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Toward Standardizing Probabilistic Risk Assessment Procedures for Combined External Hazards : A Focus on Screening Procedures

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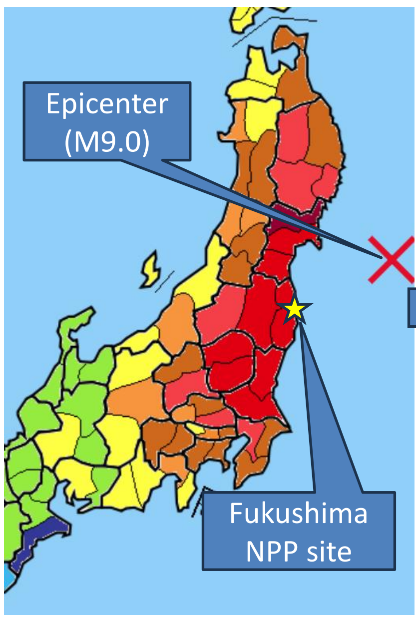
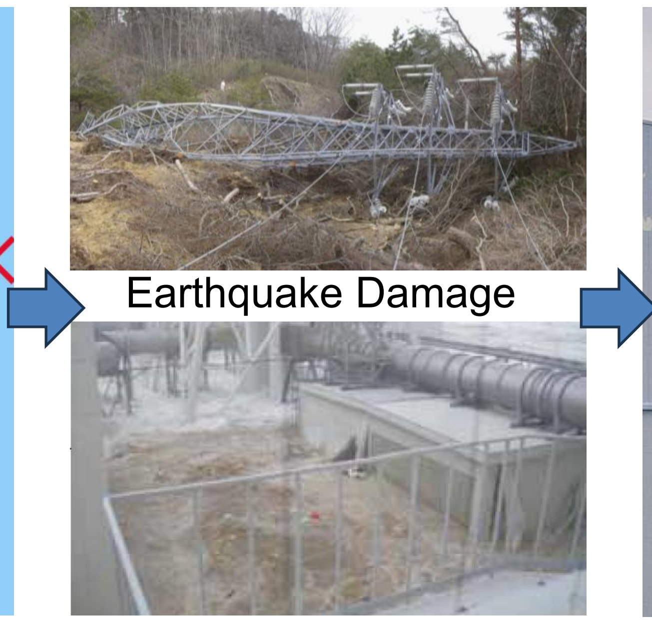
Contents

Background

- The Fukushima Daiichi Nuclear Power Plant accident in 2011 highlighted the vulnerability of nuclear facilities to combined earthquake and tsunami hazards.
- Although various methodologies for combined hazard assessment have been developed [1,2], standardized procedures for implementing combined hazard PRA have not yet been established.
- The large number of possible hazard combinations requires a systematic screening framework.



2011 Tohoku Earthquake (JMA)



Tsunami-Induced Flooding

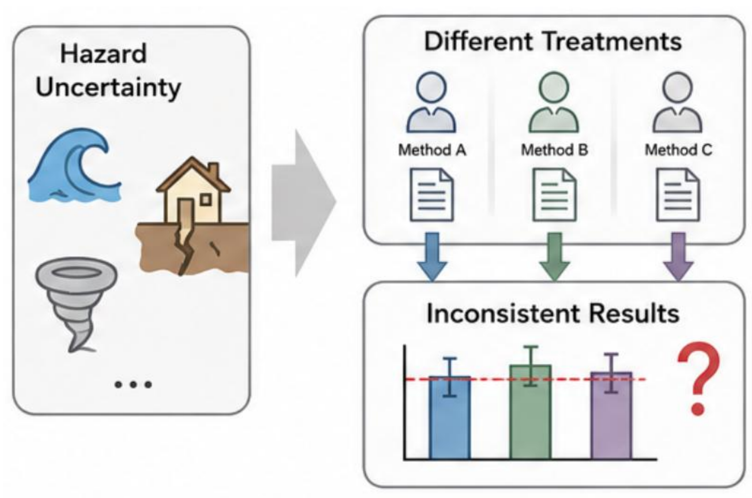
Hydrogen explosion at Fukushima NPP

[1] ASAMPSA_E (2017): List of external hazards to be considered in ASAMPSA_E.
[2] IAEA (2026): Safety Assessment of Nuclear Installations Against Combinations of Hazards Induced by External Events, TECDOC-2129, Vienna, Austria.

Objectives

- Challenges
  - Large number of possible hazard combinations.
  - Complex hazard dependencies, temporal relationships, and interactions among hazards, fragilities and plant systems.
  - Lack of standardized procedures for implementing combined hazard PRA.

- Objectives
  - Develop a systematic screening framework and a preliminary screening matrix.
  - Establish a conceptual framework for combined hazard PRA.
  - Propose standardized procedures for combined hazard PRA.



Conceptual Framework for Combined Hazard PRA

- Challenges in Combined Hazard PRA
  - Existing studies mainly classify combined hazards based on hazard dependency (consequential, associated and independent hazards) and temporal relationships [1, 2].
  - However, hazard classification alone is not sufficient for PRA because interactions may also occur at the fragility and system levels.
- Proposed Concept
  - Extend the framework to include hazard, fragility, and system dependencies.

Classification of combined hazard PRA

Hazard	Fragility	System
Dependent	Dependent	Dependent
		Independent
	Independent	Dependent
		Independent
Independent	Dependent	Dependent
		Independent
	Independent	Dependent
		Independent

[1] ASAMPSA_E (2017): List of external hazards to be considered in ASAMPSA_E.

[2] IAEA (2026): Safety Assessment of Nuclear Installations Against Combinations of Hazards Induced by External Events, TECDOC-2129, Vienna, Austria.

Example of combined hazard PRA

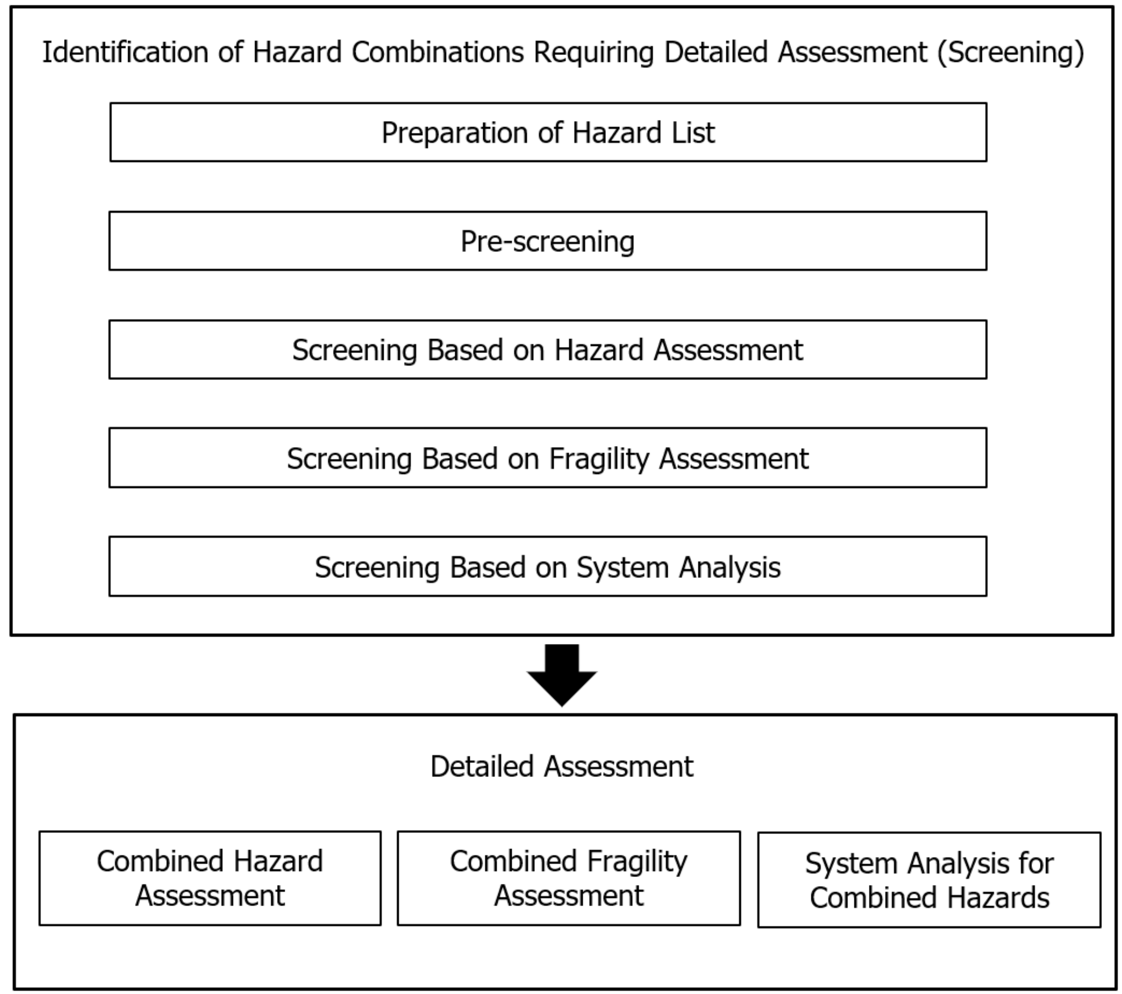
Phase		Example
Hazard	Dependent (consequential)	EQ (shaking) → Tsunami (pressure), Mainshock (shaking) → Aftershocks (shaking)
	Dependent (associated)	(EQ) Tsunami + Liquefaction, (Typhoon) Heavy rainfall + strong wind
	Independent	EQ (shaking) + Tornado (pressure)
Fragility	Dependent	Accumulated damage due to mainshock and aftershocks
	Independent	Damage due to EQ and Tsunami
System	Dependent	Reduced availability of operators due to EQ
	Independent	No shared support systems

- Consequential hazards: One hazard triggers another
- Associated hazards: Hazards originate from a common source
- Independent hazards: No causal or common-source relationship

Conceptual Framework for Combined Hazard PRA

● Screening Process for Combined Hazard PRA

- The proposed assessment flow starts with hazard identification, followed by a four-stage screening process.
- After screening, the remaining combinations are evaluated through hazard assessment, fragility assessment, and system analysis.
- This stepwise approach improves assessment efficiency while maintaining sufficient completeness.



Assessment flow for combined hazard PRA

Standardized Procedures for Combined Hazard PRA

- **Purpose**
- Provide a consistent and systematic framework for implementing combined hazard PRA.

➢ Standardized PRA Procedures (Main Text + Commentary)

Chapter 1: Introduction
Chapter 2: Definitions of Terms
Chapter 3: Selection and Screening of Combined Hazards
Chapter 4: Combined Hazard Assessment
Chapter 5: Combined Fragility Assessment
Chapter 6: System Analysis for Combined Hazards

Identification of Hazard Combinations Requiring Detailed Assessment (Screening)

Detailed Assessment

➢ References

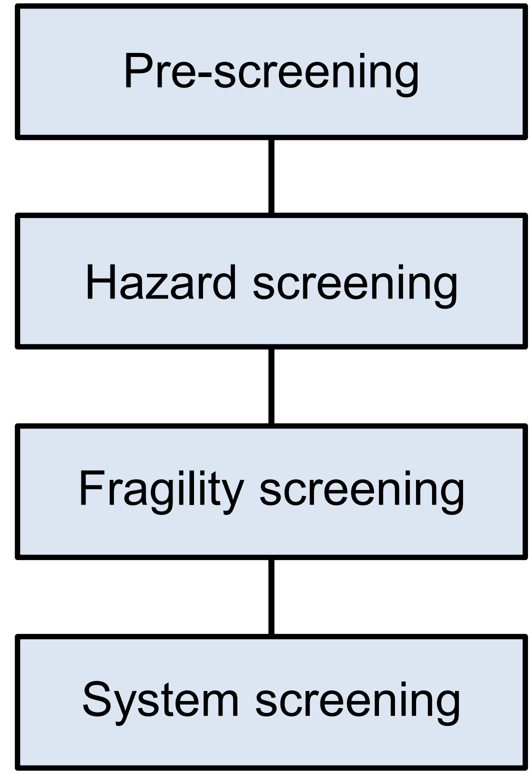
➢ Appendices

- Application Example (Seismic ground motion + Tsunami)
- Application Example (Mainshock + Aftershock)
- Application Example (Seismic ground motion + Tornado)
- Other Application Examples

Proposed structure of standardized procedures for combined hazard PRA

Screening Procedures for Combined Hazard PRA

- Why Screening?
  - Large number of possible hazard combinations.
  - Detailed PRA for all combinations is impractical.
- Screening Principles
  - Completeness
    - Ensure all risk-significant combinations are retained
  - Practical Feasibility
    - Reduce unnecessary assessment effort
- Four Screening Stages
  - Prescreening
    - Engineering judgment, operational experience
  - Hazard Screening
    - Hazard intensity, frequency, and temporal relationship
  - Fragility Screening
    - SSC behavior, residual damage, damage interaction
  - System Screening
    - Plant response, accident management, Human intervention



Four Screening Stages

Through these four stages, hazard combinations can be systematically reduced while maintaining sufficient completeness.

Screening Criteria

- The objective of screening is to retain risk-significant combinations while screening out insignificant ones.

Screening Criteria [1,3]

Screening method	Example
Mutually exclusive	High temperature + Snow
Hazard Inclusion	Aircraft accident + Fog (already included)
Enveloping	No additional impact
Progression rate	Sufficient mitigation time
Hazard frequency	$< 10^{-5}$/year [3]
CDF / LERF	CDF $< 10^{-6}$/year or LERF $<10^{-7}$/year [3]

These screening criteria provide practical guidance for systematically reducing the number of hazard combinations before detailed combined hazard PRA.

[1] ASAMPSA_E (2017): List of external hazards to be considered in ASAMPSA_E.
[3] EPRI (2015): Identification of External Hazards for Analysis in Probabilistic Risk Assessment.

Hazard Grouping

- Direct evaluation of all possible hazard combinations is impractical.

101 Candidate External Hazards [1]
- 77 Natural hazards
- 24 Human-induced hazards

Preliminary Screening
- Applicability to Japanese NPP sites
- Potential impact on plant safety
- Relevance to combined hazard assessment

25 Individual Hazards
- 17 Natural hazards
- 8 Human-induced hazards

Hazard Grouping
- Based on hazard source and characteristics

16 Hazard Groups
- 12 Natural hazard groups
- 4 Human-induced hazard groups

Hazard groups after prescreening

	Group	Hazards Screened In Through Preliminary Screening for Single Hazards
Natural Hazards	G1 Seismic / Ground	N1 Seismic Ground Motion
		N6 Ground Deformation
	G2a Seawater (Tsunami)	N7 Tsunami
		N61 Submarine Landslide
	G2b Seawater (Tide)	N18 Sea Water Level (High Waves, Tide)
	G3 Wind (Tornado)	N41 Tornado
		N46 Tornado-Generated Missiles
	G4 Rain	N8 Flash Flood / Flooding
	G5a Snow (Snow Accumulation)	N25 Heavy Snowfall
	G5b Snow (Avalanche)	N47 Avalanche
	G6 Biological Hazards	N56 HVAC Failure Caused by Birds or Insects
		N57 Cable Damage Caused by Rats or Moles
	G7 Volcano	N69 Volcanic Ash (Including Reduced Visibility)
	G8 Solar	N52 Geomagnetic Storm Caused by Solar Flare
	G9 Lightning	N39 Lightning Strike
	G10 Fog / Mist	N51 Fog (Whiteout)
Human-Induced Hazards	G11 Chemical Substances	M12 Chemical Release Caused by Vehicle Accident Near the Site
	G12 Ship	M7 Collision with Seawall
		M8 Impact on Water Intake
	G13 Offsite Power Supply	M18 Underground Cable Damage Caused by Construction Work
		M19 Disturbance of Offsite Power Grid
		M21 Electromagnetic Interference
		M22 High-Voltage Eddy Current
	G14 Fire	M73 Toxic Gas / Fire Spread Caused by Forest Fire
		M24 Human-Induced Forest Fire

- Benefits
  - Reduces the number of combinations
  - Improves practical feasibility
  - Maintains sufficient completeness

[1] ASAMPSA_E (2017): List of external hazards to be considered in ASAMPSA_E.

Preliminary Screening Matrix

- **Preliminary Screening Matrix for Combined Hazards**
- The rows and columns represent the 16 hazard groups identified through hazard grouping.
- Each cell represents a potential combination of two hazard groups.
- Hazard combinations are classified as associated, consequential, or independent based on their dependency characteristics.
- This matrix is a conceptual framework rather than a site-specific evaluation.

Example of Prescreening for G1 (Earthquake / Ground)

Combination with G1 (Earthquake / Ground)	Prescreening Decision
G2a Seawater (Tsunami)	🔴 Candidate for detailed evaluation (Screened in)
G7 Volcanic	🟡 Site-specific evaluation required
G14 Fire	🟡 Requires further evaluation
G3 Wind (Tornado)	🟢 Candidate for screening out
…	…

Preliminary screening matrix for Japanese nuclear power plant sites

Preceding / Subsequent	G1	G2a	G2b	G3	G4	G5a	G5b	G6	G7	G8	G9	G10	G11	G12	G13	G14
G1(Earthquake / Ground Conditions)		(b)				(b)	(c2)		(b) (c2)				(b)		(b)	(b)
G2a(Seawater (Tsunami))													(b)	(a)		
G2b(Seawater (Tide))																
G3(Wind (Tornado))													(b)		(b)	(b)
G4(Rain (Flood))									(c2)							
G5a(Snow (Avalanche))													(b)		(b)	
G5b(Snow (Snowfall))	(c2)														(b)	
G6(Biological Hazards)																
G7(Volcano (Volcanic Ash))	(c2)				(c2)										(b)	
G8(Solar Hazards)															(b)	
G9(Lightning)															(b)	(b)
G10(Fog / Mist)							(b)		(b)							
G11(Chemical Substances)							(b)		(b)							
G12(Ships / Marine Vessels)		(a)														
G13(Off-site Power Supply)																
G14(Fire)							(b)		(b)						(b)	

※ (a) Associated hazards, (b): Consequential hazards, (c1) Independent hazards (Short duration), (c2) Independent hazards (Long duration)

Conclusions

In summary, this study established a conceptual framework, proposed standardized PRA procedures, and developed a screening framework and preliminary screening matrix for combined hazards. These results provide a foundation for future standardization and practical implementation of combined hazard PRA.

- A conceptual framework for combined hazard PRA was established by considering hazard, fragility, and system dependencies.
- A standardized structure for implementing combined hazard PRA was proposed.
- A multi-phase screening framework consisting of prescreening, hazard screening, fragility screening, and system screening was organized.
- A preliminary screening matrix applicable to Japanese nuclear power plants was developed.

● Future Work

- Development of detailed screening criteria.
- Standardization of hazard, fragility, and system screening procedures.
- Application to practical combined hazard PRA studies
- Extension of the framework toward Level 3 PRA, including off-site consequence and public health impacts.

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Thank you

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