A Study for Identifying Multi-Unit Initiating Event and Estimating Frequency

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I.Background

Background

(Current Status of NPP Site in Korea)

Figure 1. Current Status of NPP Site in Korea

Background
(Growing Attention to Safety of Multi-Unit)

- **NSSC(Nuclear Safety and Security Commission) recommended a need of multi-unit risk assessment during the deliberation process on Shin-Kori unit 3 OL application and Shin-Kori unit 5&6 CP application.**
  - Recommendations from the multi-unit risk review committee under NSSC
    - Development of methodology for site risk assessment based on probabilistic approach
    - Development of regulatory framework for site risk
  - National Assembly initiated several bills to legislate "Multi-unit Safety Assessment"
  - NSSC launched a 5 year(2017~2021) project for multi-unit NPP safety.
    - Site risk PSA model for regulatory purpose
      - Regulatory MUPSA model
      - Preliminary site risk profile and safety insight
    - Regulatory framework for site risk
      - Site safety goal
      - Site risk metrics
      - Regulatory standard/guide

A Framework of the Research

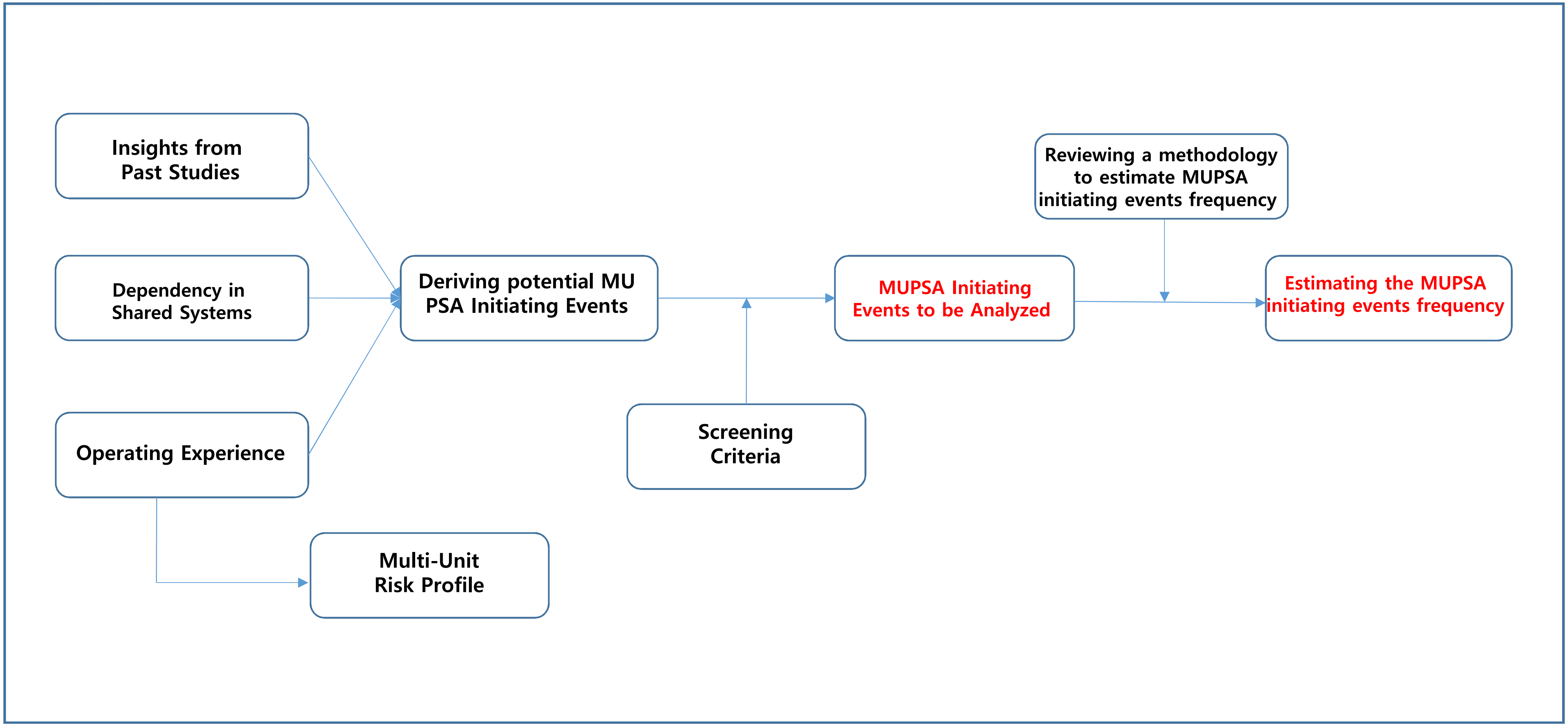

Figure 2. A Framework for the Research

KINS is a Cornerstone for a Safe Korea

II. Identification of Multi-unit Initiating Events and Estimation of Frequency

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Part 1. Insights from Related Studies

Related Studies (Seabrook Station)

Seabrook PSA(1983)

- 2 Westinghouse PWR units with minimal use of shared systems.
- PSA was used to address emergency planning issues that delayed the licensing of the plant. (Integrated Level 3 PSA of two unit station.)
- PSA scope : Internal and external hazards(fires, floods and seismic events) at full power mode and considering a site specific model of the emergency plan protective action

Table 1. Initiating Events for Integrated Seabrook Risk Model

Initiating Event Grouping	Initiating Events
Both Units Affected Concurrently in Each Instance	· LOOP · Seismic Events · Tornado and Severe Winds · External Flooding of Service Water Pumps · Truck Crash in Transmission Lines
Both Units Affected Concurrently in Certain Instances	· LOCV · Loss of Service Water · Turbine Missile Impacts
Occur Independently at Each Unit	· LOCA · General Transients Except LOCCW, Loss of one DC bus, Fires, Aircraft Crashes, Turbine Building Floods

* 58 Initiating events grouped into 3 categories.

Table 2. CDF Results from Seabrook MUPSA

PSA Scope	Risk Metric	Mean Value	Frequency Units
Unit 1 Only	Single Reactor CDF	2.3×10^{-4}	Events per year
Integrated PSA of unit 1 and 2	SUCDF	4.0×10^{-4}	Events per site year
	MUCDF	3.2×10^{-5}	
	Total SCDF	4.3×10^{-4}	

Table 3. Initiating Event Contribution to MUCDF

Contributors	Mean Frequency (Events per Station Year)	Percentage
Seismic Events	2.8×10^{-5}	87.5%
LOOP (1.4×10^{-1} Events per S.Y)	2.8×10^{-5}	8.8%
Truck Crash (2.8×10^{-4} Events per S.Y)	1.0×10^{-7}	0.3%
External Flood	1.6×10^{-6}	5.0%
Total	3.2×10^{-5}	100%

Related Studies (Browns Ferry NPPs)

- **Browns Ferry NPPs PSA(1995)**
  - TVA Submitted MUPSA report in 1995.
  - TVA provided NRC with an assessment result that a complete LOOP and loss of plant air are the two initiating events that could directly result in the shutdown of all three units.
  - Browns Ferry PSA estimated that the CDF increased by a factor of 4 for 3 units, while the Seabrook PSA shows a multiplier of 1.87 for the CDF for 2 units.

Table 4. Example of BFN Shared Systems and Considered in MUPSA

Browns Ferry 1, 2 & 3	In Multi-Unit PRA	Shared System	Cross -Tie	Comments
MECHANICAL SYSTEMS				
Auxiliary Systems				
Auxiliary Boiler System	No	YES		
Residual Heat Removal (RHR) Service Water System	YES	YES		This system serves all of the units at the plant. The RHRSW system is composed of 4 pairs of pumps assigned to the RHR systems of the 3 units. An additional set of 4 pumps co-located with the RHRSW pumps is assigned to the EECW system. There are also 4 swing pumps nominally assigned to the RHRSW system. Each pair of RHRSW pumps feeds one independent RHR service water header, which, in turn, feeds one RHR heat exchanger on each unit. Four of the RHRSW pumps can be aligned for alternative service to supply the two EECW headers. The design criterion states that two RHRSW pumps and two RHR heat exchangers are required for heat removal. The RHRSW pumps are addressed individually in the support system event tree.
Raw Cooling Water System	YES	YES		The raw cooling water system serves all 3 units. The suction headers for Units 1 and 2 are interconnected. Nominally, 3 pumps are assigned to each unit with one shared spare. The suction header for Unit 3 is independent. 7 pumps serve Units 1 and 2, and an additional 5 pumps serve Unit 3.
Raw Service Water System	No	YES		

Related Studies (MHTGR)

● Modular High Temperature Gas-Cooled Reactor(Early 90s)

- General Atomics(GA) company developed the Modular High Temperature Gas-Cooled Reactor(MHTGR) for the U.S. Department of Energy(DOE).
- MHTGR design comprised of four reactor modules with 500 Mw thermal power each.
- Purpose of PSA was to provide input for the selection of licensing basis events and safety classification of SSCs.

Table 5. Results of MHTGR PSA

Initiating Events	I.E Freq.	Results	MU Sequence
Primary Coolant Leaks	0.26/year	2.0×10^{-2}/Plant Year	Screened.
Loss of Main Loop Cooling	0.26/year	<1.0×10^{-7}/Plant Year	Considered.
Earthquakes(>0.06g)	6.0×10^{-3}/year	No event sequence with a radionuclide release w/ a mean frequency of greater than 7×10^{-7}/year	Considered. Not in accident sequence.
LOOP with Turbine Trip	5.0×10^{-3}/year	No event sequence with a radionuclide release within a mean frequency range	Considered.
Inadvertent Control Rod Withdrawal	0.1/year	No event sequence with a radionuclide release within a mean frequency range	One sequence considered.
Steam Generator Leaks	0.1/year	4.0×10^{-5}/Plant Year	Not Considered.

Related Studies (Byron/Braidwood NPPs)

- **Byron/Braidwood NPPs PRA for Risk-informed Tech. Spec. Evaluation(Late 90s)**
  - Two dual unit Westinghouse 4-loop PWRs
  - Two reactor units with shared structures for safety-related system and components
  - Single reactor PSA model for each of the 4 units with modelling dual unit dependencies
  - No requirement for MUPSA, but performed with curiosity
  - Internal fires, seismic events, and other internal and external hazards are excluded.
  - The multi-unit CDF from this PSA was about $3x10^{-5}$/site year. (Seabrook SCDF = $3.2x10^{-5}$/site year)

Table 6. Intermediate Results of Risk Evaluation for Braidwood Station

Risk Metric	Unit 1		Unit 2	
	EDG Train A	EDG Train B	EDG Train A	EDG Train B
CDF_{Base}	$4.86x10^{-5}$/Rx-year		$4.86x10^{-5}$/Rx-year	
RAW	2.71	1.07	2.71	1.07
CDF_{EDGOOS}	$5.80x10^{-5}$/ Rx-year	$4.81x10^{-5}$/ Rx-year	$5.80x10^{-5}$/ Rx-year	$4.81x10^{-5}$/ Rx-year
$LERF_{BASE}$	$4.96x10^{-6}$/Rx-year		$4.96x10^{-6}$/Rx-year	
$LERF_{EDGOOS}$	$5.43x10^{-6}$/ Rx-year	$4.92x10^{-6}$/ Rx-year	$5.43x10^{-6}$/ Rx-year	$4.92x10^{-6}$/ Rx-year

* Base = Annual average results from baseline PSA(PSA model based on existing Tech. Spec.
EDGOOS = Results assuming EDG out of service
RAW = Risk achievement worth

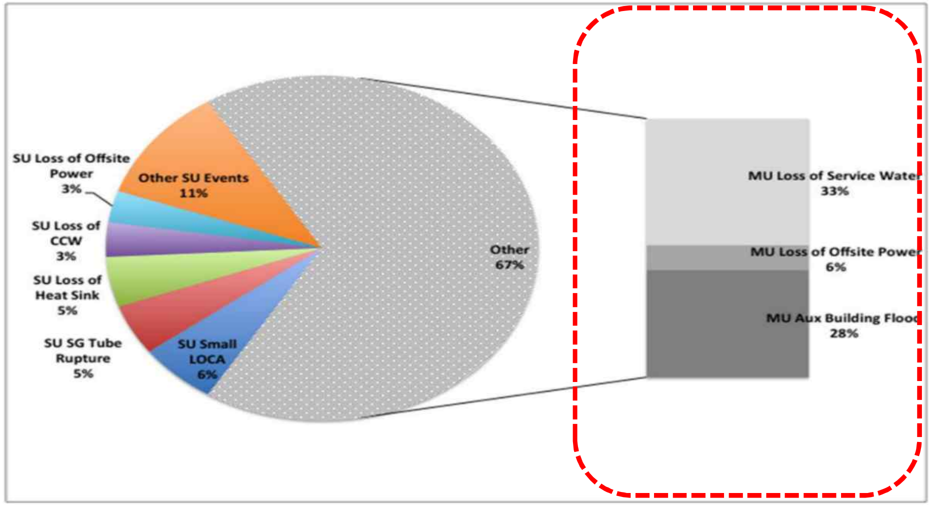

Figure 3. Braidwood 1 CDF Contribution by Initiating Events

Related Studies (IAEA)

- **Analyze Initiating Events for MUPSA**
  - Classification of Initiating Events for MUPSA
    1) Initiating Event
    2) Common Cause Failure (Single unit CCF, Multi unit CCF)
    3) Common Cause Initiating Event (e.g., Total loss of AC Power, Loss of CCW, Internal Fire or Flood)
  - Initiating Category
    1) Initiating events impacting each reactor unit separately and independently
    2) Initiating events impacts specific combinations of reactor units including the case where all reactor units on the site are impacted
    3) Initiating events that may impact two or more reactor units depending on the severity, circumstances, or plant conditions at the time of the event
  - Possible Initiating Events
    1) LOOP
    2) External Hazards
    3) Internal Hazards involving Shared System and Structures
    4) Internal Events Involving Faults in Shared System

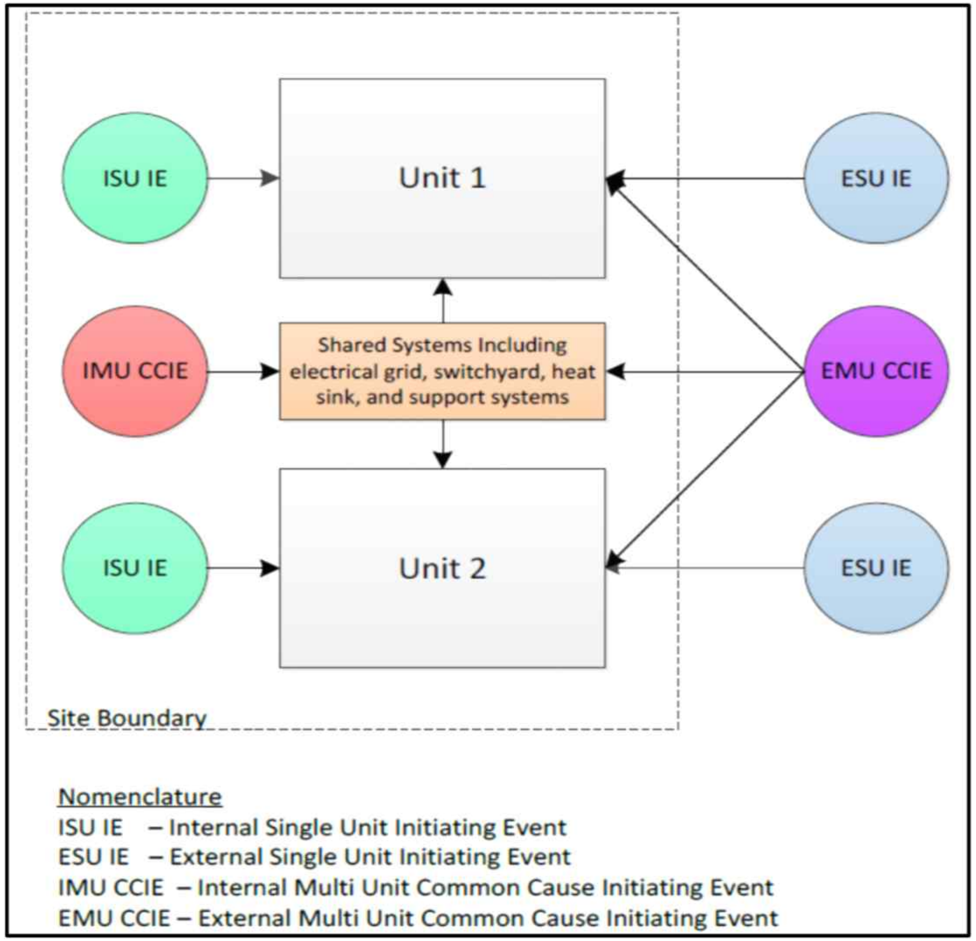

Figure 4. Definition of Initiating Event Categories for MUPSA

Related Studies (ORNL)

- **Oak Ridge National Laboratory**
  - PSAs
    1. Brown Ferry multi-unit PSA
    2. Seabrook PSA
    3. Byron/Braidwood IPE
    4. MHTGR PSA

    LOOPs caused by equipment, personnel, seismic, and failure of Shared system, unexpected events, site wide events, combined effects
  - IAEA(Work Area 8 of the International seismic safety centre's Extra budgetary programme)

    → Loss of grid, consequential LOOP, Internal and external hazards
  - Operating experience review from 1980 to 2015

    → LOOPs caused by equipment, personnel, weather, and etc.
  - Fukushima events

    → Radiological consequences from a damaged unit or damaged waste storage structures may affect the safety of other units
  - Generic Safety Issues(43-45,102,130,143,153,156,162, Item A-17, A-44, COL-ISG-022, Candidate GSI)
  - RG 1.32(Criteria for power systems for NPPs), RG 1.81(Shared electric systems for multi-unit NPPs)
  - NUREG/CP-0149, NUREG-1843, NUREG/CR-6890, NUREG/CR-5750

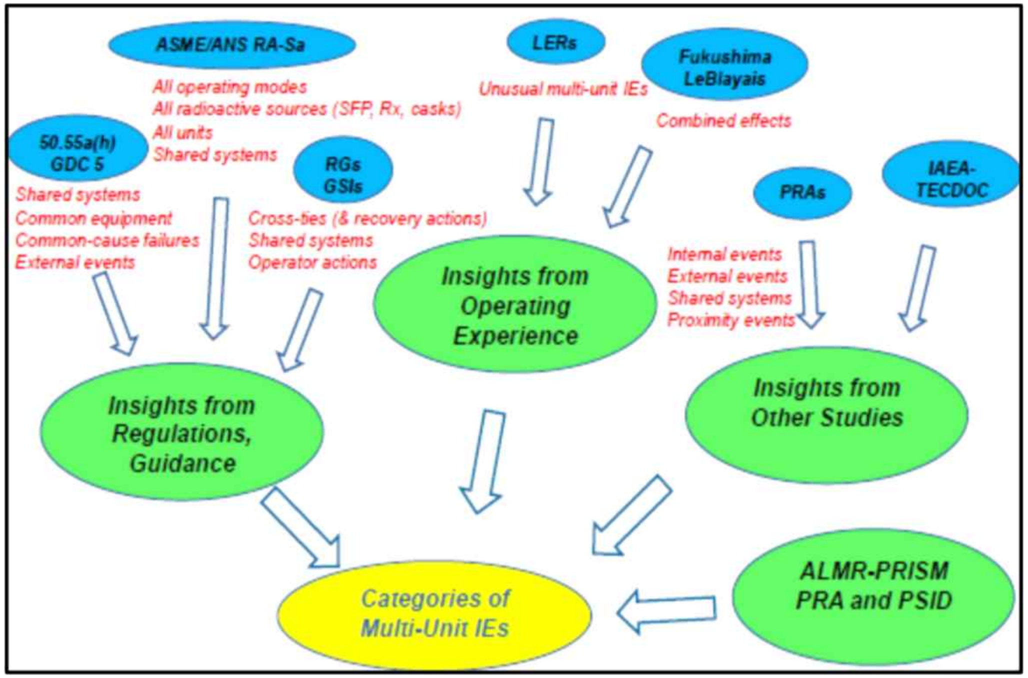

Figure 5. Source Used to Identify Multi-Unit IEs

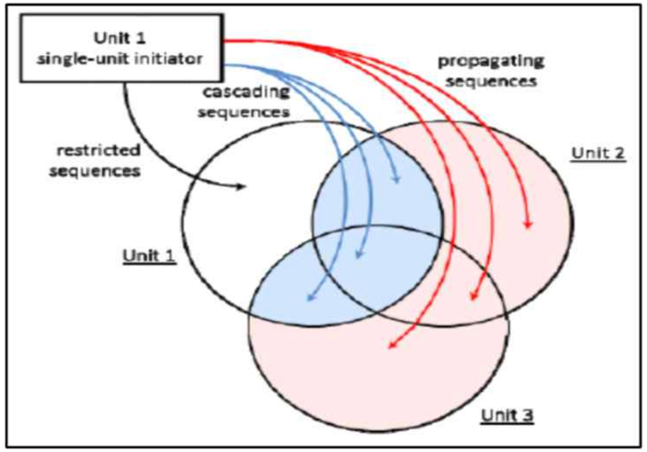

Figure 6. Types of Multi-Unit IEs

Table 7. Types of Multi-Unit IEs

Multi-unit IE Type	Example
Proximity event sequence	- Drop of 539 ton stator onto turbine deck floor caused LOOP at unit 1, transient at unit 2
Cascading event sequence	- Loss of UAT at unit 1 results in LOCCW, which was crosstied at unit 2, caused transients at both units - Incorrect operator response (manual scram) based on transient at the other unit and what the operator heard
Propagating event sequence	- Electrical fault at unit 1 caused a grid disturbances, which in turn caused a trip of unit 2 - Generator trip at unit 2 caused voltage transients on emergency buses at unit 1
External event sequence	- Grid disturbances where offsite power remained available and caused transients at both units - Undervoltage generated in switchyard, not offsite transmission system, caused transients at both units
Restricted event sequence	- IE dos not propagate or cascade to the other unit

Table 8. Preliminary Lists of MU IEs in Single or Multi-Unit PSA

Types of multi-unit IEs	Comments
Independent events	Currently addressed
Common-cause failures	Addressed in single unit, not multi-unit
Proximity events (e.g., drop of stator cause LOOP at Unit 1, transient at Unit 2)	Primarily limited to external events
Shared systems (positive and negative effects)	Typically include positive effects only
Cross-ties between/among units (positive and negative effects)	Typically include positive effects only
Missiles (e.g., missiles from a turbine disintegration striking a vulnerable part of another unit)	Not addressed in most of the multi-unit PRAs
Cascading events (e.g., loss of UAT at Unit 1 results in loss of CCW, which was cross-tied to unit 2; transients at both units)	Not addressed in most of the multi-unit PRA
Propagating event (e.g., electrical fault at Unit 1 caused a grid disturbance, which in-turn caused a trip of Unit 2)	Not addressed in most of the multi-unit PRA
Other external events in addition to seismic, flood, wind, fire (e.g., undervoltage generated in switchyard, not offsite transmission system, caused transients at both units)	Not addressed in most of the multi-unit PRA
Combined effects events including seismically-induced flood, seismically-induced systems interactions, seismic-initiated long term SBO, etc.	Not addressed
Other sources of radiological hazards (e.g., reactors, spent fuel pool, dry cask storage)	Addressed in single unit, not multi-unit
Integrated models for all site radiological sources, including consideration of model end-states, risk metrics, and mission times	Not addressed
Initiating events common to multiple reactors and/or spent fuel pools	Not addressed
Account for all operating states, not just full power (e.g., full power, low power, shutdown, refueling, damaged state, construction)	Addressed in single unit, not multi-unit
Combinations of operating states (e.g., full power/full power, full power/shutdown, shutdown/refueling, damaged state, construction)	Typically not addressed in multi-unit PRAs
Operators managing multiple units make wrong/unit wrong/train errors	Not addressed
Human errors in maintenance and testing operations on the wrong unit or wrong train causes loss of safety system and transient event	Not addressed
Effects of core damage, radiological release, and mitigation actions on operator response (including control room habitability)	Not addressed
PRA must reflect allowable plant configurations when evaluating IEs. For example, NRC identified inadequate Tech Specs for shared systems when one unit is shutdown and the other is operating. (GSI 130, GSI 162)	Not addressed
Shared stacks, ventilation systems, or other pathways for combustible gases	Not addressed
Integrated uncertainty analysis for overall site risk	Not addressed
LOOP events (grid disturbance need not occur close to the plant)	Addressed in single- and multi-unit PRAs
Grid disturbances that may or may not lead to a LOOP or transient event	Not addressed
Evaluate the potential hazards from constructing new plants (COL-ISG-022)	Not addressed

Insights From Past Studies

- **Insights from past four multi-unit PSA experience(Seabrook, Browns Ferry, MHTGR, Byron/Braidwood)**

Table 9. Preliminary Lists of MU IEs in Single or Multi-Unit PSA

Single and Multi unit Initiating Events
・LOCA ・Internal Flooding ・GTRN ・LOCV ・LOOP ・Loss of Heat Sink ・Loss of Heat Transport System ・Loss of CCW ・Turbine Missile ・Loss of Service Water ・Loss of Plant Control Air ・Loss of 500kV Grid ・Loss of Raw Cooling Water ・Loss of Preferred Water ・Loss of I&C Bus ・Loss of Reactor Building Closed Cooling Water ・Loss of Chilled Water ・Loss of One DC Bus ・Internal Fire ・Aircraft Crashes ・Seismic Event ・Tornado and Wind Event ・External Flooding ・Truck Crashes

- **Insights from international multi-unit PSA research**
  - ➢ Types of multi-unit PSA initiating events are suggested.

- **Insights from Korean multi-unit PSA research**
  - ➢ Focused on identifying multi-unit events in Korea.

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Part 2. Identification of Multi-Unit PSA Initiating Events Using OPIS Data

Event Classification Scheme for Multi-Unit Events

- S. Schroer developed event classification scheme to explore wide breadth of potential dependencies that occur at multi-unit sites.
- Also, she expected that an accurate view of a multi-unit site's risk profile could be gained.
- Six main commonality classifications have been established.
  1) Initiating Events 2) Identical Component 3) Human 4) Organizational 5) Proximity 6) Shared Connection
- Licensing event reports(LERs) from 2000 to 2010 were analyzed using proposed classification scheme.

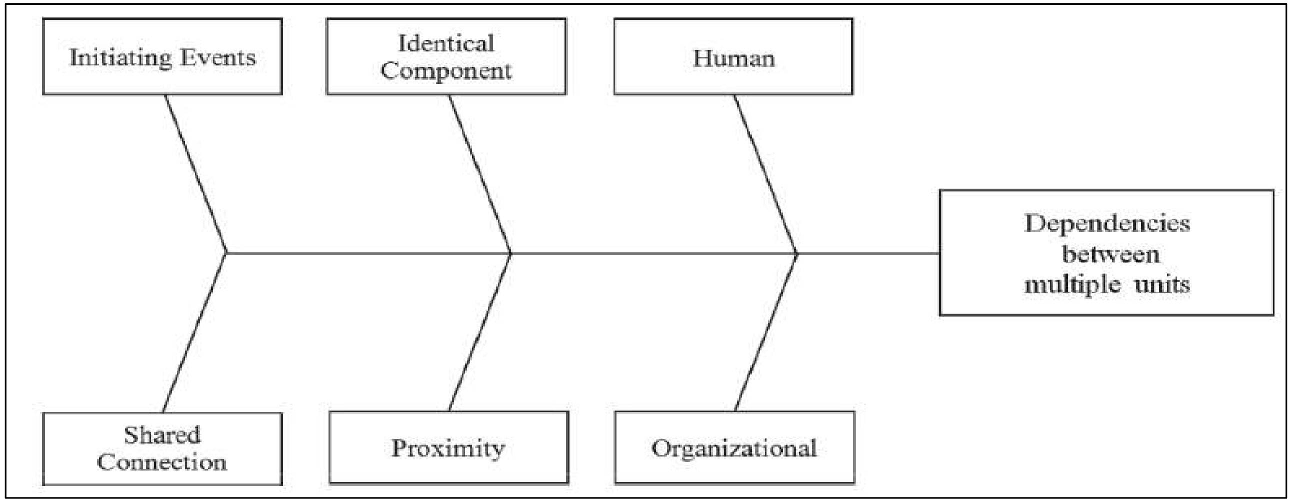

Figure 7. Commonality Classification of dependent events

Development of Modified Event Classification Scheme

- **Limitations of Using Event Classification Scheme for Multi-Unit Events**
  - It was difficult to analyze OPIS(Operation Performance Information System) data in Korea using event classification scheme.

- **Developing a Modified Event Classification Scheme for Multi-Unit Events**
  - Internal Factors

    1) Hardware factor

    - Identical component : Accident due to components that have same design, operation, the operating environment in multiple units
    - Shared component : Accident due to links that physically connect SSCs of multiple units

    2) Software factor

    - Individual : Accident due to individual human error such as maintenance error
    - Organizational : Accident due to organization's error such as safety culture, procedure and etc.

  - External Factors

    1) Lightening
    2) Severe climate change
    3) External fire
    4) External flooding
    5) Strong wind(Typhoon)
    6) Beyond design earthquake
    7) Maritime Organisms

  - Types of Multi-Unit Events

    1) Type 1 : Independent events
    2) Type 2 : Cascading events
    3) Type 3 : Common cause events

* For the types of multi-unit events, types suggested by ORNL was adopted.

Development of Modified Event Classification Scheme

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Internal	Software	Individual error	Accident due to individual human error such as maintenance error	External	1. Lightening	5. Strong Wind(Typhoon)		
		Organizational error	Accident due to organization's error such as safety culture, procedure and etc.		2. Severe Climate Change	6. Beyond Design Earthquake		
	Hardware	Identical system	Accident due to components that have same design, operation, the operating envrionment in multiple units		3. External Fire	7. Maritime Organsims		
		Shared system	Accdient due to links that physically connect SSCs of multiple units		4. External Flooding			

No.	Unit	Date of events	Case	Operation mode	실제발생/발생가능	Identical	Individual	Organizational	Shared	MU Events	Evidence	발생원인	Effects on System	Result	Possible Initiating Event	Types of events (1: Independent, 2:Propagating, 3: Common casue)
7	월성4호기	2016-09-12 19:44	경주 인근지역 지진발생에 따른 월성 4호기 지진감시기 작동 및 원자로 수동정지	75%	실제발생						실제 지진이 발생하는 경우 인근 원전에 동일한 영향 발생 가능	지진		원자로 수동정지		3
8	월성3호기	2016-09-12 19:44	경주 인근지역 지진발생에 따른 월성 3호기 지진감시기 작동 및 원자로 수동정지	86%	실제발생						실제 지진이 발생하는 경우 인근 원전에 동일한 영향 발생 가능	지진		원자로 수동정지		3
9	월성2호기	2016-09-12 19:44	경주 인근지역 지진발생에 따른 월성 2호기 지진감시기 작동 및 원자로 수동정지	86%	실제발생						실제 지진이 발생하는 경우 인근 원전에 동일한 영향 발생 가능	지진		원자로 수동정지		3
10	월성1호기	2016-09-12 19:44	경주 인근지역 지진발생에 따른 월성 1호기 지진감시기 작동 및 원자로 수동정지	94%	실제발생						실제 지진이 발생하는 경우 인근 원전에 동일한 영향 발생 가능	지진		원자로 수동정지		3
11	신월성1호기 외 1개 호기	2016-09-12 19:44	경주 인근지역 지진발생에 따른 월성본부 지진감시기 작동(해당호기 : 신월성1,2호기)	100%	실제발생						실제 지진이 발생하는 경우 인근 원전에 동일한 영향 발생 가능	지진		10% 출력감발		3

Figure 8. Modified Event Classification Scheme Used in This Study

Identification of Multi-Unit PSA Initiating Events Using OPIS Data

- **Analysis of OPIS data from 1978 to 2017**
  - Total 726 events were analyzed using modified event classification scheme and 2 analysts who have more than 10 years of operating experience at NPP participated.
  - 14 multi-unit events actually occurred.
    1) Reactor trip for maintenance due to seismic events were considered separately.
  - 37 events were identified as potential multi-unit events. (Occurred in singe-unit but could possibly progress to multi-unit events.

Table 10. Possible and Actual Multi-Unit Initiating Events

		Actual			Possible		
I.E		MUGTRN	MULOOP	MULOCV	MULOOOP	MULOCV	MUSGTR
# of events		6	3	5	29	7	1
Cause	Int.	Identical : 0%	Identical : 0%	Identical : 0%	Identical : 0%	Identical : 0%	Identical : 0%
		Shared : 50%	Shared : 0%	Shared : 0%	Shared : 52%	Shared : 0%	Shared : 0%
		Individual : 0%	Individual : 0%	Individual : 0%	Individual : 0%	Individual : 0%	Individual : 0%
		Org. : 0%	Org :0%	Org : 0%	Org : 3%	Org : 0%	Org : 100%
	Ext.	Light : 33%	Light : 0%	Light : 0%	Light : 21%	Light : 0%	Light : 0%
		Severe W.C :0%	Severe W.C :0%	Severe W.C :0%	Severe W.C :0%	Severe W.C :0%	Severe W.C :0%
		Ext. Fire : 0%	Ext. Fire : 0%	Ext. Fire : 0%	Ext. Fire : 7%	Ext. Fire : 0%	Ext. Fire : 0%
		Ext. Flooding : 0%	Ext. Flooding : 0%	Ext. Flooding : 0%	Ext. Flooding : 0%	Ext. Flooding : 14%	Ext. Flooding : 0%
		Typhoon : 17%	Typhoon : 100%	Typhoon : 0%	Typhoon : 17%	Typhoon : 14%	Typhoon : 0%
		B.D E. : 0%	B.D E. : 0%	B.D E. : 0%	B.D E. : 0%	B.D E. : 0%	B.D E. : 0%
		Mari. Org. : 0%	Mari. Org. : 0%	Mari. Org. : 100%	Mari. Org. : 0%	Mari. Org. : 72%	Mari. Org. : 0%

Identification of Multi-Unit PSA Initiating Events Using OPIS Data

Table 11. Lists of Actual Multi-unit PSA Initiating Events

	NPP	Date of Occurrence	Internal Factor/ External Factor	MU Initiating Events
1	Kori 1,2	2010.07.16	External Factor(Lightening)	MUGTRN
2	Kori 1,2,3,4	2003.09.13	External Factor(Typhoon)	
3	Hanbit 5,6	2002.11.03	External Factor(Lightening)	
4	Hanul 1,2	1993.11.23	Internal Factor(Shared System)	
5	Kori 1,2	1987.04.21	Internal Factor(Shared System)	
6	Kori 1,2	1986.10.10	Internal Factor(Shared System)	
7	Hanul 1,2	1997.01.01	External Factor(Typhoon)	MULOOP
8	Kori 1,2,3,4	1987.07.16/17	External Factor(Typhoon)	
9	Kori 3,4	1986.08.28	External Factor(Typhoon)	
10	Hanul 1,2	2006.05.18	External Factor(Maritime Organism)	MULOCV
11	Hanul 1,2	2001.08.26	External Factor(Maritime Organism)	
12	Hanul 1,2	2001.05.01	External Factor(Maritime Organism)	
13	Hanul 1,2	1997.12.28	External Factor(Maritime Organism)	
14	Hanul 1,2	1997.02.01	External Factor(Maritime Organism)	

Risk Profile for Multi-Unit Events

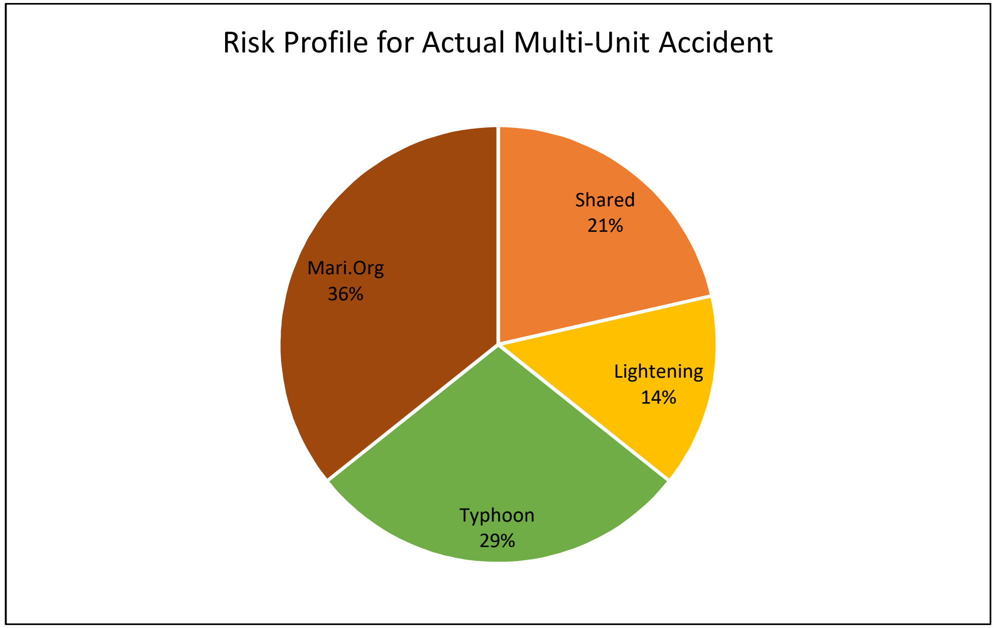

Figure 8. Risk Profile for Actual Multi-Unit Events

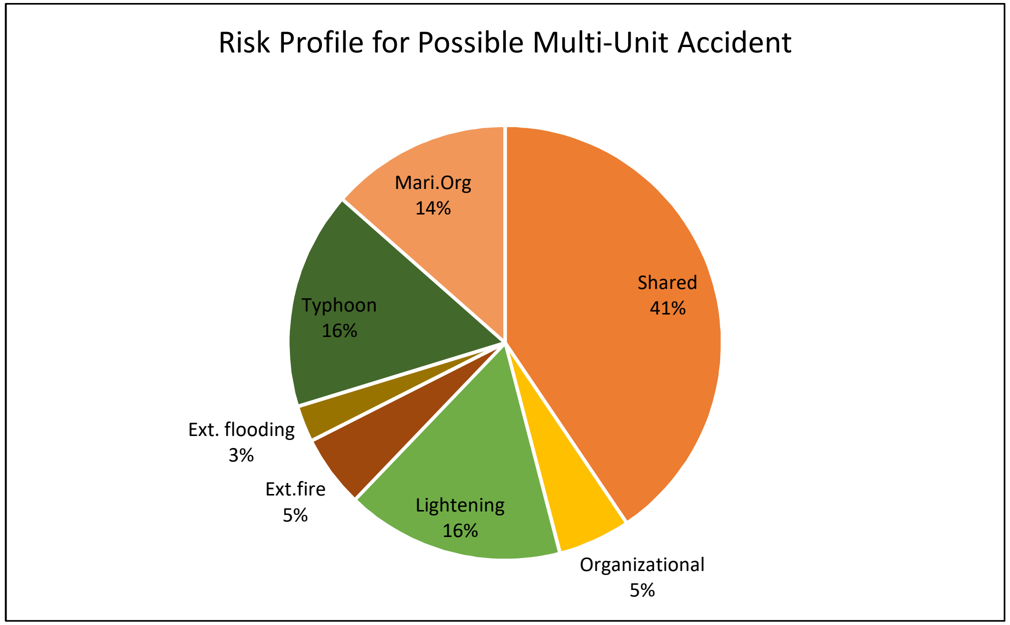

Figure 9. Risk Profile for Possible Multi-Unit Events

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Part 2. Identification of Multi-Unit PSA Initiating Events Using Dependence Analysis

Identification of Multi-Unit Initiating Events Using Dependence Analysis

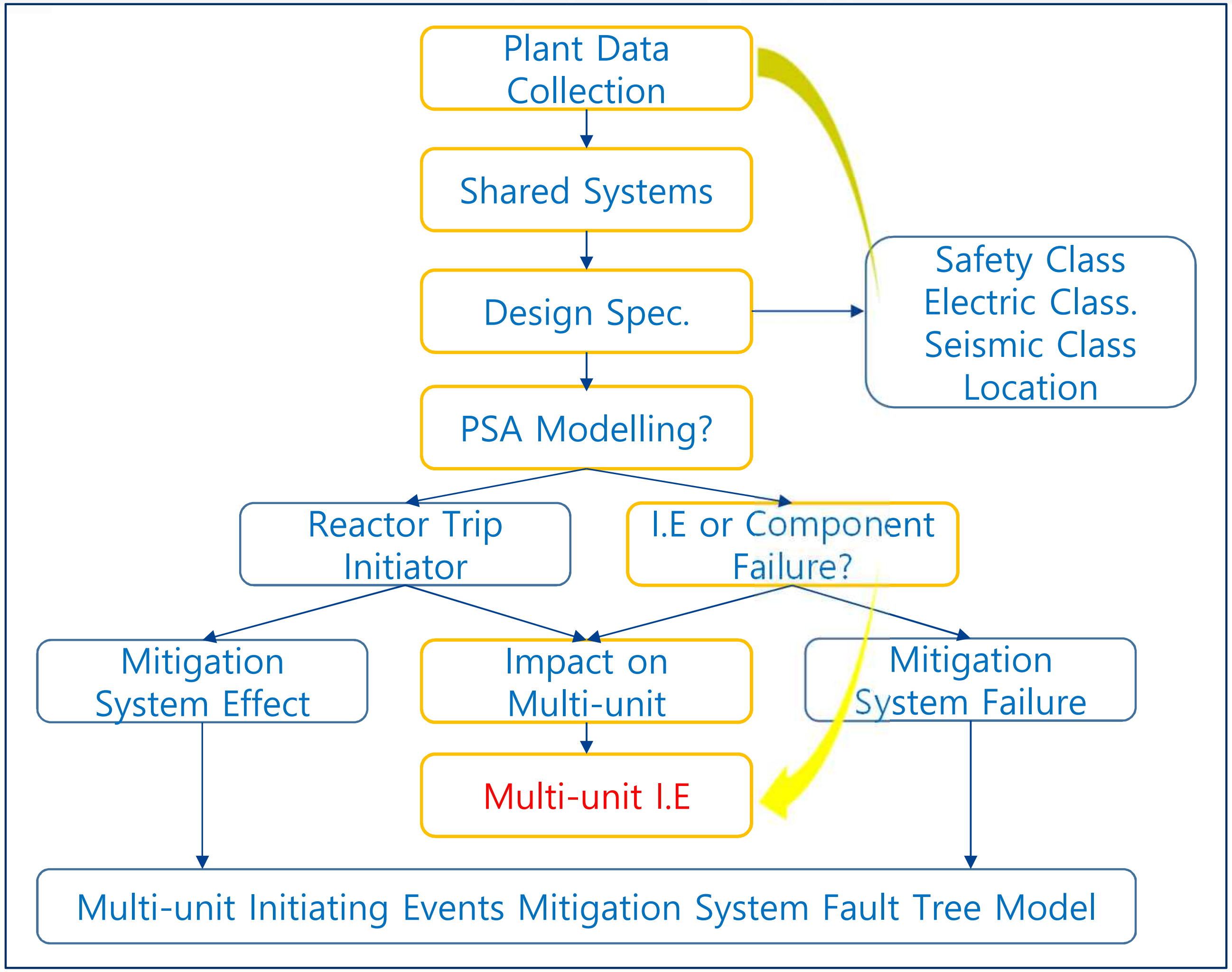

Figure 10. A Framework for Dependence Analysis

Identification of Multi-Unit Initiating Events Using Dependence Analysis

- **MULOCV, MULOIA and MULOCCW were identified based on analyzing 4 shared systems.**
  - Offsite power system : Switchyard, Grid
  - Circulating water system : Circulating water discharging conduit
  - Instrument air system : Shared connection line
  - Seismic monitoring system : Seismic monitor

Failure Mode and Effect Analysis(FMEA) was conducted for 4 shared systems.

Table 12 . Example of Failure Mode and Effect Analysis for Circulating Water System

Failure Mode	Effect	Anticipated Initiator	Multi unit effect
Loss of Component Cooling system due to Mechanical failure	- Reactor trip due to Loss of RCP seal cooling - Partial loss of relevant system (RCP, Charging pump, RHR/SDC system, Containment heat removal system, Essential chilled water system, Emergency diesel generator)	Partial Loss of Component Cooling Water	X
Loss of Essential Service Water system due to Mechanical failure	- Reactor trip due to Loss of RCP seal cooling - Partial loss of relevant system (RCP, Charging pump, RHR/SDC system, Containment heat removal system, Essential chilled water system, Emergency diesel generator)	Partial Loss of Component Cooling Water	X
Loss of Circulating Water system due to Mechanical failure	- Turbine Trip due to Loss of Condenser vacuum - Partial loss of relevant system (Turbine building component cooling water, Main feedwater, Air compressor, Non safety system HVAC)	Loss of Condenser Vacuum Loss of feedwater Loss of Instrument Air	X
Loss of Condenser pump	- Turbine Trip due to Loss of Condenser vacuum - Loss of Main feedwater pumps	Loss of Condenser Vacuum	X
Loss of Ultimate Heat sink due to External Hazard	- Reactor trip due to Loss of RCP seal cooling - Total loss of relevant system (Essential service water, Condensate water system, Turbine building component cooling water, Main feedwater, Air compressor, Aux.	Total Loss of Component cooling water* Loss of Condenser Vacuum (Loss of feedwater)	O

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Part 3. Suggestion of Multi-Unit PSA Initiating Events Screening Criteria

Literature Review on Screening Criteria for MUPSA Initiating Events

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- While many studies suggest screening criteria for traditional PSA initiating events, only few suggest for MUPSA.

Table 13. Literature Review of Screening Criteria Used in Various Countries

Reference[16]	Screening Criteria
IAEA SSG-3 (For external hazards)	• Dependent on the intensity of the hazard, no initiating event will be triggered. • The scenario develops slowly, there is sufficient time to control event, adverse consequences are very unlikely • The hazard scenario can be subsumed into another hazard • The hazard scenario has a significantly lower frequency of occurrence than other hazards, which lead to similar or worse consequences; simultaneously, the uncertainty of the frequency estimation is not significant for the risk assessment. * No quantitative recommendations on screening criteria
Western European Nuclear Regulators Association (For external hazards)	• It is not physically capable of posing a threat to nuclear safety. • The frequency of occurrence of the external hazards is higher than pre-set criteria • * Pre-set criteria may differ depending on the nature of the analysis that is to be undertaken.
OECD/NEA	• No specific guidance on screening criteria for external hazards
ASME/ANS RA-S (for external events)	• The event is of equal or lesser damage potential than the events for which the plant has been designed. • The event has significantly lower mean frequency of occurrence than another event and the event could not result in worse consequences than the consequences from the other event • The event cannot occur close enough to the plant to affect safety. • The event is included in the definition of another event. • The event is slow in developing allowing sufficient time for adequate response.
Belgium	• No screening criteria for internal and/or external hazards for consideration in PSAs
Bulgaria (for internal hazards)	• Events shall be demonstrated with qualitative arguments that the hazard has negligible contribution to the CDF; a qualitative evaluation demonstrates that the contribution to the CDF is less than 10^{-9}/year.
CANADA (for natural external hazards)	• A phenomenon which occurs slowly or with adequate warning with respect to the time required to take appropriate protective action • A phenomenon which in itself has no significant impact on the operation of an NPP and its design basis • An individual phenomenon which has an extremely low probability of occurrence. • The NPP is located at a sufficient distance from or above the postulated phenomenon • A phenomenon that is already included or enveloped by design is another phenomenon
Czech Republic (for external events)	• Qualitative screening (question of applicability, possibility, speed) • Quantitative screening (frequency of external event, hazard parameters, risk measures) • The risk from external events is insignificant, if all three of the following conditions apply - CDF (from external event) < 1% Total CDF - LERF (from external event) < 1% Total LERF - Accident scenarios from external events are not type of "Cliff edge effect" (CCDP)

*** All contexts in Table is adopted from [16] and reproduced.**

Literature Review on Screening Criteria for MUPSA Initiating Events

Table 13. Literature Review of Screening Criteria Used in Various Countries

Reference	Screening Criteria
France (For external hazards)	• Applicability : The hazard cannot occur on the site or sufficiently close to have an impact. • Inclusion : The hazard is included in the definition of other hazards analyzed for the site. • Severity : The hazard can only generate potential damage lower than or equal to that caused by similar events for which the plant was sized. • Initiating event : the hazard doesn't generate any PSA initiating event. • Kinetics : The hazard has sufficiently slow kinetics to demonstrate that there is sufficient time to either eliminate the effects or to implement a suitable response. • Frequency : The hazard has a frequency of occurrence lower than indicative target in order of a few 10-7 per reactor year. • Contribution : The risk contribution of the hazard is lower than indicative targets of a few 10^{-7} per reactor year for fuel meltdown, or of a few 10^{-7} per reactor year for large releases.
Germany	• Each event contribution is no more than 10% to the total sum of CDF and no more that 10% to the total sum of LERF by bounding analysis. • Each event shall not exceed 20% of the overall CDF and LERF by detailed analysis.

Hungary	• Distance : The event cannot occur close enough to the plant to affect it.
	• Frequency : The occurrence frequency of the event is justifiably less than a given threshold.
	  - Internal initiating events due to the failures of SSCs, and/or human errors, if the occurrence frequency is less than 10^{-5}/y for operating NPPs and 10^{-6}/y for new builds.
	  - Events induced by man-made external events applicable to the site, if the occurrence frequency is less than 10^{-7}/y, or it can be justified that the man-made hazard will not have an adverse affect on nuclear safety based on its distance from the plant.
	  - Natural external events with the occurrence frequency less than 10^{-4}/y for operating units and 10^{-5}/y for newbuilds.
	• Severity : The effects of the event are not severe enough to cause damage to the plant, since it has been designed for other loads with similar or higher strength.
	• Predictability : The event is slow in developing, and it can be demonstrated that there is sufficient time to eliminate the source of threat or to provide an adequate response.

Japan (For external hazards)	• The frequency of the hazard is apparently extremely low. • No hazard occurs in the proximity of the plant to have any impact. • Time scale for hazard progression is sufficiently longer than the time required to take countermeasure of the plant. • It is apparent that no hazard, assuming it has reached the plant, will cause any initiating event leading to core damage.
Lithuania	• Events, which are determined during design of NPP and included into analysis of design accident or are analogous to mentioned events, but less hazardous. • Event frequency is significantly smaller in comparison to frequency of other events which have similar outcomes or its outcomes are less hazardous than that of mentioned events. • Event cannot occur fairly close to NPP to influence its safety. • Event is included into definition of other event • The sequence of event development is very slow and there is enough time to eliminate hazard source or to prepare necessary security combinations.

Literature Review on Screening Criteria for MUPSA Initiating Events

Table 13. Literature Review of Screening Criteria Used in Various Countries(cont'd)

Reference	Screening Criteria
Romania	• The event is of equal or lesser damage potential than the events for which the plant has been designed. • The event has a significantly lower mean frequency of occurrence than another event taking into account the uncertainties in the estimates of both frequencies. • The event cannot occur close enough to the plant to affect it. • The event is slow in developing and it can be demonstrated that there is sufficient time to eliminate the source of the threat or to provide an adequate response.
Russia	• Qualitative screening criteria -The event cannot occur close enough to the plant to affect it. -The event is included in the definition of another event -The event is slow in developing and there is sufficient time to eliminate the source of the threat or to provide an adequate response. • Quantitative screening criteria - The event either has a very low (<$1E^{-6}$/a) mean frequency of occurrence or has a significantly lower mean frequency of occurrence than other events with similar uncertainties and could not result in worse consequences than those events. The uncertainty in the frequency estimate for the excluded event is judged as not significantly influencing the total risk. - The event is of equal or lesser damage potential than the events for which the plant has been designed or the event severity required to affect the plant has a frequency less than about $1E^{-6}$/a.
Switzerland (For external events)	• It is possible to justify qualitatively that the potential risk (in terms of frequency of core damage) contributes only marginally to CDF/FDF (e.g. in case when the impact on the facility does not invoke the activation of safety systems or the consequences are covered by accidents having significantly higher initial frequency of occurrence). • A quantitative assessment demonstrates that the potential contribution to CDF/FDF is not expected to exceed the value of 10^{-9}/a.
Ukraine	• The initiating event frequency is below 10-7/y.
USA	• The contributor or hazard cannot occur close enough to the plant to affect it. Application of this criterion must take into account the range of magnitudes and frequencies of the hazard. • Screening of contributors or hazards from a PRA based on the fact that core damage would not occur during a selected mission time (e.g., 24 hours) and core damage would not occur later, assuming no credit is taken for any compensatory measures that are implemented after the mission time is exceeded. • The contributor or hazard is included in the evaluation of another hazard or event. [NUREG-1855] • If it can be shown using a demonstrably conservative analysis that the mean value of the design-basis hazard used in the plant design is less than 10^{-5}/year and that the conditional core damage prob. Is less than 10^{-1}, given the occurrence of the design-basis-hazard event. • if it can be shown using a demonstrably conservative analysis that the CDF is less than 10^{-6}/a. It is recognized that for those new reactor designs with substantially lower risk profiles (e.g., internal events CDF below 10-6/a), the quantitative screening value should be adjusted according to the relative baseline risk value. [RG 1.200]
AREVA (For external events)	• Relevancy screening: it has the aim to discard such potential single or combined external events, which are not relevant to the nuclear power plant due to its location. • Impact screening: considers the list of site relevant external events and eliminate those potential external events which, with the maximal strength imaginable at the site, will not even have minor effects on the plant structures, cooling, and electrical transmission or on the plant operation.

Suggestion of Screening Criteria for MUPSA Initiating Events

- **Based on literature review, 4 screening criteria is suggested.**

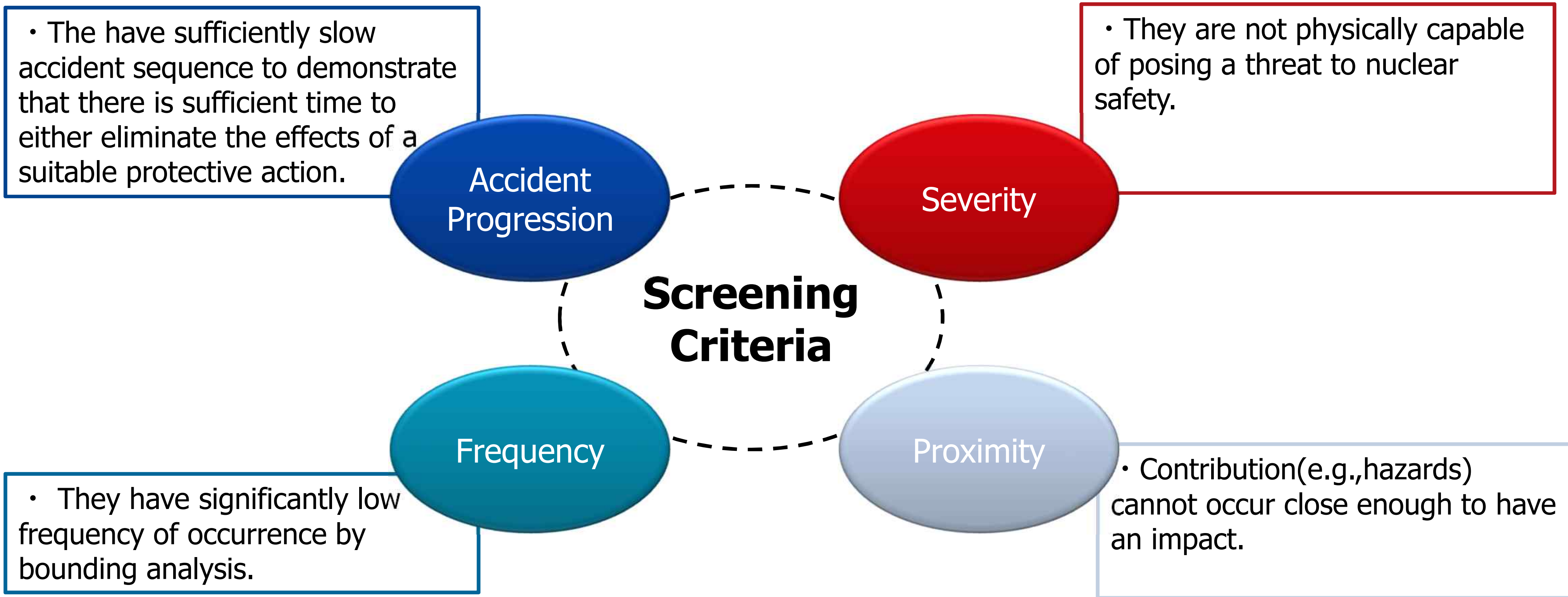

Figure 11. Screening Criteria Suggested in This Study

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Part 4. Identification of Multi-Unit PSA Initiating Events

Identification of Multi-Unit PSA Initiating Events

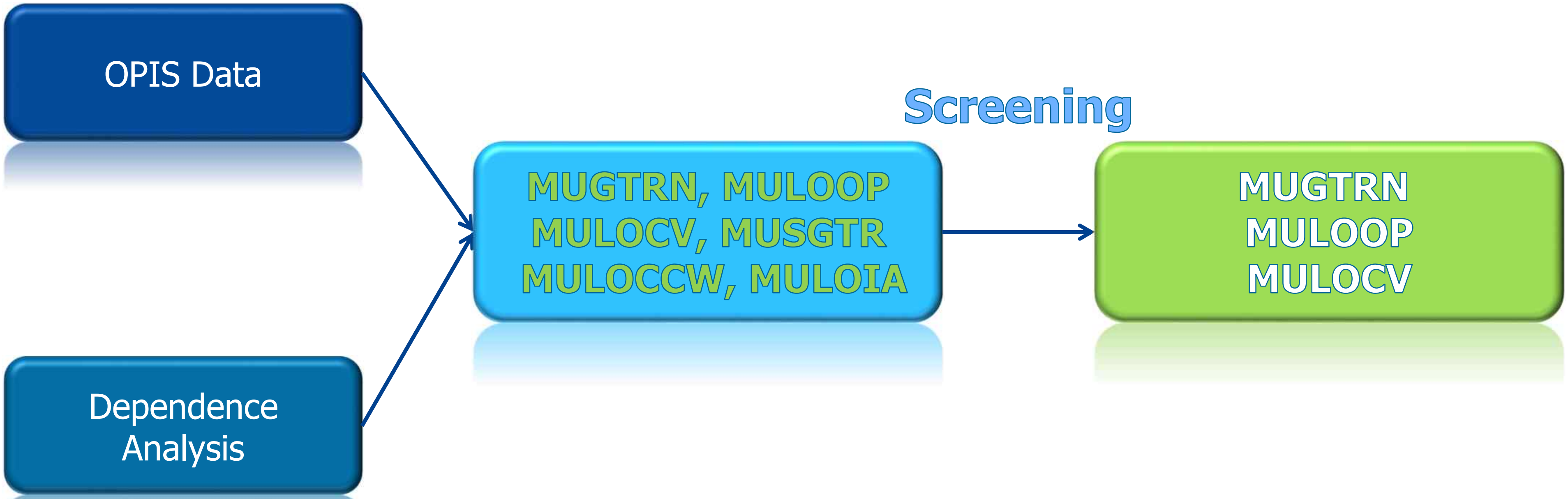

Figure 12. Identification of Multi-Unit Initiating Events

*** All contexts in Table is adopted from [16] and reproduced.**

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Part 5. Estimation of Multi-Unit PSA Initiating Event Frequency

Estimation of Multi-Unit PSA Initiating Event Frequency

- **4 assumptions were made.(Site year is estimated as of 2017.09.30)**
  - 1st assumption : Site year is calculated assuming the time when the first NPP at the site operated for 6 sites
  - 2nd assumption : Site year is calculated assuming the time when the second NPP at the site operated for 6 sites
  - 3rd assumption : Site year is calculated assuming the time when the first NPP at the site operated for 4 sites
  - 4th assumption : Site year is calculated assuming the time when the second NPP at the site operated for 4 sites

Table 14. 4 Cases of Site Year

Site	1st assumption	Site year	2nd assumption	Site Year	3rd assumption	Site Year	4th assumption	Site Year
Kori	1978.04.29	39.5	1983.07.25	34.2	1978.04.29	39.5	1983.07.25	34.2
Hanul	1988.09.10	29.1	1989.09.30	28.0	1988.09.10	29.1	1989.09.30	28.0
Hanbit	1986.08.25	31.1	1987.06.10	30.3	1986.08.25	31.1	1987.06.10	30.3
Wolsong	1983.04.22	34.5	1997.07.01	20.3	1983.04.22	34.5	1997.07.01	20.3
Shin-Kori	2011.02.28	6.6	2012.07.20	5.2	2011.02.28	-	2012.07.20	-
Shin-Wolsong	2014.07.31	3.2	2015.07.24	2.2	2014.07.31	-	2015.07.24	-
Total Site Year		144.0		120.2		134.2		112.8

Estimation of Multi-Unit Initiating Event Frequency

- **Multi-unit initiating event frequency was estimated for 4 cases.**

Table 15. Initiating Event Frequency for 1st assumption

Multi-Unit Initiating Events	Number of Occurrence	Site Year	Site Year			
			Maximum Likelihood Estimate	Gamma Distribution		
				Mean	Alpha	Beta
GTRN	6	144.0	4.17×10^{-2}	4.51×10^{-2}	6.5	144.0
LOOP	3	144.0	2.08×10^{-2}	2.43×10^{-2}	3.5	144.0
LOCV	5	144.0	3.47×10^{-2}	3.81×10^{-2}	5.5	144.0

Table 16. Initiating Event Frequency for 2nd assumption

Multi-Unit Initiating Events	Number of Occurrence	Site Year	Site Year			
			Maximum Likelihood Estimate	Gamma Distribution		
				Mean	Alpha	Beta
GTRN	6	120.2	4.99×10^{-2}	5.41×10^{-2}	6.5	120.2
LOOP	3	120.2	2.50×10^{-2}	2.91×10^{-2}	3.5	120.2
LOCV	5	120.2	4.16×10^{-2}	4.57×10^{-2}	5.5	120.2

Estimation of Multi-Unit Initiating Event Frequency

Table 17. Initiating Event Frequency for 3rd assumption

Multi-Unit Initiating Events	Number of Occurrence	Site Year	Site Year			
			Maximum Likelihood Estimate	Gamma Distribution		
				Mean	Alpha	Beta
GTRN	6	134.2	4.47×10^{-2}	4.84×10^{-2}	6.5	134.2
LOOP	3	134.2	2.23×10^{-2}	2.61×10^{-2}	3.5	134.2
LOCV	5	134.2	3.72×10^{-2}	4.10×10^{-2}	5.5	134.2

Table 18. Initiating Event Frequency for 4th assumption

Multi-Unit Initiating Events	Number of Occurrence	Site Year	Site Year			
			Maximum Likelihood Estimate	Gamma Distribution		
				Mean	Alpha	Beta
GTRN	6	112.8	5.32×10^{-2}	5.76×10^{-2}	6.5	112.8
LOOP	3	112.8	2.66×10^{-2}	3.10×10^{-2}	3.5	112.8
LOCV	5	112.8	4.43×10^{-2}	4.88×10^{-2}	5.5	112.8

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IV. Summary

Summary

- Possible multi-unit PSA initiating event was identified using OPIS data.
  - A modified event classification scheme was developed to gain risk profile on multi-unit accidents.
  - 726 OPIS data were analyzed.
- Potential multi-unit PSA initiating event was identified using dependence analysis.
  - FMEA was conducted for 4 shared systems.
- 6 possible multi-unit PSA initiating events were identified.
- 4 screening criteria for multi-unit PSA initiating events were suggested.
- 3 multi-unit PSA initiating events(MUGTRN, MULOOP, MULOCV) were selected as final candidate.
- Initiating event frequency was estimated for 4 cases.

*SU: Single Unit, MU:Multi Unit

*1: Independent, 2:Propagating, 3: Common casue

*시운전도 고려함

한수원 검토 부분

	N	Unit	Date o events	Case	Actual SU/MU IE Possible MU IE	Actual	Possibl	Types o events	외부영	On 도 시운전 여	비고	Evident (from raw data)
13	9	고리1,2호기	2010-07-16	고리 1,2 호기 송전선로 낙뢰로 인한 원자로자동정지	실제로는 MUGTRN으로 발생했으나 MULOOP 발생가능함	MUGTRN	MULOOP	3	낙뢰			고리 1,2호기 송전선로에 동시낙뢰가 발생하여 SWYD 차단기 5개가 동시에 개방되면서 고리 1,2호기의 터빈발전기 및 원자로가 정지된 사례로 자연재해로 다수호기에서 동시발생 가능성 있고, 또한 일시에 여러 발전소가 정지되면 국내 송전선로의 주파수가 저하되어 원전 운전에 부정적인 영향을 미칠 수 있음.
18	14	한울1,2호기	2006-05-18	해양생물 유입에 의한 터빈/발전기 수동정지	실제로 MULOCV 발생	MULOCV	-	3	해양생물 유입			취수구에 다량의 새우떼가 유입되어 복수기의 냉각기능이 상실되면서 터빈발전기 및 원자로를 정지한 사례로 특정 부지에 해양생물 다량 유입 시 다수호기 동시발생 가능성 있음.
19	15	고리1-4호기	2003-09-13	고리 1-4호기 태풍 "매미" 영향 송전선로 고장으로 인한 원자로 정지	실제로 MUGTRN 발생하였으며 MULOOP 발생가능	MUGTRN	MULOOP	3	태풍			강한 태풍에 의해 송전선로가 고장난 사건으로 다수호기 사고로 발생가능함
21	17	한빛5,6호기	2002-11-03	영광 5,6호기 송전계통 낙뢰에 의한 원자로 정지 (시운전)	실제로 MUGTRN 발생하였으며 MULOOP 발생가능	MUGTRN	MULOOP	3	낙뢰	시운전 (6호기)	한수원에서는 한빛6호기는 시운전이므로 PSA 분석에서 제외하였음	송전선로 낙뢰에 의한 SWYD 차단기 개방에 의한 사건으로, 다수호기 동시발생 가능함
24	20	한울1,2호기	2001-08-26	울진 1,2호기 취수구 해파리 유입에 의한 원자로 정지	실제로 MULOCV 발생	MULOCV	-	3	해양생물 유입			취수구에 다량의 해파리떼가 유입되어 순환수펌프가 정지되고 복수기의 냉각기능이 상실되면서 원자로가 정지된 사례로 특정 부지에 해양생물 다량 유입 시 다수호기 동시발생 가능성 있음.
26	22	한울1,2호기	2001-05-01	울진 2호기 새우떼 유입에 따른 미임계 진입	실제로도 MULOCV 발생	MULOCV	-	3	해양생물 유입			취수구에 다량의 새우떼가 유입되어 순환수펌프1대가 정지되어 원자로출력을 40%까지 감발. 정지된 순환수펌프 복구 후 출력을 증발하던 중 순환수펌프 정지/기동이 반복되어 원자로출력을 29%까지 감발 유지. 순환수펌프 2대가 정지되어 터빈발전기 및 원자로를 수동으로 정지한 사례로 특정 부지에 해양생물 다량 유입 시 다수호기 동시발생 가능성 있음.
29	25	한울1,2호기	1997-12-28	울진 2호기 새우떼 유입에 의한 원자로 수동정지	실제 MULOCV 발생	MULOCV	-	3	해양생물 유입			새우떼에 의해 최종냉각수원 상실로 이어질 수 있는 사건으로, 다수기 사고로 발생가능함
31	27	한울1,2호기	1997-02-01	울진 1,2호기 취수구 새우떼 유입에 의한 원자로 정지	실제로 MULOCV 발생	MULOCV	-	3	해양생물 유입			취수구에 다량의 새우떼가 유입되어 순환수여과계통 드럼스크린 표면에 흡착되면서 드럼스크린에 고차압이 발생하여 순환수펌프 2대가 정지되어 복수기의 냉각기능이 상실되면서 주급수펌프 배기구 고압에 의해 주급수펌프가 정지되면서 증기발생기 저수위+급수/증기유량 불일치 신호에 의해 원자로가 정지된 사례로 특정 부지에 해양생물 다량 유입 시 다수호기 동시발생 가능성 있음.
32	28	한울1,2호기	1997-01-01	울진 2호기 강풍 영향 송전선로 손상으로 인한 원자로 정지	실제로는 SULOOP이며 MULOOP 발생가능	MULOOP	-	3	강풍		기존에는 SULOOP이었으나, 한수원 의견 반영하여 MULOOP.	영동지방의 폭설, 강풍에 의해 울진-동해 간 송전선로가 지락에 의해 차단되고, 울진-영주간 송전선로 송전탑이 모두 무너지면서 소외전원이 상실됨. 소외전원상실로 소내부하운전 중 1,2차측 출력편차에 의해 제어봉이 고속으로 삽입되면서 출력영역 중성자속 고감소율 신호로 원자로가 정지된 사례로 자연재해 발생 시 다수호기 동시발생 가능성 있음.
35	31	한울1,2호기	1993-11-23	울진 1,2호기 울진-영주 #2 송전선로 "C"상 지락에 의한 발전기 및 원자로 정지	실제로 MUGTRN 발생하였으며 MULOOP 발생가능	MUGTRN	MULOOP	3				단로기 내 가동접촉자와 고정접촉자의 접촉불량에 의한 과열 사건으로, 송전선로 상실 가능에 의한 다수기 사고로 발생가능함
42	38	고리1,2,3,4호기	1987-07-17	태풍 셀마호의 영향으로 주발전기 차동계전기 동작으로 터빈 및 원자로 정지	실제로는 1,3,4가 MUGTRN 발생했고 2호기는 SULOCV 발생했으며 MULOOP 발생가능함	MULOOP	-	3	태풍		기존에는 MUGTRN이었으나, 한수원 의견 반영하여 MULOOP	태풍 셀마의 영향으로 변압기 및 스위치야드의 절연물에 염분 축적으로 절연이 파괴되면서 비율차동계전기가 동작하여 터빈발전기 및 원자로가 정지된 사례로 자연재해에 의한 염분내습은 다수호기 동시발생가능성 있음.
43	39	고리1,2호기	1987-04-21	전력계통 송전선로 지락 및 단락사고로 인한 터빈 및 원자로정지	실제로 MUGTRN 발생하였으며 MULOOP 발생가능	MUGTRN	MULOOP	3	회오리/돌풍			고리 및 양산주변에 강한 회오리 및 돌풍이 발생하여 고리 1,2호기 송전선로와 인근 수목과 섬락으로 지락이 발생하고, 수목 연소로 연기, 불꽃으로 순간 단락되면서 전원계통의 전압이 강하됨. 1호기는 소내모선 전압이 강하되면서 조속기 공급전압이 감소하여 조속기 기능이 상실되면서 터빈발전기 및 원자로가 정지된 사례로 자연재해에 의해 송전선로가 영향을 받는 경우 다수호기 동시발생가능성 있음.
45	41	고리1,2호기	1986-10-10	345KV 송전선 탈락사고로 인하여 주파수 및 전압이 급격히 변동하여 저압터빈 조절 밸브의 불시폐쇄로 습분분리 재열기 B측 Rupture Disk 가 파열됨에 따라 터빈 보호를 위해 터빈을 수동정지하고 이에 따라 원자로 정지	실제로 MUGTRN 발생하였으며 MULOOP 발생가능	MUGTRN	MULOOP	3				신옥천변전소와 서대구변전소 사이 345kV 송전선 탈락으로 소내발전기 전압/주파수 변동이 유발되어 터빈조속기에 의해 터빈제어밸브 및 정지밸브가 급격하게 차단/개방을 반복하던 중 MSR Rupture Disk가 파열되어 운전원이 수동으로 터빈 및 원자로를 정지한 사례로 외부 송전선로의 이상에 의해 동시에 다수호기에 파급영향을 줄 가능성 있음.
47	43	고리3,4호기	1986-08-28	태풍 베라호의 영향에 의한 원자로 정지 및 소외전원상실	실제로 SULOOP 발생하였으며 MULOOP 발생가능	MULOOP	-	3	태풍		기존에는 SULOOP이었으나, 한수원 의견 반영하여 MULOOP. 실제로는 Partial MULOOP이며, 고리 1,2호기는 정상운전중이었음	태풍의 영향으로 주변압기의 피뢰기가 단락되어 차동보호계전기가 동작하면서 터빈발전기 및 원자로가 정지되고 변압기 선로의 피뢰기 및 애자가 소손되면서 외부전원까지 상실(LOOP)된 사례로 자연재해로 다수호기의 송전선로에 동일한 현상을 유발할 가능성 있음.