Recent Approaches related to Safety Enhancement of Operating NPPs in Korea

Tae Eun JIN
KEPCO E&C
1. Introduction (NPP Status in Korea)

- **In operation**: 25 units
- **Under construction**: 7 units (incl. design)

<table>
<thead>
<tr>
<th>Type</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEC Type</td>
<td>6</td>
</tr>
<tr>
<td>CANDU Type</td>
<td>4</td>
</tr>
<tr>
<td>Framatome Type</td>
<td>2</td>
</tr>
<tr>
<td>CE Type</td>
<td>8</td>
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<tr>
<td>OPR 1000</td>
<td>4</td>
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<tr>
<td>APR 1400</td>
<td>1</td>
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<tr>
<td>APR 1400 (Cons.)</td>
<td>7</td>
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<tr>
<td>APR 1400 (UAE)</td>
<td>4</td>
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</tbody>
</table>

(MOTIE Report, 2016)

- **Hanul**: 10 units
- **Wolsung**: 6 units
- **Kori**: 10 units
- **Hanbit**: 6 units
1. Introduction (NPP Status in Korea)

Installed Capacity:
- Nuclear: 22.2%
- LNG: 33.0%
- Coal: 28.0%
- Renewable: 6.0%
- Hydraulic: 6.4%

Total: 97,649 MW

Electricity Generation:
- Nuclear: 31.7%
- LNG: 21.5%
- Coal: 40.6%
- Renewable: 3.1%
- Hydraulic: 1.2%
- Oil: 1.9%

Total: 495,000 GWh/yr

Nuclear: 22% of Elec. Capacity and 32% of Elect. Generation

*As of the end of 2015
1. Introduction (KEPCO E&C)

- Founded in Oct. 1, 1975
- Employee: ~2,300 (Jan. 1, 2017)

Major Business Areas
- NSSS Design of NPP
- BOP Design and AE of NPP
- Design of Thermal Power Plant and Renewable Energy System
- R&D in Plant Engineering

Currently Designing
- 7 Domestic NPPs (Shinkori 3~6, Shinhanul 1~2, Shinhanul 3~4)
- 4 Foreign NPPs (UAE)
<table>
<thead>
<tr>
<th>Year</th>
<th>APR+ 91</th>
<th>Under Development</th>
<th>Under Construction (11 Units)</th>
<th>Under Operation (23 Units)</th>
</tr>
</thead>
</table>
| 1970 | 34      | -                | Shin-Kori 5, 6, UAE 1~4        | Applying the secured nuclear | Making an exclusive brand for |}
|      | APR1400 (Advanced Power Reactor 1400) |                  | Shin-Hanul 1, 2, Shin-Kori 3, 4 | power plant technologies    | core technologies           |
|      | 24      |                  | Shin-Wolsong 1, 2              | Securing global              |                             |
|      | OPR+ 92 (Improved Optimized Power Reactor) |                  | Shin-Kori 1, 2                 | competitiveness             |                             |
|      | 20      |                  | Hanul 5, 6                     | Enhancement of design       |                             |
|      | OPR1000 (Optimized Power Reactor) |                  | Hanul 3, 4                     | engineering technology      |                             |
|      | 14      |                  | Hanbit 5, 6                    | Self-sufficiency in design  |                             |
|      |         |                  | Hanul 3, 4                     | engineering technology (1995)|                             |
|      | 12      |                  | Hanbit 3, 4                    | Introducing technology and   |                             |
|      | Kori 1, 2, 3, 4 / Hanbit 1, 2 / Hanul 1, 2 / Wolsong 1, 2, 3, 4 |                  | Depending on foreign design   | promoting its Independence  |                             |
|      |         |                  | -                              | engineering                 |                             |

* Kori Unit 1, 2 and Wolsong Unit 1-performed by other companies
2. Periodic Safety Review (PSR)

Definition

- A systematic safety reassessment of an operational NPP carried out at regular intervals to deal with the cumulative effects of plant ageing, modifications, operating experiences and technical developments, and aimed at ensuring a high level of safety throughout the plant service life.

- Comprehensive safety evaluation for operational nuclear power reactors in accordance with 14 safety factors IAEA recommended per every 10 years

PSR Implementation Guide

- Nuclear Act, Enforcement Regulation No. 20, 21
## 2. PSR (Tech. Requirement)

### IAEA PSR safety factors : 14

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<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>① Plant Design</td>
<td>① Actual Physical Condition of NPP</td>
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<td></td>
<td>② Actual Physical Con. of NPP</td>
<td>② Equipment Qualification</td>
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<td>③ Equipment Qualification</td>
<td>③ Management of Aging</td>
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<tr>
<td>Safety Factors relating to Safety Analysis</td>
<td>⑤ Deterministic Safety Analysis</td>
<td>④ Safety Analysis</td>
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<td>⑥ Probabilistic Safety Analysis</td>
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<td>⑦ Hazard Analysis</td>
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<tr>
<td>Safety Factors relating to Performance and Feedback of Experience</td>
<td>⑧ Safety Performance</td>
<td>⑤ Safety Performance</td>
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<td>⑨ Use of Experience of other Plants and Research Finding</td>
<td>⑥ Use of Experience of other Plants and Research Finding</td>
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<td>Safety Factors relating to Management</td>
<td>⑩ Organization, the Mgmt Sys~</td>
<td>⑦ Organization and Administration</td>
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<td>⑪ Procedures</td>
<td>⑧ Procedures</td>
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<td>⑫ Human Factors</td>
<td>⑨ Human Factors</td>
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<td>⑬ Emergency Planning</td>
<td>⑩ Emergency Planning</td>
</tr>
<tr>
<td>Safety Factors relating to Environment</td>
<td>⑭ Radiological Impact on Env.</td>
<td>⑪ Environmental Effects</td>
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2. PSR (Experience)

- **1st Round PSR** for 20 NPPs that have been operating more than 10 years have been completed.
  - Westinghouse Type: Kori 1,2,3,4, Hanbit 1,2
  - Framatome Type: Hanul 1,2
  - CE Type: Hanbit 3,4,5,6, Hanul 3,4,5,6
  - PHWR: Wolsung 1,2,3,4

- **2nd Round PSR** for 3 NPPs are currently being carry out
  - Kori 2
  - Hanbit 5,6
### 2. PSR (Safety Enhancement Activities)

- **Installation of FMS to Improve the Transient Evaluation**

<table>
<thead>
<tr>
<th>No.</th>
<th>Transient Type</th>
<th>Number of Cycle at Design Documents</th>
<th>Review Operation Experience in PSR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Actual Number of Cycles</td>
</tr>
<tr>
<td>1</td>
<td></td>
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<td></td>
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<tr>
<td>2</td>
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→ On the basis of transients counting results during last 10yrs operation, transient evaluation results showed the fatigue integrity of the pressure boundary components for the next 10yrs.
2. PSR (Safety Enhancement Activities)

✔ Synthetic Management of Wall Thinning

→ Wall thinning due to FAC and so on is synthetically analyzed and managed by the 3D based ToSPACE (Wall Thinning Management Program) to enhance the safety of piping.
2. PSR (Safety Enhancement Activities)

- Provide Systematic Aging Management Program

Aging Management Program is developed and operated for Kori Unit 1 (34 AMPs) and Wolsung Unit 1 (40 AMPs) for the systematic management of aging for the next 10 yrs.
## 2. PSR (Safety Enhancement Activities)

- **Provide Systematic AM Program: Reactor Internals (Ex)**

<table>
<thead>
<tr>
<th>Sub-comp.</th>
<th>Aging Mechanism</th>
<th>Recommended Future AMPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Core Plate (UCP)</td>
<td>Cracking / Fatigue, Wear</td>
<td>• PWR Vessel Internals → EVT-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Water Chemistry</td>
</tr>
<tr>
<td>UCP Alignment Pin</td>
<td>Loss of Materials / Wear</td>
<td>• PWR Vessel Internals → VT-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Water Chemistry</td>
</tr>
<tr>
<td>Fuel Alignment Pin</td>
<td>Cracking / IASCC, Fatigue, Loss of Preload etc.</td>
<td>• PWR Vessel Internals → VT-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Water Chemistry</td>
</tr>
<tr>
<td>Hold down Spring</td>
<td>Deformation / Loss of Preload</td>
<td>• PWR Vessel Internals → Measurement of Dimension</td>
</tr>
</tbody>
</table>
2. PSR (Safety Enhancement Activities)

- Identify Safety Improvement AIs and its Implementation

→ Nuclear utilities have to identify and implement PSR safety improvement action items (AIs) and report the implementation status to KINS every quarter in accordance with approved plan and schedule.

Source: Yun Bongyo et., 2010.11
3. Stress Test (ST)

- **Objective of Stress Test**
  - Stress Test aims to strictly reconfirm the safety of NPP by evaluating its capability to respond to large-scale natural disasters beyond the design basis.
3. Stress Test (ST)

- Evaluation areas are mainly the following 5 areas.
  - Safety of SSCs against Earthquakes
  - Safety of SSCs against Tsunami, Storm Surge, and Other Natural Disasters
  - Plant Response to Loss of Electrical Power and or Loss of the Ultimate Heat Sink
  - Severe Accident Management Capability
  - Emergency Preparedness and Response

- Implementation status of Stress Test
  - Complete for Wolsung 1 and Kori 1 in 2013~2015
  - Planned to perform ST for the all NPPs in Korea (2016~)
3. ST (Safety Enhancement Activities)

- Safety improvements of SSCs against Earthquakes, Tsunami, Storm Surge, and other Natural Disasters
  - Implementation of seismic margin analysis for equipment of Spent Fuel Pool Cooling System
  - Implementation of seismic margin analysis for replaced equipment related to safe shutdown function
  - Reinforcement of Action Procedures to take when earthquake occurs at NPP
  - Improvements of onsite suppression capability for seismic induced wide area fire
  - Installation of water-tight doors
  - Safety review of slope against earthquake beyond the design basis
  - Reinforcement of on-site fire brigade building against earthquake beyond the design basis
3. ST (Safety Enhancement Activities)

- Safety improvements against loss of electrical power and the ultimate heat sink & severe accident management
  - Installation of Mobile Generator & secure stable operation ability for MG
  - Installation of mobile water pump
  - Installation of external injection paths for the primary and secondary side & Spent fuel pool
  - Enlargement of batteries
  - Securement of communication tools between field operators and MCR or RSP (on-site satellite telephone)
  - Reinforcement of procedure and training program for operator
  - Reinforce the habitability of OSC, TSC
3. ST (Safety Enhancement Activities)

Major Improvements in Domestic Nuclear Plants

- Making the coastal barrier higher at Kori site
- Preparing a vehicle with a portable EDG at each site
- Securing the safety of emergency battery power from flooding
- Installing watertight doors at major buildings
- Water-proof sump pumps
- Installing passive H₂ removal systems which operate without electricity [PAR]
- Installing exhaust and decompression equipment

One billion USD investment over five years
3. ST (Safety Enhancement Activities)

Design Improvement for the Natural Circulating Cooling Concept
4. Earthquake in Gyeongju

**Earthquake**

- The Gyeongju earthquake near Wolsong site occurred on Sep.12, 2016.
- Measuring 5.8 on the moment magnitude scale, it was the strongest ever recorded in Korea since measurements begun in 1978.
- Fore-S : Sep. 12 19:44 (Mag 5.1), Gyeongbuk, Gyeongju, SouthernSE 9km
- Main-S : Sep. 12 20:32 (Mag 5.8), Gyeongbuk, Gyeongju, SouthernSE 8km
4. Earthquake (Safety Enhancement)

- Reg. authorities requires long term safety plan against earthquake

- Provide countermeasures (5 tasks, 22 CMs)
  - Task 1: Evaluation and countermeasures of seismic hazard near NPPs (related to PSHA)
  - Task 2: Acceleration of seismic performance enhancement
  - Task 3: Strengthening emergency response capability
  - Task 4: Continuous evaluation and enhancement of earthquake resistance
  - Task 5: Improvement of NPPs long term safety
4. Earthquake (Safety Enhancement) : Ex

- **Task 1** : Evaluation and countermeasures of seismic hazard near NPPs (related to PSHA)
  - Investigate active fault through government level
  - Update active fault information for PSHA
  - Re-evaluation of the seismic hazard including the earthquake in Gyeongju
  - Analysis of domestic earthquakes and geological characteristics

- **Task 2** : Acceleration of seismic performance enhancement
  - Strengthen the main facility like watertight doors etc. against nat. disaster
  - Implement the Stress Tests and facility reinforcement
  - Performance improvement of earthquake monitoring system
  - Reconfirm the seismic performance evaluation methodology
5. Design Improvement of New NPPs

Severe Accident Mitigation Features

ERDS: Emergency Rapid Depressurization System

SACSS: Severe Accident Containment Spray System

PECS: Passive Ex-vessel corium retaining and Cooling System

CFVS: Containment Filtered Venting System
5. Design Improvement of New NPPs

Seismic Isolation System (R&D)

- Achieving Integrity of NPP Structures and Safety-Related Equipment under Strong Earthquake Motions

Target SSE*:
- Horizontal EQ: 0.5g
- Vertical EQ: 2/3 of Horizontal EQ

Seismic Isolation
Application: Nuclear Island

Bearing Type : LRB* or FB*(EQS*)

* SSE(Safe Shutdown Earthquake)
* LRB(Lead Rubber Bearing)
* FB(Friction Bearing)
* EQS(Eradi Quake System)

- Generation of design input motions
- 3-dimensional seismic analysis considering nonlinearity of bearings
- Arrangement design of bearings in consideration of design, construction, and operation
- Innovative verification tech. with hybrid simulation test
- Umbilical design for piping system
5. Design Improvement of New NPPs

**Design Enhancements Against Large Commercial Aircraft Impact**

- New plant designs must consider the effects of impact from large commercial aircraft after WTC accident
- **Aircraft Impact Assessment (AIA)**
  - Criteria: requirements of 10CFR50.150 and methodology of Regulatory Guide 1217 (NEI 07-13, Rev. 8)
  - Assessments of physical damage, shock damage, and fire damage for Reactor Containment Building and Aux. Building:
    - Structural analysis and heat removal assessment
  - Strategy: reactor core remains cooling and spent fuel pool integrity is maintained
- **Design Enhancements**
  - Strengthened exterior walls to keep the plane out and added functional doors and HVAC dampers to remain core cooling

- **Containment Building Exterior Walls**
  - APR1400(UAE) BNPP:
    - 4ft → 4.5ft
  - APR+(Cheon-ji #1,2):
    - 4ft → 4.5ft
6. Conclusion

- Continuous safety improvements are important to the operating NPPs and can be accomplished in a variety of ways.

- Implementation of PSR safety action items contributed to the safety improvement. Site personnel who understand the safety culture have made various PSR improvement efforts to maintain a higher level of safety.

- Based on the Stress Test experience and enhancement activities of Kori 1 and Wolsung 1, it can be concluded that NPPs are safe against large-scale natural disasters beyond the design basis.

- The Gyeongju earthquake was an event that began to consider a comprehensive reevaluation in preparation for a seismic hazard.

- Finally, design improvements in the design of new NPPs can also be applied to enhance safety of the operating NPPs when needed.
Thank You!