Research Reactor: A Powerhouse of Nuclear Technology in Korea

2011. 11.
Dr. Jaejoo Ha
Korea at a Glance

- Difficult Environment (Small Land, High Population, Rare Natural Resource, Divided Country)
  - Land Size 99,000 km² (108th)
  - Population 48,875K (15th)
  - Energy Consumption 9th, Oil Consumption 7th, Oil Import 4th

- Leadership and Effort to Overcome
  - E.g., Employment of Nuclear Technology

- Fastest Developed Country in the World (Good Quality of Human Resource, High Level of Technology, Diversified Industry)
  - Trade 1,000B$ (7th)
  - GNP > 20,000$ (67$ in 1950’s)
Korean Economy and Nuclear

Contributed by Cheap Electricity Tariff of Nuclear Energy

Per Capita Income (US$)

10,000

5,000


Liberation from Japanese Colonial Rule

Korean War (1950~53)

Big Push

Six 5-Year-Economic-Development Plans

Liberation (1945)

TRIGA II Start 67(1953) 89 100(1964) 1,000(1977)

KORI#1 Operation

Financial Crisis

Source: Bank of Korea

First KSNP HANARO operation 11,432

OECD Member

PWR Fuel

CANDU Fuel

KORI#

Fuel

TRIGA II Start

18.372

OECD (1996)

F. Crisis (1997)

20,500(08)

16,291

14,193

7,355

1990

1945

1953

1961

1970

1980

1990

1995

1998

2004

2006

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Per Capita Income (US$)

10,000

5,000

The First Nuclear Electricity

Kori - the site of the 1st Korean NPP: before (top) and now (bottom).

1st unit of nuclear power plant started to build in 1971

- Turn Key basis
- 587 MWe
- Commercial operation in 1978
- Life extension after 30 years operation (2007.12)
In operation
21 units
(18,718 MW)

Under construction
7 units
(8,600 MW)

Under planning
6 units
(8,600 MW)

6 more by 2030

Radioactive Waste Disposal Facility
(Under construction)

Yong-gwang
6 units

Kori
8 units

Ulchin
8 units

Wolseong
6 units

NPP in Korea

In Operation

Under Construction
National Energy Basic Plan

Established in 2008.08

Power Plant Capacity Share (%)

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2030</th>
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</thead>
<tbody>
<tr>
<td>LNG</td>
<td>26%</td>
<td>18%</td>
</tr>
<tr>
<td>Coal</td>
<td>30%</td>
<td>31%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>26%</td>
<td>41%</td>
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</table>

Electricity Generation Share (%)

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<th>2007</th>
<th>2030</th>
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<tbody>
<tr>
<td>LNG</td>
<td>20%</td>
<td>1%</td>
</tr>
<tr>
<td>Coal</td>
<td>38%</td>
<td>29%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>36%</td>
<td>59%</td>
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</table>

※ Ref: National Energy Committee (2008)
30 years of repetitive construction fostered competitive domestic suppliers in the entire nuclear cycle.
KAERI as Technology Warehouse
- Merge and Spin-out -

- Separate Establishment: Utility(KEPCO), Heavy Industries and Construction Co.
- Spin out: KOPEC(KEPCO E&C), KNF(KEPCO NF), KINS, KIRAMS, KINAC, KRMC

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1960s</td>
<td>Atomic Energy Research Institute (AERI)</td>
</tr>
<tr>
<td>1960s</td>
<td>Radiological Research Institute (RRI)</td>
</tr>
<tr>
<td>1960s</td>
<td>Radiation Research Inst. in Agriculture (RBIA)</td>
</tr>
<tr>
<td>1966</td>
<td>Fusion Establishment of Industrial Infrastructure</td>
</tr>
<tr>
<td>1970s</td>
<td>Atomic Energy Research Institute (AERI)</td>
</tr>
<tr>
<td>1970s</td>
<td>Radiological Research Institute (RRI)</td>
</tr>
<tr>
<td>1973</td>
<td>Korea Atomic Energy Research Institute (KAERI)</td>
</tr>
<tr>
<td>1975</td>
<td>KNE (KOPEC later on)</td>
</tr>
<tr>
<td>1975</td>
<td>Establishment of Industrial Infrastructure</td>
</tr>
<tr>
<td>1976</td>
<td>Korea Nuclear Fuel Development Institute (KNFDI)</td>
</tr>
<tr>
<td>1979</td>
<td>Safety Center</td>
</tr>
<tr>
<td>1981</td>
<td>KAERI (Korea Advanced Energy Research Institute)</td>
</tr>
<tr>
<td>1982</td>
<td>KNFC</td>
</tr>
<tr>
<td>1982</td>
<td>Technology Transfer from Foreign Suppliers</td>
</tr>
<tr>
<td>1985</td>
<td>Self-Reliance</td>
</tr>
<tr>
<td>1990</td>
<td>Korea Atomic Energy Research Institute (KAERI)</td>
</tr>
<tr>
<td>1990</td>
<td>NSSS Design Team</td>
</tr>
<tr>
<td>1996</td>
<td>TCNC</td>
</tr>
<tr>
<td>1997</td>
<td>KIRAMS</td>
</tr>
<tr>
<td>1997</td>
<td>Advancement</td>
</tr>
<tr>
<td>2000s</td>
<td>Establishment of Industrial Infrastructure</td>
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<tr>
<td>2004</td>
<td>Dec 2004</td>
</tr>
<tr>
<td>2007</td>
<td>Mar 2007</td>
</tr>
<tr>
<td>2007</td>
<td>NNCA (KINAC later on)</td>
</tr>
<tr>
<td>2007</td>
<td>KIRAMS</td>
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</tbody>
</table>

• Separate Establishment: Utility(KEPCO), Heavy Industries and Construction Co.
• Spin out: KOPEC(KEPCO E&C), KNF(KEPCO NF), KINS, KIRAMS, KINAC, KRMC
Technology Self-Reliance Strategy

**Government**
- Leadership and Policy
- Legal Structure
- International Framework

**Academies**
- Critical Mass of Human Resource

**Technology Incubator and Warehouse**
- Lab., Experiment Facility, RR,...

**Real Projects**
- R&D, Realization

**Spin-off Organizations**
- Experts
- Technology

Experience Accumulation Feedback
Research Reactors in Korea
**KRR-1 & KRR-2**

**KRR-1**
- TRIGA-II in KAERI started operation in 1962
- Constructed by GA with the participation of local construction companies & researchers
- 100 kW
- Upgraded to 250 kW in 1969 by KAERI
- Basic nuclear engineering study, training
- To be the national museum

**KRR-2**
- TRIGA-III in KAERI started operation in 1972
- Constructed by GA with the participation of local construction companies & researchers
- 2 MW
- Nuclear engineering study, training, RI production, neutron scattering research, NAA
- Decommissioned in 2005
Dawning of nuclear age

The 1st Research Reactor in Korea, TRIGA Mark II (100KW)

The 1st president of Korea in the ground breaking ceremony (1959.7.14)
KRR-I (TRIGA Mk-II)

Chronology
- 1958.12: Contract with GA, USA
- 1962.3.19: 1st Criticality
- 1969.6.24: Power Upgrade: 100kW to 250kW
- 1995.1: Permanent Shutdown

Characteristics
- Open-Pool & Natural convection (250kW)
- Coolant/Reflector: H₂O / Graphite
- Fuel: Rod type UZrH with 20% U-235 in Al-clad
- Control rod: B₄C (3 EA)
- Max. Thermal Neutron Flux: 1x10¹³ n/cm²/sec

<table>
<thead>
<tr>
<th>RI Production</th>
<th>3,741 cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAA</td>
<td>7,889 cases</td>
</tr>
<tr>
<td>Other Exp.</td>
<td>3,484 cases</td>
</tr>
<tr>
<td>Education &amp; Training</td>
<td>3,417 person 9,250 hours</td>
</tr>
</tbody>
</table>
KRR-II (TRIGA Mk-III)

Chronology
- 1968: Contract with GA, USA
- 1971: Completion of reactor building
- 1972.3.10: 1st Criticality
- 1995.12: Permanent shut-down

Characteristics
- Open-Pool & Natural Convection (2 MW)
- Movable Core
- Coolant/Reflector: $\text{H}_2\text{O} / \text{H}_2\text{O}$
- Fuel: Rod type UZrH with 70% U-235 in SUS-clad
- Control rod: $\text{B}_4\text{C}$
- Irradiation facility: Beam Ports (8), Exposure room, Thermal Column, Rotary Specimen Rack
- Max. Thermal neutron-Flux: $7 \times 10^{13}$ n/cm$^2$sec

<table>
<thead>
<tr>
<th>RI Production</th>
<th>7,690 cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAA</td>
<td>12,070 cases</td>
</tr>
<tr>
<td>Neutron Beam</td>
<td>436 cases</td>
</tr>
<tr>
<td>Other Exp.</td>
<td>1,057 cases</td>
</tr>
</tbody>
</table>
Education Reactor at Kyung-Hee Univ.

**AGN-201K** (Zero Power Reactor with Homogeneous LEU Fuel Core)

**Very safe university reactor for education & training**

**History**

1967-1974: Operated at Colorado State University

1976: CSU donated to Kyung-Hee University (US DOE arrangement)

1982: Opened at KHU Reactor Lab. (0.1 watt)

2004-2007: Refurbishment by using the domestic technology

(Power uprate by 100 times, new I&C system, licensed under new rules)

2008: Reopened at KHU Reactor Research & Education Center
Part II. Introduction to HANARO

HANARO Complex in KAERI

High-flux Advanced Neutron Application Reactor

AE : Auxiliary Equipment Building for CNS
AU : Auxiliary Utility Building for CNS
CNL : Cold Neutron Laboratory
CT : Cooling Tower

IMEF : Irradiated Material Examination Facility
PH : Pump House for Secondary Cooling System
RX : Reactor Building
RIPF : Radio-Isotope Production Facility
### Chronology

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>Jan</td>
<td><strong>Start of HANARO Project</strong></td>
</tr>
<tr>
<td>1989</td>
<td>Jan</td>
<td>Start of HANARO Construction</td>
</tr>
<tr>
<td>1993</td>
<td>Aug</td>
<td>Installation of HANARO Reactor Structure</td>
</tr>
<tr>
<td>1995</td>
<td>Feb</td>
<td><strong>Fuel Loading and Achievement of Initial Criticality</strong></td>
</tr>
<tr>
<td>1996</td>
<td>Jan</td>
<td>15 MW Power Operation</td>
</tr>
<tr>
<td>1999</td>
<td>Dec</td>
<td>22 MW Power Operation</td>
</tr>
<tr>
<td>2004</td>
<td>Nov</td>
<td>30 MW (Design Power) Power Operation started</td>
</tr>
<tr>
<td>2005</td>
<td>Mar</td>
<td><strong>First Loading of HANARO Fuel made by KAERI</strong></td>
</tr>
<tr>
<td>2006</td>
<td>Apr</td>
<td>Start of Cold Neutron Laboratory Construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Completed in May 2008)</td>
</tr>
<tr>
<td>2006</td>
<td>Jul</td>
<td>Start of Fuel Test Loop Installation (Completed in Feb. 2008)</td>
</tr>
<tr>
<td>2008</td>
<td>May</td>
<td>Start of Cold Neutron Source System Installation</td>
</tr>
<tr>
<td>2009</td>
<td>Sep 3</td>
<td><strong>First Generation of Cold Neutron</strong></td>
</tr>
<tr>
<td>2009</td>
<td>Sep 28</td>
<td>Completion of FTL Commissioning Test</td>
</tr>
<tr>
<td>2010</td>
<td>Mar 30</td>
<td><strong>Contract of JRTR Project</strong></td>
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</tbody>
</table>
Mission of HANARO

Platform for Nuclear Basic Research

User Community
- Industry
- University
- Institute
- International Cooperation

National Demand
- Basic R&D
- Competitiveness in Technology

- Fuel Test Loop
- Material Irradiation
- Neutron Activation Analysis
- NTD

- Public Welfare
- Industrial Application

- Cold Neutron Beam Radiography

- Reactor Operation
  - Experimental Facility Operation

- Neutron Beam Research
- Neutron Irradiation Research
- Operation & Development
- RI Production & Utilization

HANARO SAFETY

http://www.kaeri.re.kr
Part II. Introduction to HANARO

HANARO, Past and Present

Feb. 1995

Oct. 2009
Reactor Structure and Characteristics

Features

- **Type**: Open-tank-in-pool
- **Power**: $30 \text{ MW}_\text{th}$
- **Coolant**: Light water
- **Reflector**: Heavy water
- **Fuel materials**: $\text{U}_3\text{Si}$, 19.75% enriched
- **Absorber**: Hafnium
- **Reactor building**: Confinement
- **Max thermal flux**: $5 \times 10^{14} \text{ n/cm}^2\text{s}$
- **Typical flux at port nose**: $2 \times 10^{14} \text{ n/cm}^2\text{s}$
- **7 horizontal ports & 36 vertical holes**
- **Vertical hole for cold neutron source**
- **Operation cycle**: 24 days@5 weeks
Part II. Introduction to HANARO

Beam Ports and Irradiation Holes

**Installed**
- IR1: Fuel Test Loop
- CT, IR2: Capsule Irradiation & RI Production
- OR: Capsule Irradiation & RI Production
- IP: RI Production
- HTS: Hydraulic Transfer System for RI Production
- PTS: Pneumatic Transfer System for Neutron activation Analysis
- NTD: Neutron Transmutation
  - Doping of Silicon
- CNS: Cold Source Installation

**Horizontal Tubes**

**Installed**
- ST2: High Resolution Powder Diffractometer,
  - Four Circle Diffractometer
- NR: Neutron Radiography Facility
- CN: Cold Neutron Guide
- IR: Ex-core Neutron-irradiation Facility for BNCT & DNR
- ST1: PGAA and RSI
- ST3: High Intensity Powder Diffractometer

**Under-development**
- ST3: Bio-diffractometer
- ST4: Triple Axis Spectrometer
Part II. Introduction to HANARO Reactor Operation Record

Operation Record of HANARO

- Operation days
- Power generation

CNS & FTL Installation

- Operation days per year
- Power generation (MWD)

Year:
- 1996
- 1997
- 1998
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010

Power generation (MWD):
- 1996: 2687.5
- 1997: 2035.9
- 1998: 3062.3
- 1999: 3035.7
- 2000: 3699.2
- 2001: 3770.8
- 2002: 4852.5
- 2003: 6119.2
- 2004: 4522.7
- 2005: 113.4
- 2006: 4248.2
- 2007: 107.3
- 2008: 4160.0
- 2009: 3932.6
- 2010: 5264.0

Operation days:
- 1996: 168.4
- 1997: 130.9
- 1998: 157.8
- 1999: 158.8
- 2000: 168.4
- 2001: 169.8
- 2002: 209.1
- 2003: 217.4
- 2004: 183.7
- 2005: 110.4
- 2006: 139.9
- 2007: 144.9
- 2008: 107.3
- 2009: 135.8
- 2010: 213.8
Annual No. of Users and Institute in HANARO

No. of Users
No. of Institutes

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of Users</th>
<th>No. of Institutes</th>
</tr>
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<tbody>
<tr>
<td>1996</td>
<td>19</td>
<td>14</td>
</tr>
<tr>
<td>1997</td>
<td>31</td>
<td>20</td>
</tr>
<tr>
<td>1998</td>
<td>282</td>
<td>20</td>
</tr>
<tr>
<td>1999</td>
<td>308</td>
<td>20</td>
</tr>
<tr>
<td>2000</td>
<td>399</td>
<td>20</td>
</tr>
<tr>
<td>2001</td>
<td>475</td>
<td>20</td>
</tr>
<tr>
<td>2002</td>
<td>62</td>
<td>20</td>
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<td>2003</td>
<td>581</td>
<td>71</td>
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<tr>
<td>2004</td>
<td>598</td>
<td>48</td>
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<tr>
<td>2005</td>
<td>60</td>
<td>48</td>
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<tr>
<td>2006</td>
<td>320</td>
<td>60</td>
</tr>
<tr>
<td>2007</td>
<td>309</td>
<td>59</td>
</tr>
<tr>
<td>2008</td>
<td>278</td>
<td>57</td>
</tr>
</tbody>
</table>
Material/Fuel Irradiation Using Capsule

**Reactor Materials Tests**
- Reactor Vessel Materials
- Reactor Pressure Tube Material: Zr-2.5Nb
- Structural Materials

**Fuel Materials Tests**
- HANARO Fuel
- U-Mo Fuel
- Advanced PWR Fuel
- DUPIC Fuel
- U-Zr Alloy

**Fundamental Researches**
- SPND
- Semiconductor, Magnetic Materials
- Neutron Dosimetry
- Zr-1Nb-1Sn-X Alloy, Zircaloy-4
Instrumented Capsule for Material Irradiation Test

Design Characteristics

- Total Length: ~6m (60mm D x 870mm H)
- Available Space (Max.): 40mm D x 600mm L
- 5 Stages Independent Temp. Control
- Max. Temp. Control: Up to 500°C
- He Atmosphere: 1 atm ~ $3 \times 10^{-3}$ torr (He)
- Instrumentation: 14 T/Cs, 5 Micro-Heaters, 4 Ms
- Available Specimen: Tensile, Charpy, R-CT, SP, Tube, hardness, PCVN, MBE, TEM, etc.
- Related Facilities: Temperature Control System, Supporting System, Cutter, Cask, etc.

Applications

- Material Tests
  - Reactor Pressure Vessel
  - Reactor Core Materials
  - CANDU Pressure Tube Materials
- Safety and Integrity-Related Tests
- Study on the extension of reactor lifetime
- Industry Application Material Tests
- Fundamental Research
Instrumented Capsule for Nuclear Fuel Test

**Design Characteristics**

- Total Length: 5,000 mm
- Diameter of Outer Tube: 56 mm
- Length of Outer Tube: 730 mm
- 3 Mini-Elements Fuel Rod
- Control of Irradiating Environment
- Use of Mixed Gas (He/Ne)

**Applications**

- Fuel Pellet Irradiation Test
  - Advanced PWR Fuel
- Fuel Design Data Production
  - Center/Surface Temperature of Fuel Pellet
  - Internal Pressure of Test Fuel Rod
  - Deformation of Fuel Pellet
- Fundamental Research
Creep/Fatigue Test Capsule

Design Characteristics

- Total Length : ~6,000 mm
- Diameter of Outer Tube : 60 mmD x 997 mmL
- Irradiation specimen : 1, 2 & 4
- Instrumentation : 8 TCs, 2 heaters, 1 LVDT
- Creep & fatigue tests temperature : Max. 600 ℃
- Irradiation condition : 1 atm ~ 30 torr (He)

Applications

- Examination of nuclear materials through study of creep and fatigue behaviors
- Study on the extension of reactor lifetime
- Study for Fundamental Research
Fuel Test Loop Facility

**Commissioning test:** ~ Sept. 2009

**Applications**
- 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 Temperature: 350 °C

**Out-Pile System**
Fuel Test Loop Facility

- Outer Pressure Vessel
- Inner Pressure Vessel
- Test Fuel Carrier Leg
- Flow Divider
- Insulation Gas Gap
- Test Fuel
- Downward Flow Path
- Upward Flow Path
- Outlet Nozzle
- Fuel Carrier Head
- Flow Divider
- Fuel Carrier Leg
- IPS Head
- Inner Pressure Vessel
- Outer Pressure Vessel
- Outlet Nozzle
- Fuel Carrier Head
- Flow Divider
- Fuel Carrier Leg
- Inner Pressure Vessel
Neutron Beam Science

Thermal Neutron

- Neutron Radiography Facility (NRF)
- Encore Neutron Irradiation Facility (ENF)
- Residual Stress Instrument (RS)
- Thermal Neutron Triple Axis Spectrometer (Thermal TAS)
- Bio-Diffractometer with Neutron Image Plate Camera (Bio-C)
- Bio-Diffractometer (Bio-D)
- High Intensity Powder Diffractometer (HPD)
- Four Circle Neutron Diffractometer (FCD)
- High Resolution Powder Diffractometer (HRPD)
- Vertical Neutron Reflectometer (REF-V)

Cold Neutron

- KIST-Ultra Small Angle Neutron Scattering (KIST-USANS)
- Bio-Reflectometer (Bio-REF)
- 1.8M Small Angle Neutron Scattering Instrument (1.8M SANS)
- Disk Chopper Time-of-Flight Spectrometer (DC-TOF)
- 40M Small Angle Neutron Scattering Instrument (40M SANS)
- CN-Prompt Gamma Activation Analysis (CN-PGAA)
- CN-Neutron Depth Profiling (CN-NDP)
- Guide Test Station (G-TS)

TN-Prompt Gamma Activation Analysis (TN-PGAA)

Cold Neutron Triple Axis Spectrometer (Cold-TAS)
In-service

Under way

NR Port

Neutron Radiography Facility (NRF), 1997 Upgrade

ST4 Port

Triple Axis Spectrometer (TAS), 2010

Neutron Reflectometer (REF-V), 2006 moved 2010

ST3 Port

High Intensity Powder Diff. (HIPD), 2008

ST2 Port

High Resolution Powder Diff. (HRPD), 1998

Ex-Core Neutron Irradiation Facility (ENF), 2005

ST1 Port

Prompt Gamma Neutron Activation Analysis (PGAA), 2003

Test Station (TS) & Residual Stress Instrument (RSI), 2003

CN Port

Small Angle Neutron Scattering (SANS), 2001
Currently dismantled

Cold Neutron Guide, 2009

IR Port

Ex-Core Neutron Irradiation Facility (ENF), 2005

Bio-Diffractometer (Bio-D), 2010

Neutron Reflectometer (REF-H), 2008 moved 2010

Four Circle Diffractometer (FCD), 1999 Upgrade '05-'06

Neutron Reflectometer, (REF-V), 2006 moved 2010

High Resolution Powder Diff. (HRPD), 1998

Prompt Gamma Neutron Activation Analysis (PGAA), 2003

Test Station (TS) & Residual Stress Instrument (RSI), 2003

Small Angle Neutron Scattering (SANS), 2001
Currently dismantled

Cold Neutron Guide, 2009

Ex-Core Neutron Irradiation Facility (ENF), 2005

Bio-Diffractometer (Bio-D), 2010

Neutron Reflectometer, (REF-V), 2006 moved 2010

Four Circle Diffractometer (FCD), 1999 Upgrade '05-'06

Neutron Reflectometer (REF-V), 2006 moved 2010
Cold Neutron Facility

- Hydrogen system
- Vacuum system
- He Refrigerator
- Gas blanket system

- CNS equipment room

- Guide shield

- Thermal guide

- CNLB completed (08.11.27)

- Cooling system
- He compressor

- Main shutter guide

- In-pile plug guide

- Cold TAS

- 12m SANS

- DC-TOF

- 40m SANS

- HRSANS

- Bio-REF

- REF-V

completed

conducting

completed conducting
Development of CNRF for the Operating HANARO

**Basic Design**
- Full Scale Thermo-siphon Mock-up Test Using $H_2$
- Safe & Reliable Process System Design
- Optimum Source Design at existing Reactor Structure

**Detail Design**
- System Commissioning on Schedule & the 1st Cold Neutron Expected in Sep. 2009
- Beam Instrument Layout
- Successful Installation of Neutron Guide System at High Radiation Environment

**Construction & Commissioning**

http://www.kaeri.re.kr
Part II. Introduction to HANARO

Production of high quality Si Semiconductor

Services using NTD1 & NTD2 holes

- Irradiation of 5”, 6” and 8” Ingots
- High Uniformity & Accuracy
- Commercial Service from 2003
- 10% of World Market Share

Neutron Transmutation Doping

Fz-Silicon - Neutron Irradiation - Doped Silicon - Wafer

- $^{30}\text{Si}$
- $^{31}\text{P}$

IGCT - GTO - IGBT - Rectifier Diode

Neutron irradiation and transmutation doping process for producing high-quality Si semiconductor materials.
Irradiated Material Examination Facility

M1-M4 Hot Cells for Irradiated Fuel Tests

M5, M7 Hot Cells for Irradiated Structural Material Tests

M6 Hot Cells for DUPIC project

M8 Hot Cells for ACP project
HANARO Fuel Development

~1992
- Developed Atomization Process (U₃Si powder)
- Good in-pile/out-of-pile performance
- World leading Technology

~2000
- HANARO Fuel Localization Program Launched
- R&D of Fabrication Process
- Irradiation Test of Atomized Fuel

~Now
- Start HANARO Fuel Supply (2005)
- Fabrication Capacity (45 set/yr)
HANARO Fuel Fabrication Facility

Atomization process
Radioisotope Production Facility

Bank I (4 Cells)
- $^{60}$Co, $^{192}$Ir, $^{169}$Yb

Bank II (11 Cells)
- $^{166}$Ho, $^{32,33}$P, $^{99m}$Tc, $^{51}$Cr, HDR
- $^{192}$Ir

Bank III (6 Cells)
- $^{131}$I, $^{125}$I

Bank IV (4 Cells)
- $^{99}$Mo/$^{99m}$Tc Generator

KAERI’s $^{188}$W/$^{188}$Re Generator

I-131 Solution

I-131 Capsule

Preparation Room for Cold Kits

$^{166}$Ho-CHICO
($^{166}$Ho-Chitosan Complex)

Ir-192 NDT Source
Radioisotope application in environmental industry
- \(^{46}\text{Sc}\) : Tracer for sludge digester

Process diagnosis by using radioisotope in petrochemical Industries
- \(^{140}\text{La}\) : Solid tracer
- \(^{41}\text{Ar}\) : Gas tracer
- \(^{60}\text{Co}\) : Sealed source

Efficiency test of sludge digester by using \(^{46}\text{Sc}\)

Performance test of RFCCU by using radiotracer in petrochemical plant
International Cooperation and New Research Reactor Development
Part II. Introduction to HANARO

International Cooperation

Operator Training
- 2000 Training of Taiwan RR project commissioning team
- 2004 Training of CARR(China) operators

Fuel Technology
- Export of U-Mo powders
- Export of U foil

Reactor System Technology
- 2009 Upgrade of GRR-1 (5 MW, Greece) primary cooling system
- 2009 Consultation on the upgrade of I&C for TRR-1 (2 MW, Thailand)
- 2010 Construction of JRTR (5 MW, Jordan)

Utilization Technology
- PSD(Neutron detector) for JRR-3M (20 MW, Japan)
- Tc-99m abstraction system using solvent
- I-131 distillation system, I-131 distribution system(capsule, solution)
- Ir-192 irradiator assembling equipment
KAERI Soccer Club with International Institutes

- Started to Celebrate 2002 Worldcup with Japan
- Japan (4 times), China (3 times), Vietnam (2 times), Thailand, Jordan, Malaysia (1 times), Next?
## JRTR Project Overview

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>Jordan Research and Training Reactor (JRTR) Project</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Owner</strong></td>
<td>Jordan Atomic Energy Commission (JAEC)</td>
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<tr>
<td><strong>Contractor</strong></td>
<td>Consortium of KAERI and Daewoo E&amp;C</td>
</tr>
<tr>
<td><strong>Contract Type</strong></td>
<td>Turnkey EPC Contract</td>
</tr>
<tr>
<td><strong>Project Period</strong></td>
<td>Aug. 1, 2010 to March 31, 2015 (56 months)</td>
</tr>
<tr>
<td><strong>Site</strong></td>
<td>Campus of Jordan U of Science and Technology</td>
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<tr>
<td></td>
<td>(Ramtha, Jordan)</td>
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<tr>
<td><strong>Scope of Supply</strong></td>
<td>• Design and Construction of JRTR</td>
</tr>
<tr>
<td></td>
<td>( Reactor, Reactor building, Service building</td>
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<tr>
<td></td>
<td>including RI production facility, Aux. buildings,</td>
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<tr>
<td></td>
<td>and Training Center)</td>
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<tr>
<td></td>
<td>• Education and Training of Jordanian Staffs</td>
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</tbody>
</table>
New Korean RR

Objective
- Fulfill the RI Demand
- Increase Silicon Doping capacity
- Acquire State-of-Art Technology of RR

Status
- Finished the feasibility study and Approved by Parliament
- Start the project from 2012.3.1 for 5 years

Key
- Develop Reactor Core using U-Mo plate type fuel (the first in the world)
- Construct New RI Production Facility including Fission-Molly process
- Establish U-Mo plate fuel manufacturing facility
- Fabricate U-Al atomized target for Fission-Molly
Conclusions
What you get
Sustainable Development

What you need

Policy
Technology Center
Human Resource
Infrastructure
Industries
Conclusions

1. Basis of Korean Nuclear R&D
   - Priority in Safety and Environment Protection

2. R&D for Effective Use of Nuclear Technology, Clean & Economic Fuel cycle and Nonproliferation.

3. Experiences in Research Reactor Technology
   - Design, Construction, Commissioning, Operation
   - Utilization, Modernization and Decommissioning

4. Use of Radioisotope and Radiation Technology for the Better Life of Korean

5. Ready to Share Experience with Friends