Contribution of HANARO Irradiation Facilities to National Nuclear R&D

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Status of Nuclear Plants in Korea

- **Nuclear Power Plants in Korea (30 units)**
  - 23(19 PWR, 4 CANDU) in operation
  - 5 PWR under construction
  - 2 PWR construction plan

- **Daejeon Area**
  - **KAERI (HANARO)**
  - KEPCO Nuclear Fuel (KNF)

- **2nd Research Reactor**
  - **KJRR (2017)** (Ki-Jang Research Reactor)
Panoramic views of HANARO

HANARO: Multi-purpose Research Reactor

HANARO Building

Reactor Hall
## Design Features of HANARO & KJRR

<table>
<thead>
<tr>
<th>Item</th>
<th>HANARO</th>
<th>KJRR (2017)</th>
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</thead>
<tbody>
<tr>
<td>Reactor power (MW)</td>
<td>30</td>
<td>~15</td>
</tr>
<tr>
<td>Reactor type</td>
<td>Pool type</td>
<td>Pool type</td>
</tr>
<tr>
<td>Max. thermal neutron flux (n/cm^2s)</td>
<td>&gt; 5.0x10^{14} (n/cm^2s)</td>
<td>&gt; 3.0x10^{14} (n/cm^2s)</td>
</tr>
<tr>
<td>Operation day per year</td>
<td>~300</td>
<td>~300</td>
</tr>
<tr>
<td>Reactor life (year)</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Fuel</td>
<td>U\text{}_3\text{Si} rod type (19.75%)</td>
<td>LEU U-Mo plate type (U\ loading: \sim8.0\ g/cc)</td>
</tr>
<tr>
<td>Reflector</td>
<td>Heavy water</td>
<td>Beryllium</td>
</tr>
<tr>
<td>Coolant and flow direction</td>
<td>H\text{}_2\text{O}, upward forced</td>
<td>H\text{}_2\text{O}, downward forced</td>
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</table>

### Role of HANARO
- Research by thermal & cold neutron beam
- R&D of basic nuclear science & engineering
- R&D of material irradiation
- Backup for RI production and NTD

### Role of KJRR
- R&D for the new radioisotope material
- Supply of medical & industrial radioisotope
- NTD service (~150ton/year)
Irradiation

- Small Size Specimens: RABBIT
- Standard Size Specimens: CAPSULE

Materials:
- Rabbit Capsule (HTS, IP)
- Non-Instrumented Capsule (CT/IR)
- Instrumented Capsule (L870 / Dia. 60mm)
- Fuel Capsule (L870 / Dia. 56mm)
- Non-Instrumented Capsule (L870 / Dia. 60mm)

HANARO Irradiation Facilities

Capsule Control System
• **Test Hole**: CT, IR2, OR, IP

• **Test Condition**
  - Dry He/Ne gas, H₂O
  - 40°C < 300°C < 700°C (±10°C)

• **Dimension**
  - 5 Stages with each Heater
  - Main body: 56/60mm D x 870mm H

• **Materials**
  - External Tube / Internal: STS / Al (Ti)

• **Instrumentations**
  - Micro-heater: 263W/cm, 5 sets
  - T/C: K-type, 14 sets
  - Fluence Monitor: Fe-Ni-Ti / Ag-Nb
  - He Gas Control
  - Coolant Intake Prevention: FW Tube

• **Specimens**
  - RPV, Fuel Tube, Basic Materials
  - Charpy, Tensile, CT, SP, TEM etc.
HANARO FTL (Fuel Test Loop)

APPLICATION FIELDS

- Integral Fuel Irradiation Tests
- Fuel Qualification Tests
- High Burn-up Fuel Tests
- Water Chemistry and Corrosion Tests
- Non-fissile Tests of Pressure Tube Material

In-Pile Section
- Design Pressure: 17.5 MPa
- Design Temp.: 350 °C

Out-Pile System
Neutron Transmutation Doping

NTD1&2 for 5, 6, 8 inch NTD Commercial Service

- 10~20% Share of World Market
- 6,8,12” NTD in 2\textsuperscript{nd} Research Rx.

HANARO (193 days in 2010)

<table>
<thead>
<tr>
<th>Year</th>
<th>8 inch</th>
<th>6 inch</th>
<th>5 inch</th>
<th>Total</th>
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<td>2002</td>
<td>0.2</td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>2003</td>
<td>5.8</td>
<td></td>
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<td>2004</td>
<td>8.5</td>
<td></td>
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<td>2005</td>
<td>6.9</td>
<td></td>
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<td>6.9</td>
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<tr>
<td>2006</td>
<td>10.4</td>
<td></td>
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<tr>
<td>2007</td>
<td>12.9</td>
<td></td>
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<td>12.9</td>
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<tr>
<td>2008</td>
<td>13.9</td>
<td></td>
<td></td>
<td>13.9</td>
</tr>
<tr>
<td>2009</td>
<td>17.6</td>
<td></td>
<td></td>
<td>17.6</td>
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<tr>
<td>2010</td>
<td>23.66</td>
<td></td>
<td></td>
<td>23.66</td>
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</tbody>
</table>

Total: 100 ton
Post-Irradiation Facility in HANARO

**IMEF**: 8 concrete, 1 lead & 1 steel hot cells, 1 pool

- Pool examination on post-irradiated fuel assembly
- Non-destructive tests & Destructive Tests
- Experiments in relation to reactor safety and fuel design and fabrication improvement

**PIEF**: 4 concrete & 2 lead hot cells, 1 pool

- Pool examination on post-irradiated fuel assembly
- Non-destructive tests & Destructive Tests
- Experiments in relation to reactor safety and fuel design and fabrication improvement

**IMEF** is to provide PIE services for the irradiated **fuels and materials** in the HANARO.

**PIEF** is to provide PIE services for the irradiated **fuels** from commercial reactors.
History of Neutron Irradiation in HANARO

**Capsule Development** for Material Test

**Irradiation Capsule Test**

**Control Rod Materials** for KNF/WEC AP1000 (U.S.)

**Kori-1 RPV** for Life-Extension

Nuclear Fuel Assembly Parts for KEPCO Nuclear Fuel Co.

Korean-made RPV steel for Doosan

JRTR / KJRR: Core Materials

SMART: Steam Generator Materials

FTL Irradiation for Nuclear Fuel

VHTR high-Temp. Materials for I-NERI Project (Korea-US)

2000. 3

2007. 11

2009.10~

2008. 3

2006. 4~

2001. 5~

2012. 9~

2011. 12

HANARO Criticality (1995. 2)

1997. 7

1995. 7

1994. 7
Contribution to Commercial Reactors

- **Safety & Life-Extension of PWR Reactors**
  - Fracture Toughness of RPV materials of NPPs
  - Kori-1 (1978.4 > 2008.4(30⇒40 years, Life-Ext.) > 2017

- **PWR RPV Material Development**
  - Korean made RPV material (by Doosan Heavy Industry Co.)
  - Development of Improved RPV Model Alloys

- **Nuclear Fuel Assembly Development**
  - UO₂ Fuel pellet for Advanced Fuel
  - Database of parts of Korean Fuel Assembly (by KNF Co.)
  - R&Ds of New Cladding Materials
SMART: System-Integrated Modular Advanced Reactor

SMART
- One of the most advanced SMRs
- Global demand 500-1000 units by 2050 by U.S. DOE (2007)

Design Features (-300MWth)
- Enhanced Safety by Intrinsic Safety Features
- Coolant System in a Reactor Vessel (Pressurizer, Pump, Steam Generator)

Irradiation Project (2009-2011)
- Database for ‘engineering verification and approval of standard design’
- 3 Capsules irradiated at 250±10°C
- Fracture, Tension, Hardness, Conductivity, Microstructure of Alloy 690

Project in Korea
- Launched from 1996 by KAERI
- Design Approval in 2012
- Commercial Reactor by 2017 (planning)
Contribution to RR Project (1)

- **Jordan Research Reactor (JRTR)**
  - Construction by 2015

- **2nd Research Reactor (KJRR) in Korea**
  - Specialize in Radioisotope/NTD production and Validation of Key Technology for Research Reactor Export
  - Operation in 2017 at Kijang

- **Support for RR Technology**
  - Design Improvement of Core material
  - Fuel Conversion

- **HANARO**
  - Al-U$_3$Si, 19.75% enriched
  - Rod-type 18/36 Fuel Rods

**KJRR Core Design**

**JRTR (Jordan)**

**U-Mo, Plate-type Fuel**

**Optimized Design**
Irradiation Project 1 (2011- )
- Database of Core Materials
  - Be, Graphite, Zircaloy-4
  - Growth, Swelling, Tension, Hardness, Conductivity, Microstructure
- Low Temp. Irradiation (~40°C)
- 2 Capsules irradiation (Sep. 2012 - )
- For 1 year (< 2.5x10^21 n/cm² (>1 MeV))

Irradiation Project 2 (2012- )
- Fuel Irradiation Performance Test
- U-Mo Plate in Al matrix
- Irradiation scheduled in 2013
Contribution to Future Reactors

**VHTR Reactor**
- High Temp. Material *(Fe-Cr-Mo)* Irradiation
  - International Nuclear Energy Research Initiative *(I-NERI)* Project (USA-Korea) : 2007-2009
  - R&Ds for Mod. Structural Materials for VHTR
  - 300-400°C, $10^{18} \sim 10^{19}$ n/cm$^2$ (E$>1$MeV)
- Nuclear Fuel *(TRISO)* Irradiation Capsule
  - Design/Analysis of Non-instrumented Capsule
  - Irradiation in HANARO in 2013

**SFR Reactor**
- Irradiation of U-Zr-(Ce) Fuel (in Na)
  - 1$^{st}$ Irradiation Test in 2011 (Burnup 2.73 a/o)
    (HT-9 Cladding / Cr barrier (20μm))
  - 2$^{nd}$ Irradiation Plan in 2013
- LBE (Pb-Bi Eutectic) Technology

**Fusion Reactor** (near future)
- NFRI / KAERI (ITER) Joint R&D Programs
- Irradiation Plan for New Material R&Ds
Future of HANARO

HANARO will specialize on Irradiation Researches!

Relocation of Work Scopes of Research Rxs
HANARO will specialize on Irradiation Researches!

“R&D of Advanced Irradiation Technologies”

KJRR (2017)
NTD
JRTR Project

Neutron Beam
RI Production
Material Irradiation
Neutron Utilization Technology Division

User Community
- Industry / University
- Institute / Inter. Cooperation

Platform for Nuclear R&D

National Demand
- Basic R&D
- Competitive Technology

Capsule Irradiation
Fuel Test Loop
NTD
NAA

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**Irradiation Temperature**
- **Irradiation Temperature of 250-700 °C**
  - Standard Capsule Design (Al Medium)
- **Low Temperature Irradiation**
  - Internal Rx. Coolant Flow (<100°C)
- **High Temperature Irradiation**
  - Double Thermal Media Design (<1,000°C)
  - High Temp. Thermal Media (Ti, Mo, Zr)
  - High Temp. Instrumentation Technology

**Instrumentation & Analysis**
- **Localization**
  - Thermocouple, LVDT, SPND
- **Improvement of Fab. Technology**
  - Precise Welding (& Brazing) Technology
  - Improved Drilling & Sealing
- **Improvement of Analysis Accuracy**
  - Neutron Fluence: Thermal, Fast
  - Thermal Design/Analysis Technology

**Precise Welding Technology**
- Fiber Laser Welder
- TIG (end-cap)
- Lead Wire

**Temp. Analysis**
- MCNP-5
- ANSYS
- CNS
**Strategic Future Directions**

**LWR Materials & Fuels**
- Re-Irradiation / Instrumentation
- New Cladding & RPV Irradiation
- Recovery Annealing

**NGNP Materials & Fuels**
- Severe Environments Irradiation
- Gen-IV (SFR, VHTR)
- Fusion Materials

**Advanced Materials**
- Large Diameter NTD (12 inch)
- Basic Irradiation Researches on High Tech. Materials...
Summary

- **HANARO irradiation facilities** such as capsule and rabbit systems have been developed and are actively being utilized for the irradiation testing of fuels and materials of commercially operating PWR nuclear reactors in Korea.

- Based on the accumulated experience and sophisticated requirements of users, **HANARO has recently started new R&D supports relevant to new nuclear systems** including research reactor and System-integrated Modular Advanced Reactor (SMART) and future nuclear systems such as very high temperature reactor system (VHTR) and sodium cooled fast reactor system (SFR).

- To effectively support the R&D relevant to new nuclear systems, the **development of advanced irradiation technologies** concerning irradiation temperature and instrumentation is being preferentially developed at HANARO.

- With the operation of KJRR in 2017, **HANARO is planning several strategic R&Ds** concerning **new irradiation technology** of the materials and fuels of the LWR and NGNP, and **irradiation of high-tech materials** for a relocation of the role in Korea.
Thank you for your attention!