Research Reactor : A Powerhouse of Nuclear Techology in Korea

2011. 11.

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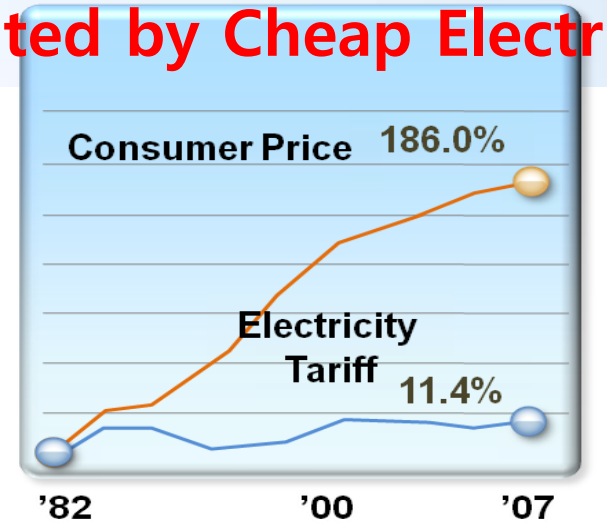
Korea at a Glance

- Difficult Environment (Small Land, High Population, Rare Natural Resource, Divided Country)
  - Land Size 99,000 km^2 (108^{th})
  - Population 48,875K (15^{th})
  - Energy Consumption 9^{th}, Oil Consumption 7^{th}, Oil Import 4^{th}
- 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$ (7^{Th})
  - GNP > 20,000$ (67$ in 1950's)

Korean Economy and Nuclear

Contributed by Cheap Electricity Tariff of Nuclear Energy



Source : Bank of Korea

Per Capita Income (US$)

20,500(08)
18,372
16,291
14,193
11,432
7,355

First KSNP
HANARO operation

PWR Fuel
CANDU Fuel
KORI#1 Operation
TRIGA II Start

10,000
5,000

Six 5-Year-Economic-Development Plans

Financial Crisis

Liberation from Japanese Colonial Rule

67(1953)
89
100(1964)
1,000(1977)

OECD Member

1945 1953 1961 1970 1980 1990 1995 1998 2004 2006

Liberation (1945) | Korean War (1950~53) | Big Push | OECD (1996) | F. Crisis (1997)

Milestones of Nuclear Program

1962.3.19
KRR-1

1972.3.10
KRR-2

1995.2.8
HANARO

2009.10
FTL

2010
CNRF

Jordan

Dawning

1960

Localization

1980

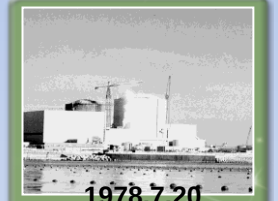
Advancement

2000

Leading

2020

1959.2.3
Establishment of KAERI



1978.7.20
NPP No.1 Operation

1987
CANDU-6 Fuel

1995.4.19
KSNP Operation

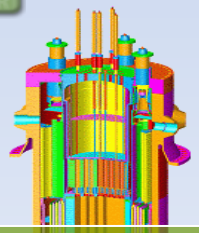
2013
APR1400

UAE

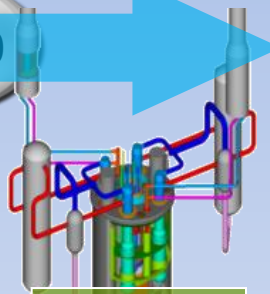
APR+

1998.8.11
OPR1000

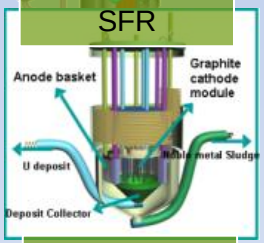
1989
PWR Fuel



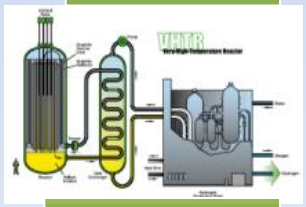
2012
SMART DC



SFR



PYRO



Hydrogen Production

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)

NPP in Korea

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)

Ulchin
8 units

Wolseong
6 units

Kori
8 units

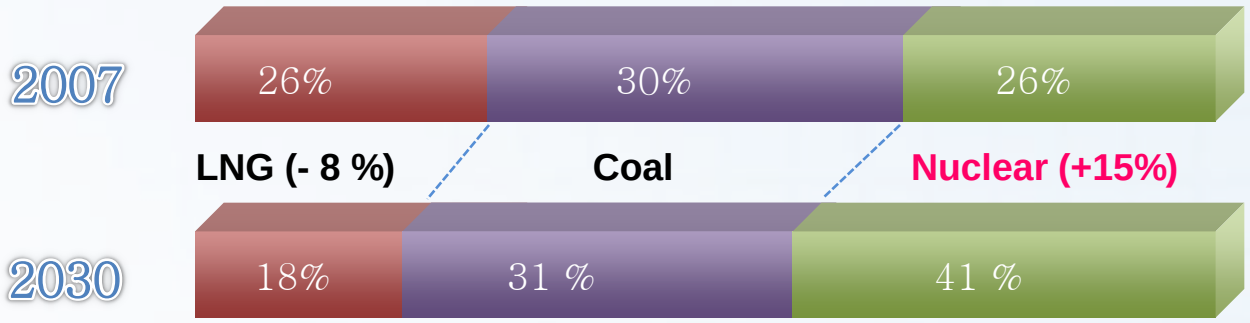
Yong-gwang
6 units

In Operation
Under Construction

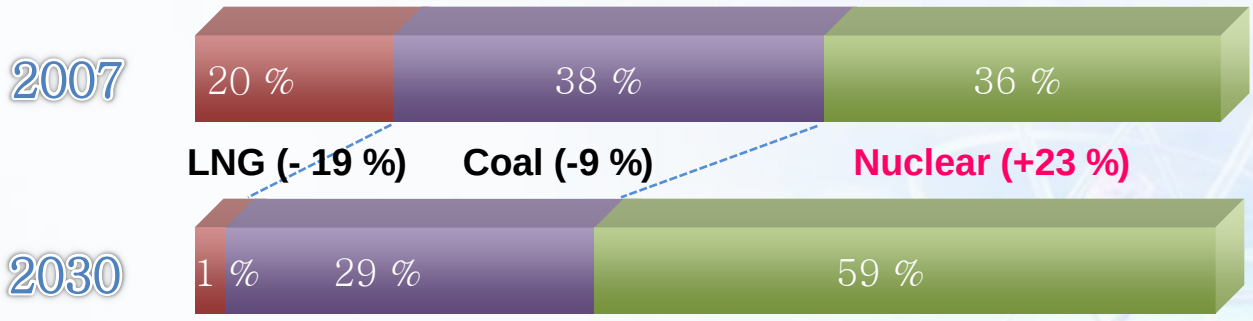
National Energy Basic Plan

Established in 2008.08

Power Plant Capacity Share (%)



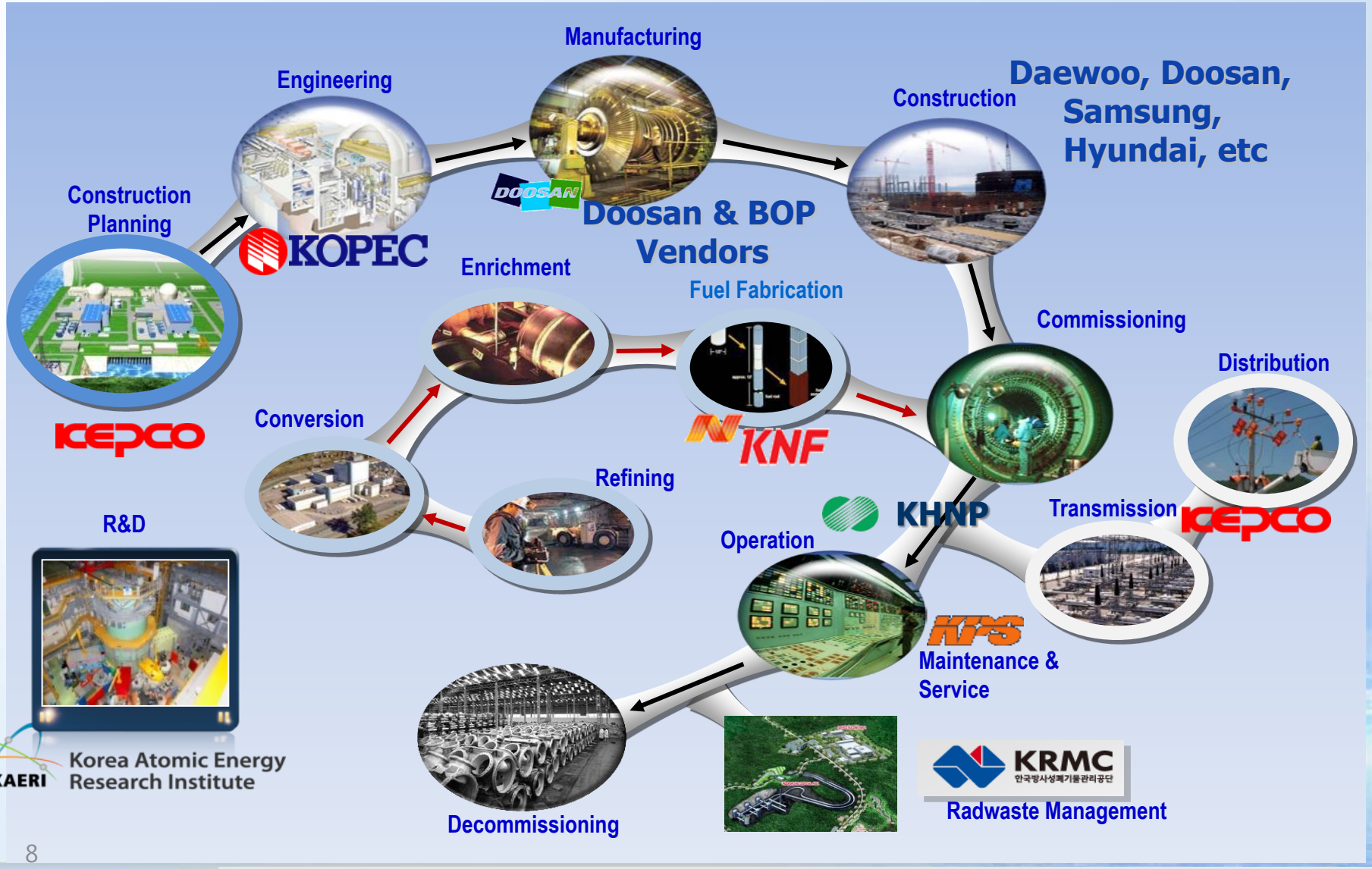
Electricity Generation Share (%)



※ ***Ref*: National Energy Committee (2008)**

Industries and Supply Chain

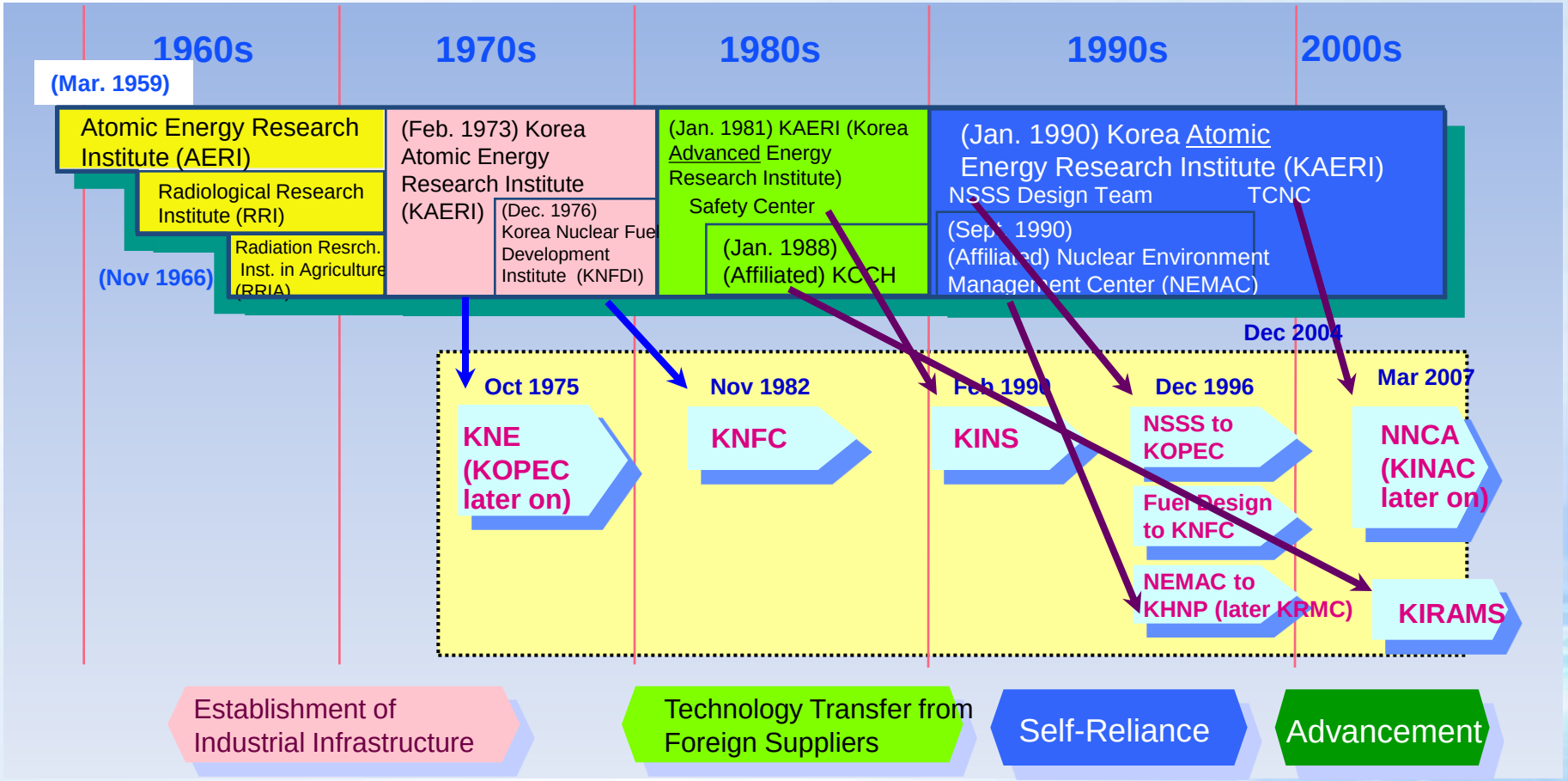
30 years of repetitive construction fostered competitive domestic suppliers in the entire nuclear cycle



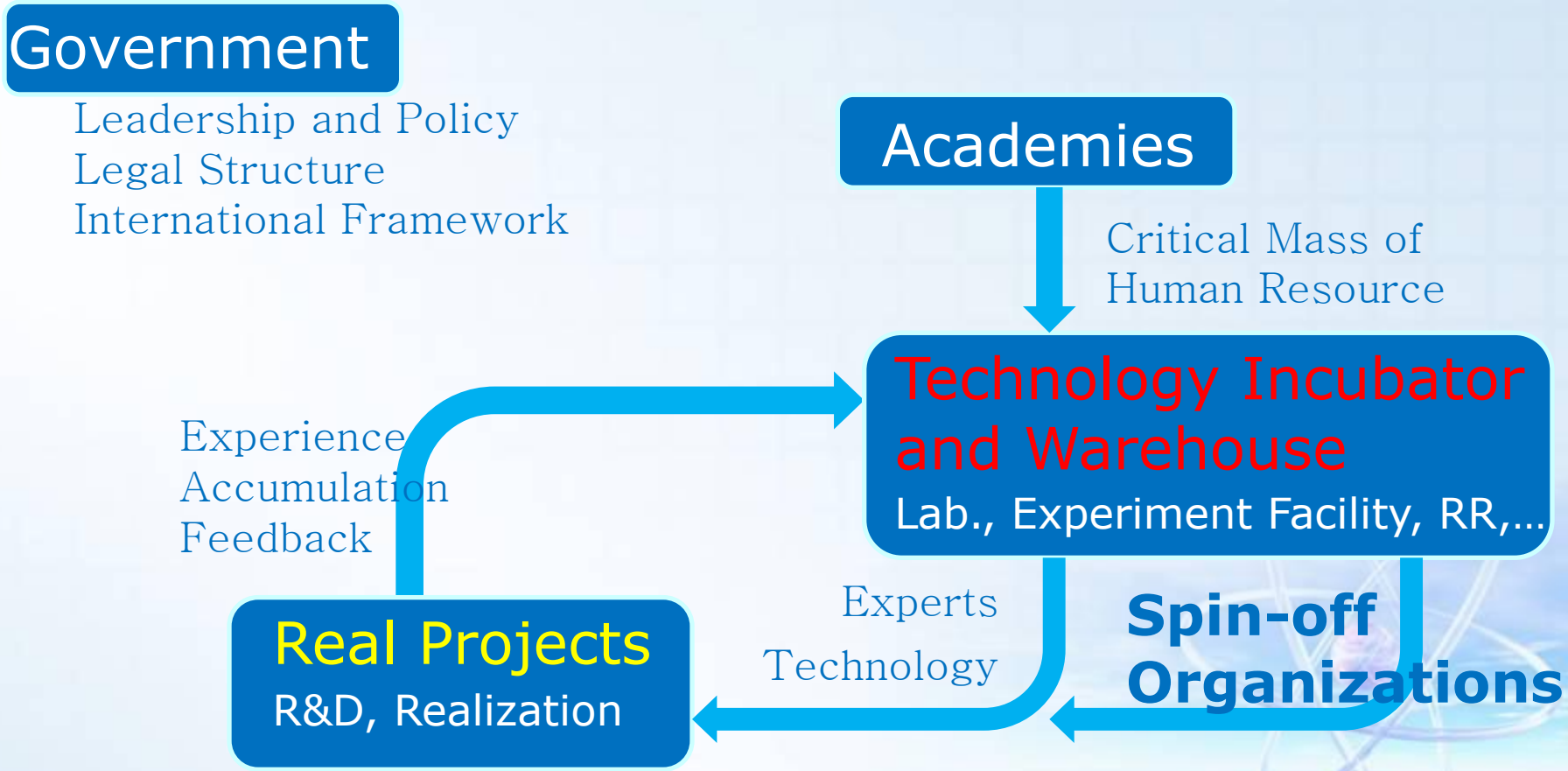
KAERI as Technology Warehouse

- 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**



Technology Self-Reliance Strategy



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

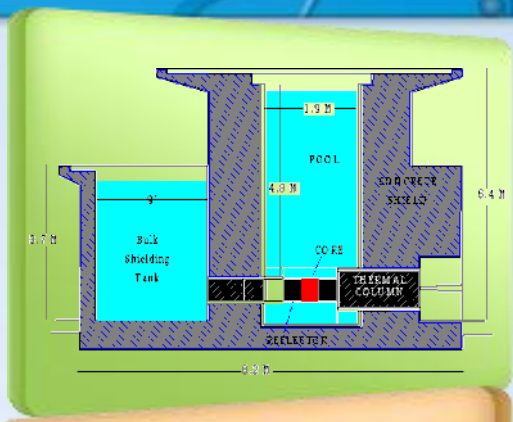
The 1st Research Reactor in Korea, TRIGA Mark II (100KW)

The 1st president of Korea in the ground breaking ceremony (1959.7.14)

KRR-I (TRIGA Mk-II)

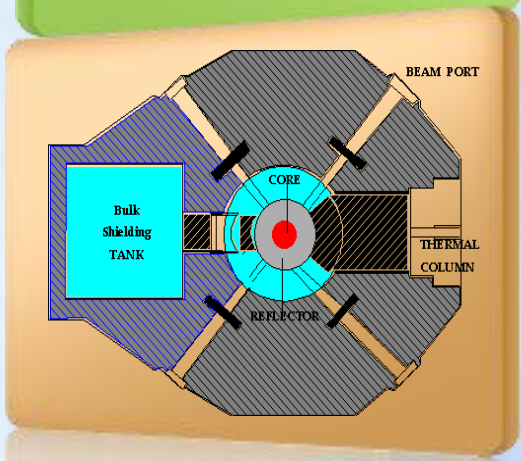
Chronology

- 1958.12 : Contract with GA, USA
- 1962. 3.19 : 1st Criticality
- 1969. 6.24 : Power Upgrade : 100kW to 250kW
- 1995. 1 : Permanent Shutdown

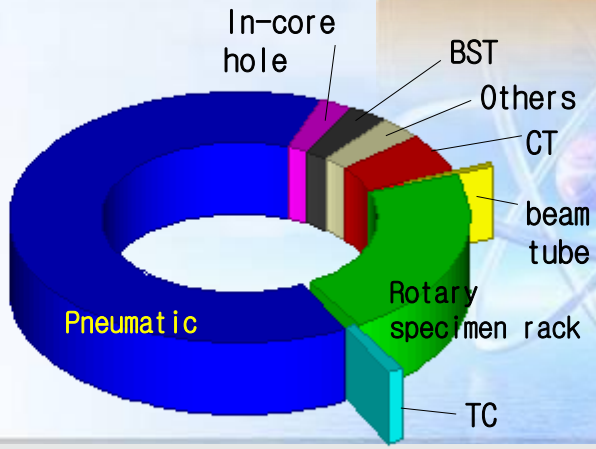


Characteristics

- Open-Pool & Natural convection (250kW)
- Coolant/Reflector : H_2O / Graphite
- Fuel : Rod type UZrH with 20% U-235 in Al-clad
- Control rod : B_4C (3 EA)
- Max. Thermal Neutron Flux : $1x10^{13}$ n/㎠sec



RI Production	3,741 cases
NAA	7,889 cases
Other Exp.	3,484 cases
Education & Training	3,417 person 9,250 hours



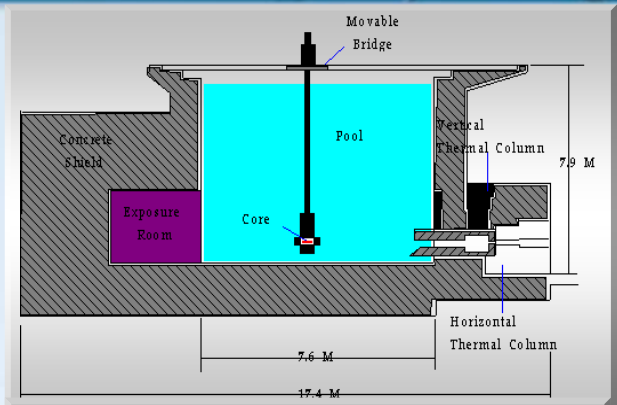
KRR-II (TRIGA Mk-III)

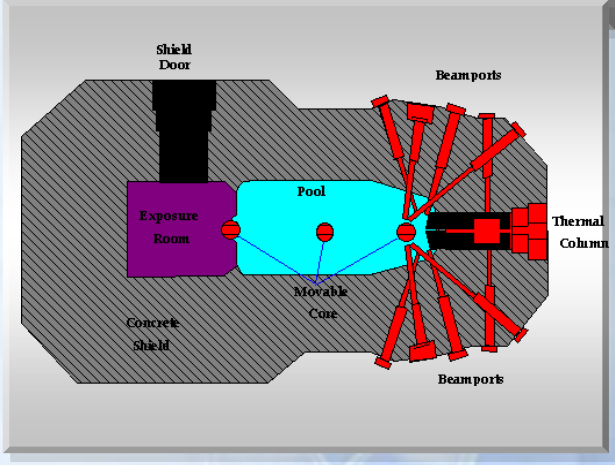
Chronology

- 1968 : Contract with GA. USA
- 1971 : Completion of reactor building
- 1972. 3. 10 : 1st Criticality
- 1995. 12 : Permanent shut-down

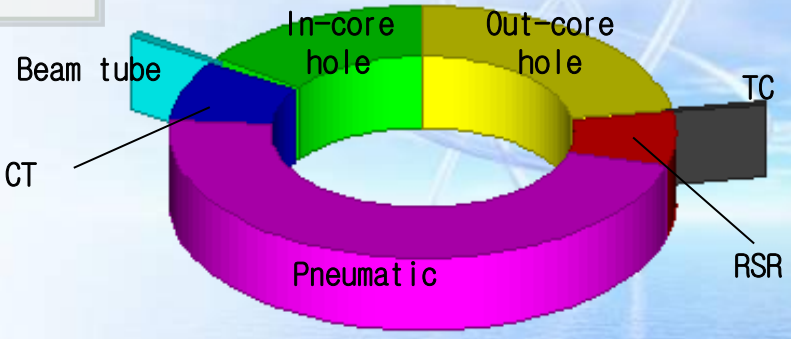
Characteristics

- Open-Pool & Natural Convection (2 MW)
- Movable Core
- Coolant/Reflector : H_2O / H_2O
- Fuel : Rod type UZrH with 70% U-235 in SUS-clad
- Control rod : B_4C
- Irradiation facility : Beam Ports (8), Exposure room, Thermal Column, Rotary Specimen Rack
- Max. Thermal neutron-Flux : $7x10^{13}$ n/㎠sec





RI Production	7,690 cases
NAA	12,070 cases
Neutron Beam	436 cases
Other Exp.	1,057 cases



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

Imported technologies of 60's

Modern domestic technologies of Korea

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

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

Mission of HANARO

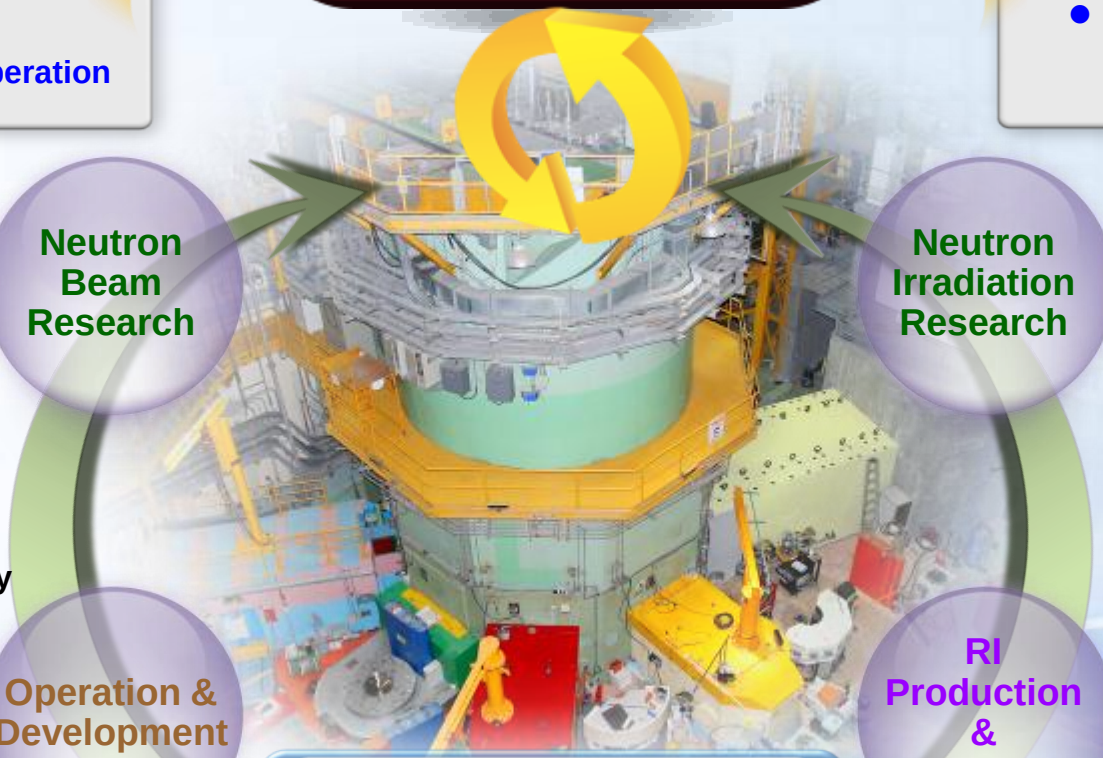
Platform for Nuclear Basic Research

User Community

- Industry
- University
- Institute
- International Cooperation

National Demand

- Basic R&D
- Competitiveness in Technology



Neutron Beam Research

- Cold Neutron Beam
- Radiography

Neutron Irradiation Research

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

Operation & Development

- Reactor Operation
- Experimental Facility Operation

RI Production & Utilization

- Public Welfare
- Industrial Application

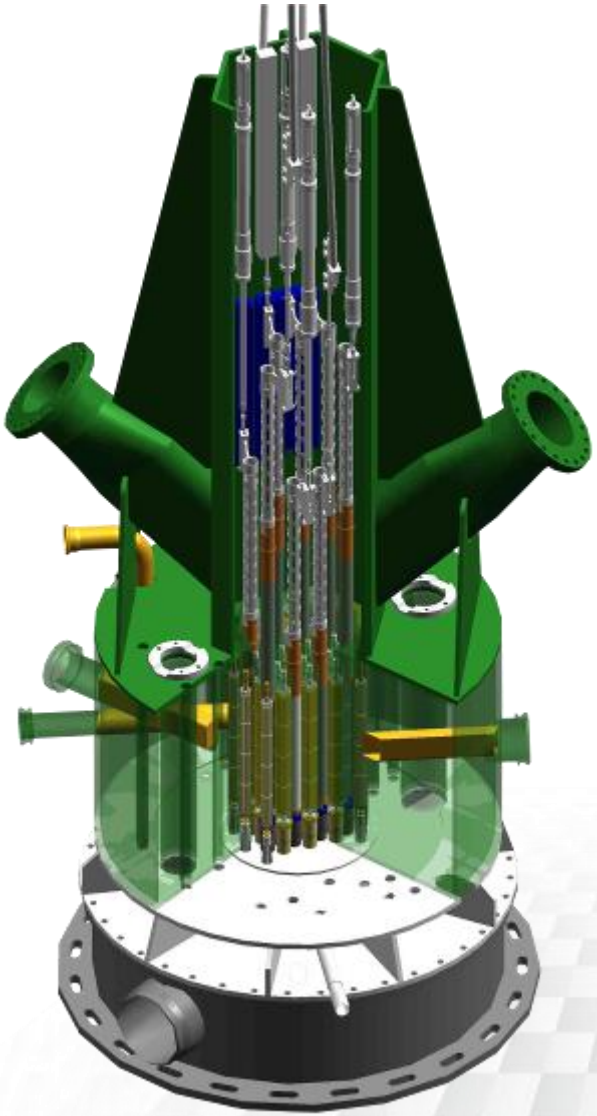
HANARO SAFETY

HANARO, Past and Present

Feb. 1995

Oct. 2009

Reactor Structure and Characteristics



Features

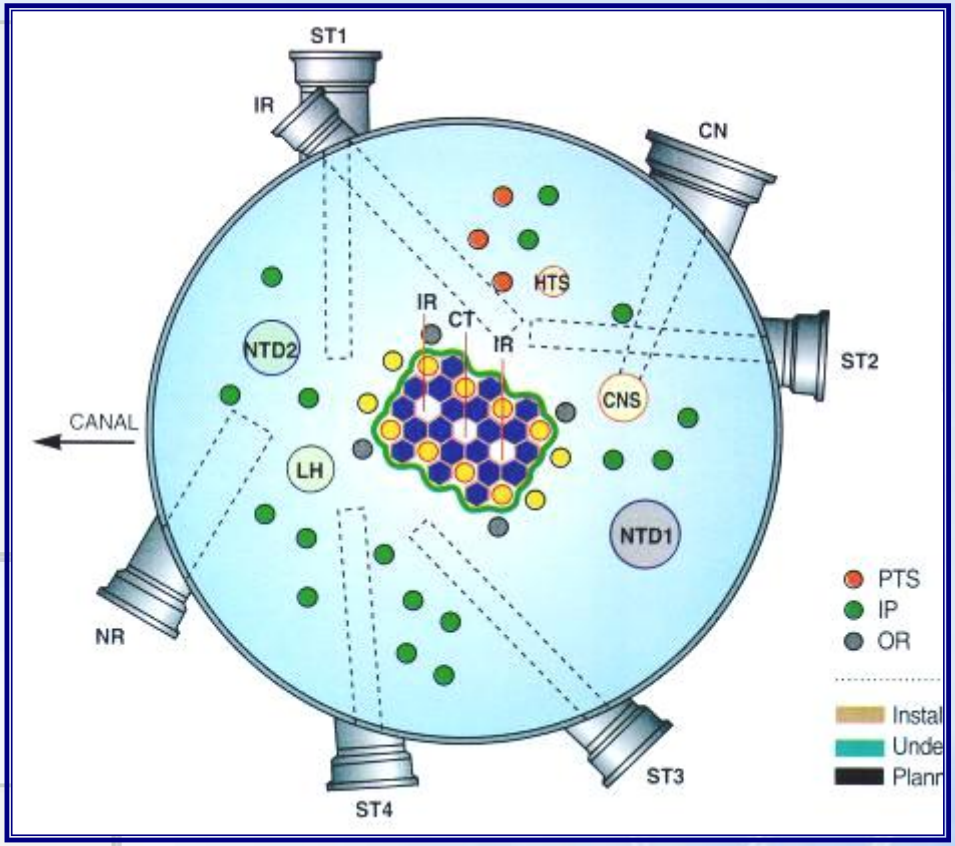
- Type: Open-tank-in-pool
- Power: 30 MW_{th}
- Coolant: Light water
- Reflector: Heavy water
- Fuel materials: U_3Si, 19.75% enriched
- Absorber: Hafnium
- Reactor building: Confinement
- Max thermal flux: $5x10^{14}$ n/cm^2s
- Typical flux at port nose: $2x10^{14}$ n/cm^2s
- 7 horizontal ports & 36 vertical holes
- Vertical hole for cold neutron source
- Operation cycle: 24 days@5 weeks

Beam Ports and Irradiation Holes

Vertical 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

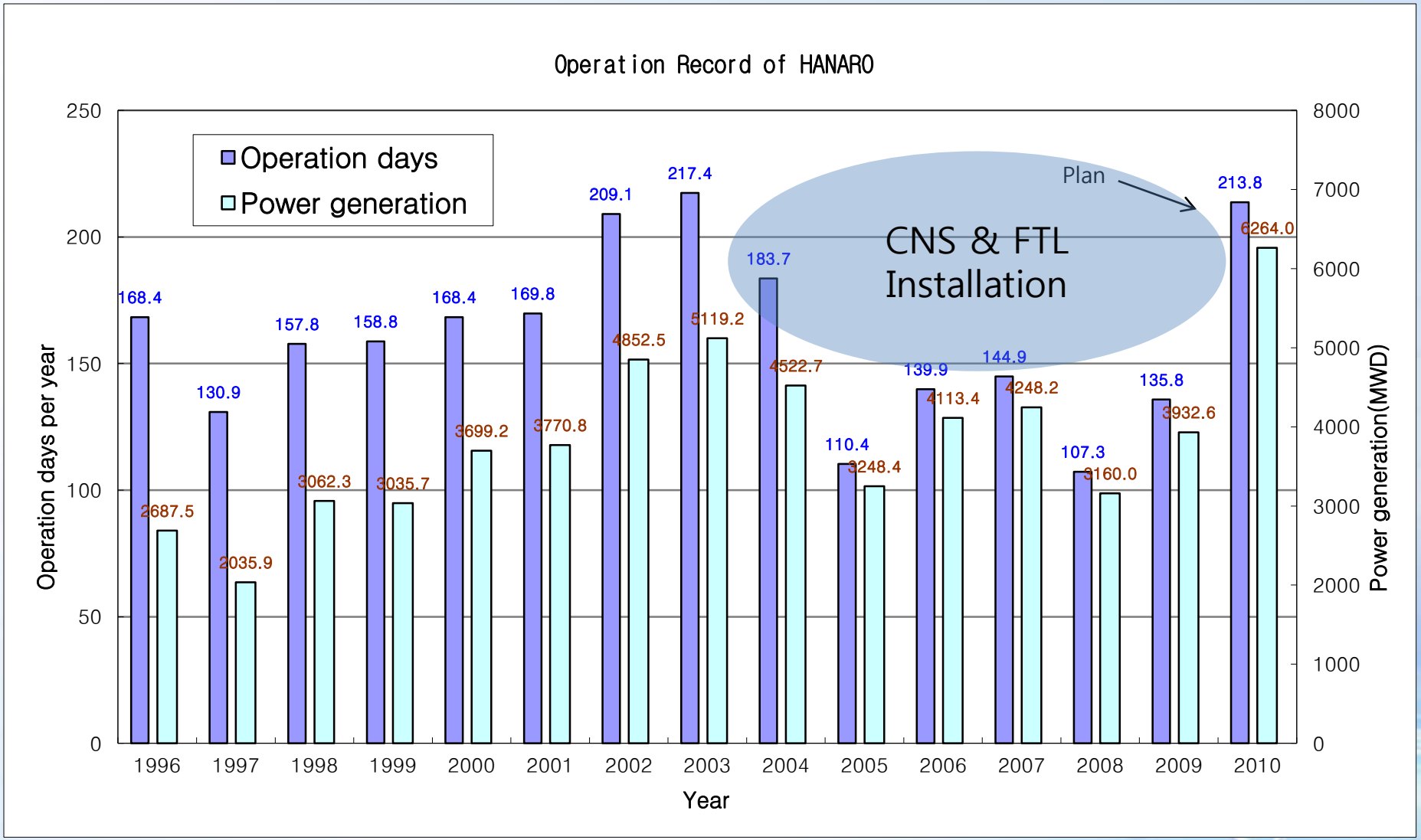
Installed

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

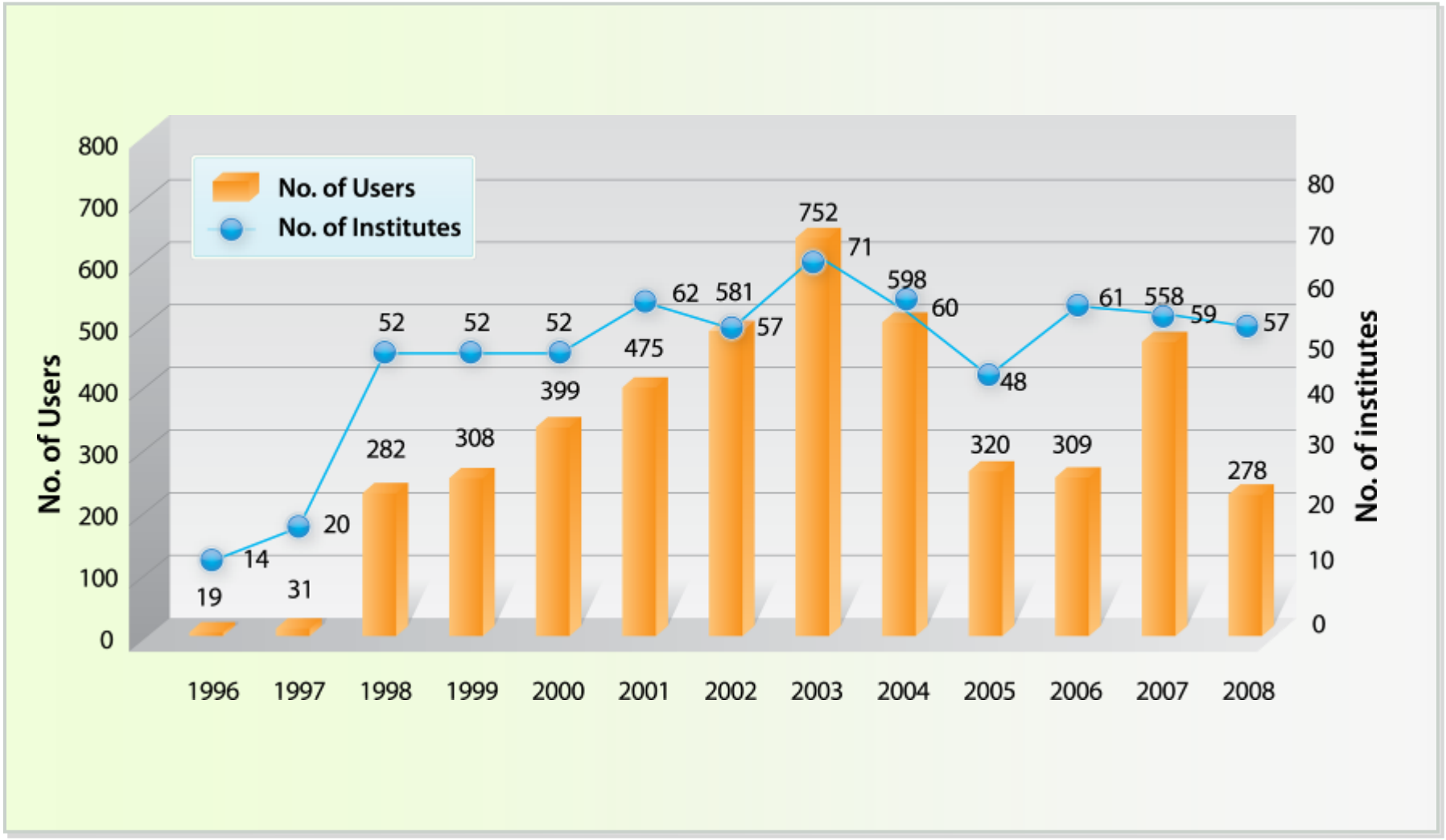
Under-development

ST3 : Bio-diffractometer
ST4 : Triple Axis Spectrometer

Reactor Operation Record



Annual No. of Users and Institute in HANARO



Material/Fuel Irradiation Using Capsule

Reactor Materials Tests

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

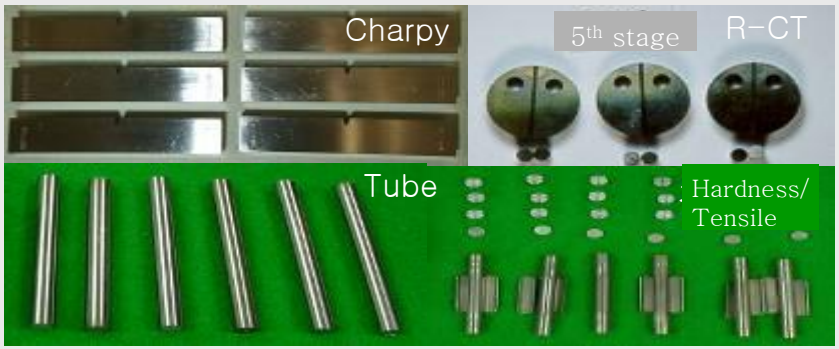
Fuel Materials Tests

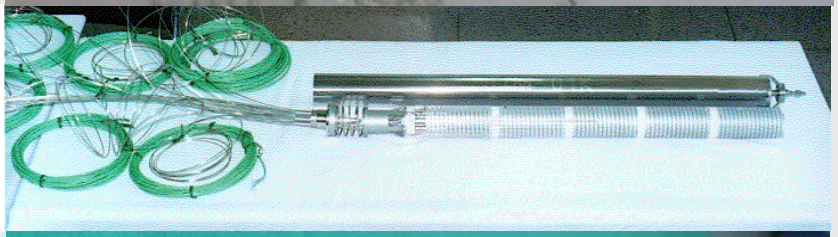
- HANARO Fuel
- U-Mo Fuel
- Advanced PWR Fuel
- DUPIC Fuel
- U-Zr Alloy

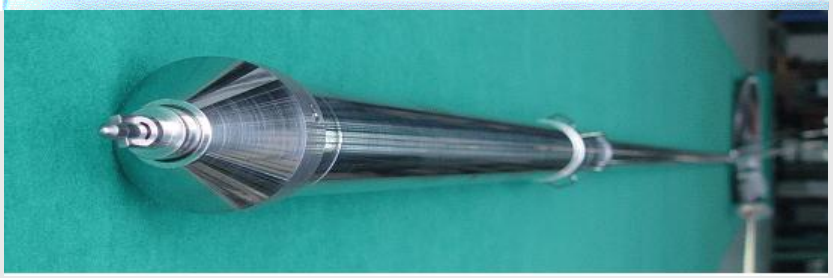
Fundamental Researches

- SPND
- Semiconductor, Magnetic Materials
- Neutron Dosimetry
- Zr-1Nb-1Sn-X Alloy, Zircaloy-4

Instrumented Capsule for Material Irradiation Test







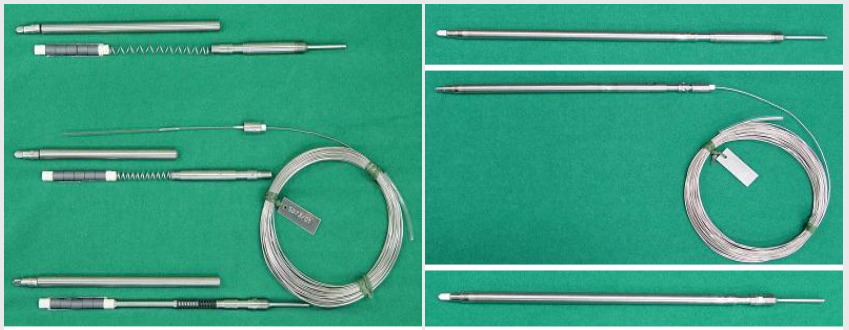
Design Characteristics

- Total Length : ~6m (60mm D x 870mm H)
- Available Space(Max.): 40mm D × 600mm L
- 5 Stages Independent Temp. Control
- Max. Temp. Control : Up to 500℃
- He Atmosphere : 1 atm~3×10^{-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

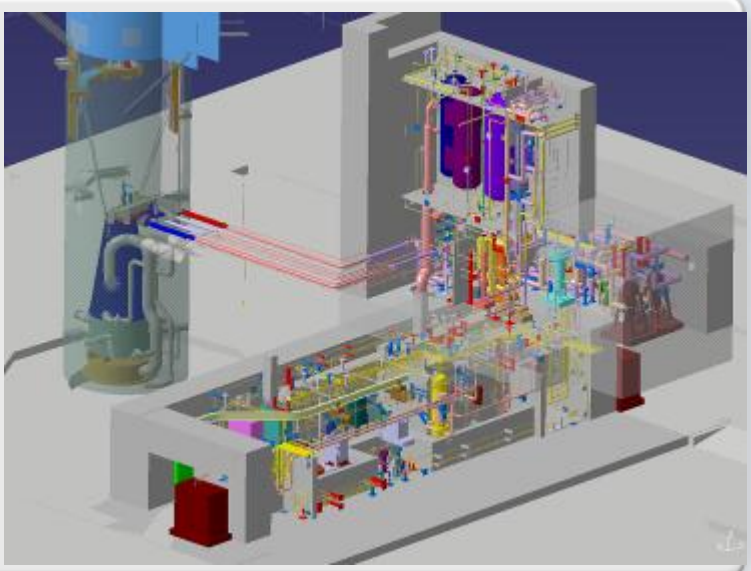
- Examination of nuclear materials through study of creep and fatigue behaviors
- Study on the extension of reactor lifetime
- Study for Fundamental Research

Fuel Test Loop Facility

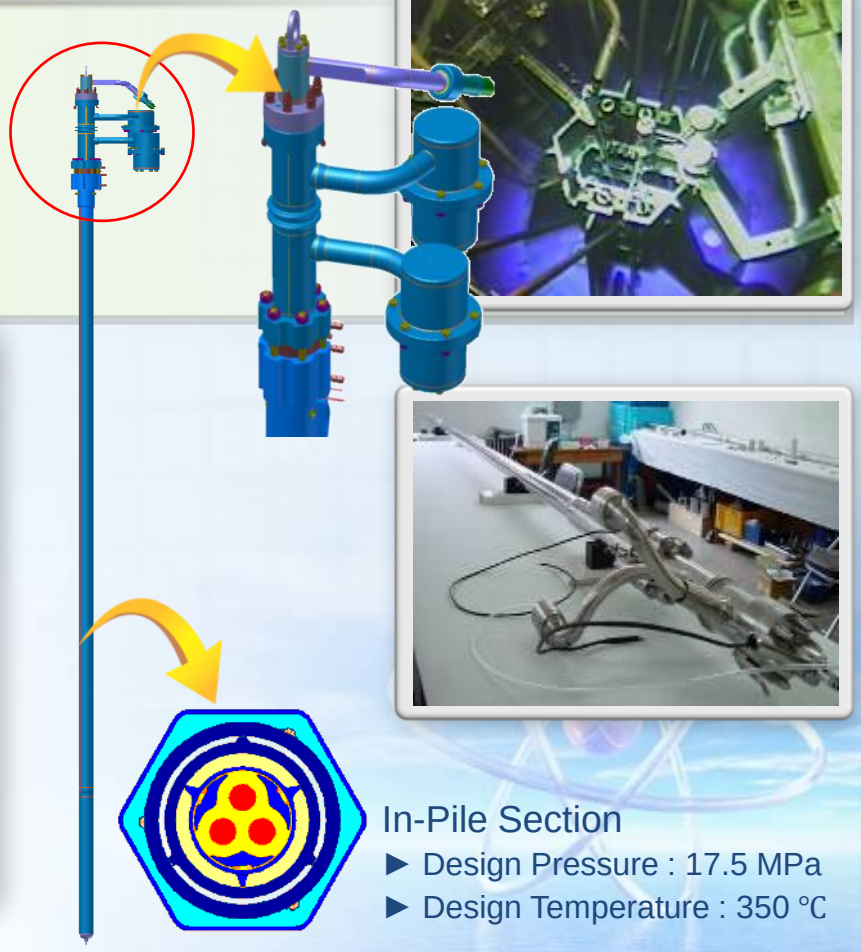
Commissioning test : ~ Sept. 2009

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



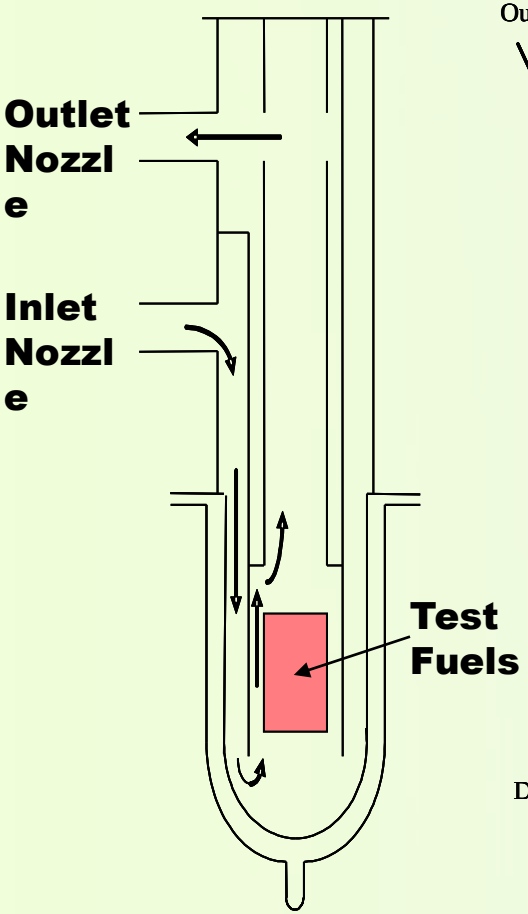
Out-Pile System

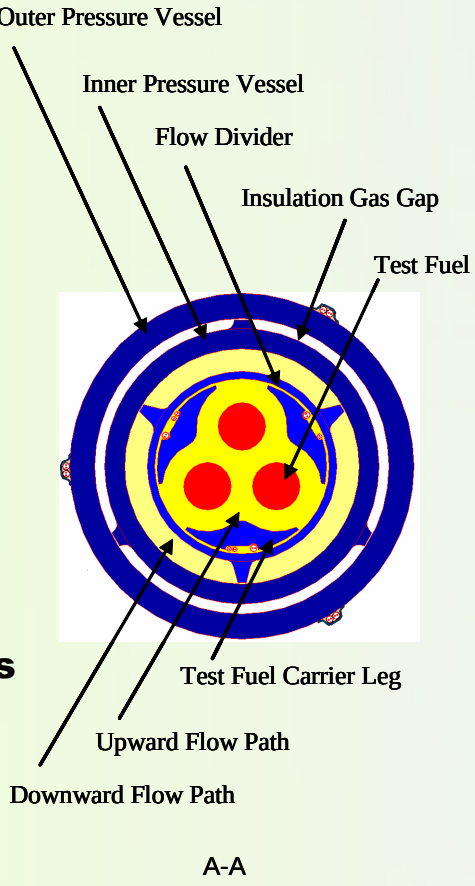


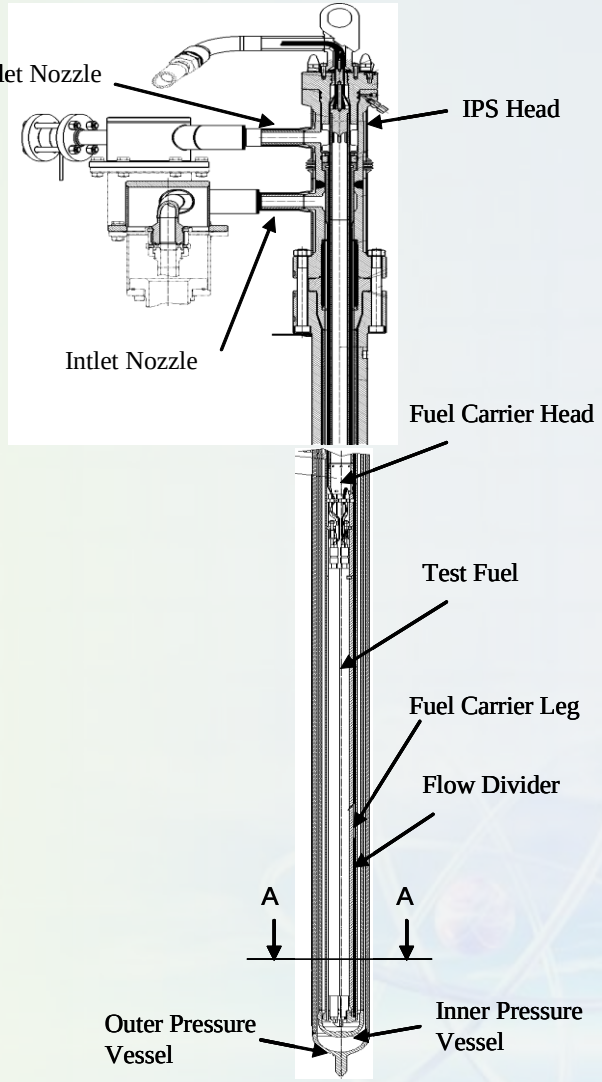
In-Pile Section

- ► Design Pressure : 17.5 MPa
- ► Design Temperature : 350 ℃

Fuel Test Loop Facility

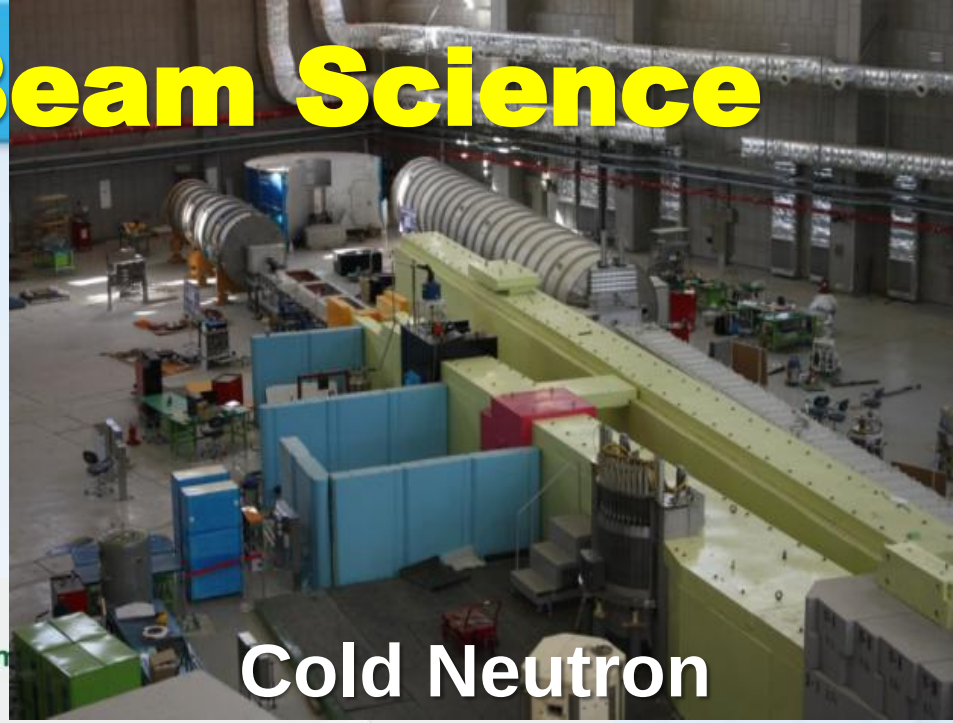




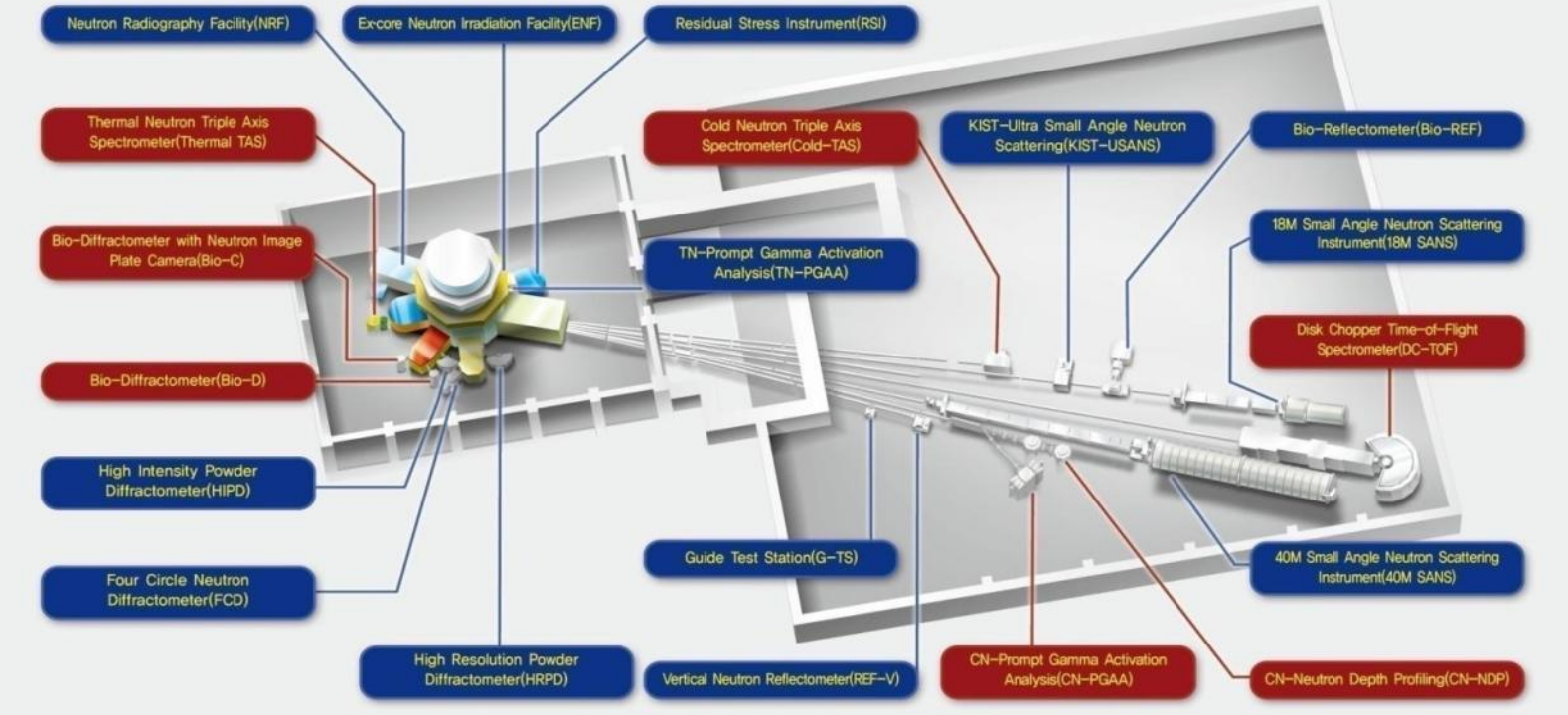


Neutron Beam Science

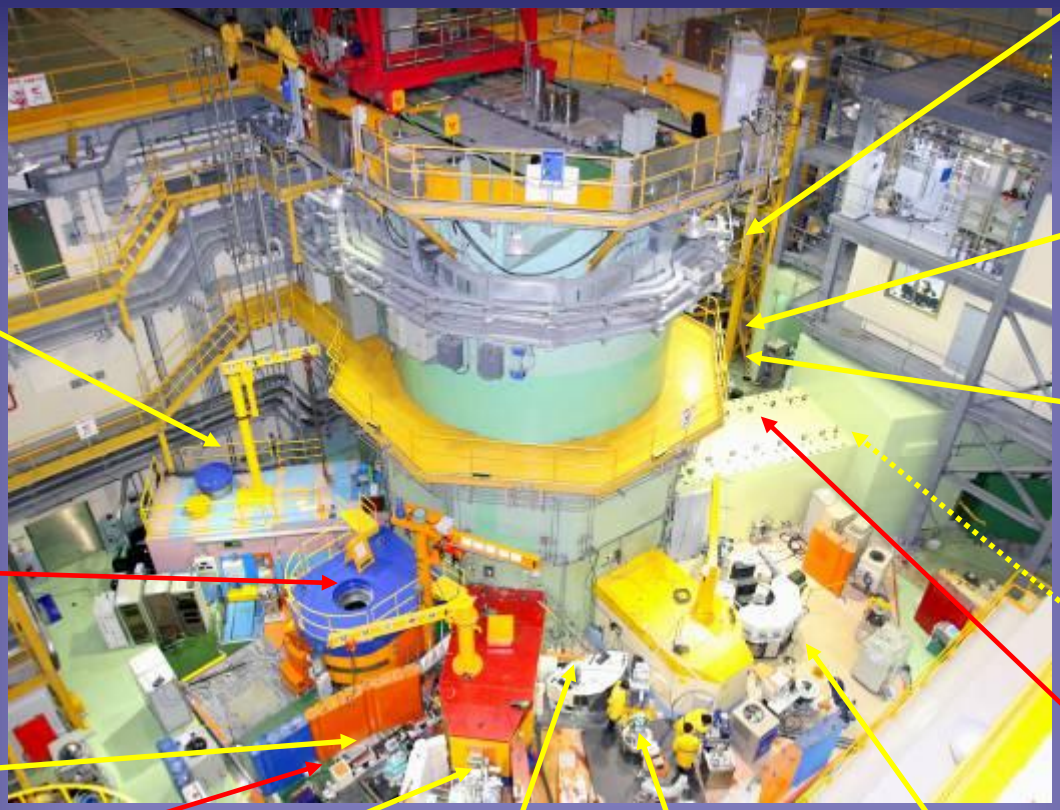
Thermal Neutron



Cold Neutron



Thermal Beams



In-service
Under way

IR Port

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

NR Port

Neutron Radiography Facility (NRF),1997 Upgrade

ST4 Port

Triple Axis Spectrometer (TAS), 2010

Neutron Reflectometer (REF-V), 2006 moved 2010

Bio-Diffractometer (Bio-D), 2010

ST3 Port

Neutron Reflectometer, (REF-H), 2008 moved 2010

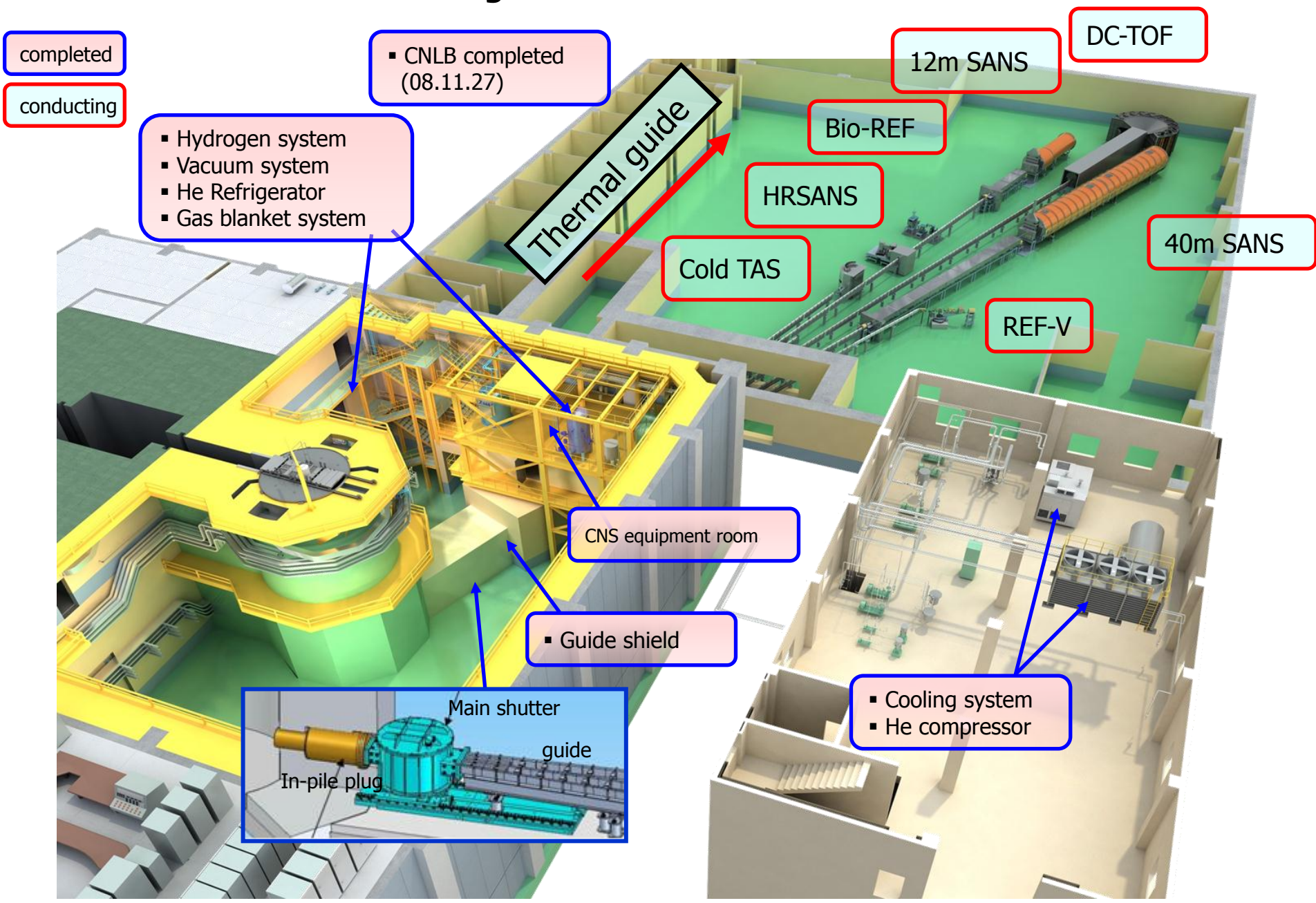
High Intensity Powder Diff. (HIPD), 2008

ST2 Port

High Resolution Powder Diff. (HRPD),1998

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

Cold Neutron Facility



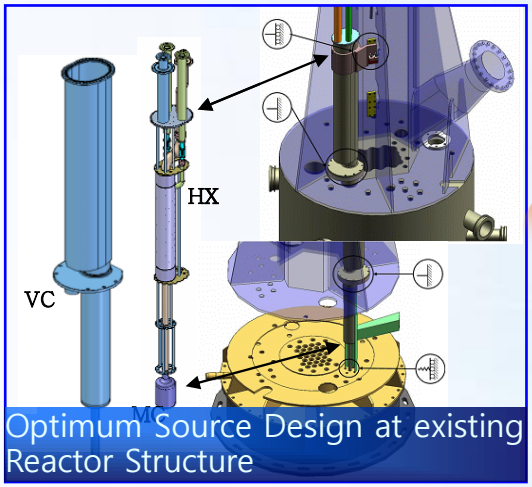
Development of CNRF for the Operating HANARO

Basic Design

Full Scale Thermo-siphon Mock-up Test Using H_2

Detail Design

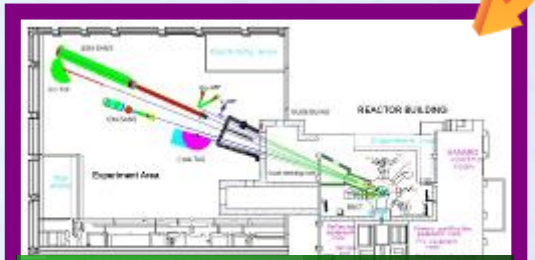
Safe & Reliable Process System Design



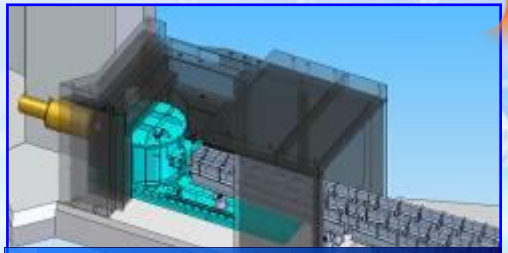
Optimum Source Design at existing Reactor Structure

Construction & Commissioning

System Commissioning on Schedule & the 1st Cold Neutron Expected in Sep. 2009



Beam Instrument Layout



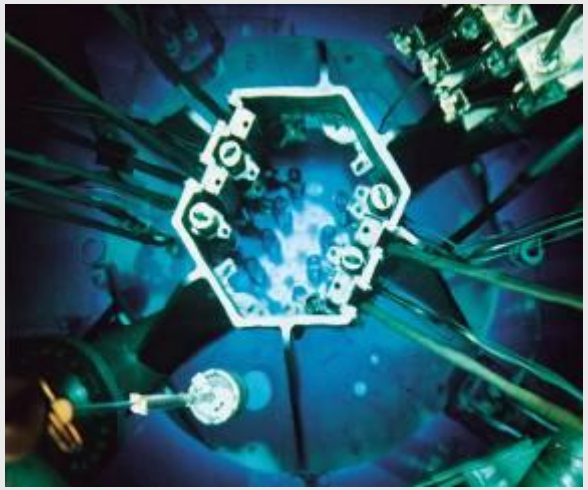
Successful Installation of Neutron Guide System at High Radiation Environment

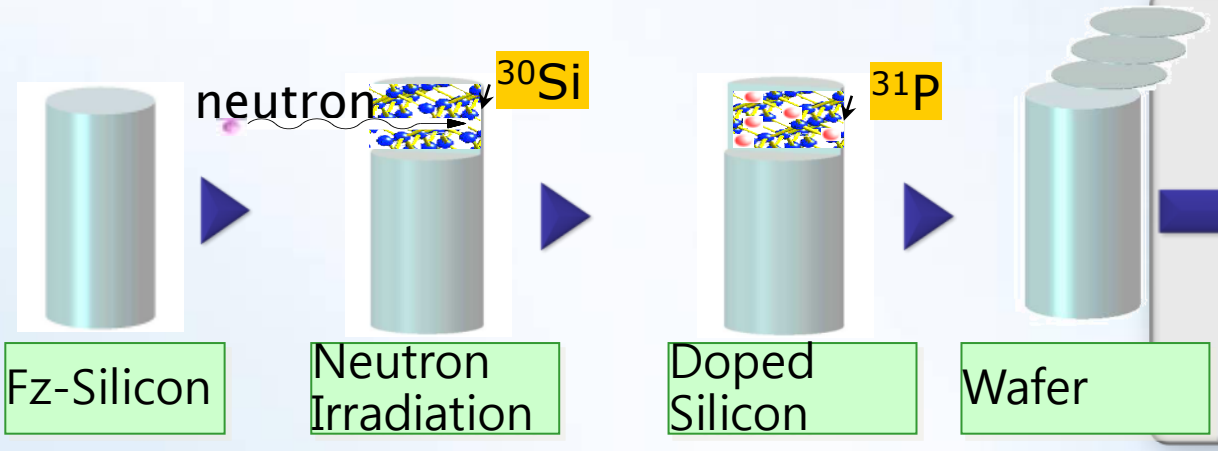
Neutron Transmutation Doping

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



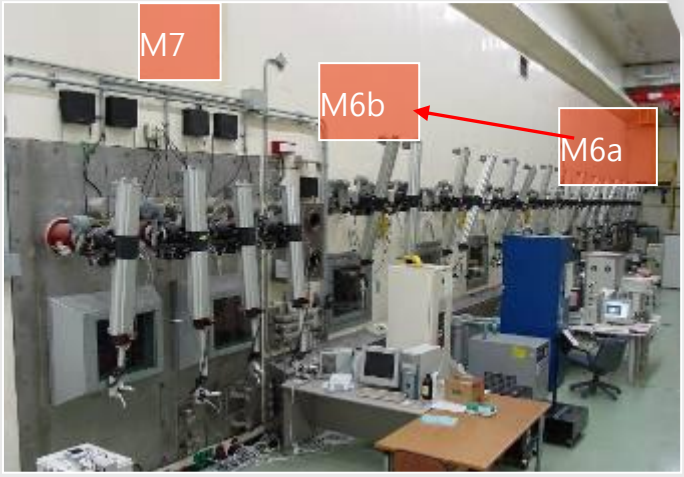


Irradiated Material Examination Facility

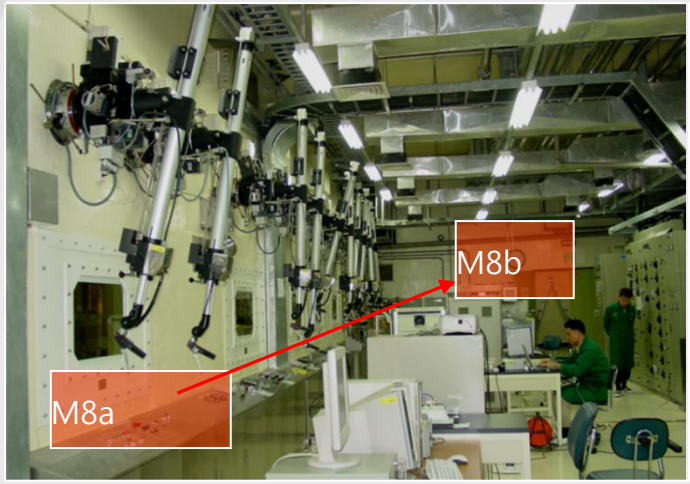
M1-M4 Hot Cells for Irradiated Fuel Tests

M5, M7 Hot Cells for Irradiated Structural Material Tests

KAERI



M6 Hot Cells for DUPIC project

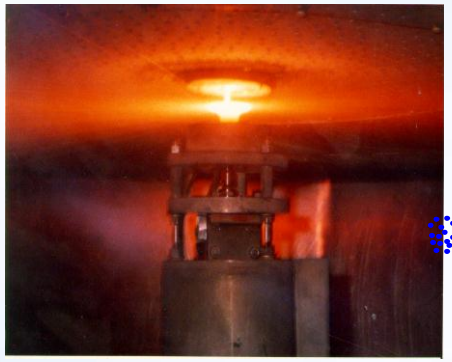


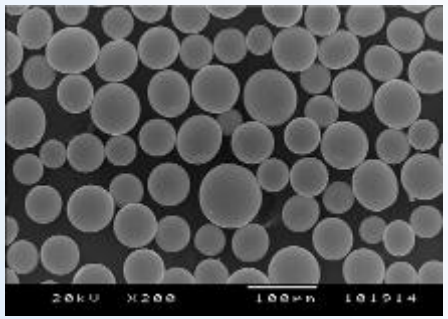
M8 Hot Cells for ACP project

HANARO Fuel Development

~1992

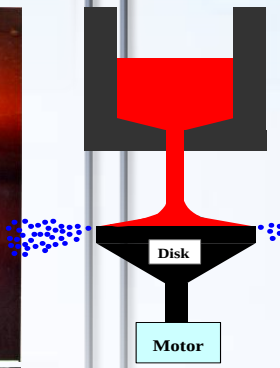
- Developed Atomization Process (U_3Si powder)
- Good in-pile/out-of-pile performance
- World leading Technology





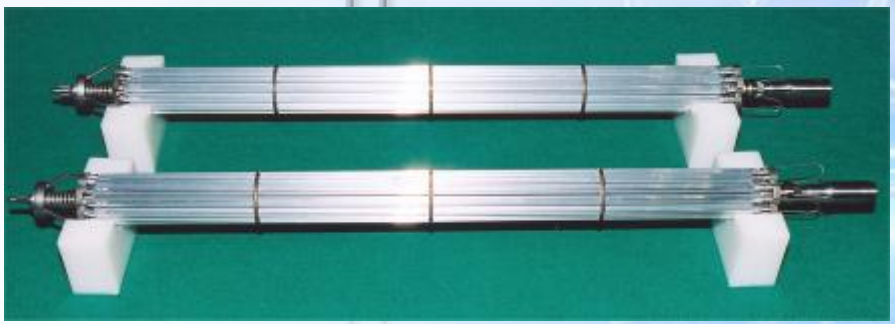
~2000

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

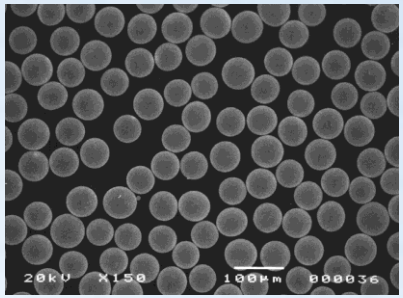


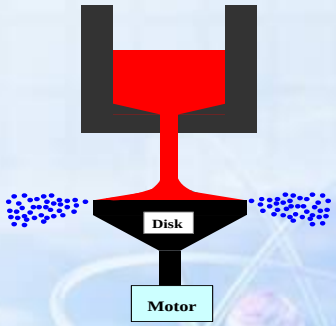
~Now

- Facility Construction (2003)
- Licensing (2004)
- Start HANARO Fuel Supply (2005)
- Fabrication Capacity (45



HANARO Fuel Fabrication Facility





Atomization process

Radioisotope Production Facility

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

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

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

I-131 Solution

I-131 Capsule

Bank I [4 Cells]
^{60}Co, ^{192}Ir, ^{169}Yb

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

Preparation Room for Cold Kits

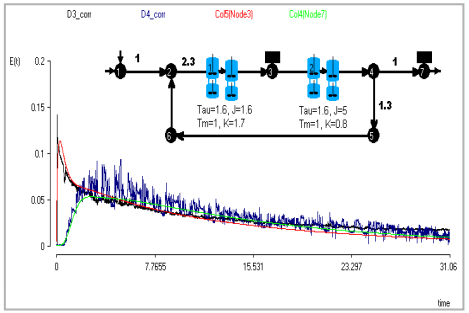
Ir-192 NDT Source

KAERI's ^{188}W/^{188}Re Generator

Industrial application of Radioisotope

- Radioisotope application in environmental industry
  - ^{46}Sc : Tracer for sludge digester

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



Efficiency test of sludge digester by using ^{46}Sc

Performance test of RFCCU by using radiotracer in petrochemical plant

International Cooperation and New Research Reactor Development

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

Project Name	Jordan Research and Training Reactor (JRTR) Project
Owner	Jordan Atomic Energy Commission (JAEC)
Contractor	Consortium of KAERI and Daewoo E&C
Contract Type	Turnkey EPC Contract
Project Period	Aug. 1, 2010 to March 31, 2015 (56 months)
Site	Campus of Jordan U of Science and Technology (Ramtha, Jordan)
Scope of Supply	▪ Design and Construction of JRTR (Reactor, Reactor building, Service building including RI production facility, Aux. buildings, and Training Center) ▪ Education and Training of Jordanian Staffs

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 Paliament
- 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

Iceberg

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**


Thank You!
KAERI
Korea Atomic Energy
Research Institute