Countermeasures against Strong Earthquakes
for Nuclear Facilities in KOREA

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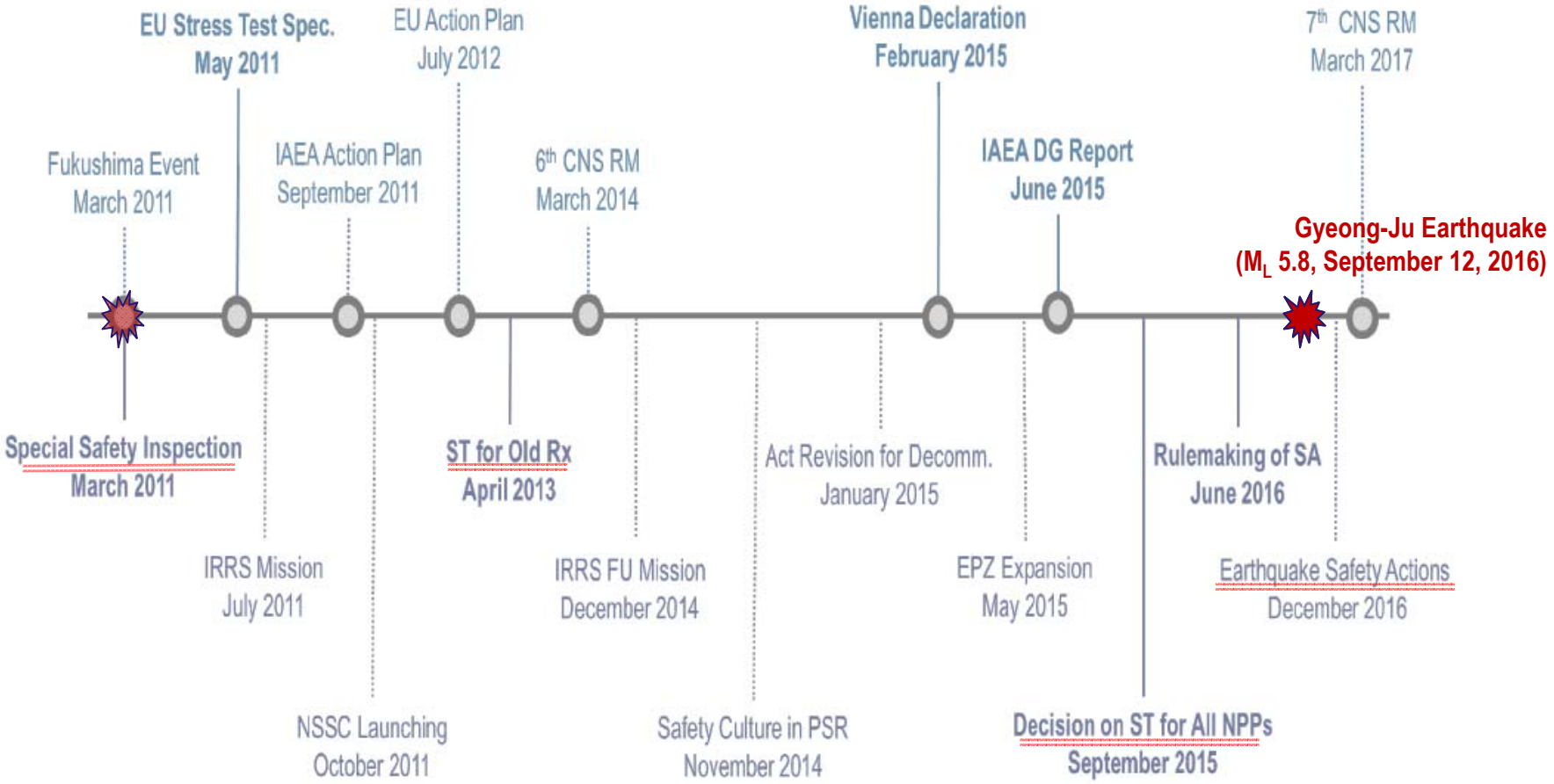
Post-Fukushima Actions in KOREA

International Efforts and Korean Measures

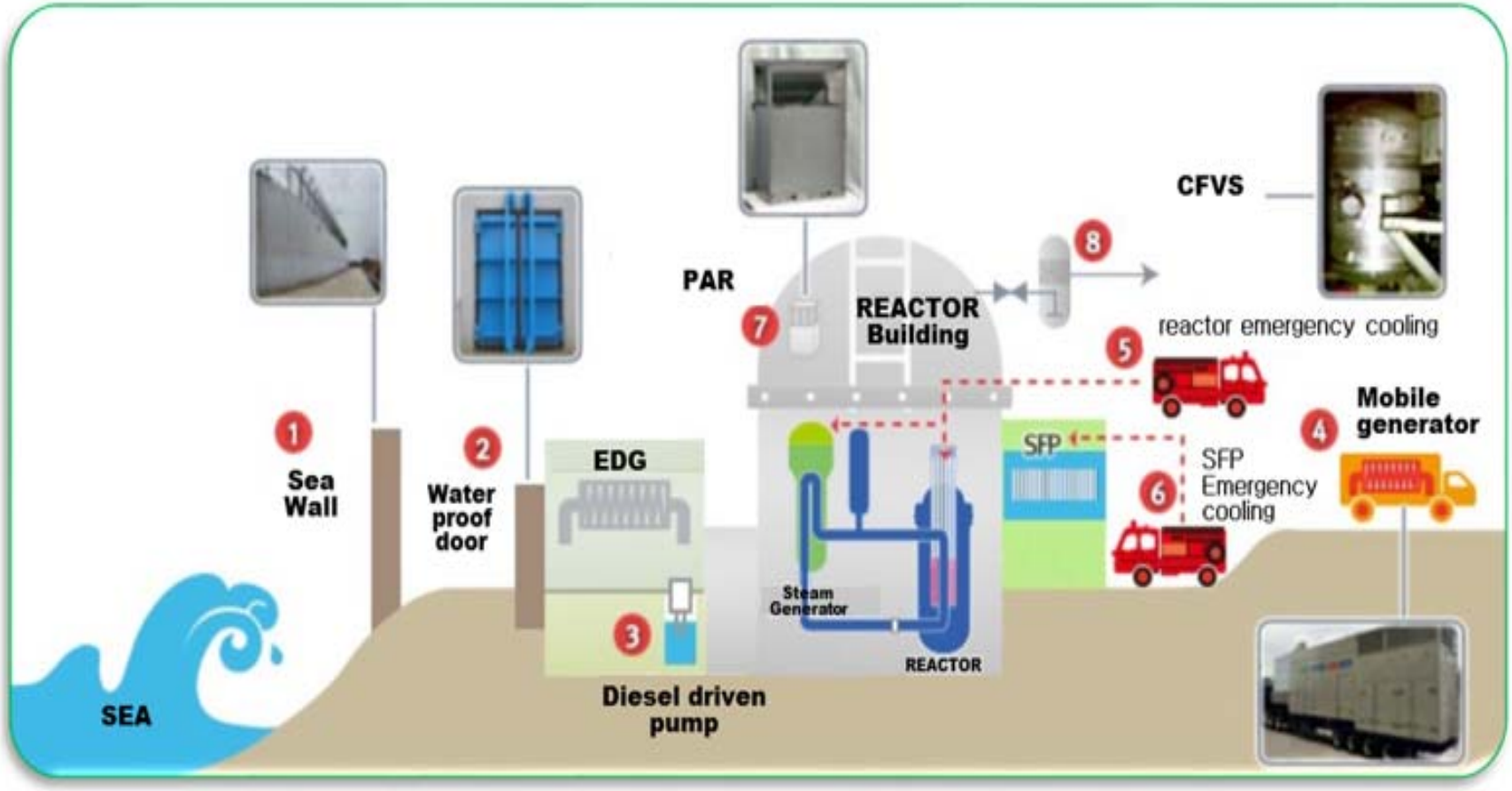


Post-Fukushima Actions in KOREA

- **Immediate Actions : Special Safety Inspection**
  - **Inspection Period and Inspectors**
    - March 21, 2011 ~ May 3, 2011
    - 73 experts (37 KINS staffs and 36 external experts)
  - **Target**
    - Safety check for Korean nuclear facilities in light of the major safety-related phenomena observed from the “Fukushima Accident”
  - **Public Acceptance**
    - Meetings with Local government, Residents, Civic organization, etc

Post-Fukushima Actions in KOREA

Safety Measures for Korean NPPs



Post-Fukushima Actions in KOREA

Implementation of Safety Action Items (53 Items)

Safety of Structures and Equipment against Earthquake	
1-1	Installation of automatic seismic trip system (ASTS)
1-2	Seismic performance improvement of safety shutdown and shutdown cooling system
1-3	Study on maximum earthquakes in nuclear power plant site
1-4	Improvement of seismic performance of earthquake alarm window in main control room
1-5	Improvement of seismic performance of Wolsong site entry bridge
Safety of Structures and Equipment against Coastal Flooding	
2-1	Extension of the height of sea wall of Kori nuclear power station
2-2	Installation of watertight doors and waterproof drain pumps
2-3	Study on design criteria for sea level at nuclear power plant site
2-4	Reinforcement of cooling water intake and improvement of facilities in case of tsunami
Securing Electrical Power and Cooling Systems	
3-1	Securement of mobile generator vehicles and electric batteries etc.
3-2	Design criteria change of alternate emergency DG
3-3	Anchoring of standby power transformers Improvement of fuel injection facility for EPG
3-4	Change of SWYD facility ownership for operation and maintenance
3-5	Setting safety measures in case of cooling function failure of SFB
3-6	Flood prevention and restoration of Ultimate Heat Sink facilities
3-7	Installation of protective barrier for outdoor tanks
3-8	Supplementation of flooding preventive facilities for MSSV room & EWS pump room
3-9	Improvement of fire protection plan and strengthening of a cooperative system
3-10	Improvement of fire protection equipment
3-11	Improvement of fire brigade's fire protection capacity
Severe Accident Response	
4-1	PAR installation in containment building
4-2	Installation of ventilation or depressurizing facility in containment building
4-3	Installation of external injection loop for emergency cooling water for reactor
4-4	Strengthening of education and training for severe accident
4-5	Revision of SAMG for increasing effectiveness of accident management strategy
4-6	Development of SAMG for lower power operation during shutdown period

Strengthening Emergency Response System	
5-1	Additional arrangement of radiation protection system for residents nearby NPPs
5-2	Revision of radiological emergency response plan to include multi-unit accident
5-3	Additional arrangement of emergency equipment in case of long-term issue
5-4	Improvement of equipment of emergency medical facility
5-5	Improvement of radiological emergency response drill
5-6	Acquisition of essential information in case of long-term power loss
5-7	Arrangement of protection plan for maintenance workers
5-8	Improvement of emergency response facility
5-9	Revision of procedure for information release to public in case of radiological emergency
5-10	Assessment of protection measures for population outside emergency planning zone
5-11	Improvement of emergency alarm system performance
Safety of Kori #1 and Long-operated NPPs	
6-1	Drastic reinforcement of safety inspection such as periodic inspection
6-2	Intensifying ISI for main components and pipes
6-3	Establishment of integrated Aging Management program(AMP)
6-4	Management of performance parameters for main active components
6-5	Fatigue monitoring system installation for high-grade quantitative fatigue management
6-6	Intensified fatigue inspection on PZR lower part to attain higher integrity
6-7	Reliability enhancement of trip related equipment
6-8	Assessment of adequacy of operating manpower
6-9	Enhancement of on-site electric power reliability
6-10	Strengthening of purchasing quality assurance system check
Safety of Research facilities, etc.	
7-1	Improvement of MCR and evaluation seismic performance of structure
7-2	Revaluation of inundation depth of HANARO site
7-3	Revision of radiation emergency plan reflecting complex radiation emergency situation
Additional Safety Action Items (April 2014)	
A-1	Re-definition of extreme events including human-induced events and counter measures
A-2	Establishment of a stand-by emergency response team for severe accident
A-3	Securement of emergency functions with dedicated features at multi-unit accident

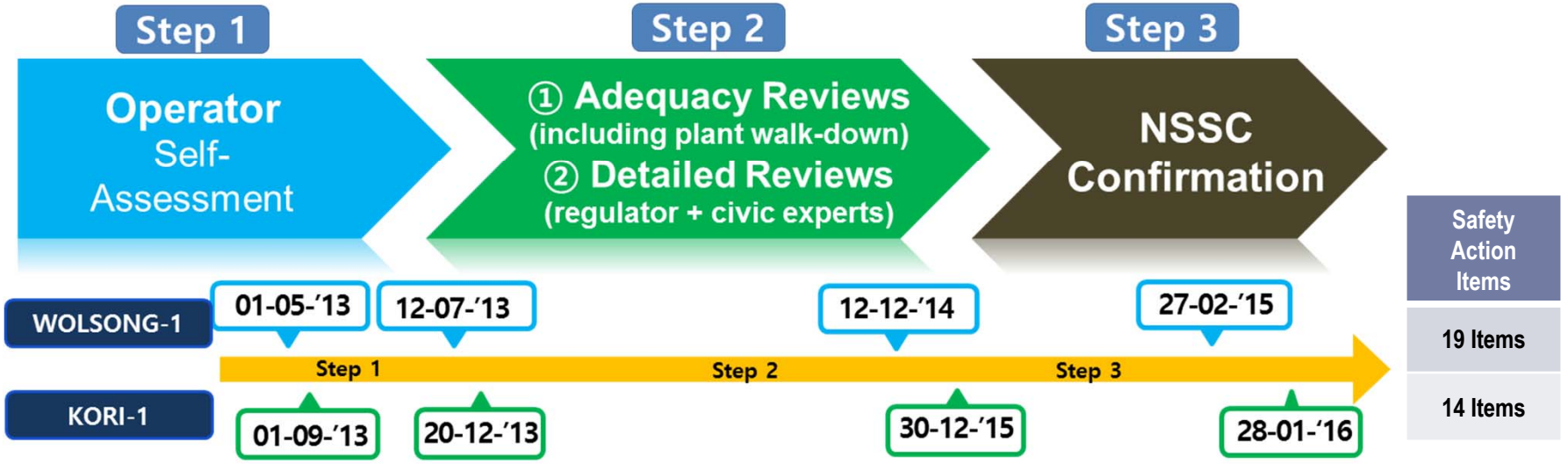
■ Implemented by the Utility (44/53) ■ Reviewed by the Regulator (44/53) ■ In Progress (9 items)

Post-Fukushima Actions in KOREA

Objective of the Stress Test

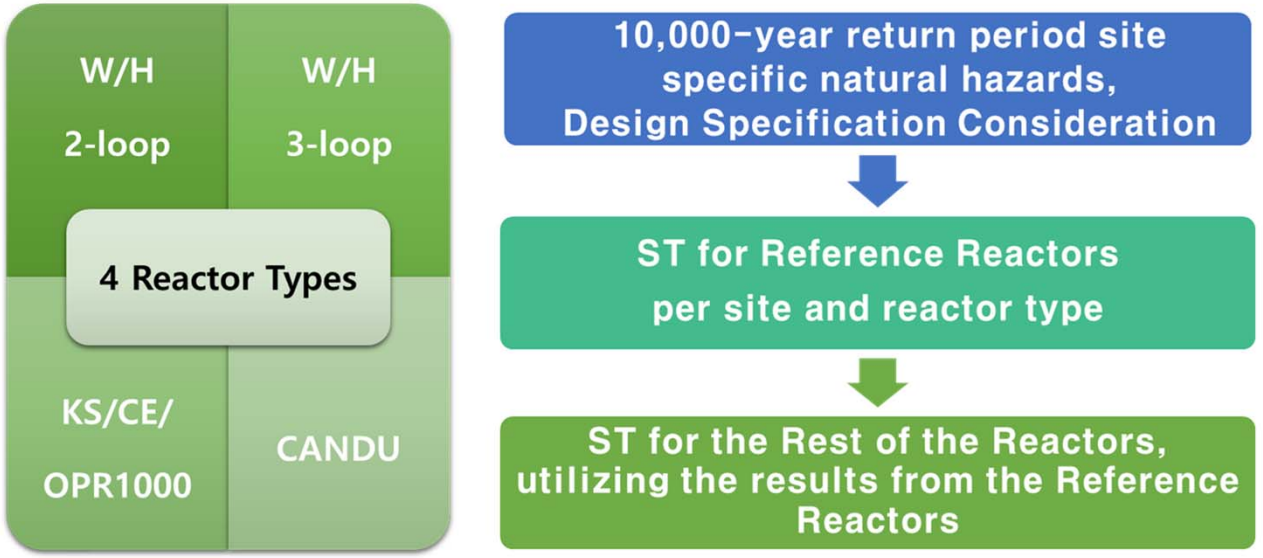
To evaluate plant response to extreme natural hazards exceeding design basis as a way to **reassess the safety of operating NPPs** and to **find the safety improvement items**

Targets	Wolsong #1, Kori #1
Items	① Earthquake ② Tsunami & others ③ Loss of Safety Function (SBO, LUHS) ④ Severe Accident ⑤ Emergency Response ⑥ Human Factors
Criteria	NSSC Stress Test Guidelines (April 30, 2013)



Post-Fukushima Actions in KOREA

- **Expand of the ST to all Operating NPPs (2016 ~ 2020)**
  - **The NSSC Decision on 45th Meeting (Sept. 2016)**



  - **KHNP will start the ST with reference reactors in turn.**
    - W/H 2-loop (Kori #2), W/H 3-loop (Hanbit #1), KS/CE/OPR (Hanul #3), CANDU (Wolsong #2)

Post-Fukushima Actions in KOREA

Stress Test Area 2: Integrity of SSC against BDBEEE Seismic Events

- **Guidelines for Integrity of SSC against seismic events (2-1)**
  - **Protective action under the DBE condition (2-1-1)**
    - To provide current seismic design of SSCs and to identify the deformation or status change through the in-situ inspection
    - To provide major operator actions for preventing core damage and fuel failure at SPF after earthquake
  - **Indirect impact of seismic event (2-1-2)**
    - To identify plausible seismic induced failures of non-seismic designed SSCs and to provide preventive measures deployed in the design
    - To evaluate the elements of retarding the access of outside supporting resources and equipment

Post-Fukushima Actions in KOREA

Stress Test Area 2: Integrity of SSC against BDBEEE Seismic Events

- The significant earthquake level (minimum 0.3g) leading to loss of major safety function or severe core- damage (2-1-3)
  - Applicable seismic PRA and Seismic Margin Approach
  - Demonstration of non-existence of degradation of safety function or core damage at 10000yr-return period of earthquake
- The significant earthquake level leading to loss of containment integrity using the seismic PRA or seismic margin approaches. (2-1-4)

Post-Fukushima Actions in KOREA

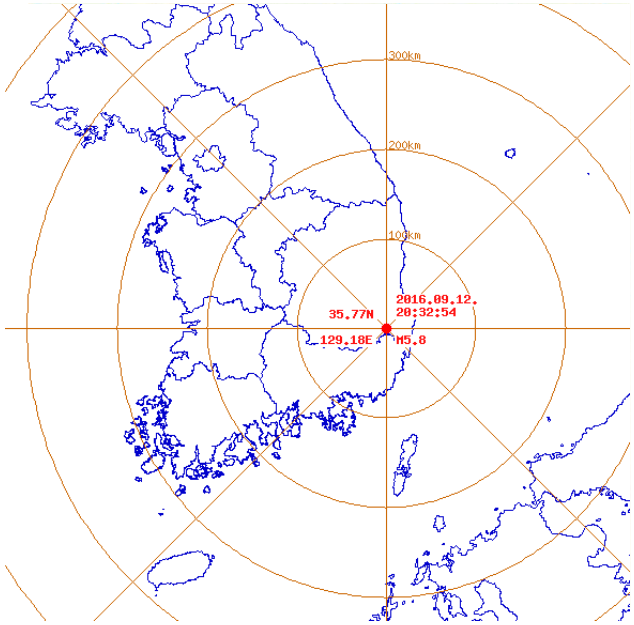
Stress Test Area 2: Integrity of SSC against BDBEEE Seismic Events

- **Guideline for Integrity of SSCs against the seismic induced internal flooding (2-2)**
  - To evaluate the probability and the consequences of seismic induced internal flooding by safety class or non-safety class SSCs with consideration of site characteristic, design and location of SSCs at 10,000 yr return period earthquake (minimum 0.3g ground acceleration)

- **Guideline for Integrity of SSCs against the seismic induced internal fire (2-3)**
  - To evaluate the probability and the consequences of seismic induced fire by safety class or non-safety class SSCs with consideration of site characteristic, design and location of SSCs at 10,000 yr return period earthquake (minimum 0.3g ground acceleration)

9.12 Gyeong-Ju Earthquake

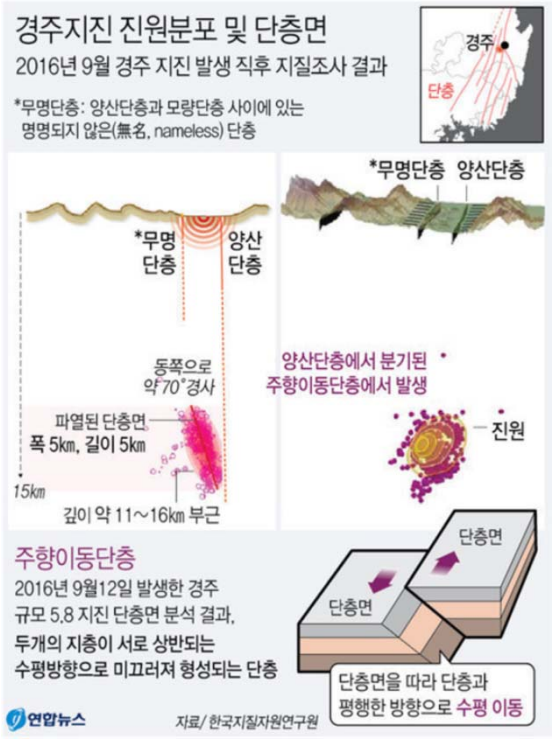
- **9.12 Gyeong-Ju Earthquake (M_L 5.8, Sept. 12, 2016)**
  - **Strongest one ever instrumentally recorded in Korean Peninsula**
  - **The hypocenter located approximately at a depth of 15 km**
  - **Presently, over 600 aftershocks have been recorded.**

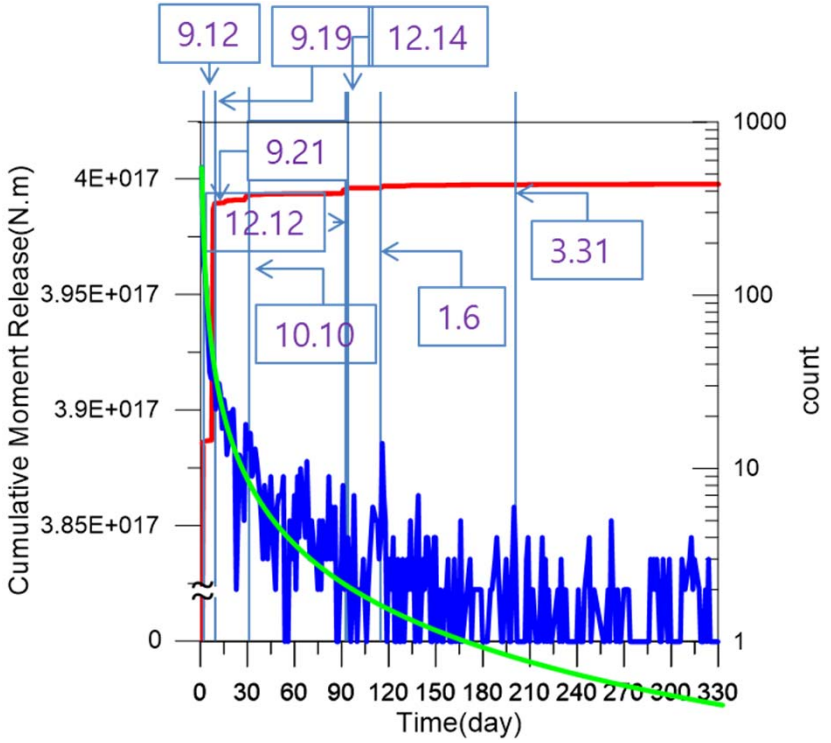


GJ Earthquake	LAT. (°N)	LON. (°E)	Depth (km)	Mag. (M_L)
Fore Shock 2016.09.12 19:44:33	35.77	129.19	15.0	5.1
Main Shock 2016.09.12 20:32:54	35.76	129.19	14.1	5.8
After Shock 2016.09.19 20:33:59	35.74	129.19	15.5	4.5
After Shock 2017.03.31 13:46:10	35.78	129.19	9.8	3.5

9.12 Gyeong-Ju Earthquake

- **9.12 Gyeong-Ju Earthquake (M_L 5.8, Sept. 12, 2016)**
  - **Over 600 aftershocks at a specific planar area with 5km width and 5km length**
  - **Potential fault plane dipping 70º ESE, at the depth between 11km and 16km**





9.12 Gyeong-Ju Earthquake

Safety Inspection and Impact to NPPs in KOREA

Evaluation and Inspection for the Seismic Safety of Wolsong NPPs

- Maximum PGA : 0.098g (Manual Shutdown : PGA > 0.1g)
- Response Spectrum slightly exceeded the OBE DGRS

Main Shock (M_L=5.8)	Wolsong	KORI	Hanul	Hanbit
Distance to Epicenter (km)	28	51	148	254
PGA (KHNP)	(#1) 0.0981 g	(#3) 0.0537 g	(#1) 0.0057 g	(#1) 0.0045 g
PGA (KINS) : reference for regulator	0.1200 g	0.00378 g	0.0076 g	0.0019 g

9.12 Gyeong-Ju Earthquake

- **Safety Inspection and Impact to NPPs in KOREA**
  - **Wolsong #1~4 : Manual Shutdown according to the Seismic Response Manual**
  - **Safety Inspection for all NPPs and Detailed Inspection for Wolsong NPP**
    - 37 KINS Inspectors, 81 days
    - Document review, Plant walkdown, Performance Test, ILRT(Integrated Leak Rate Test)
    - No obvious evidences indicating the plant and its safety function were affected by EQ
  - **Resume operation on Dec. 5th, 2016**

Post-Gyeong-Ju Earthquake Safety Actions

- **Post-Gyeong-Ju Earthquake Safety Actions**
  - **Announced at the 63rd NSSC Meeting on Dec. 22nd, 2016**
  - **23 Action Items under 6 Safety Categories**
    - Enhancement of Earthquake Response System
    - Seismic Upgrade and Vulnerability Evaluation for NPPs
    - Re-consider of Seismic Safety for LILRWR (Low-Intermediate Level Rad-Waste Repository)
    - Re-evaluation of the Design Basis Earthquake
    - On-site Emergency Response Facility
    - Strengthening Emergency Response Framework

Post-Gyeong-Ju Earthquake Safety Actions

Enhancement of EQ. Response System

Report (30 mins)

Manual Shutdown Decison
4 hrs → 2 hrs

Shortened
Response Time

≥M3.0

NSCC
NSIC

Information
Disclosure

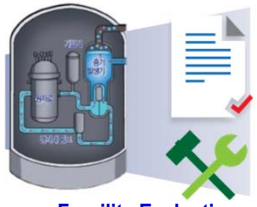
Strengthened Seismic
Monitoring System

Seismic Upgrade & Vulnerability Evaluation

0.2 g ➔ 0.3 g

Seismic Upgrade

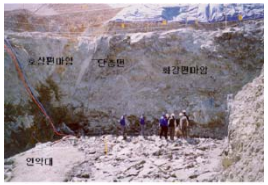
Safety Shutdown
Residual Heat Removal
RB Isolation
SFP cooling



Fragility Evaluation
(~0.5g)

Re-evaluation of
Seismic Safety

Re-evaluation of Design Basis EQ



Detailed Geological and
Seismological Survey

NSSC
MOIS
MSIT
KMA

Cross-Administrative
Department Cooperation

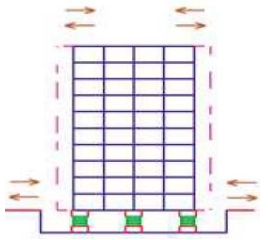
Reconsider of Seismic Safety for LILRWR

1st Phase
Underground Silo Type

2nd Phase
Surface Disposal Type

Onsite Emergency Response Facility (~2022)

500 persons
0.5 g
72 hrs Power Supply



Strengthened Emergency Response Framework

Severe Accident /
Emergency Response Team

30 experts
On-site within 6 hrs
(Finished in 2017)

Post-Gyeong-Ju Earthquake Safety Actions

1. Enhancement of Earthquake Response System

- **Strengthening Maintenance of Seismic Instruments**
  - **(KINS) Renovation of old seismic instruments of KINS for regulation**
  - **(KHNP) Additional performance inspection in every 5 yrs by certified institutes**
    - According to “Notice of the Ministry of Public Safety and Security No. 2016-120
    - Revision of KINS Reg. Guide and KHNP AOP (Abnormal Operation Procedure)
    - Accuracy of recorded data of accelerometers using shaking table tests
- **Improvement of OBE seismic alarm algorithm (~’18)**
  - **The system improvement is in progress by linking PGA and RS checks**
    - Currently, OBE seismic alarms are generated using only PGA check.

*** PGA : Peak Ground Acceleration**

Post-Gyeong-Ju Earthquake Safety Actions

1. Enhancement of Earthquake Response System

- **Prompt Post-Earthquake Action and Report Process**
  - **KHNP shall report the NPP status to the NSSC within 30 mins after an EQ.**
  - **Automatic transmission of seismic records to KINS after an EQ (~2020)**
    - "after an EQ" means seismic trigger more than 0.01 g.
  - **Shortening the time for the manual shutdown over OBE**
    - Decision to shutdown within 2 hrs (4 hrs previously) and shutdown within 4 hrs
- **Transparent Information Disclosure**
  - **KHNP shall offer plant status to public within 60 mins after an EQ.**
    - EQ with more than M_L 3.0 over within a 100 km radius of NPP site .

2. Seismic Upgrade and Vulnerability Evaluation of NPPs

Seismic Performance Upgrade of Operating NPPs (1/2)

Background and Purpose

- In light of the Post-Fukushima Safety Action 1-2, “Seismic performance improvement (PGA 0.2 g ➔ 0.3 g) for safety shutdown and shutdown cooling systems”

Technical Standards and Evaluation Methods

- EPRI TR-103959 “Methodology for Developing Seismic Fragilities”
- EPRI NP-6041 “A Methodology for Assessment of NPP Seismic Margin”
- Utilization of Seismic PSA, Existing SMA and Additional detailed seismic analysis

2. Seismic Upgrade and Vulnerability Evaluation of NPPs

Seismic Performance Upgrade of Operating NPPs (2/2)

Selection & Evaluation of the SSCs (performed by KHNP)

- Safe shutdown and cooling of the reactor, SFP cooling and Isolation of reactor building

Seismic Upgrade (< 0.3g) (performed by KHNP)

- Retrofit of SSCs structurally vulnerable (usually, anchoring part)
- Seismic verification tests of SSCs functionally vulnerable for PGA 0.3 g using shaking table
- Replacement to satisfied one to PGA 0.3 g

Current Progress

- Seismic upgrades for 21 plants were completed by KHNP and are under review by KINS.
- Kori #2 & Hanul #1,2 are planned to be completed by Oct. 2018.

2. Seismic Upgrade and Vulnerability Evaluation of NPPs

Seismic Vulnerability Evaluation of Operating NPPs (1/2)

Background and Purpose

- Seismic vulnerability evaluation on the critical safety functions
- Safe shutdown and cooling of the reactor, SFP cooling and Isolation of reactor building
- Representative NPPs : Hanul #3 (KS), Kori #3 (W/H), Wolsong #3 (CANDU)
- Against postulated big earthquakes with the PGA of 0.3g, 0.4g, and 0.5g

Technical Standards and Evaluation Methods

- EPRI TR-103959 “Methodology for Developing Seismic Fragilities”
- Utilization of Seismic PSA, Existing SMA and Additional detailed seismic analysis

Seismic Vulnerability Evaluation of Operating NPPs (2/2)

Process of Seismic Vulnerability Evaluation (performed by KHNP)

- Selection of the SSCs based on the existing Seismic PSA results and P&ID
- Seismic Walk-down and Seismic Fragility Analysis (Determine HCLPF values)
- Scenario analysis for postulated EQ with 0.3g, 0.4g and 0.5g and consider mobile equipment (ex, mobile generator, mobile drainage pump) to the scenario
- Summary of the seismic vulnerabilities
  - NPPs are intact against PGA 0.3g and 0.5g only when additional mobile type facilities are applied.

Current Progress

- KHNP completed its evaluation on April 2017 and KINS reviewed the result (~ July 2017).
- An external expert team reviewed the KHNP's results independently (Aug.~ Dec. 2017).

2. Seismic Upgrade and Vulnerability Evaluation of NPPs

Current Status of Seismic Upgrades or Verification Tests

NPP Sites		SSCs (evaluated)	SSCs (< 0.3g)	Upgraded/ Verified	Schedule	Units
KORI		5,575	505	309	~June '18	6
HANBIT		5,076	14	14	Completed	6
WOLSONG		5,348	61	61	Completed	6
HANUL	1,2	1.794	-	-	~June '18	2
	3~6	3,543	26	26	Completed	4
Total		21,336	606	410	196 + α	24

Types	Object	Completed	In Progress	Note
Reinforcement	277	277	-	
Seismic Test	96	96	-	
Replacement	233	37	196	
Total	606	410	196+ α	

2. Seismic Upgrade and Vulnerability Evaluation of NPPs

Follow-up Action Items

Tentative Summary of the Follow-up Action Items

- Development of Detailed Technical Standards, Methodologies and Procedures
- Credibility Improvement of the Input Database
- Update of the SSCs List for Seismic Performance Evaluation
- Implementation of the Follow-up Actions of the Seismic Walk-down
- Reconfirmation of the Plant/System HCLFP through the Revaluation of Critical SSCs

Implementation

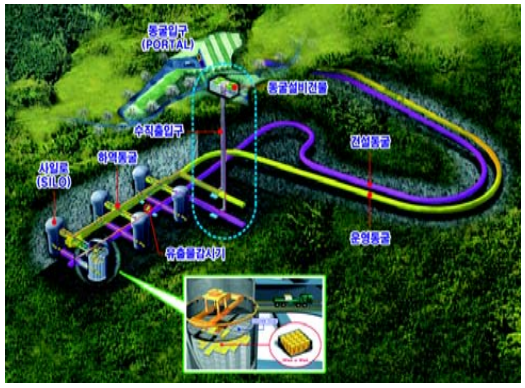
- Preparation of the Implementation Plan for the Follow-up Action Items (by KHNP)
- Justification of the KHNP's Implementation Plan (by KINS and an External Expert Team)
- Confirmation and Initiation Order of the Plan (by the NSSC)

Post-Gyeong-Ju Earthquake Safety Actions

3. Re-Consider of Seismic Safety for LILRWR

- **Strengthening Emergency Response System**
  - Implementing remote data acquisition and observation function to existing seismic monitoring system
  - D/B establishment for variation of groundwater drainage volume (~2018)
  - Installation of additional seismic instruments at the LILRWR site (~2020)

LILRWR
(Low-Intermediate Level Rad Waste Repository)



1st Phase
Underground Silo Type

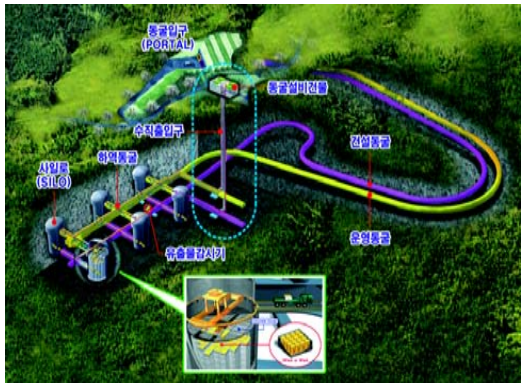
2nd Phase
Surface Disposal Type

Post-Gyeong-Ju Earthquake Safety Actions

3. Re-Consider of Seismic Safety for LILRWR

- **Seismic Performance Reconfirmation for the 1st Phase LILRWR**
  - Major facilities : Silo, Rad-waste Bldg. and so on
  - Installation of supplementary facilities for drainage and power supply system
- **Seismic Upgrade for the 2nd Phase LILRWR**
  - Seismic upgrade (0.2 g ➔ 0.3 g) of Repository Structure, Mobile Crane ….

LILRWR
(Low-Intermediate Level Rad Waste Repository)



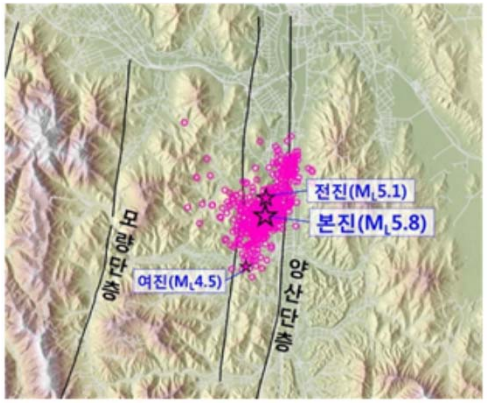
1st Phase
Underground Silo Type

2nd Phase
Surface Disposal Type

Post-Gyeong-Ju Earthquake Safety Actions

4. Re-evaluation of the Design Basis Earthquake

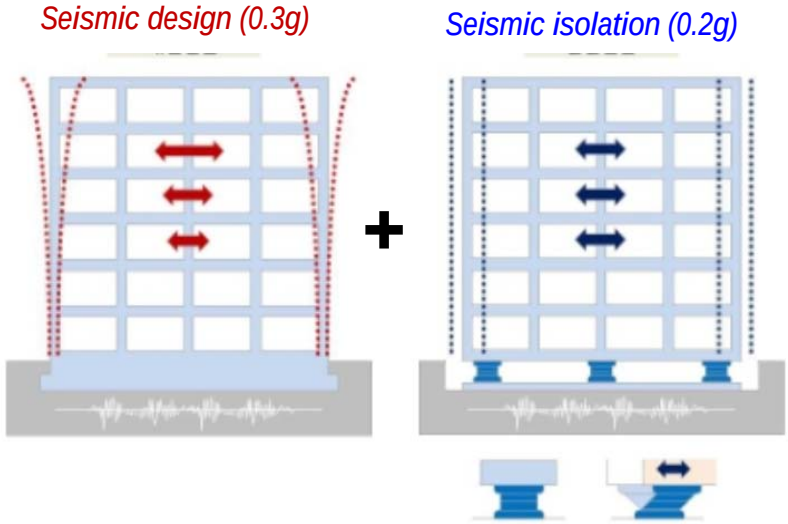
- **Background and Purpose**
  - Characterization of the causative fault that generated the G-J earthquake
  - Determination of the maximum potential earthquake (PGA)
  - Re-evaluation of the design basis earthquake of adjacent NPPs
- **Research Activities of the NSSC (2017 ~ 2021)**
  - Monitoring and analyzing micro-seismicity around the epicenter
    - Planned to install 140 mobile seismometers
  - Geophysical survey of deep-seated seismic fault distribution
  - Establishment of seismic input data and applicable methodology



Post-Gyeong-Ju Earthquake Safety Actions

5. On-site Emergency Response Center

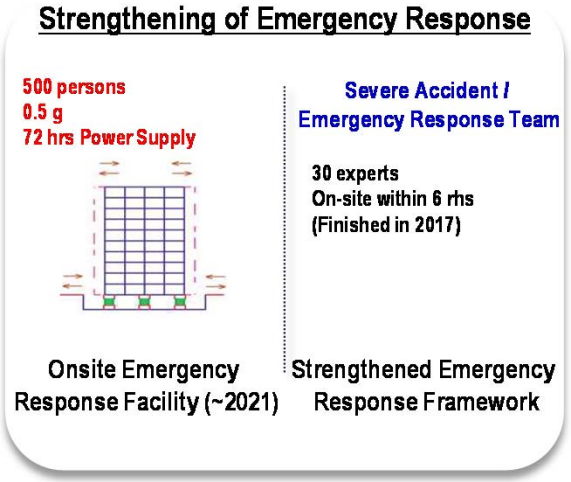
- **Installation of On-site Emergency Response Center**
  - Location : 1 ERC on 13 m above sea-level at each NPP site
  - Capacity : 4 ~ 5 stories building, 5,000 m^2, accommodating 500 people
  - Function : PGA of 0.5g seismic design (combination with 0.2g seismic isolation), Radiation-proof, 72 hrs power supply, Emergency food, and so on
- **Current Staus**
  - 1st Phase : Wolsong Site (~2020)
  - 2nd Phase : The Other Sites (~2022)



Post-Gyeong-Ju Earthquake Safety Actions

6. Strengthening Emergency Response Framework

- **Establishing Severe Accident Emergency Response Team (2017)**
  - Composed of 30 severe accident / emergency specialists at KHNP CRI
- **Seismic Safety Experts Recruitment for the NSSC and KINS (~2018)**
  - NSSC : 2 (headquarter) and 4 (regional office) (2017)
  - KINS : 3 experts related to seismic safety (~ 2018)
- **Strengthening Education and Training Program (~2019)**
  - Developing a long-term education program,
  - Implementing seismic disaster scenario, and so forth



Concluding Remarks

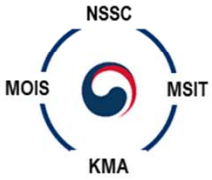
The 23 safety action items to be managed and monitored through quarterly progress review report and semi-annual progress review meeting (~ 2022).

Enhancement of EQ. Response System

Seismic Upgrade & Vulnerability Evaluation

Re-evaluation of Design Basis EQ

Detailed Geological and Seismological Survey



Cross-Administrative Department Cooperation

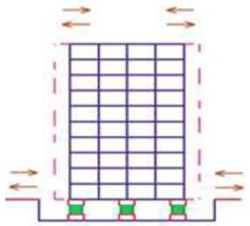
Reconsider of Seismic Safety for LILRWR

1st Phase Underground Silo Type

2nd Phase Surface Disposal Type

Onsite Emergency Response Facility (~2022)

500 persons
0.5 g
72 hrs Power Supply



Strengthened Emergency Response Framework

Severe Accident / Emergency Response Team

30 experts
On-site within 6 hrs
(Finished in 2017)

Thank you for your kind attention

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