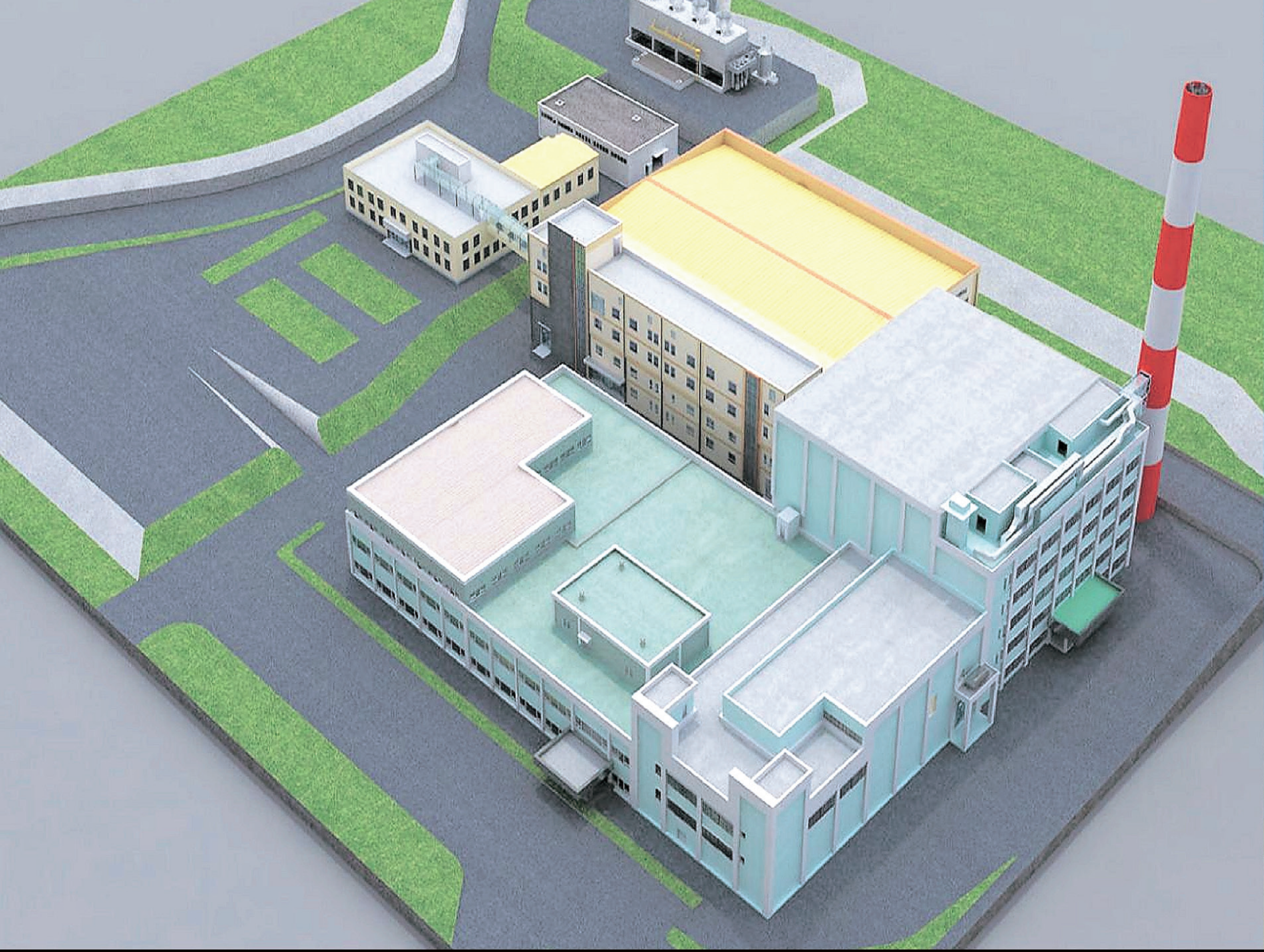

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November 5-7, 2008, KAERI, Daejeon, Korea

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Under the Arrangement for Cooperation in the field of peaceful uses of Nuclear Energy between the Korea Atomic Energy Research Institute (KAERI) and the Japan Atomic Energy Agency (JAEA), the 2008 KAERI-JAEA Joint Seminar on Advanced Irradiation and PIE (post-irradiation examination) Technologies has been held at KAERI in Daejeon, Korea, from November 5 to 7, 2008. This seminar was organized by the PIE & Radwaste Division, Research Reactor Engineering Division, and HANARO Management Division in KAERI. It was also the first time to hold the seminar under the agreement signed September 4, 2008.

This triennial seminar is the sixth in series of bilateral exchange of irradiation technologies. Since the first joint seminar on Post Irradiation Examination Technology between JAERI and KAERI held at JAERI Oarai center, Japan in 1992, it has been a good model of international cooperation program between KAERI and JAEA in the field of neutron irradiation uses. At the fifth seminar in 2005, irradiation technology field was included to the joint seminar, moreover in this time it is expanded to the research reactor management field for covering whole areas of irradiation using in research reactors.

The seminar was divided into three technical sessions; the sessions addressed the general topics of “research reactor management”, “advanced irradiation technology” and “post-irradiation examination technology”. Total 46 presentations were made, and active information exchange was done among participants. This proceeding is containing the papers or manuscripts presented in the 2008 KAERI-JAEA Joint Seminar on Advanced Irradiation and PIE Technologies.

Keywords ; Material Testing Reactor, Research Reactor, Hot Laboratory, Irradiation Technology, PIE Technology

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2008照射試験・照射後試験技術に関する日韓セミナー　論文集

2008年11月5-7日　韓国　大田　韓国原子力研究院

日本原子力研究開発機構　大洗研究開発センター　照射試験炉センター

（編）Woo-Seog Ryu*[1]，石原　正博

（2008年11月10日受理）

韓国原子力研究院(以下、「KAERI」という)と日本原子力研究開発機構(以下、「JAEA」という)が締結した「原子力の平和利用分野における協力のための取決め」に基づいて、韓国の大田にあるKAERIにおいて、「2008照射試験・照射後試験技術に関する日韓セミナー」が2008年11月5日～7日の間で開催された。本セミナーは、KAERIの 照射試験部、研究炉工学部及びHANARO運営部が主催により、2008年9月4日に締結された取決めのもとで初めて開催された。

照射技術に関する情報交換として、３年毎に開催されているこの日韓セミナーは、今回で第6回目である。1992年に日本の日本原子力研究所（以下、「JAERI」という）大洗研究所（現在のJAEA大洗研究開発センター）において、JAERIとKAERIとの照射後試験技術に関する第1回日韓セミナーが開催されて以来、中性子照射利用の分野におけるKAERIとJAEAの国際協力が進められてきた。2005年の第5回日韓セミナーにおいて、照射技術の分野、さらに今回原子炉の管理分野が加わり、試験研究炉を用いた広範な照射利用の情報交換となった。

本セミナーは、「試験研究炉の管理」、「照射技術」及び「照射後試験技術」の３つのセッションにおいて46件の講演が行われた。本報告書は、この「2008照射試験・照射後試験技術に関する日韓セミナー」で発表された論文を収録したものである。

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1. Opening Addresses

1.1 Opening Address

Kwang-Yong Jee
Honorary Chair of the 2008 KAERI-JAEA Joint Seminar
Vice President of Applied Nuclear Technology Development
Korea Atomic Energy Research Institute

On behalf of the Organizing Committee of the KAERI-JAEA Joint Seminar, it is my great pleasure to open “2008 KAERI-JAEA Joint Seminar on Advanced Irradiation and PIE Technologies” at KAERI, Korea. I would like to welcome all of you to the 2008 joint seminar; especially to express my special appreciation to 20 Japanese participants who have traveled long times to be here with us today.

This triennial seminar is the sixth in series of bilateral exchange devoted for irradiation technologies and friendship. Since the first joint seminar on Post Irradiation Examination Technology between JAERI and KAERI held at JAERI Oarai center, Japan in 1992, it has been a good model of international cooperation program between KAERI and JAEA in the field of neutron irradiation uses. At the fifth seminar in 2005, irradiation technology field was included to the joint seminar, and this time it is expanded to the research reactor management field. I would celebrate by ourselves to combine the three fields together for covering whole areas of irradiation test using research reactors.

Renaissance of nuclear era comes and world becomes small. The irradiation testing is a key issue for researching the fuels and materials for the generation-IV systems as well as existing nuclear plants. This JAEA-KAERI joint seminar covering the three fields of test reactor management, irradiation technology, and post-irradiation examination will be an opportunity contributing to make the clean world in terms of the peaceful uses of nuclear energy.

Through the past five joint seminars for 13 years, more than 150 papers have been presented, and they are very profitable and informative to irradiation field of both countries. This 2008 seminar becomes the largest seminar in scale of number of papers, participants and subjects. I sincerely desire that many excellent and common interesting papers would be presented here, so this seminar will be greatly fruitful to get a technical improvement of both countries. I also hope this meeting would confirm the friendship of the long standing again, and would further promote the close partnership of both sides.

Once again, I would welcome all the participants for taking time together, and express my thanks to those who have prepared this seminar in their efforts.

1.2 Opening Address

Ichiro Nakajima
Executive director, Japan Atomic Energy Agency

It is our great pleasure to hold “2008 KAERI/JAEA Joint Seminar on Advanced Irradiation and PIE Technologies” hosted by the KAERI. This is the first time to hold the joint seminar under the newly concluded the “Arrangement for Cooperation in the Field of Peaceful Uses of Nuclear Energy between the KAERI and the JAEA” on 4th September, 2008. At first, I should express my deep gratitude to all involved persons on arranging this seminar; those are chairpersons, member of steering committee, secretaries and so on in both KAERI and JAEA.

This seminar has been held alternately every three years at the KAERI and the JAERI, former organization of the JAEA, since the first seminar was held in 1992 at the Oarai Research Establishment, JAERI. We have done valuable information exchange in the field of irradiation technology and post irradiation technology through past five seminars.

As well known, the significance for the nuclear energy is re-recognized under the global warming situation in this century together with so-called "3S", namely Safety, Security and Safeguard, in Hokkaido-Toyako Summit Discussion held this July in Japan. The new nuclear technology era, so-called "Nuclear Renaissance", is coming globally now in close relation to the future of "Our Earth and Our Human Society". In this seminar, I believe that effective and worthwhile information exchanges for both organizations can be made under such circumstances.

In this seminar, total 46 presentations concerning three R&D fields, those are the research reactor management, advanced irradiation technology and post irradiation examination technology, are going to be presented. I will expect that those interested presentations can be sure to contribute to making good and fruitful opportunities for all participants to establish the valuable close relationship for future research cooperation, and also can be sure to contribute to promoting the R&Ds in the field of peaceful uses of nuclear energy between the KAERI and the JAEA.

2. Plenary Session

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2.1 PRESENT STATUS AND FUTURE PLAN OF JMTR PROJECT

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ABSTRACT

The Japan Materials Testing Reactor (JMTR) of Japan Atomic Energy Agency (JAEA) is a light water cooling tank typed reactor with first criticality in March 1968. The JMTR has been applied to fuel/material irradiation examinations for LWRs, HTGR, fusion reactor and RI production. Owing to the connection between the JMTR and hot laboratory by a canal, easy re-irradiation tests can conduct with safety and quick transportation of irradiated samples. The JMTR operation was stopped in August 2006 in order to conduct its refurbishment. The reactor facilities will be refurbished during four years from the beginning of FY 2007, and necessary examination and work are carrying out on schedule. The renewed JMTR will be started from FY 2011, and be operated for a period of about 20 years (until around FY 2030). The usability improvement of the JMTR, e.g. higher reactor available factor, shortening turnaround time to get irradiation results, attractive irradiation cost, business confidence, is also discussing as the preparations for re-operation.

INTRODUCTION

The JMTR of JAEA is a light water cooling tank typed reactor. The JMTR has been used for fuel and material irradiation studies for LWRs, HTGR, fusion reactor and RI production. Since the JMTR is connected with hot laboratory through the canal, re-irradiation tests can conduct easily by safety and quick transportation of irradiation samples. First criticality was achieved in March 1968, and operation was stopped from August, 2006 for the refurbishment.

The reactor facilities are refurbished during four years from the beginning of FY 2007, and necessary examination and work are carrying out on schedule as follows.

- Aged-investigation: Primary and secondly cooling tubes and so on were confirmed as a good condition by the investigation.
- Component replacement: Control rod drive mechanism, reactor control system, primary cooling pumps, secondary cooling pumps, electric power supply system and so on, were decided to replace.
- Specific designs for component replacement; Designs were finished, and replacement components were decided from a viewpoint of future maintenance, reliability and so on.

The renewed and upgraded JMTR will start from FY 2011 and operate for a period of about 20 years (until around FY 2030). The usability improvement of the JMTR, such as higher reactor available factor, shortening turnaround time to get irradiation results, attractive irradiation cost, business confidence, is also discussing as the preparations for re-operation.

OUTLINE OF JMTR

The JMTR is a testing reactor conducted to the irradiation tests of materials and fuels. It had achieved first criticality in March 1968. High neutron flux generated in the core of the JMTR is utilized for the irradiation experiments of fuels and materials, as well as for radioisotope productions. The JMTR provides various irradiation facilities, such as many types of irradiation capsules, shroud irradiation facility and hydraulic rabbit irradiation facility.

For post irradiation examinations (PIE), irradiated capsules or specimens are transferred to the hot laboratory, which is connected to the reactor building through a water canal. Owing to the shielding capability of the water, irradiated radioactive capsules or specimens are safely transferred underwater through the canal. Cross section of the JMTR and hot laboratory are shown in Fig.1.

The reactor pressure vessel, 9.5m high with 3m in inner diameter, is made of low carbon stainless steel (SUS304L) and is located in the reactor pool, which is 13m deep. The control rod drive mechanisms are located under the pressure vessel for easy handling of the irradiation facilities and fuels in the core.

The core of the JMTR is in a cylindrical shape with 1.56m in diameter and 0.75m high made up of 24 standard fuel elements, five control rods with fuel followers, reflectors and H-shaped beryllium frame.

Cooling water in primary cooling system is pressurized at about 1.5MPa to avoid local boiling in the core during power operation.

The heat generated in the core is removed by the cooling water in the primary cooling system. The cooling water flows downwards in the core and transfers the heat from the core to secondary cooling system through heat exchangers. The heat transferred to the secondary cooling system is removed away into the atmosphere in cooling towers. Cutaway view of reactor is shown in Fig.2.

The JMTR is utilized for the basic and the applied researchers on the fuels and materials of fission reactors and fusion reactor, and also utilized for radioisotope productions. Power ramping tests for the nuclear fuels are also performed to study the integrity and safety of the fuels.

Test specimens irradiated in the JMTR are transferred to the hot laboratory for the PIE. The data obtained are used for the development of nuclear fuels and materials as well as safety assessment of the LWRs.

Radioisotopes produced in the JMTR are widely utilized in the medical treatment, industries and agriculture [1-3].

START OF NEW JMTR

The reactor facilities are refurbished during four years from beginning of FY 2007, and the operation of new JMTR will start in FY 2011.

The usability improvement of the JMTR

The usability of the JMTR will also be improved to be attractive to users, shown as follows.

(1) Achievement of the reactor available factor from 50% to 70%.

(2) Shortening of turnaround time to get irradiation results earlier.

(3) Realization of more attractive irradiation cost in comparison with other testing

reactors in the world.

(4) Establishment of more simple irradiation procedure and more satisfied technical support system.

(5) Guard of the business confidence by perfect information control, etc.

As for the item (1), the possibility of reactor scram by the accident will be decreased by the replacement of reactor components as described above. In addition, even if the failure of components occurs, the repairing the failed components will also become easier. These will shorten the time of out-of-operation. Actually, The JMTR has already had a experience of high capability of operation, that is more than 180days in a year in two times. Then, the replacement of old and unreliable components leads the higher capability of operation. Furthermore, optimization of the overhaul time of the reactor defined once per year by the Japanese regulation will take longer operation period during one year. Items from (2) to (5) are now under discussion taking users requests into consideration.

Target of new JMTR

(1) Proposal of Attractive Irradiation Tests

Proposal of attractive irradiation test will be carried out by advanced technologies such as new irradiation technology, new measuring technology and new PIE technology. Cooperation with various nearby PIE facilities, surrounding the JMTR, is also under discussion in order to extend the capability of the PIE.

(2) Establishment of International Center

Construction of the research base utilized internationally as an Asian center of testing reactors is now under consideration. In Asian area, some excellent testing reactors are operated, such as HANARO in Korea, OPAL in Australia. Each of these reactors has individual and original characteristics, and can take supplementary role in each other.

(3) User-Friendly Management

User-friendly management must be established by above-mentioned improvement on usability of the JMTR. The technical support system for users will be established from the support by specialists of irradiation technology and irradiation research, such as specialists of reactor fuel and reactor materials. The users will be able to discuss sufficiently on the detail irradiation method with these specialists at the planning stage of irradiation. This is an example of the improvement of the usability easy to use for many users due to the fulfillment of the technical support system.

Expected roles of new JMTR

As described above, the JMTR will be refurbished by the replacement of old-designed components and development of new irradiation facilities. Also, the usability is planned to be improved. As for these improvements, the following roles are expected on the new JMTR.

(1) Lifetime Extension of LWRs
- Aging management of LWRs
- Development of next generation LWRs

(2) Progress of Science and Technologies
- Development of fusion reactor materials and developments
- Development of HTGR (High Temperature Gas cooled Reactor) fuels and materials
- Basic research on nuclear energy, etc.

(3) Expansion of Industrial Use
- Production of silicon semiconductor for hybrid car
- Production of ^{99}Mo - ^{99m}Tc for medical diagnosis medicine

(4) Education and training of nuclear scientists and engineers

Above expected role of the new JMTR is shown in Fig.3. The new JMTR is planned to contribute the worldwide research fields and industrial fields by playing these important roles.

REFURBISHMENT OF JMTR

Refurbishment of the JMTR is promoted by two projects, "replacement of reactor components" and "construction of new irradiation facilities".

(i) Replacement of reactor components

The replaced components are decided from the accumulated experience/knowledge through these forty years operation. Aged or old-designed components of control rod drive mechanism, reactor control system, primary cooling pumps, secondary cooling pumps, electric power supply system and so on, will be replaced by present-designed ones. For example, the circuits of reactor control system and process control system which consist of a huge amount of relays and soldered wirings will be replaced by present-designed integrated circuits.

As for un-replacing facilities, for example heat exchangers, pressure vessel, secondary cooling towers etc, safety review was carried out from a view point of view of the aging. Their long-term operation in future has been certified by this investigation.

By these replacements aiming at the safe/steady reactor operation, the failure possibility of each component will be decreased, and the failed component will be able to repair promptly. This leads improvement of the rate of reactor operation in future.

Replacement of reactor components is shown in Fig.4 and component replacement schedule is shown in Fig.5.

(ii) Construction of new irradiation facilities

New irradiation facilities, i.e. irradiation test facilities of materials and fuels, production facilities for silicon semiconductor and medical radioisotopes, will be installed in the JMTR.

- New material and fuel irradiation tests

Irradiation test facilities of materials and fuels are now being developed and will be installed in the JMTR during a shutdown period of about 4 years until 2010 with requirements from both regulatory and development uses of LWRs for the purpose of the long term/up-graded operations.

Requirements are addressed on high performance of LWRs, e.g. power up rating, longer operation cycles and modified water chemistries for lifetime extension of the power plants to obtain evaluation data of fuel and materials under irradiation conditions. To meet one of these requirements, an irradiation capsule with larger test section with large sized specimen of reactor materials is now being developed to investigate the scale effect on the IASCC behavior. A new type of a power ramp test facility is also under development to provide the constant surface temperature of fuel rod specimen during a boiling transient. It is planned to realize the linear test-fuel power by controlling the pressure of surrounding ^{3}He gas screen, absorber of neutrons.

- New irradiation facility for industrial purpose

Present development plan of irradiation facility for industrial purpose includes the development of irradiation facility for production of silicon semiconductor. Target of the development is to establish the irradiation facility of large sized silicon ingot with 8 inches in diameter which meets the trend requirement of the field of hybrid cars and so on.

Another plan is to provide the ^{99m}Tc for medical use. The hydraulic rabbit irradiation facility, which is well developed and already used in the JMTR irradiation, can be applied. Now, investigation of production performance and costs estimation are being carried out [4].

CONCLUSIONS

The JAEA considered that the JMTR is a testing reactor supporting the basic technology of the nuclear energy, and decided the refurbishment of the reactor facilities during four years from FY 2007; operation of the new JMTR will be started from FY 2011.

In the same time, irradiation facilities corresponding to the user needs, such as Nuclear and Industrial Safety Agency, will be installed in the JMTR to contribute the lifetime extension of LWRs by the user's fund. Additionally, the contribution to the development of the ITER and the industrial use etc., are under discussion in the JAEA.

In the practical use of the JMTR, the JAEA will promote the expansion of the JMTR utilization, and will improve the usability (e.g. improvement of the reactor available factor, shortening of the turnaround time, achievement of the attractive irradiation cost, establishment of the satisfied technical support system, retention of the business confidence) taking account of the opinion obtained from external experts such as “the JMTR user's committee”, “the Council for Science and Technology Policy” and so on.

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[3] Department of JMTR, "JMTR Japan Material Testing Reactor", booklet, (2005)

[4] Koichi IIMURA, et al., "Conceptual Study of ^{99}Mo production Facility in JMTR", JAEA-Technology 2008-035

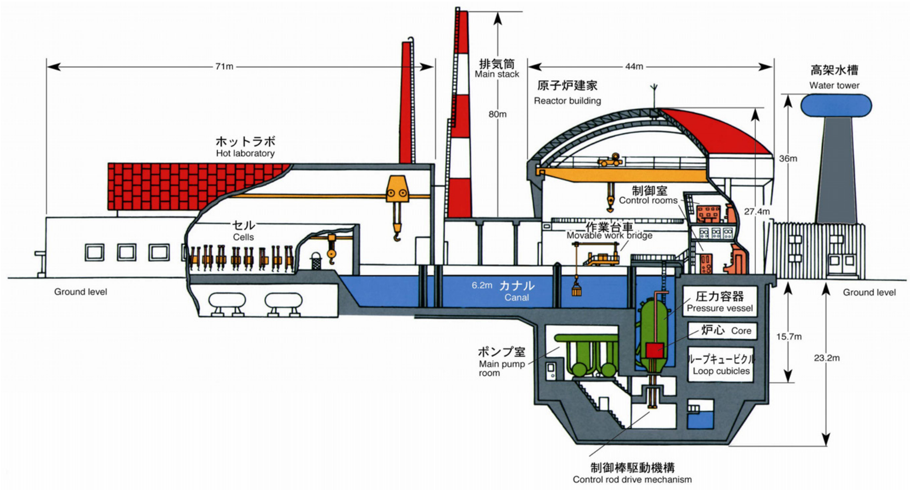

Fig.1 Cross section of JMTR and hot laboratory.

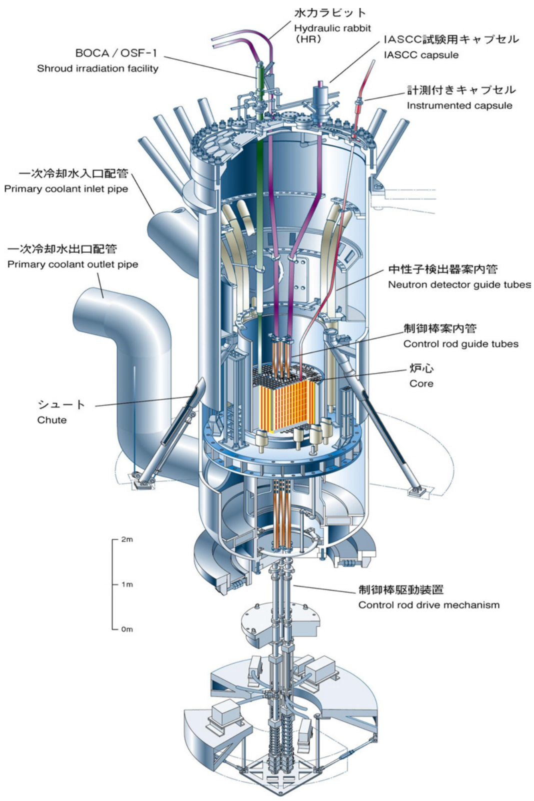

Fig.2 Cutaway view of reactor.

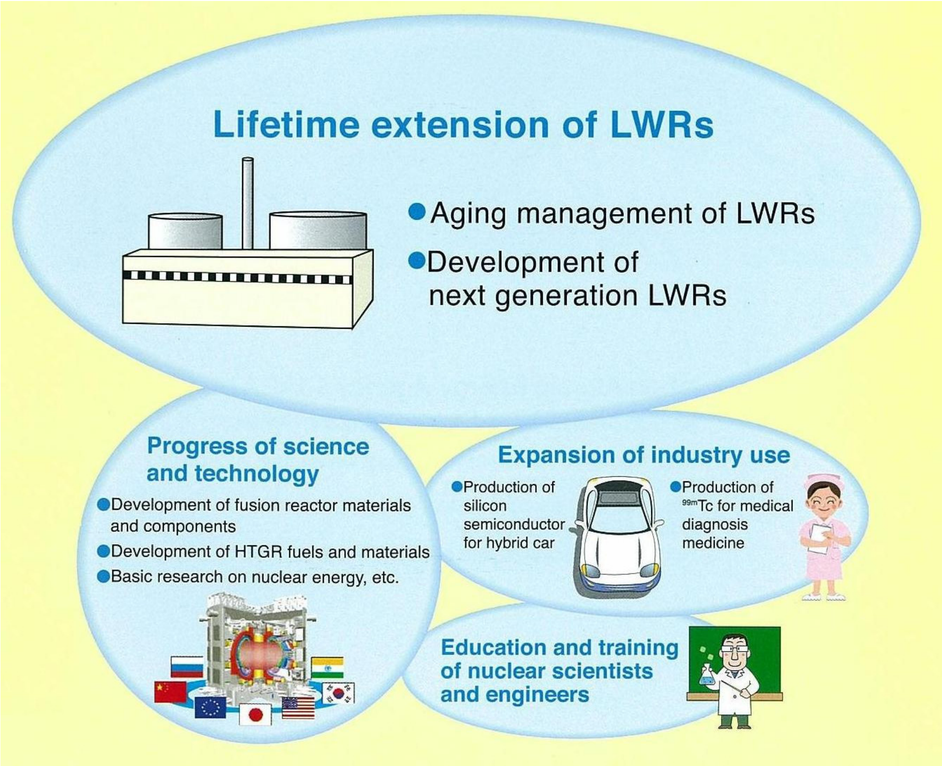

Fig.3 Expected role of the new JMTR.

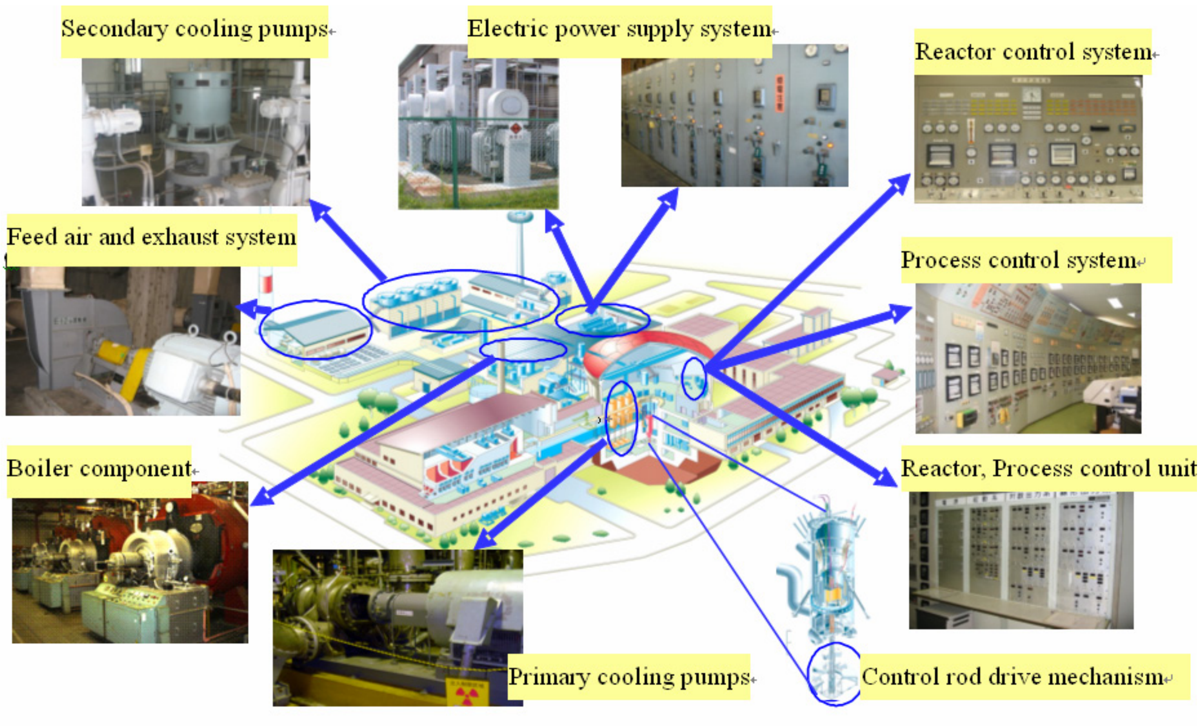

Fig.4 Replacement of reactor components.

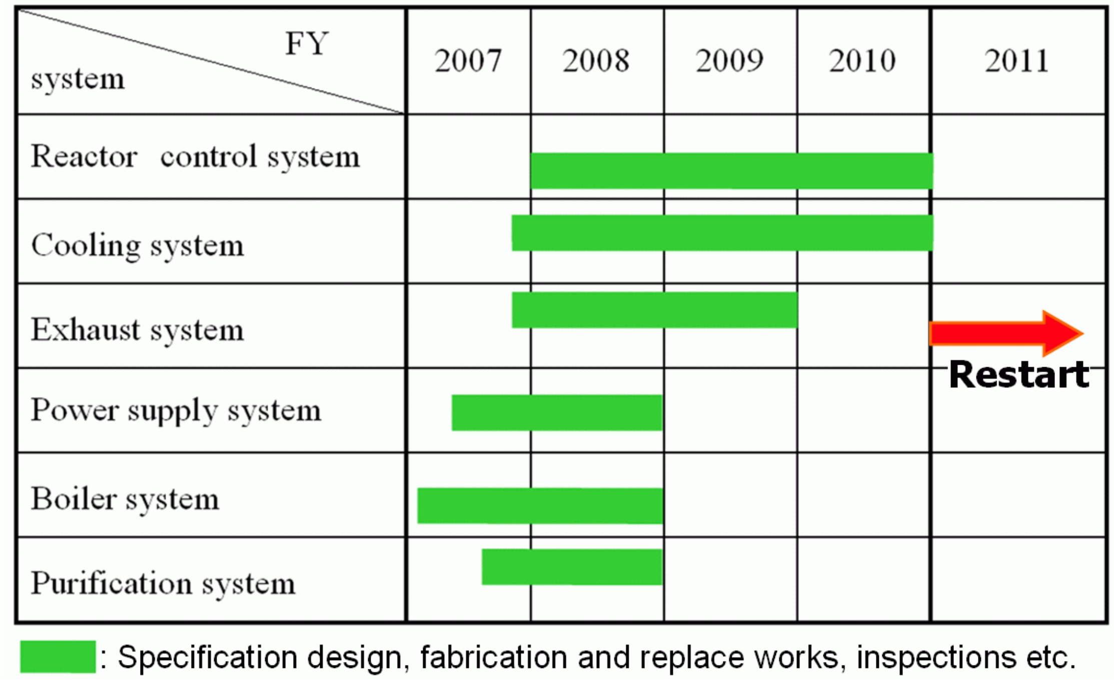

Fig.5 Component replacement schedule.

2.2 RECORD OF SYSTEM UPGRADE AND AGEING MANAGEMENT OF HANARO

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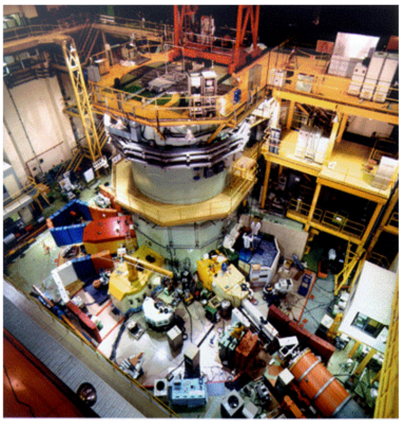
HANARO is a powerful neutron source providing important nation-wide benefits, including neutron beam research, radioisotope (RI) supply, and medical and industrial applications. Its operation started in 1995 and its operation-day reached 2000 days in the April of 2008. During these 13 years, various activities were conducted for the improvement of system upgrade and the ageing management. The system upgrade activities include the improvements of reactor systems to resolve the issues found during the power operation and those to integrate the new experimental facilities such as a fuel test loop and the irradiation facilities. HANARO is a relative young facility but it is not in the exception in view of ageing management. The integrity of the structure components including the reactor vessel was examined bases on the ISI plan. The major equipments of the primary cooling system were over-hauled. The safety of the reactor building was examined and some repair was conducted. This presentation provides the summary of these activities and the further ageing management plan for the coming 10 years.

Record of System Upgrade & Ageing Management of HANARO



Nov. 5, 2008

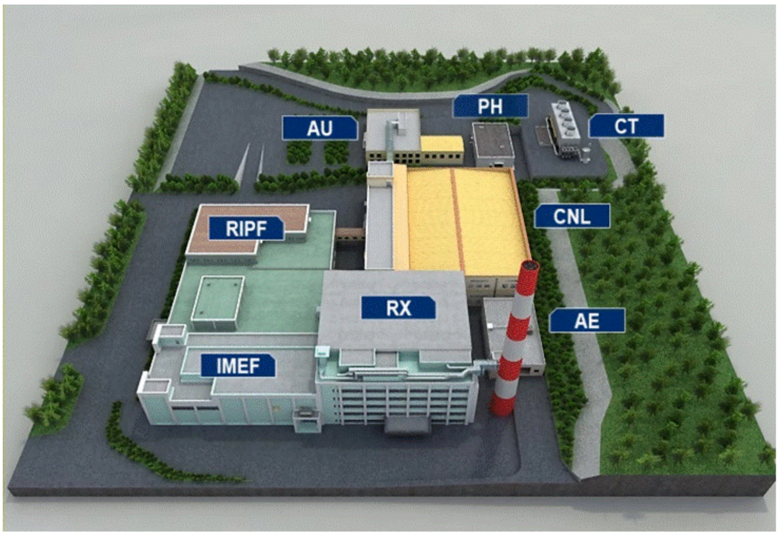
In-Cheol LIM

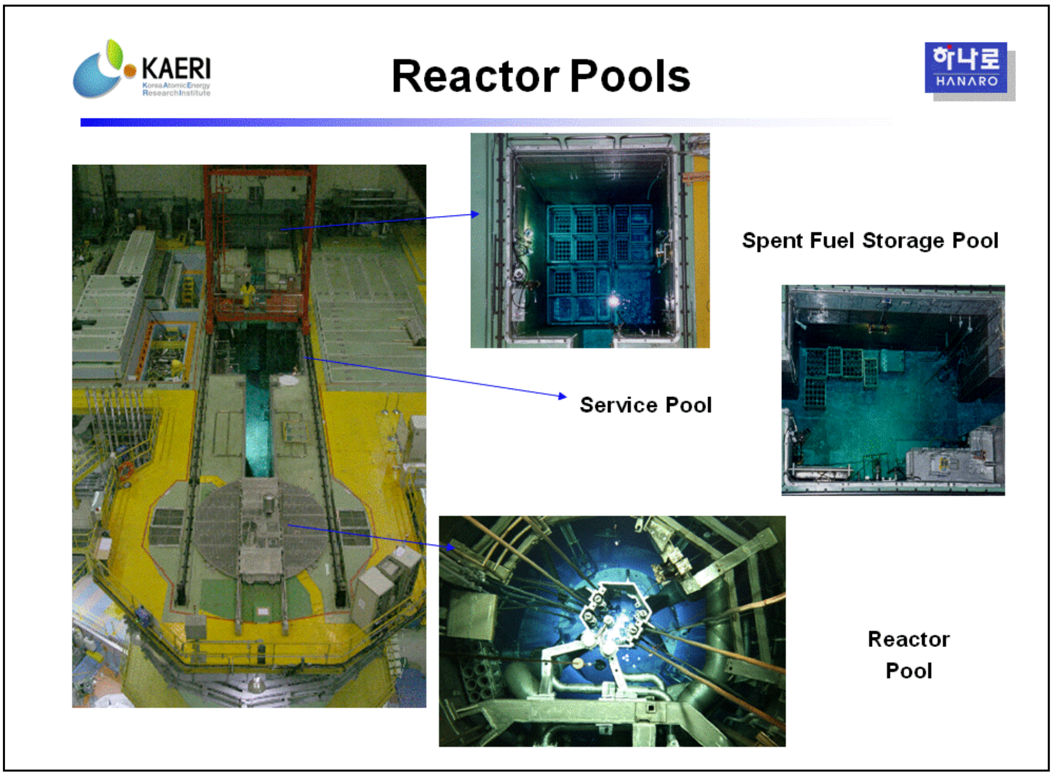
Korea Atomic Energy Research Institute

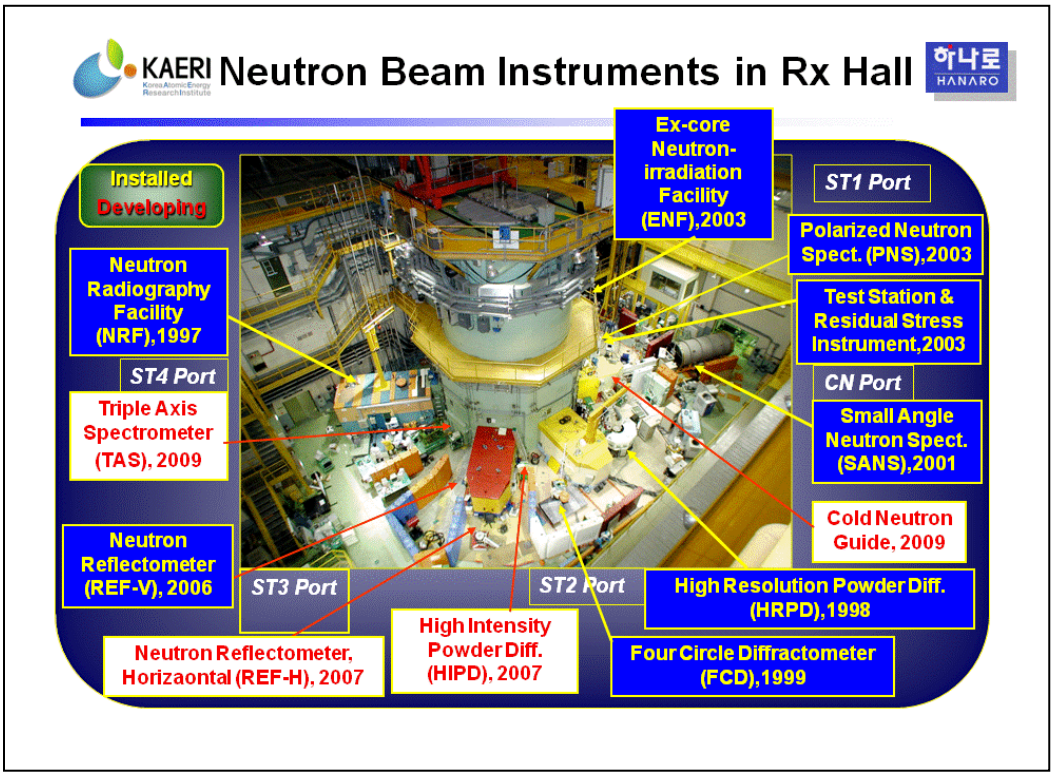
Contents

- Introduction to HANARO
- Characteristics of HANARO
- Chronology
- System Upgrade and Ageing Management
- Future Plan

HANARO Complex



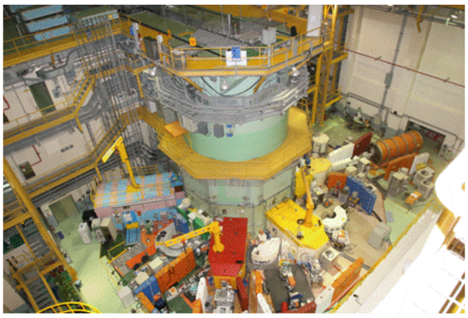

KAERI
Reactor Pools
하나로 HANARO
Spent Fuel Storage Pool
Service Pool
Reactor Pool


KAERI
Neutron Beam Instruments in Rx Hall
하나로 HANARO
Installed
Developing
Ex-core Neutron-irradiation Facility (ENF),2003
ST1 Port
Polarized Neutron Spect. (PNS),2003
Test Station & Residual Stress Instrument,2003
CN Port
Small Angle Neutron Spect. (SANS),2001
Cold Neutron Guide, 2009
High Resolution Powder Diff. (HRPD),1998
Four Circle Diffractometer (FCD),1999
ST2 Port
High Intensity Powder Diff. (HIPD), 2007
Neutron Reflectometer, Horizaontal (REF-H), 2007
ST3 Port
Neutron Reflectometer (REF-V), 2006
Triple Axis Spectrometer (TAS), 2009
ST4 Port
Neutron Radiography Facility (NRF),1997

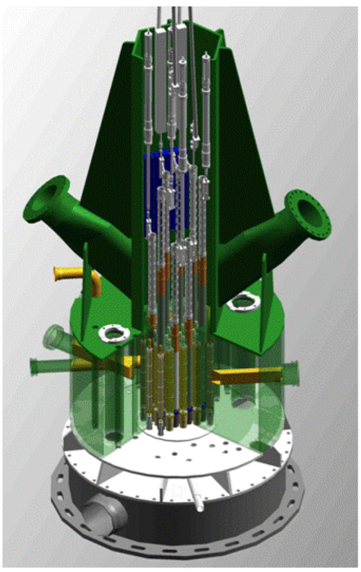
HANARO, Past and Present

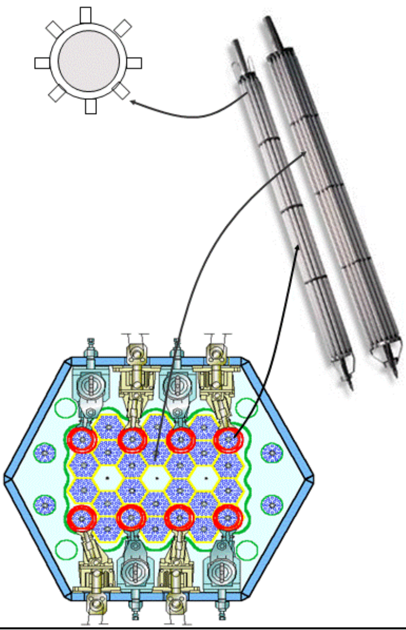
Feb., 1995

March, 2008

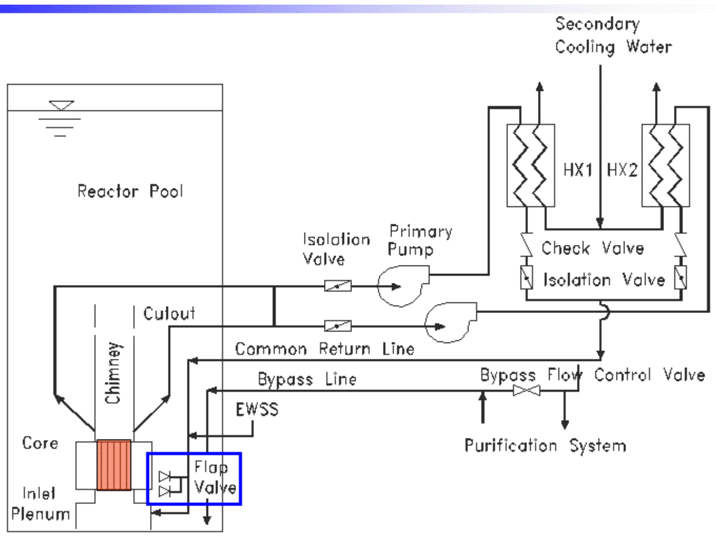


Reactor Structure and Fuel

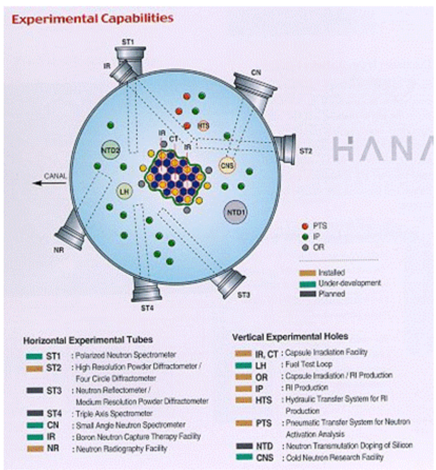




Primary Cooling System



Characteristics of HANARO



Design Feature

- Type Open-tank-in-pool
- Power 30MWth
- Coolant Light Water
- Reflector Heavy water
- Fuel Materials enriched U_3Si, 19.75%
- Absorber Hafnium
- Reactor Building Confinement
- Typical flux at port nose 2×10^{14} nv
- 7 horizontal ports & 36 vertical holes
- Vertical hole for cold neutron source
- Operation Cycle 24 days@5 weeks

Utilization

- ❑ Beam Experiments
- ❑ Fuel and Material Irradiation Tests
- ❑ RI Production
- ❑ Neutron Activation Analysis
- ❑ Neutron Radiography
- ❑ Neutron Transmutation Doping

Status of Experimental Facilities

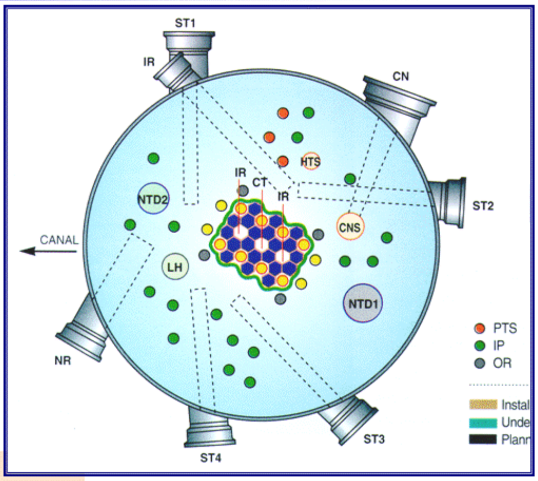
Vertical Holes

Installed

IR,CT: Capsule Irradiation Facility
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

Under-development

IR: Fuel Test Loop
CNRF : Cold Neutron Research Facility



Horizontal Tubes

Installed

ST2 : High Resolution Powder Diffractometer, Four Circle Diffractometer
NR : Neutron Radiography Facility
CN : Small Angle Neutron Spectrometer
IR : Excore Neutron-irradiation Facility for BNCT & DNR
ST1 : Polarized Neutron Spectrometer, PGAA, RSI
ST3 : Vertical Reflectometer
ST3 : Horizontal Reflectometer
ST3 : High Intensity Powder Diffractometer

Under-development

ST4 : Triple Axis Spectrometer

KAERI

Chronology

HANARO

- 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 15MW Power Operation
- 1999 DEC 22MW Power Operation
- 2004 NOV 30MW (Design Power) Power Operation
- 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 (To be opened for users in May 2010)

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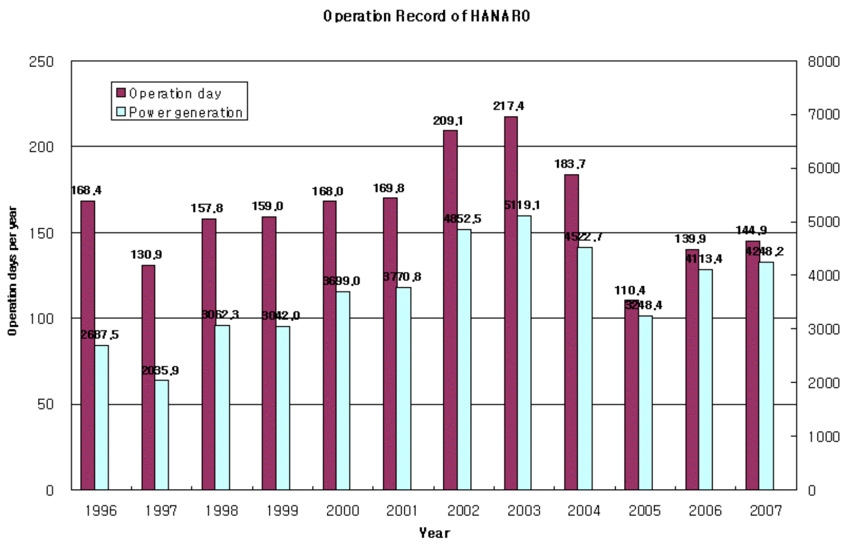
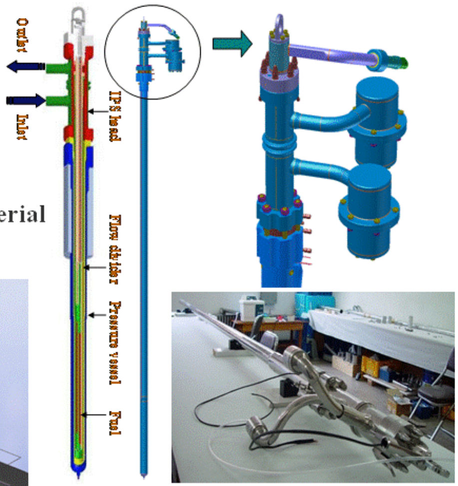
Operation Record

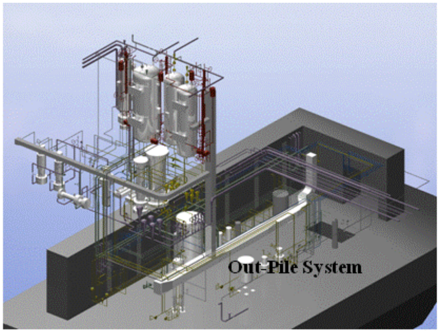
HANARO



Fuel Test Loop (FTL)

- **Under commissioning**
- **Applications**
  - Integral Fuel Performance Tests
  - Fuel Qualification Tests
  - Water Chemistry and Corrosion Tests
  - Non-fissile Tests of Pressure Tube Material

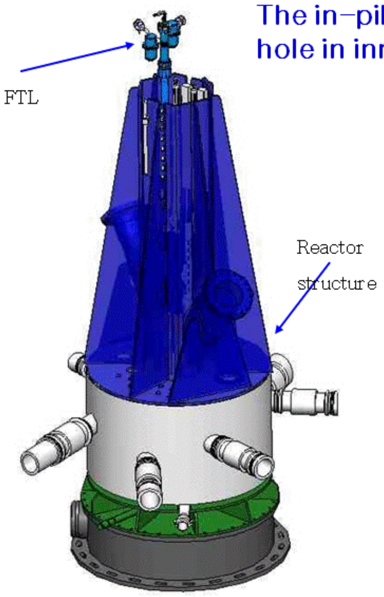


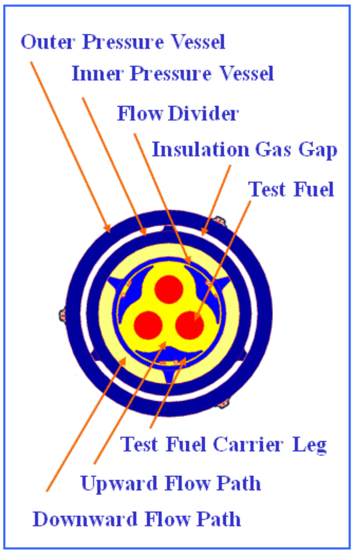


In-Pile Section
- Design Pressure : 17.5 MPa
- Design Temperature : 350 ℃

Fuel Test Loop

The in-pile section of installed into IR1 hole in inner core.

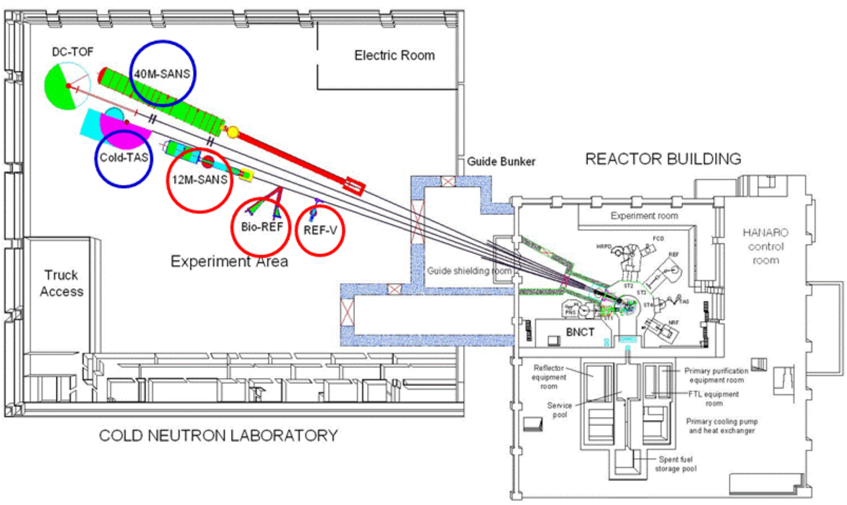




Cold Neutron Research Facility

- **Project :** ***Development of the Cold Neutron Research Facility and Utilization Technology***
- **Project Period : 2003. 7 – 2010. 4**
- **Major parts of the CNRF project**
  - Cold Neutron Source and System Utilities (CNS)
  - Neutron Guides (NG)
  - Neutron Spectrometers (NS)
  - Users program and international collaboration
  - *Cold Neutron Laboratory (CNL)*
    - ✓ ***To be finished by May 2008***

Instrument Layout for CNRF



○ : New instrument　　○ : Instruments from Rx hall

Major System Upgrade

- Installation of hot-water layer system
- Replacement of NaI detectors with delayed neutron detectors for failed fuel detection
- Installation of gamma ion chambers for power measurement and trip signal replacing the thermal power measurement system
- Upgrade of OWS (Operator Work Station)
  - Installation of Window Based System in 2002
  - Replacement in 2007 to integrate FTL system
- Upgrade of RMS data acquisition system in 2007
- Installation of a steel compartment to confine D_2O system in 2005
- Installation of steel tanks in the reactor hall for the temporary storage of pool water
- Re-structuring of the user rooms in the reactor hall for the improvement in fire-resistance

Ageing Management of Reactor Structure Components

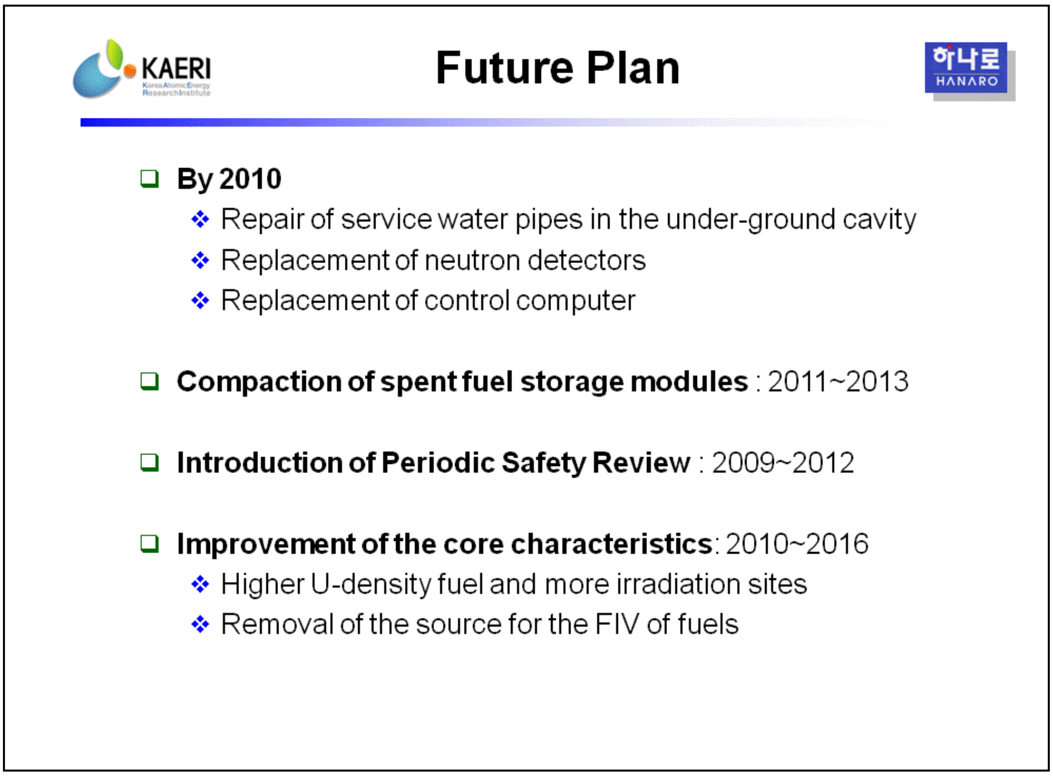
- **ISI plan**
- **2000 : 1st Visual inspection**
- **2004**
  - Measurement of inner-shell straightness
  - Visual inspection of SOR/CAR and fuel channels
- **Extended endurance test of SOR for life extension**

Ageing Management of Cooling System

- **Preventive maintenance of primary pumps**
  - 2004: No.2, 2005: No.1
- **Maintenance of primary heat exchangers**
  - 2004: Removal of scale in the secondary side of HX02
  - 2005: Removal of scale in the secondary side of HX01
- **Maintenance of reflector pumps**
  - 2004: Replacement of the bearing housing of pump No. 1
  - 2005: Preventive maintenance of pump No.2

Ageing Management of Other System

- **Overhaul of compressed air system 2006**
- **Electrical system**
  - Replacement of AC120V & DC24V UPS in 2005
  - Overhaul in 2006 & 2007
- **Building**
  - Safety review and repair of reactor building and cooling tower building in 2006


KAERI
Future Plan
하나로
HANARO
By 2010
Repair of service water pipes in the under-ground cavity
Replacement of neutron detectors
Replacement of control computer
Compaction of spent fuel storage modules : 2011~2013
Introduction of Periodic Safety Review : 2009~2012
Improvement of the core characteristics: 2010~2016
Higher U-density fuel and more irradiation sites
Removal of the source for the FIV of fuels

2.3 STATUS OF IRRADIATION TECHNOLOGY DEVELOPMENT IN JMTR

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ABSTRACT

Irradiation Engineering Section of the Neutron Irradiation and Testing Reactor Center was organized to development the new irradiation technology for the application at JMTR re-operation. The new irradiation engineering building was remodeled from the old RI development building, and was started to use from the end of September, 2008.

Advanced in-situ instrumentation technology (high temperature multi-paired thermocouple, ceramic sensor, application of optical measurement), ^{99}Mo production technology by new Mo solution irradiation method, recycling technology on used beryllium reflector, and so on are planned as the development of new irradiation technologies. The development will be also important for the education and training programs through the development of young generation in not only Japan but also Asian counties.

In this report, as the status of the development the new irradiation technology, new irradiation engineering building, high temperature multi-paired thermocouple, experiences of optical measurement, recycling technology on used beryllium reflector are introduced.

INTRODUCTION

The JMTR has been widely used for the irradiation tests to meet user requirements, and many types of irradiation techniques have been developed since started JMTR irradiation service from 1971. Recent irradiation research needs more accurate control and evaluation of environmental parameters such as temperature, neutron flux/fluence, surrounded condition of sample and so on.

The reactor facilities are refurbishing during four years from the beginning of FY 2007, and the re-operation of the new JMTR will start in FY 2011 as scheduled. The new JMTR will be operated for a period of about 20 years until around FY 2030 [1].

The new JMTR is planned to contribute the worldwide research fields and industrial fields. Expected roles of new JMTR are the lifetime extension of LWRs (aging management, development of next generation), progress of science and technologies (development of fusion reactor and HTGR, basic research), expansion of industrial use (production of Si semiconductor, medical RI) and education and training. To carry out these irradiation tests, the attractive irradiation tests using advanced technologies such as a new instrument technology under neutron irradiation and a new PIE technology are proposed as a target of new JMTR [1].

As a status of the development for new irradiation technology, mentioned in this paper are the new irradiation engineering building, high temperature multi-paired thermocouple and experiences of optical measurement as advanced instrumentation, recycling technology on used beryllium reflector.

TECHNOLOGY DEVELOPMENT PLAN

Outline of the technology development plan is shown in Fig. 1. The irradiation technology for LWRs and ^{99}Mo production using the hydraulic rabbit irradiation facility is developing aiming at the use of the re-operated JMTR. ^{99}Mo production by molybdenum solution irradiation method is also developing as a future production technology. Above mentioned technology development is introduced by the other paper in this seminar. Development of many kinds of instrumentation will be carried out as an advanced technology taking a long term.

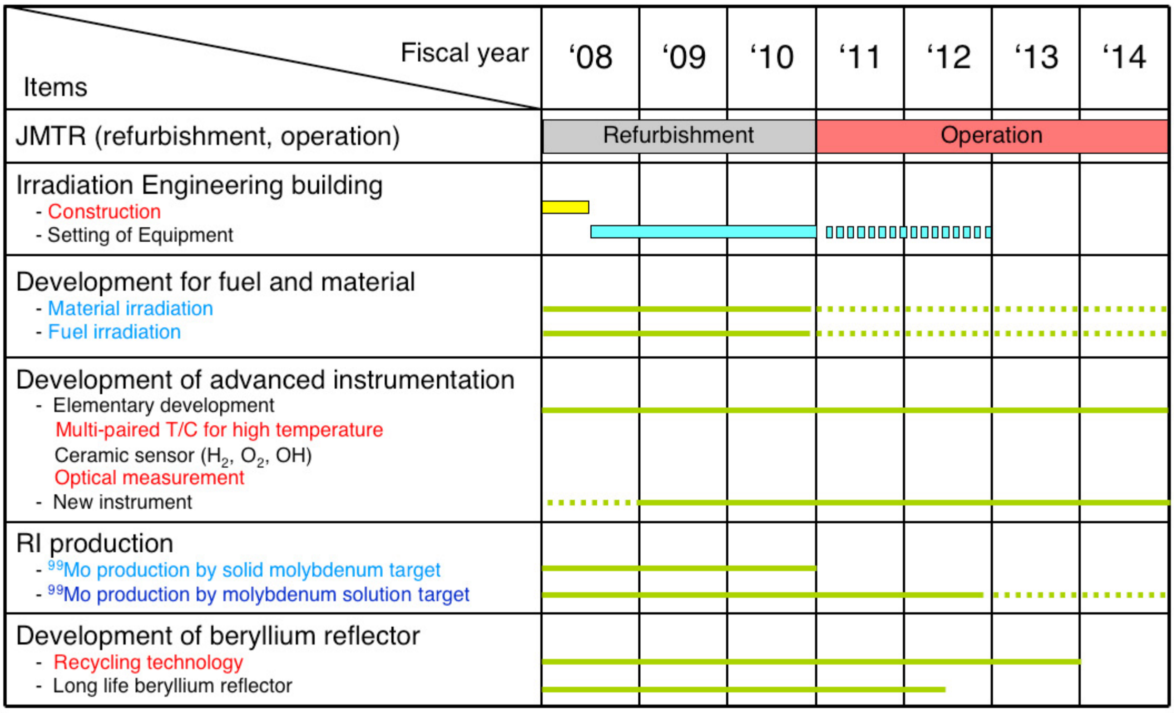

Fig. 1. Technology development plan.

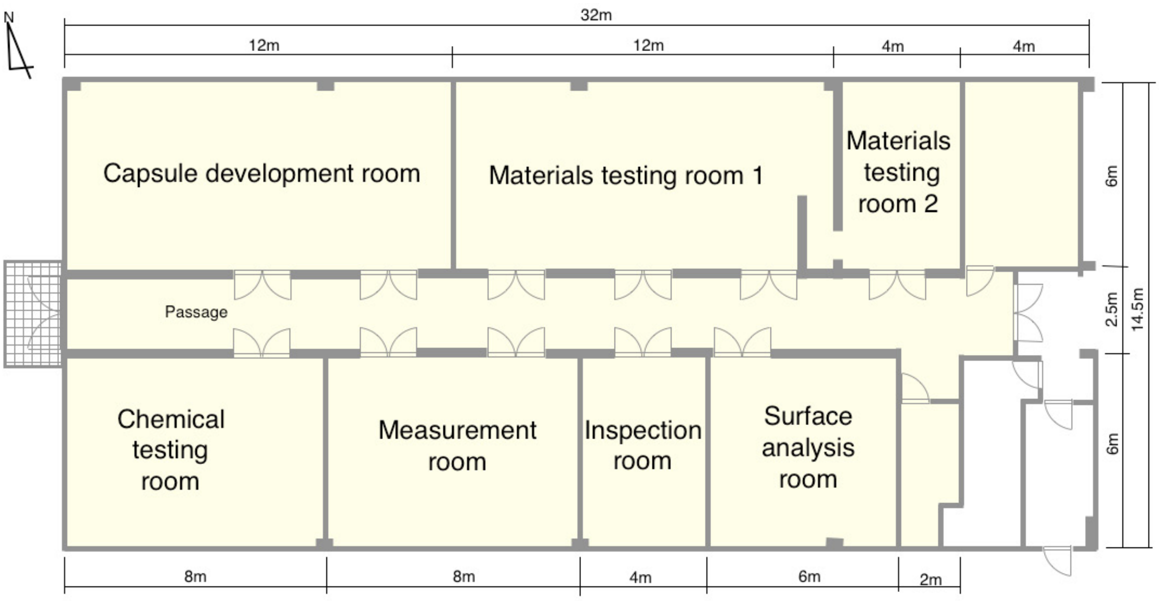

Fig. 2. Layout of new irradiation engineering building.

To carry out the cold tests for irradiation capsule development, new irradiation engineering building was remodeled from the old RI development building. Layout of new irradiation engineering building is shown in Fig. 2. The construction was completed in the end of August, 2008. Photographs of passage and entrance of the building before and after construction are shown in Fig. 3 and Fig. 4.

Fig. 3. Passage of new irradiation engineering building.

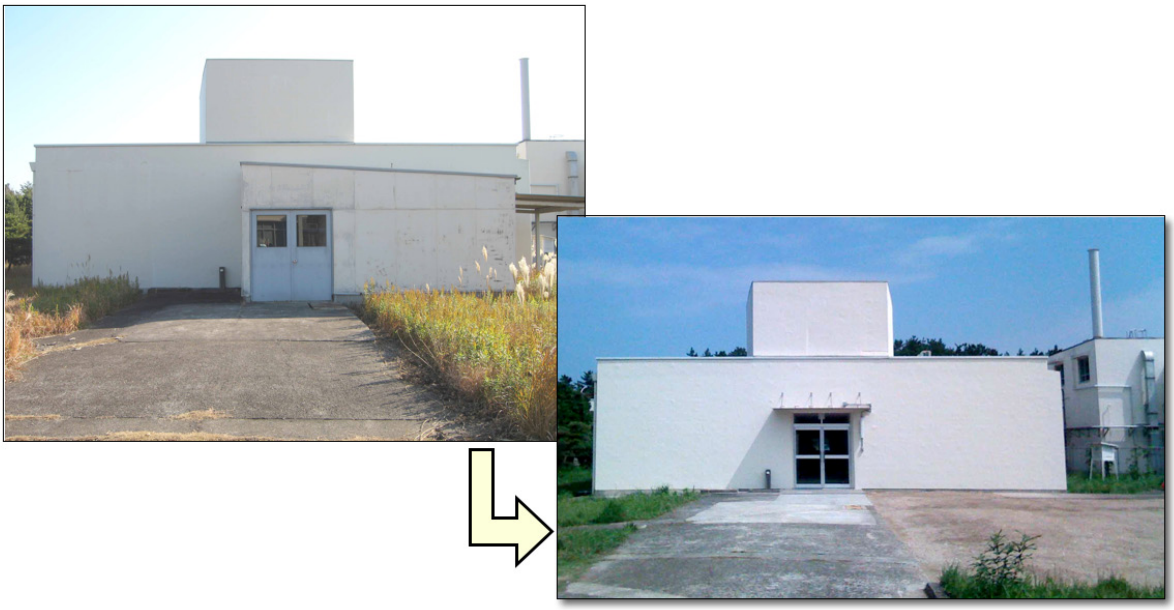

Fig. 4. Entrance of new irradiation engineering building.

ADVANCED INSTRUMENTATION TECHNOLOGY

Multi-paired T/C for high temperature

Maximum 7 points temperatures by K type multi-paired T/C have successfully measured. It was soundly measured for 17,000 hours at 400˚C (maximum 700˚C) in the irradiation test of tritium breeder pebbles bed for the fusion blanket. Outline of these conventional multi-paired T/C is shown in Fig. 5 and Table 1.

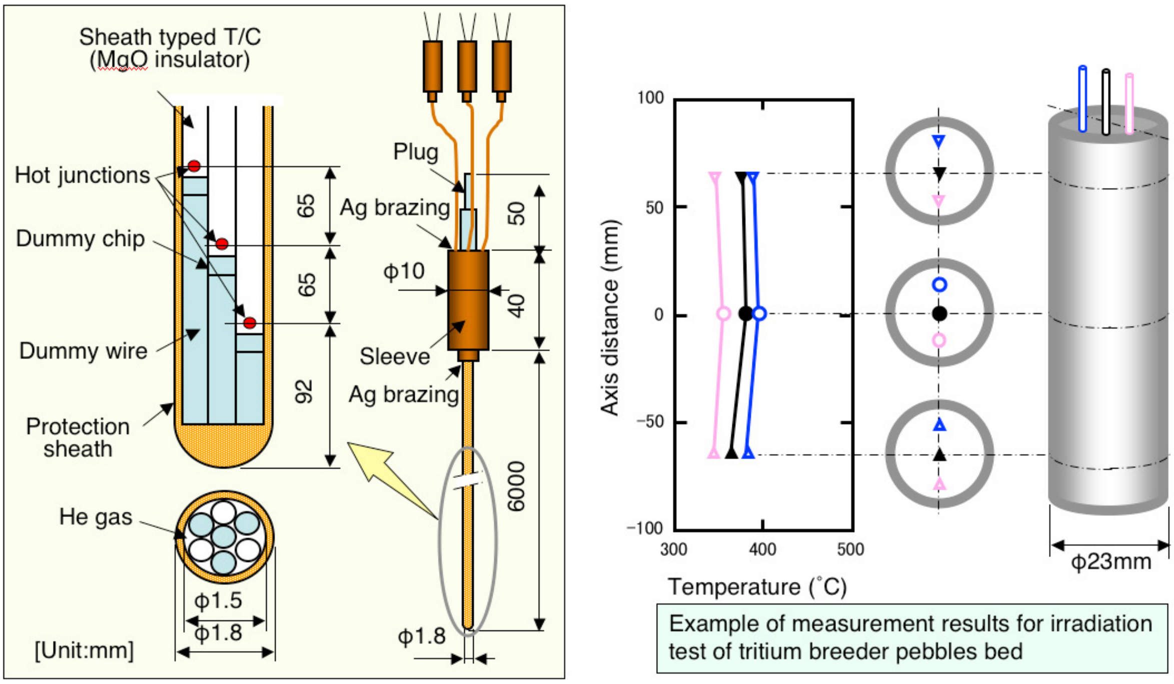

Fig. 5. Example of structure and measurement for K type multi-paired T/C.

However, being necessary of higher temperature irradiation tests like the LWRs fuel, the development of new multi-paired T/C for the higher temperature measurement is carrying out. For the first step, N (nicrosil-nisil) type multi-paired T/C usable at over 1000℃ under the neutron irradiation, was developed and the trial fabrication test was conducted [2]. Main specifications of N type multi-paired T/C is shown in Table 1, and the trial fabrication test was carried out in the same specifications of K type multi-paired T/C. Accuracy for the manufactured axis position of hot junction and temperature measurement was verified by the trial fabrication test, and these results are shown in Fig. 6 and Fig.7.

Table 1. Main specifications of multi-paired T/C

Items	Conventional	New developed
Type	K(C/A)	N(Nicrosil-Nisil)
Maximum temperature	~700˚C	~1100˚C
Protection sheath diameter	ϕ 1.8mm	ϕ 1.8mm
Minimum distance of hot junctions	20mm	20mm
The number of hot junctions	3-7points	3-7points
Manufacture accuracy of hot junction positions	±1mm	±1mm

Positions of hot junctions		A	B	C
Distance between hot junctions (designed value, mm)		50.0	30.0	30.0
N type Multi-paired T/C (measured value,mm)	No.1	49.0	30.0	30.0
	No.2	49.0	30.5	30.0
	No.3	49.0	29.5	29.5

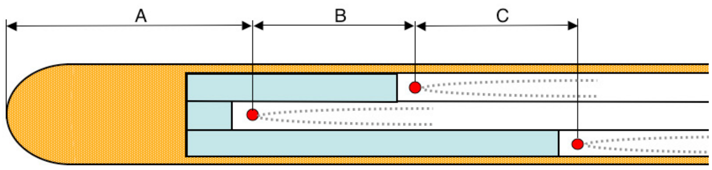

Fig. 6. Accuracy for the manufactured axis position of hot junction.

It is clear that accuracy of the hot junction axis position is ±1mm, and accuracy of s temperature measurement is ±1% up to 1050˚C. These results also shows that fabrication of N type multi-paired T/C is possible with same specifications of K type multi-paired T/C. For the higher temperature measurement, the W/Re type multi-paired T/C will be started as an advanced technology in near future.

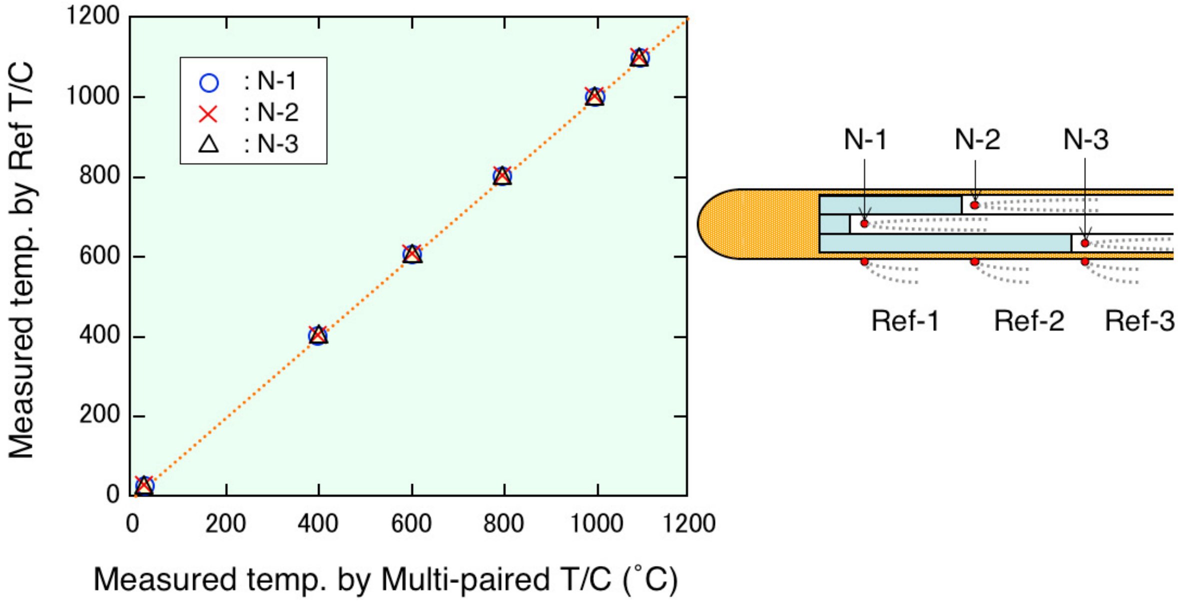

Fig. 7 Accuracy of temperature measurement.

Optical measurement

Optical measurement is attractive method because of the small sensor using optical fiber and getting many information from sample (or surrounded gas, etc.) under the neutron irradiation. Therefore, many irradiation tests were carried out in the JMTR using the optical fiber, optical comportments like as windows and mirrors, so on. The neutron irradiation tests on the window and mirror materials proposed as optical elements for plasma diagnostic components for fusion reactor are introduced as an example.

Specimens were sapphire as the window material and an aluminum Corner Cubic Reflector (CCR) for mirror material. These materials were irradiated by the JMTR, and transmission and refraction spectrum were observed [3]. Special irradiation capsule was developed for this measurement, so called "in-situ optical measurement capsule". Outline of capsule is shown in Fig. 8 and Fig. 9. Capsule mainly consisted of 2 axis driving system, sample stage and CCR. Light axis was adjusted by the two axes driving system to compensate the shift by thermal expansion of capsule.

Result of irradiation test for the windows is shown in Fig 8. Induced loss of sapphire increased with neutron fluence, and transmission spectrum was affected by neutron irradiation at low temperature even in low neutron fluence. Induced loss of reflection spectrum is shown in Fig 9. The change of reflectivity for Al-CCR could not be observed (induced loss at short wavelength might be caused to induce loss of optical fiber). These irradiation tests were unique in the world, and results contributed ITER design.

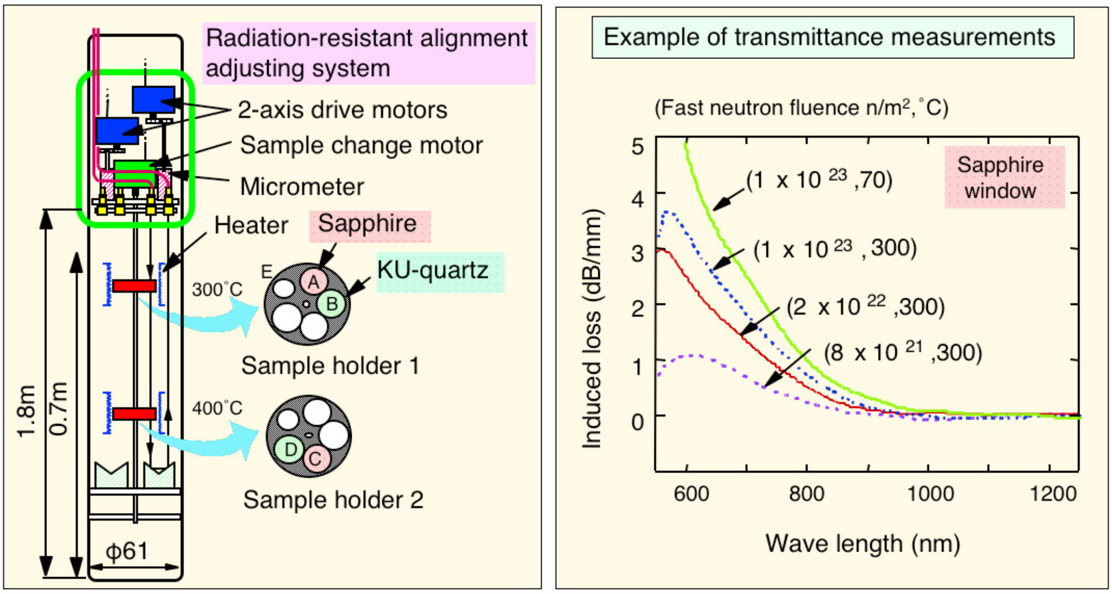

Fig. 8. Capsule and measurement results of window materials.

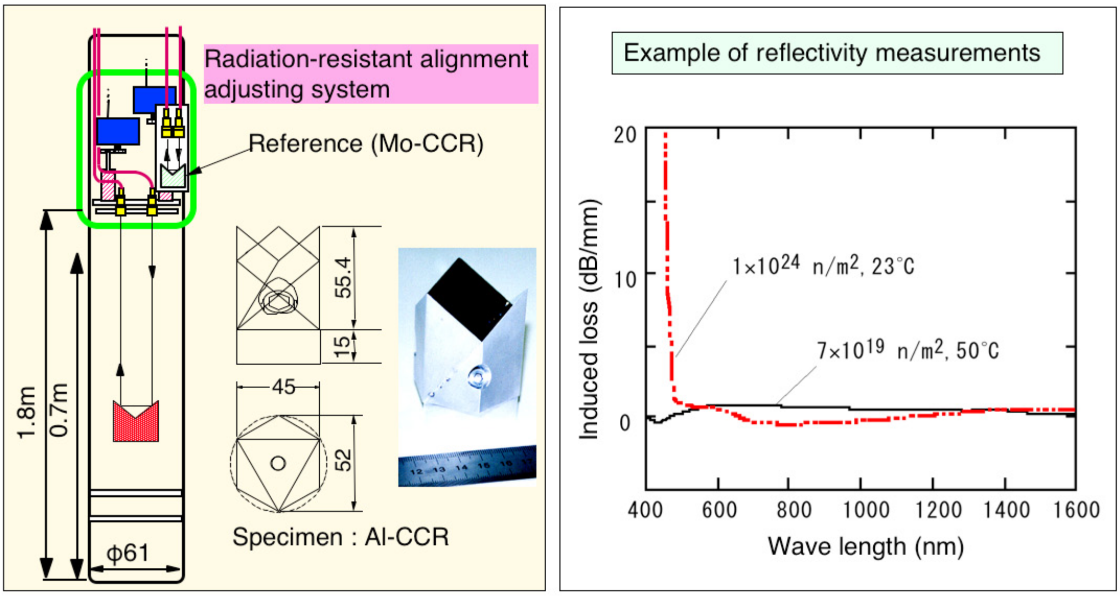

Fig. 9. Capsule and measurement results of mirror material.

Example of induced loss for optical fiber by the neutron irradiation is shown in Fig 10 [4,5]. Generally, as above-mentioned, the induced loss at short wavelength of optical fiber increases by irradiation defects, and furthermore, it is impossible to use in the IR region. Therefore, development of new light guide will be necessary for the optical measurements, because information of these wide wavelengths includes information of the electronic state and molecule vibration for samples. Another point of view, insensitive region by neutron irradiation exists on about 1000 nm. This region will be usable as the image observation, displace measurement, etc. New development of optical measurement will be started at these points of view.

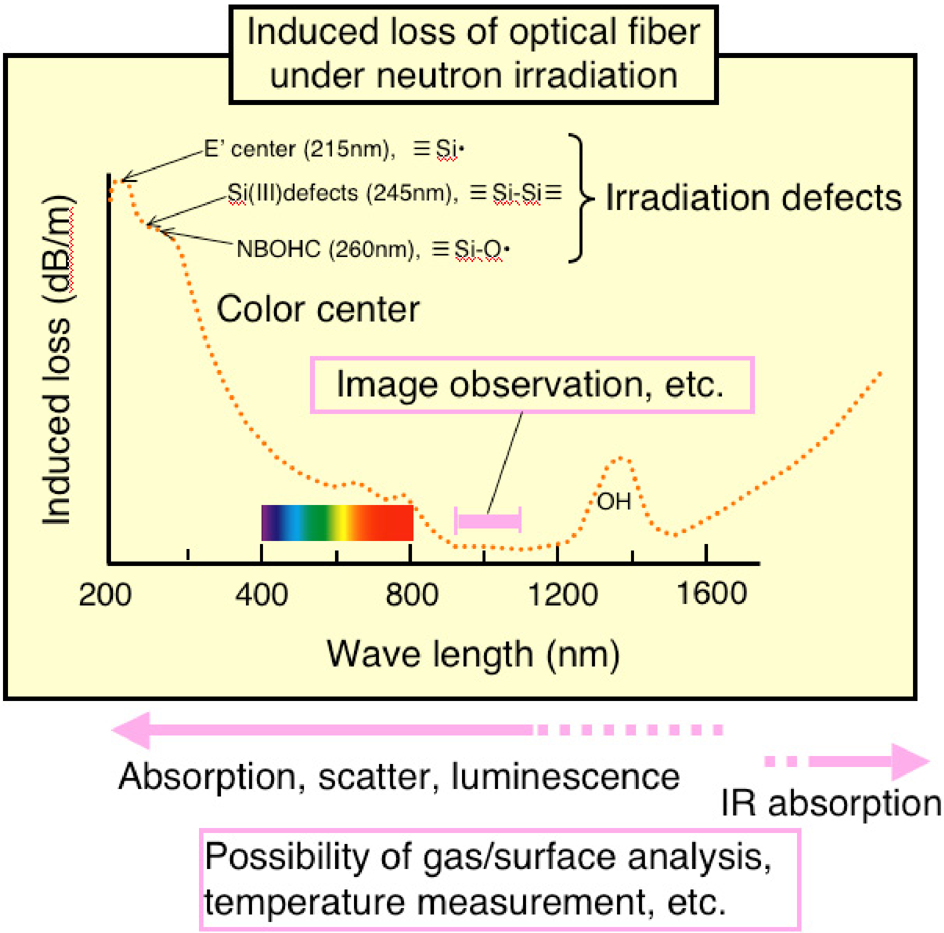

Fig. 10. Example of induced loss by the neutron irradiation.

DEVELOPMENT OF BERYLLIUM REFLECTOR

Beryllium has been utilized as a moderator and/or reflector in a number of materials testing reactors. However, it is difficult to reprocess irradiated beryllium because of the high induced radioactivity. Disposal has also been difficult because of toxicity issues and special nuclear material controls. Therefore, study of lifetime extension and reprocessing of beryllium reflector had been started [6].

For the lifetime extension of beryllium reflector, the discussion of fundamental changes of design for the beryllium reflector frame and the choice of material grade were started, and irradiation tests will be planed with specialist group.

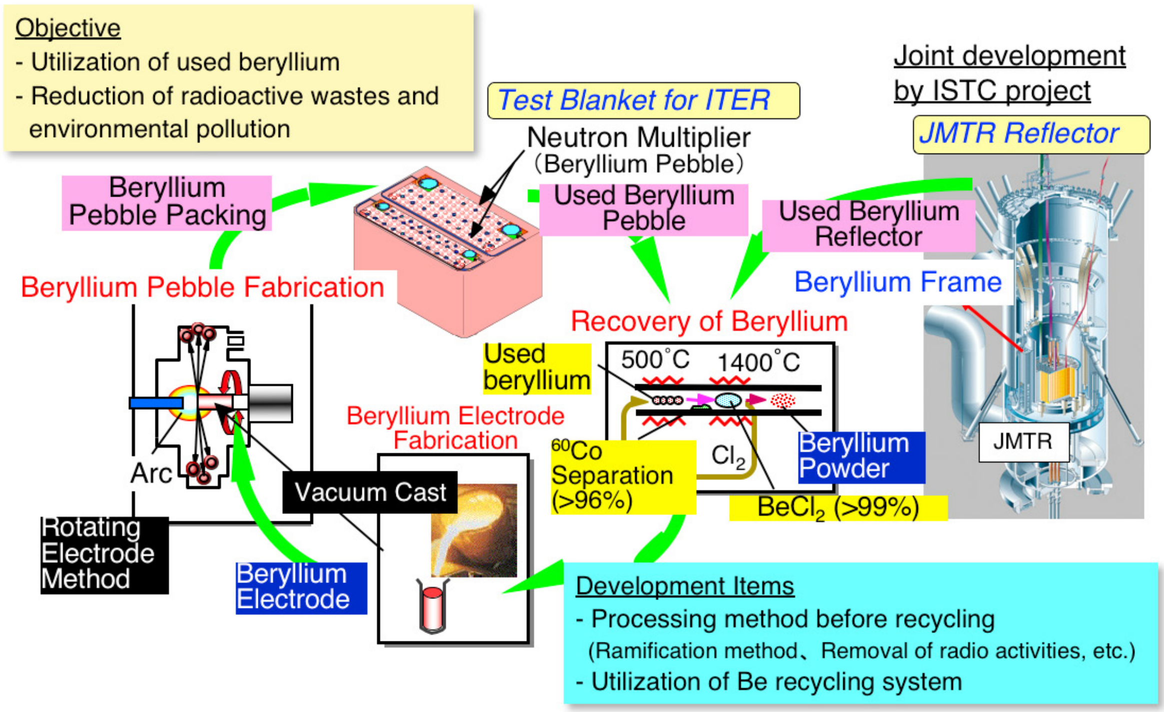

Fig. 11. Concept of recycling of irradiated beryllium reflectors.

For the reprocessing of the irradiated beryllium, the concept of recycling of irradiated beryllium reflectors is shown in Fig. 11. Recycling process consists of (1) beryllium separation from activated nuclides as impurities in the beryllium, (2) beryllium purification from recovered beryllium compounds, and (3) re-fabrication of metallic beryllium. The beryllium pebbles for fusion reactors will be fabricated with the purified beryllium.

Preliminary tests on beryllium separation and purification steps using irradiated beryllium were carried out as the initial stage. The beryllium separation utilizes the reaction between beryllium and chlorine, and beryllium chloride ($BeCl_2$) with sufficiently low melting temperature is generated by this reaction. A kg-scale demonstration test with used beryllium is proposed under the ISTC project in Kazakhstan collaborated by Japan and EU.

CONCLUSIONS

To propose attractive irradiation tests in the new JMTR, development of the advanced irradiation technology is planed and started. The construction of new irradiation engineering building for the cold tests aiming at the irradiation capsule development was completed. Status of the development of advanced irradiation technology such as N type multi-paired T/C, optical measurement, recycling technology on used beryllium reflector, etc. are introduced.

These activities are also proposed as education and training programs through the development for young generation not only Japanese but also Asian countries in the FNCA meeting.

ACKNOWLEDGMENTS

The authors greatly appreciate the helpful comments on this paper by Dr. M. Ishihara, deputy director of Neutron Irradiation and Testing Reactor Center.

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Reactors", International Symposium on Material Testing Reactors, JAEA-Oarai, Japan, July 16-17, 2008.

2.4 NUCLEAR FUELS AND MATERIALS IRRADIATION TECHNOLOGY DEVELOPMENT IN HANARO

Bong Goo Kim, Kee-Nam Choo, Jae Min Sohn, Man-Soon Cho, Young-Hwan Kang, Yoon-Taek Shin, Seng-Jae Park and Young-Ki Kim

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The equipments for the irradiation tests of nuclear fuels and materials in the HANARO are classified into a capsule and an FTL (Fuel Test Loop). Capsules for irradiation tests of nuclear fuels and materials in HANARO have been developed. Also, extensive efforts have been made to establish the design/manufacturing and irradiation technologies for irradiating nuclear fuels and materials by using these capsules and their control systems, which should be compatible with HANARO's characteristics. Other devices consisting of a fixing of the capsule during an irradiation test in the HANARO, a cutting and a transporting of the capsule main body after an irradiation test were also developed. These capsules and others have been actively utilized for various material irradiation tests requested by users. Based on the accumulated experiences and a user's sophisticated requirements, capsules for a creep test and a fatigue test of materials during an irradiation in HANARO have been developed. And, the irradiation plans related to developing the Gen-IV reactor systems by using capsules in HANARO will mean more emphasis on the development of capsules by focusing on the irradiation tests of materials or nuclear fuels for Gen-IV reactor systems, such as the SFR and the VHTR. The FTL is one of the irradiation devices, which can conduct an irradiation test of a nuclear fuel in HANARO under the operating conditions of commercial nuclear power plants. The 3-test fuel rods can be irradiated in HANARO by using the FTL. The installation of the FTL was completed in March 2007. Currently, the commissioning test of the FTL is being performed. At first the FTL will be used for the irradiation test of an advanced nuclear fuel for a PWR from the end of this year. In this paper, the status and the perspective in the field of material irradiation tests in HANARO are described.

KAERI HANARO

Nuclear Fuels and Materials Irradiation Technology Development in HANARO

2008. 11. 5.

Bong Goo KIM*, Kee-Nam CHOO, Jae Min SOHN, Man-Soon CHO, Young-Hwan KANG, Yoon-Taek SHIN, Seng-Jae PARK, Sung Ho AHN, and Young Ki KIM

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2008 KAERI-JAEA Joint Seminar on Advanced Irradiation and PIE Technologies, Nov. 5th – 7th, 2008, KAERI, Daejeon, Korea

KAERI HANARO

Contents

- ❑ Fields of Utilization in the HANARO
- ❑ Irradiation Facilities/Irradiation Tests in the HANARO
- ❑ Irradiation Test Plan related to Nuclear R&D Programs in the HANARO
- ❑ Closing Remarks

KAERI HANARO

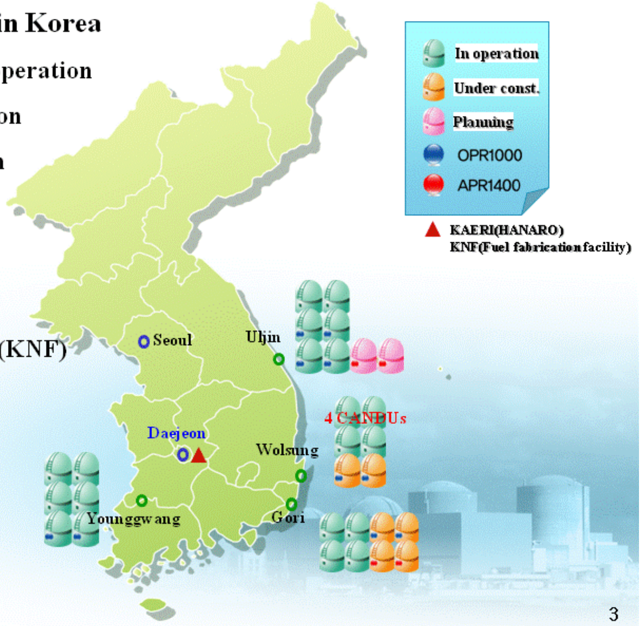
Status of Nuclear Plants in Korea

❑ Nuclear Power Plants in Korea

- 16 PWRs, 4 CNADUs in operation
- 6 PWRs under construction
- 2 PWRs construction plan

❑ Daejeon Area

- KAERI(HANARO)
- Fuel Fabrication Facility (KNF)



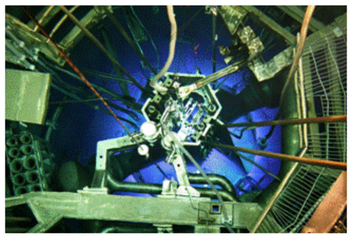
3

KAERI HANARO

HANARO (High-flux Advanced Neutron Application ReactOr)

HANARO means, in Korean, "uniqueness", which reflects the country's resolve to achieve self-reliance in nuclear technology.

HANARO Building



Panoramic views of HANARO

Reactor Hall

4

KAERI HANARO

Status of Experimental Facilities in HANARO

- Multi-purpose research reactor; 32 vertical holes & 7 horizontal beam ports

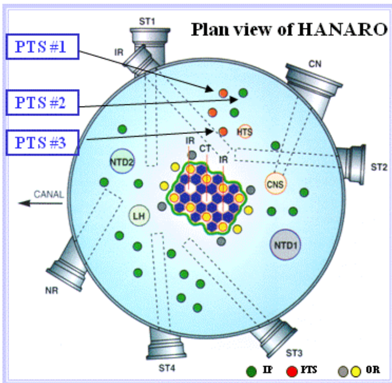
Vertical Test Holes

Installed

IR,CT : Capsule Irradiation & RI Production
OR : Capsule Irradiation & RI Production
IP, LH : RI Production
HTS : Hydraulic Transfer System for RI Production
PTS : Pneumatic Transfer System for Neutron activation Analysis
NTD : Neutron Transmutation Doping of Silicon
IR : Fuel Test Loop (under Test Operation)

Under-development

CNS : Cold Neutron Research Facility



Horizontal Beam Ports

Installed

ST1 : PGNAA, RSI Test Station, PNS
ST2 : High Resolution Powder Diffractometer, Four Circle Diffractometer
ST3 : Neutron Reflectometer-Vertical
NR : Neutron Radiography Facility
CN : Small Angle Neutron Spectrometer
IR : BNCT & Dynamic Radiography

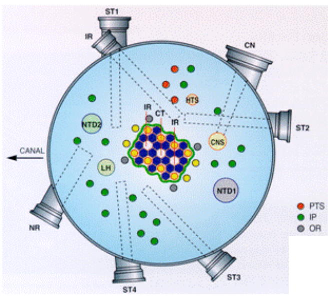
Under-development

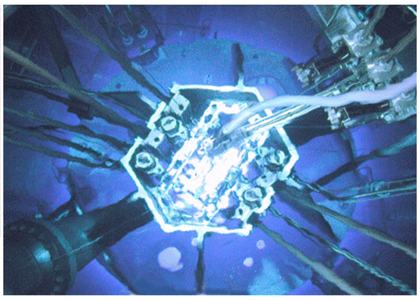
ST3 : Neutron Reflectometer-Horizonal, High Intensity Powder Diffractometer
ST4 : Triple Axis Spectrometer (thermal)

5

KAERI HANARO

Test Holes for Material Irradiation in the HANARO





Location	Hole		Inside Dia. (cm)	Neutron Flux (n/cm² . sec)		Remarks
	Name	No.		Fast (>0.82 Mev)	Thermal (<0.625 ev)	
Core	CT IR OR	1 2 4	7.44 7.44 6.00	2.10×10^{14} 1.95×10^{14} 2.23×10^{13}	4.39×10^{14} 3.93×10^{14} 3.36×10^{14}	Fuel/material irradiation, isotope production
Reflector	LH HTS IP	1 1 17	15.0 10.0 6.0	6.62×10^{11} 9.44×10^{10} 1.45×10^{9} ~ 2.20×10^{12}	9.77×10^{13} 47.97×10^{13} 2.40×10^{13} ~ 1.95×10^{14}	Fuel/material irradiation, Isotope production

6

KAERI HANARO

Fields of Utilization in HANARO

The HANARO has been operated since its first criticality in February 1995, and is now successfully utilized in many areas.

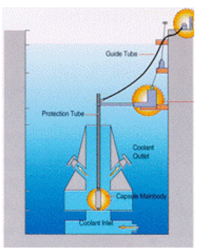
- **Fuel/Material Irradiation Tests**
  - Capsules
  - Fuel Test Loop
- **Neutron Beam Applications**
  - Scattering & Diffraction
  - Neutron Radiography
  - Ex-core Neutron Irradiation Facility (BNCT, Dynamic NR)
- **RI Production**
- **Neutron Activation Analysis**
- **Neutron Transmutation Doping of Semiconductor**

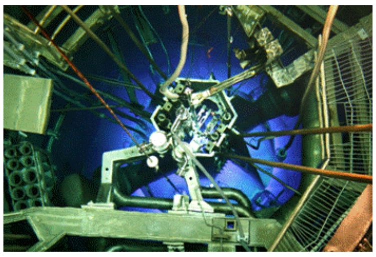
7

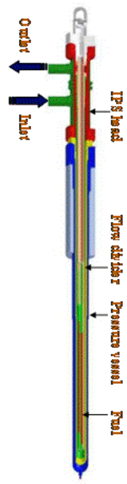
KAERI HANARO

Irradiation Facilities in HANARO

- **Capsules**
  - Non-instrumented and instrumented capsules for materials
  - Non-instrumented and instrumented capsule for nuclear fuel
  - Creep capsule and fatigue capsules for materials
- **Fuel Test Loop (FTL)**
  - FTL Installation and commissioning test
    - Project period : '01. 12 – '09. 02
  - OPS(Out-Pile System)
  - IPS(In-Pile Test Section) for fuel irradiation under the condition of NPPs (PWR and CANDU type fuels)







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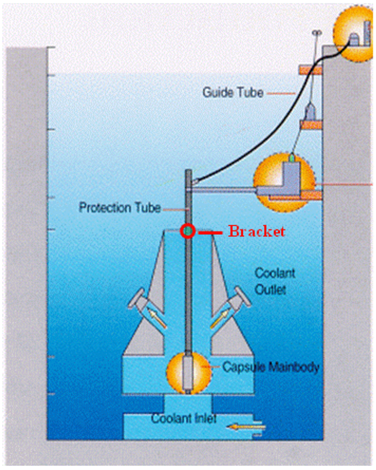
Schematic View of Capsule Irradiation in the HANARO

- ❑ **Capsule**
- ❑ **Capsule Related Facilities**
  - Temp. Control System
  - Supporting System (Robot Arm)
  - In-Chimney Bracket
  - Capsule Cutting System
  - Cask for Transfer to Hot Cell



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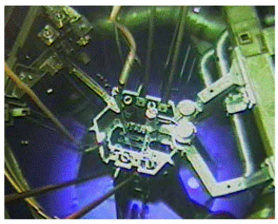
Chronicles of Irradiation Device Development

- 2007. 4 Capsule for Fatigue Test
- 2006. 11 Capsule for Irradiation Temp. & Fluence Control
- 2006. 5 Capsule for Creep Test
- 2004. 10 Capsule for precise Control of Irradiation Temp. ← 0 years Operation of HANARO (2006. 2)
- 2003. 3 Instrumented Capsule for Nuclear Fuel Irradiation Test
- 2002. 10 Verification Test of Design for CreepCapsule for Material Test
- 2002. 9 Out-of-Pile Verification Test of Instrumented Capsule for Nuclear Fuel Test
- 2000. 3. Starting of Instrumented Capsule for Nuclear Fuel Irradiation Test
- 1999. 11 Starting of Project for Users Supproting
- 1999. 5 Non-Instrumented Capsule for Nuclear Fuel Irradiation Test
- 1998. 3 Verification Test of Design for InstrumentedCapsule for Material Test
- 1997. 10~11 SAR in relation to Capsule
- 1997. 7~9 Instrumented Capsule for Material Test & Temp. Control System
- 1996. 7 Capsule Cutting Device, Instrumented Capsule for Material Test
- 1996. 1 Safety Analysis for Capsule and related Devices
- 1995. 7 Capsule Supporting System ← HANARO Initial Criticality (1995. 2)
- 1994. 12 Vibration Test of Instrumented Capsule for Material Test
- 1994. 7 Starting of Capsule for Material Test



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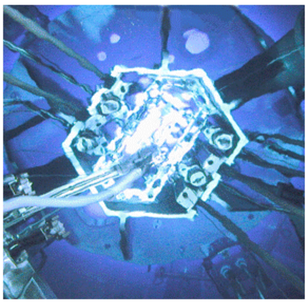
Current Application of Capsules

- **Reactor Materials Tests**
  - Reactor Vessel Materials
  - Reactor Pressure Tube Material: Zr-2.5Nb
  - Structural Materials
- **Nuclear Fuels Tests**
  - Advanced PWR Fuel
  - DUPIC Fuel
  - U-Zr Alloy
- **Fundamental Researches**
  - SPND
  - Semiconductor, Magnetic Materials
  - Neutron Dosimetry
  - Zr-1Nb-1Sn-X Alloy, Zircaloy-4



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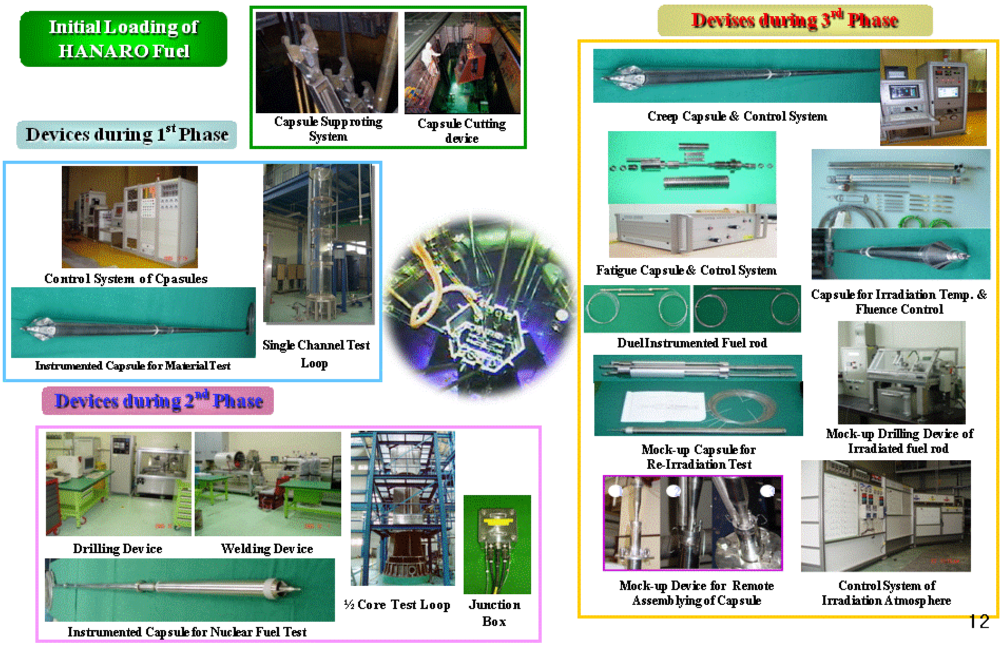
Status of Irradiation Devices



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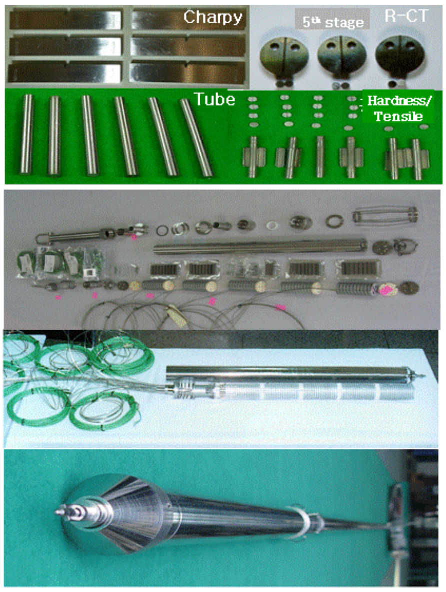
High-flux Advanced Neutron Application Reactor

Instrumented Capsule for Material 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 Heaters, 4 F/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

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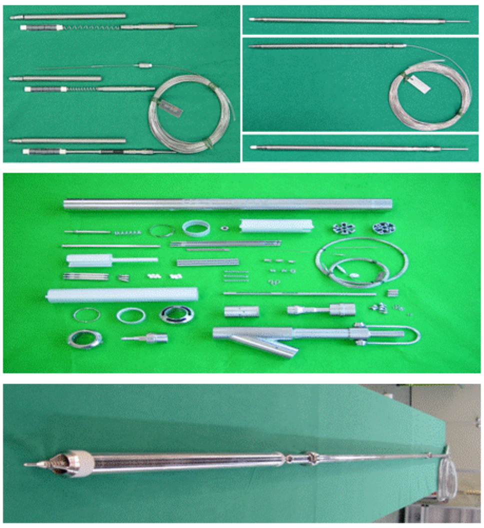
KAERI HANARO
High-flux Advanced Neutron Application Reactor

Instrumented Capsule for Nuclear Fuel



❑ 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 Using Mixed Gas(He/Ne)

❑ Applications

- ✓Fuel Pellet Irradiation Test
  - Advanced PWR Fuel
- ✓Fuel Design Data Production
  - Surface Temperature of Fuel Pellet
  - Internal Pressure of Element Fuel Rod
  - Deformation of Fuel Pellet
- ✓Fundamental Research

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Advanced Capsule for Creep & Fatigue Test

❑ Design Characteristics

- ✓Total Length : ~6,000 mm
- ✓Diameter of Outer Tube : 60 mmD x 997 mmL
- ✓Irradiation specimen : 1, 2, 4
- ✓Instrumentation : 8 TC, 2 heaters, 1 LVDT
- ✓Creep test 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

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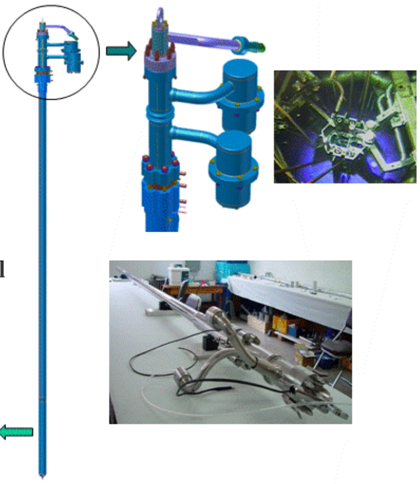
Fuel Test Loop (FTL)

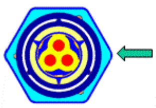
❑ Installation of OPS : Feb. 2008

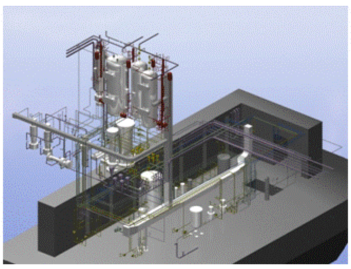
❑ Commissioning test : Nov. 2008.

❑ 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 ℃

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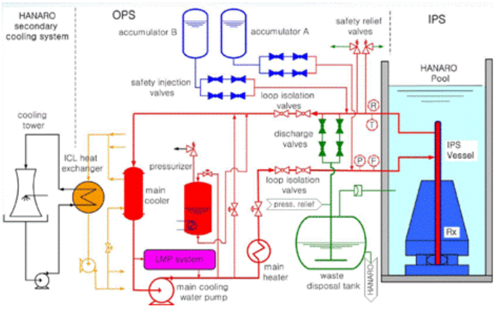
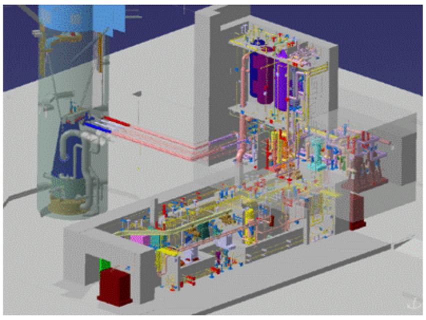
High-flux Advanced Neutron Application Reactor

Schematic Diagram and 3-D view of FTL



Schematic diagram



3-D view

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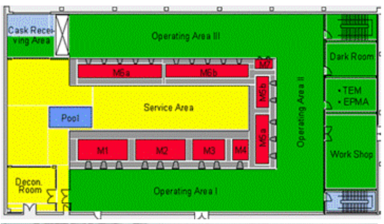
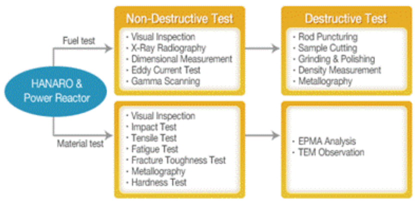
High-flux Advanced Neutron Application Reactor

IMEF (Irradiated Material Examination Facility) PIEF (Post-Irradiation Examination Facility)



Layout of IMEF

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



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**

The main mission of IMEF is to provide PIE services for the irradiated fuels and materials in the HANARO. And, PIEF is essentially employed for testing and then evaluating the performance and the integrity of nuclear fuels discharged from reactors.

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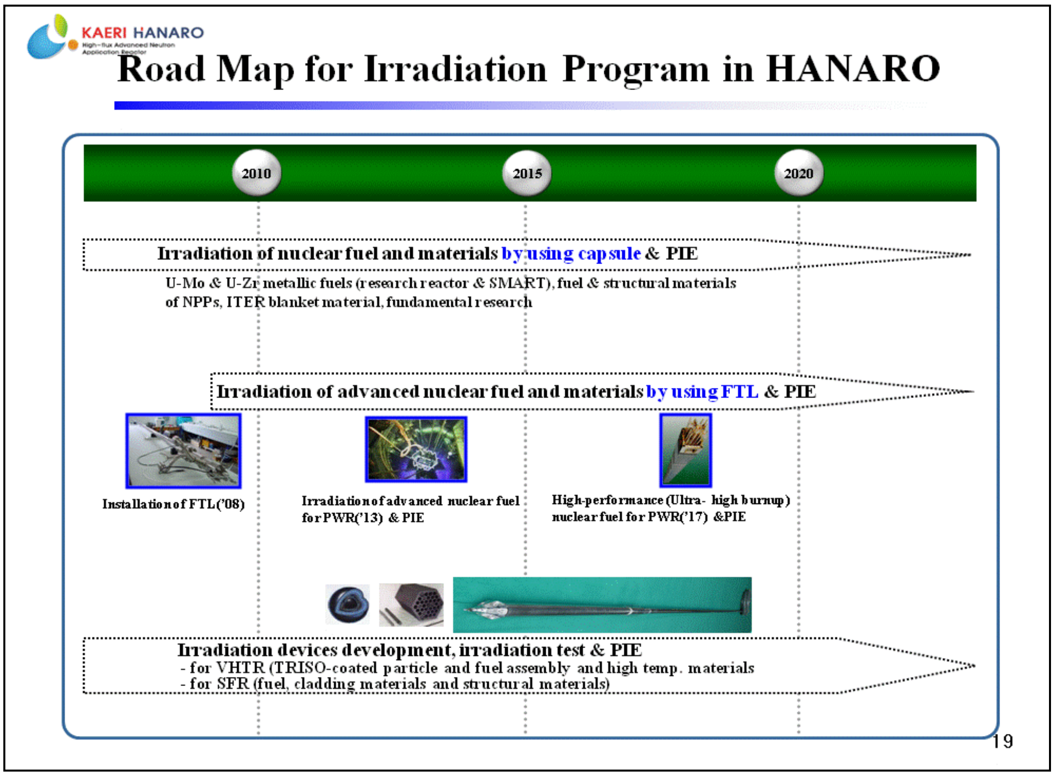
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Road Map for Irradiation Program in HANARO
2010
2015
2020
Irradiation of nuclear fuel and materials by using capsule & PIE
U-Mo & U-Zr metallic fuels (research reactor & SMART), fuel & structural materials of NPPs, ITER blanket material, fundamental research
Irradiation of advanced nuclear fuel and materials by using FTL & PIE
Installation of FTL('08)
Irradiation of advanced nuclear fuel for PWR('13) & PIE
High-performance (Ultra- high burnup) nuclear fuel for PWR('17) &PIE
Irradiation devices development, irradiation test & PIE
- for VHTR (TRISO-coated particle and fuel assembly and high temp. materials
- for SFR (fuel, cladding materials and structural materials)
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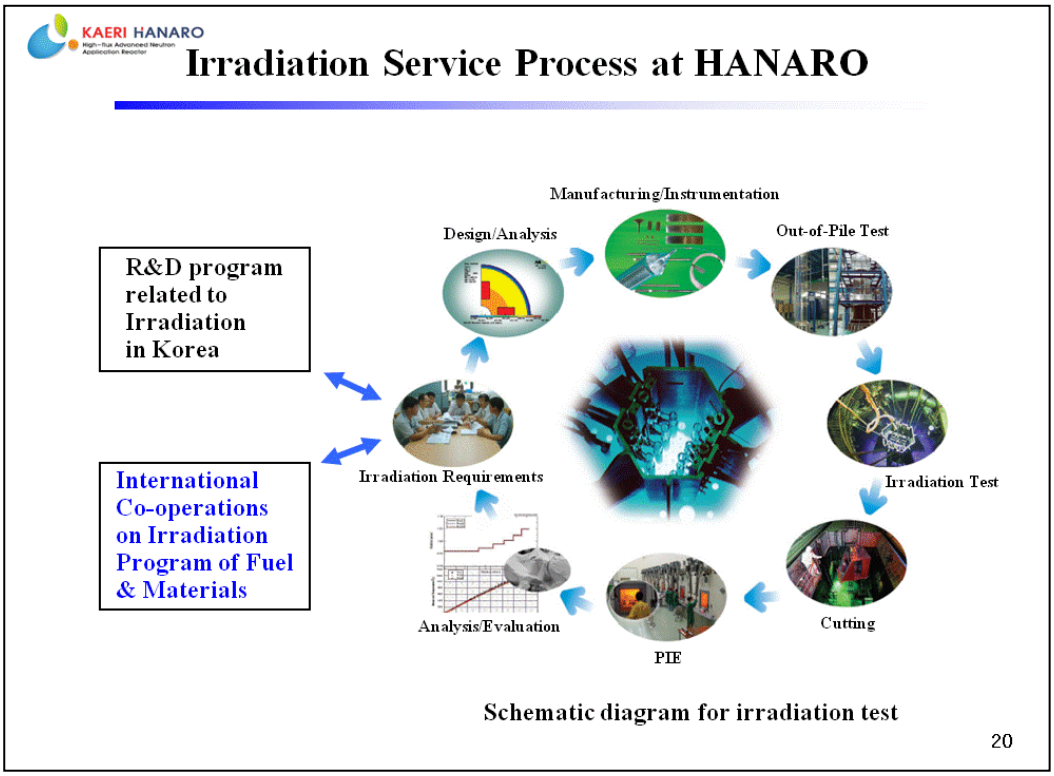
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Irradiation Service Process at HANARO
R&D program related to Irradiation in Korea
International Co-operations on Irradiation Program of Fuel & Materials
Manufacturing/Instrumentation
Design/Analysis
Out-of-Pile Test
Irradiation Requirements
Irradiation Test
Cutting
PIE
Analysis/Evaluation
Schematic diagram for irradiation test
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High-flux Advanced Neutron Application Reactor

Concluding Remarks

- Many Experimental Facilities Installed for
  - Fuel and Material Test, Neutron Beam Research, NAA
  - RI Production, BNCT, NTD, etc
- Irradiation & PIE at the HANARO
  - Capsules for irradiating fuel and materials
  - FTL for LWR/CANDU fuel irradiation test
  - IMEF & PIEF
- Irradiation Test Plan related to Nuclear R&D Program
  - Reactor materials and nuclear fuels
  - Nuclear System Development for Gen-IV
- Strengthen an International Cooperation

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2.5 PRESENT ACTIVITIES OF POST IRRADIATION EXAMINATIONS IN THE JMTR HOT LABORATORY

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ABSTRACT

The hot laboratory accompanied with the Japan Materials Testing Reactor (JMTR-HL) was founded in 1971 to examine objects irradiated mainly at the JMTR. The JMTR-HL has three kinds of beta-gamma hot-cell lines for research and development of nuclear fuels and materials. The JMTR-HL has the advantage of being connected by a canal between the hot cell and the JMTR. Hence, it is easy to transport irradiated capsules and specimens through the canal. Since 1971, about 2,400 irradiated capsules have been treated in the JMTR-HL. Many various post irradiation examinations (PIEs) have been widely performed here as well. Mentioned below are overviews of the hot laboratory, the present organization, the current status of the PIEs, and the modification plan of the facility to treat high burn-up fuels up to about 100 GWd/t in this presentation.

Keywords: Japan Material Testing Reactor, Hot Laboratory, Post Irradiation Examination, BOCA, IASCC, SEM-EBSD.

INTRODUCTION

The hot laboratory accompanied with the Japan Materials Testing Reactor (JMTR-HL) was founded in 1971 to examine the material specimens and fuel specimens irradiated mainly at the JMTR. The JMTR-HL is directly connected with the reactor core by a water canal which is 6m deep and 3m wide, as shown in Figure 1. Hence, irradiated radioactive capsules are efficiently transported under water through the canal in a short time. In this report, we describe the current and future status of the JMTR-HL.

ORGANIZATION OF JMTR HOT LABORATORY

The organization of JMTR-HL consist of “Planning section”, “Improvement planning section”, “PIE section 1”, “PIE section 2”, and “PIE section 3”. Figure 2 shows the outline of organization of JMTR-HL.

With the restarting of the JMTR, the Improvement planning section was newly founded for the purpose of improvement and renewal of facilities and equipment at JMTR-HL in April, 2008.

OUTLINE OF FACILITIES OF THE JMTR-HL AND MAIN TEST APPARATUSES

The JMTR-HL has three hot cell lines for post irradiation examinations (PIEs); a concrete cell line, a lead cell line, and a steel cell line, respectively. Figure 3 shows the year each facility was put into service. [1]

The concrete cell line consists of eight cells and is shielded by heavy concrete that is 1.1m in thickness, as shown in Figure 4 [1]. It was put into service in 1971. Inside the concrete cells, dismantling irradiated capsules, re-capsuling, visual inspections, X-ray radiography, dimensional measurements, gamma scans, and eddy current tests are carried out on fuel specimens as PIEs. Metallography by optical microscope and hardening tests are carried out in four microscope cells that are shielded by lead that is 0.18m in thickness and are connected to the concrete cells.

The lead cell line consists of seven cells shielded by lead that is 0.15m in thickness, as shown in Figure 5 [1]. It was put into service in 1971 for PIEs on irradiated materials.

The steel cell line consists of five cells shielded by steel that is 0.35m in thickness. It was put into service in 1982 for PIEs on irradiated materials. The tensile test, instrumented impact tests on reactor material, and PIEs related to mechanical properties on fusion reactor material are performed in these cells.

EXPERIENCES OF PIES IN THE JMTR-HL

The JMTR-HL has been operating for about 40 years for PIEs of many objects irradiated at JMTR and other facilities. Through the PIEs, the JMTR-HL contributes not only to research of materials for light water reactors (LWRs), fast reactors, high temperature gas reactor, and fusion reactor, but also to the production of domestic industrial radio isotopes like Iridium-192.

The JMTR-HL treated about 2,400 capsules and about 90,000 irradiated specimens, and performed over 9,500 PIEs from 1971 to 2006 [2]. Figure 6 shows the statistics of the irradiated capsules according to their purpose. The contribution of material tests is 55%, of fuel tests is 21% and of isotope productions is 24%. All of the fuel tests consisted of 65% tests for LWRs, 13% tests for high temperature gas reactors, and 8% tests for basic research. The material tests consist of 29% tests for basic research, 28% tests for LWRs, 9% tests for fusion reactors, and 9% tests for high temperature reactors. [1]

THE TREND OF PIES IN THE JMTR-HL

The following are topics of recent PIEs.

Assembling and dismantling of BOCA capsules

Power ramping tests in the JMTR using BOCA (Boiling Water Capsule) were performed for the purpose of safety research of load following operations on LWR fuels. The JMTR-HL developed an installing apparatus for irradiated fuel rods into the BOCA, an assembling apparatus for capsules, and a dismantling apparatus for capsules after irradiation [3]. These apparatuses have been installed in the hot cells, as shown in Figure 7 [1]. After these tests, BOCA was used for power ramping tests in the JMTR for research of high burn up tests for LWR fuels. These tests were performed over the course of about 20 years from 1981 to 1999, and it contributed to safety research and achievement of high burn-up of LWR fuels.

Irradiation assisted stress corrosion cracking experiments in a hot cell

Irradiation assisted stress corrosion cracking (IASCC) occurring in stainless steel is considered to be one of the key issues from a viewpoint of the life management of core components in the aged LWRs.

To simulate IASCC behavior in BWRs for PIEs, crack growth tests and slow strain rate tests are performed under high temperature and high pressure water conditions on specimens irradiated up to a neutron fluence that is higher than so-called IASCC threshold fluence in a test reactor.

Due to crack growth tests in a simulated BWR environment, the maximum operational parameters of the IASCC growth test apparatus installed in the hot cell are as follows; load capacity: 10kN, temperature: 573K, pressure: 10MPa, and flow rate: 30 liters per hour. The DO concentration can be controlled with the range of 10ppb-30ppm to simulate BWR environment in the circulating system. Furthermore, the ECP of the specimen is measured by the silver/silver chloride type external reference electrode. Crack length of pre-irradiated CT specimens is monitored by the reverse DC potential drop method during the IASCC growth test. [4]

Figure 8 shows the developed IASCC experiment apparatus installed in the hot cell [5]. Over 200 irradiated specimens were tested by this apparatus. It contributed to the basic research of materials of LWRs.

The in-pile IASCC experiments -Assembling techniques for test capsules

In order to investigate the behavior of IASCC caused by the simultaneous effects of neutron irradiation and high temperature water environment in such a LWR, crack growth tests and slow strain rate tests of pre-irradiated specimens were performed in the JMTR. These tests were performed by in-pile IASCC test capsules that simulate LWR water conditions under irradiation. And the results were compared with those of PIEs.

There were, however, some technical hurdles to overcome for the experiments. To perform in-pile IASCC tests, pre-irradiated specimens were relocated from pre-irradiation capsules to an in-pile test capsule in a hot cell by remote handling. Hence, a remote TIG welding technique was developed for assembling the in-pile test capsules [6, 7]. Figure 9 shows the outline of the remote-assembly work. Eight in-pile IASCC test capsules were assembled and the testing time about 20,000 hours in total was achieved [7].

SEM/EBSD

In order to obtain a fractography of the test specimens after mechanical tests, a remote-handling type scanning-electron microscope (SEM) was developed and introduced into the JMTR-HL in 1995. It contributes greatly to the study of generation mechanisms of IASCC and IGSCC (inter granular stress corrosion cracking) in structural materials of LWRs.

Furthermore, in order to investigate generation mechanisms of IASCC and IGSCC in more detail, the Orientation Imaging Microscopy (OIM) was introduced in the JMTR-HL in 2001. A new hardware device, an electron-backscattering diffraction-pattern (EBSD) detector was added onto the conventional SEM, as shown in Figure 10 [1]. Additionally a new software system, called OIM, was added. Thus a remote-handling type crystal orientation analyzer was realized as an in-cell system for the first time [8]. It is the only one of its kind in the world. Through the OIM observations using heavily irradiated specimens such as structural materials in LWR, the JMTR-HL is contributing to the further development of research in the fields of IASCC and IGSCC.

IMPROVEMENT PLAN OF THE JMTR-HL

In order to accept a higher burn-up fuel, up to about 100 GWd/t, a improvement of the JMTR-HL from 2008 to 2011 is planned as follows;

Correspondence to high burn-up fuel

A power ramping test for high burn-up LWR fuels is planned using BOCA in the JMTR. LWR fuel pins irradiated at commercial power plants will be loaded into the BOCA capsules in the hot cell of the JMTR-HL and then they will be re-irradiated in the reactor core of the JMTR.

(a) Reinforcement of the neutron shielding capacity of the hot cells

Because the burn-up rate of the accepted fuel will be higher than that of the present license, a reinforcement of the neutron shielding capability is required. Therefore, a reinforced design is planned for the concrete cells as shown in Figure 11 [1].

(b) Center-hole drilling technique for irradiated fuel pellets

The BOCA irradiation program requires installation of instrumentations for fuel-center temperature and fuel-gas pressure. As shown in Figure 12, the center-hole drilling technique for installation of a thermocouple and the welding technique for the end-plug of the fuel pins had been developed by the JMTR-HL in the previous BOCA program [1]. The JMTR-HL is now planning to improve the center-hole drilling apparatus. It is considered on the remote maintainability through minimizing the volume, unitizing the functions, and simplifying the structure to prevent surface contamination.

(c) Assembling and dismantling apparatus for BOCA capsules

In order to treat the high burn-up fuels mentioned above (a), the design of in-cell apparatus for assembling and dismantling of BOCA capsules is planned as shown in Figure 13. The shielding container becomes unnecessary when we change the loading method from a horizontal gamma gate loading method to an underwater loading method, thus man power and working hours can be saved.

Renewal of aged facilities

The facilities of the JMTR-HL have become aged by continuous operation for about 40 years. Therefore, replacement of main equipment, e.g., power manipulators, normal manipulators, etc., is planned before the restarting of the JMTR in 2011.

CONCLUSIONS

Through the experiences of many PIEs and the development of the new techniques for PIEs, the JMTR-HL has contributed to the research and development for fuels and materials of various nuclear reactors for many years. The improvement plan underway for the JMTR-HL will make it the most important facility for PIEs in Japan.

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[8] Yoshiaki KATO, et al., “Installation of remote-handling typed EBSD-OIM analyzer for heavy irradiated reactor materials,” JAEA-Testing 2008-005, 2008.

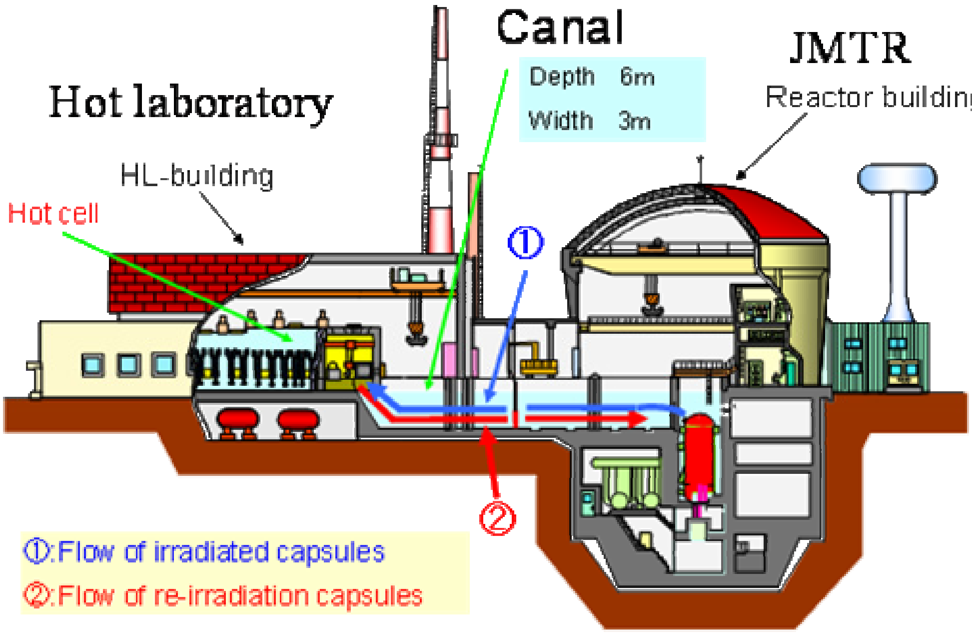


Fig.1 Canal between the JMTR and the Hot laboratory

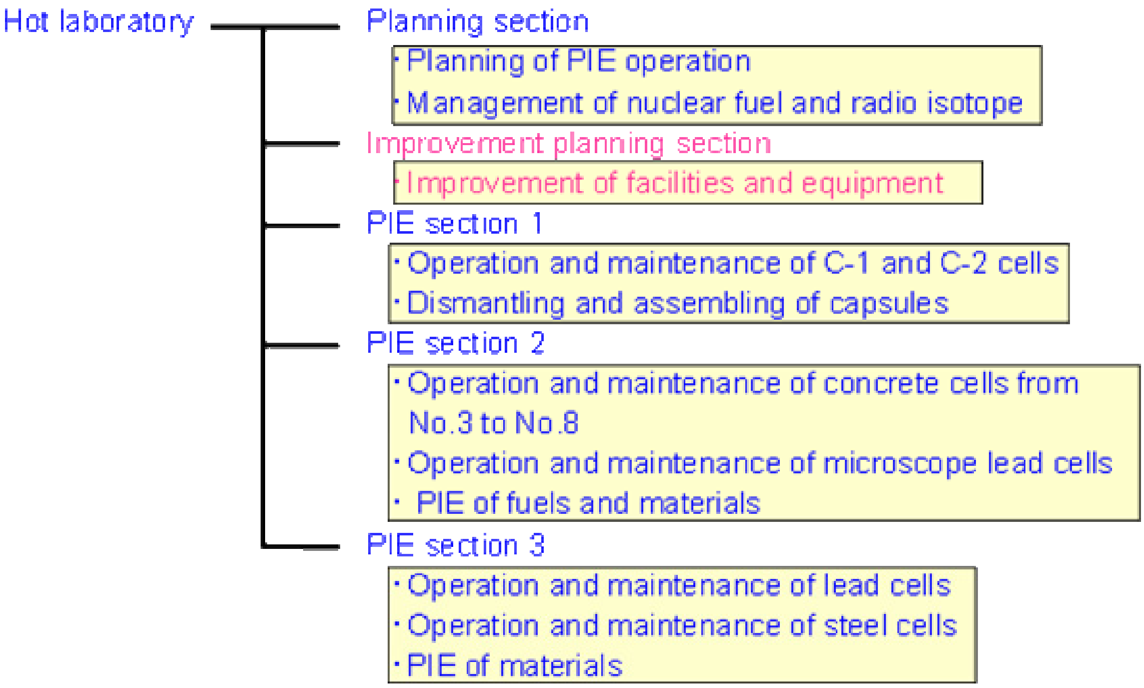


Fig.2 Organization of JMTR Hot laboratory

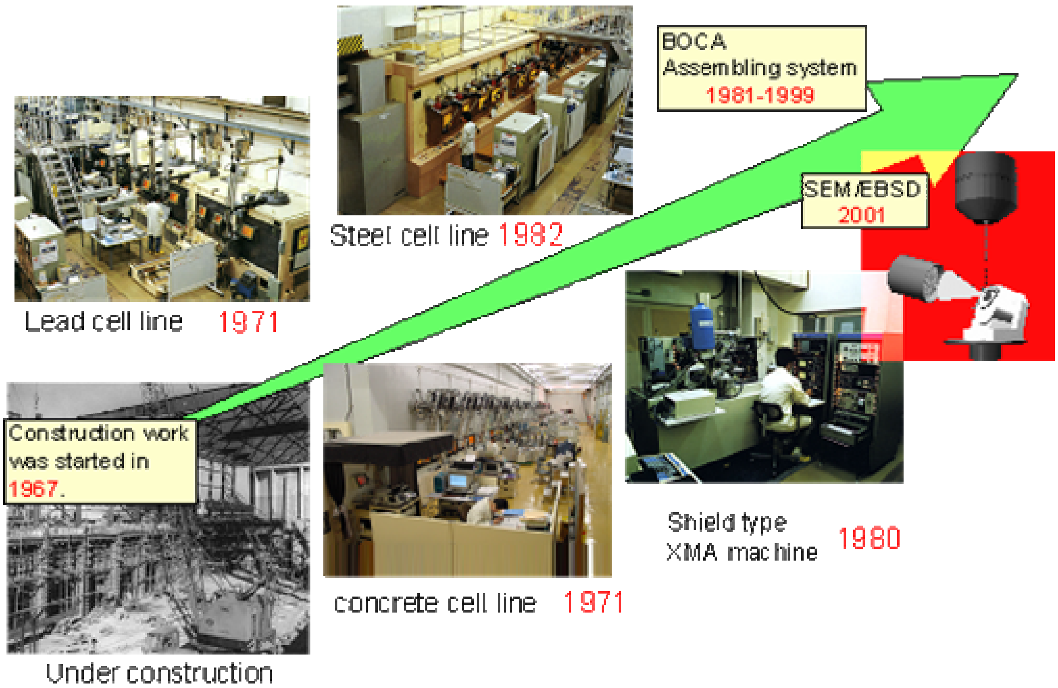


Fig.3 History of the JMTR Hot Laboratory

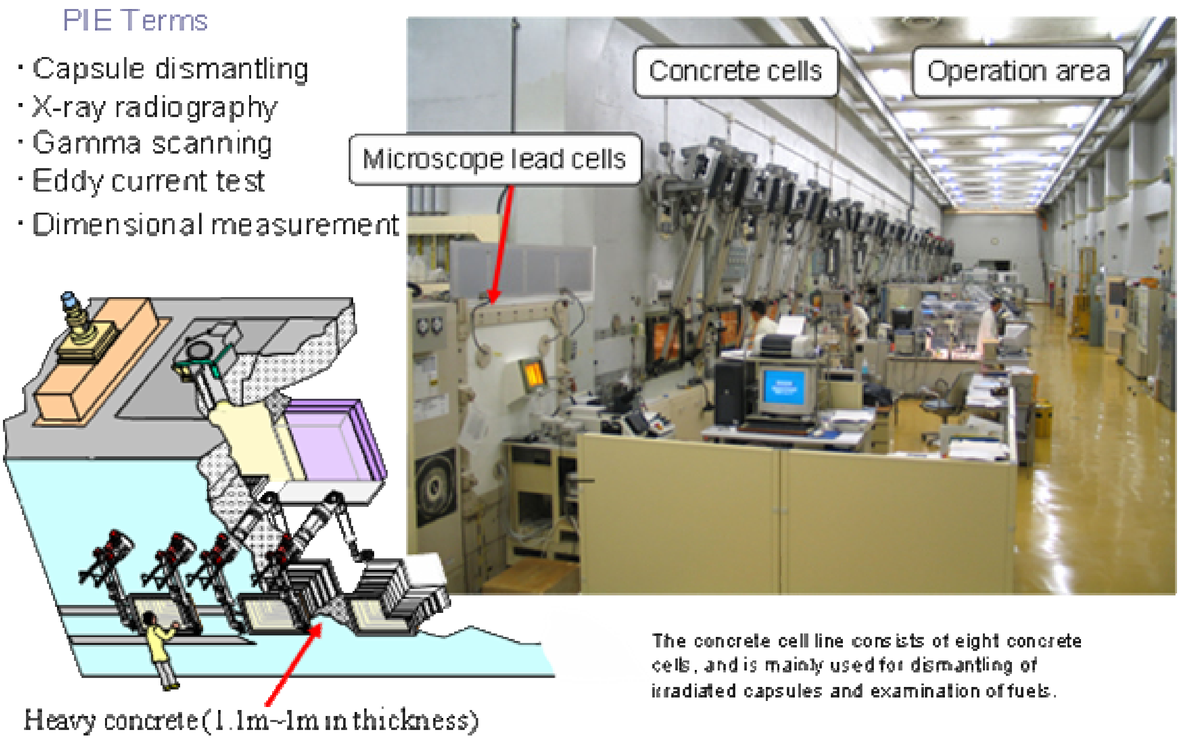


Fig.4 Concrete Cell Line

Fig. 5 Lead and Steel Cell Lines

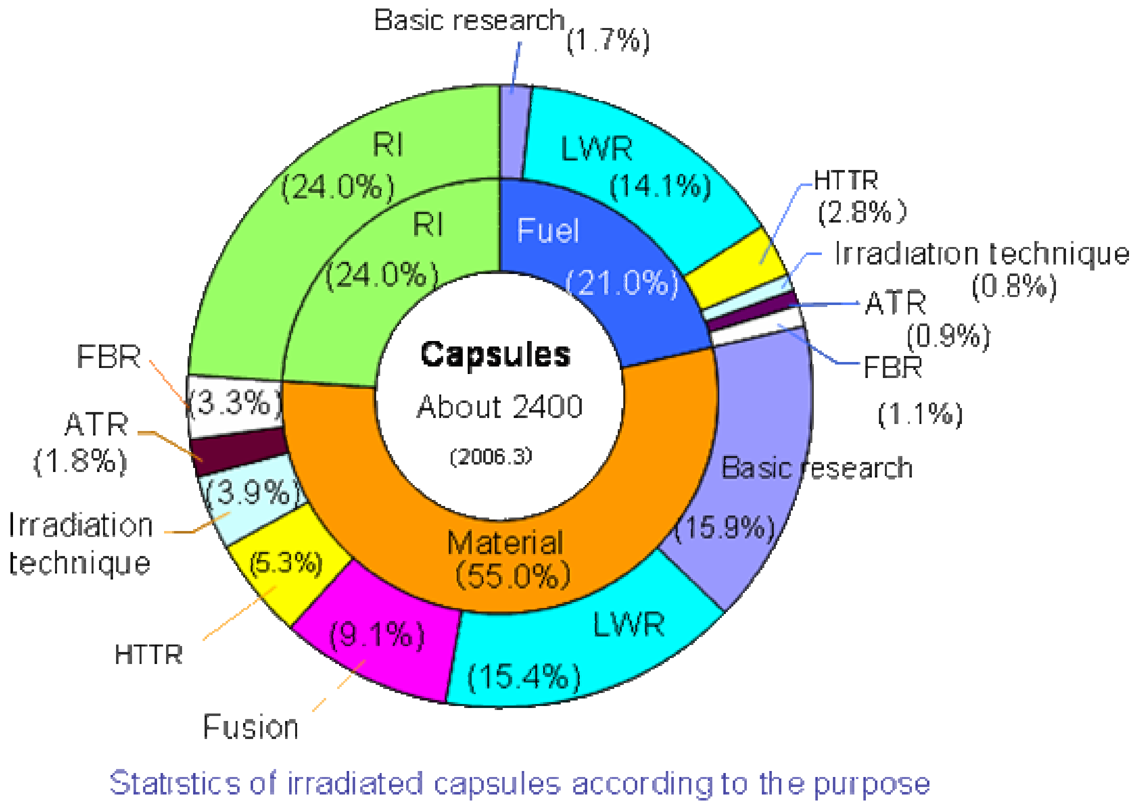


Fig.6 Experiences of PIEs in the JMTR-HL from 1971 to 2006.

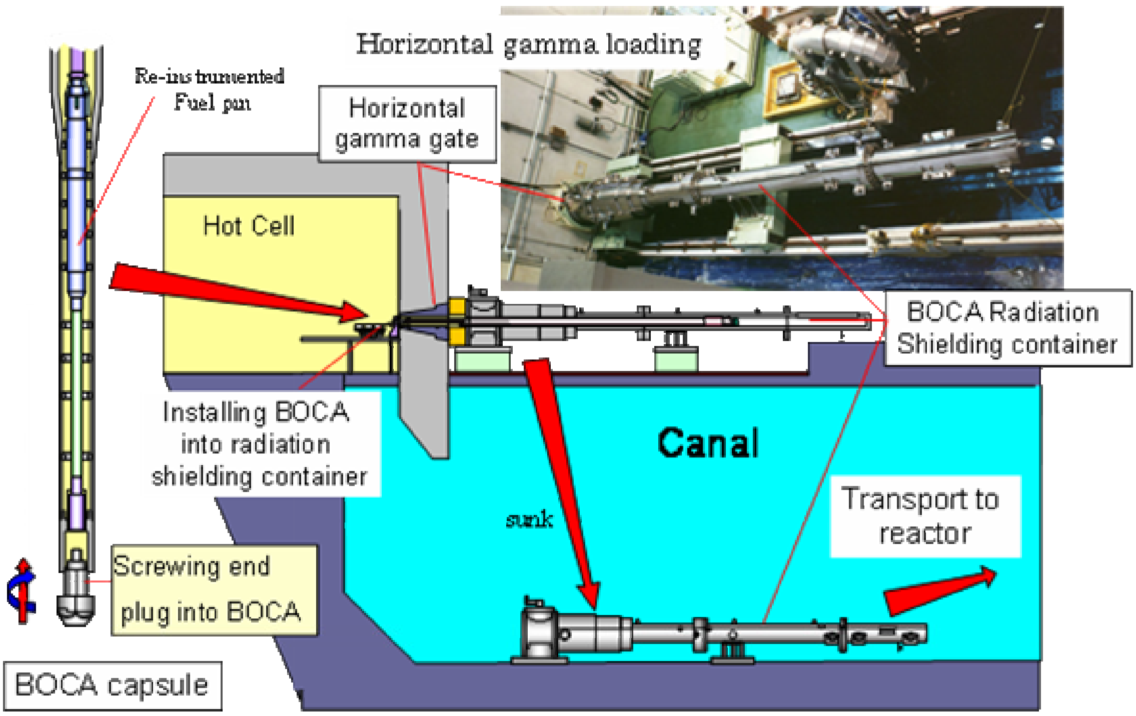
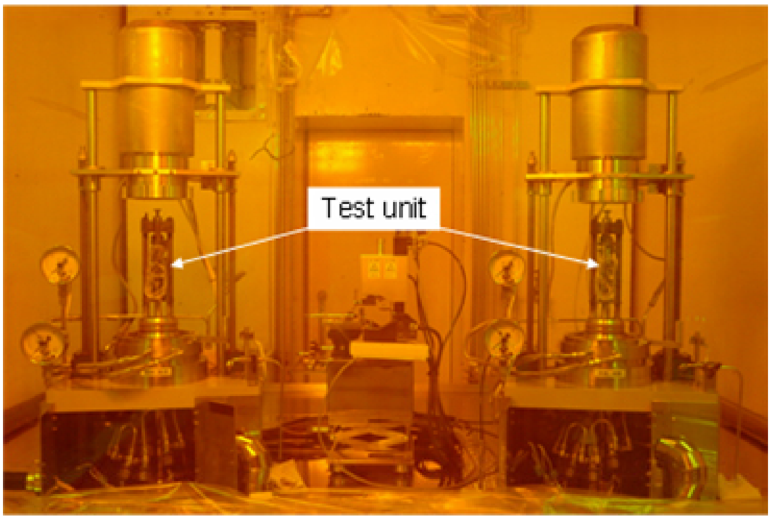


Fig.7 Assembling and dismantling of BOCA capsule



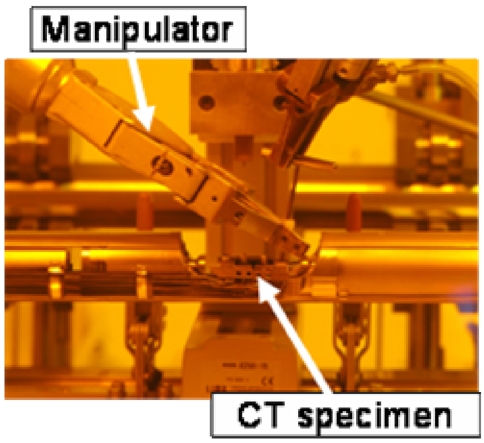
Specifications	
Maximum load	10 kN
Maximum stroke	30 mm
Maximum temperature	573 K
Maximum pressure	10 MPa
Maximum flow rate	30 ℓ/h [total] (15 ℓ/h [1 autoclave])

Test time 1500~2000Hr

This apparatus simulates environmental conditions in the reactor core of BWRs, excepting with neutron irradiation.

Test specimens; 0.5T-CT type specimens irradiated in the JMTR.

Fig.8 Outline of IASCC growth test apparatus



Installation of pre-irradiated specimen into the capsule

In-cell welding of inner and outer tubes of the capsule

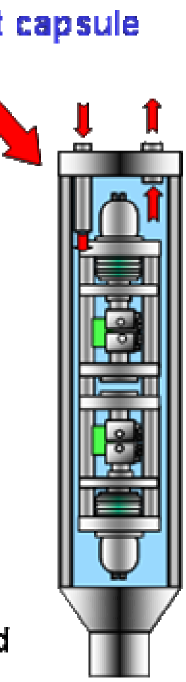


Fig.9 Assembling of In-pile IASCC test capsule in the hot cell

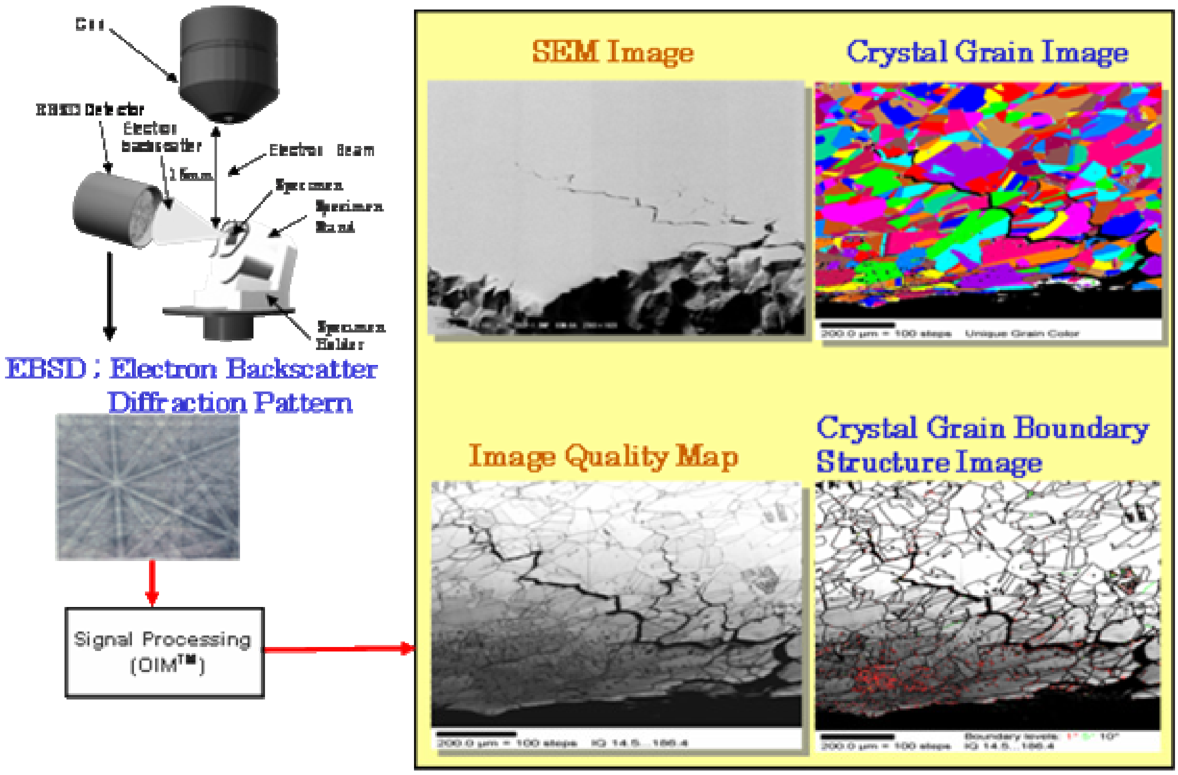


Fig.10 Orientation Imaging Microscopy using EBSD

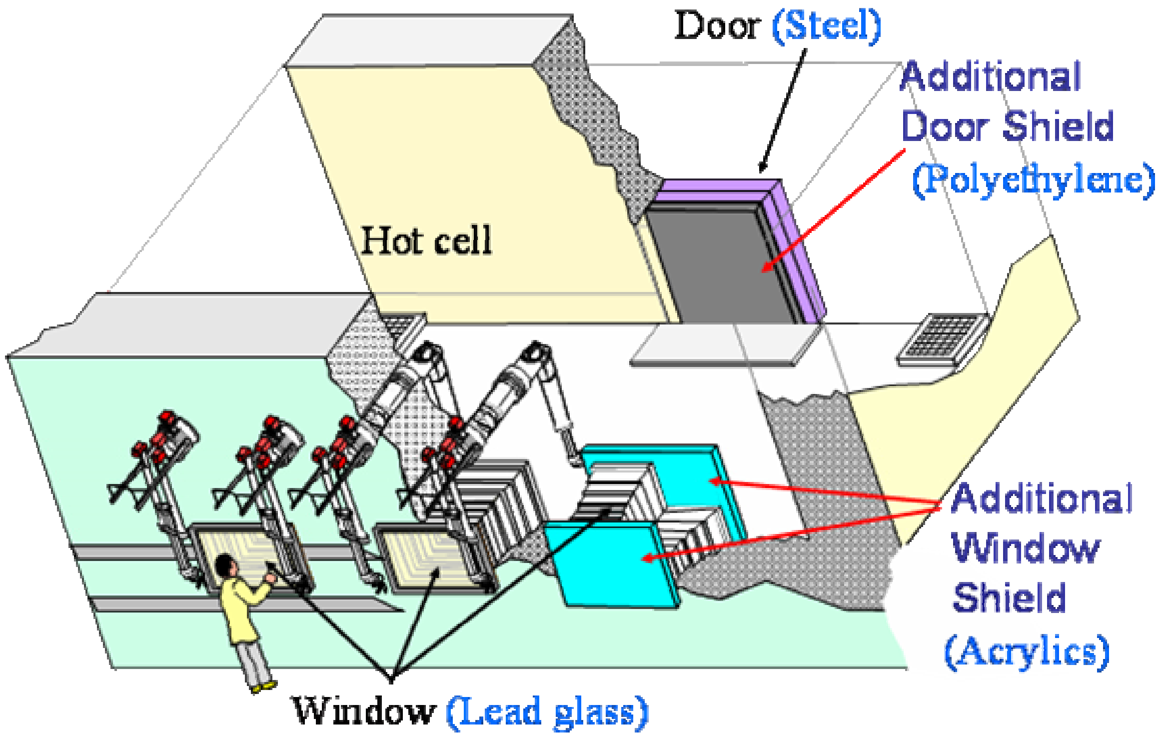


Fig.11 Reinforcement of neutron shielding capacity of the hot cell

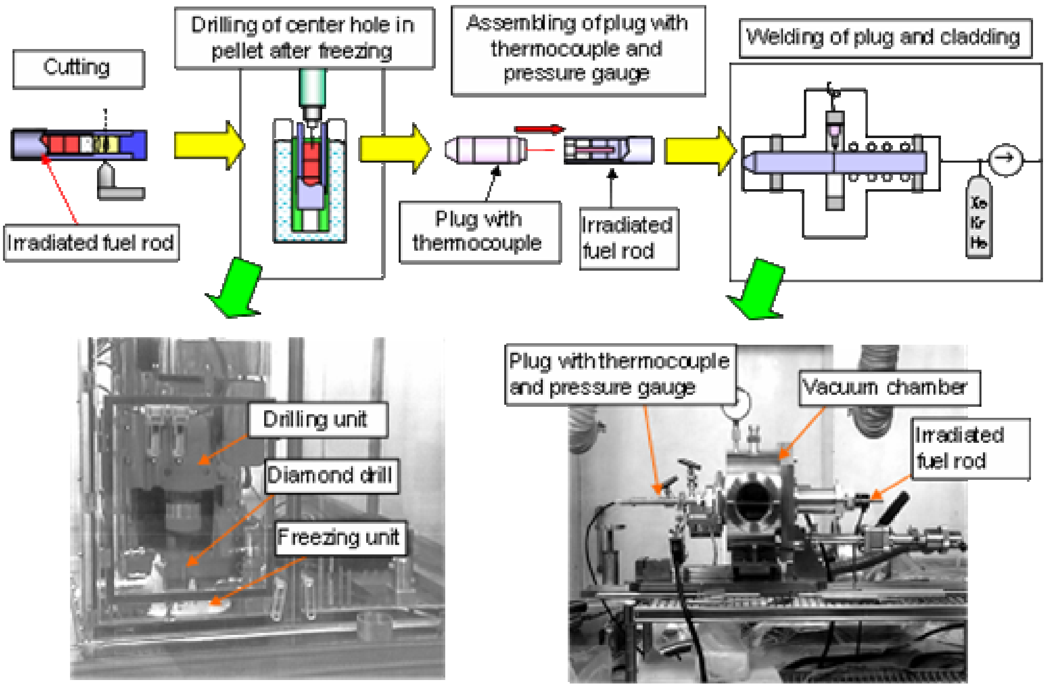


Fig.12 Outline of installing of a thermocouple and a pressure gauge in a fuel pin

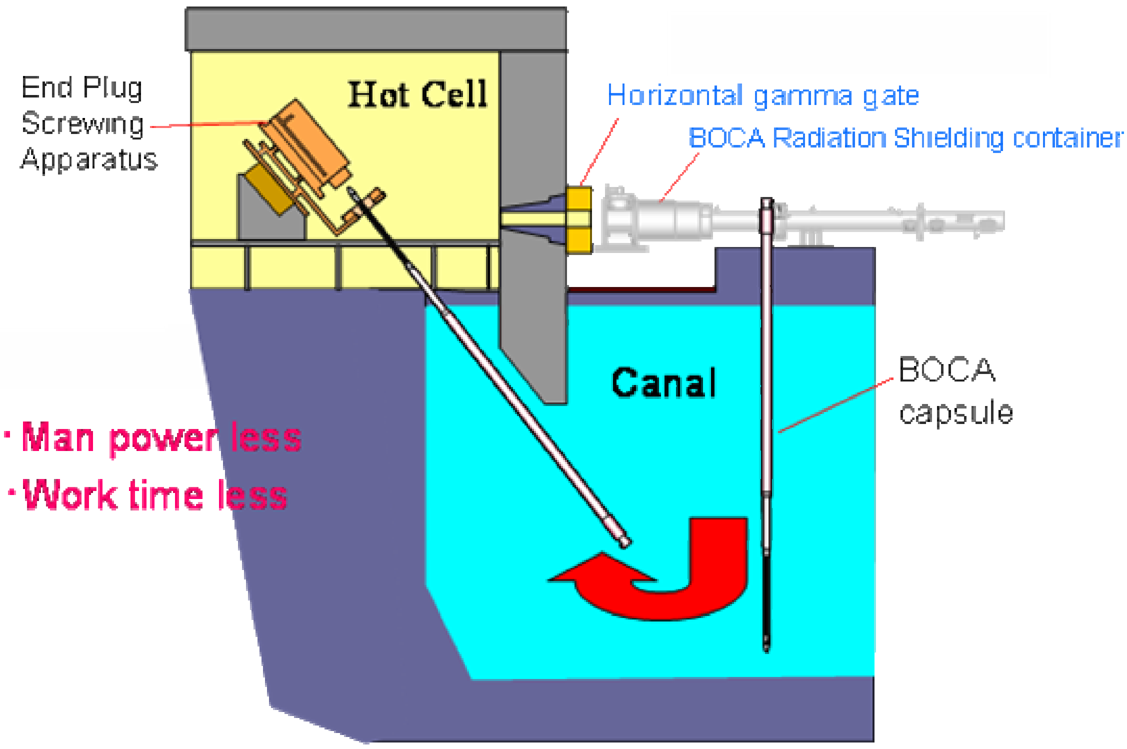


Fig.13 New loading method for BOCA capsules

2.6 CURRENT ACTIVITIES OF POST-IRRADIATION EXAMINATION AT KAERI

Y.B. Chun, D.K. Min, S.B. Ahn, and W.S.Ryu

Development of Systems for Cold Neutron Source Project, KAERI
1045 Daedeok-daero, Yuseong, Daejeon 305-353, Korea
ybchun@kaeri.re.kr

A wide range of post-irradiation examination (PIE) for the nuclear fuels irradiated at NPPs with different design characteristics have been carried out at PIEF at KAERI.

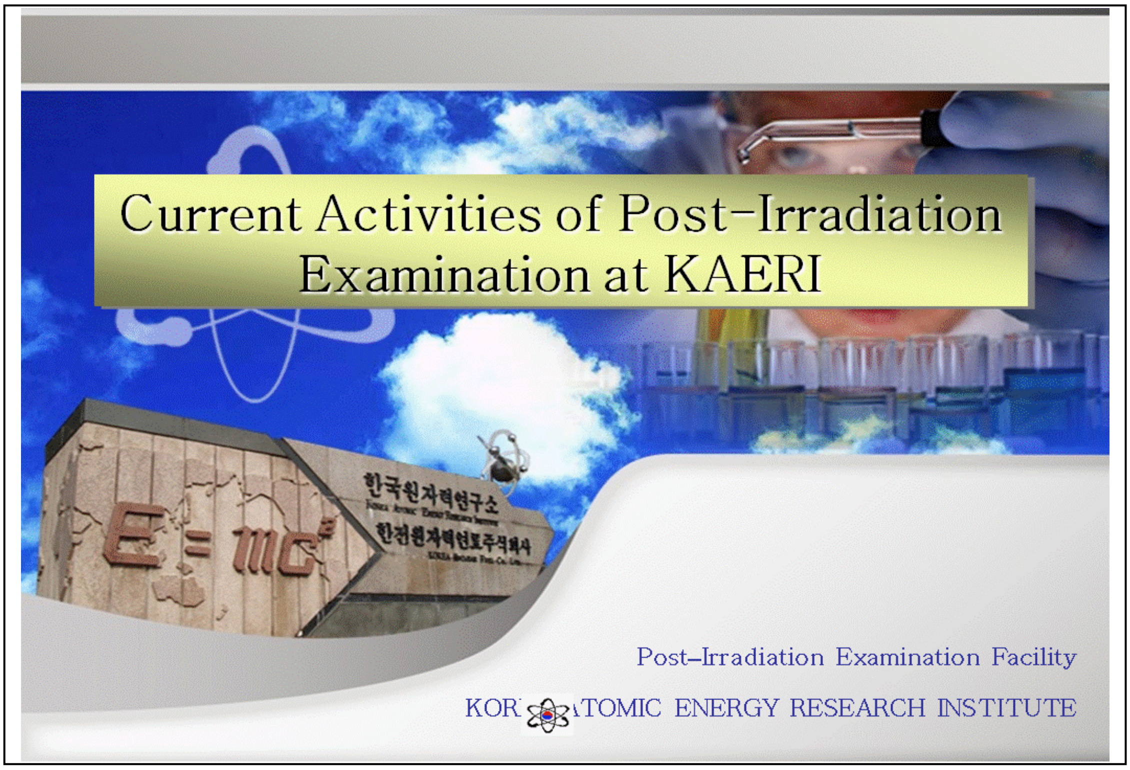
The examination was conducted to evaluate the irradiation performances as well as the fuel integrities. The input data leading to the design upgrades of the nuclear fuels have mostly been obtained from the PIE of the irradiated fuels.

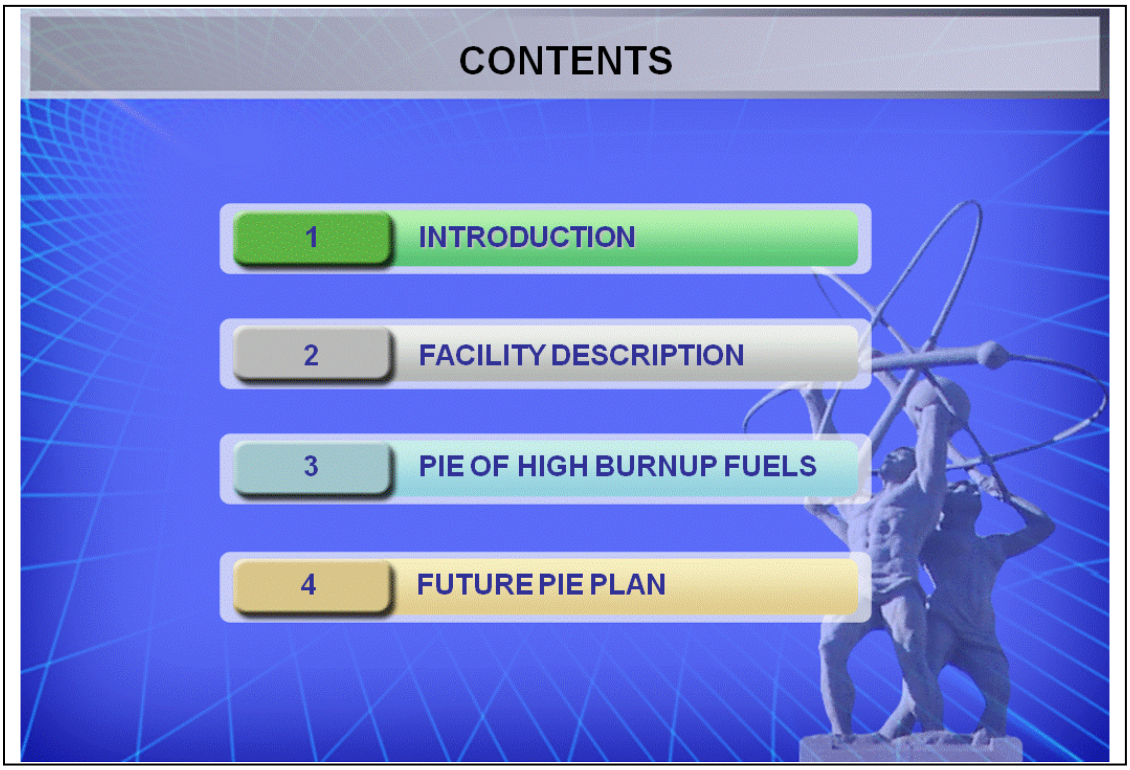
A comprehensive non-destructive and destructive examination equipment are incorporated with the hot cell examination system.

The main activity of PIEF is concentrated on the commercial nuclear fuel examination as the IMEF focused on the HANARO irradiated fuel and material examination.

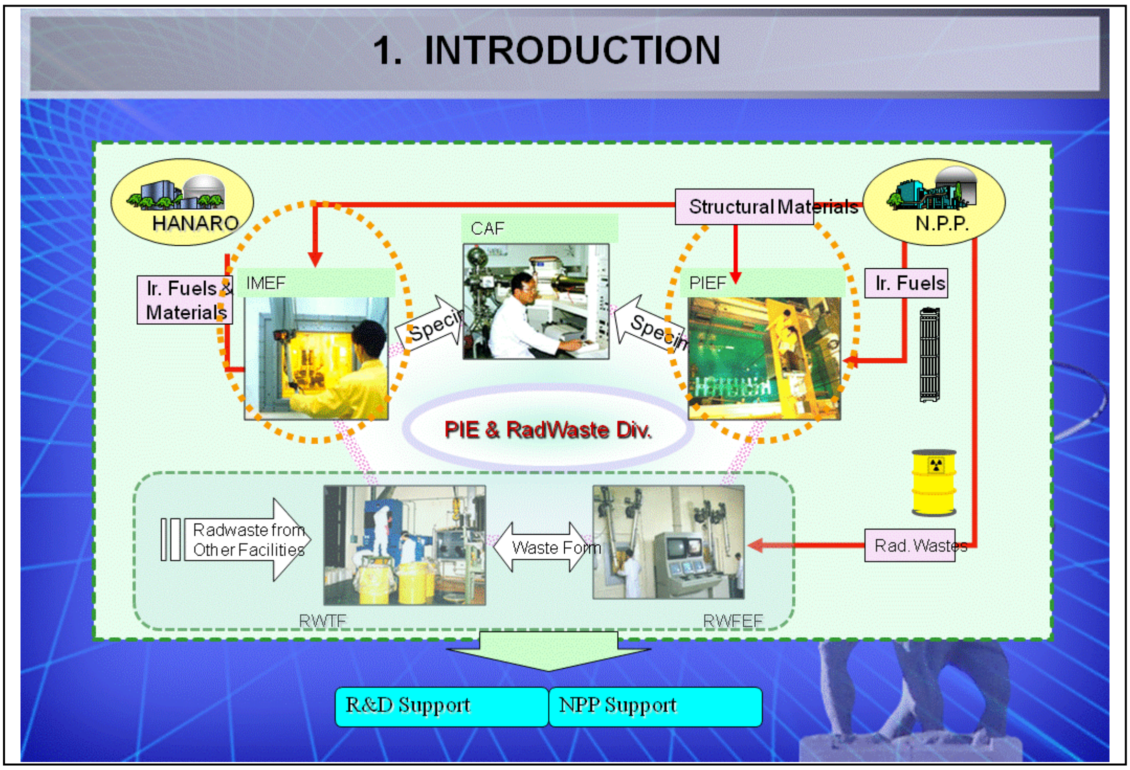
Recently, the above mentioned two facilities put great concentrations on the examination of the structural components of the fuel assembly such as skeleton, spacer grid and hold down spring elements to cope with the safety requirements of fuel integrities to meet a highly extended burn up conditions.

In this paper, a brief and general activity of the both facilities and the future scope of work are introduced.

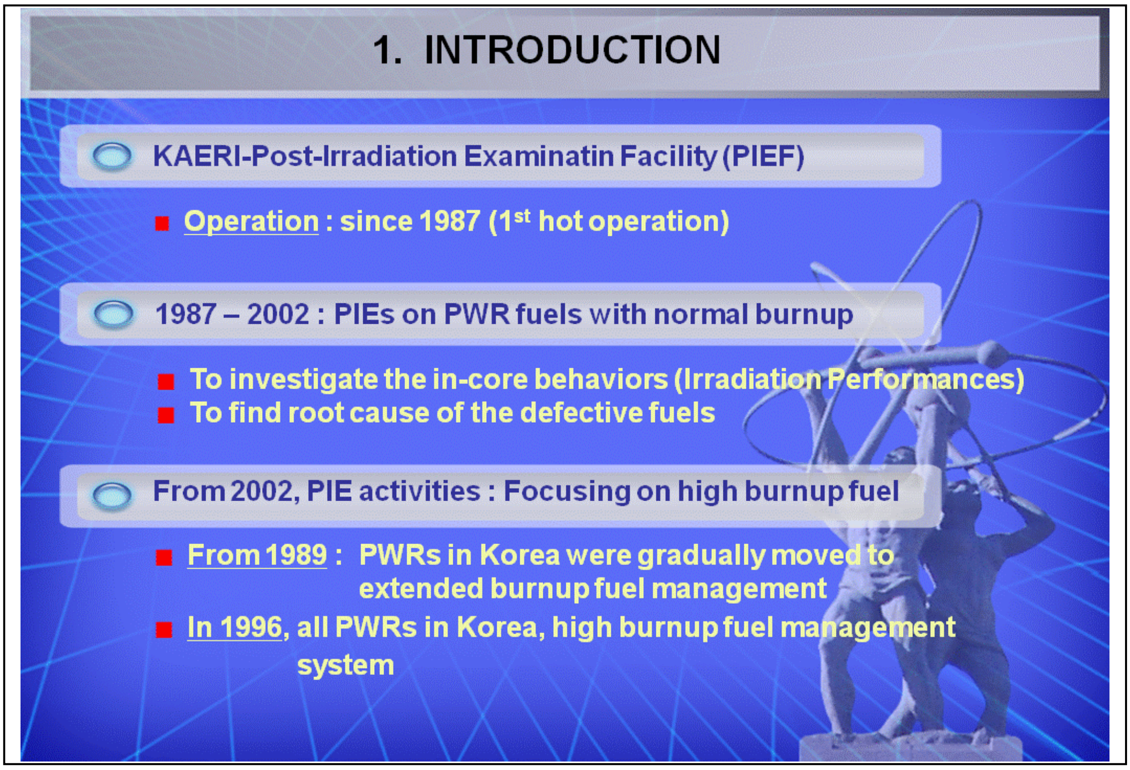

Current Activities of Post-Irradiation Examination at KAERI
E = mc²
Post–Irradiation Examination Facility
KOR TOMIC ENERGY RESEARCH INSTITUTE

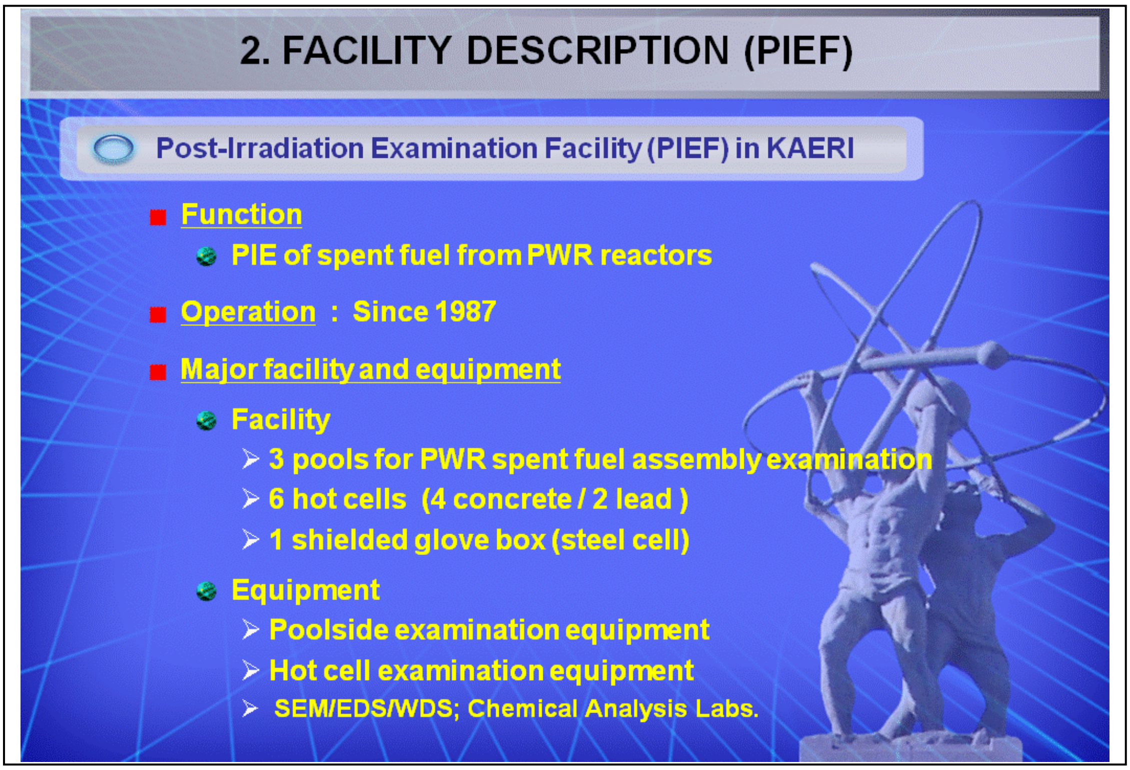

CONTENTS
1 INTRODUCTION
2 FACILITY DESCRIPTION
3 PIE OF HIGH BURNUP FUELS
4 FUTURE PIE PLAN

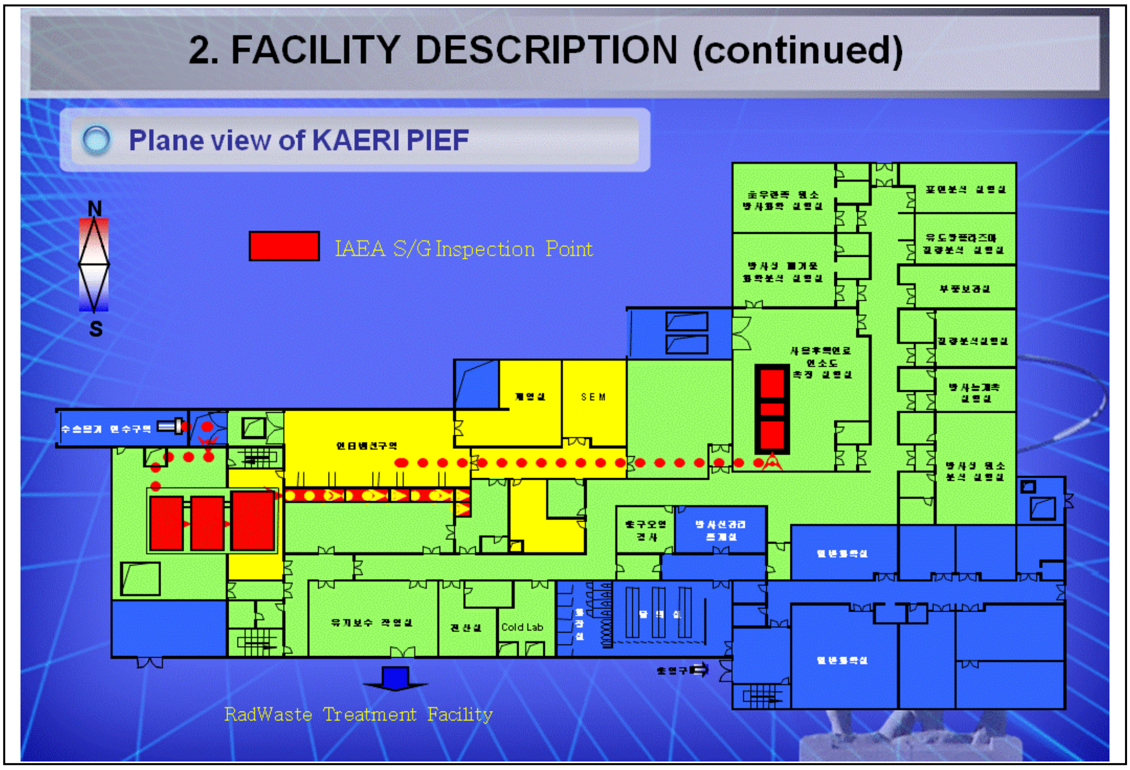
Location
Solar Evaporation Facility
Waste Storage Facility
HANARO
PIEF
IMEF
RWFEF
RWTF
◦ 10 persons
◦ 3 pools and 6 hot cells
(4 concrete, 2 lead cells)
◦ 13 persons
◦ 3 hot cell rows
- fuel test, material test
and multi-use row
◦ 9 persons
◦ 3 facilities
- waste treatment and storage,
solar evaporation facility
◦ 3 persons
◦ 1 concrete hot cell
Site Area : 1.4 M m², 54 Buildings

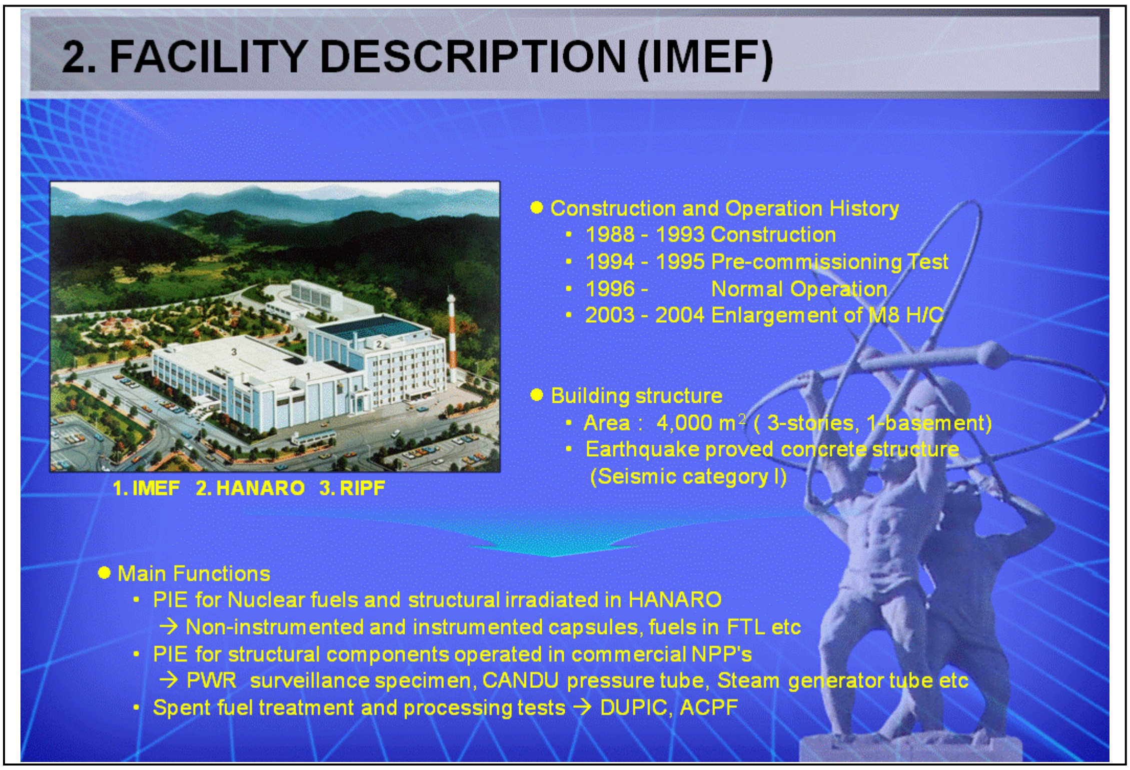


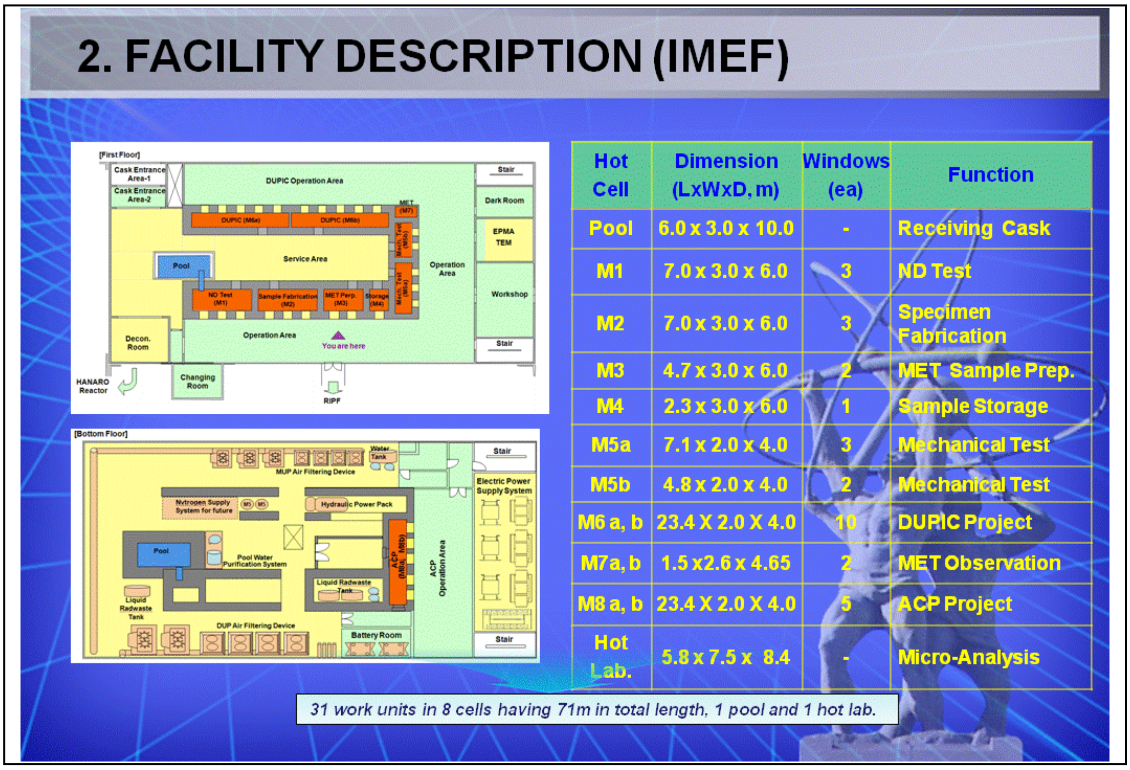
1. INTRODUCTION
HANARO
N.P.P.
Structural Materials
CAF
IMEF
PIEF
Ir. Fuels & Materials
Ir. Fuels
PIE & RadWaste Div.
Radwaste from Other Facilities
Waste Form
Rad. Wastes
RWTF
RWFEF
R&D Support
NPP Support


1. INTRODUCTION
KAERI-Post-Irradiation Examinatin Facility (PIEF)
Operation : since 1987 (1st hot operation)
1987 – 2002 : PIEs on PWR fuels with normal burnup
To investigate the in-core behaviors (Irradiation Performances)
To find root cause of the defective fuels
From 2002, PIE activities : Focusing on high burnup fuel
From 1989 : PWRs in Korea were gradually moved to extended burnup fuel management
In 1996, all PWRs in Korea, high burnup fuel management system


2. FACILITY DESCRIPTION (PIEF)
Post-Irradiation Examination Facility (PIEF) in KAERI
Function
PIE of spent fuel from PWR reactors
Operation : Since 1987
Major facility and equipment
Facility
3 pools for PWR spent fuel assembly examination
6 hot cells (4 concrete / 2 lead)
1 shielded glove box (steel cell)
Equipment
Poolside examination equipment
Hot cell examination equipment
SEM/EDS/WDS; Chemical Analysis Labs.

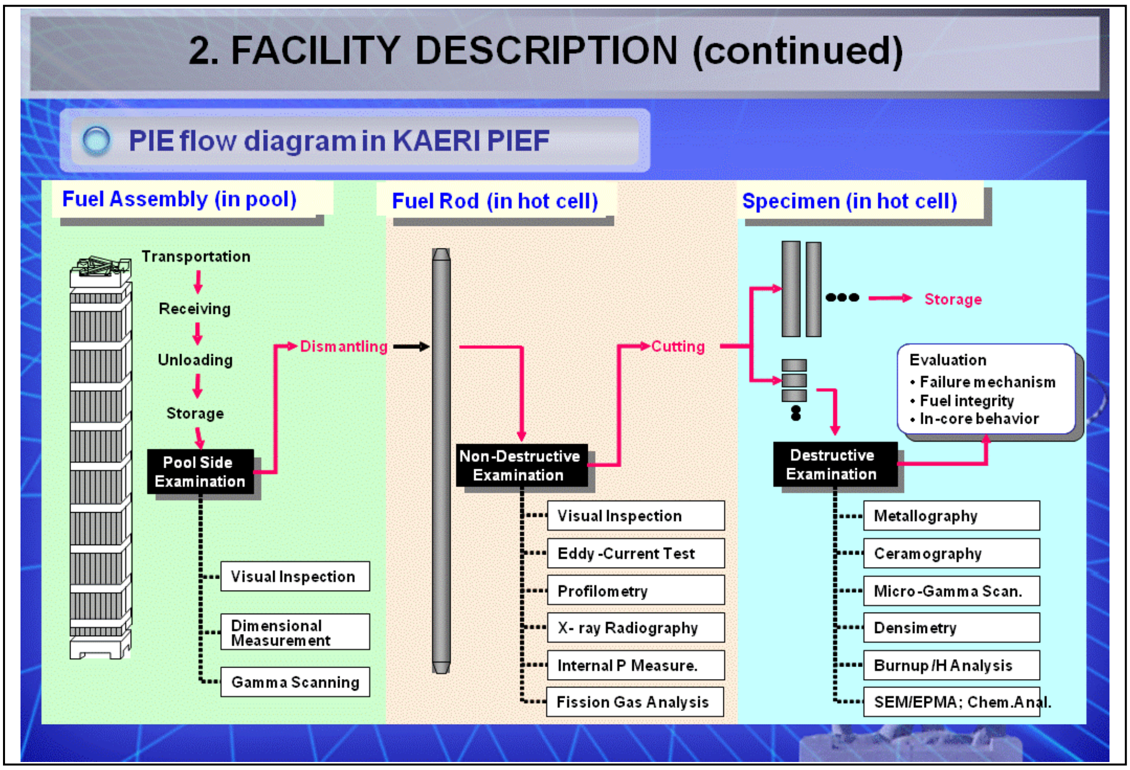

2. FACILITY DESCRIPTION (continued)
Plane view of KAERI PIEF
N
S
IAEA S/G Inspection Point
SEM
Cold Lab
RadWaste Treatment Facility

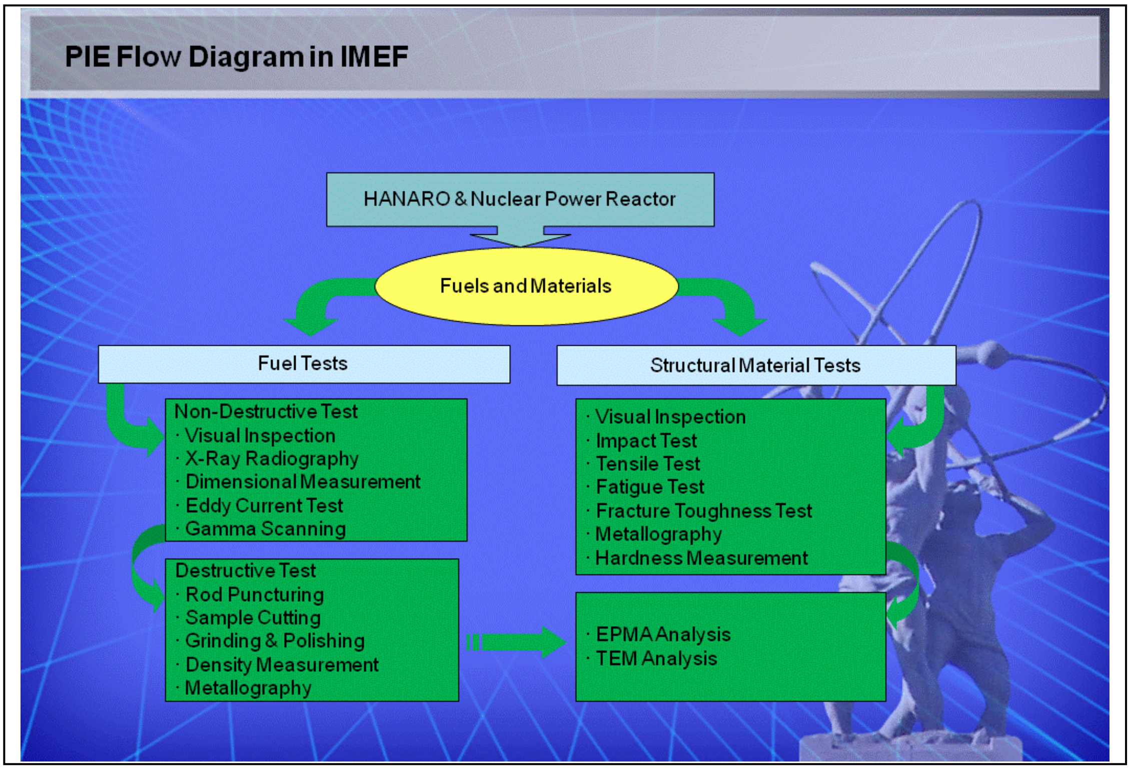

2. FACILITY DESCRIPTION (IMEF)
1. IMEF 2. HANARO 3. RIPF
Construction and Operation History
1988 - 1993 Construction
1994 - 1995 Pre-commissioning Test
1996 - Normal Operation
2003 - 2004 Enlargement of M8 H/C
Building structure
Area : 4,000 m² (3-stories, 1-basement)
Earthquake proved concrete structure
(Seismic category I)
Main Functions
PIE for Nuclear fuels and structural irradiated in HANARO
→ Non-instrumented and instrumented capsules, fuels in FTL etc
PIE for structural components operated in commercial NPP's
→ PWR surveillance specimen, CANDU pressure tube, Steam generator tube etc
Spent fuel treatment and processing tests → DUPIC, ACPF

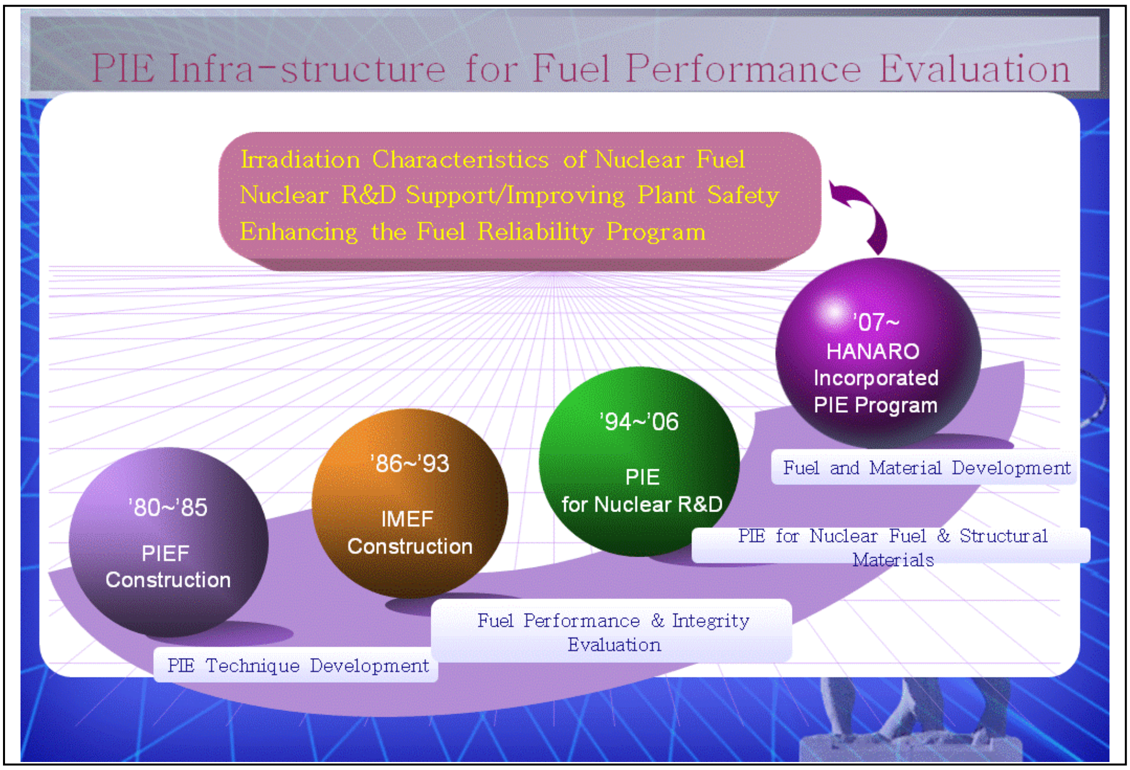

2. FACILITY DESCRIPTION (IMEF)
[First Floor]
[Bottom Floor]

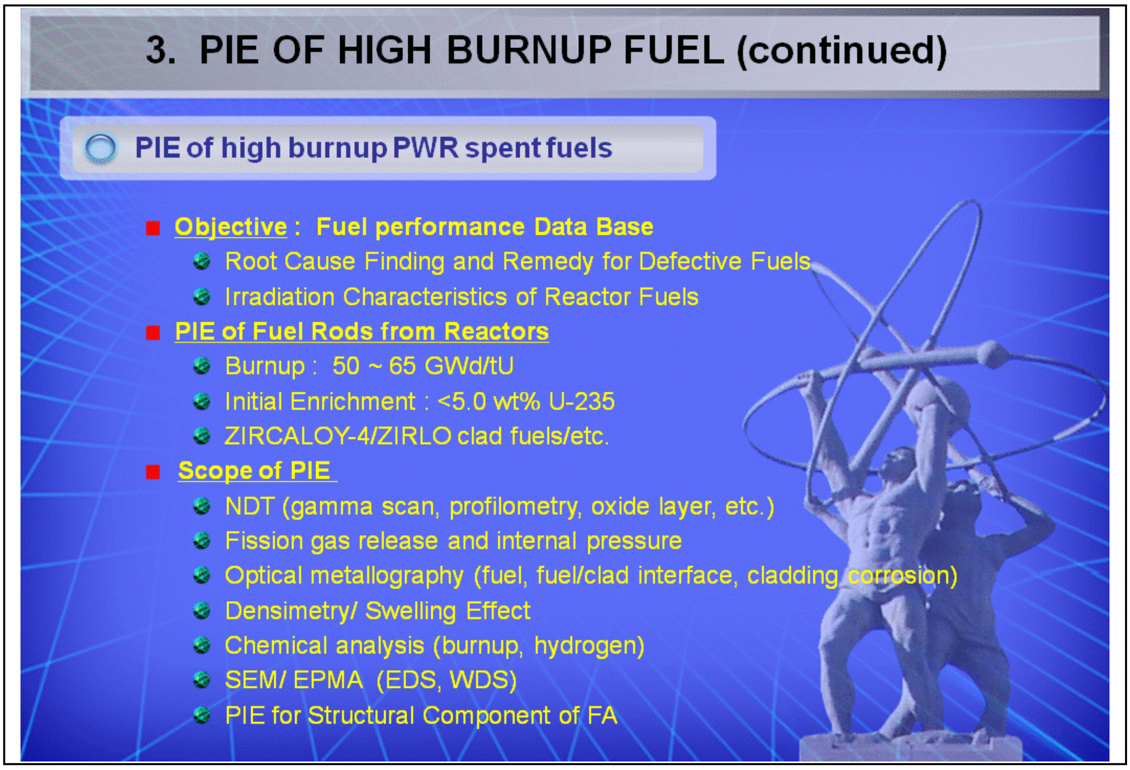
Hot Cell	Dimension (LxWxD, m)	Windows (ea)	Function
Pool	6.0 x 3.0 x 10.0	-	Receiving Cask
M1	7.0 x 3.0 x 6.0	3	ND Test
M2	7.0 x 3.0 x 6.0	3	Specimen Fabrication
M3	4.7 x 3.0 x 6.0	2	MET Sample Prep.
M4	2.3 x 3.0 x 6.0	1	Sample Storage
M5a	7.1 x 2.0 x 4.0	3	Mechanical Test
M5b	4.8 x 2.0 x 4.0	2	Mechanical Test
M6 a, b	23.4 X 2.0 X 4.0	10	DUPIC Project
M7a, b	1.5 x2.6 x 4.65	2	MET Observation
M8 a, b	23.4 X 2.0 X 4.0	5	ACP Project
Hot Lab.	5.8 x 7.5 x 8.4	-	Micro-Analysis

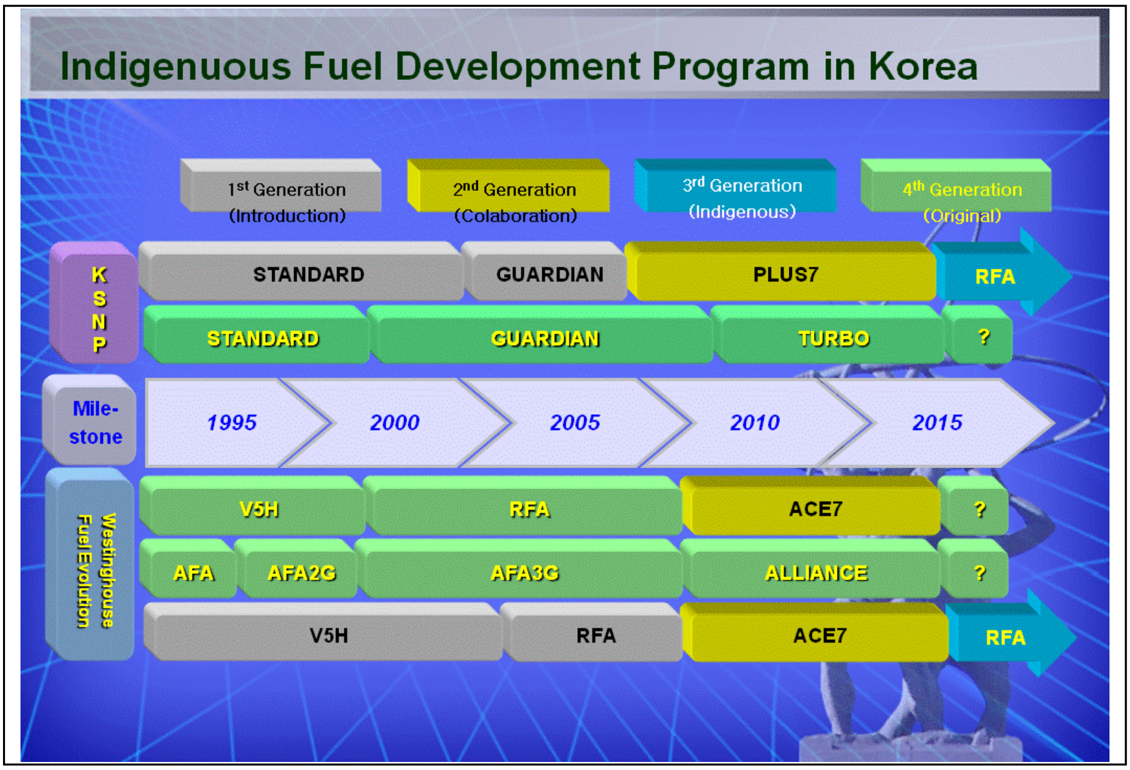
31 work units in 8 cells having 71m in total length, 1 pool and 1 hot lab.

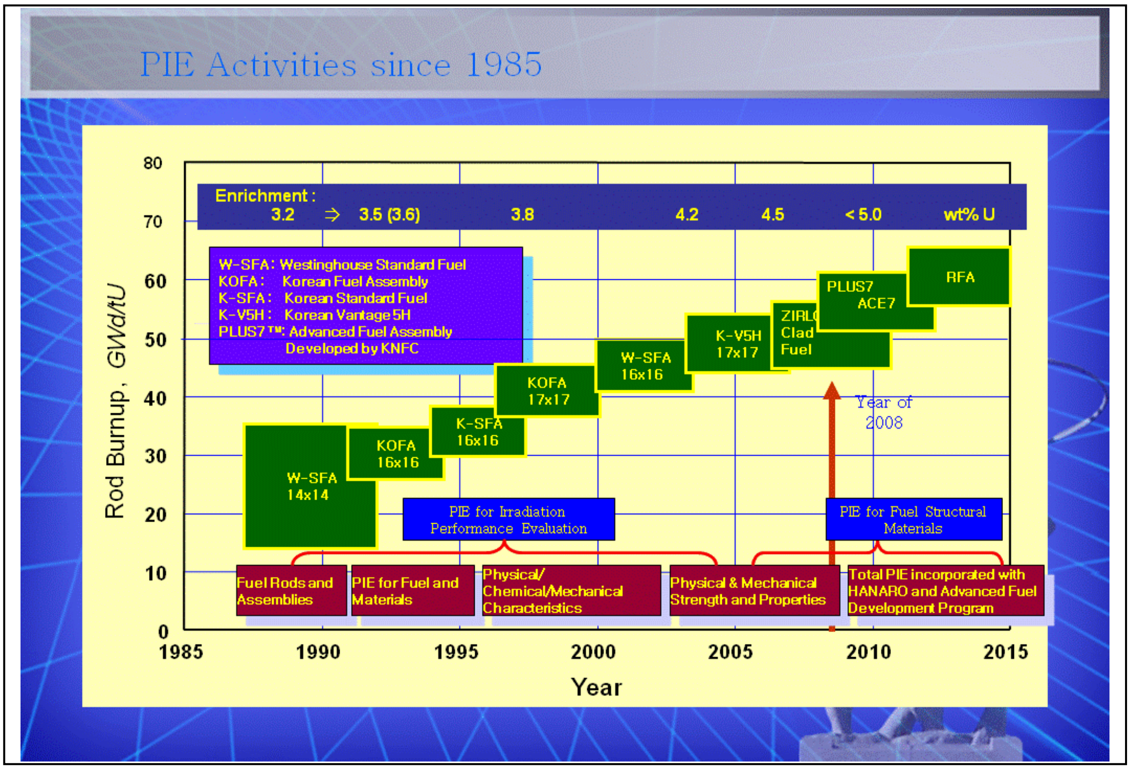

2. FACILITY DESCRIPTION (continued)
PIE flow diagram in KAERI PIEF
Fuel Assembly (in pool)
Fuel Rod (in hot cell)
Specimen (in hot cell)
Transportation
Receiving
Unloading
Storage
Pool Side Examination
Dismantling
Visual Inspection
Dimensional Measurement
Gamma Scanning
Non-Destructive Examination
Cutting
Visual Inspection
Eddy-Current Test
Profilometry
X- ray Radiography
Internal P Measure.
Fission Gas Analysis
Storage
Evaluation
• Failure mechanism
• Fuel integrity
• In-core behavior
Destructive Examination
Metallography
Ceramography
Micro-Gamma Scan.
Densimetry
Burnup/H Analysis
SEM/EPMA; Chem.Anal.

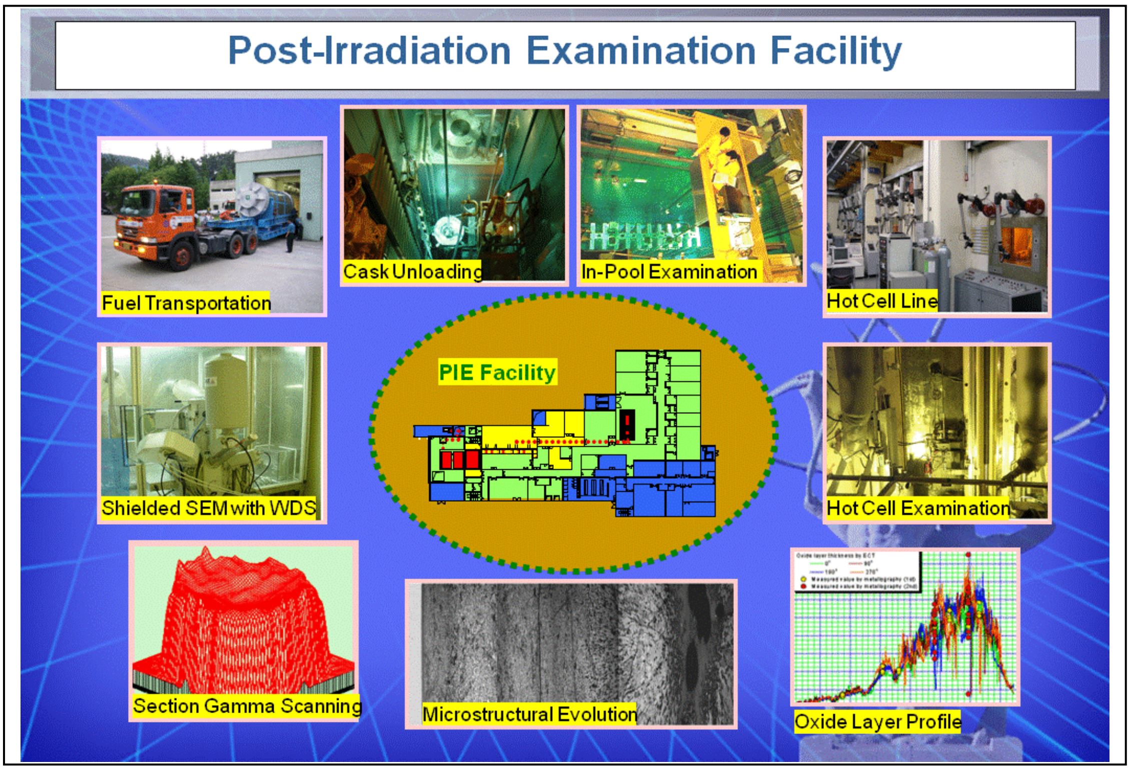

PIE Flow Diagram in IMEF
HANARO & Nuclear Power Reactor
Fuels and Materials
Fuel Tests
Structural Material Tests
Non-Destructive Test
· Visual Inspection
· X-Ray Radiography
· Dimensional Measurement
· Eddy Current Test
· Gamma Scanning
Destructive Test
· Rod Puncturing
· Sample Cutting
· Grinding & Polishing
· Density Measurement
· Metallography
· Visual Inspection
· Impact Test
· Tensile Test
· Fatigue Test
· Fracture Toughness Test
· Metallography
· Hardness Measurement
· EPMA Analysis
· TEM Analysis

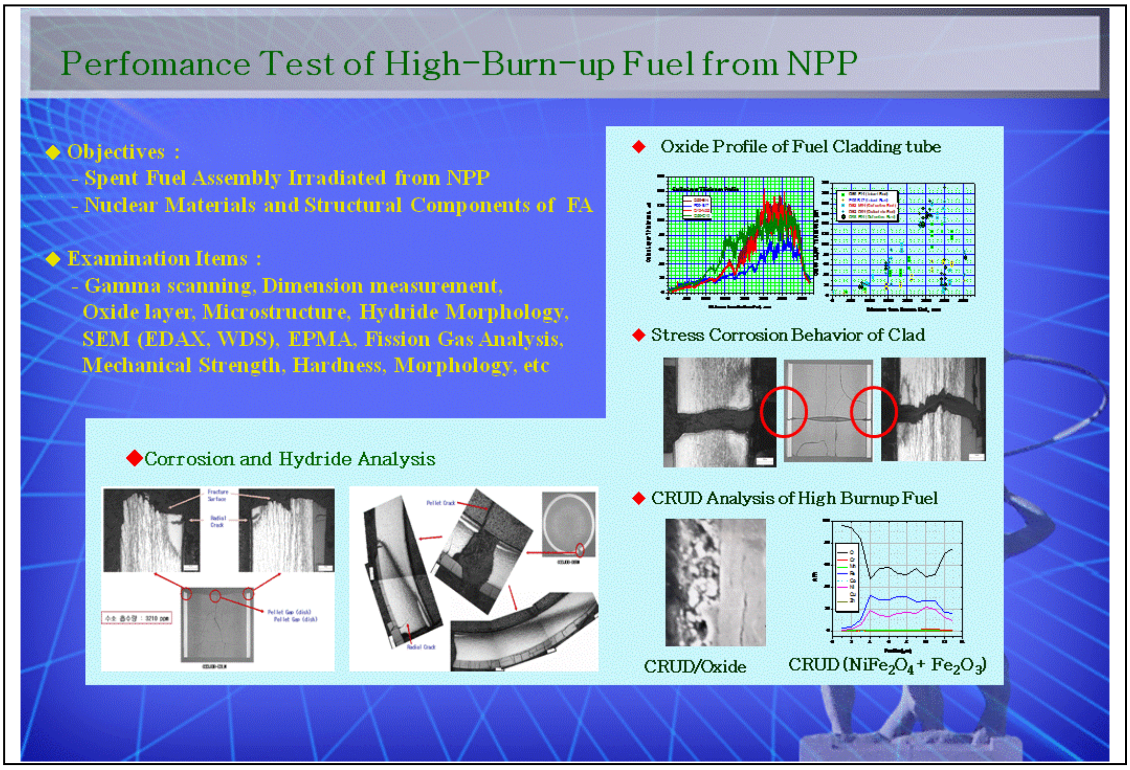

PIE Infra-structure for Fuel Performance Evaluation
Irradiation Characteristics of Nuclear Fuel
Nuclear R&D Support/Improving Plant Safety
Enhancing the Fuel Reliability Program
'07~
HANARO
Incorporated
PIE Program
'94~'06
PIE
for Nuclear R&D
'86~'93
IMEF
Construction
'80~'85
PIEF
Construction
Fuel and Material Development
PIE for Nuclear Fuel & Structural Materials
Fuel Performance & Integrity Evaluation
PIE Technique Development

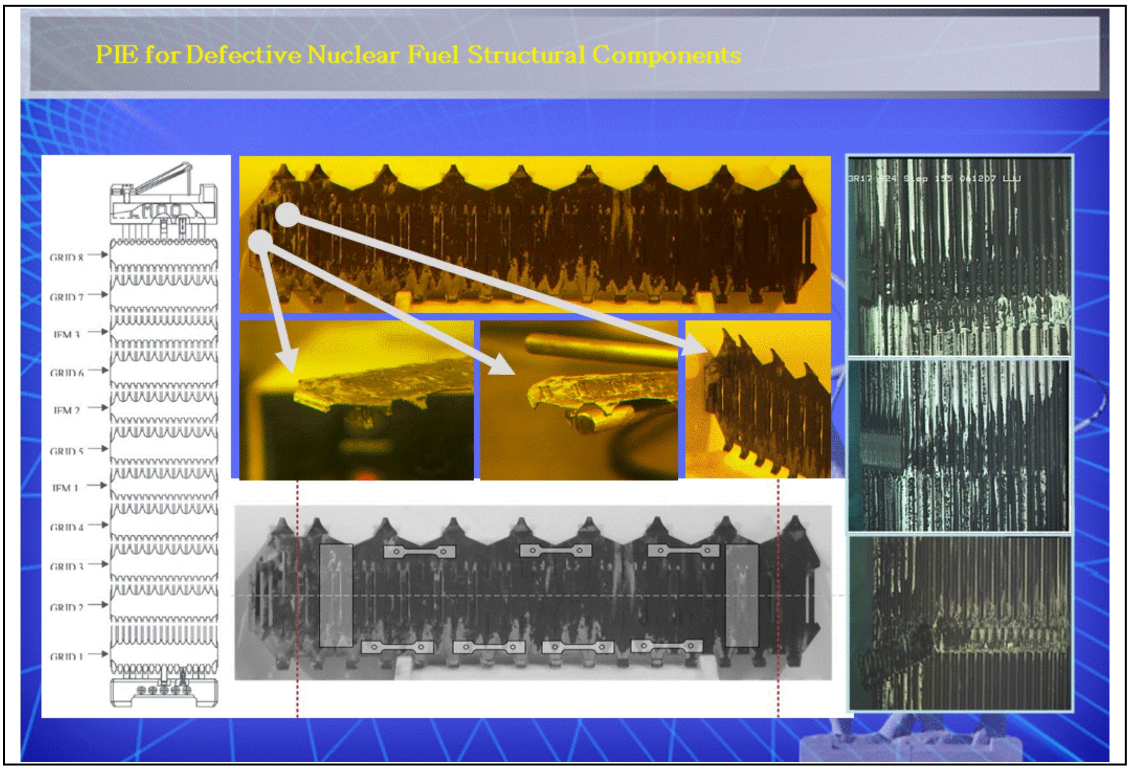

3. PIE OF HIGH BURNUP FUEL (continued)
PIE of high burnup PWR spent fuels
Objective : Fuel performance Data Base
Root Cause Finding and Remedy for Defective Fuels
Irradiation Characteristics of Reactor Fuels
PIE of Fuel Rods from Reactors
Burnup : 50 ~ 65 GWd/tU
Initial Enrichment : <5.0 wt% U-235
ZIRCALOY-4/ZIRLO clad fuels/etc.
Scope of PIE
NDT (gamma scan, profilometry, oxide layer, etc.)
Fission gas release and internal pressure
Optical metallography (fuel, fuel/clad interface, cladding corrosion)
Densimetry/ Swelling Effect
Chemical analysis (burnup, hydrogen)
SEM/ EPMA (EDS, WDS)
PIE for Structural Component of FA

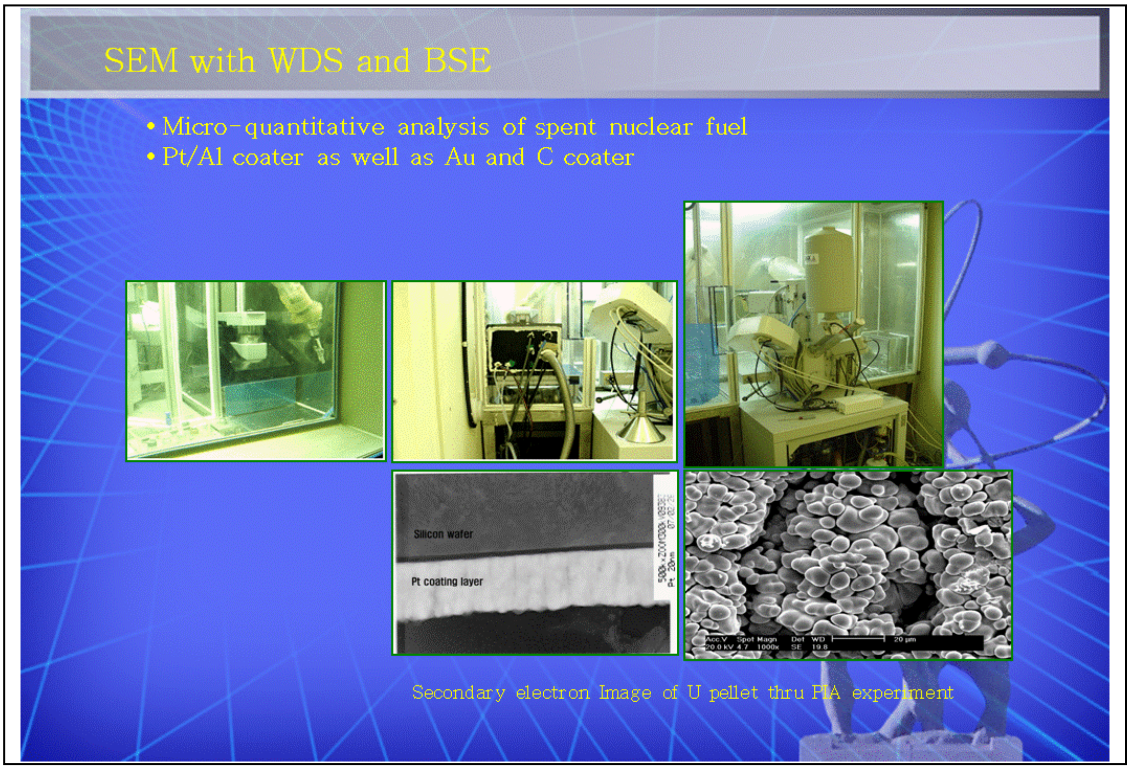

Indigenuous Fuel Development Program in Korea
1st Generation (Introduction)
2nd Generation (Colaboration)
3rd Generation (Indigenous)
4th Generation (Original)
KSNP
STANDARD
GUARDIAN
PLUS7
RFA
STANDARD
GUARDIAN
TURBO
?
Mile-stone
1995
2000
2005
2010
2015
Westinghouse Fuel Evolution
V5H
RFA
ACE7
?
AFA
AFA2G
AFA3G
ALLIANCE
?
V5H
RFA
ACE7
RFA

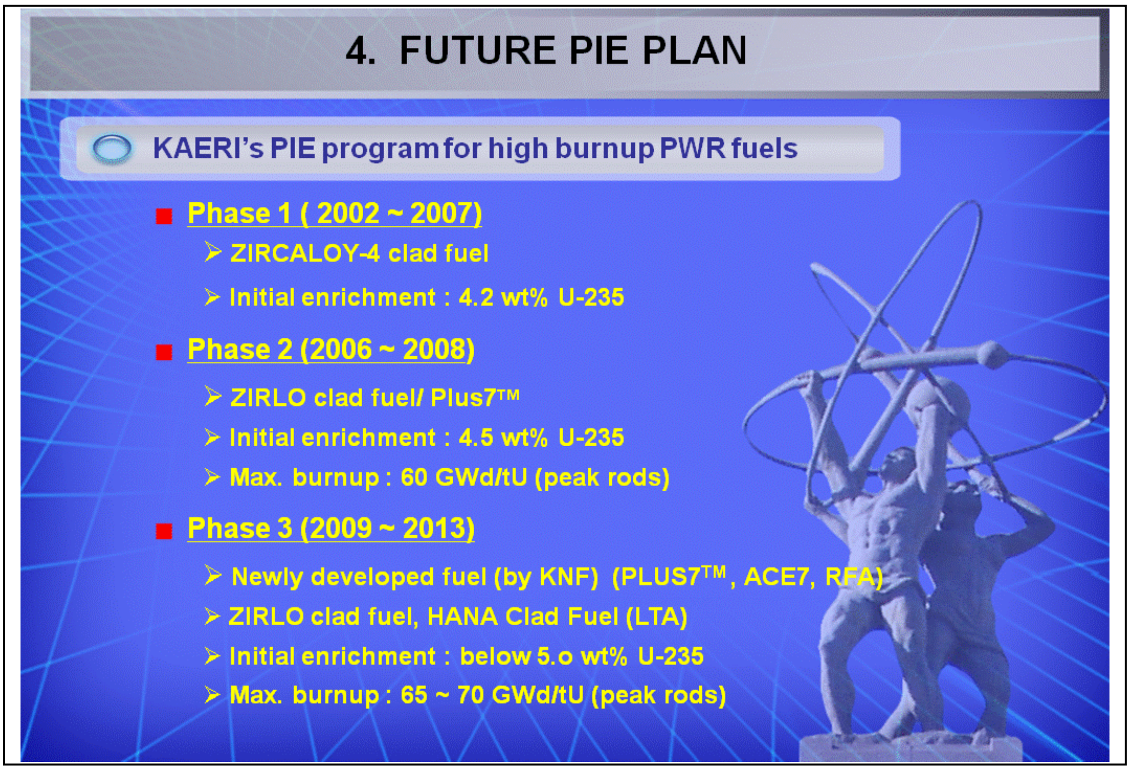

PIE Activities since 1985
Enrichment :
3.2 → 3.5 (3.6) 3.8 4.2 4.5 < 5.0 wt% U
W-SFA : Westinghouse Standard Fuel
KOFA : Korean Fuel Assembly
K-SFA : Korean Standard Fuel
K-V5H : Korean Vantage 5H
PLUS7™: Advanced Fuel Assembly
Developed by KNFC
W-SFA 14x14
KOFA 16x16
K-SFA 16x16
KOFA 17x17
W-SFA 16x16
K-V5H 17x17
ZIRLO Clad Fuel
PLUS7 ACE7
RFA
Year of 2008
PIE for Irradiation Performance Evaluation
PIE for Fuel Structural Materials
Fuel Rods and Assemblies
PIE for Fuel and Materials
Physical/ Chemical/Mechanical Characteristics
Physical & Mechanical Strength and Properties
Total PIE incorporated with HANARO and Advanced Fuel Development Program
Rod Burnup, GWd/tU
Year
0
10
20
30
40
50
60
70
80
1985
1990
1995
2000
2005
2010
2015

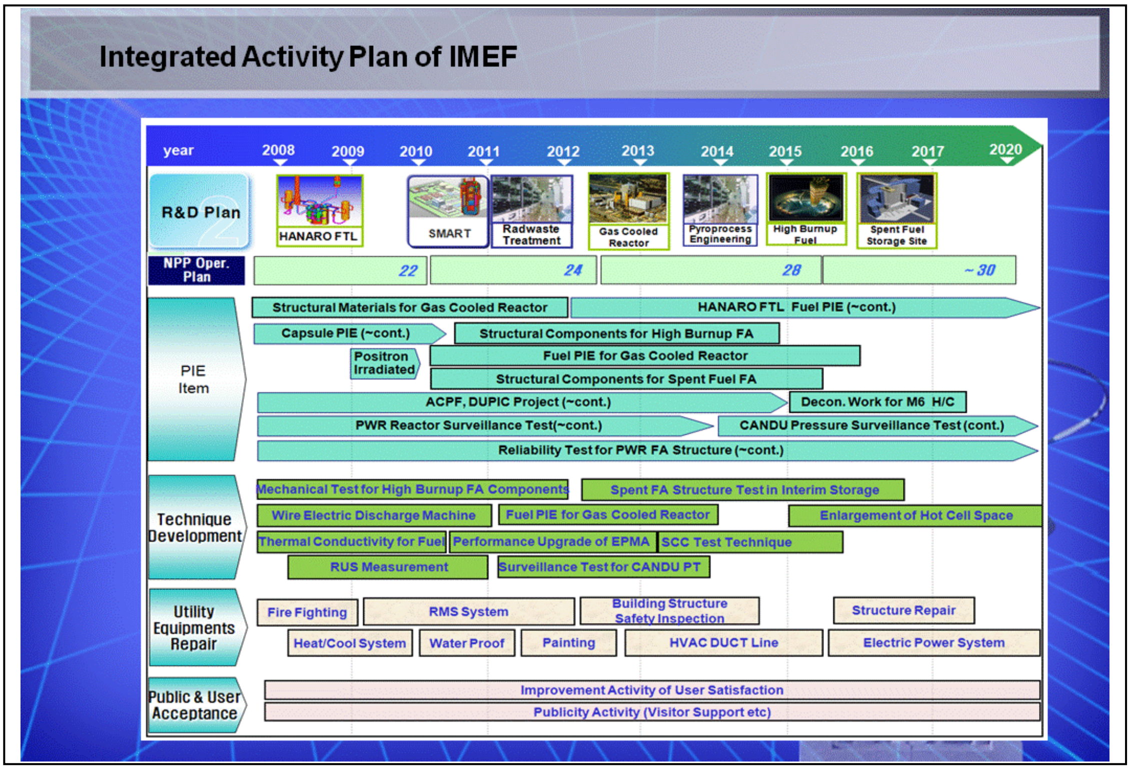

Post-Irradiation Examination Facility
Fuel Transportation
Cask Unloading
In-Pool Examination
Hot Cell Line
Shielded SEM with WDS
PIE Facility
Hot Cell Examination
Section Gamma Scanning
Microstructural Evolution
Oxide Layer Profile


Perfomance Test of High-Burn-up Fuel from NPP
◆ Objectives :
- Spent Fuel Assembly Irradiated from NPP
- Nuclear Materials and Structural Components of FA
◆ Examination Items :
- Gamma scanning, Dimension measurement,
Oxide layer, Microstructure, Hydride Morphology,
SEM (EDAX, WDS), EPMA, Fission Gas Analysis,
Mechanical Strength, Hardness, Morphology, etc
◆ Oxide Profile of Fuel Cladding tube
◆ Stress Corrosion Behavior of Clad
◆ Corrosion and Hydride Analysis
◆ CRUD Analysis of High Burnup Fuel
CRUD/Oxide
CRUD ($NiFe_2O_4$ + Fe_2O_3)


PIE for Defective Nuclear Fuel Structural Components


SEM with WDS and BSE
• Micro-quantitative analysis of spent nuclear fuel
• Pt/Al coater as well as Au and C coater
Silicon wafer
Pt coating layer
Secondary electron Image of U pellet thru PIA experiment


4. FUTURE PIE PLAN
KAERI's PIE program for high burnup PWR fuels
Phase 1 (2002 ~ 2007)
ZIRCALOY-4 clad fuel
Initial enrichment : 4.2 wt% U-235
Phase 2 (2006 ~ 2008)
ZIRLO clad fuel/ Plus7™
Initial enrichment : 4.5 wt% U-235
Max. burnup : 60 GWd/tU (peak rods)
Phase 3 (2009 ~ 2013)
Newly developed fuel (by KNF) (PLUS7™, ACE7, RFA)
ZIRLO clad fuel, HANA Clad Fuel (LTA)
Initial enrichment : below 5.o wt% U-235
Max. burnup : 65 ~ 70 GWd/tU (peak rods)


Integrated Activity Plan of IMEF
year
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2020
R&D Plan
HANARO FTL
SMART
Radwaste Treatment
Gas Cooled Reactor
Pyroprocess Engineering
High Burnup Fuel
Spent Fuel Storage Site
NPP Oper. Plan
22
24
28
~30
PIE Item
Structural Materials for Gas Cooled Reactor
HANARO FTL Fuel PIE (~cont.)
Capsule PIE (~cont.)
Structural Components for High Burnup FA
Positron Irradiated
Fuel PIE for Gas Cooled Reactor
Structural Components for Spent Fuel FA
ACPF, DUPIC Project (~cont.)
Decon. Work for M6 H/C
PWR Reactor Surveillance Test(~cont.)
CANDU Pressure Surveillance Test (cont.)
Reliability Test for PWR FA Structure (~cont.)
Technique Development
Mechanical Test for High Burnup FA Components
Spent FA Structure Test in Interim Storage
Wire Electric Discharge Machine
Fuel PIE for Gas Cooled Reactor
Enlargement of Hot Cell Space
Thermal Conductivity for Fuel
Performance Upgrade of EPMA
SCC Test Technique
RUS Measurement
Surveillance Test for CANDU PT
Utility Equipments Repair
Fire Fighting
RMS System
Building Structure Safety Inspection
Structure Repair
Heat/Cool System
Water Proof
Painting
HVAC DUCT Line
Electric Power System
Public & User Acceptance
Improvement Activity of User Satisfaction
Publicity Activity (Visitor Support etc)


Thank You
for Your Attention

3. Research Reactor Management

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3.1 UTILIZATION OF THE IRRADIATION HOLES IN THE CORE AT HANARO

Choongsung Lee and Gukhoon Ahn

HANARO Management Division, Korea Atomic Energy Research Institute
1045 Daedeok-daero, Yuseong, Daejeon 305-353, Korea
cslee1@kaeri.re.kr and ghahn@kaeri.re.kr

HANARO is a multipurpose research reactor. The three hexagonal and four circular holes are reserved for the irradiation tests in the core. Twenty holes including two NTD(Neutron Transmutation Doping) holes, a LH(Large Hole) and NAA holes are located in the reflector tank. These holes have been used for radioisotope production, material and fuel irradiation tests, beam application research and neutron activation analysis. In the initial stage of normal operation, the using time of irradiation holes located in the core was less than 40% of the reactor operation day. To raise utilization of irradiation holes, the equipments and facilities have been developed such as various capsules. Another area for increasing the utilization of HANARO was the fuel irradiation tests to develop the new fuels. Various fuel irradiation tests have been performed. Recently, the usage time of the irradiation holes in the core was more than 90% of the reactor operation day. If the FTL starts an irradiation service, the irradiation holes in the core will be fully used. In this paper describes the status of utilization of irradiation holes in the core.

KAERI

하나로 HANARO

Utilization of the irradiation holes in the core at HANARO

2008. 11. 6

Choong-Sung Lee

Korea Atomic Energy Research Institute

KAERI HANARO

High-flux Advanced Neutron Application Reactor

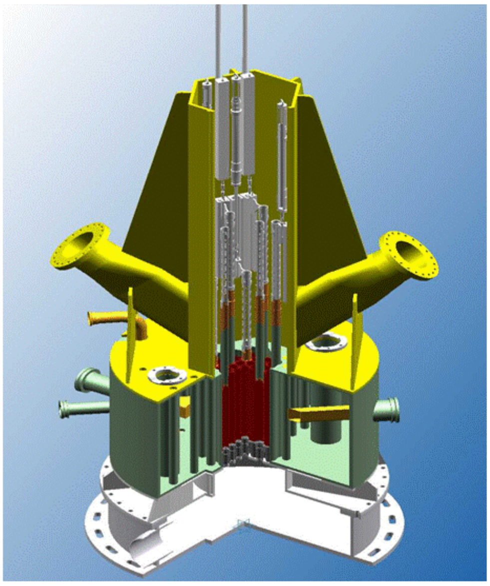
HANARO Characteristics

하나로 HANARO

Reactor Type	Open-tank-in-pool
Power	30 MW_{th}
Coolant	H_2O
Reflector	D_2O
Core Cooling	Upward Forced Convection Flow
First criticality	1996

Use for

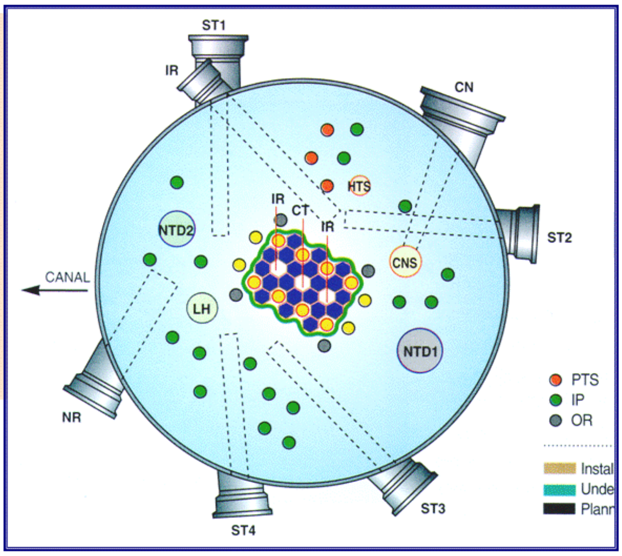
- Radioisotope production
- Material and fuel irradiation test
- Beam application
- NAA



KAERI HANARO
High-flux Advanced Neutron Application Reactor

Status of Irradiation Holes

IR,CT: Capsule Irradiation Facility
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
IR: Fuel Test Loop



KAERI HANARO
High-flux Advanced Neutron Application Reactor

Irradiation Holes in the Core

❑ CT & IR holes
- Average Neutron Flux
  - Thermal : 2.7 ~ 3.0 x 10^{14}
  - Fast : 1.3 ~ 1.4×10^{14}
- Use for
  - Material irradiation test
  - RI production

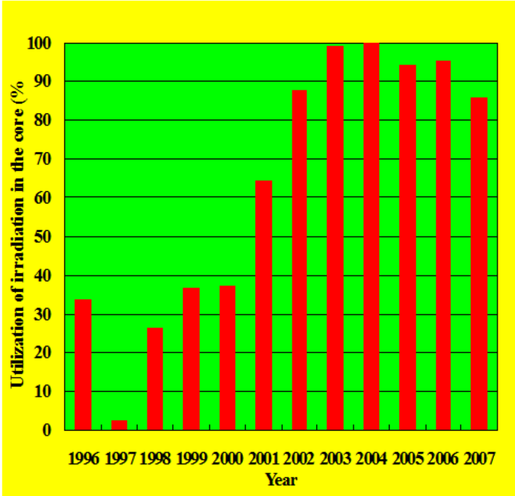
❑ OR holes
- Average Neutron Flux
  - Thermal : 2.0 ~ 2.5×10^{14}
  - Fast : 1.2 ~ 1.5×10^{13}
- Use for
  - Fuel irradiation test
  - RI production

KAERI HANARO
High-flux Advanced Neutron Application Reactor

Utilization of Irradiation Holes

하나로 HANARO

- **In the initial stage of a normal operation**
  - The utilization of the HANARO was not active.
  - Delay of the development of equipments such as a capsule and rig for the irradiating material, RI targets and test fuel .
- **The irradiation test started in 1996 with two kinds of tests at the irradiation holes in the inner core.**
  - HANARO structure material test using a non-instrumented capsule in CT hole
  - HANARO fuel test as the HANARO fuel qualification program at a high power until 1998 in IR holes



Utilization rate of the irradiation holes

(The ratio of the occupied days of the irradiation holes to reactor operation days)

KAERI HANARO
High-flux Advanced Neutron Application Reactor

Development of Capsules and Fuels

하나로 HANARO

- **The development of capsules and fuel increased the utilization of the irradiation holes.**
- **Development of Capsules**
  - Non-instrumented and Instrumented capsules for material irradiation
  - Capsules for radio isotope production (MoO_3 and Iridium capsule)
  - Non-instrumented and Instrumented capsules for fuel irradiation
  - Creep capsule and fatigue capsule for material test
- **Development of Fuel**
  - HANARO fuel for localization
  - U-Mo fuel for developing a new fuel for a research reactor
  - DUPIC fuel (Direct Use of spent PWR fuels in CANDU reactors)
  - U-Zr fuel for small and medium reactor for an electricity generation and sea water desalination.
  - UO_2 fuel with a large grained UO_2 pellets developed for high burnup

Use of Irradiation holes

Irradiation Hole	1996	1997	1998	1999	2000	2001
CT,IR1,IR2	CAP HANARO (3 rods)	HANARO (3 rods)	HANARO (3 rods)	ICAP HANARO (KAERI)	ICAP HANARO (KAERI)	ICAP Ir-CAP
OR Holes			HANARO (6rods)	HANARO (6rods) ANL-fuel DUPIC Ir-CAP RI-CAP	ANL-fuel DUPIC Ir-CAP RI-CAP	UMo UZr DUPIC Ir-CAP RI-CAP

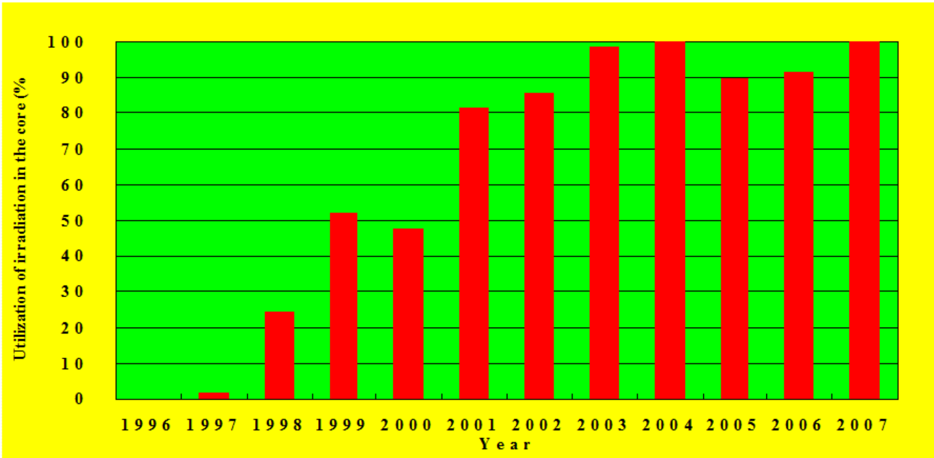
- The first LEU U_3Si fuel produced by atomization process for HANARO fuel localization : 1998
- The first instrumented capsule for material test, iridium and RI capsules : 1999
- As a demand for the fuel test increased, the capsule for producing Ir-192 at the irradiation holes(IR1, IR2 and CT) located in the inner core was developed in 2001.
- A qualification program for rod type fuel of the atomized U-Mo was initiated in 2000.
- The first irradiation tests of U-Mo : 2001

Use of Irradiation holes

Irradiation Hole	2002	2003	2004	2005	2006	2007
CT,IR1,IR2	ICAP Ir-CAP	ICAP Ir-CAP	ICAP Ir-CAP	ICAP Ir-CAP	ICAP Ir-CAP	ICAP Ir-CAP
OR Holes	DUPIC UO2 Ir-CAP RI-CAP	UMo UZr UO2 Fuel-ICAP Ir-CAP RI-CAP	UMo UZr DUPIC UO2 Fuel-ICAP Ir-CAP RI-CAP	UZr UO2 Ir-CAP RI-CAP	UMo UZr DUPIC UO2 Ir-CAP RI-CAP	UMo UO2 Fuel-ICAP Ir-CAP RI-CAP

- The 2nd, 3rd irradiation tests of U-Mo : 2003, 2006
- Fuel instrumented capsule : 2003
- 3 times of U-Zr fuel irradiation test : 2003 ~ 2006
- DUPIC fuel irradiation tests were performed 6 times
- UO_2 fuel irradiation with a large grained UO_2 pellets from 2002

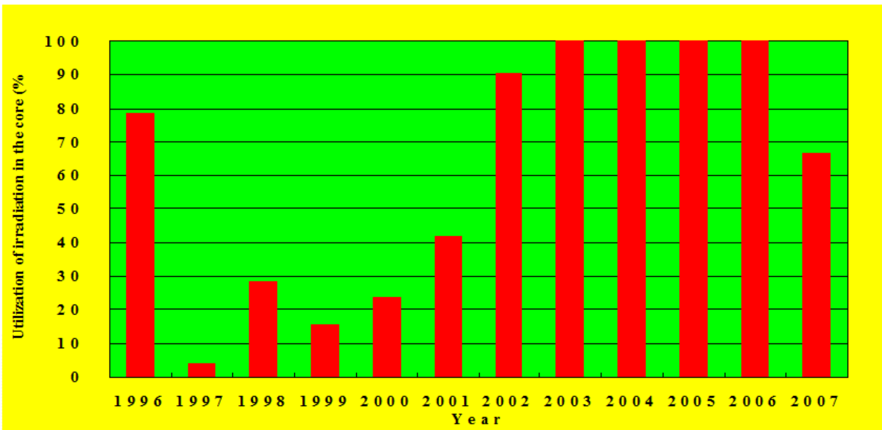
Use of Irradiation holes(OR holes)



Utilization rate of the OR holes

(The ratio of the occupied days of OR holes to reactor operation days)

Use of Irradiation holes(CT,IR holes)



Utilization rate of the CT and IR holes

(The ratio of the occupied days of CT and IR holes to reactor operation days)

KAERI HANARO
High-flux Advanced Neutron Application Reactor

Conclusion

하나로 HANARO

- When the HANARO started its first power operation, the utilization of the irradiation holes was inactive.
- The development of the various capsules for fuel and material tests and RI production contributed that the users can use the HANARO with ease.
- On the basis of the experiences of the fuel irradiation test, FTL (Fuel Test Loop) has been installed in the core(IR1 hole) to extend the utilization of the fuel irradiation. FTL is a test facility that irradiate the three fuel pins for PWR and CANDU fuel under the environments of a commercial power reactor with a high pressure and temperature. it will operate from 2008 with the three fuel pins of PWR fuel.
- Recently, the using time of the irradiation holes in the core is more than 90% of the reactor operation day. If the FTL starts an irradiation service, the irradiation holes in the core will be fully used.

3.2 INSTALLATION OF THE SAG COMPENSATOR FOR HANARO

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Electric power is essential for all industrial plants and also for nuclear facilities. HANARO is a research reactor which produces a 30MW thermal power. HANARO is designed to be tripped automatically when interruptions or some extent of sags occur. HANARO has the reactor regulation system(RRS) and reactor protection system(RPS).

HANARO is designed so as to be tripped automatically by insertion of control absorber rods(CAR) and shut-off rods(SOR). When voltage sag or momentary interruption occurs, the reactor has an unwanted trip by insertion of CARs and SORs even though the process systems are still in operation. HANARO was experienced in a nuisance trip as often as the unexpected voltage sag and/or momentary interruption occurs. We installed the voltage sag compensator on the power supply for CARs and SORs so as to prevent an unwanted trip. We undertook voltage sag assessment of the AC coil contactor which is a component of the power supply unit for the SORs. The compensation time is determined to be less than 1 sec in consideration of the reactor safety.

This paper is concerned with the impact of the momentary interruption on the reactor and the effect of the voltage sag compensator.

Installation of the Sag Compensator for HANARO

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KAERI

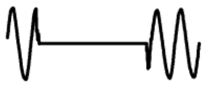
Introduction

- Reactor has tripped 136 times unexpectedly since HANARO was operated in 1995
  - ✓ Until 2000, the major reasons of the reactor trips were the system problem and human error.
  - ✓ The reactor trips by the system problem and human error are decreasing as the system is stabilizing and the operators are skilled
  - ✓ Electric fail has become the major reason of reactor trip since 2001

Reason of Trip	Until 2000	After 2000	Total
System problem	82 (68.9 %)	8 (47.0 %)	90 (66.1%)
Human error	29 (24.3 %)	1 (6.0 %)	30 (22.1 %)
Electric fail	8 (6.8 %)	8 (47.0%)	16 (11.8 %)
Total	119	17	136

Power Quality

- 68.7% of reactor trips by electric fails are caused by the momentary interruption or voltage sag
- Power quality problem
  - ✓ The concept of powering and grounding sensitivity electronic equipment in a manner that is suitable to the operation of that equipment. (IEEE Std. 1159)
  - ✓ Power quality problem is due to motor starting, transformer energizing, system fault and regulation problem, etc.
  - ✓ Interruption
    - the complete loss of the voltage (< 0.1 pu) on one or more phase conductors
    - Interruption is classified into
    - Momentary interruption ; Interruption lasts up to 3 seconds
    - Sustained interruption ; Interruption lasts more than 3 seconds
  - ✓ Voltage sag
    - Decrease to between 0.1 and 0.9 pu in rms voltage
    - Duration ; 0.5 cycle to 1 min
    - 87% of instability of power

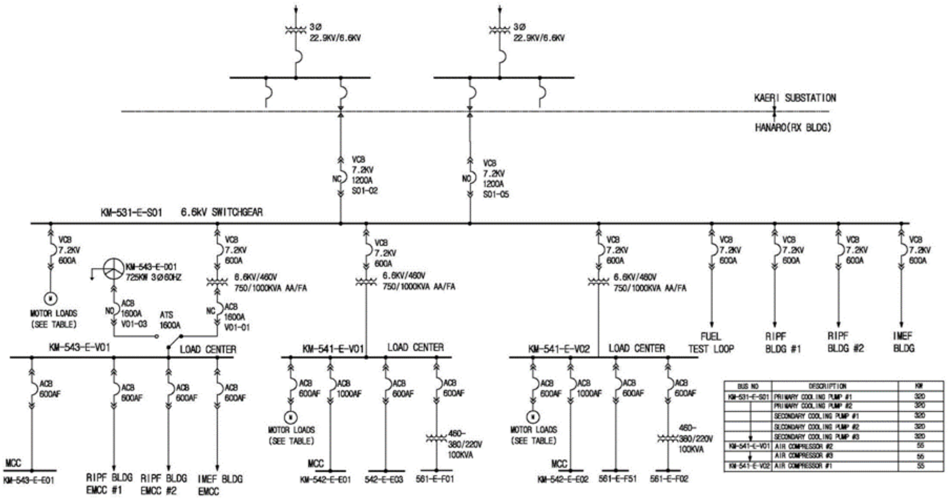

Voltage Interruption


Voltage Sag

Electric System of HANARO

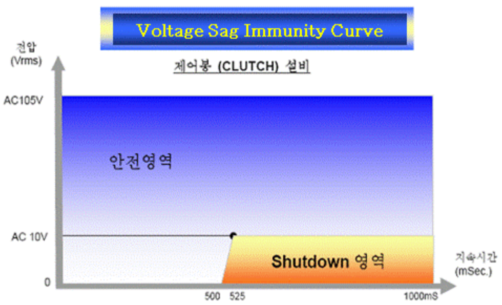
- Consist of electric system
  - ✓ Be supplied with 6.6kV power from KAERI substation
    - Consist of two feeder ; primary, alternate
  - ✓ One diesel generator with a capacity of 725 kW is provided in preparation for a failure of the offsite power
  - ✓ AC and DC UPS power to the safety-related instrumentation & control equipment
- Classified into four classes according to the reliability of the power
  - ✓ Class 4 : Commercial AC power (off-site power)
  - ✓ Class 3 : Emergency AC electric power
    - Connected to a diesel generator
  - ✓ Class 2 : AC UPS power
    - Class 3 power connected to batteries
  - ✓ Class 1 : DC UPS power

Electric System of HANARO



Impact of Electric Fail

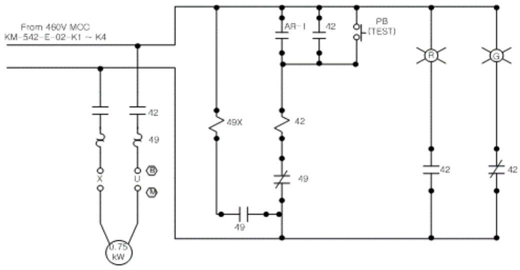
- Impact on CAR System
  - CAR is connected to driver through a magnetic clutch
  - 12V DC power is supplied to magnetic clutch
    - Power supply input : class 4, 110Vac, 60Hz
    - Output : 12Vdc
  - The reactor is tripped by dropping control rods automatically on loss of power.
- Sag immunity test for DC power supply in CAR system
  - 10Vac is the minimum steady state voltage of DC powe supply
  - Even at interruption, DC power supply still supplies the power until duration of 500msec
  - DC power supply has good immunity from voltage variation
  - 12V DC power is supplied to magnetic clutch
    - Consist of transformer, inductor, capacitor which are able to store the electrical energy

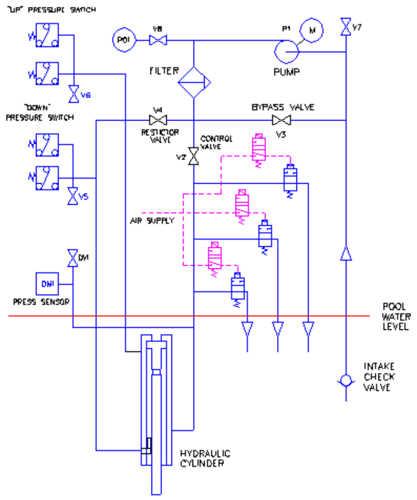


The characteristic curve of dc power supply for the voltage sag

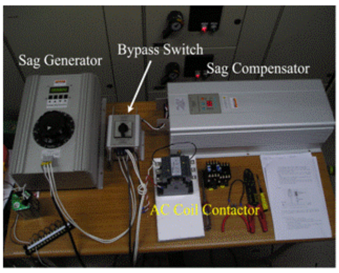
Impact of Electric Fail (Cont')

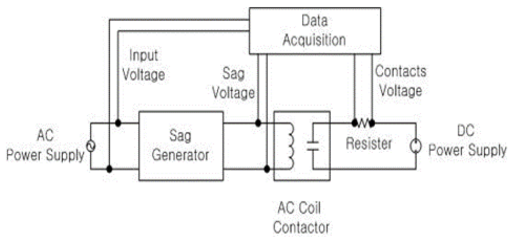
- SOR system consists of shut-off rod (SOR), hydraulic pump, hydraulic cylinder, solenoid valves and a power supply unit
- Electric fail leads to loss of hydraulic pressure in the hydraulic circuit, consequently SORs drop into reactor core
  - ✓ MCC supplies 110Vac to pump motor using ac coil contactor as switching component
  - ✓ Ac coil contactor is most sensitive to voltage sag of all control circuit components.





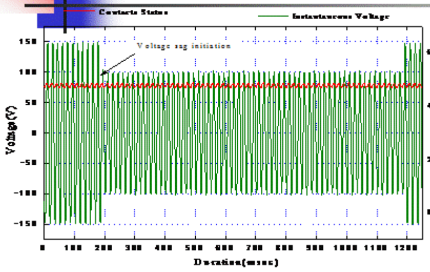
Impact of Electric Fail (Cont')



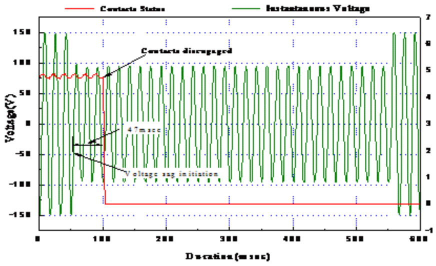


- Sag immunity test for ac coil contactor of SOR system
  - ✓ Test setup is composed of AC power supply, DC power supply, resistor, sag generator, sag compensator, data acquisition system
  - ✓ Sag generator provides the voltage sag with a varying magnitude and duration
  - ✓ Data is sampled with 1 kHz

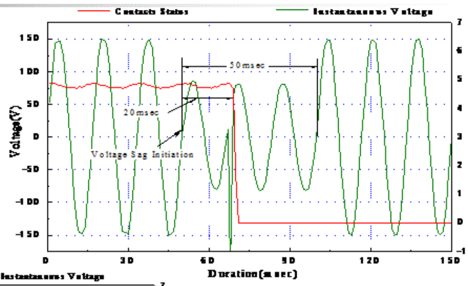
Impact of Electric Fail (Cont')



Waveform at voltage sag to 75V, 1000msec



Waveform at voltage sag to 70V, 500msec



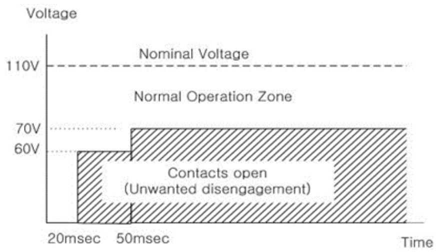
Waveform at voltage sag to 60V, 50msec

Impact of Electric Fail (Cont')

	amplitude, duration	contacts open	remark
1	80V, 1000msec	No	chattering
2	80V, 600msec	No	"
3	80V, 500msec	No	"
4	75V, 1000msec	No	"
5	70V, 500msec	Yes	
6	70V, 400msec	Yes	
7	70V, 300msec	Yes	
8	70V, 200msec	Yes	
9	70V, 100msec	Yes	
10	70V, 50msec	No	
11	60V, 50msec	Yes	

➤Test Result

- ✓Contacts begin to be disengaged
  - at voltage sag to 70V and duration of 50msec
  - at voltage sag to 60V and duration of 20msec
- ✓MSSHIV (minimum steady state hold in voltage) is 70V

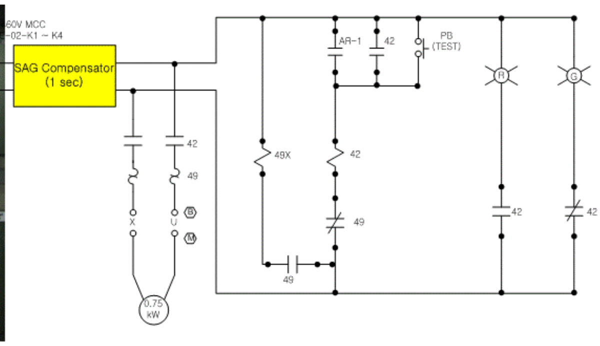


Voltage tolerance curve of AC coil contactor

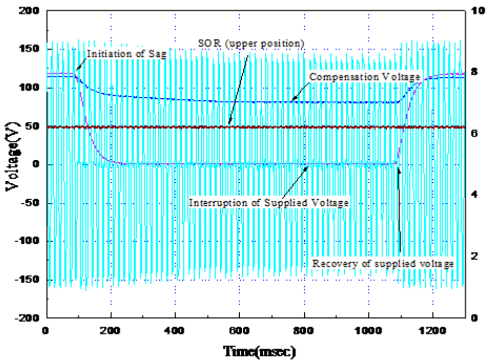
Installation of Sag Compensator

- Installation of the sag compensator to reduce the unwanted reactor trips by electric power fail such as voltage sag and/or momentary interruption.
  - To determine compensation time be less than 1 sec in consideration of reactor safety
- Carry out the accident analysis to demonstrate the fuel temperature and MCHFR do not come up to safety limits even though the reactor trip is delayed 1 sec by sag compensator
  - Confirm that the sag compensation for 1 sec does not impact on the safety
- Primary and Secondary cooling system
  - PCPs and SCPs are still running
  - At the momentary interruption for 1 sec,
    - the flow of SCS is 925.5kg/sec, a decrease of 2.6% compared with the normal flow.
    - Reactor trip signal is not initiated by PCS low flow.
  - On the assumption that the temperature of coolant is constant during 1 sec and the reactor power is 30MW, the thermal power decreases only 0.78MW
- Reflector cooling system
  - The reactor trips when the flow of the reflector coolant reduces to 60% of the normal flow and lasts more than 60secs.
- Momentary interruption with 1 sec does not impact on process systems

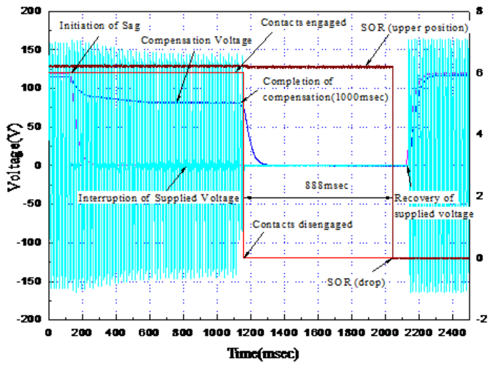
Installation of Sag Compensator (Cont')



Installation of Sag Compensator (Cont')



Performance test result
(compensation time : 1 sec, duration : 1 msec)



Performance test result
(compensation time : 1 sec, duration : 2 msec)

Conclusion

- The voltage sag compensator was installed to operate HANARO without unwanted trip by momentary interruption or voltage sag.
- The sag compensation of power supply for SOR and CAR system be coordinated with undervoltage protection system of main power supply
- The performance of the compensator was established by test. The reactor safety was proved by the accident analysis.
- The unwanted trip by electric fail of HANARO could be reduced.
  - After installation of sag compensator in 2007, momentary interruption or voltage sag occurred 2 times in operation.
  - Thanks to the voltage compensator, HANARO could prevent unwanted trip.

3.3 REFURBISHMENT STATUS ON REACTOR FACILITIES OF JMTR

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ABSTRACT

The JMTR (Japan Materials Testing Reactor), a light-water-cooling tank-type reactor with a 50MW thermal power, was shutdown in August 2006. The reactor facilities are to be refurbished during four years from the beginning of FY 2007, and the renewed JMTR will restart from FY 2011.

In advance of the reactor refurbishment, equipments on reactor facilities to be renewed and to be continuously used were selected from a viewpoint of ensuring safety, improvement of operating availability, etc. The selected equipments to be renewed were the reactor instrument and control system, cooling system, radioactive waste facility, power supply system, boiler, etc.

This report describes the basic idea on selection of the renewal facilities and schedule of refurbishment work.

KEYWORDS : JMTR, Refurbishment, Maintenance management, Operating availability, Periodical safety inspection

INTRODUCTION

The JMTR (Japan Materials Testing Reactor), which is a light-water-cooling tank-type reactor with a 50MW thermal power, was shutdown in August 2006[1] and its refurbishment was decided by JAEA on December 2006. The refurbishment work was started on FY 2007[2][3][4]. As for the refurbishment schedule, the reactor facilities are to be refurbished during four years from the beginning of FY 2007. The renewed JMTR will restart from FY 2011 until around FY 2030 at least.

All of the reactor facilities / equipments conditions, such as the frequency of troubles, service life, the prospects of the purchase of spare parts for the future, were investigated for the planning of the refurbishment. The schedule of refurbishment work was planned on the basis of the data of its conditions.

JMTR FACILITIES / EQUIPENTS

The JMTR is utilized for various irradiation tests, such as LWRs fuels and materials, fusion reactor materials, fundamental research, radioisotope productions, etc.

The reactor core is a cylindrical shape with 1.56m in diameter and 0.75m high, it consists of 24 standard fuel elements, five control rods with fuel followers, reflectors and H-shaped beryllium frame. The reactor pressure vessel, 9.5m high with 3m in inner diameter, is located in the reactor pool of reactor building which is 13m deep. The engineering data of JMTR is shown in Table 1.

The JMTR consists of the facilities on equipments of primary cooling system, secondary cooling system, UCL (utility cooling loop) system, boiler component, feed and exhaust air system, electric supply power system, etc. (See Fig.1) These facilities had been basically used since the construction of the JMTR except for the renewal in parts, such as the valve, the motor, the cooling tower, the cooling fan, the process control instruments, etc.

INVESTIGATION OF REACTOR FACILITIES / EQUIPMENTS CONDITIONS

1 Concept and investigation

In advance of the reactor refurbishment, the reactor facilities / equipments were selected to be renewed from a viewpoint of ensuring safety, improvement of operating availability, maintenance management, etc.

The basic criteria for selection of the reactor facilities / equipments to be renewed were examined from a viewpoint of ensuring safety and operating availability. The criteria for deciding are as follows;

(1) Aging during 20 years

(2) The importance of reactor facilities / equipments
(3) Surveillance of the conditions of facilities / equipments
(4) Supply of spare parts for facilities / equipments in the maintenance management during 20 years

All of the reactor facilities / equipments were investigated of those conditions, such as the number of troubles, service life, the prospects of the purchase of spare parts for the future, aging degradation, etc.

2 Results

As the results of the investigation, facilities / equipments to be renewed were selected by the basic criteria. The selected facilities / equipments to be renewed are shown in Fig.1. The details of the selected facilities / equipments are as follows;

(1) Primary cooling system（See Fig.2）

The primary cooling system had been used since the construction of the JMTR except for the renewal in parts of main pump piping, valves and modification of the piping support structure of primary cooling pump bypass line, etc.

As the results of the investigation, it was confirmed that primary cooling pumps, heat exchangers, main piping, main electrical valves were to maintain the present conditions.

The selected equipments to be renewed in primary cooling system are the motors of primary pump, the actuator of main valves, the electromagnetic coil of reactor pool connecting valve, etc. The actuator and electromagnetic coil are to be renewed with the same performance as existing ones for the purpose of improvement of maintenance. The motors of primary pump are to be renewed for the purpose of improvement of reliability. As for the renewal of the motor, a specification of coast down curve was considered from the viewpoint of the reactor safety analysis.

(2) Secondary cooling system（See Fig.3）

The secondary cooling system had been also used since the construction of the JMTR except for the renewal in parts of valves, cooling tower fan, cooling tower, etc.

As the results of the investigation, the motors and the pumps of circulating pump and auxiliary pump, main diaphragm valves, the motors and the decelerator of cooling tower fan, etc. were selected to be renewed. Those are to be renewed with the same performance as existing ones for the purpose of improvement of maintenance and reliability.

On the other hand, the strength or functionality of the main piping of secondary cooling system were evaluated to have been maintained by usual operation and maintenance, and repair of inner lining of the piping during the refurbishment work is to be carried out to long term utilization after restart of JMTR from a viewpoint of preventive maintenance.

(3) UCL（Utility cooling loop） system（See Fig.4）

The UCL system had been also used since the construction of the JMTR except for the renewal in parts of cooling tower, auxiliary pump, etc. As the results of the investigation, the pumps and the motors of circulating pump and storage pump, the outlet valve of storage pump, the motors and the decelerator of cooling tower fan, etc. were selected to be renewed. Those are to be renewed with the same performance as existing ones for the purpose of improvement of maintenance and reliability.

(4) Instrument and control system（See Fig.5）

Instrument and control system consists of reactor control board, nuclear instrumentation unit, control rod drive mechanism and process control system. The reactor control board, the nuclear instrumentation unit, and the control rod drive mechanism had been used since the construction of the JMTR except for the renewal in parts, and the process control system had been used since installation at 1966.

As the results of the investigation, the reactor control board, the nuclear instrumentation unit and the process control system were selected to be complete renewed because of difficulty in getting spare parts, and the circuits of them which consist of a huge amount of relays and soldered wirings will be replaced by present-designed integrated circuits for the purpose of improvement of reliability.

Moreover, indicators, switches, etc. of the control board are classified and arranged at every feature, and are designed from a viewpoint of improvement of man-machine interface so as to be able to operate reactor more easily and visually. Install of pre-amplifier in start-up channels, renewal of the earth wire in the nuclear instrumentation unit are to be carried out to protect noises, and the instrumentation unit was modularized to reduce loose electrical connection for the purpose of improvement of reliability.

As the results of the investigation, the fundamental structure of the control rod drive mechanism was decided not to be changed, however reed switches, electromagnet, ball screw of the control rod drive mechanism are replaced for the purpose of improvement of reliability and maintenance management. The neutron absorber and the shock section of control rods are possible to maintain the present conditions.

The reactor building, the reactor pressure vessel, the primary cooling system piping, etc. are possible to maintain the present conditions in accordance with the periodic safety review of the JMTR[5]. After restart of the JMTR, the maintenance activity will be carried forward based on the maintenance program[6] of the periodic safety review of the JMTR, and condition based maintenance are to be applied. Furthermore, the facilities are to be renewed properly in case of appearance of extraordinary sign.

As the almost of all the selected facilities to be renewed have been being used since the construction of the JMTR, design and fabrication of renewal facilities have fundamentally done, of course, based on the design principle at the construction. Furthermore, following new guidelines in Japan were taken into consideration;

(1) Safety design examination guides for water-cooled reactors for test and research (Mar. 2001, Nuclear Safety Commission of Japan)
(2) Regulatory guide for reviewing fire protection of light water nuclear power reactor facilities (Nov. 2002, Nuclear Safety Commission of Japan)
(3) Reviewing seismic design of nuclear power reactor facilities (Nov. 2006, Nuclear Safety Commission of Japan)

PLANNING OF REFURBISHMENT WORK

1 Operating management of reactor facilities

Concerning operating management of reactor facilities in reactor shutdown during the refurbishment work, several facilities require operating. These reactor facilities are as follows;

(1) Reactor pressure vessel and primary cooling system
It consists of reactor coolant boundary to maintain flooding function of the reactor core.
(2) Storage facility
It is necessary to store fresh and spent fuels with keeping subcriticality.
(3) Gaseous-waste exhaust facility
It is necessary to maintain working environment during the refurbishment.
(4) Reactor containment and ventilation facilities
It is necessary to keep confinement of radioactive materials.

(5) Diesel generator, emergency power supply system
It is necessary for ensuring safety in a commercial power blackout.

Above reactor facilities are inspected by regulatory authority as the periodical inspections a year.

2 Progress of refurbishment work

Since various as well as many facilities are to be renewed in the refurbishment with maintenance activity performed and the term of refurbishment of reactor facilities is only four years from beginning of FY 2007 until restart of the JMTR in FY 2011, refurbishment work is necessary to be scheduled efficiently.

While the feed and exhaust air system, ventilation facility for reactor building, is under renewal, there is no ventilation in the controlled area (the reactor building). Also the utility facilities, such as electric supply power system, boiler component, etc. are necessary to carry out refurbishment work in the reactor building comfortably.

The schedule of refurbishment work is summarized in Fig.6. Renewal of the feed and exhaust air system is carried out at first, and renewal of utility facilities of electric power supply system, boiler component, etc. is carried out in the same time. Then, the facilities in the reactor building are to be finally renewed.

SUMMARY

Reactor facilities / equipments to be renewed were selected based on these results of investigation and basic criteria for selection. At present, the refurbishment work is on going as scheduled from FY 2007. For example, the air conditioning system, demineralized water storage tank, boiler component, etc. were already renewed.

Renewal of feed and exhaust air system, UCL system, etc. will finish by the end of FY 2008, and renewal of cooling system, Beryllium frame, instrument and control system, etc. will start from FY2009 as scheduled.

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Table 1 Engineering data of JMTR.

Reactor type		Light water moderated and cooled tank type
Thermal power		50MW
Fuel element	^{235}U enrichment	20wt%
	Fuel meat	U_3Si_2-Al
	Cladding material	Aluminum
Reflector		Beryllium, Aluminum
Power density		425 MW/m^3
Primary Coolant	Core inlet temperature(Max.)	49℃
	Core outlet temperature	56℃
	Flow rate	6,000m^3/h
	Operating pressure	1.5MPa
Irradiation facilities	capsules (Irraditation positions)	~200
	Shroud facility	1
	Hydraulic rabbit	1

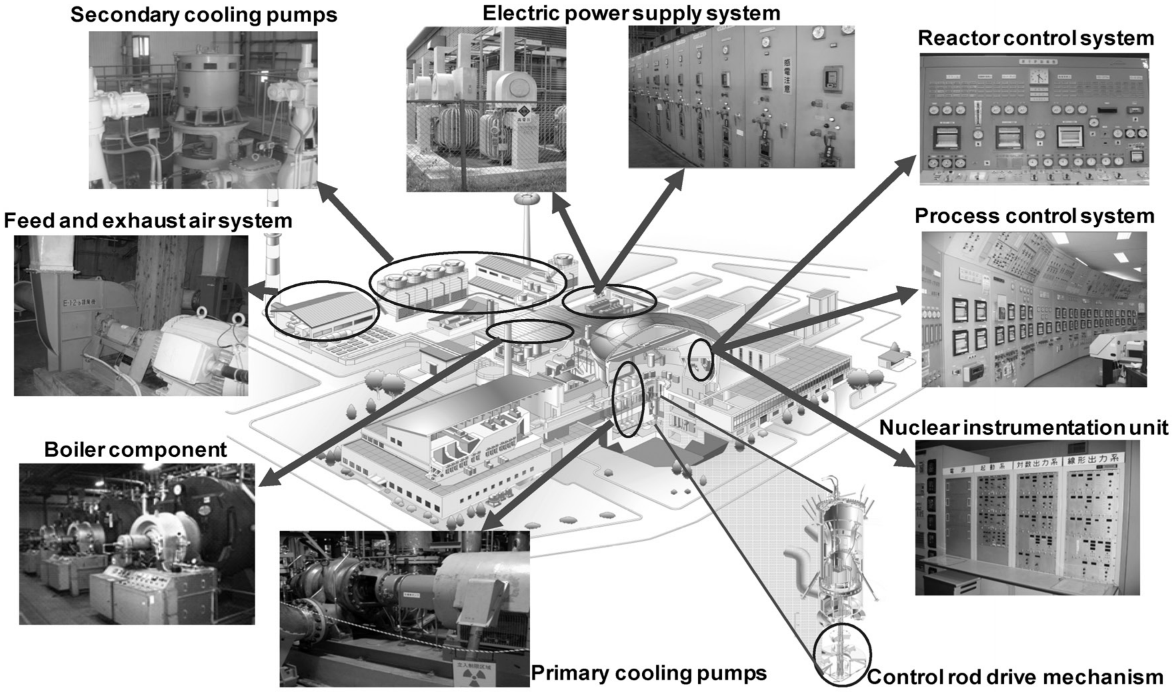

Fig.1 Refurbishment of reactor components.

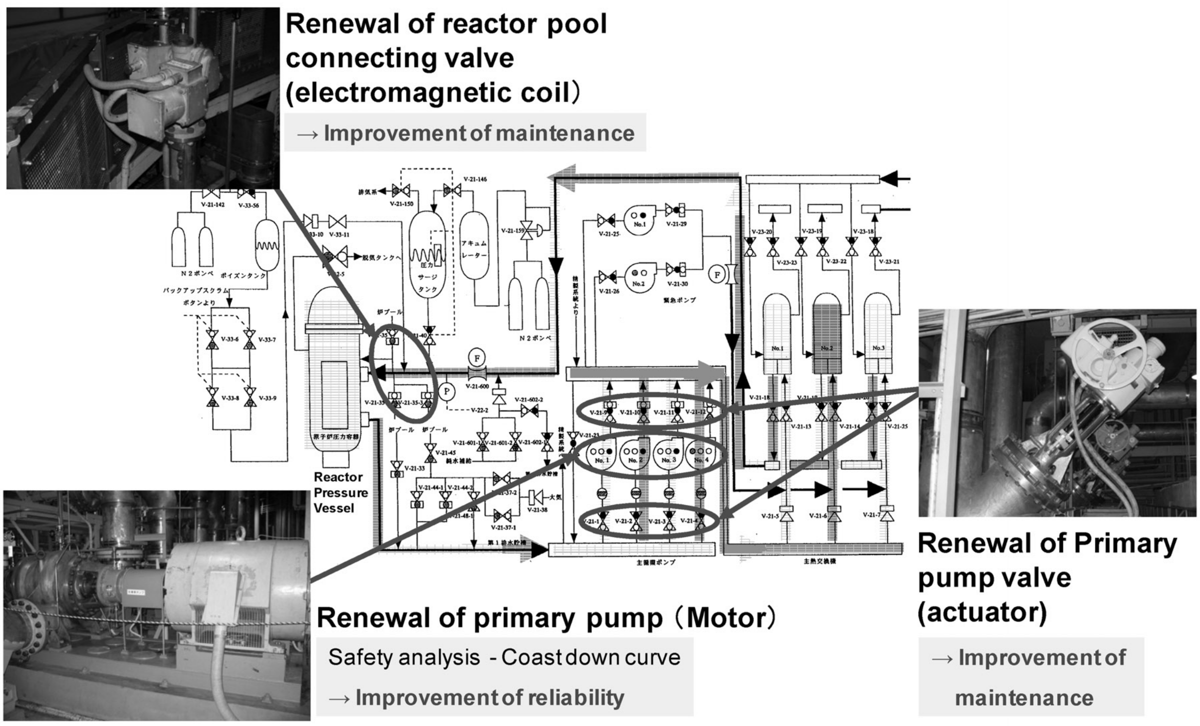

Fig.2 Refurbishment of primary cooling system.

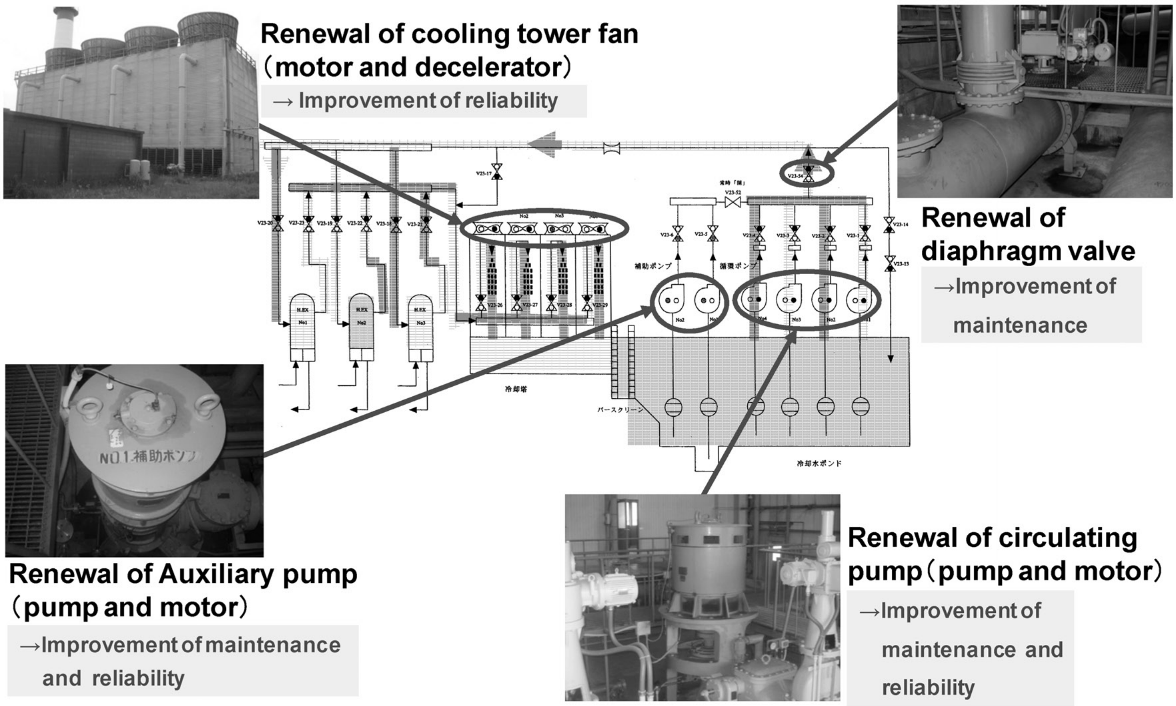

Fig.3 Refurbishment of secondary cooling system.

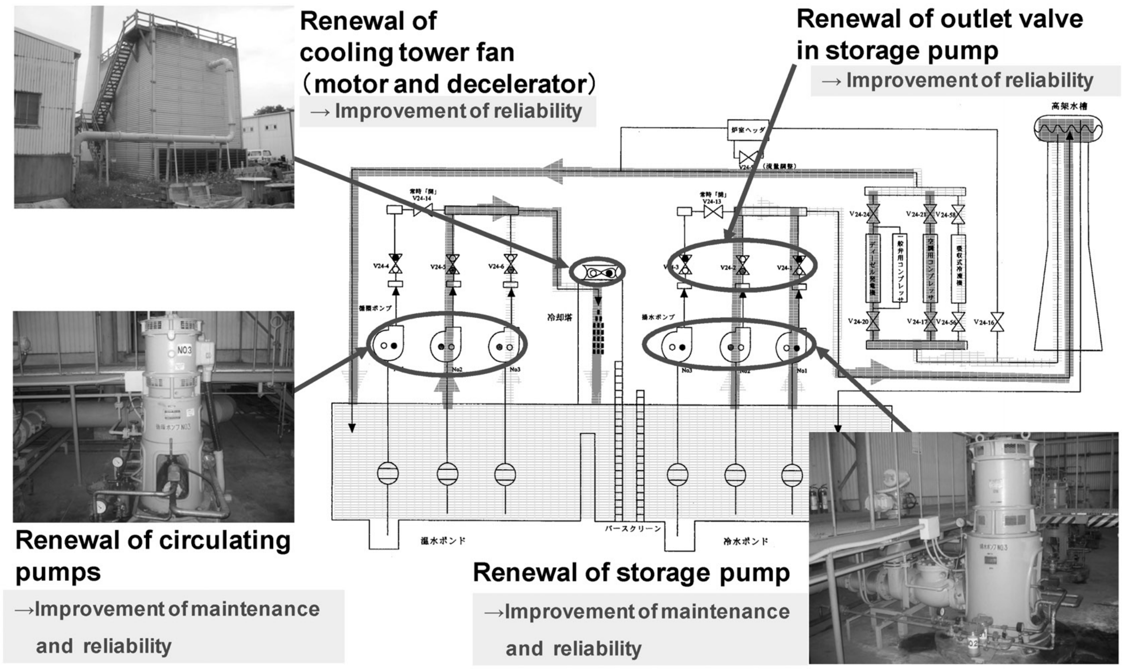

Fig.4 Refurbishment of Utility Cooling Loop system, (UCL system).

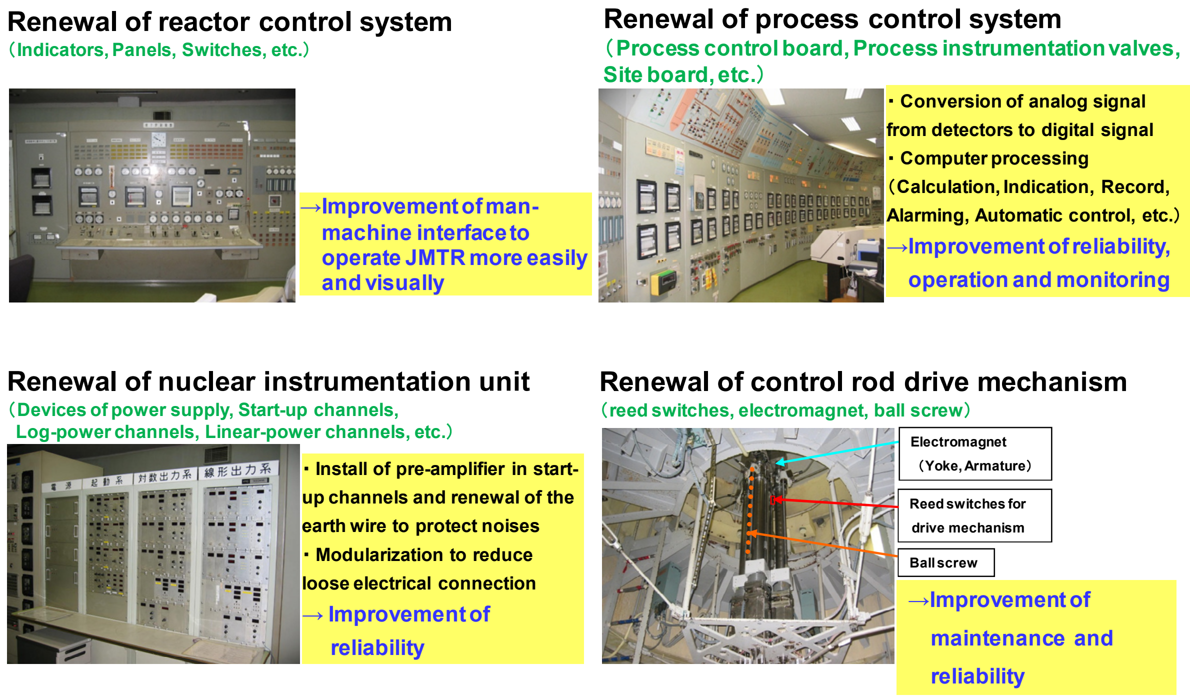

Fig.5 Refurbishment of instrument and control system.

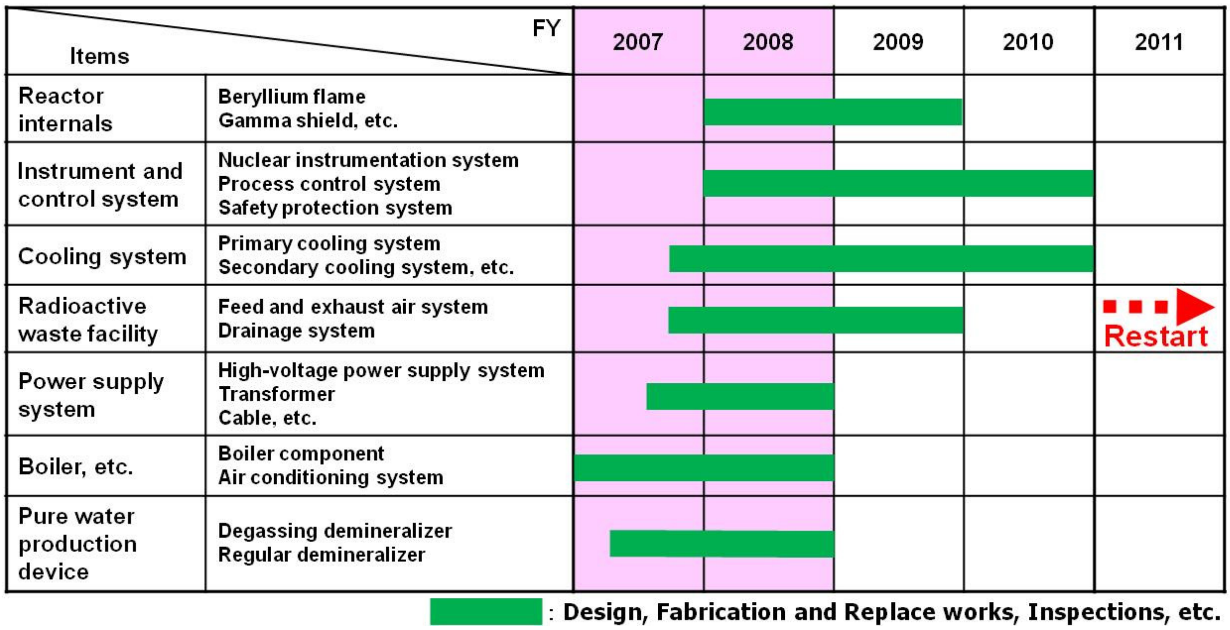

Fig.6 Schedule of refurbishment work.

3.4 IMPLEMENTATION OF THE SAFETY CULTURE FOR HANARO SAFETY MANAGEMENT

Jongsup Wu, Geeyang Han and Iksoo Kim

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Safety is the fundamental principal upon which the management system is based. The IAEA INSAG(International Nuclear Safety Group) states the general aims of the safety management system. One of which is to foster and support a strong safety culture through the development and reinforcement of good safety attitudes and behavior in individuals and teams so as to allow them to carry out their tasks safety. The safety culture activities have been implemented and the importance of safety management in nuclear activities for a reactor application and utilization has also been emphasized more than 10 years in HANARO which is a 30 MW multi-purpose research reactor and achieved its first criticality in February 1995. The safety culture activities and implementations have been conducted continuously to enhance its safe operation like the seminars and lectures related to safety matters, participation in international workshops, the development of safety culture indicators, the survey on the attitude of safety culture, the development of operational safety performance indicators (SPIs), the preparation of a safety text book and the development of an e-Learning program for safety education.

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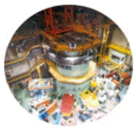

2008 KAERI/JAEA Joint Seminar on Advanced Irradiation and PIE Technologies

Implementation of the Safety Culture for HANARO Safety Management

Jongsup WU, Geeyang Han and Iksoo Kim

Korea Atomic Energy Research Institute

KAERI HANARO

High-flux Advanced Neutron Application Reactor

Abstract

Safety is the fundamental principal upon which a management system is based. The IAEA INSAG(International Nuclear Safety Group) states the general aims of a safety management system. One of which is to foster and support a strong safety culture through the development and reinforcement of good safety attitudes and behavior in individuals and teams, so as to allow them to carry out their tasks safety. The safety culture activities have been implemented and the importance of a safety management in nuclear activities for a reactor application and utilization has also been emphasized for more than 10 years in HANARO which is a 30 MW multi-purpose research reactor that achieved its first criticality in February 1995. The safety culture activities and implementations have been conducted continuously to enhance its safe operation such as the seminars and lectures related to safety matters, participation in international workshops and the development of safety culture indicators, a survey on the attitude of HANARO staff toward the safety culture, the development of operational safety performance indicators (SPIs), the preparation of a safety text book and the development of an e-Learning program for a safety education purpose.

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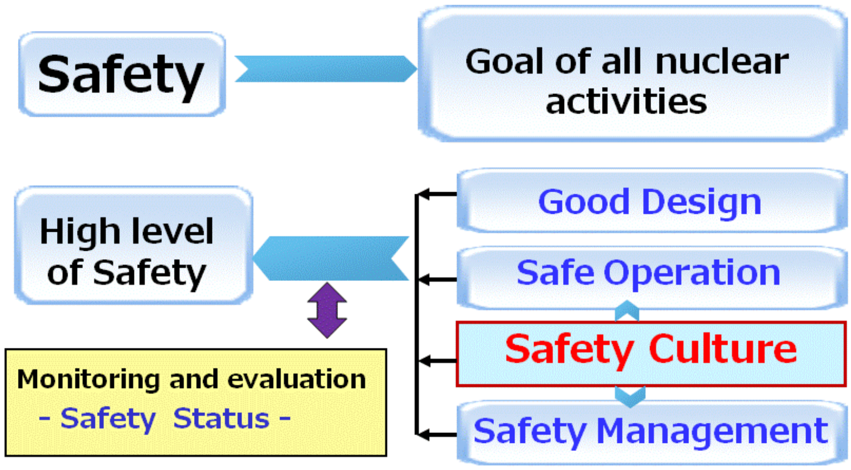
INTRODUCTION - *General*



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INTRODUCTION - *Safety Culture*

- **The aims of management system for nuclear facilities :**
  - to improve its safety performance
  - to foster and support a strong safety culture
- **HANARO safety culture activities ;**
  1) Seminars and lectures on the subject of safety
  2) Follow up the safety culture workshop FNCA (Forum for Nuclear Cooperation in Asia)
  3) Development of the safety culture indicators
  4) Survey on the attitude of safety culture
  5) Development of the operational safety performance indicators (SPIs)
  6) Preparation of an e-Learning program for safety education

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Safety culture activities

01 Seminars and lectures on safety

Category	Number of activities		
	2006	2007	2008 (Jan-Oct)
1. Technical seminar	4(15%)	9(23%)	3
2. Education on safety	4(15%)	12(31%)	6
3. Experience propagation	4(15%)	5(13%)	2
4. Lectures by invited specialists	3(11%)	3(8%)	4
5. Information on safety activities & others	12(44%)	10(25%)	5
Total	27	39	(20)

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Safety culture activities

02 FNCA Safety Culture Workshop

- Subject : Safety culture activities for nuclear research facilities
- Asian 9 countries (Australia, Japan, Korea, ----) from 1998.
- 7th FNCA Workshop held at KAERI in 2004.
- Peer review at HANARO: 30 good practices, 32 recommendations

Fields	NO. of Recommendation
Organization & management	6
Emergency preparedness	2
Education & training	2
Operation & maintenance	7
Radiation protection	6
Others	9
Total	32

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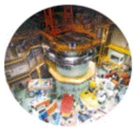
Safety culture activities



03 Development of Safety Culture Indicators

- **Purpose**
  - To evaluate the safety culture attitude of HANARO
  - To prepare the overall plan for promotion of safety culture
  - To improve the reliability and acceptance of nuclear
- **Development**
  - Based on the IAEA-TECDOC-860, ASCOT Guidelines
  - Reflect the characteristics of HANARO
  - Select the HANARO Safety Culture Indicators
    - 4 Categories
    - 15 evaluation items
    - 48 detail Indicators

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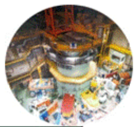

Safety Culture Indicators for HANARO

Categories	Evaluation Items
A. Operating organization (Corporation level)	1. Safety policy at the corporate level
	2. Safety practices at the corporate level
B. Operating organization (Plant level)	1. Highlighting safety
	2. Definition of responsibility
	3. Selection of managers
	4. Relations between plant management and regulators
	5. Review of safety performance
	6. Training
	7. Local practices
	8. Field supervision by management
	9. Work-load
	10. Attitudes of managers
	11. Attitudes of individuals
C. Research organization	1. Research input to safety analyses
D. Design organization	1. Design review process

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04

Safety culture activities

Survey on Safety Culture Attitude

- Based on the HANARO safety culture indicators, a survey was conducted in July 2008. It includes 68 questions ;
  - 55 Attitude of safety culture
  - 8 Supplementary safety senses (general safety activities, organizational culture, safety performances, etc.)
  - 5 Basic questions (duty, age, position and experiences)

- 5 point scale was applied for the grade of the answers;
  - strongly agree : 5 points
  - strongly disagree : 1 point

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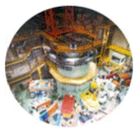
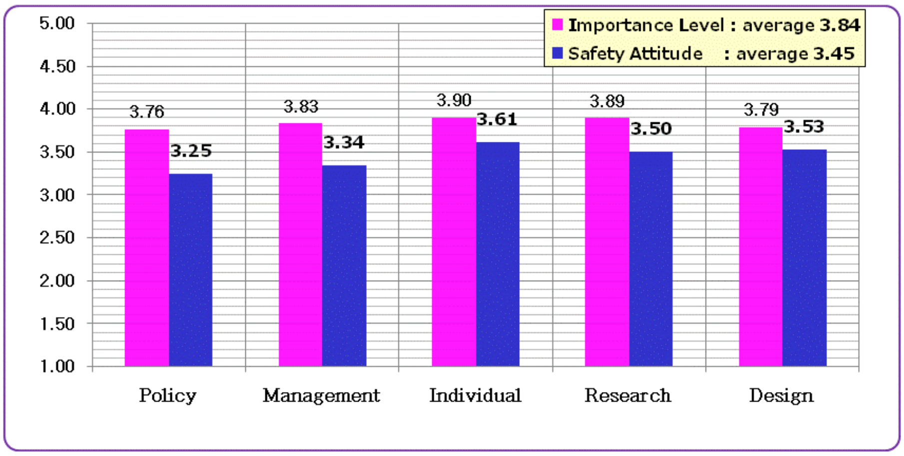


2008 Survey Result 1/2

- Reply : 190 out of the 253 employees = 75%
- Average score of safety culture attitude : 3.45(out of 5.0), 69%



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2008 Survey Result 2/2

- **Good safety attitudes ;**
  - Emphasis on the safety
  - Working together in case of accidents
  - Safety education & training
- **Bad safety attitudes ;**
  - Conflict with safety and output (work result)
  - Demand of side works
  - Lack of evaluation tool for management
- **Organizational safety culture attitude ; 3.06 (61%)**
- **Safety Culture program contributes to enhance the HANARO Safety.**

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Safety culture activities

05

Development of Operational Safety Performance Indicators (SPIs)

Safety PIs of NPP

Mission & Vision KAERI and HANARO

BSC Measures In HANARO

[Review]
- Operation & Maintenance Data
- Periodic Inspection & Surveillance Data
- History of Audit by Regulatory body & QA
- Safety Characteristics of HANARO

* Ref. IAEA TECDOC-1141- Operational Safety Performance Indicators in NPP

[Selection of HANARO SPIs]
- Safety attributes 4
- Overall indicators 10
- Strategic indicators 22
- Specific indicators 42

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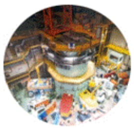
HANARO – Operational SPIs



Attributes	Overall Indicators (10)	Specific Indicators (42)
Operate Smoothly	Operating Performance	13
	State of SSC	
	Events	
Operate with Low Risk	Challenges to Safety System	10
	Plant Ability to Respond to a Challenge	
	Plant Configuration Risk	
Operate with a Positive Safety Attitude	Attitude towards Safety	13
	Striving for Improvement	
Operate with a Safe Utilization	State of Experimental Equipment	6
	User Ability to Respond to a Challenge from Field Work	

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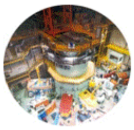
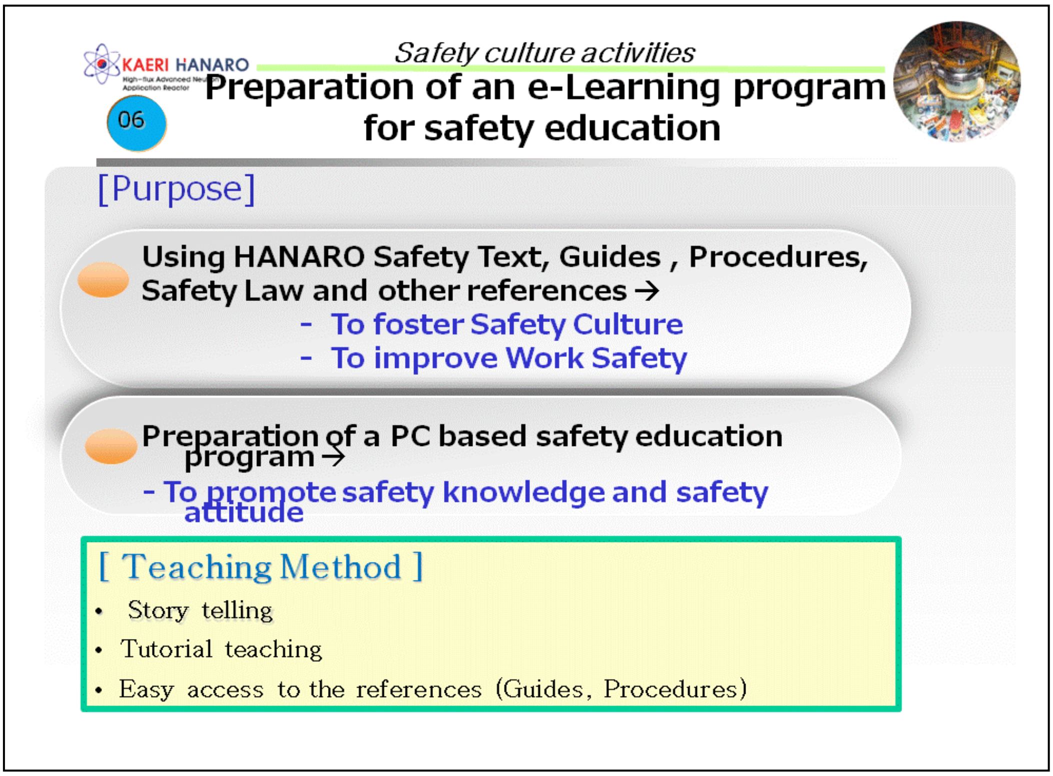
Application of SPIs



- ✔ HANARO started to systematically gather the information on the operation / maintenance data and to study the evaluation method.
- ✔ Through reviewing these indicators, it is expected to obtain the following information;
  - Plant safety status and trend
  - Scheme to improve the plant safety
  - Early warning for decision making
- ✔ HANARO will implement the SPI program and continuously pursue the trends of the safety performance for an effective safety management of a reactor operation and its utilization.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Safety culture activities
06
Preparation of an e-Learning program for safety education
[Purpose]
Using HANARO Safety Text, Guides , Procedures, Safety Law and other references →
- To foster Safety Culture
- To improve Work Safety
Preparation of a PC based safety education program →
- To promote safety knowledge and safety attitude
[Teaching Method]
• Story telling
• Tutorial teaching
• Easy access to the references (Guides, Procedures)


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e-Learning
HANARO Safety Education
Orientation
Introduction
Pre-test
References
Study
Main text
Summary
Key Points
Test
Examination
Evaluation
Report
Contents
1. Safety General
2. Work Guides & Procedures
3. Technical Administration Procedures
4. Radioactivity Safety
5. Nuclear Quality Assurance
6. Nuclear Law, Regulation and Notification

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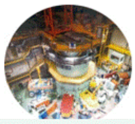

Summary

1. Promotion of safety culture

- Training & education *[e-learning program]*
- Application of HANARO safety culture indicators
- Improvement of safety culture attitude
- Leading the strong safety culture

2. Monitoring the safety performance

- Evaluation of safety status and trends
- Preparation of safety improvement plan

HANARO safety management conducts continuously;

- To develop a program to foster a strong safety culture
- To analysis and evaluate the operational safety performance

3.5 THE OPERATION STATUS AND PROSPECT OF RADIOISOTOPE PRODUCTION FACILITY IN HANARO

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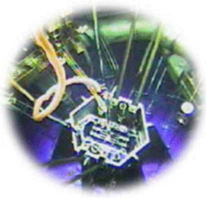
Researches and production of radio-isotopes, radio-pharmaceuticals and cold kits are carried out in the Radio-isotope Production Facility (RIPF). Four concrete hot cells in Bank-1 are to produce the Ir-192 source for NDT. Eleven lead hot cells in Bank-2 are to produce Ho-166, Cr-51, P-32/33, Tc-99m, Lu-177, Sr-90/Y-90 and W-188/Re-188 for research purpose. Six lead hot cells in Bank-3 are used for the production of I-131 for diagnosis and therapy of cancer in the hospital. A hot cell in Bank-3 is also utilized for the research of I-125 and Br-82. Four lead hot cells in Bank-4, are utilized for the production of Mo-99/Tc-99m generators since 2005.

The major systems including the Heat and Ventilated Air Conditioning (HVAC) system and the air cleaning system such as charcoal & HEPA filter trains to filter the radioactive contaminants are in operation. So are the systems such as power supply and distribution system, UPS, fire protection system, liquid radioactive waste collection systems. Recently the repair work and replacements of the air cleaning system are successfully finished and the replacement of the electric power supply systems is in progress because they almost reached the lifespan of the electrical components. In order to monitor the gas effluent of the building, a continuous air monitoring system is in operation to measure the concentration of I-131, noble gas and the particle at the stack of RIPF. Modification and upgrade of the main control panel and fire alarm and receiving panel are also in consideration to utilize the state-of-the-art technology so that the remote control and supervisory of RIPF would be enabled in near future.



The Operation Status and prospect of Radioisotope Production Facility in HANARO

2008. 11. 5.

Minjin Kim, I. C. Lim

Korea Atomic Energy Research Institute

Contents

- The History of RIPF
- Hot Cell Banks
- RI Production Facility
- Cold Kits & Radio-pharmaceutical production facility
- Animal Lab
- HTS (Hydraulic Transfer System)
- PTS (Pneumatic Transfer System)
- Licensed Capacity of RI production
- RI Production Equipments for Neutron Irradiation
- Reactor RI Production
- Cold Kits Production
- Tc-99m Generator Production by a resident company
- RI Supply Records
- Addition of RMS Monitor at Aux. Stack in 2006
- Installation of New Charcoal Filter in 2007
- Future Work

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The History of RIPF

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- 1960's
  - Installation of 100kW Research Reactor (TRIGA MARK II)
  - Installation of RI Production Hot Cell and Produced RI Supply Started (Au-198 collodid, I-131 etc.)
  - Radio-pharmaceutical Production License Acquired in 1968
- 1970's
  - Installation & operation of 2MW Research Reactor (TRIGA MARK III)
  - Production and Supply of P-32, Cr-51, Tc-99m, Ir-192 for NDT started
- 1980's
  - RI Sales License Acquired. Quantity of RI Supply Increased (Tc-99m extraction apparatus, Mo-99, Tc-99m Kit)
  - Design of HANARO (30MW open pool type) Research Reactor started
- 1990's
  - Construction of HANARO, RIPF, Clean Room completed and Operation started
  - Supply of I-131 Capsule, Ho-166, Ir-192 Seed etc. started
- '2000's
  - Localization of Tc-99m Generator
  - Supply of localized RI's (I-131, Ir-192, Co-60) increased and Export of the RI's started
  - ISO 9001:2000 acquired for the RI production and service
  - Nuclear Safety Mark acquired for Ir-192 NDT source assembly)

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Hot Cell Banks

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BANK I

BANK II

BANK III

BANK IV

- **Bank I**
  Concrete Hot Cell 4 units
  (Co-60, Ir-192 Production)
- **Bank II**
  Lead Hot Cell 11 units
  (P-32/33, Tc-99m, Cr-51, Lu-177, Sr-90/Y-90, W-188/Re-188, Ir-192 for cancer treatment)
- **Bank III**
  Lead Hot Cell 6 units
  (production of I-131, Ho-166, I-125, Br-82)
- **Bank IV**
  Lead Hot Cell (Mo-99/Tc-99m Generator)

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RI Production Facility

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Region	Facility	Specification	Number of Cells
Bank I	·Concrete Hot Cell	W x D x H, mm 2800 x 2500 x 4500	4
Bank II	·Lead Hot Cell	2400 x 1400 x 1500	11
Bank III	·Lead Hot Cell	2400 x 1400 x 1500	6
Bank IV	·Clean Room ·Lead Hot Cell	·Clean class 10,000 (150m², with lead hot cells) 1490 x 1150 x 1260(3) 1260 x 1190 x 1260(1)	4
Clean zone	·Clean Room Facility(1st fl.) ·Clean Room Facility(2nd fl.)	·Clean class 100,000 (60m², Service are of lead hot cells) ·Clean class 10,000(136m²) ·Clean class 100,000(134m², cold kit lab.)	
	·Co-60 Storage Pool	2400 x 1400 x 1500	1

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Cold Kits & Radio-pharmaceutical production facility

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* Cold Kit: imaging diagnosis reagent using ^{99m}Tc

Auto Clave installed in Clean room

Preparation Room for Cold Kits

Vial Washing System

Water Purification System

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Animal Lab

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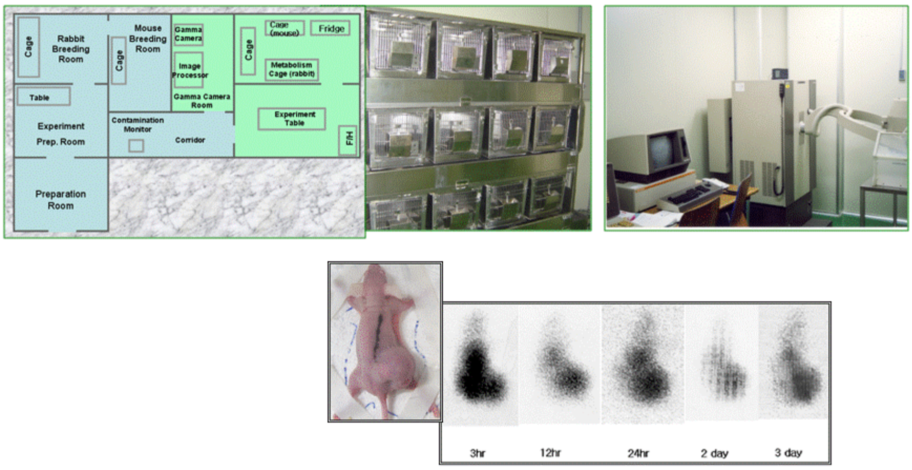
❑ Quality Control of Radio-pharmaceutical & related research



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HTS(Hydraulic Transfer System)

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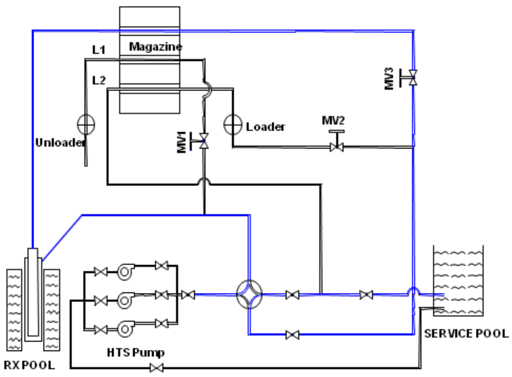

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PTS (Pneumatic Transfer System)

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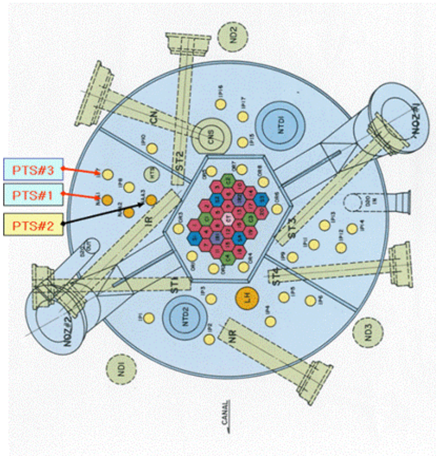

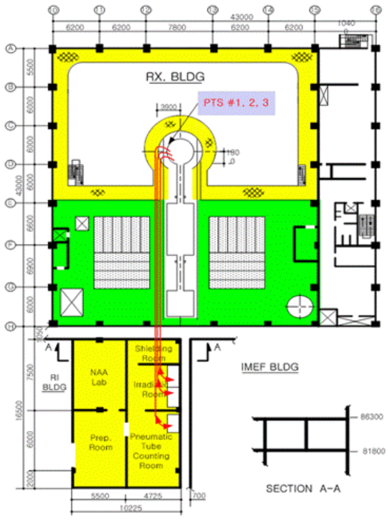

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Licensed Capacity of RI production

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Hot Cell	RI	Target State	Max Cap. per batch (Ci)	Max Cap. Per year (Ci)
Bank 1	Co-60 Ir-192 Others(3)	Metal Metal *c.f. SAR*	50,000 100,000 *c.f. SAR*	100,000 200,000 *c.f. SAR*
Bank 2	P-32 Cr-51 Others(84)	Powder Powder *c.f. SAR*	30 10 *c.f. SAR*	100 100 *c.f. SAR*
Bank 3	I-131 I-125 Others(3)	Volatile Volatile *c.f. SAR*	60 10 *c.f. SAR*	2,000 200 *c.f. SAR*
Bank 4	Tc-99m Re-188 & others(4)	Powder Powder *c.f. SAR*	1 10 *c.f. SAR*	10,000 100 *c.f. SAR*

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RI Production Equipment for Neutron Irradiation

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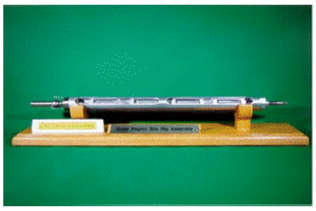
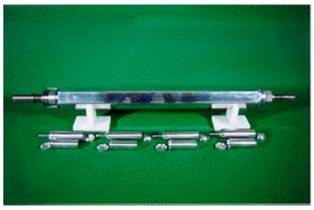
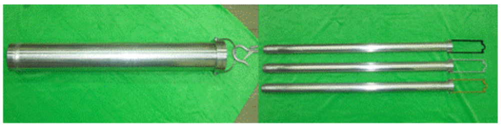


Outer Region (OR) Rig



Inner Region (IR) Rig

Working table for irradiated target handling in service pool



LH Plug and Rig

Transfer container

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Reactor RI Production (1)

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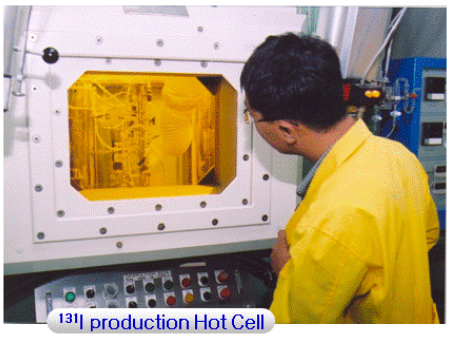
❑ ^{131}I Production for treatment

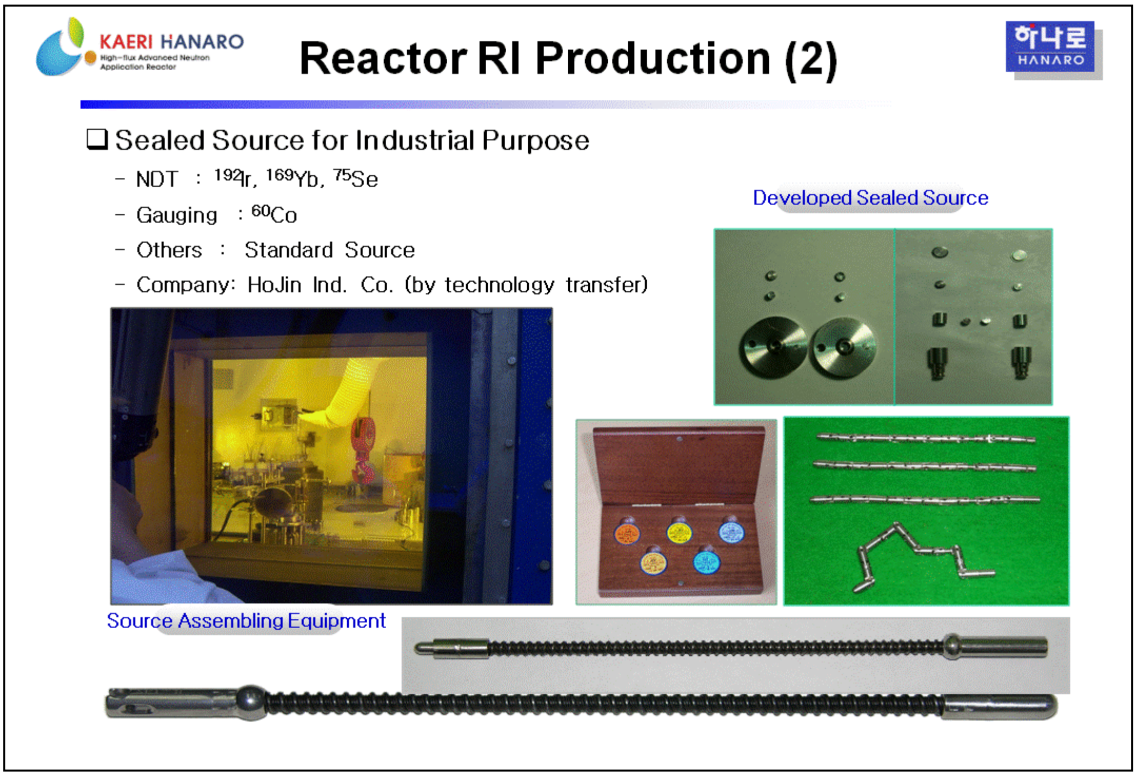
- Process Dry Distillation Method
- Product Solution & Capsule (NaI)
- Uses Diagnosis & Treatment of Thyroid Cancer
- Yield 30-40 Ci/batch



^{131}I production Hot Cell

^{131}I Solution

^{131}I Capsule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Reactor RI Production (2)
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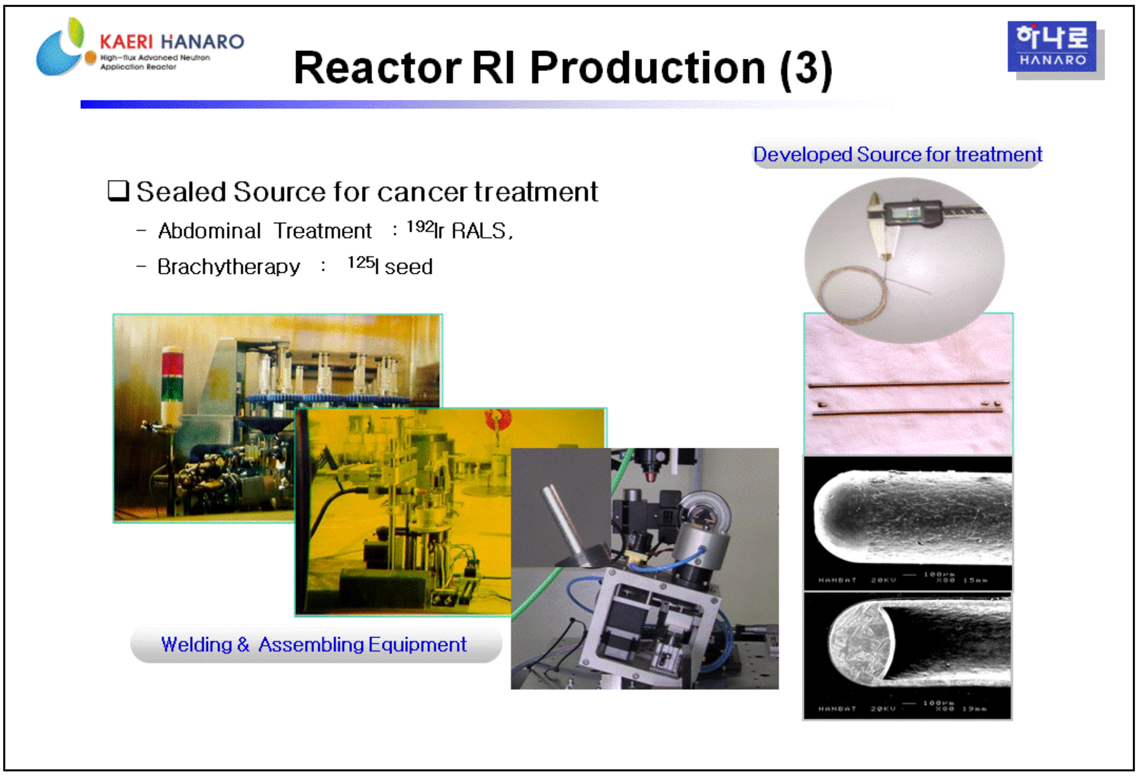
❑ Sealed Source for Industrial Purpose
- NDT : ^{192}Ir, ^{169}Yb, ^{75}Se
- Gauging : ^{60}Co
- Others : Standard Source
- Company: HoJin Ind. Co. (by technology transfer)
Developed Sealed Source
Source Assembling Equipment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Reactor RI Production (3)
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Developed Source for treatment
❑ Sealed Source for cancer treatment
- Abdominal Treatment : ^{192}Ir RALS,
- Brachytherapy : ^{125}I seed
Welding & Assembling Equipment

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Cold Kits Production

❑ ^{99m}Tc Cold Kits Production

Cold Kits Products

Compound	Diagnosis
Phytate	Liver
MDP	Bone & metastasized tumor
DISIDA	Hepatobiliary test
DTPA	Kidney
PYP	Myocardium infraction
Sn colloid	Liver
HSA	Plasma test
MAA	Lung
ASC	Lymph system
DMSA	Kidney
HMPAO	Brain

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RI Production by a resident company

❑ ^{99m}Tc Generator Production

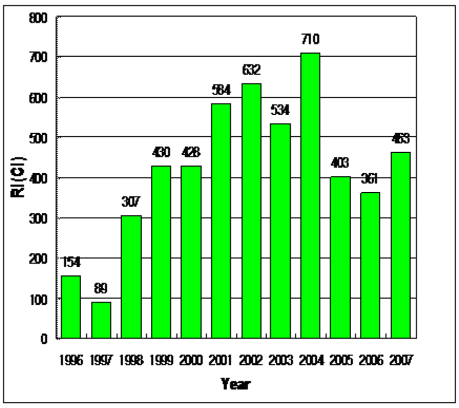
- Hot Cell Bank IV leased to Samyoung Unitech for production
- Technology imported from IPPE Russia
- Yield : approx 60 units/week for domestic use and export

Tc-99m Generator Production Facility

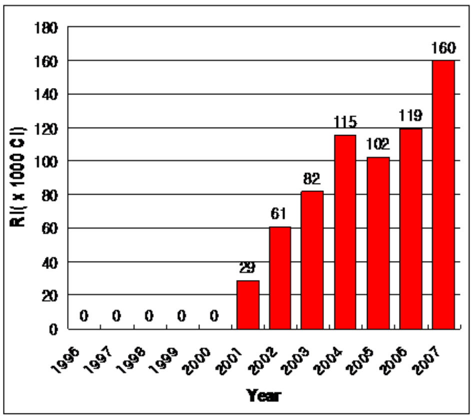
^{99}Mo/^{99m}Tc generator

11.1 GBq (300mCi)
18.5 GBq (500mCi)
37 GBq (1000mCi).

RI Supply Records



Medical application



Industrial application

Addition of RMS Monitor at Aux. Stack in 2006

- Continuous RMS monitor installed at the auxiliary stack in 2006 in addition to the RMS monitor at the main stack

Air Sample Collecting Element inside the Auxiliary Stack

Continuous Effluent RMS Monitor (for Iodine & Particle) at the auxiliary stack

KAERI HANARO
High-flux Advanced Neutron Application Reactor

Installation of New Charcoal Filter Housing in 2007

하나로 HANARO

Housing Leak Test at the shop

Duct Welding & Liquid Penetration Test

1st Stage Charcoal Filter Housing Installation Completed

2nd Stage Charcoal Filter Housing Installation Completed

KAERI HANARO
High-flux Advanced Neutron Application Reactor

Future Work

하나로 HANARO

❑ Replacement of Uninterruptible Power Supply System

- Fabrication is underway at the factory and to be installed in Mar. 2009.

❑ Replacement of Battery System

- Fabrication is underway at the factory and to be installed around the end of Oct. 2009.

❑ Enabling the Remote Monitoring and Alerting of the important parameters of Control Panel

- Preparation of Design Requirement is underway.

3.6 RI-PRODUCTION PLAN USING JMTR

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ABSTRACT

At Oarai Research and Development Center, Japan Atomic Energy Agency (JAEA) is advancing the plan of refurbishing Japan Materials Testing Reactor (JMTR) to start the operation from FY 2011. At the JMTR, the iridium-192 (^{192}Ir) source for the medical treatment as well as for the industrial using in the non-destructive inspection has been irradiated. As one of effective use of the renewed JMTR, JAEA has a plan to product molybdenum-99 (^{99}Mo), a parent nuclide of technetium-99 (^{99m}Tc). ^{99m}Tc is most commonly used as a radiopharmaceutical in the field of nuclear medicine. Furthermore, production of radioisotope (RI) for which increasing demand is expected, e.g. rhenium-188 (^{188}Re) which being expected as a cancer treatment medicine.

INTRODUCTION

In Japan, research reactors for production of RIs are JRR-3, JRR-4 at Nuclear Science Research Institute and the JMTR, at Oarai Research and Development Center. Now, the latter JMTR is advancing its refurbishment to restart from FY 2011. In the JMTR, the ^{192}Ir source for the medical treatment also for the industrial using in the non-destructive inspection has been produced up to now. For the production after re-operated JMTR, the JAEA has a plan to product ^{99}Mo, a parent nuclide of ^{99m}Tc, as one of effective use of the renewed JMTR. Here, reminding the ^{99m}Tc is most commonly used as a radiopharmaceutical in the field of nuclear medicine.

In this report, current status and future prospects of RI production by the renewed JMTR are treated.

STATUS OF RI-PRODUCTION

On the basis of the production needs, many kinds of refined RIs have been made through active research and development at Japan Atomic Energy Research Institute (JAERI), the former organization of JAEA. Moreover, research and development about the production of RI for the industrial use and RI for the medical treatment was done. Specially, as for the ^{192}Ir source for the non-destruction inspection, stable supply with six times a year was realized by the domestic production.

JMTR had operated 165 cycles from first critical 1968, to August 2006, and now, JAEA is advancing the plan of refurbishing JMTR to start the operation from FY 2011. One operation cycle has 30 operation days. We have done the operation of six cycles in one year. However increasing 7 or 8 cycles in one year will be planned after the re-operation.

Irradiated capsules or specimens are transferred to the hot laboratory, which is connected to the reactor building through a water canal, for post irradiation examinations (PIE). Owing to the shielding capability of the water, irradiated radioactive capsules or specimens are safely transferred underwater through the canal. Cross section of the JMTR and hot laboratory is shown in Fig. 1.

Capsule irradiation facility is one of irradiation facilities at JMTR, which can be inserted at arbitrary position in the reactor core. There are about 60 insertion positions for capsules in the core. The capsule irradiation facility was used for two kinds of ^{192}Ir sources. The one is the medical irradiation source for ‘Remote After-Loading System (RALS)’, and the other is the industrial source for the non-destruction inspection.

However, by the arrangement rationalization of special public corporations, produced nuclides were limited to short half-life RIs, and technologies move to the private company by the rationalization of the RI production and distribution.

At present, domestic RI production using research reactors of JAEA is carried out only by the technologies transferred private company.

FUTURE PLAN OF RI-PRODUCTION

RI production using JMTR after re-operation, becomes important part in Japan. From now on, RIs such as ^{99}Mo-^{99m}Tc、^{89}Sr、^{188}W-^{188}Re、^{90}Sr-^{90}Y、^{125}I, etc. will be important in the medical field such as the diagnosis and treatment medicine for the cancers.

Currently, the supplying of ^{99}Mo is filly depend on import from foreign countries in Japan. Therefore, JAEA is aiming at a part of domestic production in cooperation with the industrial circles. The amount of ^{99}Mo demand is 1,110TBq per year in Japan, which corresponds to about 10% of the world demand. Namely, ^{99}Mo of 22.2TBq is imported from foreign countries every week. As a part of effective use of JMTR, JAEA is planning to product ^{99}Mo, a parent nuclide of ^{99m}Tc. Here, ^{99m}Tc is most commonly used as a radiopharmaceutical in the field of nuclear medicine.

The hydraulic rabbit irradiation facility of JMTR is a water loop system to transfer the small sized (150mm length) capsule, so called rabbit, into the core and take out from the core by the water flow in the loop. This facility is widely utilized mainly for short term irradiation for the basic researches and for the production of RIs, such as ^{99m}Tc for medical diagnosis medicine.

^{99}Mo production in JMTR was studied in order to make ^{99}Mo domestic production partially, and the irradiation hole D-5 was selected for ^{99}Mo production. Since the hydraulic rabbit irradiation facility has already been installed in this irradiation hole, the irradiation facility would be adjusted to ^{99}Mo production in future. The rabbit tube is a double tube structure, and it is possible to insert maximum three rabbits.

The molybdenum trioxide (MoO_3) will be selected as the source material of ^{98}Mo (n, γ) ^{99}Mo reaction for production process. MoO_3 will be processed to pellet-type target, and inserted to irradiation rabbit. After irradiation, ^{99}Mo is dissolved from the MoO_3 pellet by an easy chemical treatment. The chemical treatment will be carried out in JMTR-HL cell after transfer through the canal. The providing method of ^{99}Mo has been studied to use an absorber such as PZC (Poly Zirconium Compound). Conceptual design for ^{99}Mo production by rabbit system in JMTR is shown in Fig.2.

JMTR will be able to provide ^{99}Mo medical use isotope for industrial circles with 3.7TBq/week by above system.

CONCLUSION

At Oarai Research and Development Center, JAEA is conducting the refurbishing project of the JMTR to restart its operation from FY 2011. At the JMTR, the ^{192}Ir source for the medical treatment and for the industrial using in the non-destructive inspection has been irradiated. As one of effective use of the renewed JMTR, JAEA has a plan to product ^{99}Mo, a parent nuclide of ^{99m}Tc, which is most commonly used as a radiopharmaceutical in the field of nuclear medicine. The hydraulic rabbit irradiation facility, which is well developed and already used for irradiation in JMTR, can be applied. Now, production performance is investigated to realize the ^{99}Mo supply in future.

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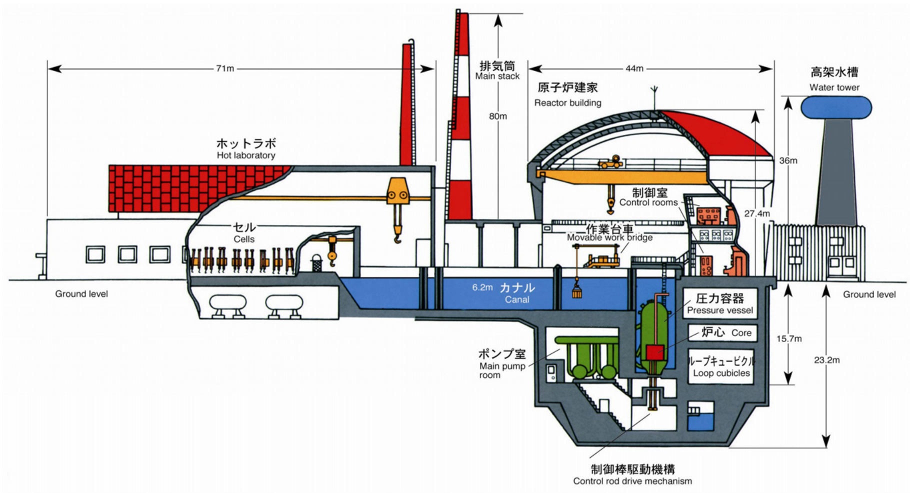

Fig.1 Cross section of JMTR and hot laboratory.

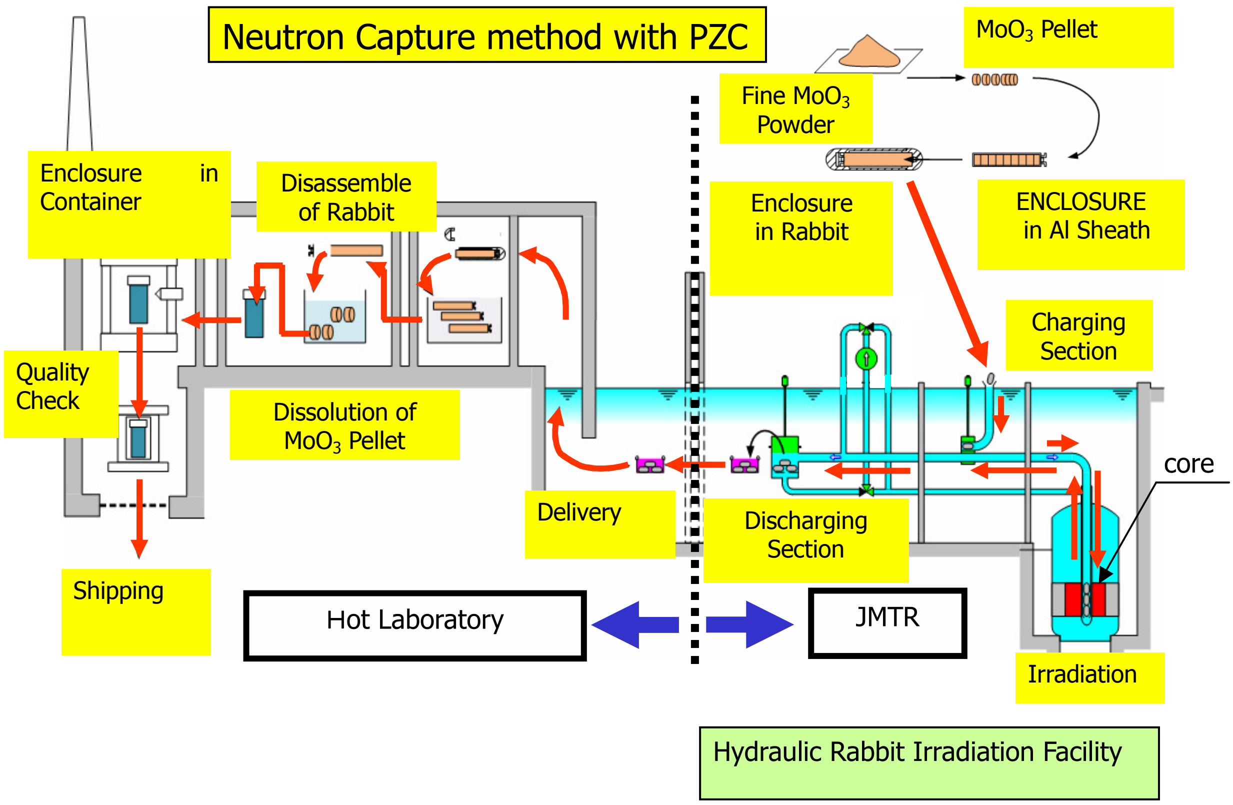

Fig.2 ^{99}Mo production by hydraulic rabbit irradiation Facility in JMTR.

3.7 STATUS OF THE REACTOR TRIP IN HANARO

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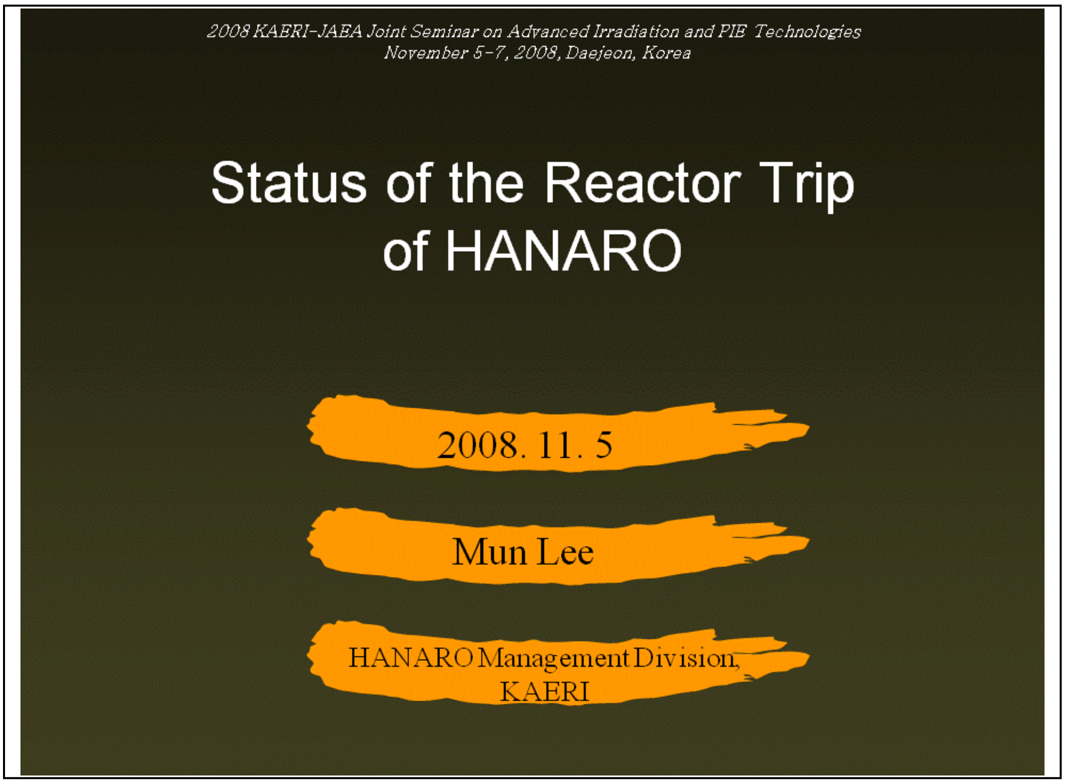
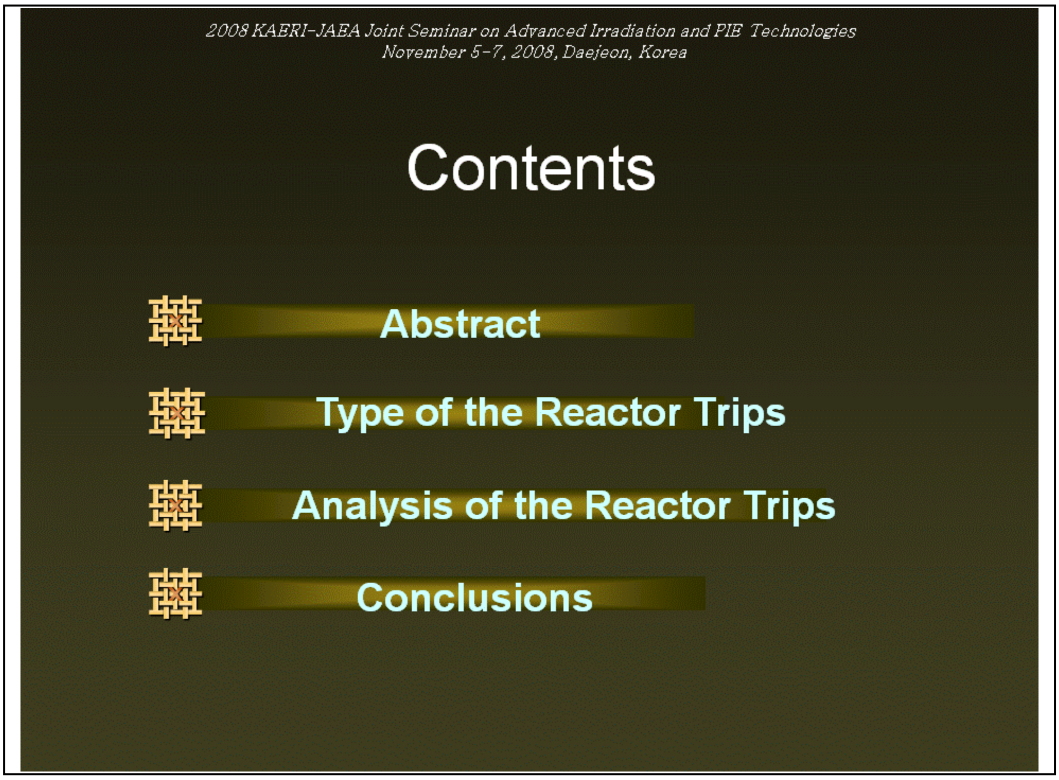
Unexpected reactor trip in HANARO since the first criticality in February, 1995 was investigated. The total numbers of the reactor trip events were 136 and it was 10.4 cases on average each year. During the early stage of the HANARO operation from 1995 to 1997, unexpected reactor trips were occurred frequently. 67 % of the total unexpected reactor trips were occurred in that period, which were 91 cases. That duration was for a power ascension test as one of the reactor performance tests. The unexpected reactor trips were mainly caused by system problems and operators' error. Some cases were caused by electric power failure. The most frequent system problem was originated from fluctuation of the signal of the neutron power measuring system. To prevent the reactor trips by this phenomenon, the circuit of the reactor protection system was changed. Operators' error were occurred by mismatching of the neutron and thermal power, which was caused when the deviation of the neutron and thermal power is larger than 3 MW while the reactor power increases. To reduce reactor operators' error, operational procedure was revised and the operators have been trained with the revised one. That has on effect on reducing unexpected reactor trips dramatically. Reactor trips have been occurred by the class-IV power failure or a few problems of system error but never by operators' error since 2000.

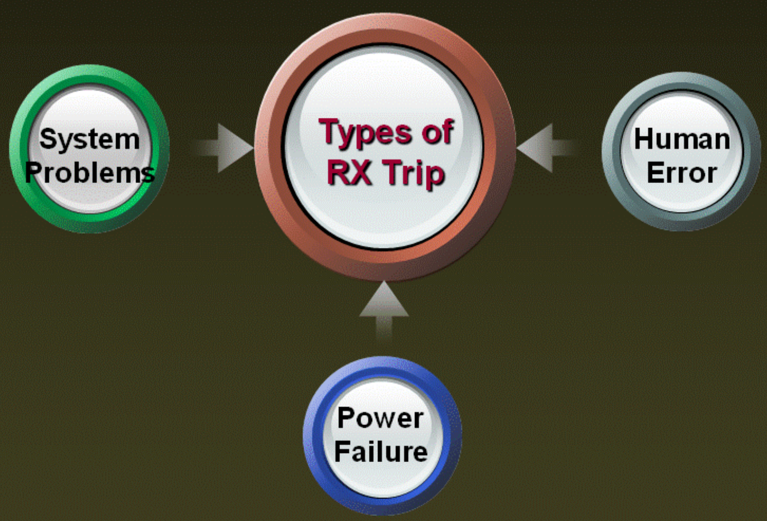

2008 KAERI-JAEA Joint Seminar on Advanced Irradiation and PIE Technologies
November 5-7, 2008, Daejeon, Korea
Status of the Reactor Trip of HANARO
2008. 11. 5
Mun Lee
HANARO Management Division, KAERI

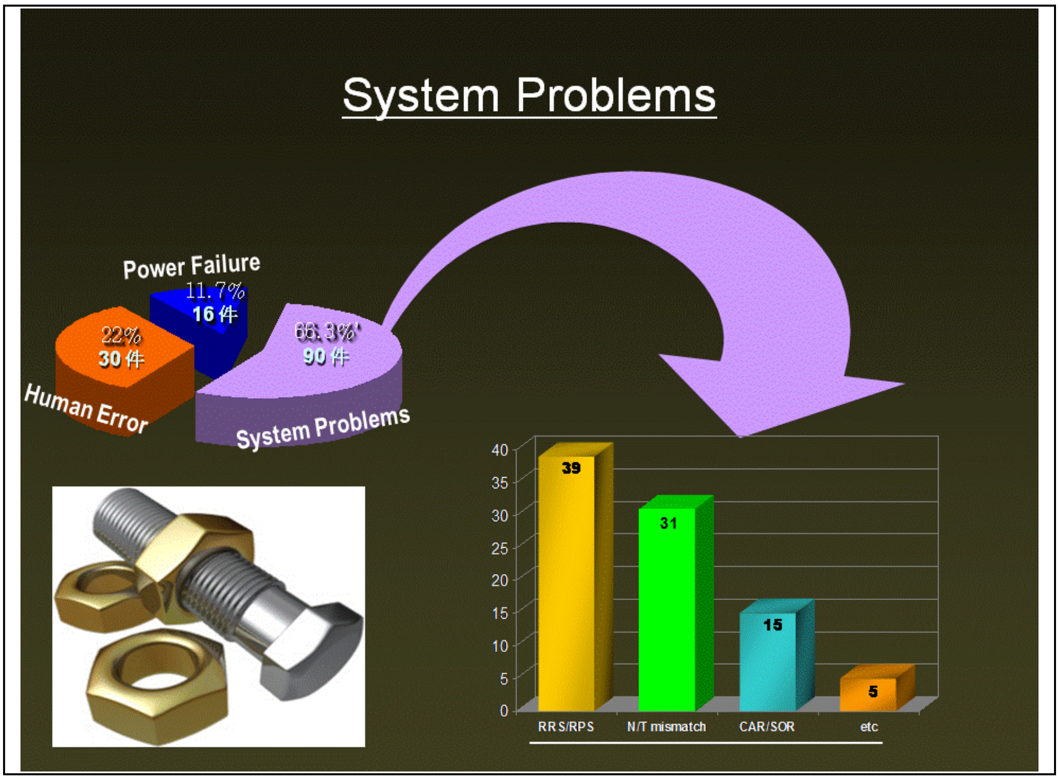

2008 KAERI-JAEA Joint Seminar on Advanced Irradiation and PIE Technologies
November 5-7, 2008, Daejeon, Korea
Contents
Abstract
Type of the Reactor Trips
Analysis of the Reactor Trips
Conclusions

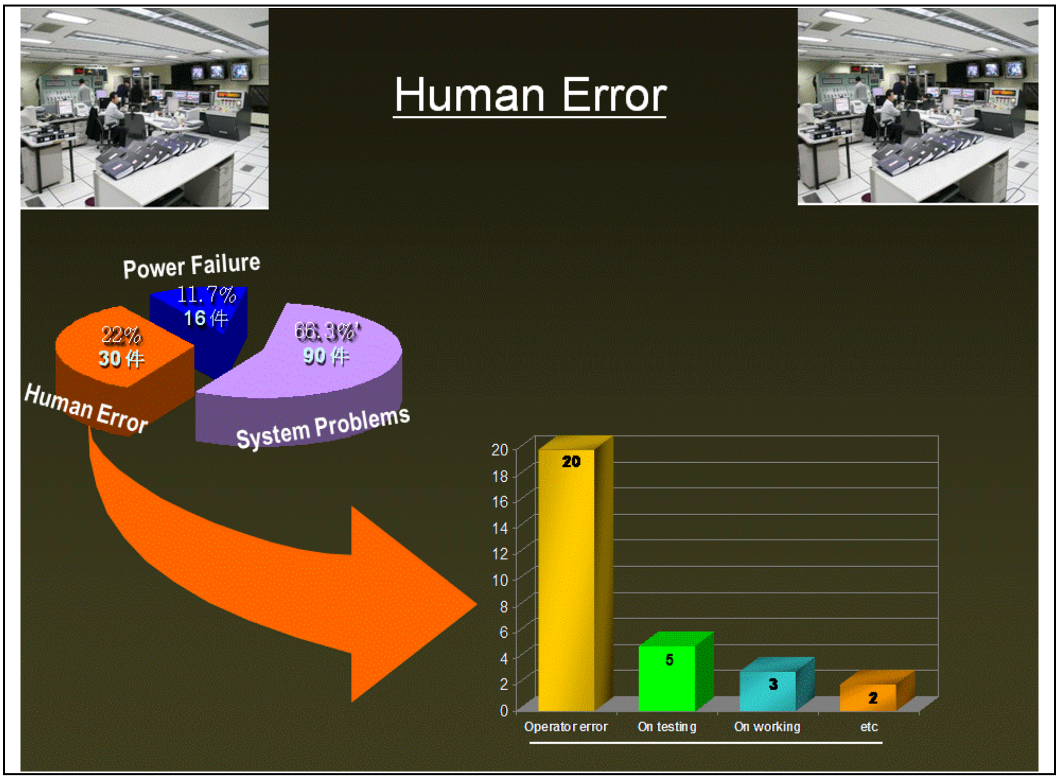
Abstract

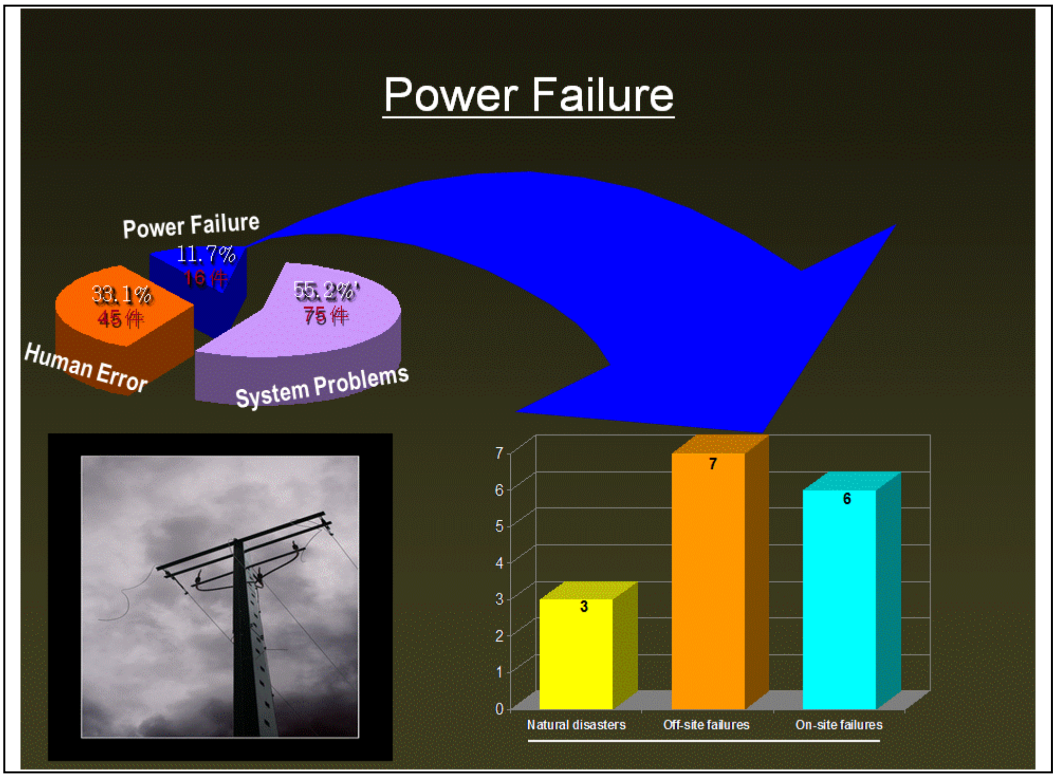
- Total unexpected reactor trips from 1995 to 2007: 136 times
- Reactor trips at the beginning of HANARO operation from 1995 to 1997: 91 times
- Causes:
  - System problems: 90 times
  - Human error: 30 times
  - Power failure: 16 times
- The frequency of the reactor trips:
  - Start-up
  - March
  - Winter season

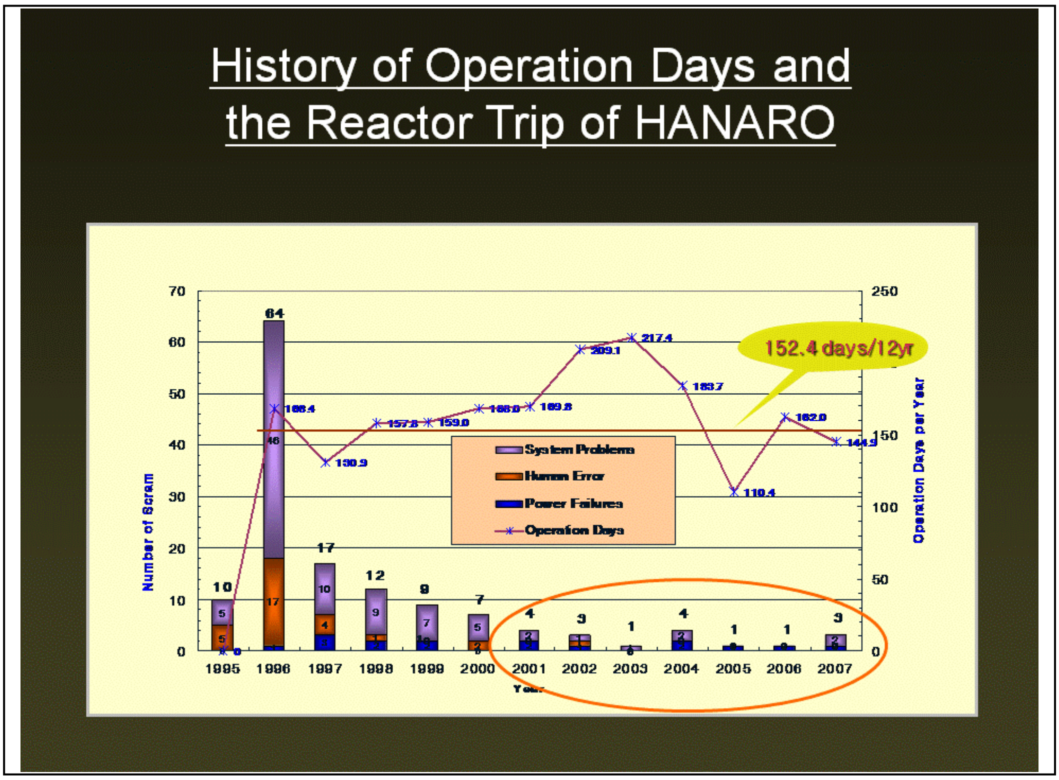
Three Major Types of the Reactor Trip of HANARO

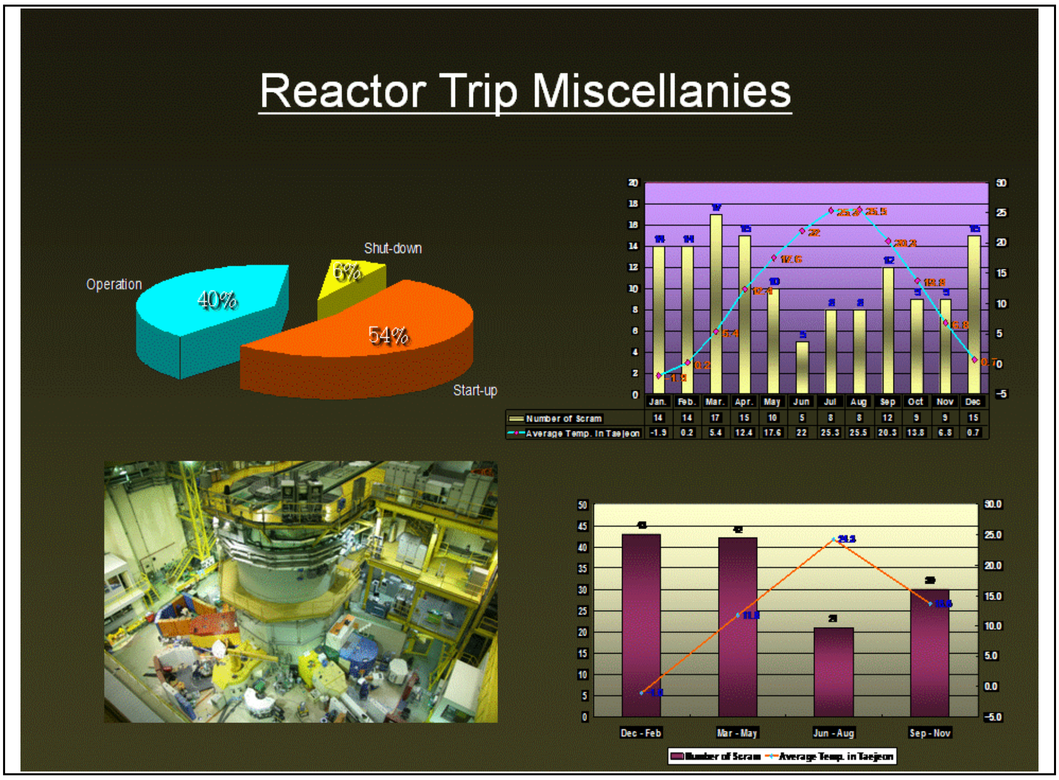


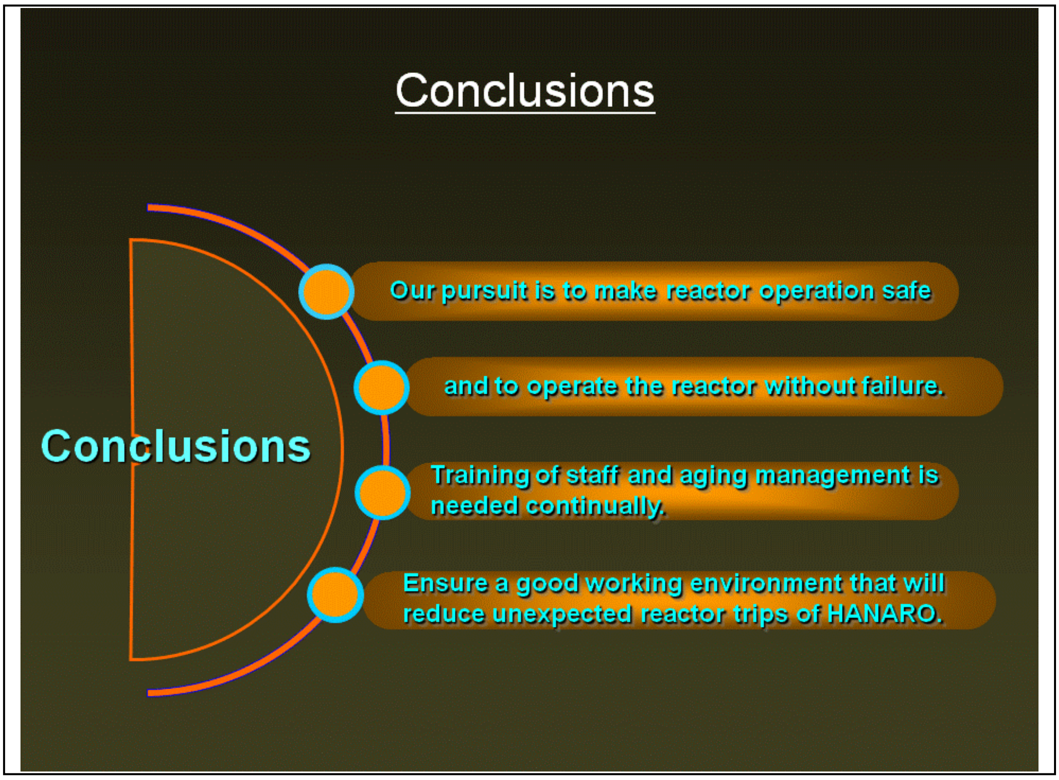

System Problems
Power Failure
11.7%
16 件
22%
30 件
Human Error
66.3%
90 件
System Problems
39
31
15
5
RRS/RPS
N/T mismatch
CAR/SOR
etc


Human Error
Power Failure
11.7%
16 件
22%
30 件
Human Error
66.3%
90 件
System Problems
20
5
3
2
Operator error
On testing
On working
etc


Power Failure
Power Failure
11.7%
16 件
33.1%
45 件
55.2%
75 件
Human Error
System Problems
Natural disasters
Off-site failures
On-site failures
3
7
6


History of Operation Days and
the Reactor Trip of HANARO
152.4 days/12yr
System Problems
Human Error
Power Failures
Operation Days
Number of Scram
Operation Days per Year
217.4
209.1
110.4
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007


Reactor Trip Miscellanies
Operation 40%
Shut-down 6%
Start-up 54%
Jan. Feb. Mar. Apr. May Jun Jul Aug Sep Oct Nov Dec
Number of Scram 14 14 17 15 10 5 8 8 12 9 9 15
Average Temp. In Taejeon -1.9 0.2 5.4 12.4 17.6 22 25.3 25.5 20.3 13.8 6.8 0.7
Dec - Feb Mar - May Jun - Aug Sep - Nov
Number of Scram
Average Temp. in Taejeon


Conclusions
Conclusions
Our pursuit is to make reactor operation safe
and to operate the reactor without failure.
Training of staff and aging management is needed continually.
Ensure a good working environment that will reduce unexpected reactor trips of HANARO.


Thank You !