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Current Status of KURT and its Long-term Experimental Research Programme

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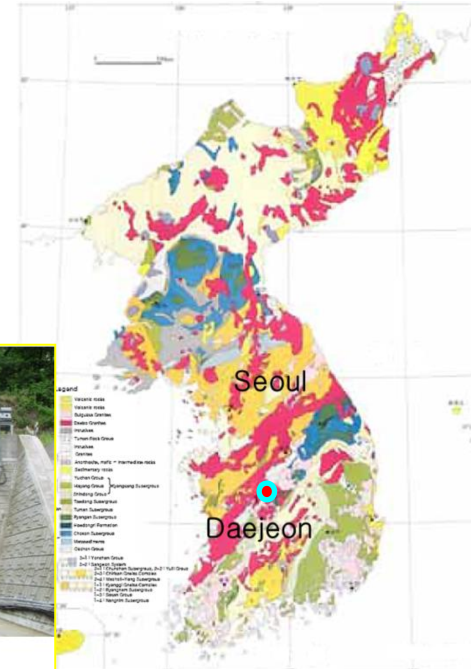
Contents

What is the KURT?

- **KURT** = **K**AERI **U**nderground **R**esearch **T**unnel
  - Located in KAERI, Daejeon
  - Generic URL & R&D site, not potential site for waste disposal
  - Purpose-built, not pre-existing excavation
  - Crystalline basement rock (two-mica granite)
  - No radioactive material

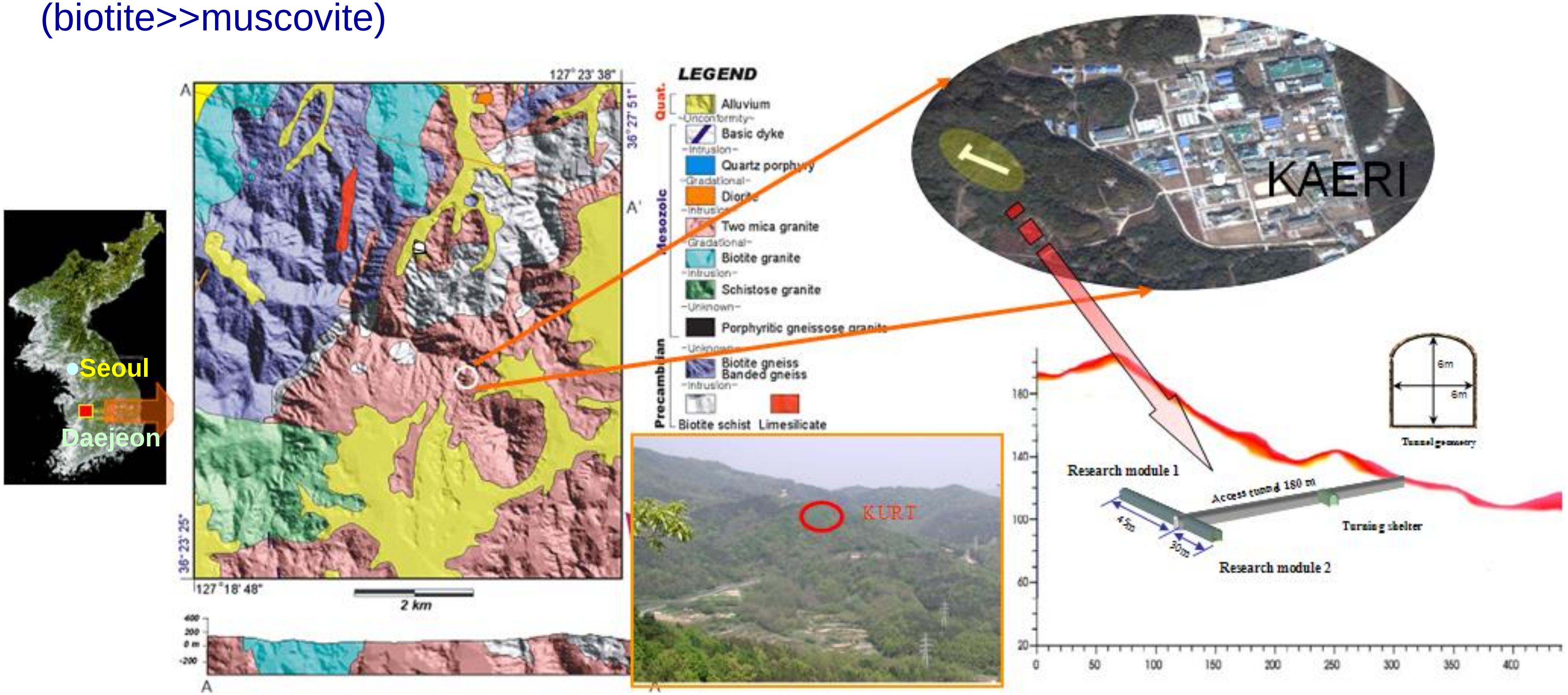
Tunnel portal



		S. Korea	Peninsula
Plutonic rocks	- *Proterozoic and Mesozoic*	*25.6%*	*35.2%*
Metamorphic rocks	- *Gneiss, Schist, etc*	*29.5%*	*30.0%*
Volcanic rocks	- *Intrusive and Extrusive*	*16.2%*	*13.6%*
Sedimentary rocks	- *Paleozoic and Mesozoic*	*25.4%*	*16.0%*
Others	- *Unconsolidated and Quaternary*	*3.3%*	*5.2%*

KURT - Location & Geology

- **KAERI & KURT (KAERI Underground Research Tunnel)** in Daejeon city
- Geology around KAERI site : Pre-Cambrian metamorphic rocks (biotite gneiss and banded gneiss, limesilicate, biotite schist), Mesozoic plutonic rocks (schistose granite, biotite granite, two mica granite), dykes
- KURT located in western part of KAERI site : medium to coarse-grained **two-mica granite** (biotite>>muscovite)



KURT – Objectives

- **Main Objectives of the KURT Project**
  - To obtain information on the geologic environment, and the behavior and performance of engineered barriers under repository conditions
  - To establish the techniques for site investigation, data analysis and integrated assessment of the deep geological environment
  - To develop and demonstrate the proposed disposal concept and the technologies needed for the construction, operation and closure of a repository.
  - Public relations : information center for public and stakeholders, > 1,400 visitors/year

Understanding of Deep Geological Environment

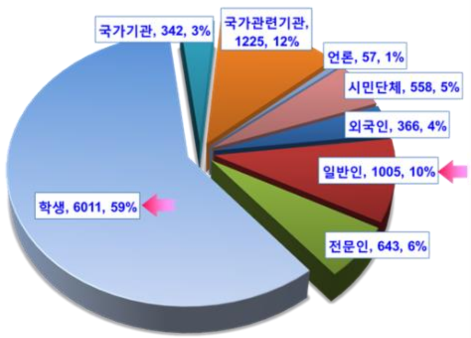
Performance Validation of Multi-barrier system

In-situ Experiments (KURT)

No radioactive material

Public Relations

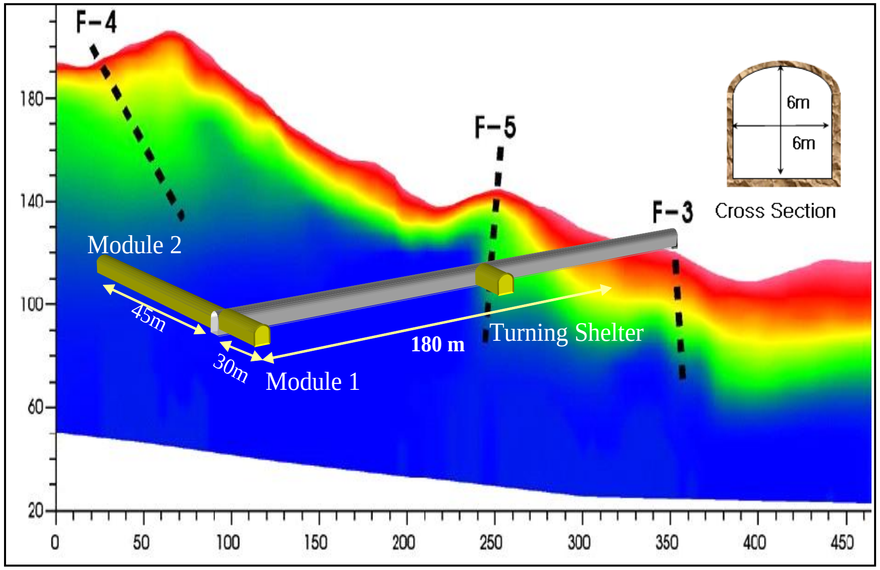
Validation of the technical feasibility of construction and operation techniques



10,207 visitors since Nov. 2006

Layout of KURT

Phase I : 2006~2014



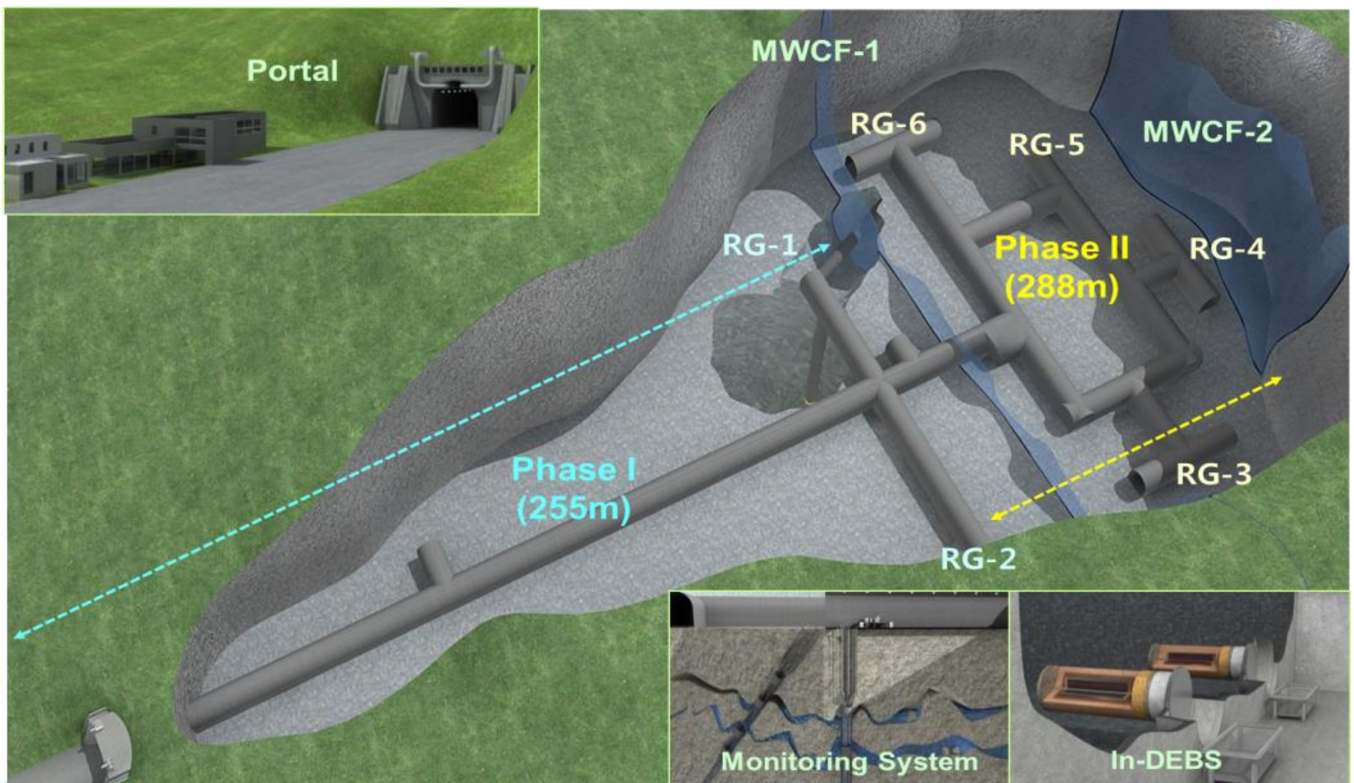
- Mar. 2005~Nov. 2006: Construction
- ~2013 : Phase I Operation
- Access tunnel of 180 m length and two research modules of 45 m and 30 m length at the dead end of the access tunnel
- 90 m depth below the surface
- Cross sections : horseshoe shape with 6m x 6m

Phase II : 2015 ~

- Extension work was completed in Nov. 2014
- 2015 ~ : Phase II in-situ tests and experiments to develop and demonstrate the proposed disposal concept and technologies

Current Layout of KURT

- Total 543 m length with 6 research modules
  - ✓ Additional tunnel of ~288 m length and 4 research modules
  - ✓ 165 m looped shape access tunnel + 42 m connection tunnel + 4 research modules with a total length of 81 m
- Horseshoe shape with 6m(W) x 6m (H) (same as Phase I tunnel)
- Maximum depth of research module: ~120 m from the peak of the mountain



Why KURT?

Current Status of NPPs in Korea

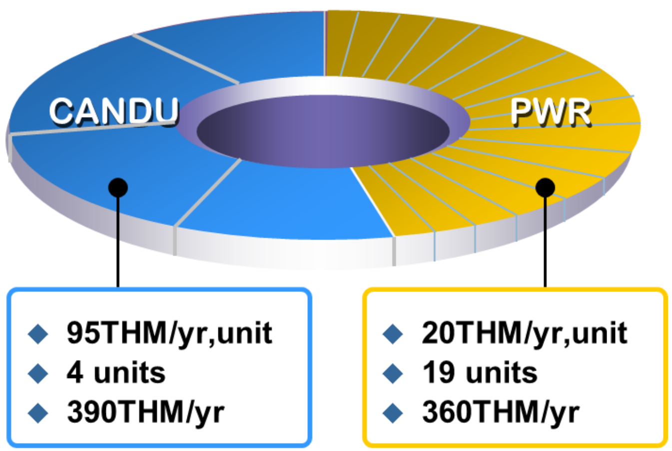
- 23 operating reactors in 4 NPP sites, ~26% of the total electricity production capacity in 2013
- 1st National Energy Basic Plan in 2008 : increase up to 41% by 2030
- The first draft by the joint working group for the 2nd National Energy Basic Plan in 2013 : proposed maintaining in the range of 22~29% by 2035.
- The government determined the target ratio of nuclear power generation in total as 29% by 2035 in December 2013

In Operation	23 Units (20,716MW)
Under Const.	5 Units (6,600MW)
Planning	6 Units (8,600MW)

Total 34 Units by 2024

Spent Fuel Generation and Storage at NPPs

❖ Annual Spent Fuel Generation ~750THM/yr



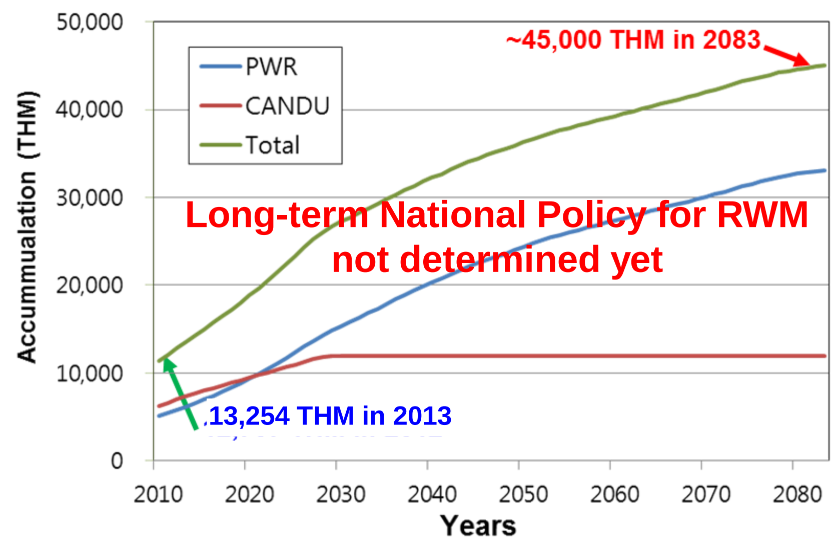
❖ Safely managed in storage facilities at reactor sites

SNF Storage Capacity (THM) by Power Plants (Dec. 2013)

	NPP Site	No.	Capacity	Stored	%	Saturation Exp.	
PWR	Kori	6	2,691	2,081	77	2016	2028
	Youngwang (Hanbit)	6	3,318	2,146	65	2021	2024
	Uljin (Hanul)	6	2,960	1,848	62	2018	2028
	Shin-Wolsong	1	219	27	12	2017	2026
	sub-total	19	9,188	6,102	66		
PHWR	Wolsong	4	9,441	7,152	76	2017	2026
	Total	23	18,629	13,254	71		

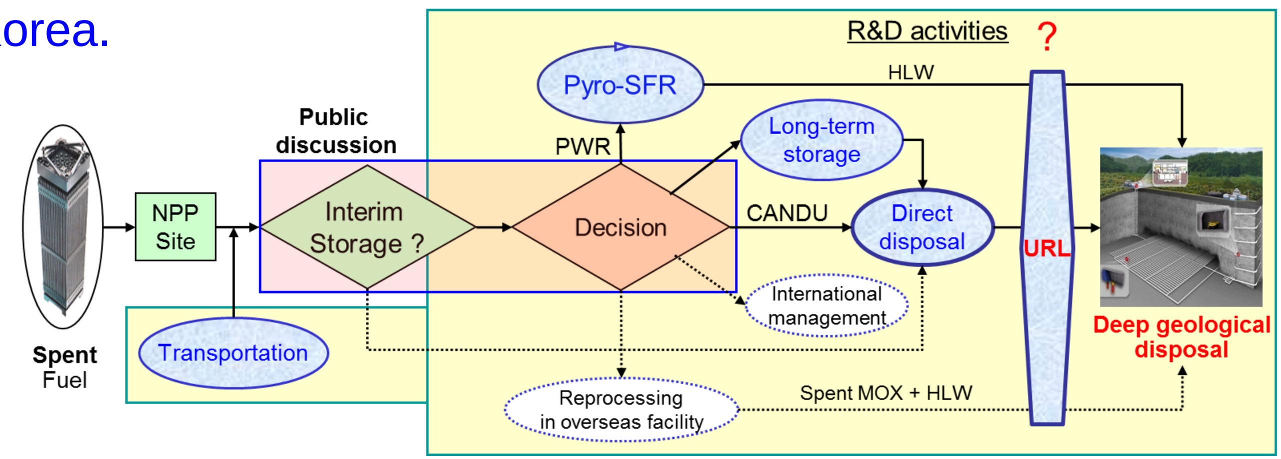
- About 750 THM of SF are generated every year from 23 NPPs.
- SFs are stored temporarily at each NPP sites.
- 13,254 THM as of the end of 2013 (6,102 THM from PWR and 7,152 THM from PHWR (CANDU)).
- By the year of 2083, ~45,000 THM (33,000 THM from PWR and 12,000 THM from PHWR) from 34 units based on the 5th basic plan of electricity supply and demand.
- Saturation will start in 2016 starting with Kori power plant.
- NPP sites are expected to reach their maximum capacity from 2024 despite the expansion of the capacity (high-density storage racks or transportations among storages).

❖ Projection of Spent Fuel Generation



Why KURT?

- The Korea government has determined the target ratio of nuclear power generation in total as 29% by 2035 in December 2013.
- The NPP sites will be reached their maximum temporary storage capacity from 2024.
- Long-term National Policy for SNF management has not been determined yet.
- Must prepare the final disposal, whatever Government will determine in the future; centralized interim storage or direct disposal or reprocessing
- KAERI has been developing safe and reliable geological disposal techniques for HWL and performing various experiments at KURT to test their feasibility, safety and stability.
- The KURT is not real deep URL for final disposal.
- But, KURT must play a major role in development and demonstration of the proposed disposal concept and the technologies, and especially in public acceptance, until and/or after the real deep URL in Korea.



KURT and R&D Activities for the HWL Geological Disposal in Korea

R&D for HLW Disposal Technology Development

- Preliminary R&D programs for spent fuel disposal
- Development of a conceptual direct disposal system (KRS) for SNF generated from PWRs and PHWRs
- Construction of KURT

- Development of A-KRS to integrate all radioactive waste to be generated in the future nuclear energy system
- Demonstration of its safety and long-term performance in the KURT

KURT

1997 | 2002 | 2007 | 2012 | 2017 | 2022

Milestone → **Concept Development** → **KRS design** → **A-KRS Conceptual Design** → **Demonstration** → **A-KRS+ Development**

Start of R&D for SF Disposal

- Concept Analysis, R&D strategy
- Safety Evaluation

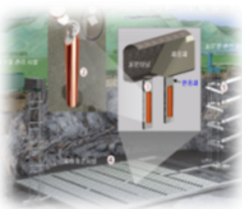
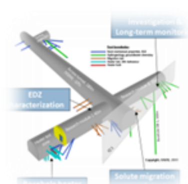
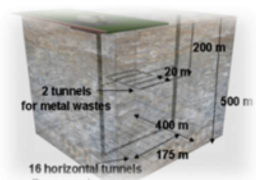
- SF direct disposal system(KRS) development
- Construction of KURT

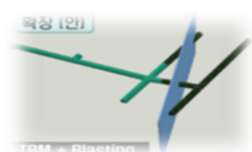
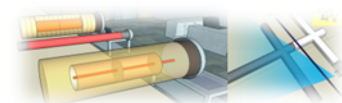
Start of R&D for Pyro-wastes disposal

- Conceptual Design of Pyrowaste Disposal System
- IAEA Peer Review

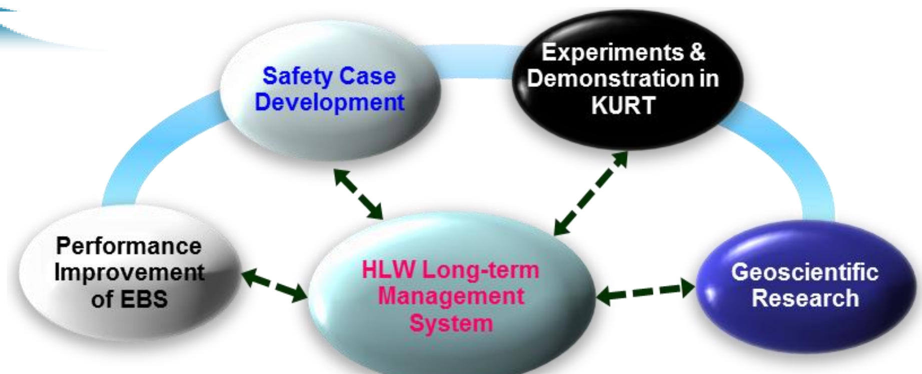
- 1/3 Scale EBS Manufacturing & Performance Demonstration
- Safety Case Development of KURT site

- Retrievable Disposal System Development
- Upgraded EBS & Performance Evaluation

- KAERI is developing a reference geological disposal system for HLW and long-lived wastes to be generated from pyro-processing.
  - ✓ Development of EBS to secure its long-term performance
  - ✓ Establishment of safety cases based on KURT environment
  - ✓ Uncertainty minimization of NBS
  - ✓ Research gallery extension of KURT



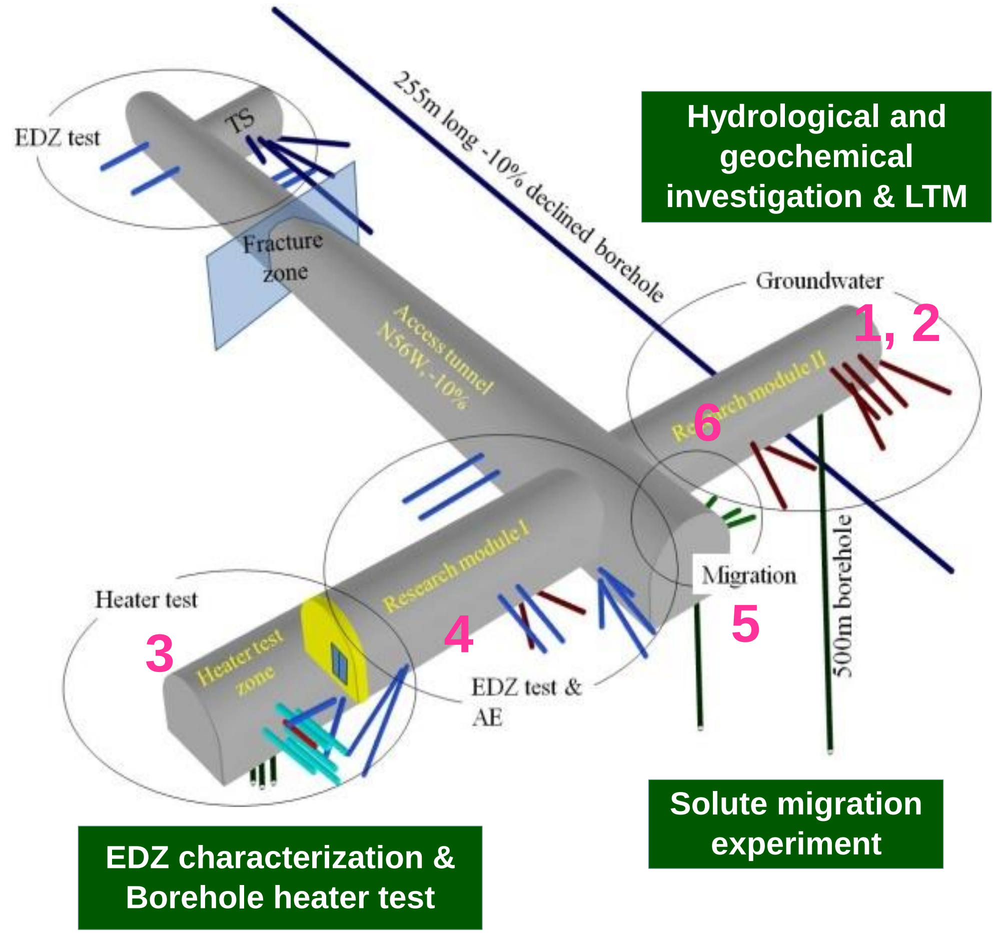
History of KURT-Phase I

- It was necessary to investigate experimentally the performance of approved disposal system under repository conditions (deep geological condition) for the assessment of feasibility, stability, and safety of the proposed HLW disposal concept.

- 2002 Planning Committee for the Korean Nuclear Energy R&D Programme
- Mar. 2003 ~ Nov. 2004 Site characterization, design and licensing for construction
- Mar. 2005 ~ Phase I construction started
- **Nov. 11, 2006 Phase I construction completed and operation started**


Tests and Experiments in Phase I

1. ***Deep Borehole Investigation***: to get deep hydrological and hydrochemical data and to develop site investigation techniques
2. ***Hydrological and geochemical monitoring***: to monitor the hydrological and geochemical parameters and to construct site descriptive models
3. ***Single hole heater test***: to investigate the thermo-mechanical behavior of the rock mass during the heating phase up to 90°C
4. ***EDZ characterization***: to compare the thermal, mechanical, and hydraulic property changes before and after the tunnel excavation by test and modeling
5. ***Solute migration experiment***: to investigate the transport properties in fractured rock mass.
6. ***Long-term Corrosion Experiment***: to estimate long-term corrosion rate of disposal canister materials and the effect of DO, Eh, and pH on the corrosion behavior
7. ***International collaboration project with SNL***: cubic law testing for flow in a single fracture and investigation of the correlation between the streaming potential (SP) signal and fracture flow



Tests and Experiments in Phase I

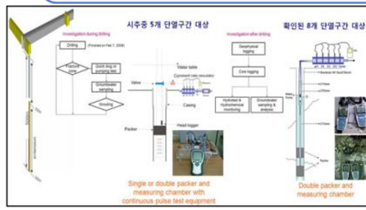
Geoscientific Activities

① Development of geoscientific investigation technologies for the site characterization

② Hydrogeological and hydrochemical investigation with deep drilling and long term monitoring using multi-packer system

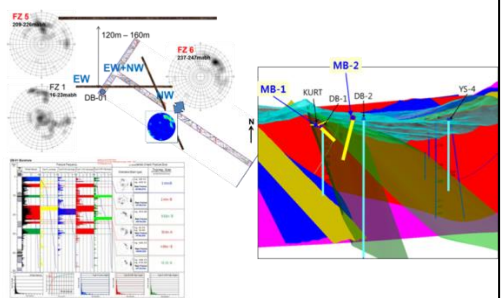
③ Construction of hydrogeological site descriptive model and groundwater flow model

Deep drilling investigation in KURT



Hydrological and hydrochemical monitoring

Construction of site descriptive model



Borehole heater test

① Design and development of the heater test system

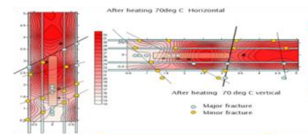
② In situ test of thermo-mechanical behavior of rock under heating condition

③ Assessment of heat transfer mechanism and thermal stress in fractured rock mass of KURT

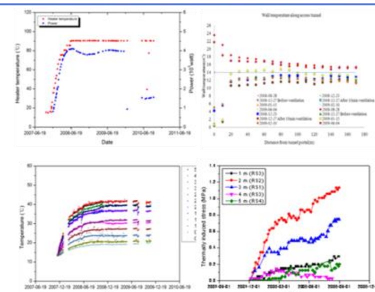
④ Validation of THM modeling with the test results

KURT borehole heater test system

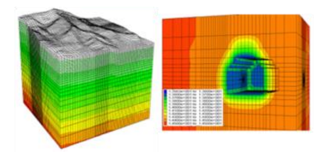
Assessment of heat transfer mechanism



Thermo-mechanical behavior during heating



THM modeling



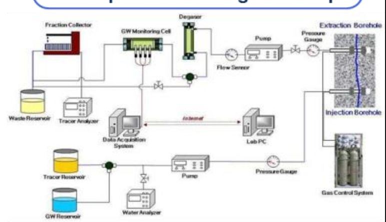
Solute migration experiment

① Development and installation of migration experiment system in KURT

② Migration exp. using non-sorbing(Uranine, Eosin, Br)/sorbing tracers(Rb, Ni, Sm, Zr)

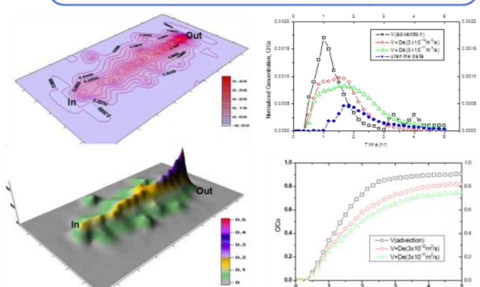
③ Development and improvement of solute migration model

Concept of solute migration exp.



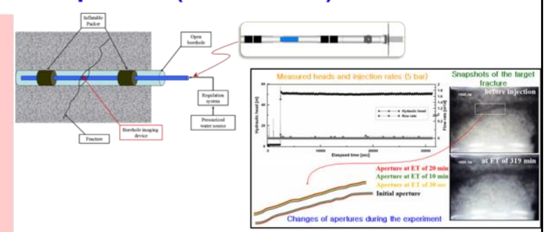
Migration experiment system in KURT

Solute migration modeling using SIMIGF



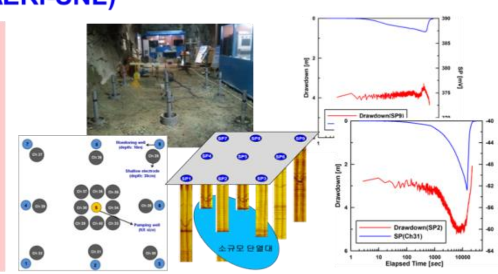
Influence of GW Pressure on Fracture Aperture (KAERI-SNL)

- To evaluate the influence of groundwater pressure on a fracture aperture size that controls the fracture hydraulic parameters
- Direct observation of fracture apertures and groundwater flow rates under various water pressure condition using specific equipment
- In-situ experiments focused on single fracture in borehole with specific equipment.



Streaming Potential Experiment (KAERI-SNL)

- To determine hydraulic properties and behavior of a 3D subsurface volume of saturated fractured rock using hydraulic head and streaming potential data.
- Production pumping test with simultaneous monitoring of hydraulic head and streaming potentials at the installed well in KURT
- Estimation of the correlation between SP signal and fracture flow with their governing equations

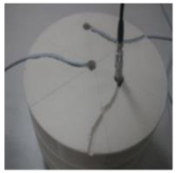


Tunnel Extension for Phase II

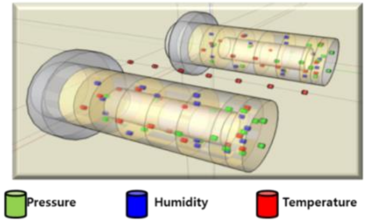
Background

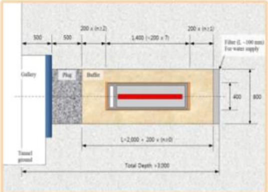
- Five-year R&D programme for HLW long-term management system development during FY2012 to FY2016 (Phase II) focuses on
  - ① Enhancement of the performance of EBS
  - ② Development of safety cases based on the KURT environment.
  - ③ Characterization of the MWCF: Hydrogeology, Geochemistry, Transport property
  - ④ Establishment of the infrastructure for in-situ demonstrations at KURT

Development of EBS
- Development of high thermal-efficiency buffer
- Development of cold-spray copper coating technology
- Long-term performance assessment of 1/3 scale in-situ EBS facility (In-DEBS) in KURT



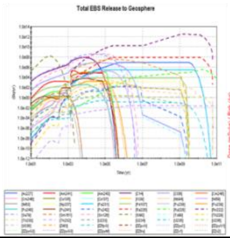
Laboratory EBS facility

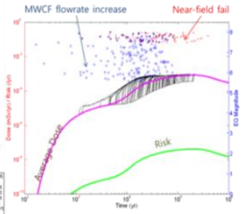




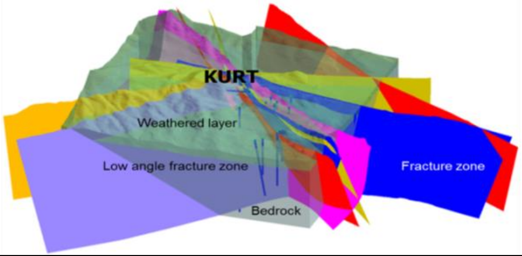
Design of in-situ EBS facility

Establishment of safety cases
- Development of safety assessment tool to check the design feasibility of reference disposal system
- Development of complex exposure scenarios and supplementary safety indicators
- Establishment of safety cases based on KURT deep geological environments

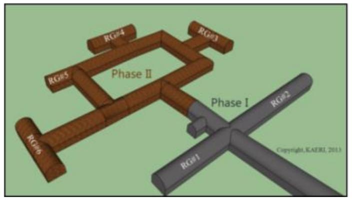




Uncertainty minimization of NBS
- Integrated site descriptive modeling (geological, hydrogeological, geochemical, and rock mechanical)
- Identification MWCF properties and long-term tracer test

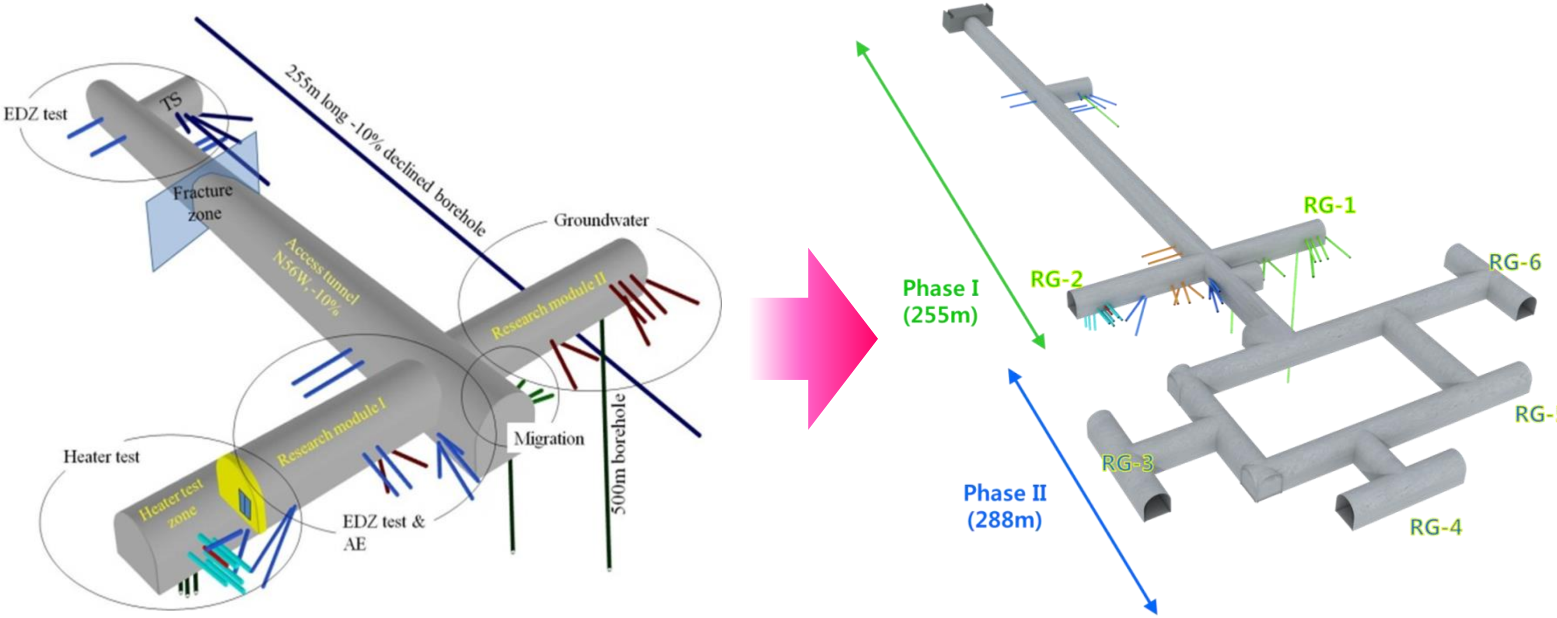


Research gallery extension of KURT
- Partner facility of IAEA URF Network
- Extension construction by 2014
- Phase II (2015 ~) in-situ tests and experiments to develop and demonstrate the proposed disposal concept and technologies



History of Phase II KURT Extension

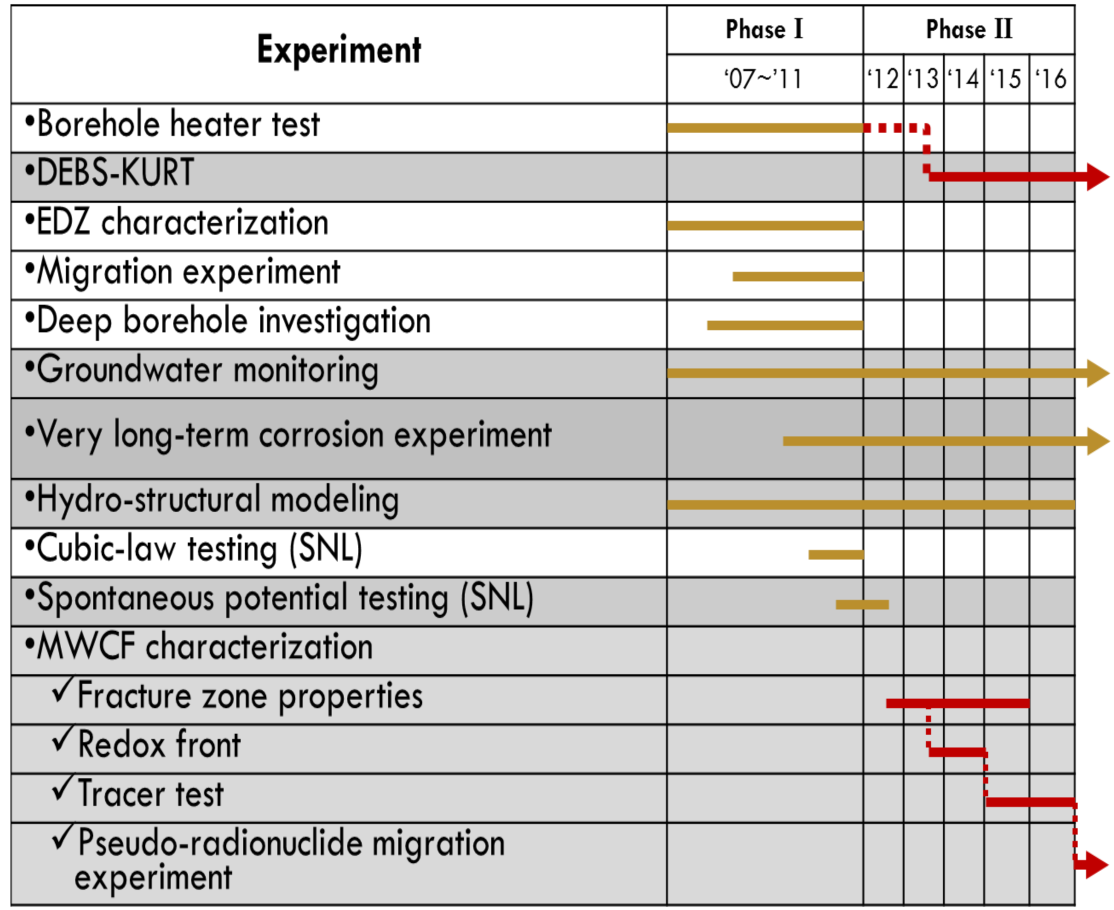
- Additional experiments and tests for the Phase II research project are required.
- Phase I KURT facility is too small to carry out the planned tests and experiments.
- Feb 2012 Approved by the government
- ~ Mar. 2013 Site characterization and design for construction
- ~ Sep. 2013 Licensing for construction, (from local government & people)
- ~ Oct. 2013 Installation of monitoring system for the extension
- **2013 ~ 2014 Phase II construction**
- **2015 ~ Start Phase II test and experiments**
- **Nov. 17-21, 2014 IAEA URF Network Annual Meeting in Daejeon, KAERI**



KURT Phase II Tunnel

Planned Tests and Experiments in Phase II

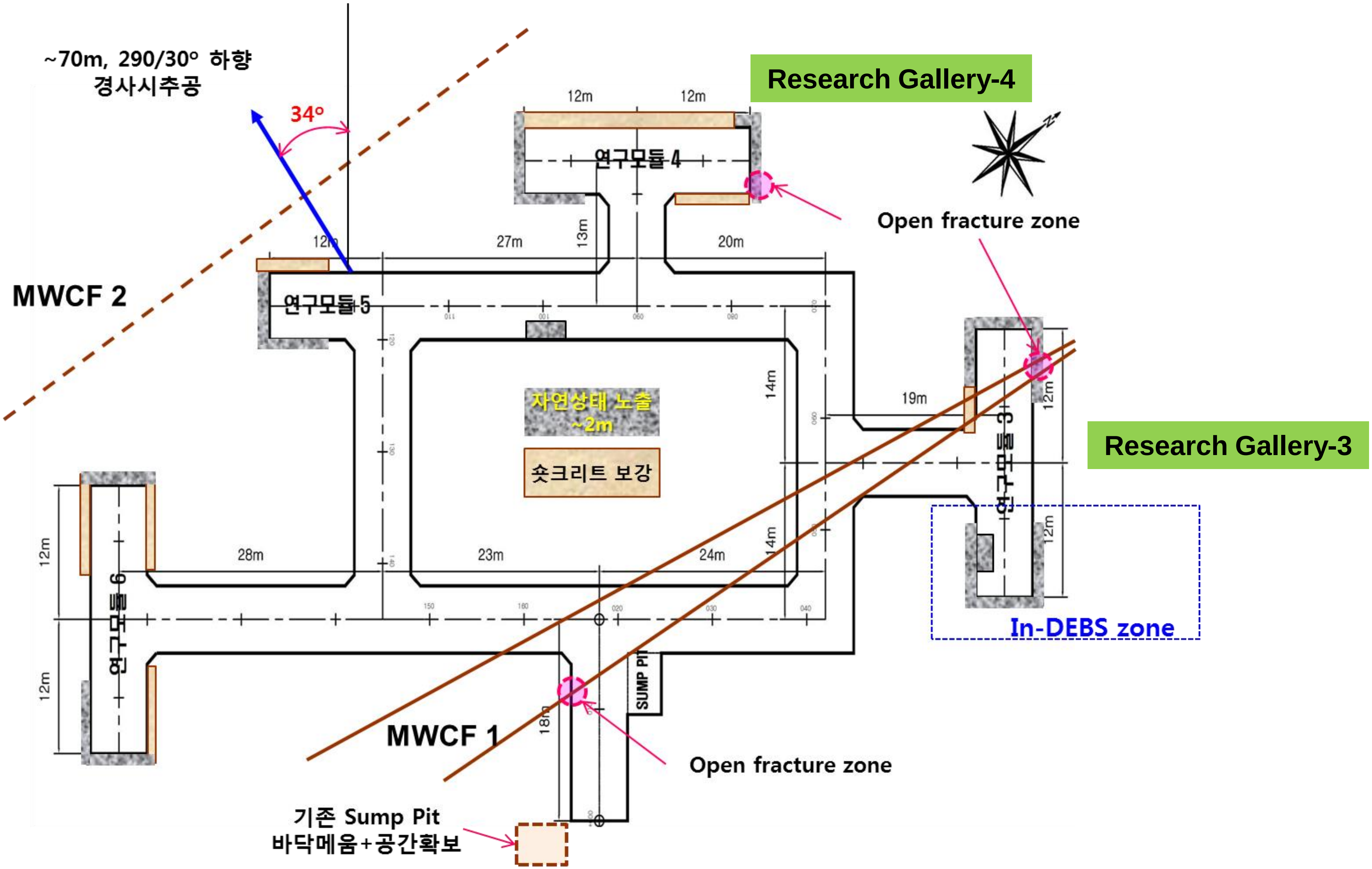
- **Phase II tests and experiments proposed by the KURT research fellows**
  - ✓ ***Hydrological and hydrochemical monitoring:*** basic activity during construction and operation stage
  - ✓ ***Long-term corrosion experiment:*** bentonite and copper canister using deep groundwater
  - ✓ ***Establishment of site descriptive model***: based on the data obtained during the excavation.
  - ✓ ***MWCF characterization:*** before, during and after the excavation
  - ✓ ***In-DEBS:*** design and preparation for engineering scale EBS performance tests was initiated in 2013, and site investigation for the In-DEBS and manufacturing of the system will be started in 2015.
  - ✓ ***International collaboration project with UFDC (SNL):*** SP test, started in FY2013.



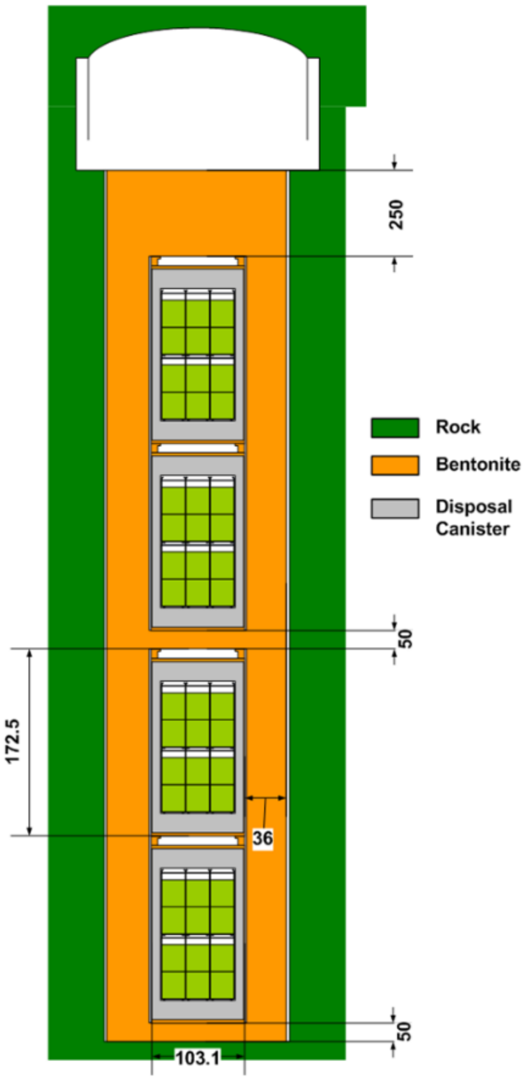
In-DEBS – Objectives

- **In-DEBS? In-situ Demonstration of EBS performance at KURT**
- **Purposes of In-DEBS**
  - **Demonstration of manufacturing techniques** for a large scale disposal canister and buffer
  - **Demonstration of installation** of a unit module of disposal system
  - Acquisition of the **long-term THM behavior data around EBS**: temperature, relative humidity, pore pressure, and total pressure
  - **Validation of the modeling techniques** for THM-coupled behavior
  - Demonstration of site characterization technique around a deposition tunnel
  - Measurement of in-situ corrosion rates of copper canister
  - **Development and demonstration of monitoring techniques** for major parameters in buffer: temperature, total pressure and hydraulic conductivity

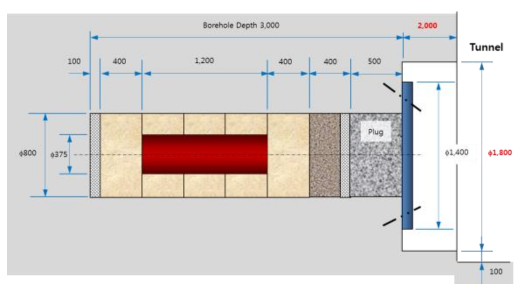
In-DEBS – Location in KURT

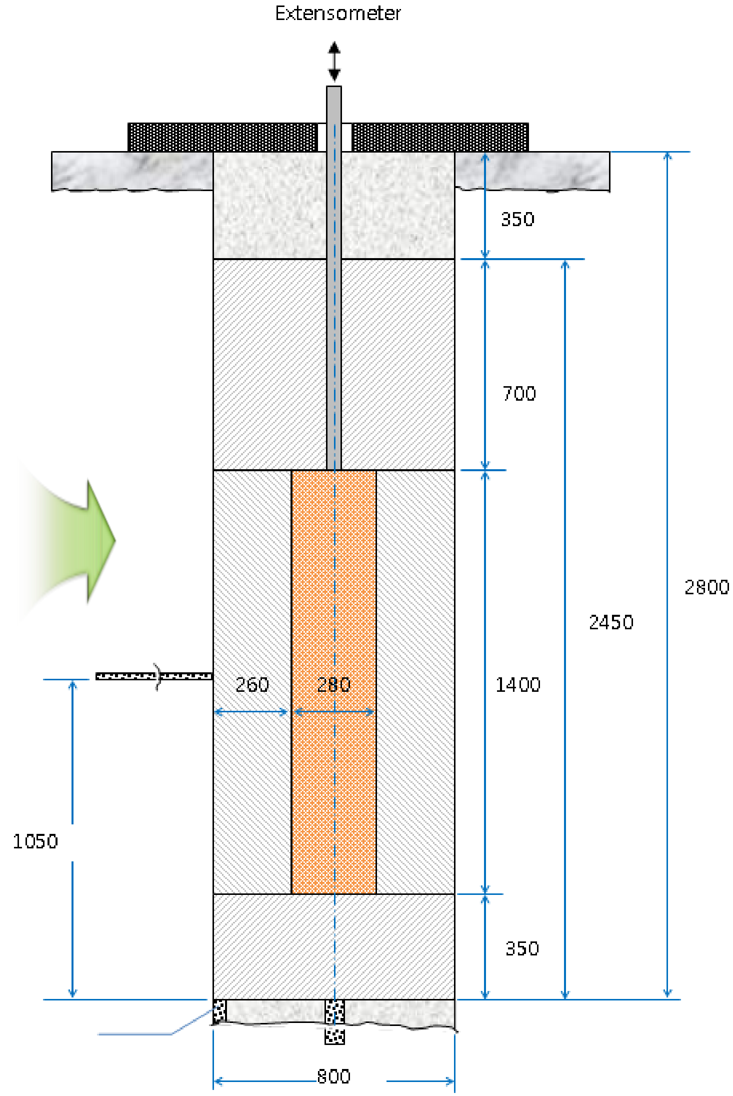


In-DEBS – Design, ver.3.0



- HLW: Monazite from pyro-processing of PWR SNF
- Geology: two mica granite
- Deposition method: Vertical deposition hole (changed from horizontal type)
- Disposal Canister: Copper-Cast iron
- Buffer: Korean domestic Ca-bentonite





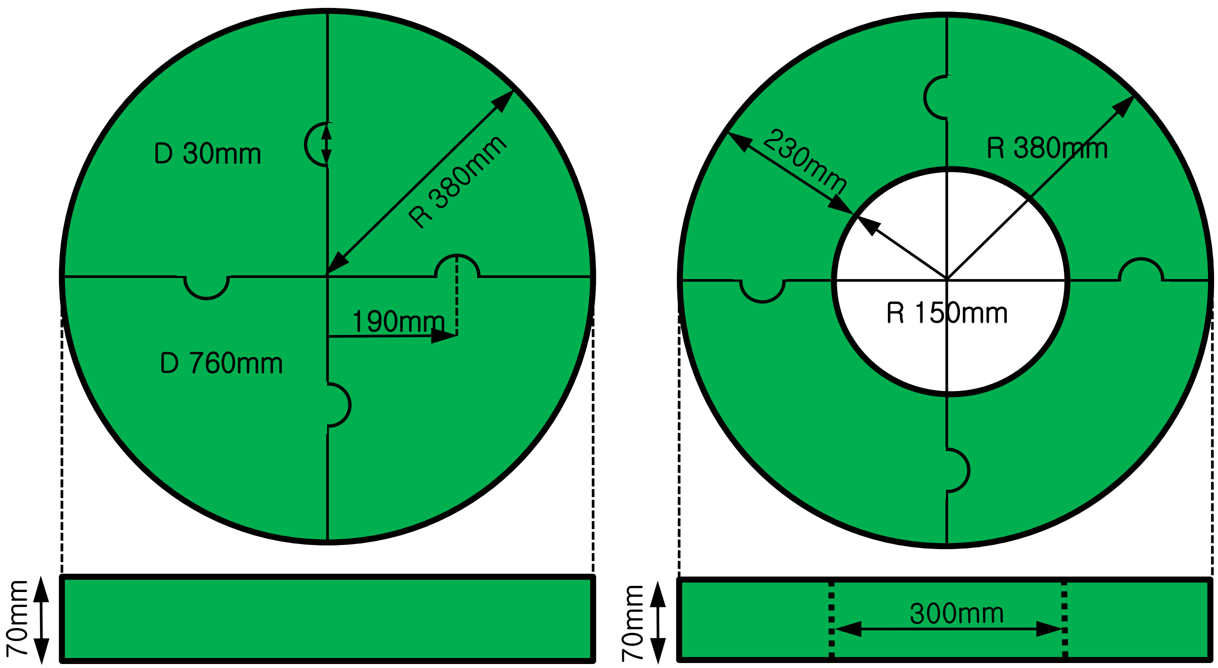
AKRS

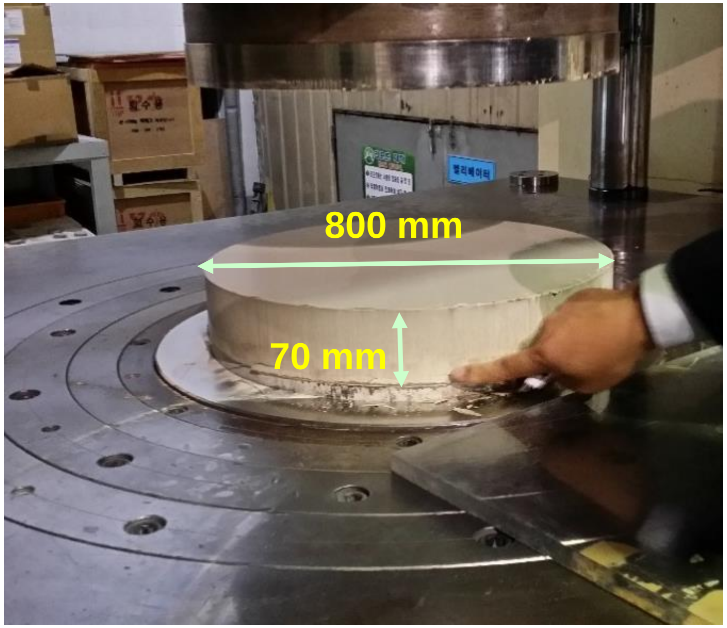
In-DEBS = 1/2.3 AKRS

In-DEBS

In-DEBS – Buffer

- Material: Korean domestic Ca-bentonite (montmorillonite > 70%)
- Dry density: 1.6 g/cc (= bulk density 1.825 g/cc)
- Fabrication: three types are under discussion. The size will be fixed depending on the capacity of a press available
- Thickness of a block: 70 mm (under discussion)

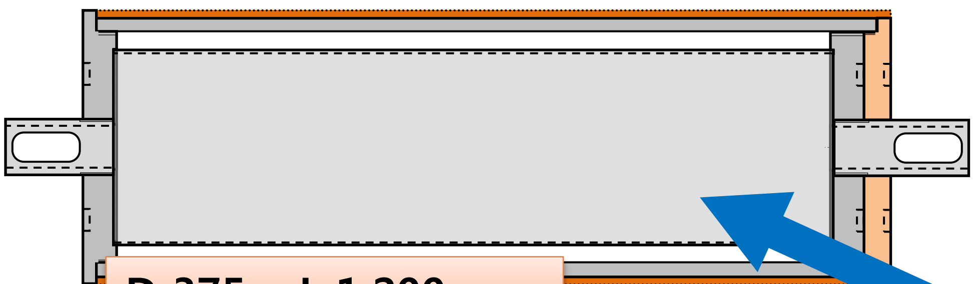




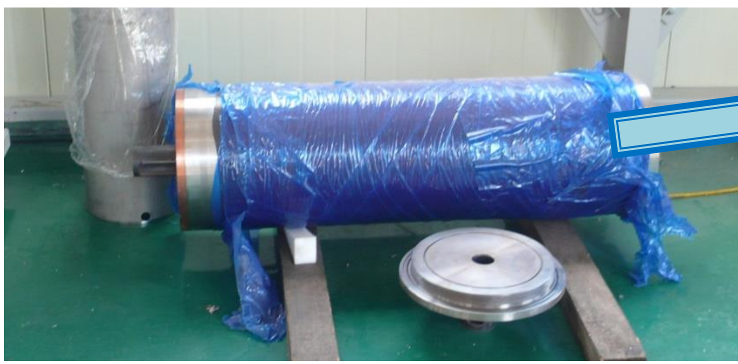
Ref) Jae Owan Lee, Won Jin Cho, Sangki Kwon, Suction and water uptake in unsaturated compacted bentonite, Annals of Nuclear Energy, Vol. 38, pp.520-526, 2011

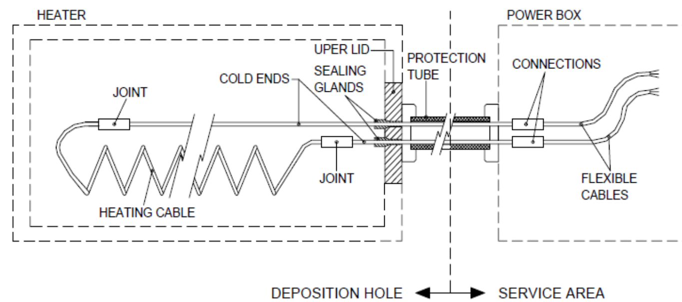
In-DEBS – Canister

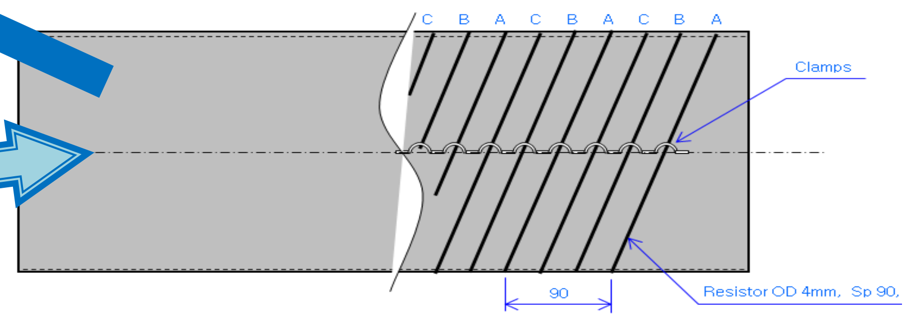
- Material: Copper-nodular cast iron
- Copper layer: Cold spray coating technique (under discussion)
- Heater: three 1.2 kW sheath heaters for redundancy



D 375 x L 1,200 mm



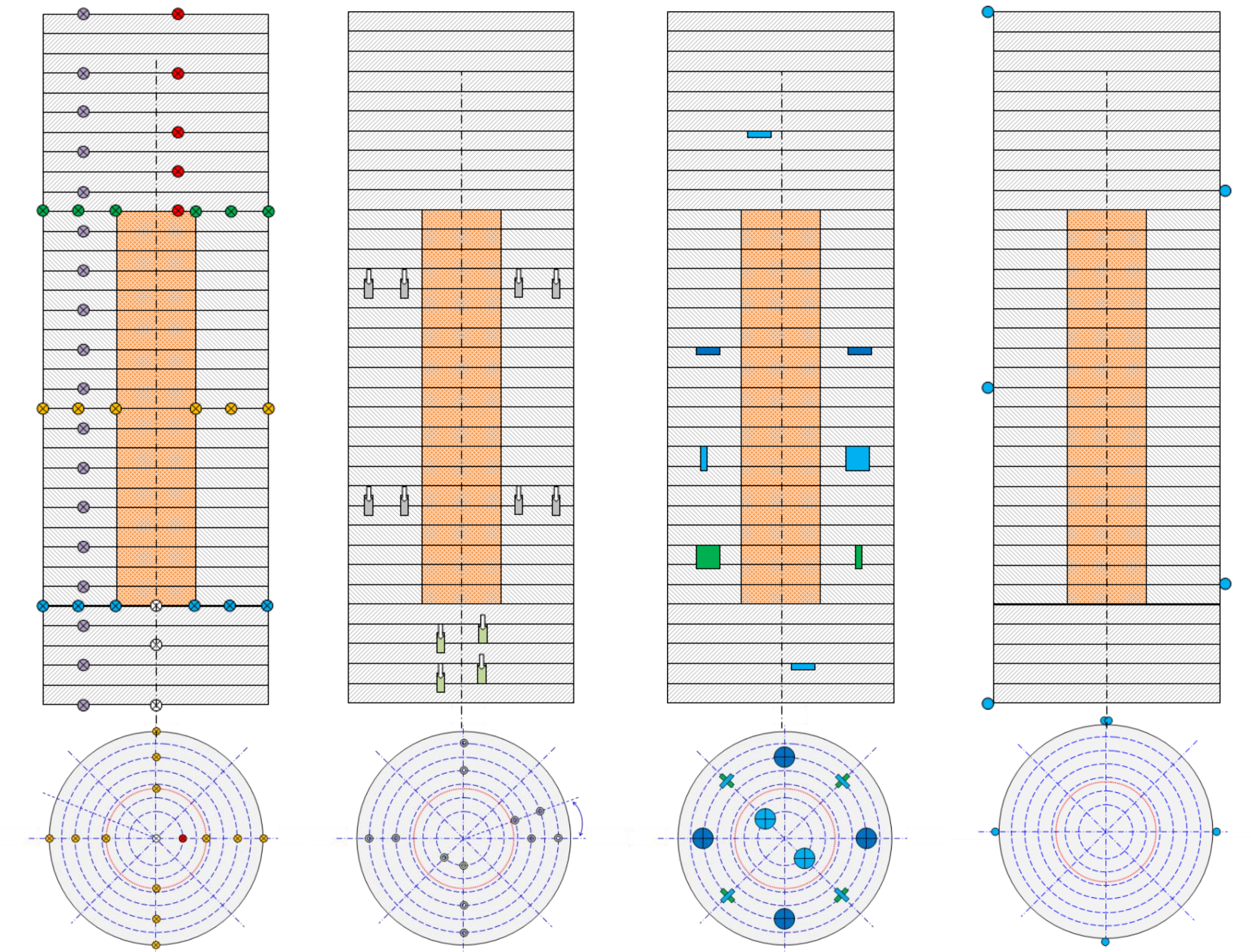




Heater 220 V, 1.2 kW, D4.8 mm x 8M, 3ea
Cold Lead Section D10 mm x L300

Ref) Heui-Joo CHOI, Minsoo Lee, Jong Youl Lee, Application of a cold spray technique to the fabrication of a copper canister for the geological disposal of CANDU spent fuels , Nuclear Engineering and Design, Vol. 240, pp.2714-2720, 2010.

In-DEBS – Sensors

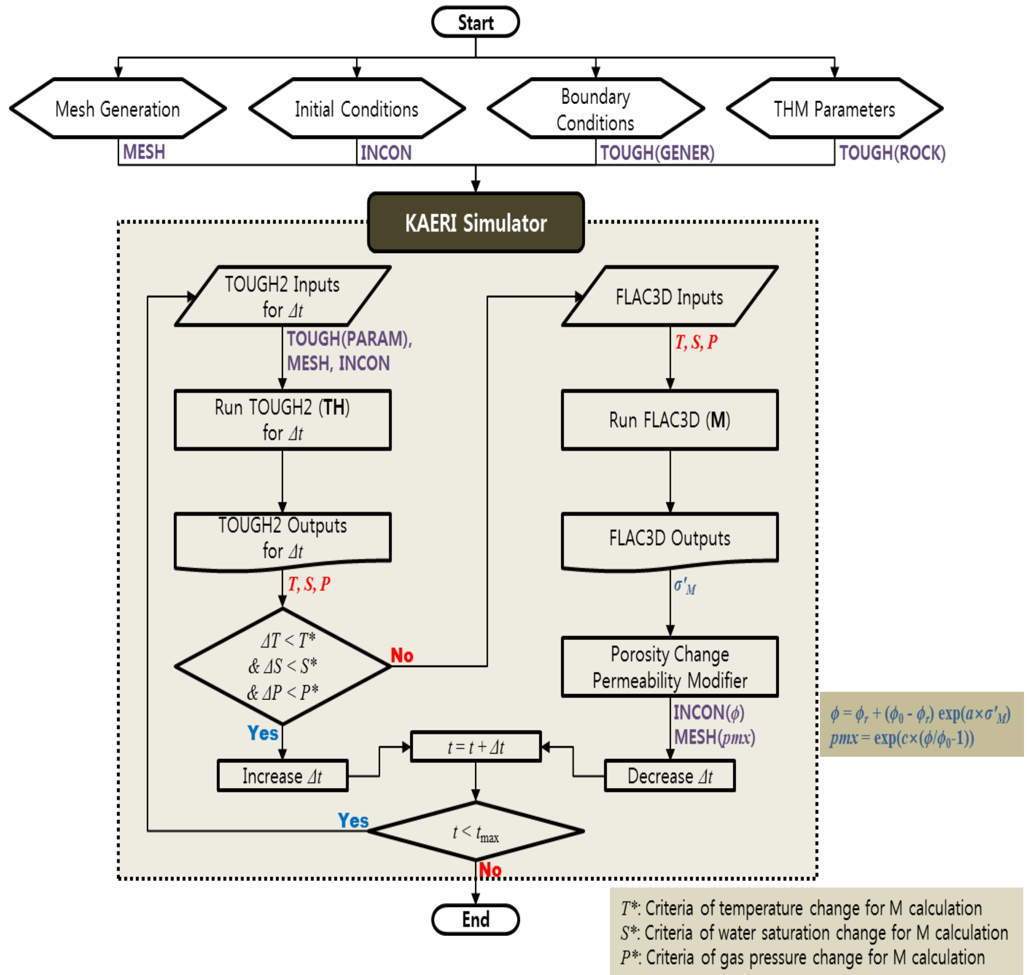


Temperature Relative humidity Total pressure Pore pressure

Sensors	# in use
Temperature	62
Relative Humidity	27
Total Pressure	14
Hydraulic pressure	5
Total	108

In-DEBS – Modeling and Simulation

- Preliminary analysis
  - Determine a heater capacity
  - Determine the location of sensors
  - Determine the distance between the deposition holes
  - Confirm the input parameters needed for the performance analysis
  - Check the boundary conditions and initial conditions
- Computer codes: TOUGH2-FLAC3D using KS (KAERI Simulator)
- In progress together with Inha University



Overviews of Main Activities in KURT

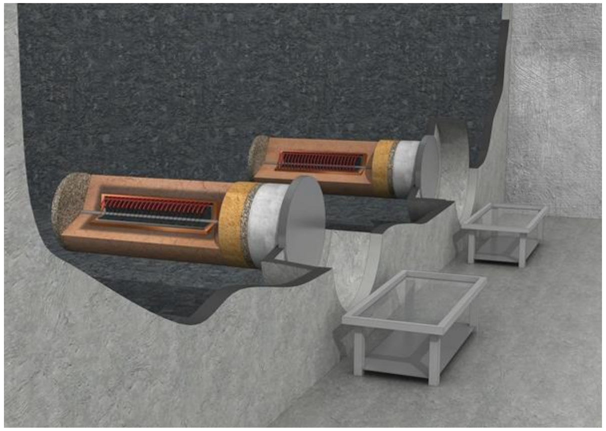
- **Site characterization (March 2003 - November 2004)**
  - ✓ Surface based investigation including geological mapping, lineament analysis, geophysical survey, and Borehole investigation including hydraulic and hydrochemical investigations, borehole geophysical logging using deep boreholes (200~500m depths), etc.
- **Construction of phase I (March 2005 - November 2006) & phase II (March 2013 - November 2014)**
  - ✓ Geological mapping, hydraulic and hydrochemical investigation/monitoring, and rock mechanical investigation
- **Characterization of Excavation Damaged Zone (EDZ) at KURT (March 2006 - February 2016)**
  - ✓ Investigations of physical, thermal, hydraulic and mechanical properties in EDZ at KURT using lab tests, in-situ tests and numerical modellings during the construction and the extension of the KURT
- **Hydrological and hydrochemical monitoring using the deepest borehole (DB-1) in KURT (October 2007 - February 2017)**
  - ✓ Monitoring hydrological and hydrochemical parameters to develop site descriptive models
- **Borehole heater test (June 2007 - June 2011)**
  - ✓ In-situ test of thermo-mechanical behaviour of rock under thermal condition to assess of heat transfer mechanism and thermal stress in fractured rock mass of KURT
- **In-situ solute migration experiments (October 2007 – February 2012)**
  - ✓ In-situ migration experiments for sorbing/non-sorbing tracers and colloids in fractured rocks
- **Long-term in-situ corrosion test of canister materials (October 2010 - September 2021 (Mid) – October 2030 (Final))**
  - ✓ Measuring the corrosion rate of the canister materials in a simulated underground environment using the KURT underground water enforced to flow through the LOT-corrosion chambers continuously.

Overviews of Main Activities in KURT

- **SP (Streaming Potential) test (March 2011 – December 2012)**
  - ✓ Estimation of the correlation between SP signals and fracture flows with their governing equations
- **GW pressure experiment on fracture aperture (February 2010 - July 2011)**
  - ✓ Direct observation of fracture apertures and groundwater flow rates under various water pressure conditions using specialized equipments
- **Application of hydrochemical properties to SP (Streaming Potential) (March 2013 – 2017)**
  - ✓ Test to integrate electrochemical processes with hydrologic flows in a fractured rock
- **Geochemical investigation of redox disturbance by MWCF (January 2013 – December 2015)**
  - ✓ Geochemical investigation of redox processes to influence redox sensitive elements behaviours by the change in redox condition of groundwater due to MWCF in KURT
- **Hydro-Mechanical Coupled Behaviours of Bentonite Buffer (K-LOT) (June 2014 - December 2015)**
  - ✓ In-situ test to investigate the HM coupled behaviours in bentonite focusing on the effect of rock joint
- **Long-term sorption and diffusion experiments (March 2017 – February 2021)**
  - ✓ Long-term in-situ experiments to investigate sorption and diffusion of nuclides to estimate Kd and diffusivity
- **Long-Term Monitoring of the THM Evolution of an Engineered Barrier system (In-DEBS project) (March 2016 - February 2021 (mid) - February 2025 (Final))**
  - ✓ Monitoring of thermo-hydro-mechanical-chemical evolution of the Engineered Barrier System at 1/2.3 scale of the A-KRS (Advanced-KAERI Repository System) and development of THM model based on the experimental observations

Summary of KURT Project

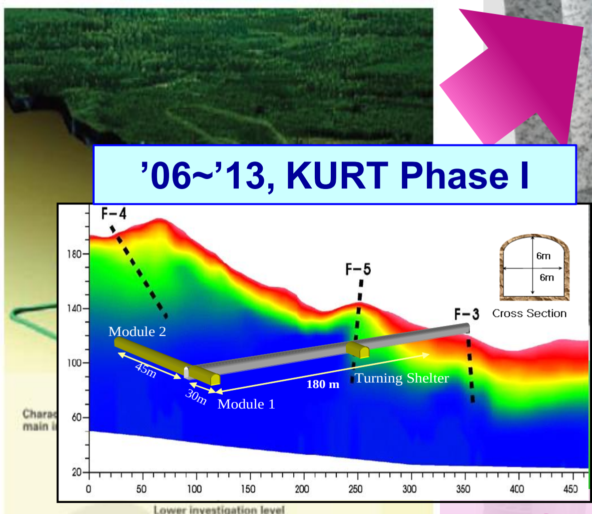
- For the development of safe and reliable disposal techniques for high-level radioactive waste in the deep geological environment, KAERI is performing various experimental studies at KURT to test their feasibility, safety, stability, and appropriateness.
- Long-term experimental research programme at KURT has been prepared for the phase II KURT project.
- Tunnel extension was completed in Nov. 2014 and phase II programme has been started.
- The research experiences gained using KURT are providing important information to validate the safety and feasibility of the disposal system and making an important contribution to the successful implementation of a geological repository programme in the future.
- The Public Engagement Commission will propose a national spent fuel management policy probably including URL and final disposal by June 2015.



Why KURT? –Answer

Final HLW Disposal in Korea

’06~’13, KURT Phase I



’14~ KURT Phae II

Licensing +
Establishment of public confidence

Securing of safety and confidence of HLW disposal
and relevant technologies
◁ ▷ Demonstration of performance and safety of the proposed disposal concepts and technologies in Korean deep environment

Development of Advanced Korean Reference Disposal System
and its related technologies

Thank You for Your Attention !