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Fukushima Related R&D

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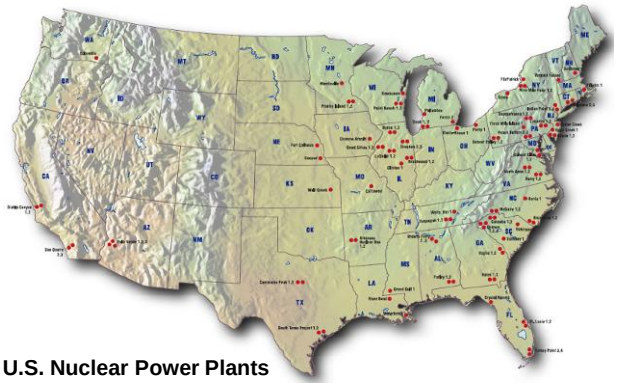
International Collaboration Model

U.S. Participants



U.S. Nuclear Power Plants

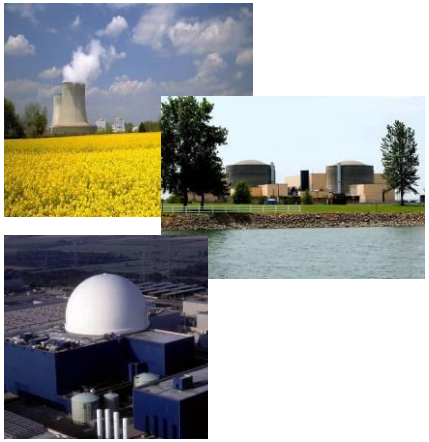
Source: NEI Website, 2009

- All U.S. nuclear owners/operators
- 104 reactors

Non-U.S. Participants

- 20 countries, >220 reactors

Global Breadth and Depth



- >75% of the world's commercial nuclear units

Participants Encompass Most Nuclear Reactor Designs

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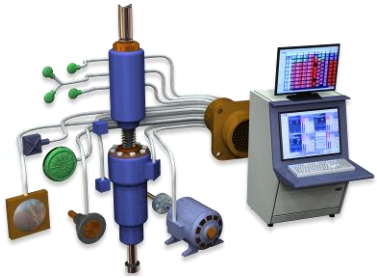
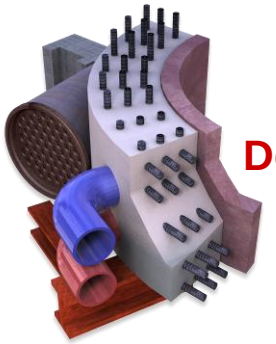
Nuclear Sector Research Areas

Inspection

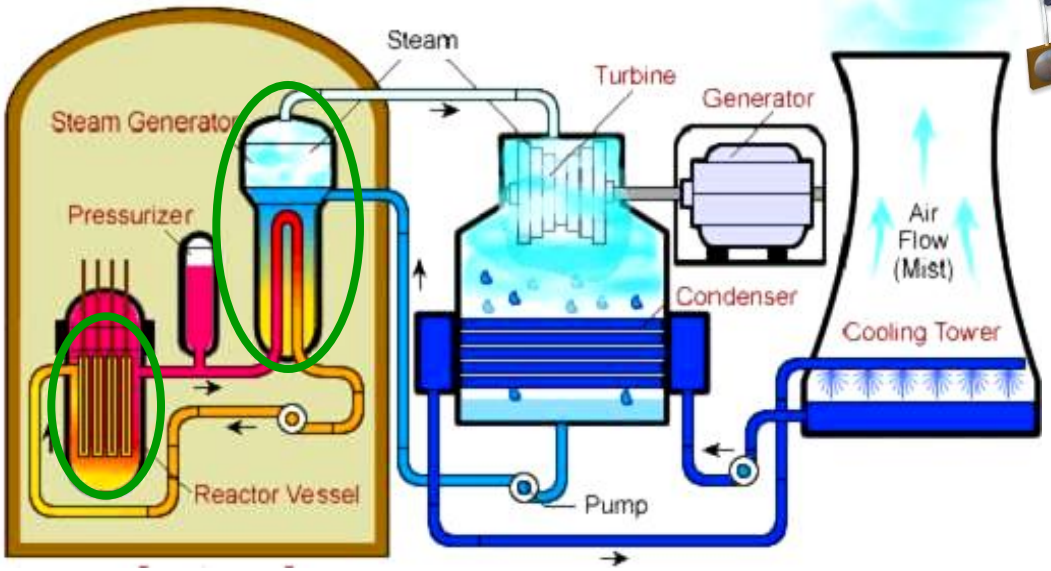
Risk & Safety

Equipment Reliability

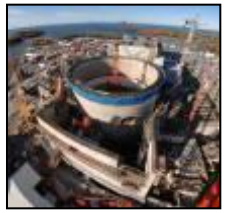


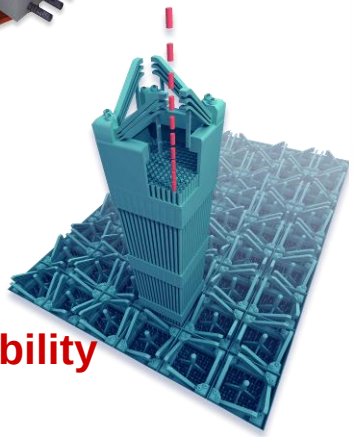


Material Degradation



Advanced Nuclear Technology





Fuel Reliability

Radiation Exposure and Waste Management

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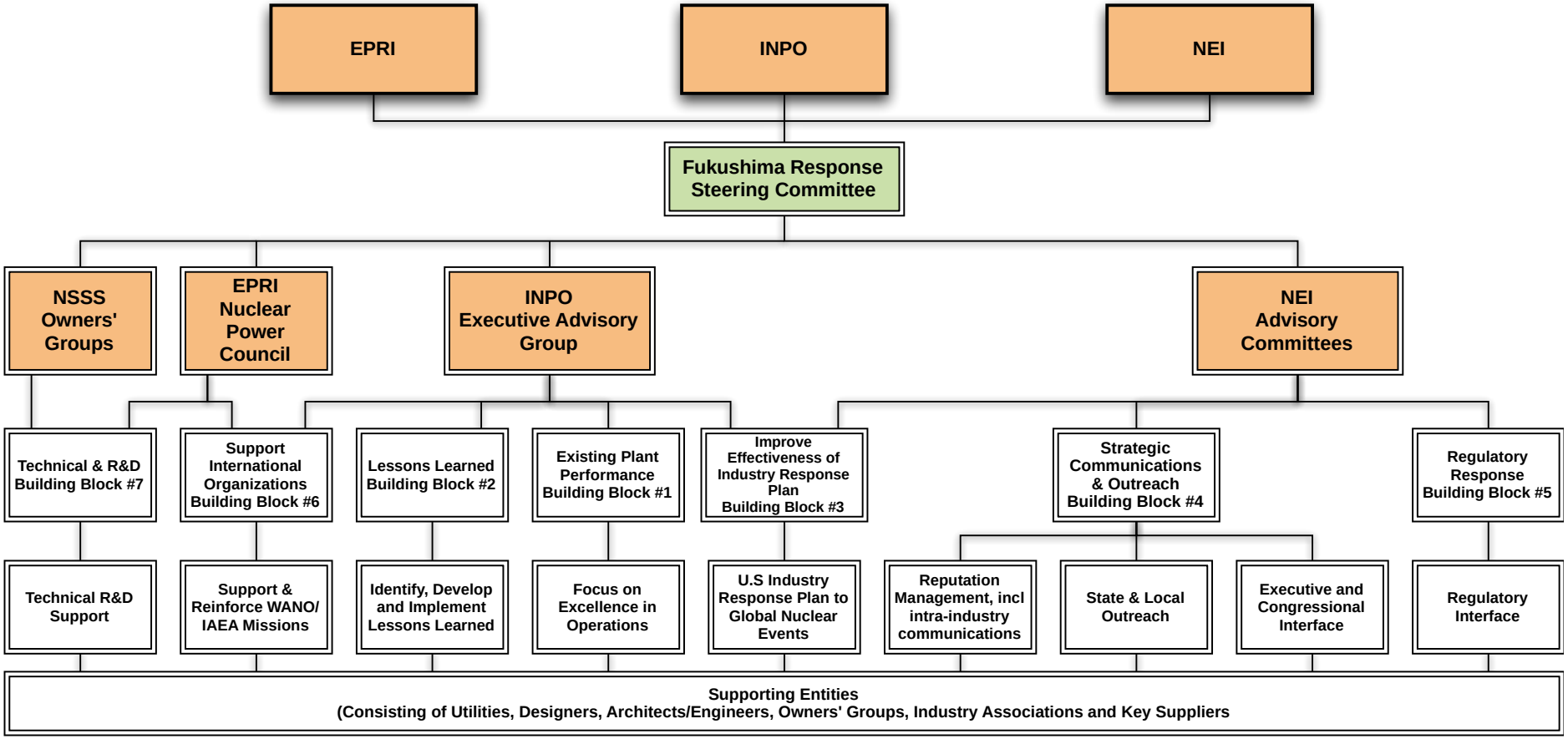
U.S. Organized Response to Fukushima Accident -- The Way Forward Initiative



Shaded blocks are standing committees. All other organizations are temporary bodies for the life of this project

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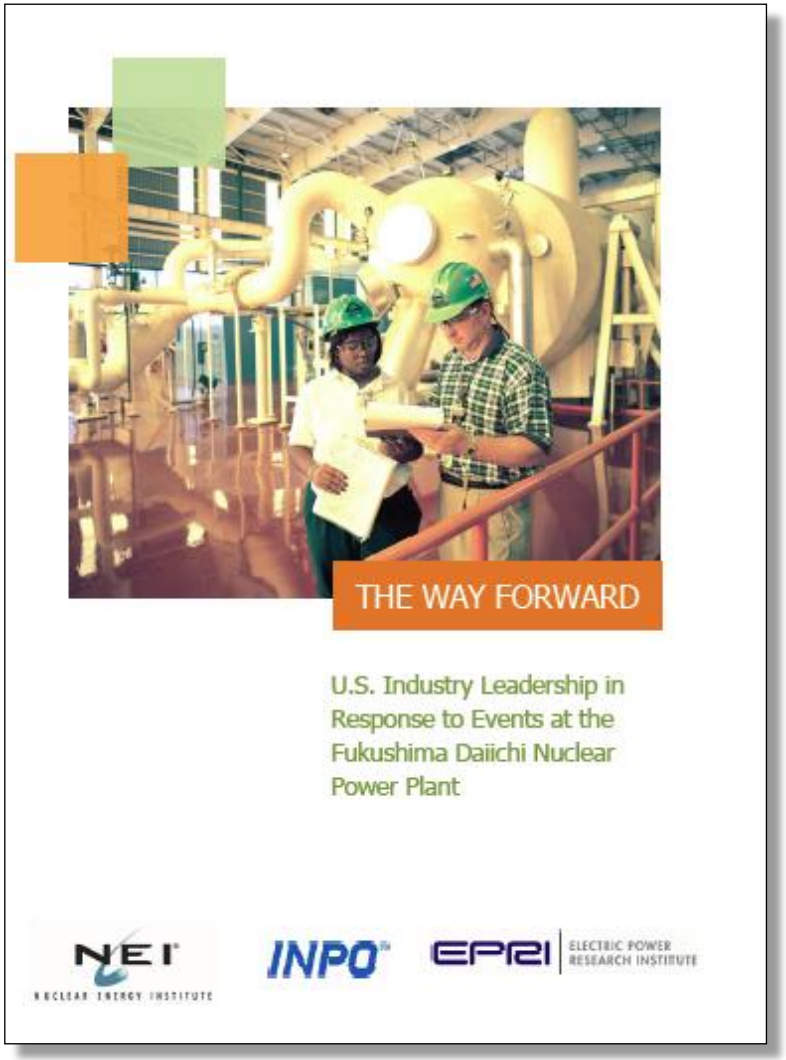
Post-Fukushima R&D Scope

- Fukushima Accident Technical Evaluation
- External Events
  - Seismic, Floods, High Winds, Others
  - Hazards Characterization
- Severe Accident Management
- Radiological Release Mitigation
- Spent Fuel Pools
- Advanced Fuel designs



Considerable and Ongoing…Global Applicability

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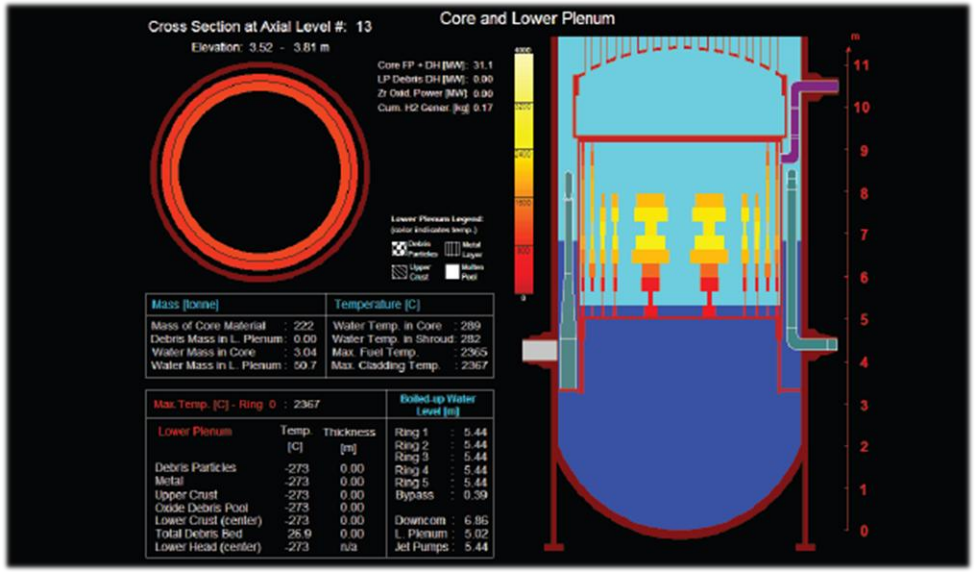
Fukushima Accident Technical Evaluation



Understand the physics of the event(s).

EPRI severe accident code – MAAP5

- Understand detailed accident sequences
- Compare models predictions to observed data
- Update and benchmark MAAP5 models
- Inform future technical safety and regulatory debate

Large Collaborative Effort

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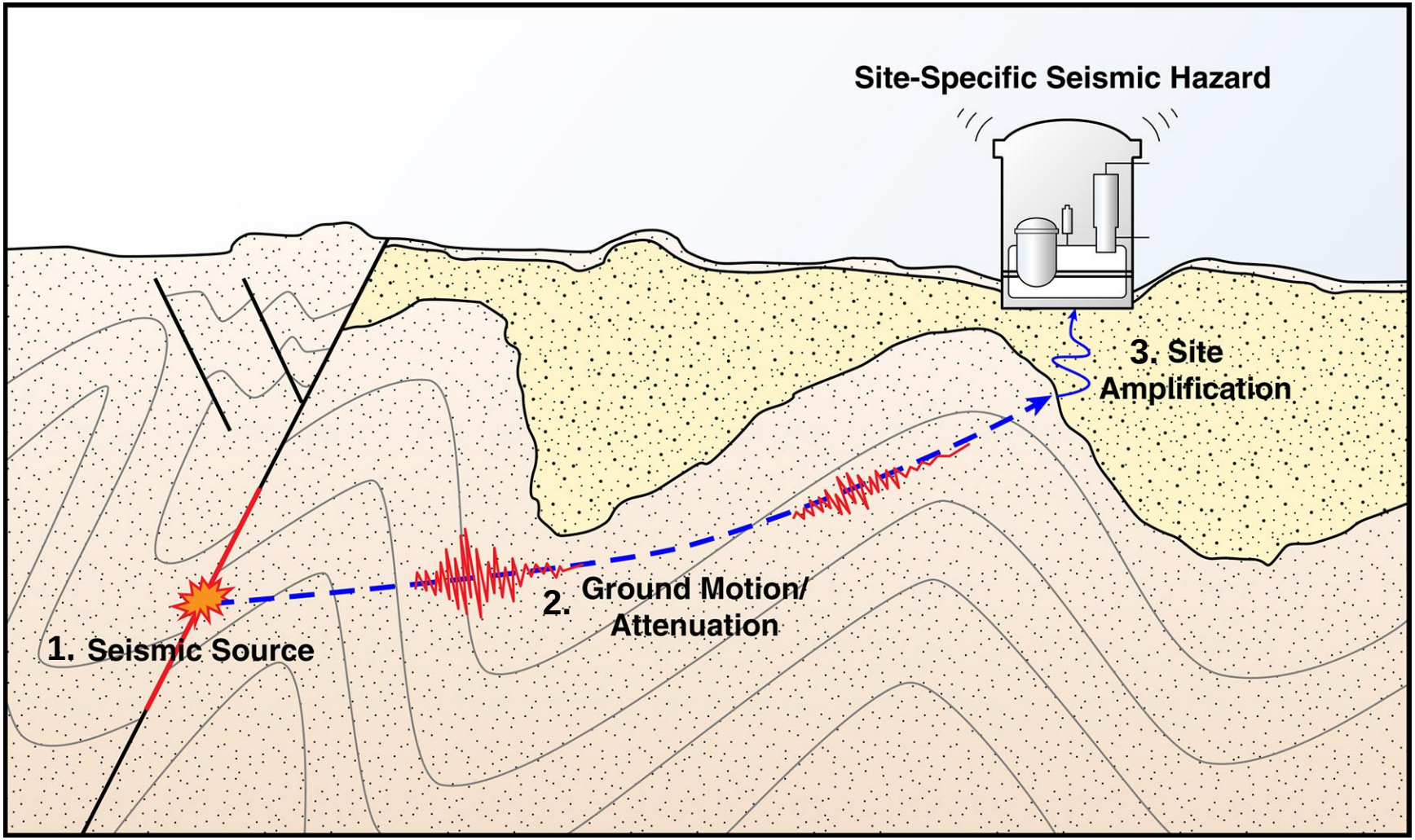
Seismic Risks



Graphic Source: SIGMA Project Plan

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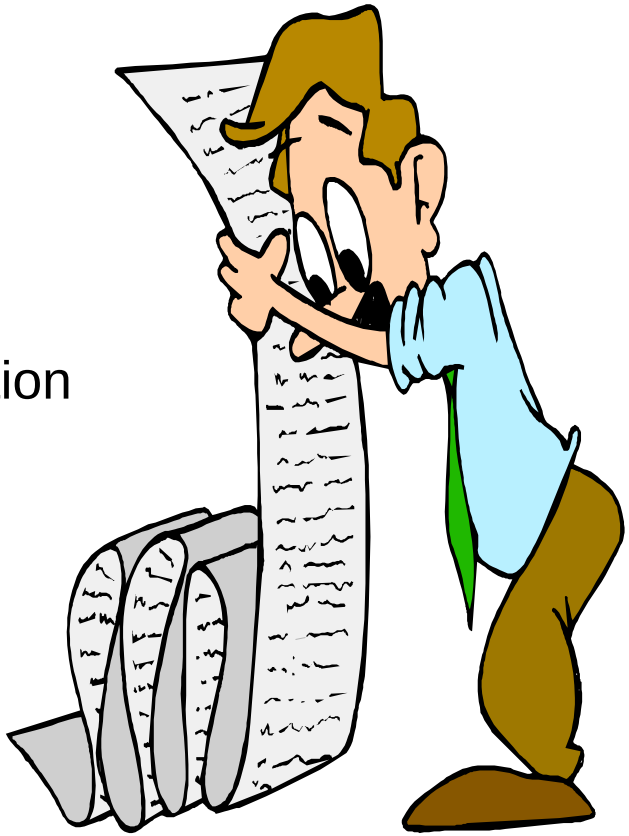
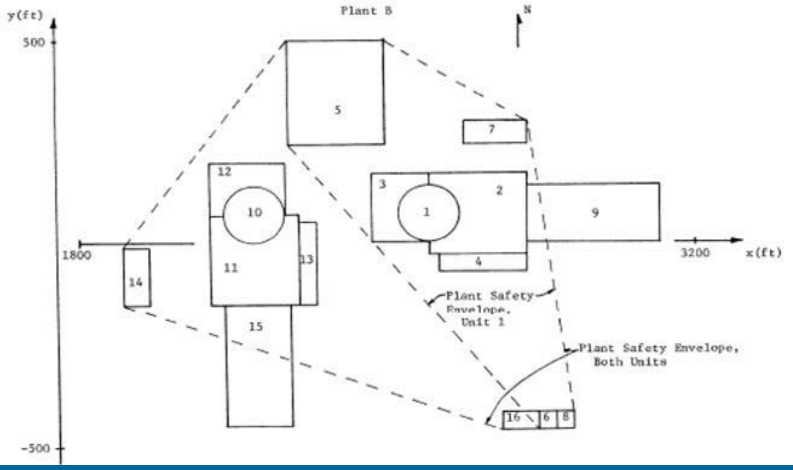
Outline of Seismic PRA Implementation Guide

- Seismic Hazard
- Building Response model
- Seismic Fragility Analysis
- Seismic Equipment List
- SPRA Modeling Level 1 and Level 2
  - Quantification tools
  - Seismic HRA
  - Seismic Induced Fires and Floods
  - Level 1 and 2 modeling and quantification
  - Correlations
  - Uncertainties
- Walk-downs
- Peer Review
- Documentation



Tornado Missile Protection Requirements

- **Structures, Systems & Components (SSCs) required to be protected against tornados**
  - 14 categories of essential safety-related SSCs
  - Includes emergency electrical power and those used to support the main categories
- **Methods of protection**
  - Structures and components themselves must withstand the effects of tornado missiles
  - Protective barriers to preclude tornado damage
  - Physical separation of redundant SSCs not generally considered adequate
- **Example with Region II parameters**
  - Large crushable type missile (automobile)
  - Weight 4000 lb (1810 kg)
  - Horizontal velocity 80 mph (130 kmph)



Two Unit Site SSC Protection Requirements
Many Major Buildings Included in Requirements

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EPRI Technical Work Related to Wind Hazards

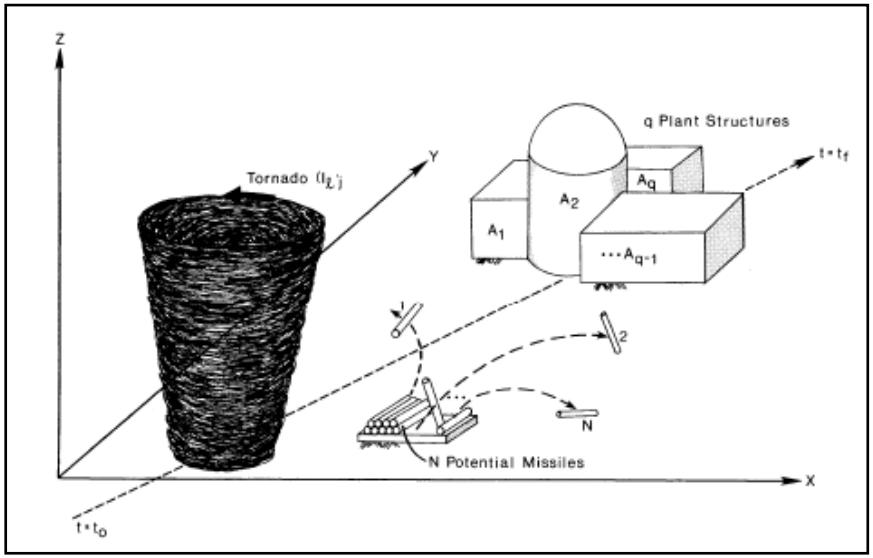
EPRI Historical Activities on High Winds and Wind Propelled Missiles	
Wind field and trajectory models	NP-748, "Wind field and trajectory models for tornado propelled missiles" NP-2898, "Wind field and trajectory models for tornado –propelled objects"
Impact tests and analyses	NP-148, "Full scale tornado missile impact tests" NP-440, "Full scale tornado missile impact tests" NP-1217, "Local response of reinforced concrete to missile impact" NP-1883, "Pipe missile impact experiments on concrete materials" NP-2745, "Full-scale missile concrete impact experiments"
Integrated tornado and missile risk analysis	NP-154, "Tornado missile risk analysis" NP-768, "Tornado missile risk analysis" NP-769, "Tornado missile risk analysis" NP-2005, "Tornado missile simulation and design methodology"
EPRI Future Plans for Wind Hazard Research	
2013 – "Update"	Update propelled missile methods and integrated risk analysis tool (TORMIS)
2014 - "Expand"	Extension of propelled missile methods to hurricanes

EPRI Tornado Missile Probabilistic Assessment

TORMIS Methodology General Capabilities:

- Probability that a single missile impacts and damages specified targets.
- Total impact and damage probability of each target from all postulated missiles.
- Probability that a combination of targets (e.g., redundant components) will be damaged by a tornado strike.
- Impact and damage probabilities for the entire plant.
- Barrier thicknesses corresponding to specified levels of impact and damage risk
- Variances of the predicted probabilities.

TORMIS Simulation Diagram



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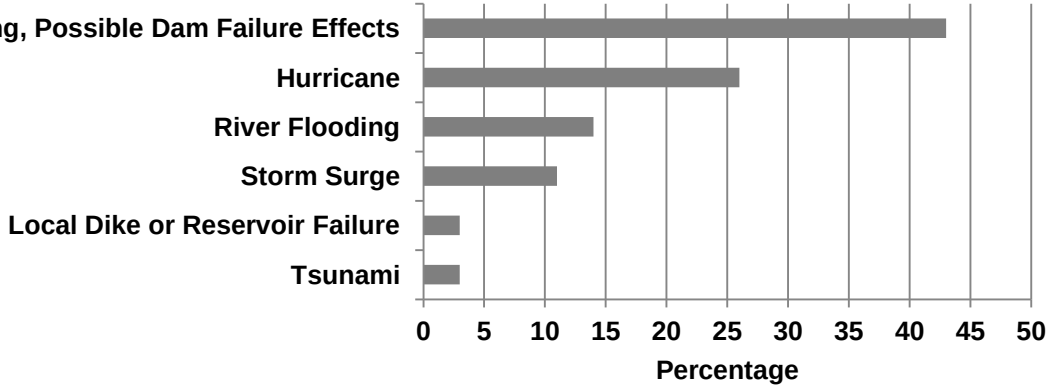
Recent EPRI Flooding Related Technical Work

Fort Calhoun Station

U.S. Site Flooding Hazard Types
(Local Intense Precipitation Hazard Not Included)



EPRI Activities to Advance Flooding Hazard State-of-Practice

Screening Guidance	EPRI 1022997, "Identification of External Hazards for Analysis in Probabilistic Risk Assessment (PRA)"
Statistical Trials	Collaboration with EDF on statistical methods and trial applications using plant flooding data
Modeling Benchmarking	Benchmarking of state-of-the art methods for probabilistic modeling of flood causing phenomena

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Severe-Accident Management Guidelines (SAMGs)

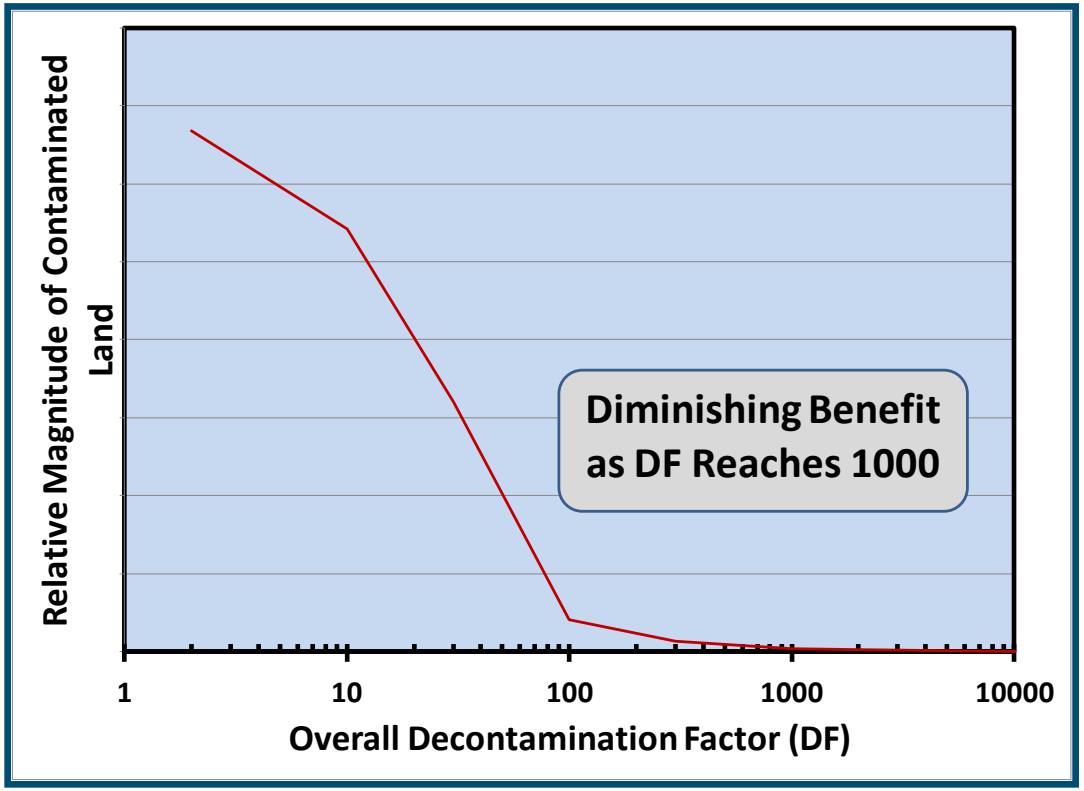
Genesis of SAMGs: part of long-term response to Three Mile Island accident

- Update *Technical Basis Report*: underpinning of SAMGs
  - Address insights from Fukushima
  - Incorporate new information from severe-accident research and analysis since 1992
- Support industry SAMG improvements

Technical work completed July 2012 – publication in October

Radiological Release Mitigation

- To avoid radiological releases – avoid core damage
- The most effective strategies improve the containment function
- Decontamination factor (DF) is the figure of merit



(DF = 1 / fraction of cesium released)

Diminishing benefits as DF exceeds 1000

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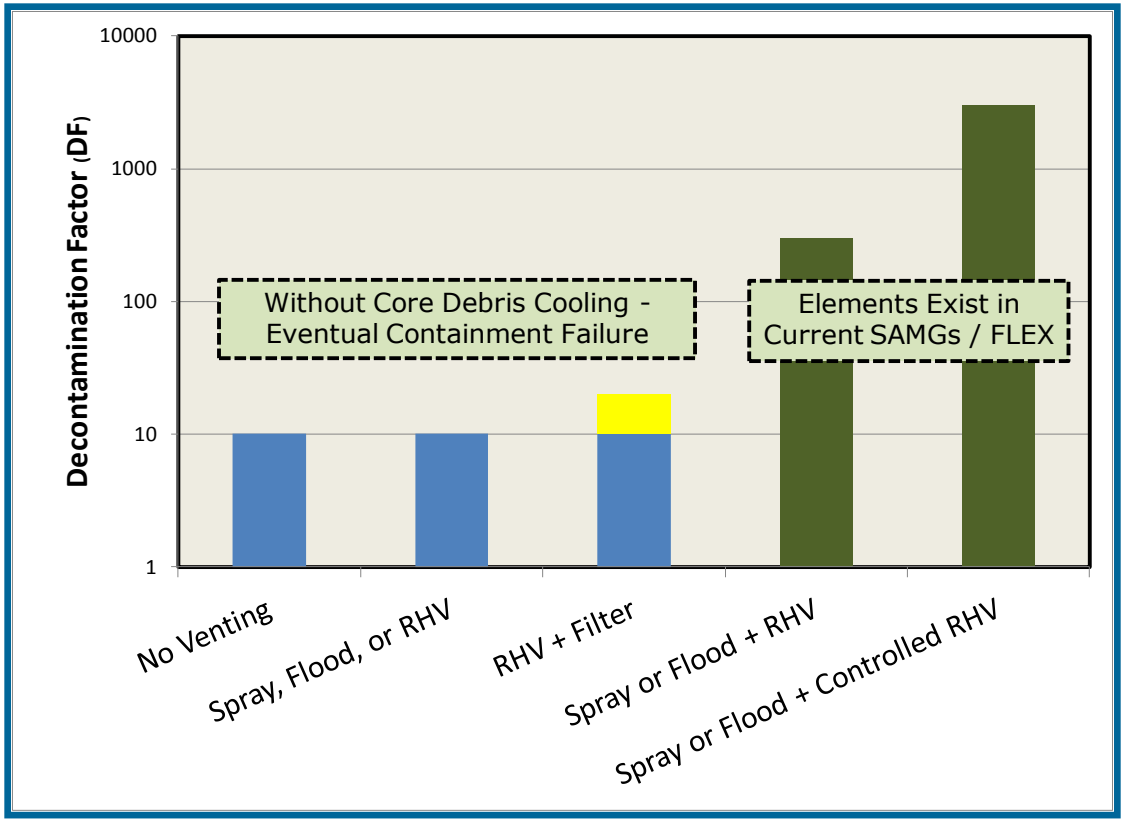
Representative Results of Strategies (BWR Mark I)

- Core debris heat removal is required
- Spray/flood retains fission products
- Vent provides heat removal
- Cycling of vent is important



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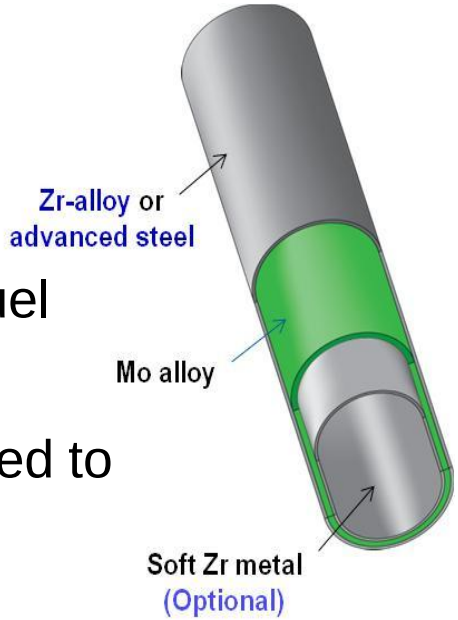
Assessing and Addressing Spent Fuel Pool Risk

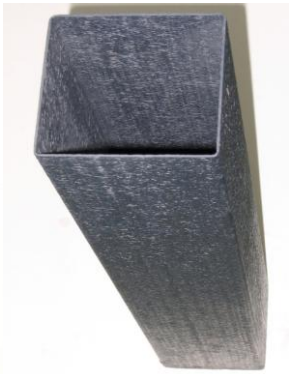
- Relevant characteristics of existing spent-fuel pools
  - Potential losses of inventory or cooling
  - Shared systems and facilities with core-cooling functions
  - Interactions with reactor systems
- Enhanced modeling of thermal-hydraulic response (MAAP5)
- Generic risk models for BWR and PWR
- Implementation of pilot risk studies
  - Exelon/Peach Bottom
  - Seeking interested PWR

Accident Tolerant Fuel : Mo-Based Metallic Cladding



- the Fukushima Daiichi underscored the need for a fuel that could increase operator coping time.
- A successful Mo-based metallic cladding is anticipated to possess the following characteristics at accident temperatures of 1000-1500°C:
  - Good tensile and creep strength to maintain fuel integrity at high temperatures
  - High melting temperature
  - Reduced hydrogen generation rate by 70-80%,
  - No licensing issues for DB LOCA.
- Objective: Feasibility of developing an accident tolerant fuel design and material based on molybdenum alloy

Research Objectives & Industry Value: SiC Channels for BWRs



- Stability of SiC in a reactor environment offer revolutionary performance improvements over existing zirconium alloy based components
  - Eliminates BWR channel bow
  - Oxidation rate is reduced (5% of current materials) in high temperature steam
  - Coolable geometry maintained longer in a loss of coolant accident
  - Can be used many more cycles than current Zr-based channels
  - Improved neutronic properties can lead to $3 million in savings per reload
- Could be applied to PWR structures as well
- Project Objectives: Evaluate the feasibility of using SiC_f-SiC_m composites as a nuclear fuel structural material

Summary

- R&D has critical role going forward
- New facts are learned
- Safety analysis methods are substantially expanded and improved
- Operational and coping strategies are informed
- Advanced technologies are actively considered
- Impact on future plant design are thoroughly evaluated

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Together…Shaping the Future of Electricity

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