KINGS KEPCO INTERNATIONAL NUCLEAR GRADUATE SCHOOL

A Review on the Scope of Accident Management in the Accident Management Plan of Nuclear Power Plant

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Contents

Introduction (1/3)

- Background
  - After the Fukushima Daiichi accident, extensive reviews and stress test program were carried out across the countries operating NPPs and the relevant safety requirements were updated to strengthen the safety of NPP in major countries.
    - ❖ IAEA SSR-2/1, Rev.1 (2016)
    - ❖ European Utility Requirements (EUR), Rev.E (2016)
    - ❖ Western European Nuclear Regulators Association (WENRA) (2014)
    - ❖ YVL Guide (STUK) (2013)
    - ❖ Korean Nuclear Safety Act and Subordinate Regulations (2016)
    - ❖ 10CFR50.155 (U.S.NRC) (2019)

Introduction (2/3)

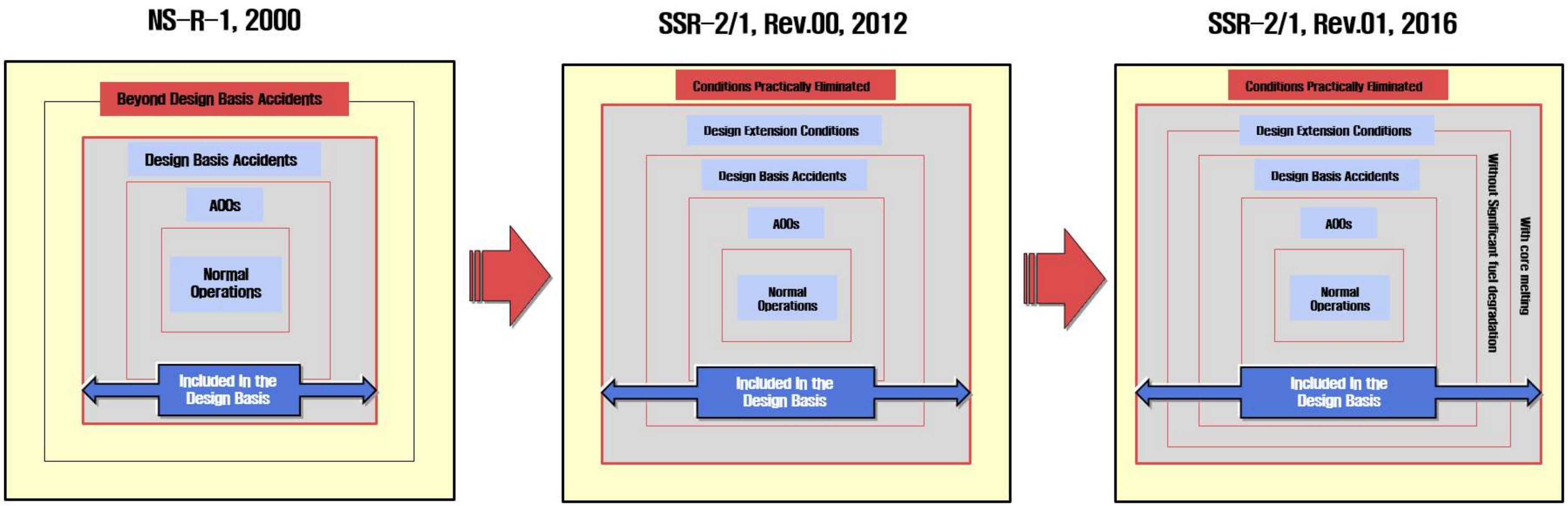
- Background
  - In accordance with the updated regulatory requirements, existing design frameworks have to be modified in consideration of beyond design basis event which is same concept as design extension condition.
  - The items necessary to modify existing design frameworks are as follows.
    - ❖Review the existing design frameworks
    - ❖Define the scope of beyond design basis accident to be addressed in design process
    - ❖Identify the additional accident scenarios to be addressed in the design process
    - ❖Establish analysis methodology & acceptance criteria for the additional accident scenarios
    - ❖Strengthen the defense in depth

Introduction (3/3)

- Objectives
  - o This study was conducted on the aspect of preliminary research for identifying a complete set of Postulated Initial Events (PIEs) including DEC. A complete set of Design Basis Events (DBEs) and DEC is very important to design of NPP because it could be determined the scope of the mitigation systems and strategies against PIEs.
  - o The main purpose of this study is;
    - ❖ To provide current status and implementations of DEC concept
    - ❖ To summarize the scope of accident management in the Accident Management Plan (AMP) of the Korean Nuclear Safety Act
    - ❖ To present the additional works required for the selection of PIEs including DEC for domestic NPP

Design Extension Condition Concept (1/5)

- Trend of plant states considered in design has changed after the Fukushima accident.



IAEA Approach to Beyond Design Basis Accident

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Design Extension Condition Concept (2/5)

- U.S NRC adopted the mitigation of beyond design basis events (MBDBE) rule, 10CFR50.155 which is different from the design extension condition concept.

Name of the Rule	Effective Date	Major Provisions
10CFR50.155	Sep. 9, 2019	• Based on the NRC's assessment of the costs and benefits of the rule, MBDBE rule is justified and published • Step-by-step procedures are not necessary for many aspects of the mitigation strategies and guidelines. Rather, the strategies and guidelines are intended to be flexible, and enable plant personnel to adapt them to the conditions that result from the beyond-design-basis external event • MBDBE rule is "patchwork" of previous beyond design basis requirements

U.S NRC Approach to Beyond Design Basis Accident

Design Extension Condition Concept (3/5)

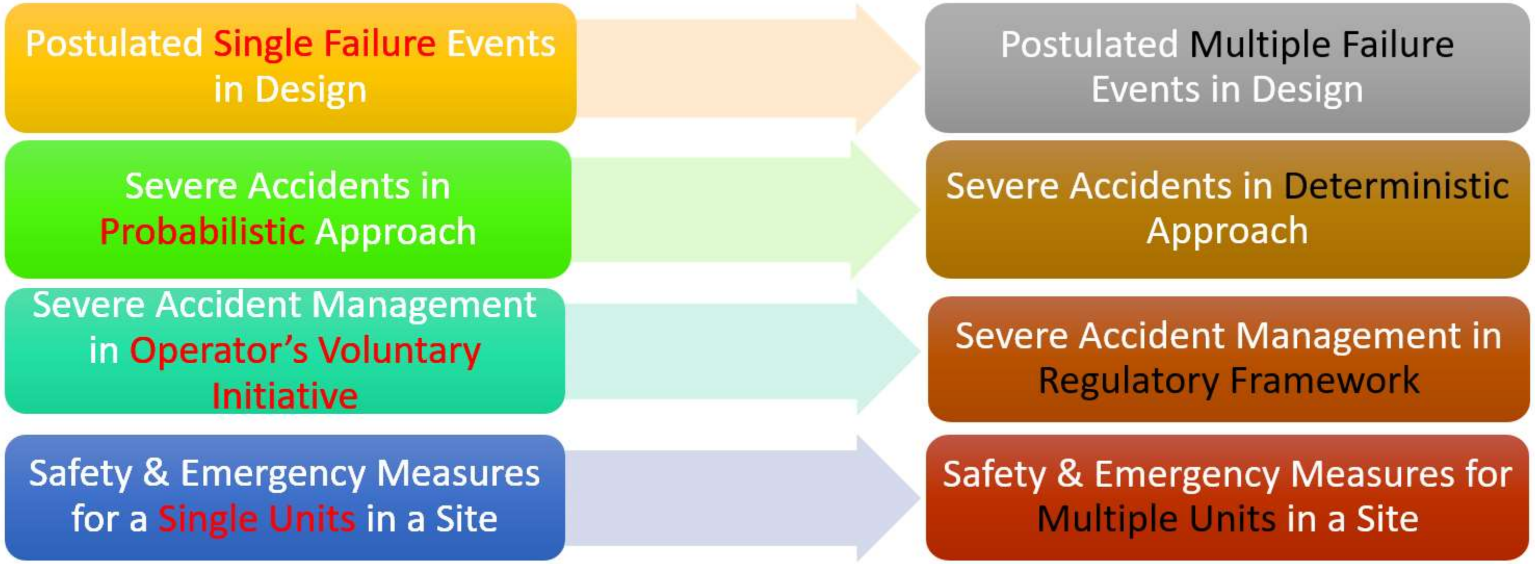
- Korean nuclear safety act and subordinate regulations have been revised reflecting design extension condition concept.

Name of the Law	Date of Revision	Major Substance of Revision
Nuclear Safety Act	June 22, 2016	• Include design extension conditions into the scope of accident management • Add accident management plan regarding operation as part of documents for operating license • Expand the scope of radiological environment impact assessment to include design extension conditions • Carry out periodic inspection on accident management including design extension conditions against operating NPPs

Korean Government Approach to Beyond Design Basis Accident

Design Extension Condition Concept (4/5)

- Typical trend in safety demonstration in design process has changed.



Source: BDBA in Design Process, Colloquiumat Dept. of Nuclear & Quantum Engineering, KAIST, Daejeon, Nov. 29, 2016

Design Extension Condition Concept (5/5)

- Definition DEC and Beyond Design Basis Accident

Source	Definition
IAEA SSR-2/1 (Rev.1)	**Design Extension Conditions** *Postulated accident conditions that are not considered for design basis accidents, but that are considered in the design process for the facility in accordance with best estimate methodology, and for which releases of radioactive material are kept within acceptable limits.*
EUR, Rev.D	**Design Extension Conditions** *A specific set of accident sequences that goes beyond design basis conditions (DBC), to be selected on deterministic and probabilistic basis and including;* • *Complex sequences* • *Severe accidents*
U.S. NRC Homepage	**Beyond Design Basis Accident** *This term is used as a technical way to discuss accident sequences that are possible but were not fully considered in the design process because they were judged to be too unlikely. (In that sense, they are considered beyond the scope of design-basis accidents that a nuclear facility must be designed and built to withstand.) As the regulatory process strives to be as thorough as possible, "beyond design-basis" accident sequences are analyzed to fully understand the capability of a design.*

Scope of Accident Management (1/8)

- The definition of accident management presented in Korea Nuclear Safety Act (NSA) is as follows;
  - The term "accident management" means all measures taken, when any accident occurs in a nuclear reactor facility, to prevent the expansion of the accident, to mitigate the consequences of the accident, and to restore the required level of safety, and includes management of any accident causing significant damage to a reactor core exceeding the criteria for design determined by the Nuclear Safety and Security Commission (severe accident)

Scope of Accident Management (2/8)

- Scope of accident management presented in the regulations on technical standards for nuclear reactor facilities, etc. is as follows;
  - Design Basis Events
    - Normal Operation
    - Anticipated Operational Occurrence
    - Design Basis Accident
  - Multiple Failure Events
  - Natural and Man-Made Hazards Exceeding External Events Considered in the Design Criteria
  - Severe Accident

Scope of Accident Management (3/8)

- Design Basis Events
  - DBEs are traditionally classified into seven categories according to the U.S. Regulatory Guide (RG) 1.70 and NUREG-0800 Chapter 15.
    - ❖ Increase in Heat Removal by the Secondary System
    - ❖ Decrease in Heat Removal by the Secondary System
    - ❖ Decrease in Reactor Coolant System (RCS) Flow Rate
    - ❖ Reactivity and Power Distribution Anomaly
    - ❖ Increase in RCS Inventory
    - ❖ Decrease in RCS Inventory
    - ❖ Radioactive Release from a Subsystem or Component

Scope of Accident Management (4/8)

- Design Basis Events
  - In each category, there are divided into AOOs and Postulated Accident (PA) based on the frequency of occurrence and a total of 33 PIEs have been selected and presented in SAR Chapter 15 for APR1400.
  - However, there are no systematic selection methods or documentation for the list of DBEs presented in SAR Chapter 15.
  - So, further work for identifying the DBEs is needed to determine whether the DBEs for the digital-based NPP match the list of those of RG 1.70. For example, a potential common cause failure in digital control systems could trigger initiating events which have not been considered in the analog systems.

Scope of Accident Management (5/8)

- Multiple Failure Events
  - According to the regulation related to the Accident Management Plan (AMP), the list of multiple failure events is as follows;
    - ❖ Anticipated Transient Without Scram (ATWS)
    - ❖ Station Black Out (SBO)
    - ❖ Multiple Steam Generator Tube Rupture (MSGTR)
    - ❖ Total Loss of Feedwater (TLOFW)
    - ❖ Interfacing System Loss of Coolant Accident (ISLOCA)
    - ❖ Loss of Ultimate Heat Sink (LOUHS)
    - ❖ Small Break LOCA plus Loss of Emergency Core Cooling System
    - ❖ Loss of Fuel Pool Cooling

Scope of Accident Management (6/8)

- Multiple Failure Events
  - A set of multiple failure events should be derived and justified as representative, based on the engineering judgement, combination of deterministic and probabilistic method.
  - In the nuclear safety commission notice No. 2016-2, “Regulations on the scope of accident management”, it states that additional multiple failure events with a similar level of likelihood and impact to those that are essential to be considered should be derived through PSA.
  - However, there is no official basis document regarding additional multiple failure events derived from PSA results.

Scope of Accident Management (7/8)

- Natural and Man-Made External Hazards Exceeding Design Basis
  - Natural Hazards
    - ❖ Earthquake
    - ❖ Excessive Rainfall
    - ❖ Tsunami Caused by Earthquake
    - ❖ Storm Surge
    - ❖ Extreme Winds
    - ❖ Excessive Snowfall
    - ❖ Thunderstorms
    - ❖ Extreme Temperature
  - Man-Made Hazards
    - ❖ Aircraft Crash

Scope of Accident Management (8/8)

- Severe Accident
  - IAEA definition for Severe Accident (SA) is;
    - ❖ Accident conditions more severe than a design basis accident and involving significant core degradation
  - The severe accidents management system mitigates SAs and maintains containment integrity. This system includes a large dry pre-stressed concrete containment, hydrogen management system, large reactor cavity and core debris chamber, cavity flooding system, in-vessel corium retention and external reactor vessel cooling system, safety depressurization and vent system, emergency containment spray backup system, and sever accident management procedure.

Source: https://home.kepco.co.kr/kepco/EN/G/htmlView/ENGEHP00105.do?menuCd=EN07060105

Summary and Further Work (1/4)

- The accident management strategy after the Fukushima accident has been significantly changed compared to the previous one due to the reflection of the DEC concept.
- According to the AMP regulations for the domestic NPP, the selection of PIEs is the starting point for designing of the NPP. Therefore, systematic and complete identification for the PIEs by engineering judgement, deterministic and probabilistic method are important for effective AMP management and to enhance the safety of NPP.

Summary and Further Work (2/4)

- As a result of review for the regulations regarding the scope of accident management, the following further works are identified to make a complete set of PIEs.
  - Review the existing design frameworks
  - Find out the basis of the DBEs list
  - Derive additional DBEs which have not been considered in the SAR Chapter 15 by reflecting operating experience and licensing issues etc.
  - Define the scope of beyond design basis accident to be addressed in design process
  - Identify additional accident scenarios to be addressed in the design process
  - Re-establish the event classification
  - Strengthen the defense in depth

Summary and Further Work (3/4)

- Application of Event Classification for APR1400 (Example)

EVENT FREQUENCY RANGE (per Reactor-Year)	IAEA/WENRA	EUR/France	Finland (STUK)	Canada (CNSC)	10CFR50 AppA	RG 1.70 Rev.2	Republic of Korea
Planned Operations	Normal	Normal (DBC 1/ PCC 1)	Normal (DBC 1)	Normal	Normal	Normal	Normal
10^{-1} – 10^{-2}	AOO	Incidents (DBC 2/ PCC 2)	AOO (DBC 2)	AOO	AOO	MF / IF	AOO
10^{-2} – 10^{-4} (10^{-3})	DBA	Accidents (DBC 3/ PCC 3)	PA 1 (DBC 3)	DBA	PA	Limiting Faults	PA
10^{-4} – 10^{-6} (10^{-5})	DEC without significant fuel degradation	DEC / Accidents (DBC 4/ PCC4)	DEC / PA 2 (DBC 4)	DBA	PA	Limiting Faults	PA
NA	DEC with core melt	DEC / -	DEC / SA / -	BDBA (DEC, SA)	PA	Limiting Faults	DEC: Complex Sequences and External Hazard / Severe Accident

Previous → After Amended

Summary and Further Work (4/4)

- Application of Defense in Depth for APR1400 (Example)

<table>
<tr><th>DID Level</th><th>Plant Status</th><th>Application of Mitigation Features
(Diverse and Independence)</th><th>Electric Power Supply</th><th>Procedures</th></tr>
<tr><td>Level 1</td><td>Normal Operation</td><td>• Control Systems (Non-safety System, DCS (Distributed Control System) Platform)
- Power control system (PCS)
- Pressurizer level control system (PLCS)
- Pressurizer pressure control system (PPCS)
- Feedwater control system (FWCS)
- Chemical and volume control system (CVCS)
- Steam bypass control system (SBCS)
• Non-safety Alarm and Indication System</td><td>Normal Power</td><td>Operating Procedures (OPs), Abnormal Operating Procedures (AOPs)</td></tr>
<tr><td>Level 2</td><td>Anticipated Operational Occurrences (AOOs)</td><td rowspan="2">• Plant Protection System
(Safety System, PLC (Programmable Logic Controller) Platform)
- Reactor Protection System (RPS)
- Engineered Safety Features Actuation System (ESFAS)
• Shutdown Cooling System
• Qualified Indication and Alarm System (QIAS)</td><td rowspan="2">Normal Power, Emergency AC Power (in case of LOOP event)</td><td rowspan="3">Emergency Operating Procedures (EOPs)</td></tr>
<tr><td>Level 3a</td><td>Design Basis Accidents (DBAs)</td></tr>
<tr><td>Level 3b</td><td>Design Extension Conditions (DECs)</td><td>• Diverse Protection System (Non-safety system, FLC (FPGA-based Logic Controller) Platform)
- Diverse Rx. Trip signal (HPPT, HCP)
- Diverse AFW actuation signal
- Diverse Turbine Trip Signal
• Diverse Indication System (Non-safety system, FLC Platform)
• Diverse Manual ESF Actuation (DMA) Switch</td><td>Normal Power, Emergency AC Power, Alternate AC Power (in case of SBO)</td></tr>
<tr><td>Level 4</td><td>Severe Accidents (SA)</td><td>• SA Mitigation Systems
- Hydrogen Mitigation System
- Cavity Flooding System
- Portable Onsite Equipment (FLEX)</td><td>Portable Generators</td><td>Severe Accident Management Guidelines (SAMGs)</td></tr>
<tr><td>Level 5</td><td>After SA</td><td>• All Available Systems and Components</td><td>All Available Electric Power</td><td>Radiological Emergency Plan</td></tr>
</table>

Before generating the reactor trip signal

After generating the reactor trip signal

Thank You!

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