KHNP’s strategies for Multi-unit Extreme Hazards Response

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2018. 5. 8

Safety Technology Center
Central Research Institute, KHNP
Nuclear Power Program

- **In Operation**: 24 units
- **Under Construction**: 5 units
- **Permanently Shutdown**: 4 units

(As of April 2018)

- **Hanul**
- **Wolsong**
- **Kori**
- **Hanbit**

24 NPPs Currently in Operation

3 units **BNPP 1,2,3 & 4** in UAE
Post Fukushima Safety Measures
Post Fukushima Safety Measures

- **‘11.3 : Fukushima nuclear accidents**
  - ‘11.5 : NSSC, performed “Integrated Safety Review” of all plants
    - √ Identified and requested 46 safety improvement action items
    - √ KHNP’s self-assessment added additional 10 action items

- **‘13.4 : NSSC, Stress tests for old plants (Wolsong 1, Kori 1)**
  - Coupled Licensing Renewal of old plants with modified EU ST Spec.

- **‘14.3 : Critical Safety Improvements(3 items) were supplemented**
  - √ Evaluation of extreme disaster (natural + Artificial) and SSCs improve.
  - √ Expert support system for case of beyond & SA scenarios
  - √ Facilities for emergency responses, command & control

- **‘15.6 : Revised Nuclear Safety law for AMP and ordered ST for all plants**
  - √ Accident Management Plan (AMP) by 2019.6
  - √ Stress Tests (ST) for all operating plants by 2019.12

- **‘16.3 : KHNP, started the AMP development projects**

- **‘16.6 : NSSC, confirmed government notifications related to AMP**
Post Fukushima Safety Measures

11. Additional radiation protective equipment for the sake of residents

10. Passive hydrogen removal equipment Containment Filtered Vent System

15. Mobile generator vehicles Primary & secondary external Inj. Direct make-up path to SFP

20. ASTS Sea wall height extension

- Emergency Response
- Severe Accident
- Electrical Power and Cooling Capability
- Earthquake and Tsunami

* ASTS : Automatic Seismic Trip System, SAMG : Severe Accident Management Guideline, SFP : Spent Fuel Pool
Post Fukushima Safety Measures

Major Improvements

① Height extension of the seawall
② Installation of waterproof doors
③ Installation of waterproof drain pumps
④ Mobile generator vehicles
⑤ Installation of primary/secondary external injection path
⑥ External injection loop for SFP
⑦ Installation of passive hydrogen removal equipment
⑧ Containment Filtered Vent System
## Post Fukushima Safety Measures

### Centralized expert team and center
- SAFE-T: Severe Accident Fast Response Expert Team
- Can be dispatched to the emergency site within 6 Hr from the KHNP CRI (Central Research Institute) in Daejeon

<table>
<thead>
<tr>
<th>SAFE-T (30)</th>
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</thead>
<tbody>
<tr>
<td><strong>Accident Strategy Support (16)</strong></td>
</tr>
<tr>
<td>WECType (4)</td>
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<tr>
<td>OPR1000 (4)</td>
</tr>
<tr>
<td>CANDU (4)</td>
</tr>
<tr>
<td>APR1400 (2)</td>
</tr>
<tr>
<td>Framatone (2)</td>
</tr>
<tr>
<td><strong>Facilities O&amp;M Support (12)</strong></td>
</tr>
<tr>
<td>Mechanical (4)</td>
</tr>
<tr>
<td>Electrical (4)</td>
</tr>
<tr>
<td>I&amp;C (4)</td>
</tr>
</tbody>
</table>

### Emergency response center: Seismic Safety Degree 0.5g
- To reinforce the accident response command and control
2. Stress Tests
Stress Tests for old plants

Areas

① Earthquake ② Tsunami ③ Loss of Safety Functions (SBO + LUHS) ④ Severe accident Management ⑤ Emergency res.

Guideline

Stress Tests Specifications of NSSC (2013.04.30)

Step 1
Operator Self-Assessment

Step 2
① Adequacy Reviews (including plant walk-down) ② Detailed Reviews (regulator + private experts)

Step 3
NSSC Reviews

License Renewal

Permanent Shutdown

WOLSONG-1

KORI-1

′13.5.1 ′13.7.12 ′14.12.12 ′15.2.27

′13.7.12 ′13.12.20 ′15.12.30 ′16.1.28
Stress Tests for old plants

- **Wolsong Unit 1**
  - 10 year extension of operational permission
  - 19 safety improvement actions items identified
    - (Natural Hazards) 3 items
    - (Safety Function Failure) 3 items
    - (Severe Accident) 7 items
    - (Emergency response) 6 items

- **Kori Unit 1**
  - Permanently shutdown
  - 14 safety improvement actions items identified
    - (Natural Hazards) 2 items
    - (Safety Function Failure) 3 items
    - (Severe Accident) 1 items
    - (Emergency response) 8 items
NSSC decided to re-evaluate all existing NPP safety applying ST spec. (‘15.09.24)
NSSC confirmed Stress Tests Specification (‘16.10.27)
KHNP submitted Stress Tests implementation plan (‘16.11.11)

**Background**

**Contents**

**Area 1**
Characteristics of extreme natural events exceeding the design basis
- Earthquake, flooding, tsunami and storm surge
※ Return period of 10,000 years

**Area 2**
SSCs Integrity against extreme natural events
- Earthquake, internal flooding, internal fire, etc.

**Area 3**
Plant’s capability to cope with the loss of safety functions
- Essential coping equipment identification
- Plant response to loss of all AC power and UHS (Scenario 1-6)
- Plant response to above scenario accompanying extreme natural events (Scenario 7-9)

**Area 4**
Severe accident management
- Core cooling, containment integrity prevention capability evaluation
- SPF shielding and cooling capability evaluation

**Area 5**
Emergency preparedness and response
- Emergency response capability evaluation
- Decision making adequacy evaluation
- Emergency response facility habitability evaluation

**Area 6**
Evaluation of accident coping capability
- Accident management strategies, operators’ action, off-site resources, procedures, education and training, human factors engineering evaluation, multi-unit accident response capability evaluation

Newly added
Stress Tests for All Operational NPPs

1st Step: Assessment of representative reactors (by JUN 2018)

- Divided into 5 Reactor Types out of 24 nuclear plants in operation
- Westinghouse 2-loop, 3-loop, CANDU, Framatom, OPR 1000 (Optimized Power Reactor)

2nd Step: Assessment of the rest NPPs (by JUN 2019)

- Gap analysis between the representative reactors and the rest
- First step results will be incorporated to the rest nuclear power plants
Integrated Accident Management Plan
Meaning of AMP

- Nuclear law revision (Jun 2016)
  “...all operating NPPs should submit accident management plans...”
- Schedule: Jan 2017 - Jun 2019
- The legal document for the integrated accident management from DBA to SA

MOG : MACST Operating Guideline
MACST : Multi-barrier Accident Coping Strategy

Accident Management Plan (AMP)

- EOP
- DBA management
- MOG/EDMG
- SAMG

AMP Contents
- AMP Strategies & Equipments Accident Management
- Implementation Structure
- AM Capability Evaluation
- Emergency Operating Procedure Guideline
- Extreme Disaster Mitigation Guideline
- Severe Accident Mitigation Guideline
- AM Education & Training Plan

√ Nuclear law revision (Jun 2016)
√ Schedule: Jan 2017 - Jun 2019
√ The legal document for the integrated accident management from DBA to SA

MOG : MACST Operating Guideline
MACST : Multi-barrier Accident Coping Strategy

Extreme Hazard management

√ Nuclear law revision (Jun 2016)
√ Schedule: Jan 2017 - Jun 2019
√ The legal document for the integrated accident management from DBA to SA
Structure of AMP

Risk Matrix

Severe Accident Policy Statement (Order, '01)

Accident Management Plan (Law, '16)

PSA Level 1
Core Damage Frequency (CDF) < 1.0E-4 < 1.0E-4 (0.1 for New plants)

PSA Level 2
Large Early Release Frequency (LERF) < 1.0E-5 < 1.0E-5 (0.1 for New plants)

Cs-137 100TBq Release - < 1.0E-6
Strategies for AMP & Added Facilities

- Main Target Event: (Site Common) ELAP, LUHS
  - ELAP: Extended Loss of AC Power
  - LUHS: Loss of Ultimate Heat Sink
- Establish a defense-in-depth severe-accident preventing & mitigating (coping) strategy
- 3-Phases Strategy: use of installed (Phase 1), onsite portable (Phase 2) and offsite supplemental resources (Phase 3)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Equipment</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>Installed equipment</td>
<td>EP: Battery (extension)</td>
</tr>
<tr>
<td>(0 - 8hr)</td>
<td>**</td>
<td>CW: Turbine Driven AFWP</td>
</tr>
<tr>
<td>Phase 2</td>
<td>Onsite Portable Equipment</td>
<td>EP: Mobile DG (4.16 kV, 1 MW)</td>
</tr>
<tr>
<td>(- 72hr)</td>
<td>* SAFE-T</td>
<td>CW: Small &amp; Medium Mobile Pump</td>
</tr>
<tr>
<td>Phase 3</td>
<td>Offsite Equipment</td>
<td>EP: Mobile DG (4.16 kV, 32 MW)</td>
</tr>
<tr>
<td>(72hr - )</td>
<td>* SAFE-T + Outside support</td>
<td>CW: Large Mobile Pump</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High Capacity Spray Pump</td>
</tr>
</tbody>
</table>

** Shift Operation Staff supplemented by additional EOF onsite staff
Strategies for AMP & Added Facilities

<at Design>

EDG A  EDG B

AAC  DG

High flow Mobile Pump

Mobile Heat Exchanger

Mobile Purifi. Facility

Communication Equipment

Portable generator

IMW Mobile generator

High Pr. Mobile Pump

Mid. Pr. Mobile Pump

High Pr. Mobile Pump

Low Pr. Mobile Pump

CFVS  PAR

3.2MW Mobile Generator

<post Fukushima Safety Measures>

AMP & ST for Multi Unit Hazards
Multi-unit(Site) Risk Analyses

- Issuing MUPSA in Korea
  - After Fukushima, multi-unit accident was highlighted in Korea
  - Another ways to cope the multi-unit extreme disasters by probabilistic means
  - Issued in the Operating Licensing process of Shin-Kori 3 (Oct. 2015)
  - Issued in the Construction Licensing process of Shin-Kori 5&6 (Jun. 2016)

  How to establish
  Korean specific MUR Methodology/Safety Goal?

- Post actions for the issues
  - NSSC (Nuclear Safety & Security Commission) launched the project to set up regulatory requirements for MUPSA by the end of 2021
  - KHNP started the project to develop methodology and pilot MUPSA model for Kori Site (six units in operation and three units in construction)
    - Preliminary assessment will be done by Jun. of 2018
    - Final assessment will be done by Jun. of 2020
Multi-unit(Site) Risk Analyses

- Equipment improvement: CFVS, PAR, MDG, External Make-up ...
- Guideline, Procedure: SAMG, MOG, EDMG...
- Researches for severe accident phenomena

Technical Standard
(Regulation, Method, Scope, Quality...)

International Research Results

- Single-unit Risk Assessment
  - Evaluate the effect of post-Fukushima action
  - External PSA
  - Level 2,3 PSA optimization (SOARCA)
  - Develop Low Power/Shutdown PSA and SAMG

Input

Feedback

PSR (Safety Goal)

Safety Goal (Not developed)

Multi-unit Risk Assessment
- Establish the roadmap for multi unit risk assessment
- Develop the method for assessing the multi unit risk
- Develop multi unit risk model (simplified & detailed)
  - OM: FP/LP Internal/External event Level 1, 2
  - IEs: LOOP, LOCV, Seismic, Tsunami events

Input

Feedback

Safety Improvement
- Update and manage the risk
- Suggest safety improvement measures based on risk

Public Acceptance

IAEA: MUR TECDOC Case Study, Best Practice: COG: Methodology & Pickering(pilot)
# Development effect of AMP

## Category: Design Basis

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Preventing Core Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal</td>
<td>Keeping normal condition</td>
</tr>
<tr>
<td>Status</td>
<td>Normal Operation</td>
</tr>
<tr>
<td>Procedure</td>
<td>NOP</td>
</tr>
<tr>
<td>Safety Assessment</td>
<td>Final Safety Analysis Report</td>
</tr>
</tbody>
</table>

## Beyond Design Basis

### Mitigating Core Transient

- Preventing Core Damage
- Mitigating Core Transient
- Keeping normal condition
- Control abnormal condition
- Control emergency condition within DB

### Mitigating SA

- Preventing Core Damage
- Mitigating core damage
- Keeping radioactive particles

## PSA Level 1

- DEC(BDA)
- Extreme Hazard
- EOP/AOP
- MOG
- EDMG

## PSA Level 2

- DEC Analysis
- Natural Hazard Analysis (ST)
- Aircraft Impact Analysis
- Deterministic SA Analysis

## EP, Disaster Response Manual

- Accident Management Plan

- SAMG

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*ICHNP*
4. Safety Objectives of PFA, ST, AMP
<table>
<thead>
<tr>
<th>Safety Objectives</th>
<th>Prompt Remedy to SSC</th>
<th>Stress Tests Applying European Standard</th>
<th>Establishing Integrated Accident Management System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Fukushima Safety Review</td>
<td>✓ Ensuring Coping Capability against Extreme Natural Hazards</td>
<td>✓ Introduced as one of presidential election pledge (2013)</td>
<td>✓ Nuclear Law Revision (June 2016)</td>
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<tr>
<td></td>
<td>✓ Regulatory body-University-Research Institute Collaboration</td>
<td>✓ Modified EU Stress tests Specification</td>
<td>✓ “All operating NPPs should submit accident management plan by 2019.6”</td>
</tr>
<tr>
<td></td>
<td>✓ Short Period Evaluation (21 Mar. 2011 – 30 Apr. 2011)</td>
<td>✓ First Application : License Renewal Plant (Kori-1, Wolsong1)</td>
<td>✓ Include DBA, BDBA (Extreme Natural Hazards + Air Craft Impact), Severe accident management Strategies</td>
</tr>
<tr>
<td></td>
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<td>✓ Extended to all NPPs : Total 22 units (Sep. 2015 – June 2019)</td>
<td>✓ Accident management strategy effectiveness assessment and Safety goal achievement * Mandatory Requirements</td>
</tr>
</tbody>
</table>
## Safety Objective of (AMP + ST)

<table>
<thead>
<tr>
<th>Classified</th>
<th>Regulatory Status</th>
<th>Industry Actions</th>
<th>Equipment</th>
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<tr>
<td></td>
<td>Stress Test</td>
<td>Strategies and Assessment</td>
<td>Equipment</td>
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<td></td>
<td>BDBEE Legalization</td>
<td>Natural Hazard Assessment</td>
<td>Severe Accident Prevention</td>
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<td>Man-induced Hazard Assessment</td>
<td>Emergency Response Organization</td>
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<tr>
<td></td>
<td></td>
<td>Severe Accident Prevention Strategies</td>
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<tr>
<td>USA</td>
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<td>Japan</td>
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<td>France</td>
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<tr>
<td>Korea</td>
<td>○</td>
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[● Complete  ○ ongoing  ○ Planning]

Overall, we are implementing world-class post Fukushima actions, but we need to reinforce the prevention of severe accidents and establish concrete strategies.
### Safety Objective of (AMP + ST)

#### Regulatory Status
- Stress Test
- BDBEE Legalization
- Natural Hazard Assessment
- Man-Induced Hazard Assessment

#### Strategies and Assessment
- Severe Accident Prevention Strategies
- Severe Accident Emergency Response Organization

#### Equipment
- Natural Hazard
- Severe Accident Prevention
- Severe Accident Mitigation

#### Industry Actions
- Stress Test (‘17.2 ~ ‘19.12)
- AMP (‘17.1 ~ ‘19.6)

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**Korea**
- AMP+ ST = Ensure the World-class Safety by Integrating the Advantages of each country

- **USA**
  - FLEX strategies by Phase 1/2/3
  - Severe Accident Prevention Strategies by Mobile Equipment

- **France**
  - Stress Test conduction for All NPPs
  - Off-site support by severe accident emergency response organization

- **Japan**
  - Legalization of reinforcement of the facility for the accident
  - Conservative approach of selecting the accident equipment and strategies
Comprehensive response capability against nuclear accident

- Improve Installed Equipment
- Add Mobile Equipment
- Secure Operating Capability
- Extend the scope from unit to site

Reinforcement Safety for BDBA

- Post Fukushima actions
- Stress Test
- Accident Management Plan

- Secure the national consensus about Periodic Safety Review, Safety of Life Cycles, ETC.
- Establish infrastructure and specific systems for Safety
Thank You!
(Q&A)