphouse Fire Pump Day Tank	N	Y	N	N	N	Y
77	Pumphouse/Intake	16-F	Pumphouse Safety-Related Piping	Y	Y	N	N	N	N
78	Pumphouse/Intake	17-A	Intake Structure Pump Area Division I	Y	Y	N	N	N	N
79	Pumphouse/Intake	17-B	Intake Structure Pump Area Division II	Y	Y	N	N	N	N
80	Pumphouse/Intake	17-C	Intake Structure Screen Area Division I	Y	Y	N	N	N	N
81	Pumphouse/Intake	17-D	Intake Structure Screen Area Division II	Y	Y	N	N	N	N
82	Security/TSC/DAC	18-A	Security Center Security Power	N	Y	N	N	(1)	Y
83	Security/TSC/DAC	18-B	Security Center Lobby, Ingress and Egress Search Area	N	Y	N	N	(1)	Y
84	Security/TSC/DAC	18-C	Security Cntr Rm, Dir. Off, Lckr, Batt, & Elect/Inst Repair Rms	N	Y	N	N	(1)	Y
85	Security/TSC/DAC	18-D	Security Center Equipment Room	N	Y	N	N	(1)	Y
86	Security/TSC/DAC	19-A	Tech Support Ctr, Doc Control Ctr, Library, and Office Area	N	Y	N	N	(1)	Y
87	Security/TSC/DAC	19-B	Technical Support Center Mechanical Room	N	Y	N	N	(1)	Y
88	Security/TSC/DAC	19-C	Data Acquisition Center - Computer Room	N	Y	N	N	(1)	Y
89	Security/TSC/DAC	19-D	Data Acquisition Center - First Floor Area	N	Y	N	N	(1)	Y

NO.	FIRE AREA	COMP ID	COMPARTMENT DESCRIPTION	SSE	FIE	PHASE I STEP #4 SCREEN	PHASE I STEP #5 SCREEN	PFS	PHASE I STEP #6 SCREEN
90	Security/TSC/DAC	19-E	Data Acquisition Center - Second Floor Area	N	Y	N	N	(1)	Y
91	Admin Bldg	20-A	First Floor Area	N	Y	N	N	(1)	Y
92	Admin Bldg	20-B	Second Floor Area	N	Y	N	N	(1)	Y
93	Admin Bldg	20-C	Third Floor Area	N	Y	N	N	(1)	Y
94	LLRPSF	21-A	Surge Tank Room (Room 802)	N	Y	N	N	(1)	Y
95	LLRPSF	21-B	Future Expansion North (Room 801)	N	Y	N	N	(1)	Y
96	LLRPSF	21-C	DAW Storage Area (Room 804)	N	Y	N	N	(1)	Y
97	LLRPSF	21-D	Spend Resins Storage Area (Room 803)	N	Y	N	N	(1)	Y
98	LLRPSF	21-E	Truck Load Bay, Access Areas, & Mezz. (Rms 800, 805, 806, & 842)	N	Y	N	N	(1)	Y
99	LLRPSF	21-F	QA/QC Inspection Office (Room 808)	N	Y	N	N	(1)	Y
100	LLRPSF	21-G	Corr, Misc Rms & Expn. Area (Rms 807, 810, 826, 834-837, 839-841)	N	Y	N	N	(1)	Y
101	LLRPSF	21-H	Container Storage Area (Room 838)	N	Y	N	N	(1)	Y
102	LLRPSF	21-I	Sump Room (Room 809)	N	Y	N	N	(1)	Y
103	LLRPSF	21-J	HP Office and Count Rooms (Rooms 832, 833)	N	Y	N	N	(1)	Y
104	LLRPSF	21-K	Processing Area (Rooms 811 thru 825)	N	Y	N	N	(1)	Y
105	LLRPSF	21-L	Mask Cleaning Area (Room 831)	N	Y	N	N	(1)	Y
106	LLRPSF	21-M	Railroad Bay Extension (Room 827)	N	Y	N	N	(1)	Y
107	LLRPSF	21-N	HVAC & Elec. EQ Room (Room 862)	N	Y	N	N	(1)	Y
108	LLRPSF	21-O	Hydrolazing Decontamination Area (Room 829)	N	Y	N	N	(1)	Y
109	LLRPSF	21-P	Storage and Corridor (Rooms 859, 861, 863)	N	Y	N	N	(1)	Y
110	LLRPSF	21-Q	Mezzanine Future Expansion (Room 860)	N	Y	N	N	(1)	Y
111	LLRPSF	21-R	Radwaste Offices & Crane Control Room (Rooms 844-858)	N	Y	N	N	(1)	Y
112	LLRPSF	21-S	Tool & Equipment Storage (Room 828)	N	Y	N	N	(1)	Y
113	LLRPSF	21-T	Future Storage Area & Chemistry Dept Equip Room (Room 843)	N	Y	N	N	(1)	Y
114	LLRPSF	21-U	Future Expansion Upper Level (Room 864)	N	Y	N	N	(1)	Y

NOTES:

(1): As each of these buildings contains no safe shutdown equipment, the individual compartments of each building are conservatively combined into a single fire compartment so as not to unnecessarily expend effort performing Fire Compartment Interaction Analysis.

PHASE I STEP #4 SCREEN:
- Initial quick screen
- IF SSE=N AND FIE=N THEN SCREEN=Y
- ELSE SCREEN=N

PHASE I STEP #5 SCREEN:
- Only compartments with safe shutdown equipment addressed
- IF SSE=Y AND FIE=Y THEN SCREEN=N
- IF SSE=Y AND FIE=N THEN SCREEN=Y
- ELSE SCREEN=N

PHASE I STEP #6 SCREEN:
- Investigate potential for fire spread between compartments
- IF PFS=N AND (SSE=N OR FIE=N) THEN SCREEN=Y
- ELSE SCREEN=N

DAEC Example ISDS Worksheet

Fire Compartment Ignition Source Data Sheet (ISDS)

Compartment Description
- Fire Area
- Fire Compartment

Compartment Fire Ignition Frequency
Step 1.1   Plant Location ID   RB
           Plant Location Description   Reactor Building (BWR)

Step 1.2   Location Weighting Factor (WFL)   1.00E+00

Compartment Ignition Sources (FIF)

Fire Ignition/Fuel Source	Sources in Compartment (A)	Sources in Plant Location (B)	Weighting Factor WFLS=(A)/(B)	Fire Frequency (FF)	Ignition Source Frequency (FIF)
1 Electrical Cabinets	0	3.83E+02	0.00E+00	5.0E-02	0.0E+00
2 Pumps	2	7.90E+01	2.53E-02	2.5E-02	6.3E-04
3	0	0.00E+00	0.00E+00	0.0E+00	0.0E+00
4	0	0.00E+00	0.00E+00	0.0E+00	0.0E+00
5	0	0.00E+00	0.00E+00	0.0E+00	0.0E+00
6	0	0.00E+00	0.00E+00	0.0E+00	0.0E+00
7	0	0.00E+00	0.00E+00	0.0E+00	0.0E+00

Plant Wide Ignition Sources

	(A)	(C)	(A)/(C)	Reference 1.2	
Fire Protection Panels	0	0.00E+00	0.00E+00	2.4E-03	0.0E+00
RPS MG Sets	0	4.00E+00	0.00E+00	5.5E-03	0.0E+00
Non-qualified Cable Run	0	0.00E+00	0.00E+00	6.3E-03	0.0E+00
Junction box/Splice in Non-qualified Cable	0	0.00E+00	0.00E+00	1.6E-03	0.0E+00
Junction Box in Qualified Cable	0	0.00E+00	0.00E+00	1.6E-03	0.0E+00
Transformers	0	1.60E+01	0.00E+00	7.9E-03	0.0E+00
Battery Chargers	0	0.00E+00	0.00E+00	4.0E-03	0.0E+00
Off-gas/Hydrogen Recombiner (BWR)	0	0.00E+00	0.00E+00	8.6E-02	0.0E+00
Hydrogen Tanks	0	0.00E+00	0.00E+00	3.2E-03	0.0E+00
Miscellaneous Hydrogen Fires (Y/N)	N	7.70E+01	0.00E+00	3.2E-03	0.0E+00
Gas Turbines	0	0.00E+00	0.00E+00	3.1E-02	0.0E+00
Air Compressors	0	0.00E+00	0.00E+00	4.7E-03	0.0E+00
Ventilation Subsystems	0	1.63E+02	0.00E+00	9.5E-03	0.0E+00
Elevator Motors	0	0.00E+00	0.00E+00	6.3E-03	0.0E+00
Dryers	0	0.00E+00	0.00E+00	8.7E-03	0.0E+00
Cable Fires Caused by Welding	N/A	7.70E+01	1.30E-02	5.1E-03	6.6E-05
Transient Fires Caused by Welding/Cutting	N/A	7.70E+01	1.30E-02	3.1E-02	4.0E-04

Transients:	(Y/N)	8		1.3E-03	1.4E-04
Cigarette Smoking	N	0			
Extension Cords	Y	4			
Heater	Y	3			
Candle	N	0			
Overheating	N	0			
Hot Pipe	Y	1			

Compartment Fire Frequency (FL)
Step 1.4   Compartment Fire Frequency   1.24E-03
           Fire Compartment CSDS Required   Yes

Notes:
(A) Number of Ignition Sources in Compartment
(B) Total Number of Ignition Sources in Selected Plant Location
(C) Total Number of Ignition Sources/Compartments in Plant

Ignition Source Frequency: FIF = WFL*WFLS*FF
Compartment Fire Frequency: FL = SUM(FIF)

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DAEC Fire Ignition Frequency Estimates

Fire Compartment	Fire Ignition Frequency (Per Yr)
1-A	1.24E-03
1-B	2.64E-03
1-C	7.34E-04
1-D	1.87E-03
1-E	1.94E-03
1-F	4.02E-03
1-G	6.04E-04
1-H	1.24E-03
2A/2B/2C	2.43E-02
2-D	6.62E-04

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DAEC Fire Ignition Frequency Estimates (continued)

Fire Compartment	Fire Ignition Frequency (Per Yr)
2-G	6.04E-04
3A/3B	2.73E-02
3-D	7.82E-03
4-A	3.18E-03
7A/8A/8C/8D/9B	1.30E-02
7-B	4.15E-03
7-C	1.07E-03
7-E	4.06E-03
8-F	2.97E-02
8-G	6.45E-04
8-H	2.97E-02

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WCEGS Phase II Step 2 Summary Results, Screened Compartments

Fire Area	Room Number(s)	Phase I	Event Type	Ig Freq (ISF)	Cond Core Dmg (CCDP)	(ISF)(CCDP)	Phase II
A-1A	1115	Y *	TRA	7.690E-04	2.746E-06	2.112E-09	Y
A-1B	1201, 1202, 1203, 1204	N	TRA	5.650E-04	1.214E-05	6.859E-09	Y
A-1C	1101	N	TRA	6.060E-04	4.111E-04	2.491E-07	Y
A-1D	1102, 1103, 1104, 1105, 1106, 1120, 1123, 1124, 1125	N	TRA	2.770E-03	2.305E-06	6.385E-09	Y
A-1E	1121,1122, 1128, 1129, 1130,1205	N	TRA	2.820E-03	3.365E-04	9.489E-07	Y
A-2	1111, 1112, 1113, 1114	N	TRA	2.640E-03	9.109E-06	2.405E-08	Y
A-3	1116, 1117, 1407	N	TRA	1.690E-03	6.301E-05	1.065E-07	Y
A-4	1107, 1108, 1109, 1110	N	TRA	2.640E-03	2.278E-05	6.014E-08	Y
A-5	1119	N	TRA	1.950E-03	2.305E-06	4.495E-09	Y
A-7	1126	N	TRA	1.410E-03	2.305E-06	3.250E-09	Y
A-9	1309	N	TRA	3.760E-04	3.315E-06	1.246E-09	Y
A-10	1310	N	TRA	3.760E-04	9.067E-06	3.409E-09	Y
A-11	1335	N	TRA	3.760E-04	2.053E-03	7.719E-07	Y
A-12	1336	N	TRA	3.760E-04	6.278E-06	2.361E-09	Y
A-13	1325	N	TRA	7.690E-04	6.528E-04	5.020E-07	Y
A-14	1326	N	TRA	7.690E-04	2.905E-05	2.234E-08	Y
A-15	1331	N	TRA	9.040E-04	2.905E-05	2.626E-08	Y
A-20	1502, 1503, 1505, 1507	N	TRA	1.380E-03	1.218E-05	1.681E-08	Y
A-21	1501	N	TRO	2.600E-03	2.820E-04	7.332E-07	Y
A-23	1411, 1412, 1508, 1509	N	MSLB	3.760E-04	1.871E-03	7.035E-07	Y
A-24	1323	N	TRA	3.760E-04	7.137E-05	2.684E-08	Y
A-25	1322	N	TRA	3.760E-04	6.278E-06	2.361E-09	Y
A-26	1405, 1415	N	TRA	3.760E-04	1.052E-04	3.956E-08	Y
A-28A	1413, Train A	N	TRA	5.590E-04	2.574E-05	1.439E-08	Y
A-28B	1413, Train B	N	TRA	5.590E-04	2.530E-05	1.414E-08	Y
A-29	1304, 1324, 1327	N	TRA	3.760E-04	4.833E-06	1.817E-09	Y
A-30	1305, 1328, 1330	N	TRA	3.760E-04	2.575E-05	9.682E-09	Y
A-33	1206, 1207, 1329	N	TRA	3.760E-04	5.679E-04	2.135E-07	Y
C-8	3229	N	TRA	3.760E-04	2.749E-06	1.034E-09	Y

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WCEGS Phase II Step 2 Summary Results, Unscreened Compartments

Fire Area	Room Number(s)	Phase I	Event Type	Ig Freq (ISF)	Cond Core Dmg (CCDP)	(ISF)(CCDP)	Phase II
A-6	1127	N	TRO	3.760E-04	9.747E-03	3.665E-06	N
A-8D	1301, 1313, 1314, 1315, 1318, 1320, 1321	N	TRO	5.990E-03	9.058E-01	5.426E-03	N
A-16	1401, 1402, 1406, 1408	N	CCW	7.930E-03	7.627E-01	6.048E-03	N
A-17	1409	N	TRA	1.720E-03	2.827E-03	4.862E-06	N
A-18	1410	N	TRA	1.820E-03	8.271E-02	1.505E-04	N
A-19	1504, 1506, 1513	N	TRO	4.330E-03	3.324E-01	1.439E-03	N
A-22	1512	N	TRO	1.460E-03	2.592E-02	3.784E-05	N
A-27	1403	N	TRA	7.390E-03	1.423E-01	1.052E-03	N
C-1A	3101	N	SWS	1.760E-03	2.813E-01	4.951E-04	N
C-1B	3104	N	TRA	3.760E-04	3.326E-03	1.251E-06	N
C-5	CNAC, 3212, 3216, 3218, 3219, 3220, 3222, 3223	N	TRA	5.590E-04	9.164E-03	5.123E-06	N
C-6	CSAC, 3203, 3205, 3207, 3208, 3209, 3211	N	TRA	2.860E-03	3.326E-03	9.512E-06	N
C-7	3230	N	TRA	3.760E-04	3.476E-03	1.307E-06	N
C-9	3301	N	TRA	1.910E-03	5.509E-03	1.052E-05	N
C-10	3302	N	TRA	1.870E-03	5.362E-03	1.003E-05	N
C-11	3305	N	TRA	3.760E-04	3.461E-03	1.301E-06	N
C-12	3306	N	TRA	3.760E-04	3.609E-03	1.357E-06	N
C-17	3418	N	DC4	3.760E-04	7.276E-03	2.736E-06	N
C-18	3419	N	DC1	3.760E-04	1.013E-01	3.809E-05	N
C-21	3501	N	TRO	4.230E-04	1.139E-01	4.818E-05	N
C-22	3801	N	TRO	4.230E-04	1.143E-01	4.835E-05	N
C-23	3505	N	TRA	3.760E-04	9.340E-03	3.512E-06	N
C-24	3504	N	TRO	3.760E-04	1.045E-01	3.929E-05	N
C-27	3601, 3603, 3604, 3605, 3606	N			Control Room Analysis		N
C-30	3617	N	TRA	3.760E-04	1.216E-02	4.572E-06	N
C-33	3804	N	TRA	3.760E-04	6.569E-02	2.470E-05	N
CC-1D	3225, 3226, 3227, 3228	N	LSP	7.240E-04	6.676E-03	4.833E-06	N
CC-1F	3303, 3304, 3402, 3503	N	LSP	3.420E-03	6.695E-03	2.290E-05	N
T-2A	Turbine Building General	N	TRO	4.750E-02	3.060E-04	1.454E-05	N

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Example DAEC Phase III Walkdown Checklist

AREA DESCRIPTION: *Laydown Area*	
FIRE ZONE: *3-A*	
BUILDING: *Reactor Building*	ELEVATION: *786' - 0"*

WALKDOWN VERIFICATION PURPOSE(S)

- Verification of IPEEE fire analysis issues
- Verification of IPEEE high wind analysis issues
- Other _____

WALKDOWN VERIFICATION CHECKLIST

Verification Item	Verified Yes	No	Comments
1. Verify that the ignition sources in this fire compartment are as listed in the Ignition Source Data Sheet.			
2. Verify that the fire protection systems in this fire compartment are as listed in the Critical Screen Data Sheet.			
3. Verify that, in the event of spurious fire protection system actuation, redundant safe shutdown trains are not susceptible to damage from the suppressant. Consider coverage of suppression system and existing barriers/shields protecting equipment.			
4. Verify the fire barriers, fire dampers, fire doors, and penetration seals are maintained under the plant surveillance and maintenance program.			
5. Verify that the boundaries of this fire area satisfy the definition for fire compartment barriers as described in FIVE.			

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Example DAEC Phase III Walkdown Checklist (continued)

AREA DESCRIPTION: *Laydown Area*		
FIRE ZONE: *3-A*		
BUILDING: *Reactor Building*	ELEVATION: *786' - 0"*	
6. Verify FCIA screening criteria selected for the compartment boundaries is appropriate.		
7. Verify that fixed combustibles are as listed in the Fire Hazards Analysis.		
8. Verify quantities of fixed combustibles are as listed on the Critical Combustible Data Sheet.		
9. Identify any flammable liquid or gas storage vessels or piping (e.g., H2) and whether these are outliers with respect to leakage under seismic conditions.		
10. Note the existence and dimensions of dikes that would contain flammable liquid spills.		
11. Review expected operations in area and verify that the expected transient combustibles in this area are as considered in the Critical Screen Data Sheet.		
12. Verify that the approximate quantities of expected transient combustibles is as considered in the Critical Combustible Data Sheet.		
13. Verify that the approximate distance between fire sources and targets is consistent with that used in the fire modeling of this fire compartment.		
14. Review controls on control room panels to determine the extent of damage given the postulated fire event.		
15. Verify that control room back panels are compartmentalized so as to minimize the spread of fire from one panel to another.		
16. Verify that external doors and vents are protected by interior missile barriers.		
ANALYST:	DATE:	

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Fire PRA

P-204

April 2009

Update on Fire PRA

- **Joint NRC-RES/EPRI development effort**
  - **NUREG/CR-6850 (September 2005)**
    EPRI 1011989
- **Aimed primarily at practitioners of Fire PRA**
- **Assumes Fire PRA team comprises experts in:**
  - **Fire analysis**
  - **General PRA**
  - **Human Reliability Analysis**
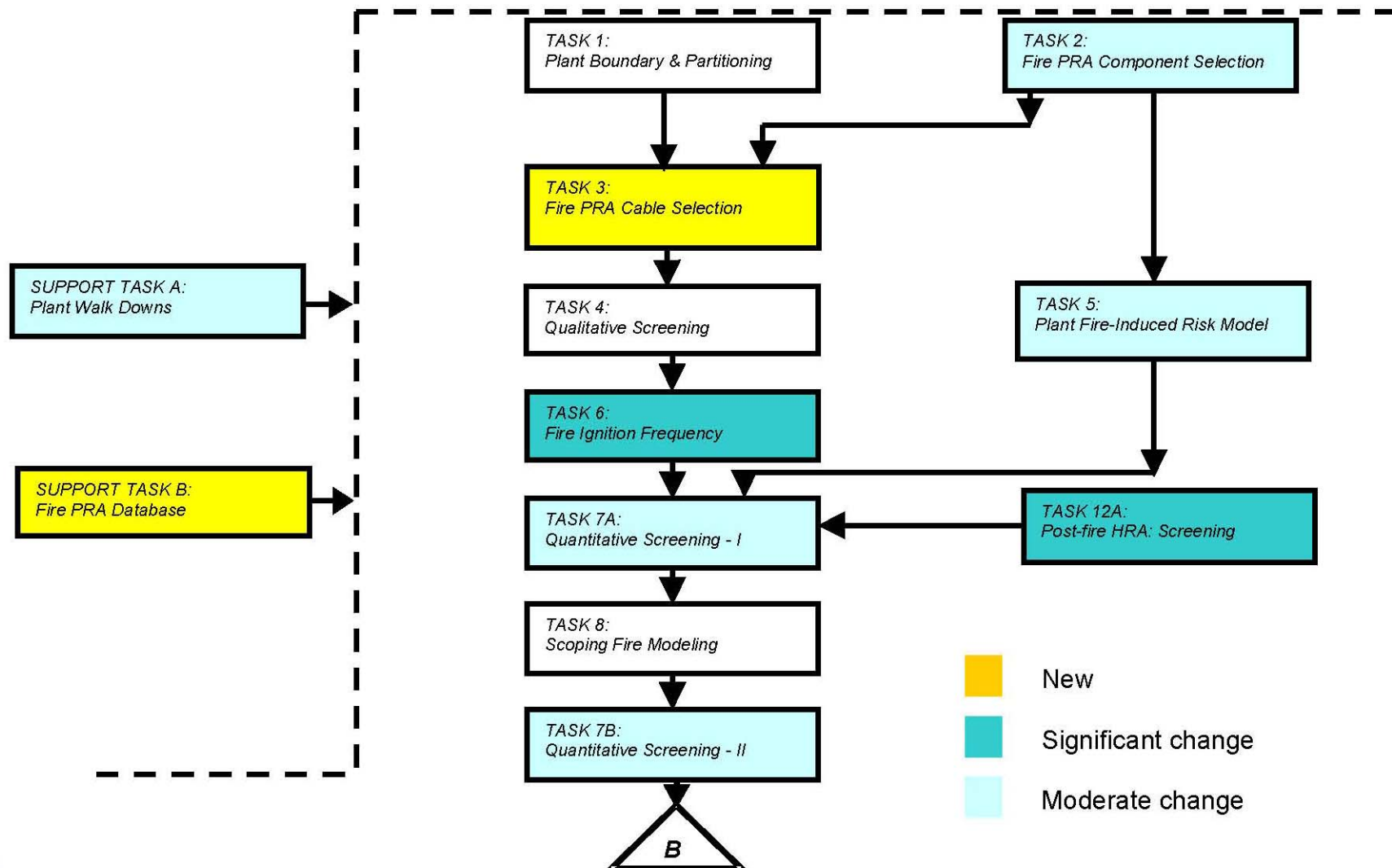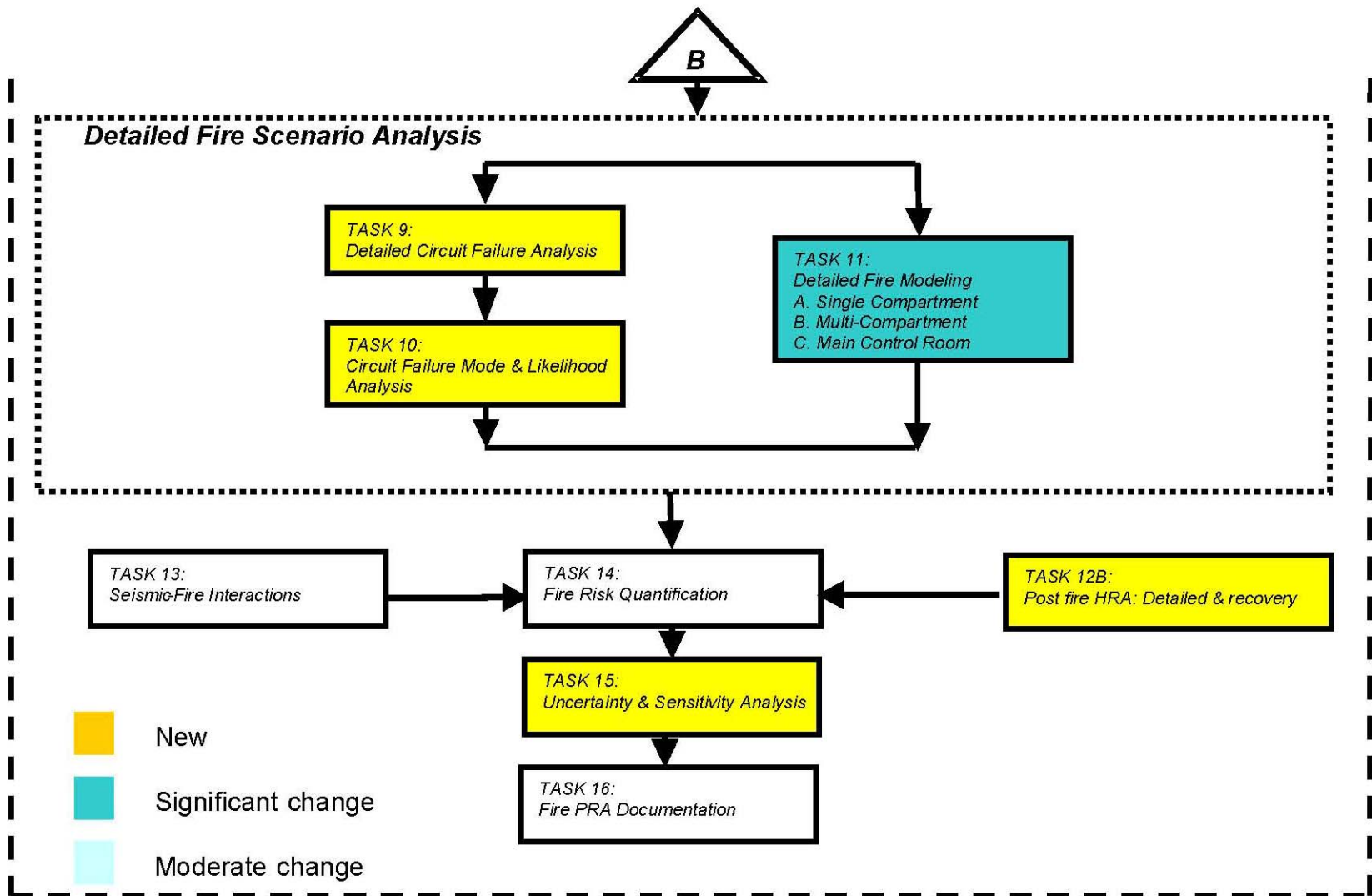 - **Electrical Analysis**

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Figure 1
Overview of the Fire PRA Process

Figure 1
Overview of the Fire PRA Process (Continued

Task 1 – Plant Boundary & Partitioning

- **Two-phase task**
  - **Global plant areas (boundary) identified**
    - **E.g., at building level**
  - **Fire "Compartments" identified**
    - **Effective at containing fire damage under most conditions**
    - **This is the basis for subsequent analysis**
      - **Typically defined by physical fire barriers**
    - **Not necessarily the same as regulatory defined fire areas or zones**

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Task 2 – Component Selection

- **Components selected become focus of analysis**

- **Utilizes info from Internal Events PRA and Fire Safe Shutdown Analysis**
    - **Internal events PRA reviewed and applicable core damage sequences identified**

- **Also need to consider spurious actuation of equipment important to human response**

- **As with most PRA tasks, this is an iterative process**

- **Results support Cable Selection (Task 3)**

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Task 3 – Cable Selection

- **Objective is to identify important cables/circuits and their routing**

- **Starts with component list from task 2**

  – **Vital reference information:**

    Appendix R circuit analysis

    Plant-specific cable location data

    Resource of last-resort – manual review of drawings and cable location walkdowns

- **Together with component list, identifies important fire compartments/areas/locations**

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Task 4 – Qualitative Screening

- **Compartment is screened if:**
  - **It does not contain any equipment or cables from Tasks 2 or 3**
  - **Fire in compartment will NOT lead to:**
    - **Auto Rx trip**
    - **Manual trip per plant procedure**
    - **Required trip per plant tech specs or LCO**
- **Screened compartments will be reexamined in the context of multi-compartment fire scenarios**

Task 5 – Fire-Induced Risk Model

- **Internal events PRA modified to incorporate:**
    - **Unscreened compartments**
    - **Equipment identified in task 2**
        - **Uses database developed as support task B**
- **Iterative process, model will be progressively refined**

Task 6 – Fire Ignition Frequencies

- **Ignition sources in unscreened fire compartments**
- **Fire ignition bins and associated (generic) frequencies provided (Table 6-1, 37 bins)**
  - **Frequencies updated with plant-specific data (if available)**
- **Locations mapped into generic locations (Table 6-2, 8)**
  - **Weighting factors determined (W_L)**
- **Ignition source counts (# of sources in compartment J of location L)**
  - **Weighting factors determined ($W_{IS,J,L}$)**
- **Transient weighting factors calculated for selected location**
  - **Procedure provided, generic frequencies include transients**

Task 7 – Quantitative Screening

- **Fire PRA (from task 5) quantified for each compartment**
  - **Ignition frequencies (task 6)**
  - **All equipment in compartment assumed failed**
  - **Screening HRA values used**
- **Criteria**

  Total screened CDF < 0.1 Internal Events CDF

  Total screened LERF < 0.1 I.E. LERF

  Total screened ICDP < 1E-6

  Total screened ILERP < 1E-7

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Task 8 – Scoping Fire Model

- **Assesses the potential for ignition sources to affect equipment within a compartment**
  - **i.e., fire ≠ auto failure of all equipment (task 7)**
- **Walkdown each compartment/ignition-source**
  - **Zone of Influence (ZOI) calculated for each source**
    - **Some sources might be screened (no targets in ZOI**
- **Unscreened sources**
  - **Heat Release Rate (HRR) estimated (tables provided)**
  - **Severity Factors (SF) estimated based on comparison between calculated HRR for target (within ZOI) and 98% HRR of source (tables provided)**
  - **SF used as a modifier on ignition frequency**

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Task 9 – Detailed Circuit Failure Analysis

- **Failure modes and effects analysis performed on all relevant cables in all un-screened compartments**
  - Information entered into Fire PRA database
- **Cable failure modes**
  - Shorts-to-ground
  - Hot shorts
- **Failure effects**
  - Spurious operation
  - Loss of power
  - Loss of control
  - Erroneous indication
  - Others

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Task 10 – Circuit Failure Mode Likelihood Analysis

- **Develops likelihoods for cable failure modes**

- **Table provided lists failure probabilities**
  - **By cable type: Thermoset vs. Thermoplastic**
  - **By raceway: tray vs. conduit vs. armored tray**

- **Computational method also provided**
  - **More complex, but less conservative**

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Task 11 – Detailed Fire Modeling

- **Explicit identification and quantification of each fire scenario**
  - **Each scenario includes a specific ignition source and specific target(s)**
  - **Requires the use of fire modeling tools (for fire growth and propagation analysis)**
- $\lambda_k = \lambda_{i,k} * SF_k * P_{ns,k}$
  - **where:**
  - λ_k = **frequency of fire scenario k**
  - $\lambda_{i,k}$ = **fire ignition frequency of source i, associated with scenario k**
  - SF_k = **Severity factor of fire scenario k**
  - $P_{ns,k}$ = **non-suppression prob. of fire scenario k**
- **Guidance provided for both SF and P_{ns} for each of the 37 generic locations (see task 6)**

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Task 12 – Post-Fire HRA

- **Basically a Human Reliability Analysis for each fire scenario**
  - **Identify and add Human Failure Events (HFEs) to Fire PRA model**
  - **Develop initial screening values for Human Error Probabilities (HEPs)**
    - **All HEPs set to 1.0, or**
    - **Follow guidance procedure to assign all HFEs into 1 of 4 sets (e.g., set 1 = PRA value x 10)**
  - **Detailed, best-estimate HRA analysis of important HFEs**

Task 13 – Seismic-Fire Interactions Assessment

- **Fire Risk Scoping Study (NUREG/CR-5088, 1989) identified four issues**

  - **Seismically induced fires**

    - **E.g., rupture of a flammable material container**

  - **Degradation of fire suppression**

  - **Spurious actuation of suppression and/or detection**

  - **Degradation of manual firefighting effectiveness**

- **Issues are assessed qualitatively, guidance is provided**

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Task 14 – Fire Risk Quantification

- **Combines all information into the Fire PRA model and calculates:**
  - **Core Damage Frequency**
  - **Large Early Release Frequency**
- **Identify dominant contributors to CDF and LERF**
- **Identify sensitivity studies to be performed**

Task 15 – Uncertainty and Sensitivity Analysis

- **Integrated with all other tasks**
  - **Each task includes identification of uncertainties**
- **In practice, two classes of uncertainties**
  - **Modeling (logic, phenomenology, completeness, etc.)**
  - **Data (e.g., statistical confidence)**
- **Identify which uncertainties will be addressed and how**

Task 16 – Fire PRA Documentation

- **Documents background information, assumptions, and activities**
  - **Should allow independent review of Fire PRA**
- **Suggested outline provided in guidance document**

Task 17 – Plant Walkdowns (Support Task A)

- Generally, several walkdowns are performed

  1. Initial (tasks 1 & 2)

  2. Cable routing confirmation (task 3, 9, 10)

  3. Component count (task 5)

  4. Scoping fire modeling (task 8)

  5. Detailed analysis (task 11)

  6. Human reliability (task 12)

  7. Seismic fire interactions (task 13)

Task 18 – Fire PRA Database (Support Task B)

- **Detailed bookkeeping system**
  - **components, cables, locations, compartments, sources, targets, etc.**

- **Relational database**
  - **Sample database structure provided**

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NUREG/CR-6850

Review Table of Contents

Fire Risk Observations

P-204

April 2009

Sandia Fire Risk Scoping Study (NUREG/CR-5088) Issues

- **FRSS Issues:**
  - **Seismic/Fire Interactions**
  - **Fire Barrier Qualifications**
  - **Manual Fire Fighting Effectiveness**
  - **Total Environment Equipment Survival**
  - **Control System Interactions**
  - **Improved Analytical Codes**
- **Disposition of FRSS Issues**
  - **The FRSS issues have been addressed qualitatively**
  - **Review of plant design and other relevant documents, and plant walkdown**

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Insights from Fire IPEEE Review (NUREG-1742)

- Analyses are based on FIVE (15), fire PRA (13) or a combination of methods (42).

- Fire CDF varied from 3.6E-08 per year to 1.9E-04 per year.

- Results varied significantly across analyses because of variations in methods, assumptions, and data used, level of conservatism, and quality of analysis.

- Fire can be a potentially important contributor to overall CDF.

- No consistent definition of vulnerability.

- Fire scenarios affecting the control room, cable spreading room, and switchgear rooms are major contributors to fire risk in many submittals. Turbine building was found to be important at some plants.

- Important locations, such as cable spreading room or control room, were screened from detailed analysis in some submittals due to low fire initiation likelihood.

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Fire IPEEE Review (continued)

- **Electrical panel fires were the most significant fire CDF contributors in most submittals.**

- **Some submittals used optimistic guidelines and data described in NSAC/181 or EPRI's Fire PRA Implementation Guide.**

- **Optimistic assumptions made on electrical cabinet fires (excluded as credible fire sources, low heat release rates used, inter-cabinet propagation not considered, etc.).**

- **Screening of fire zones sometimes made on the basis of fixed ignition sources only.**

- **A few identified transient combustibles as significant. Some submittals dismissed transient fire sources from specific fire zones based on administrative control.**

- **Fire-induced transients (LOFW, MSIVC, LOSP, loss of support system) were found to be the most important accident sequences.**

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Fire IPEEE Review (continued)

- Possibility of a fire causing an initiating event other than reactor trip is not always addressed.

- Fire-induced LOCAs, including spurious opening of SRVs/PORVs, were considered for many plants and were not found to be important. RCP seal LOCAs were found to be important contributors for many Westinghouse PWR plants.

- Most licensees screened all scenarios involving propagation of a fire from one zone to another or concluded that these scenarios were not significant.

- Failure of fire barriers has not have been properly accounted for in many cases.

- Only a few submittals explicitly treated potential variation in fire size for each fire area.

- Self-ignited cable fires generally assumed possible only for IEEE-383 unqualified cables.

Fire IPEEE Review (continued)

- **The possibility of a small fire damaging critical cables and equipment in close proximity within a very short time was not considered.**

- **For submittals that only considered Appendix R equipment cables, it is not clear that all IPE components and associated cables not included in the list of safe shutdown systems were assumed to be in failed states.**

- **Evaluation of fire-induced cable failure modes (e.g., hot short) was generally not discussed adequately.**

- **A simple model was used for fire suppression (automatic and manual combined). Many IPEEE submittals did not model manual fire suppression (except for control room fires).**

- **Generic values for suppression system reliability were used that were not based on system design features and compliance to the NFPA standards.**

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Fire IPEEE Review (continued)

- **Human errors were shown to be important. Operator actions in response to effects of fire (smoke, heat, loss of lighting, spurious indications, etc.) were rarely modeled in detail.**

- **Possibility of simultaneous multiple unit core damage not addressed.**
  - **Shared area.**
  - **Operator response to fire.**
  - **Propagation scenarios between fire zones of adjacent units.**

- **Unavailability of cross-connected equipment due to outage at adjacent unit not accounted for.**

- **Insufficient details were provided in some submittals for the FRSS issues response; e.g., control system interactions, seismic/fire interactions.**

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Fire IPEEE Review (continued)

- **However, insights about plant features important to safe plant operation were gained, despite the above shortcomings.**

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Key Observations from Review of NPP Fire Events

- **Fire can pose a serious threat to nuclear safety**
  - **SBO, loss of core cooling functions**
- **Operator actions are influenced by and do influence the chain of events in a fire incident**
- **Multiple fires are a possibility**
  - **An initial event may lead to multiple fires**
  - **A primary fire may lead to secondary fires**
- **Fire in non-safety areas may be important**
  - **Large turbine building fires have had significant impact**
  - **Non-safety switchgear fire**

Key Observations from Review of NPP Fire Events (continued)

- **Materials of construction and plant layout can have a strong influence on the outcome of a fire.**

- **Smoke propagation can be an important element of a fire scenario.**

- **A fire involving cables may cause unexpected circuit faulting effects.**

- **Long duration fires may not be so rare.**

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Lessons Learned from NFPA-805 Pilots

- **Issues raised during pilot process being monitored and resolved via Frequently Asked Questions (FAQ) process**
  - **Some issues resolved**
  - **Some pending**
  - **Some have defied resolution to date**

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Some "Closed" FAQs

- **FAQ 06-0016: Electrical cabinet counting guidance**
  - Provides clarifying examples of "vertical section" counting guidance
- **FAQ 06-0017: High Energy Arc Faults in electrical cabinets**
  - Provides clarifying guidance for counting cabinets in the context of HEAF ignition frequency
  - Provides a frequency split between low and medium voltage cabinets
  - Clarifies treatment of HEAF in MCCs

Some "Closed" FAQs

- **FAQ 06-0031: Ignition source counting guidance clarifications and extensions**

  - **Bin 14 – Electric motors: clarifies guidance, provides for excluding small motors of 5hp or less and totally enclosed motors.**

  - **Bin 21 – Pumps: provides for excluding small sampling pumps, and other pumps of 5hp or less**

  - **Bin 23 – Transformers: provides for excluding dry transformers of 45KVA or less**

  - **Bin 26 – Ventilation subsystems: clarifies that intent is to exclude small subsystems powered by motors of 5hp or less (consistent with electric motors bin 14)**

Some FAQs Pending Resolution

- **FAQ 07-0035: High energy arc faults in bus ducts**
  - **Issue:**
    - **Guidance document is silent on topic**
  - **General approach to resolution:**
    - **Acknowledge potential for such events (e.g., Diablo Canyon 5/2000)**
    - **Provide plant wide frequency and counting/partitioning guidance**
    - **Provide zone of influence and scenario development guidance**

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Some FAQs Pending Resolution

- **FAQ 08-0044: Large fires due to spilled oil**
  - **Issue:**
    - **Guidance for large oil spill and fire is generating conservative results especially in the case of MFW pump fires (high frequency of large release compared to experience base)**
  - **General approach to resolution:**
    - **Provide an alternative approach and revised fire frequencies for leaks and spills from higher volume circulating oil/lubrication systems**

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Some FAQs Where Consensus Has Not Been Achieved

- **FAQ 08-0046: Incipient Fire Detection**

  - **Issue:**

    - **Methodology provides no approach for crediting incipient fire detection systems**

  - **General approach to resolution:**

    - **Develop an approach that would credit these systems**

Some FAQs Where Consensus Has Not Been Achieved

- **FAQ 08-0048: Fire frequencies**
  - **Issue:**
    - **Fire frequency analysis may not reflect industry trends (i.e., towards reduced fire frequencies**
  - **General approach to resolution:**
    - **EPRI has published interim report with updated frequencies**
      - <u>**Fire PRA Methods Enhancements: Additions, Clarifications, and Refinements to EPRI 1019189**</u>**, Interim Report 1016735, December 2008**
    - **NRC has not accepted EPRI results**
    - **Discussion ongoing**

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Fire PRA Lessons Learned from NFPA-805 Pilots

- **Fire PRA component list will be larger than Appendix R and internal PRA component list**
  - **New components whose omission will be non-conservative:**
    - **For multiple spurious operation considerations**
    - **For fire-specific operator manual actions**

- **Cable selection is probably the single biggest factor that drives resource requirements**

  - **Burden comes largely with the need to trace selected cables**

  - **Need an *accessible* cable database, and constructing such a database from existing system may not be so easy**
    - **Depends a lot on depth of cable tracing and nature of current tracking system**

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Fire PRA Lessons Learned from NFPA-805 Pilots

- **Circuit analysis may be far more resource intensive than expected**
  - Screening analysis producing high CCDP: when interlocks and permissives in internal events fault trees are failed, widespread equipment failure results
  - Resolution of conservatism requires more, and more detailed, circuit analysis than anticipated
- **Fire modeling in single compartments**
  - Hand calculations will suffice for many cases, but more sophisticated modeling (e.g., compartment fire models) also has a place
- **Fire modeling in the main control room**
  - Fire zone or field models are necessary
  - Will require detailed system analysis and HRA
  - Smoke removal system can significantly impact abandonment and risk

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Fire SDP vs. Fire PRA Concepts and Terminology

P-204

April 2009

Concepts and Terminology

- **Objectives:**

  - **Outline the basic quantification process used in fire risk analysis**

  - **Define the factors that go into quantification**

  - **Define key terms**

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Risk

- **Risk combines the likelihood that something undesirable will happen with the severity of resulting consequences**

- **In context of NRC mission, risk is most correctly measured based on potential public health consequence:**

  - **Atomic energy act empowers NRC to establish and enforce standards governing the commercial use of nuclear materials and facilities as "the Commission may deem necessary or desirable in order to protect health and safety and minimize danger to life or property."**

- **That implies risk measures such as acut and latent fatalities**

- **Primary measure of fire risk is Core Damage Frequency (CDF)**

  - **CDF is a surrogate for public health consequence risk**

  - **Large Early Release Frequency (LERF) not used for fire protection SDP**

How we estimate Fire CDF

- **We calculate CDF using four basic factors:**
  - **Fire Frequency (F)**
  - **Severity Factor (SF)**
  - **Probability of Non-Suppression (PNS)**
  - **Conditional Core Damage Probability (CCDP)**

- **Note that in fire PRA SF is sometimes folded in as a part of 'F' or 'PNS' depending on analyst preference**
  - **It is called out explicitly as a factor in fire SDP**

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Fire Risk (cont.)

- **For one fire scenario:**

$$CDF_i = F_i * SF_i * PNS_i * CCDP_i$$

- **Do as many fire scenarios as needed, add them up (carefully), and that is the risk estimate**

- **Roll-up risk values at different levels:**

  - **One fire scenario**

  - **One fire ignition source – multiple scenarios**

  - **One fire area – multiple ignition sources**

  - **One building – multiple fire areas**

  - **Entire unit**

  - **Entire plant site**

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Fire Risk (cont.)

- **SDP focuses on fire area roll-up**
  - Question: what is the risk impact of a specific performance deficiency?
  - Deficiency is assumed to be tied to one or two fire areas
  - We estimate risk for the impacted area(s)
- **Remember that some issues cut across fire areas – examples:**
  - Post-fire manual actions
  - Manual fire brigade
  - Circuit analysis issues
- **We don't do the cross-cutting issues (yet)**
  - You have to tie your finding to one or more fire areas
  - No guidance for picking areas for a cross-cutting issue

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Fire Frequency (F):

- **Definition: The likelihood that a fire will occur during some time period**
  - **Time period is generally 12 months of at-power reactor operations**
    - **one reactor year (ry)**
- **Calculated based on past experience**
  - **Database contains nearly 1500 reported "fires"**
    - **EPRI Fire Event Database updated through 2002**
  - **Industry average capacity factors are factored in**
- **General units of measure:**
  - **fires/ry**

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Fire Frequency (cont.)

- **You might hear that not all events reported as a fire hold the potential to challenge nuclear safety – TRUE!**

    - **Events were "screened out" if there was no potential for a safety challenge**

    - **The values provided for SDP should not be adjusted beyond the instructions provided – leave that to Phase 3**

    - **In the end, we retain about ½ of the fire "events" as potentially challenging**

        - **Actual percentage retained depends on nature of fire source**

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Event screening

- **Sounds easy, but can lead to problems if you're not careful**

- **Important to maintain independence**
  - **Other steps in analysis take credit for things you might be "counting" when you screen events**
  - **Basic assumptions tend to flow from the "event set" you choose as representing your fire frequency**

- **Be careful when particular events appear to not be relevant to fire risk**
  - **They might not be, but their basis for rejecting might be included with another factor credited elsewhere**

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More on Fire Frequency

- **Statistics give us the frequency of a fire somewhere, or involving something, in the plant**
  - **Tied to a location or fire ignition source**
  - **We assume this frequency is the same for all plants**
- **What we want is the frequency for a fire involving a specific ignition source in a specific location**
  - **For most cases, component based fire frequencies do this directly – e.g., you get frequency for one motor**
  - **In some cases we apply a partitioning factor to reflect a critical location out of all possible locations**
    - **Area ratio factors – e.g., transients, welding**
    - **Linear feet ratio factors – e.g., cable trays, control room panels**

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If We Need a Room Fire Frequency

- We can use a generic fire area fire frequency based on average industry experience for similar fire areas
  - SDP through Step 2.3

    OR

- We can add up the contribution from all the individual sources in that particular fire area
  - SDP beginning with Step 2.4

- Don't expect to get the same answer both ways
  - For SDP, the generic values are intended to be slightly conservative – especially in Phase 1
  - This won't be a universal truth, but differences should not be significant

Grouping Fire Ignition Sources

- You can group some individual ignitions sources, and treat the group rather than each individual
    - Common example is electrical cabinets/panels
    - All members of the group need to be "the same"
        - Fire characteristics
        - Proximity to targets (damage) and secondary combustibles (fire spread)
- Frequency for the group is sum of frequency of each individual member
    - If 10 panels, fire frequency = 10 times frequency for a single panel

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Severity Factor (SF)

- **General Definition: A value between 0 and 1 reflecting the fraction of all fires that are considered threatening in the context of a specific fire scenario**

Severity Factors: Fire SDP

- **SDP approach ties SF to fire intensity**
  - **Current PRA practice, but not same as typical IPEEE**
- **Why:**
  - **Burn an electrical panel 10 times, and you'll probably get 11 different burn profiles**
  - **Fire intensity profile is inherently uncertain**
    - **All things being equal, still some fires will remain small, some will get big**
  - **If it takes a big fire to cause problems (and it usually does) we reflect this through the severity factor**

Severity Factors (cont.)

- **SDP Definition: SF = the fraction of fires big enough to cause damage to at least one potential target and/or spread fire to secondary combustibles**
  - **We calculate "big enough" on a case-specific basis**
    - **How big is the fire (use peak HRR)**
    - **How close are the damage targets and secondary combustibles**
  - **We use two HRR values for each fire ignition source**
    - **Lower HRR represents 90% of all fires – SF = 0.9**
    - **Larger HRR represents worst 10% of fires – SF = 0.1**
  - **In effect we split each fire ignition source into two possible fires – one big and one not so big**
  - **If only the larger HRR leads to spread/damage, we end up with a net severity factor – SF = 0.1**

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Illustration of SF Concept:

- Even looking at a single fire ignition source, not all fires will be the same some will be big, some not so big

- Fire Intensity or heat release rate (HRR) is not a point value!

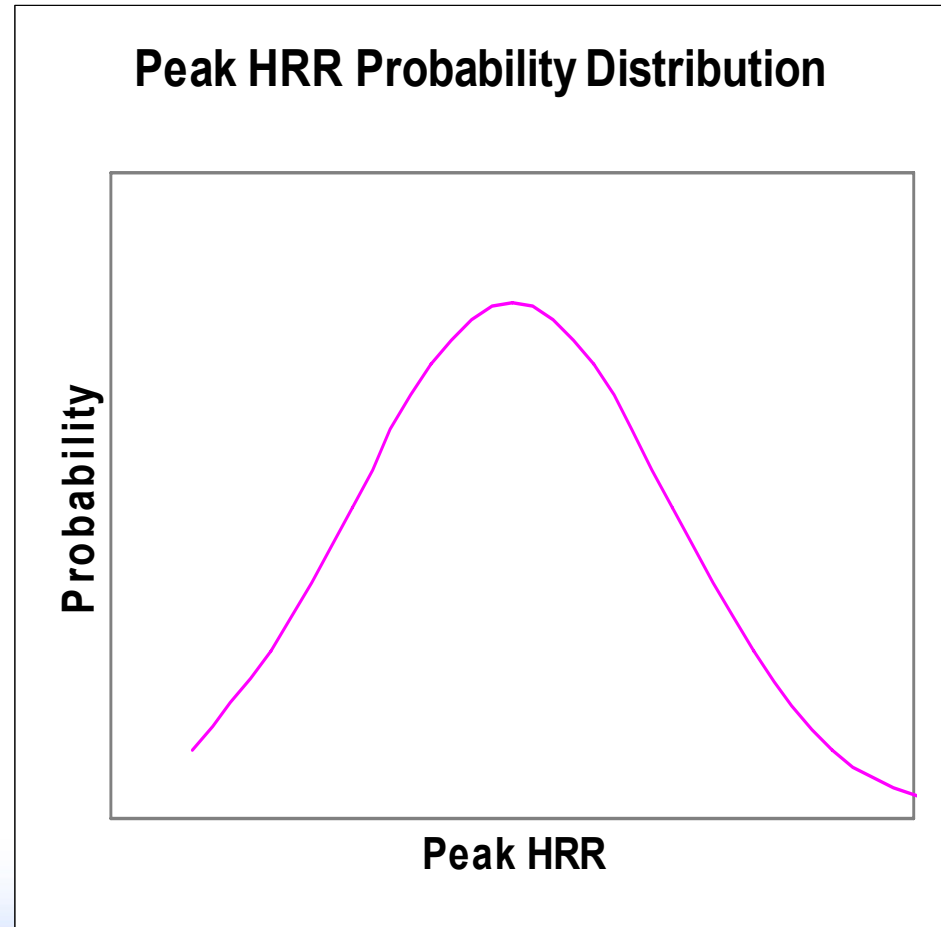- We model uncertainty in peak HRR with a probability distribution

Peak HRR Probability Distribution

Probability (y-axis)

Peak HRR (x-axis)

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Illustration of SF Concept - General

- We look for the smallest fire leading to fire damage and/or spread

- Fires that large or larger are the "risky" ones

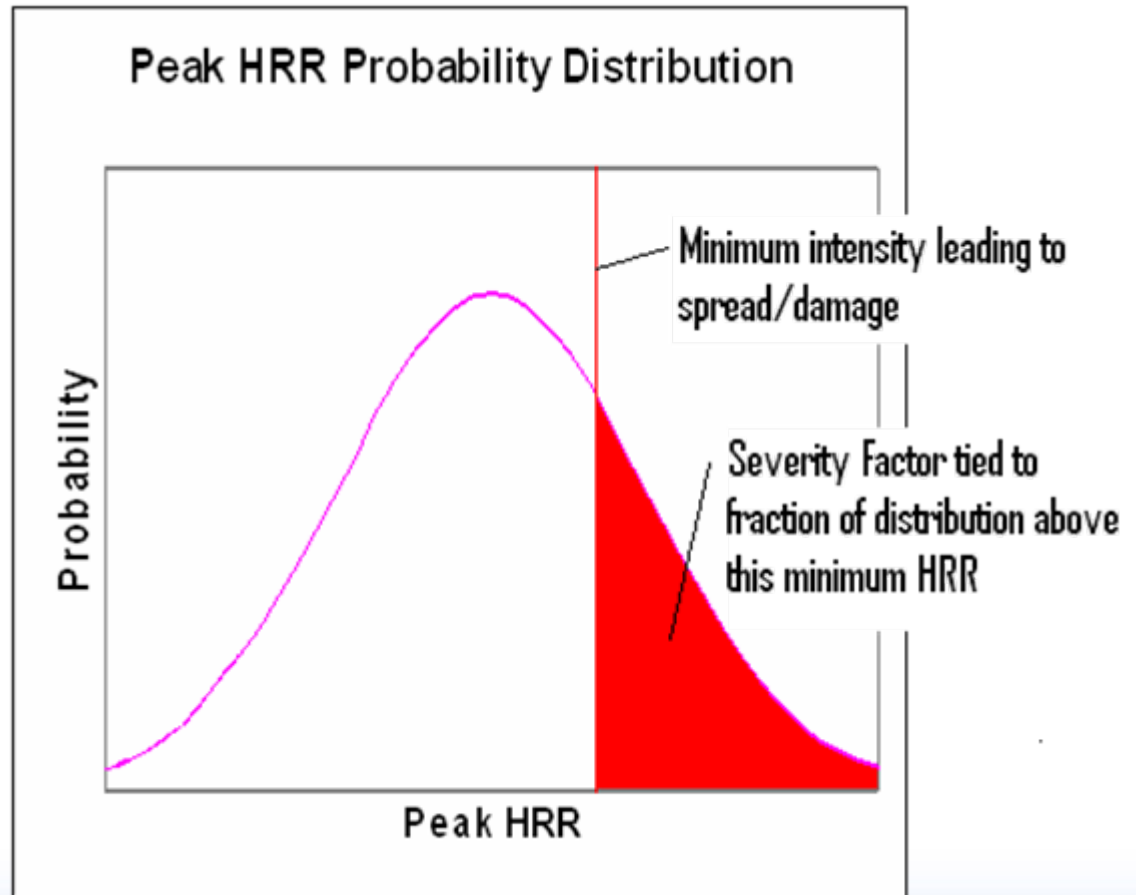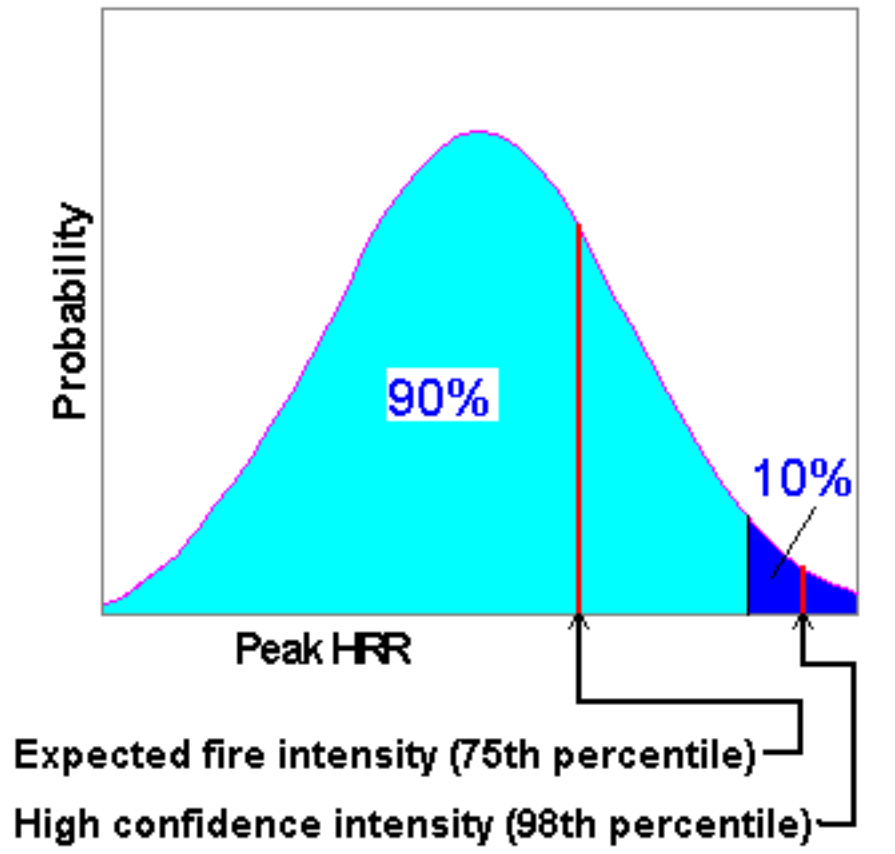- We tie SF to the fraction of fires that large or larger

Peak HRR Probability Distribution

Probability

Peak HRR

Minimum intensity leading to spread/damage

Severity Factor tied to fraction of distribution above this minimum HRR

Illustration of SF Concept - SDP

- **For SDP we use a simplified version**

- **Two fire HRR values for each fire ignition source**

    - **Expected value represents 90% of fires**

    - **High confidence value represents 10% of fire**

Peak HRR Probability Distribution

Probability

90%

10%

Peak HRR

Expected fire intensity (75th percentile)

High confidence intensity (98th percentile)

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SDP approach – quick review

- **SDP using simplified version of general approach**
  - **Two fire intensity (HRR) values used represent the full distribution for each fire ignition source**
    - **'Expected' and 'High Confidence' or 75% and 98%**
    - **Words/numbers not important – it's the concept that counts**
    - **Assigned SF of 0.9 and 0.1 respectively**
  - **You assess the spread/damage potential for these two HRR values**
  - **The final risk results combine these two cases using SF as, in effect, a weighting factor on fire frequency**
  - **Net severity factor depends on whether each intensity value causes damage**

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Obtaining HRR Values

- **Discrete HRR values were suggested based on NRC-sponsored research**

- **Review and discussion by SDP fire scenario team including NRC and Industry reps. – an expert panel**

- **Final values ultimately accepted for SDP**

- **Some adjustments made in HRR values to reflect SDP team/panel input**

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Severity Factor – Past Red Flag Issue for Fire PRA

- Some cases of abusive application were seen in the IPEEEs, so take care when someone cites those

- Can find severity factors crediting:

  - Prompt suppression, self-extinguished fires, fires that caused no trip, fires that did not spread, fires that did not damage secondary components, fires in non-vital areas, and … the kitchen sink

Severity Factors (Summary)

- **Before you buy, remember the three "D"'s of PRA:**
    - **Dependency, dependency, dependency**
    - **The same factors may be accounted for elsewhere in the PRA – either implicitly or explicitly**
    - **When you see the use of one (or heaven forbid more than one) severity factor in quantification you have to ask if they are double counting somewhere**

Probability of Non-Suppression (PNS)

- **Definition: PNS - The conditional probability that, *given the fire*, the fire will <u>not</u> be suppressed prior to the failure of a specific set of damage targets or ignition of secondary combustibles**

  - **Key 1: Specific to a particular fire ignition source scenario**

    - **May be a grouped set of fire ignition sources**

  - **Key 2: Specific to a particular target set**

  - **PNS reflects the probability that given the fire, these targets will fail or ignite**

Target Set

- **A collection of components and/or cables that may be threatened by a postulated fire**
  - **This could be anything from one cable to everything in the fire area**

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Target Sets (cont.)

- **The target set either survives or fails as a whole**
  - **If you need to break down a target set, you really need to define more than one target set**

- **Target sets can be progressive if needed – one set represents expansion of another smaller set:**
    - **Target Set 1 = {item 1}**
    - **Target Set 2 = {items 1,2,3} …**
    - **Helpful if two trains are threatened but separated (for example)**

- **Different fire ignition sources may have the same target set(s) or different target set(s)**

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Target Sets (cont.)

- **For any one fire ignition source:**
  - **Most often one target set is enough**
  - **You may define a series of expanding target sets reflecting growth and spread of the fire**
    - **Don't go overboard – one, two, or at most three, should handle most situations**

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Target Sets (cont.)

- **Poor cable routing data actually makes this step easier**

  - **If you don't know where specific cables are, you basically have to assume the worst**

- **Good cable routing data can actually complicate the choice**

  - **You may be tempted to define many target sets as each tray becomes involved**

    - **Don't – keep it simple**

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Back to PNS…

- PNS is a 'probabilistic' horse race: time to damage versus time to suppression

- Time to damage depends on:
    - How close targets are to the fire
    - Target failure threshold
    - How big the fire is
    - Possibly: How quickly fire spreads

- The plant's chances of putting the fire out within this time depends on:
    - What sort of fixed fire suppression capability is available
    - Timing of manual fire response (e.g., the brigade)

Time to Damage

- **We can predict time to damage in three steps:**
  - **Set the damage threshold**
    - **Targets are usually cables**
    - **Two basic cable types: thermoset (robust) and thermoplastic (wimpy)**
  - **Predict the exposure conditions**
    - **Plume, direct radiant heating, or hot gas layer**
    - **Estimate temperature or heat flux at target location using Fire Dynamics Tool (FDT)**
  - **Convert exposure condition to damage time**
    - **SDP uses look-up tables**

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Cables insulation/jacket types

- **Thermoplastic**
  - **Melt if heated, solidify if cooled,**
  - **Drip and burn as a liquid pool**
  - **More wimpy**
  - **Examples:**
    - **Polyethylene (PE)**
    - **Polyvinylchloride (PVC)**
  - **Generally not qualified**

- **Thermoset**
  - **Don't melt**
  - **Burn/char in place if heated enough**
  - **More macho**
  - **Examples:**
    - **Cross-linked polyethylene (XLPE or XPE)**
    - **Ethylene-Propylene rubber (EPR)**
  - **Generally qualified**

Damage Thresholds

Screening Criteria for Assessment of Ignition and Damage Potential of Electrical Cables

Cable Type: Thermoplastic	(Metric)	(English)
Heat flux	6 kW/m^2	0.5 BTU/ft^2 s
Temperature	205°C	400°F
Cable type: Thermoset	(Metric)	(English)
Heat flux	11 kW/m^2	1.0 BTU/ft^2 s
Temperature	330°C	625°F

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Damage Time Look-Up Table (Example*)
*Table A7.1 from IMC 0609, Appendix F, Attachment 7, 02/28/05

Table A7.1 - Failure Time-Temperature Relationship for Thermoset Cables		
Exposure Temperature		Time to Failure (minutes)
°C	°F	
330 ≤ T < 335	625 ≤ T < 634	28
335 ≤ T < 340	634 ≤ T < 642	24
340 ≤ T < 345	642 ≤ T < 651	20
345 ≤ T < 350	651 ≤ T < 660	16
350 ≤ T < 360	660 ≤ T < 680	13
360 ≤ T < 370	680 ≤ T < 700	10
370 ≤ T < 380	700 ≤ T < 716	9
380 ≤ T < 390	716 ≤ T < 735	8
390 ≤ T < 400	735 ≤ T < 752	7
400 ≤ T < 410	752 ≤ T < 770	6
410 ≤ T < 430	770 ≤ T < 805	5
430 ≤ T < 450	805 ≤ T < 840	4
450 ≤ T < 470	840 ≤ T < 880	3
470 ≤ T < 490	880 ≤ T < 915	2
T ≥ 490	T ≥ 915	1

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Automatic suppression time

- **We can predict time to actuation for an automatic suppression system using a simple spreadsheet tool**
  - **E.g., a sprinkler head looks just like a heat detector**
  - **Fire Dynamics Tool (FDT)**
- **That give us a number**
  - **x:x minutes:seconds**

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PNS for Automatic Suppression

- **We don't want to do a straight yes/no comparison between damage time and suppression time – this can be very misleading**

  - **Damage time = 10 min**

  - **Suppression time = 9 min, 30 sec.**

  - **Nominally suppression wins, but what is your confidence in this answer**

    - **Is it really yes/no or fail/no fail**

  - **To acknowledge uncertainties in the time estimates, we use the margin between damage time and suppression time**
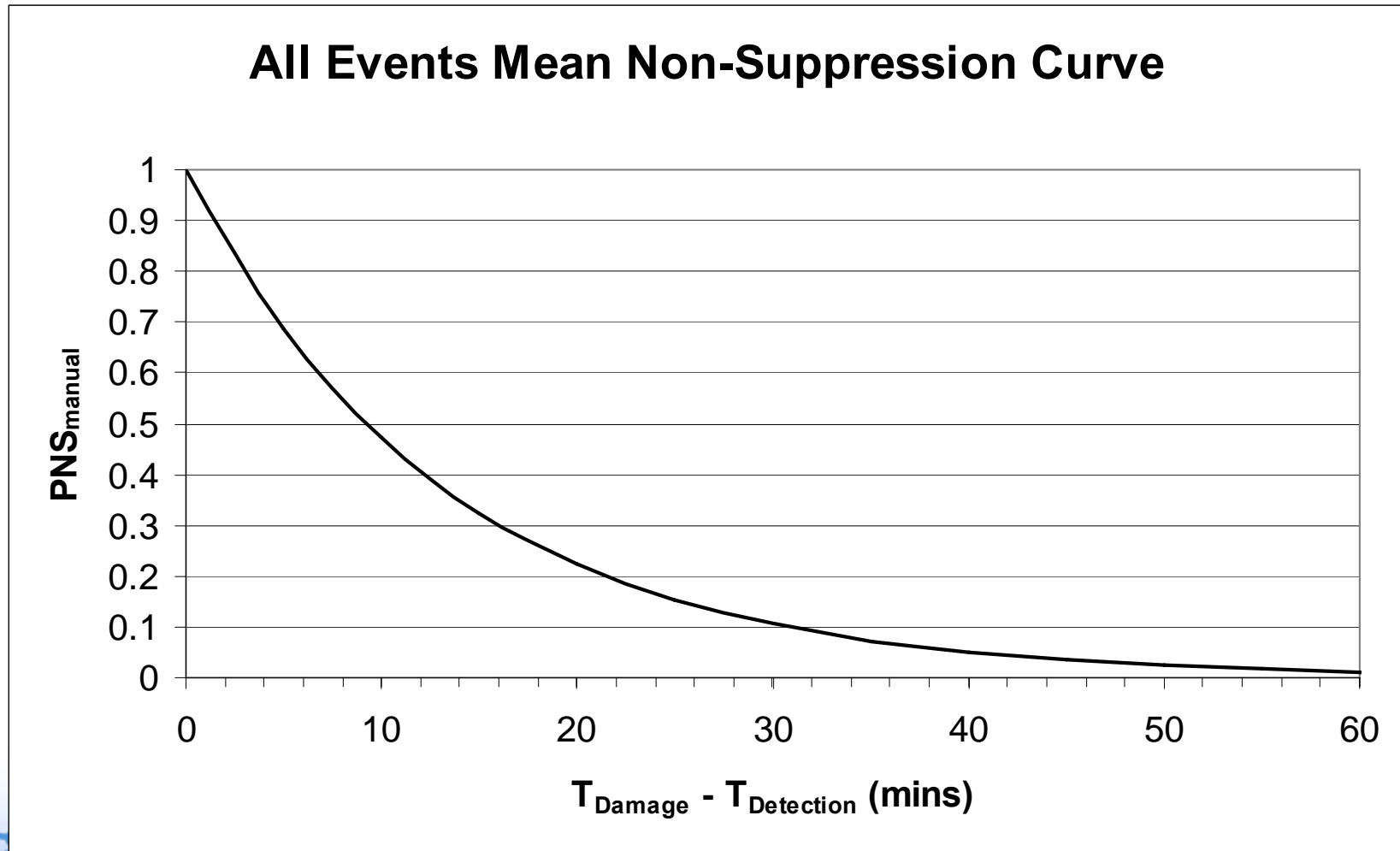
Probability table for Automatic Suppression

Probability of Non-suppression for Fixed Fire Suppression Systems Based on the Absolute Difference Between Damage Time and Suppression Time

Time Delta: ($t_{Damage} - t_{Suppress}$)	PNS_{Fixed}
Negative Time up to 1 Minute	1.0
> 1 Minute to 2 Minutes	.95
> 2 Minutes to 4 Minutes	.80
> 4 Minutes to 6 Minutes	.5
> 6 Minutes to 8 Minutes	.25
> 8 Minutes to 10 Minutes	.1
> 10 Minutes	0.0

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PNS and Manual Suppression

- **PNS for Manual estimated from empirical fire duration curves**
  - **The vast majority of fires are manually suppressed**
  - **We get fire duration data for enough of the reported fires to develop a fire duration curve**
- **Pick the appropriate duration curve**
- **Estimate ($t_{damage} - t_{detection}$)**
  - **Remember that detection triggers manual response, but damage time measured from time of ignition (t = 0)**
- **Pick off PNS_{manual}**
  - **Values also available in a lookup table**

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Duration Curve Example (PNS$_{manual}$)

All Events Mean Non-Suppression Curve

Y-axis: PNS$_{manual}$ (0 to 1)

X-axis: T$_{Damage}$ - T$_{Detection}$ (mins) (0 to 60)

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Auto vs. Manual Suppression

- **If auto is present, we assume it will be primary suppression means**

- **If auto fails, manual is always the backup**
  - **We assume that a water based automatic suppression system will fail on demand 2% of the time**
  - **Gaseous systems – 5%**

- **If no auto system, then manual is all there is**

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Manual fixed Suppression

- **Fixed fire suppression systems that have no automatic actuation mechanism – human action is required**

- **No hard/fast rule possible – use following:**

  - **Estimate detection time**

  - **Estimate physical response time**

  - **Review decision criteria and estimate decision making time**

    - **Nominal value is 2 minutes**

    - **Increase if circumstances warrant**

  - **Actuation time is sum of these three**

Combining Manual and Auto-Suppression

- **Again, if auto system is present, it is assumed first line of defense**

- **Auto systems don't always work:**

  - **Water based system ~2% failure on demand**

  - **Gaseous systems ~5% failure on demand**

  - **Values reflect both reliability and availability (out-of-service time)**

- **Manual is always available as a backup**

Combining Manual and Auto-Suppression

For Water-based systems:

$$PNS_{scenario} = (0.98 \times PNS_{fixed\text{-}scenario})$$
$$+ (0.02 \times PNS_{manual\text{-}scenario})$$

For Dry-pipe and Gaseous systems:

$$PNS_{scenario} = (0.95 \times PNS_{fixed\text{-}scenario})$$
$$+ (0.05 \times PNS_{manual\text{-}scenario})$$

$$** \ PNS_{scenario} \leq PNS_{manual\text{-}scenario}$$

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Special Consideration For Degraded Gaseous System

- **If gaseous suppression system cannot maintain adequate concentration for a sufficient time to assure fire extinguishment, then manual fire fighting <u>must</u> do the final mop-up**

    - **The degraded gaseous system cannot permanently extinguish the fire, but does buy the fire brigade some additional response time**

    - **We assume that the fire will be held in check during the time that the fire suppressant concentration is maintained at design level**

    - **Upon dissipation of suppressant fire will re-flash**

        - **We assume it will pick up right where it left off**

Degraded Gaseous Systems (cont.)

- **To get PNS$_{fixed}$ we need to compare damage time to a suppression time-line with the following elements:**

  - **Actuation time for gaseous system (manual or automatic as normally analyzed)**

  - **The probability table that reflects our confidence that system actuation is timely compared to fire damage time**

  - **Hold time / soak time for design concentration that system can deliver**

  - **Manual response following loss of concentration**

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Degraded Gaseous System PNS Analysis

- First we calculate a PNS for manual response as if gaseous system were not in place (or were to fail)

- Select the appropriate fire duration curve, based on ignition source

- Estimate fire detection time in the usual manner
  - Assume a valid actuation signal on gaseous system will trigger a fire detection signal as well

- Calculate t_{damage}-$t_{detection}$

- Estimate PNS_{manual} in the usual manner

Degraded Gaseous System PNS Analysis

- Next we look at timeliness of the system discharge:

- Estimate discharge/actuation time ($t_{suppress}$) as you would for any fixed system

    - Could be automatic or manual actuation of fixed system

- Calculate the time margin ("Time Delta") between the actuation time and fire damage time in the normal manner

    - Time Delta = (t_{damage} - $t_{suppress}$)

- Use the general PNS_{fixed} probability table (IMC, 0609, App F, Att 8, Table A8.2) to assess probability that suppression system actuation is timely in relation to estimated fire damage time.

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Degraded Gaseous System PNS Analysis

- **Based on PNS_{fixed} decide whether to credit gaseous system at all:**

- **If PNS_{fixed} is 1.0, then the gaseous system will not be credited.**

  - **Use $PNS_{scenario} = PNS_{manual}$**

  - **Analysis is complete.**

- **If PNS_{fixed} value is less than 1.0, then gaseous system will be credited.**

  - **Continue this analysis to estimate $PNS_{scenario}$.**

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Degraded Gaseous System PNS Analysis

- **Now do the case where the system buys some added time for fire brigade response:**

- **Calculate modified fire damage time as follows:**

  - $t_{damage\_new} = t_{damage} + t_{maintain\_gas}$

- **where $t_{maintain\_gas}$ is the time suppressant concentration can be maintained.**

- **Calculate modified time available for manual suppression:**

  - $[t_{damage\_new} - t_{detection}]$

- **Estimate PNS_{gas_manual} in the manner normally applied to PNS_{manual}**

  - **Use appropriate fire duration curve with the modified time available**

Degraded Gaseous System PNS Analysis

To get final PNS$_{scenario}$ we now need to combine three cases:

- **Case 1: Suppression system works (0.95 - no random failure), the actuation is timely (1- PNS$_{fixed}$), and fire brigade fails to respond with extra time available (PNS$_{gas\_manual}$)**

- **Case 2: Suppression system works (95% - no random failure), but discharge of the fire suppression system is not timely (PNS$_{fixed}$), manual brigade must respond within original fire damage time (no extra time available – PNS$_{manual}$)**

- **Case 3: Gaseous suppression system suffers random failure on demand (0.05), fire brigade must respond within the originally estimated fire damage time (PNS$_{manual}$)**

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Degraded Gaseous System PNS Analysis

- **And the final reduced equation is…**

$$PNS_{scenario} = 0.95 \times (1 - PNS_{fixed}) \times PNS_{gas\_manual}$$
$$+ [(0.95 \times PNS_{fixed}) + 0.05] \times PNS_{manual}$$

- **Verify that $(PNS_{scenario} \leq PNS_{manual})$**

  - **As in other cases, the manual brigade response given the original fire damage time is the minimum credit given to fire suppression for any scenario**

  If $(PNS_{scenario} > PNS_{manual})$ reset $(PNS_{scenario} = PNS_{manual})$

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Conditional Core Damage Probability (CCDP)

- **Definition: The conditional probability that post-fire safe shutdown efforts will fail to achieve safe and stable hot shutdown conditions, thus resulting in core damage**

  - **Risk analyses don't generally look at ability to achieve cold shutdown**

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CCDP (cont.)

- **CCDP is calculated using a post-fire safe shutdown plant response model**

  - **Screening estimates may only credit the designated post-fire safe shutdown path**

  - **For more detail, we use a broader plant response model that may credit components and systems beyond Appendix R**

  - **SDP uses the plant notebooks and pre-solved worksheets**

CCDP (cont.)

- **We won't go into depth on this topic, but some high level rules:**

    - **To credit a system or function, you must have reasonable assurance that it will not be damaged by the fire - your judgment counts**

    - **We do credit manual actions – guidance is provided – but complex sets of actions will likely get little credit in Phase 2**

    - **Spurious operations may be a part of CCDP calculation – you may need help here**

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That's pretty much it.

$$CDF_i = F_i * SF_i * PNS_i * CCDP_i$$

Of course, the devil's in the details…

Fire Scenarios

P-204

April 2009

More On Fire Scenarios

- **Definition: A fire scenario is a postulated sequence of events <u>starting</u> with the ignition of a fire and <u>ending</u> either in plant safe shutdown or core damage.**

Fire Scenario

- **What is a Fire Scenario:**

  (Fire Scenario) = (fire ignition source scenario)

  AND (fire growth and damage scenario)

  AND (fire suppression scenario)

  AND (plant SSD response scenario)

  Change any element and you have a new fire scenario!

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Fire Ignition Source Scenario

- **Definition: Defines the physical characteristics of the fire that will develop for a particular fire ignition source – key factors:**
  - **Placement of fire "origin" – how close is origin to targets**
  - **Heat release rate (HRR)**

- **SDP bins fire sources by type, and ties characteristics to each type**
  - **Five HRR values used to characterize all (simple) fires**

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Table 2.3.1 - Mapping of General Fire Scenario Characterization Type Bins to Fire Intensity Characteristics

Fire Size Bins	Generic Fire Type Bins with Simple Predefined Fire Characteristics					
	Small Electrical Fire	Large Electrical Fire	Indoor Oil-Filled Transformers	Very Large Fire Sources	Engines and Heaters	Solid and Transient Combustibles
70 kW	50th Percentile Fire				50th Percentile Fire	50th Percentile Fire
200 kW	95th Percentile Fire	50th Percentile Fire			95th Percentile Fire	95th Percentile Fire
650 kW		95th Percentile Fire	50th Percentile Fire	50th Percentile Fire		
2 MW			95th Percentile Fire			
10 MW				95th Percentile Fire		

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Fire Origin

- **The fire origin is a <u>conceptual</u> point at which we will assume the fire originates.**

  - **Horizontal placement determines what is overhead and therefore in the fire plume**

  - **Vertical placement will affect plume temperature for exposure of overhead targets**

- **Choice depends on the nature of the fire source**

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Heat Release Rate (HRR)

- **HRR characterizes the fire intensity or the amount of heat generated by a fire per unit time**

  – **Typical units are either KW or BTU/hr**

- **This is generally the most critical of all fire characterization input values**

- **Remember – SDP ties fire intensity to severity factor**

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Convective / Radiative Fractions

- **Heat transfer from fire is via two primary mechanisms:**
  - **Convective transfer– the mixing of hot fire products with ambient air resulting in direct heating of the surrounding air that in turn causes buoyancy and fire plume behaviors**
  - **Radiative transfer– the luminosity of a fire's flame zone results in direct radiant heating of opaque targets (including soot-laden air)**
- **Recommended split fractions are:**
- **0.7 convective, 0.3 radiative**
  - **Paired values must sum to 1.0**

Fire Growth and Damage Scenario

- **Definition: characteristics of fire spread to secondary combustibles if such occurs, and the behaviors leading to failure of an identified thermal damage target set**

  - **You must define a target set (i.e., equipment threatened by fire that could affect safe shutdown)**

  - **Damaging conditions may be created either due to burning of the ignition source alone, or due to fire spread**

    - **If fire ignition source alone is not enough, and fire cannot spread, then damage is not possible**

SDP Fire Damage States (FDS)

- **FDS0 – loss of only the fire ignition source**
  - Not analyzed as a risk contributor
- **FDS1 – localized damage near (especially directly above) the fire ignition source**
  - Keys factors: plume heating, upward spread of fire, and direct radiant heating
- **FDS2 – widespread damage within a single fire area**
  - Key factors: horizontal fire spread, hot gas layer, and failure of degraded raceway fire barriers
- **FDS3 – fire damage impacting two (or more) fire areas (room-to-room)**
  - Key factor: failure of an inter-compartment fire barrier element

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Fire Detection and Suppression

- We credit all available means of fire detection and suppression

- Detection is important mainly because it triggers the manual response

  - Plant personnel become aware of the fire

  - Fire procedures may kick in (check plant process for when this really happens)

  - The fire brigade is activated

- Fixed automatic suppression systems require no prior detection signal, but usually are tied to alarm circuits

Fire Suppression (cont.)

- **Remember, in fire PRA/SDP space, it's a horse race**
  - **Question is not so much "does suppression fail?"**
  - **But rather, "does suppression fail to put out the fire before damage occurs?"**
- **All fires are put out (or go out) eventually – we want to know if suppression is timely in the context of our specific target set**

CCDP

- **CCDP characterized plant/operator response to the fire**

- **Objective is safe shutdown (hot shutdown)**

- **This part can be complex**

Developing a Fire Time Line

- **Key events on the time line**
  - **Fire ignites (define this as time = 0)**
  - **Fire is detected ($t_{detection}$)**
    - **Manual/operator response begins**
    - **Fire brigade is activated**
  - **Target set fails (t_{damage})**
    - **Remember: t_{damage} measured from t = 0**
  - **Automatic suppression activates (t_{supp_auto})**
  - **Manual suppression is successful (t_{supp_man})**
- **Order of these events is TBD!**

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