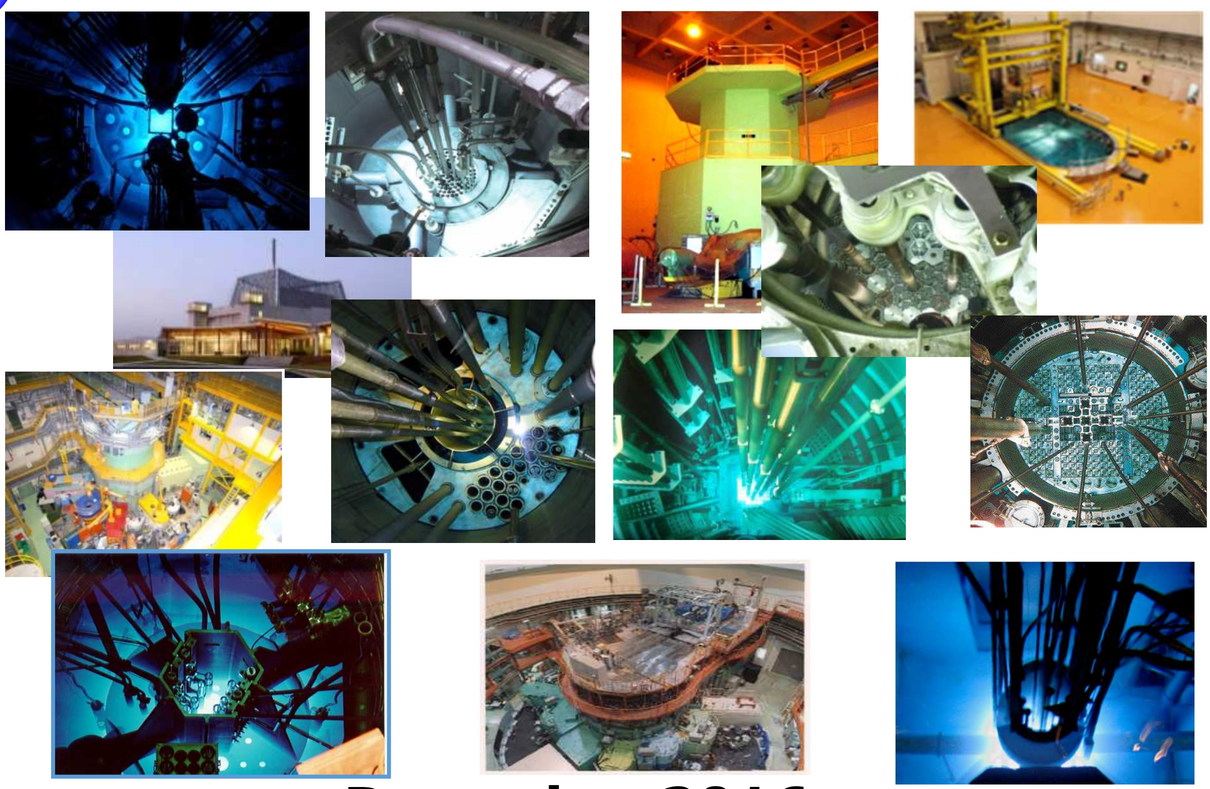
FNCA
Forum for Nuclear Cooperation in Asia

FNCA Research and Test Reactors Catalogue



December 2016

FNCA Research Reactor Network Project

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FNCA Research and Test Reactors Catalogue

***Reactor Name:* OPAL**

***Organization:* Australian Nuclear Science and Technology Organisation (ANSTO)**

Australian Nuclear Science and Technology Organisation (ANSTO)
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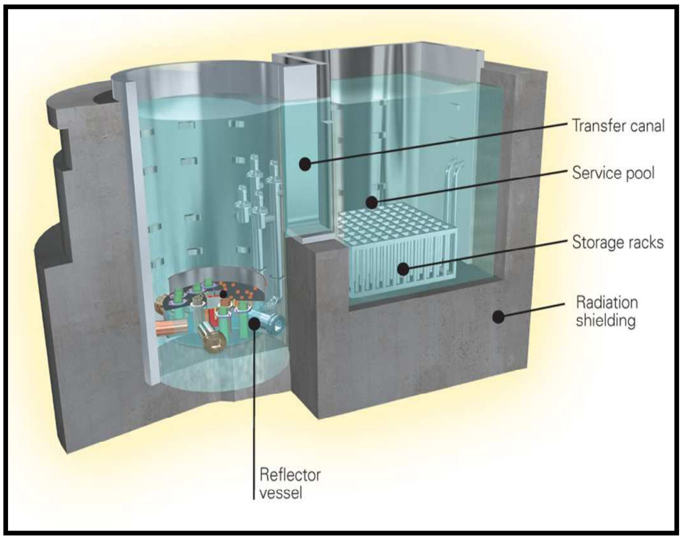
1. General information

OPAL is a 20 MW, multipurpose open pool reactor. Construction of OPAL commenced in 2002 and first criticality was achieved on 12 August 2006. OPAL is light water cooled and moderated. The reactor core is surrounded by a cylindrical vessel containing heavy water. The reactor core consists of 16 plate type fuel assemblies controlled by five control rods which also act as the fast acting first shutdown system.

The reactor is cooled by forced circulation of light water during operation and natural convection during shutdown.

For further information see www.ansto.gov.au



Opal Reactor cross-section

2. Reactor and Facilities

The reactor facility incorporates five horizontal primary neutron beams, two of which are optimized for thermal flux and two which are optimized for cold neutrons. Cold neutrons are generated from a liquid deuterium cold neutron source which sits adjacent to the core. Thirteen neutron beam instruments are located within a dedicated neutron guide hall. These instruments are:

- High-Resolution Powder Diffractometer
- High-Intensity Powder Diffractometer
- Laue Diffractometer
- Strain Scanner
- Neutron Reflectometer
- Small-Angle Neutron Scattering
- Thermal Neutron 3-Axis Spectrometer
- Ultra Small-Angle Neutron Scattering
- Time-of-Flight Spectrometer
- Neutron Radiography/Imaging/ Tomography
- Cold Neutron 3-Axis Spectrometer
- Small-Angle Neutron Scattering Instrument
- High-Resolution Backscattering

Irradiations are performed in vertical facilities penetrating into the heavy water reflector vessel which surrounds the core. A variety of irradiation facilities are provided to allow for a range of irradiations to be undertaken depending on irradiation time, physical target size and cooling capacity required by the target. The primary use of the irradiation facilities are for radioisotope production, specifically molybdenum-99, and the neutron transmutation doping of silicon. Irradiation facilities are also provided for materials research and delayed neutron activation analysis and neutron activation analysis.

3. Related engineering and research infrastructure

3.1 Experimental material logistics

3.2 Hot cells, PIE facilities

Hot cell facilities are available within the reactor area to support the preparation and logistics management of irradiated targets and samples. PIE, hot cells and facilities are available at the ANSTO Lucas Heights site.

3.3 Capabilities to design and manufacture experimental devices and measurement systems including human resources development

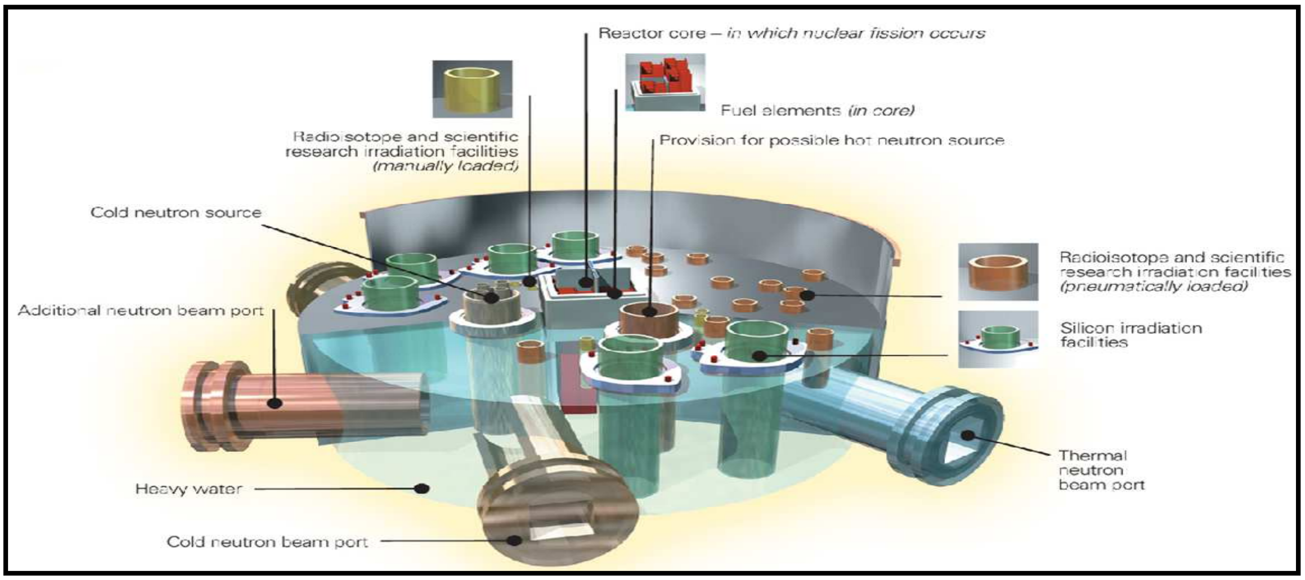
4. Recent achievements

Significant research based achievements have been highlighted in regards to the utilisation of neutron beam facilities and instruments of the OPAL reactor. The recent publication of Neutron News (Volume 27, issue April/May/June 2016) has reported on a number of scientific highlights with regards to neutron beam instrument usage and outcomes.

5. Other useful/ important information

REFERENCES

[1] www.ansto.gov.au



OPAL Reflector Vessel

FNCA Research and Test Reactors Catalogue

Reactor Name: 3 MW TRIGA Mark-II Research Reactor

Organization: BAEC (Bangladesh Atomic Energy Commission)

Bangladesh Atomic Energy Commission

CSO and Head, RPED, INST, AERE, GPO BOX #3787, DHAKA-1000, Bangladesh

Contact Person: Dr. Md. Jahirul Haque Khan, ***e-mail***: *mjhk1970@gmail.com*

1. General Information

The 3 MW TRIGA Mark-II [1] research reactor is the only nuclear reactor facility in Bangladesh satisfying its academic, training and research objectives and it is an excellent source of neutron. The Bangladesh Atomic Energy Commission (BAEC) has been operating the TRIGA (Training, Research, Isotope production, General Atomics) Mark-II research reactor (shown in Fig. 1) with a maximum thermal flux 7.46×10^{13} n/cm^2/sec in the center of the core at full power 3 MW since September 1986. Since then, the reactor is designed for multipurpose uses like manpower training, radio-isotope production and various R&D activities in the field of neutron activation analysis (NAA), neutron radiography (NR) and neutron scattering (NS) experiments. It is a light-water-cooled, graphite-reflected, cylindrical shaped pool type research reactor, which uses uranium-zirconium hydride fuel elements in a circular grid array. The array also contains graphite dummy elements, which serves to reflect neutrons back into the core.

Fig. 1: 3 MW TRIGA Mark-II Research Reactor

The core is situated near the bottom of water filled tank and the tank is surrounded by a concrete bio-shield, which acts as a radiation shield and structural support. As the reactor deals with the Fission Chain Reaction, it is an excellent source of neutrons and gamma radiation. The reactor is licensed by the Bangladesh Atomic Energy Regulatory Authority (BAERA) to operate at a maximum steady state power of 3 MW (thermal) and can also be pulsed up to a peak power of about 852 MW with a maximum reactivity insertion of up to $2.00 having a half–maximum pulse width of nearly 18.6 milliseconds.

The unique safety feature of the TRIGA reactor is the prompt negative temperature coefficient of reactivity of its U-ZrH fuel-moderator material. This characteristic allows sudden large insertions of reactivity in which the power level increases many thousand times on periods of less than 2.0 msec. The control is based on the negative temperature coefficient of reactivity, which decreases the power level to normal operating values in a fraction of a second. The same characteristics also restrict the upper steady state thermal power level that may be obtained with a given amount of fuel. Thus, both transient and steady state operation have inherent safeguards which do not require manual, electronic or mechanical control. Radiation levels are so low due to vertical water shield above the core that personnel can view the core and experimental devices with complete safety during pulsed or steady-state operation. The principal design parameters of the reactor are shown in Table 1.

Table 1: Principal Design Parameters of the TRIGA Mark-II Research Reactor.

Sl. No.	Principal Design Parameters [1]	
1.	Reactor type	TRIGA Mark-II
2.	Maximum steady state power level	3 MW
3.	Maximum pulse	1.4% δk/k, $ 2.00, 852 MW
4.	Fuel moderator material	$U\text{-}ZrH_{1.6}$
5.	Uranium content	20 wt%
6.	Uranium enrichment	19.7% ^{235} U
7.	Burnable poison	0.47 wt% ^{166}Er and^{166}Er
8.	Shape	Cylindrical
9.	Overall length of fuel	38.1 cm (15 inch)
10.	Outside diameter of the fuel	3.63 cm (1.43 inch)
11.	Cladding material	Type 304 stainless steel
12.	Total reactivity worth of control rods	10% δk/k
13.	Number of control rods	6

2. Reactor and Facilities

The reactor is housed in a hall of 23.5 m × 20.12 m having a height of 17.4 m. The reactor tank (which is also called the pool liner) accommodates the reactor core. The reactor core is located near the bottom of the reactor tank (shown in Fig. 2).

The tank is made of aluminum alloy of type 6061-T6 which is installed inside the reactor shield structure. The length and diameter of the tank is 8.23 m and 1.98 m. The tank is filled up with 24,865 liters of de-mineralized water.

The reactor core (shown in Fig. 3) consists of 100 fuel elements (93 standard fuel elements, 5 fuel follower control rods (FFCR) and 2 instrumented fuel elements), 6 control rods (5 FFCR and 1 air follower control rod), 18 graphite dummy elements, 1 Dry Central Thimble, 1 pneumatic transfer system irradiation terminus (Rabbit system) and 1 Am-Be neutron source (strength: 3 Ci). All these elements are placed and supported in-between two 55.25 cm diameter grid plates and arranged in a hexagonal lattice.

The TRIGA reactor is equipped with a number of experimental and irradiation facilities. It can be used to provide intense fluxes of neutron and gamma for research, training and radioisotope production. The name of these facilities and corresponding neutron flux are given below:

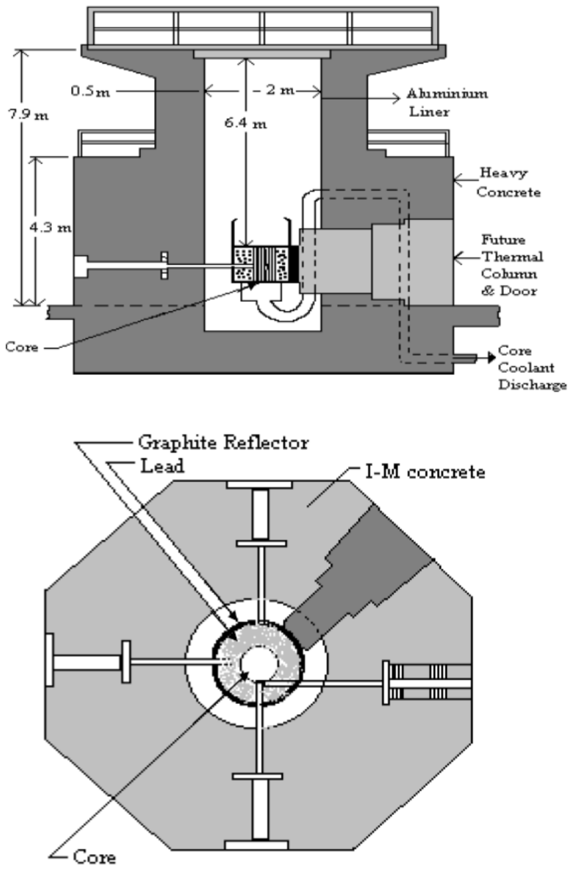


Fig. 2: Cut-away View of TRIGA Mark-II RR

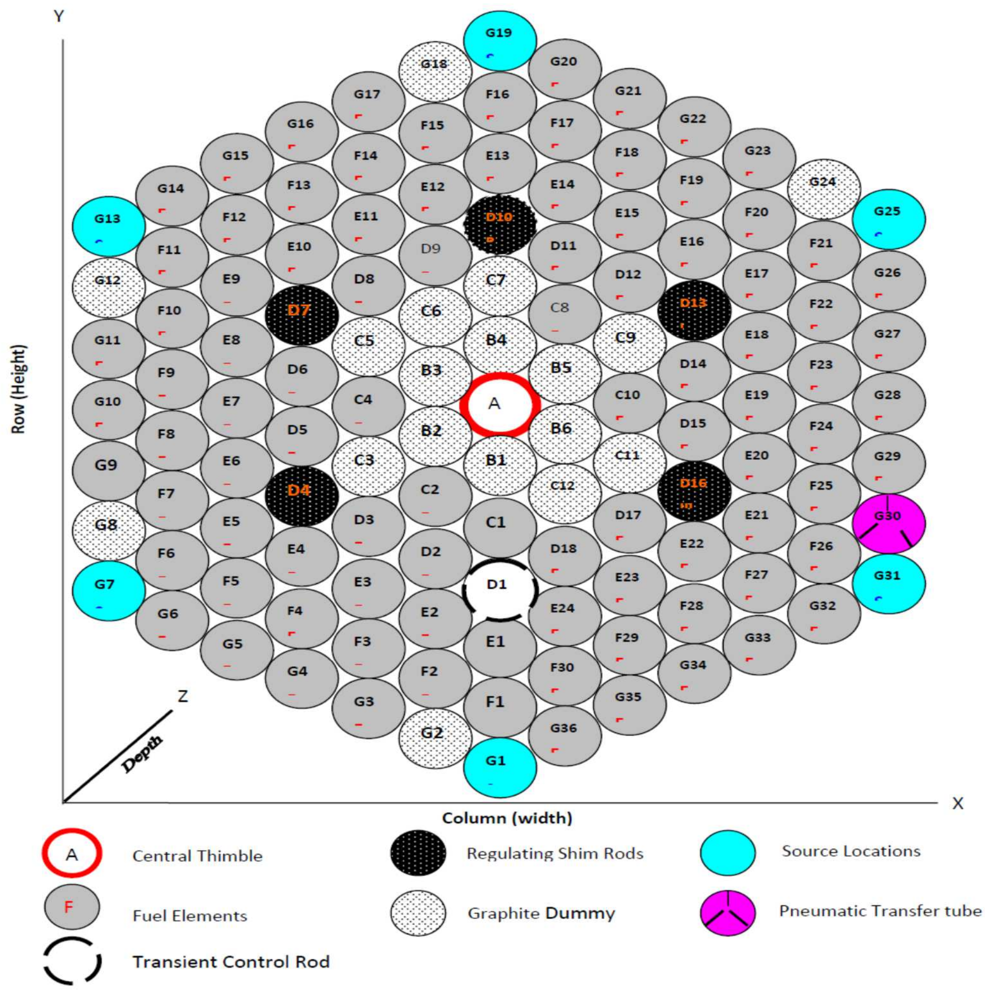


Fig. 3: The Core Configuration of 3 MW TRIGA Mark-II RR.

The reactor can be operated for short time periods at power levels up to 500 kW with natural convection cooling of the core. For higher-power or long-term operation at low power, the forced-flow mode of operation is required to transfer the reactor heat to the cooling tower. The open pool design affords direct viewing of the reactor and in-pool experiments during full-power steady-state or pulsing operation. The water-cooling and purification systems maintain low water conductivity, remove impurities, maintain the optical clarity of the water, and provide a means of dissipating the reactor heat.

2.1 General Description of Experimental and Irradiation Facilities

The TRIGA reactor is equipped with a number of experimental and irradiation facilities. It can be used to provide intense fluxes of neutron and gamma for research, training and radioisotope production. The name of these facilities and corresponding neutron flux are given below:

i) A rotary specimen rack (Lazy Susan) accommodates up to 81 samples simultaneously for activation analysis and isotope production. It is located in the upper part of the graphite reflector assembly around the reactor core. The Lazy Susan assembly consists of a stainless steel rack that holds specimens during irradiation and ring-shaped, seal-welded aluminum housing. The neutron flux in this facility is 1.39×10^{13} n/cm^2/sec.

ii) A pneumatically operated "rabbit" transfer system is located in the G ring of the core, which penetrates the reactor core lattice. A cylindrical shaped specimen capsule of 3.17-cm diameter (outside) and 13.97-cm length is used here. The system is used for the production of very short-lived radioisotopes. This system rapidly conveys a specimen to and from the reactor core. It allows the transfer of a sample to be irradiated, into the reactor core or out from there in about 4.6 seconds, thus allowing handling of short lived radioisotopes, particularly for the purpose of neutron activation analysis (NAA). The neutron flux in this facility is 1.0×10^{13} n/cm²/sec.

iii) The Dry Central Thimble (DCT) is located at the center of the reactor core and provides space for irradiation of samples at the point of maximum flux, which is about 7.46×10^{13} n/cm²/sec. It also makes possible the extraction of a highly collimated beam of neutron and gamma radiation. It is provided with a dogleg bend located at a depth of about 4.7 m from the pool water surface. This bend helps avoid direct streaming of radiation from the core. This is the very important location where Tellurium Dioxide is irradiated for the production of Iodine-131. This location (tube) is also used to irradiate the samples of water, sand, human hair, vegetables, soil, etc. for the determination of elements content like arsenic, chromium, uranium, thorium in it. Thus DCT is also being used for Neutron Activation Analysis (NAA) at low power (during natural convection mode of steady state operation up to 500 kW).

iv) The reactor is equipped with four beam tubes (BT), named as Tangential BT, Piercing BT, Radial BT #1 and Radial BT #2. The tangential BT is used for neutron radiography. The neutron flux in the tangential BT at a distance of 140 cm from the wall to the sample is 1.13×10^{6} n/cm²/sec. The piercing BT is being used for neutron scattering studies by using Triple Axes Spectrometer (TAS) and its flux level is 1.42×10^{5} n/cm²/sec. Radial BT #2 is used for High Performance Powder Diffractometer (HRPD) and its flux level is 4.75×10^{4} n/cm²/sec.

v) Cutouts in Grid Plate: There are two nos. of triangular cut-out in the core and one no. of hexagonal cut-out at the center of the core. The triangular and hexagonal cutouts in the top grid plate allow in-core irradiation of large diameter samples. This facility is not used yet.

vi) Thermal column: This facility filled with heavy concrete blocks is not yet used.

2.2 Components of Reactor Core

2.2.1. Fuel

Fuel of the BAEC TRIGA reactor (shown in Fig. 4) is composed of 20% (wt) Uranium enriched to 19.7 % (the amount of ^{235}U isotope is 19.7 %), Zirconium hydride ($ZrH_{1.6}$) and burnable poison Erbium (^{167}Er). The inherent safety feature of the TRIGA fuel design has been achieved through the use of Erbium Uranium Zirconium hydride (Er-UZrH) material for the fuel-moderator elements. This gives the TRIGA core a large prompt negative temperature coefficient of reactivity and thus makes the core to withstand pulsing operation. The nominal value of prompt negative temperature coefficient of reactivity for the reactor is about 1.07×10^{-4} % Δk/k/°C. The burnable poison Erbium in the U-Zr matrix contributes to the long core lifetime for the TRIGA reactors.

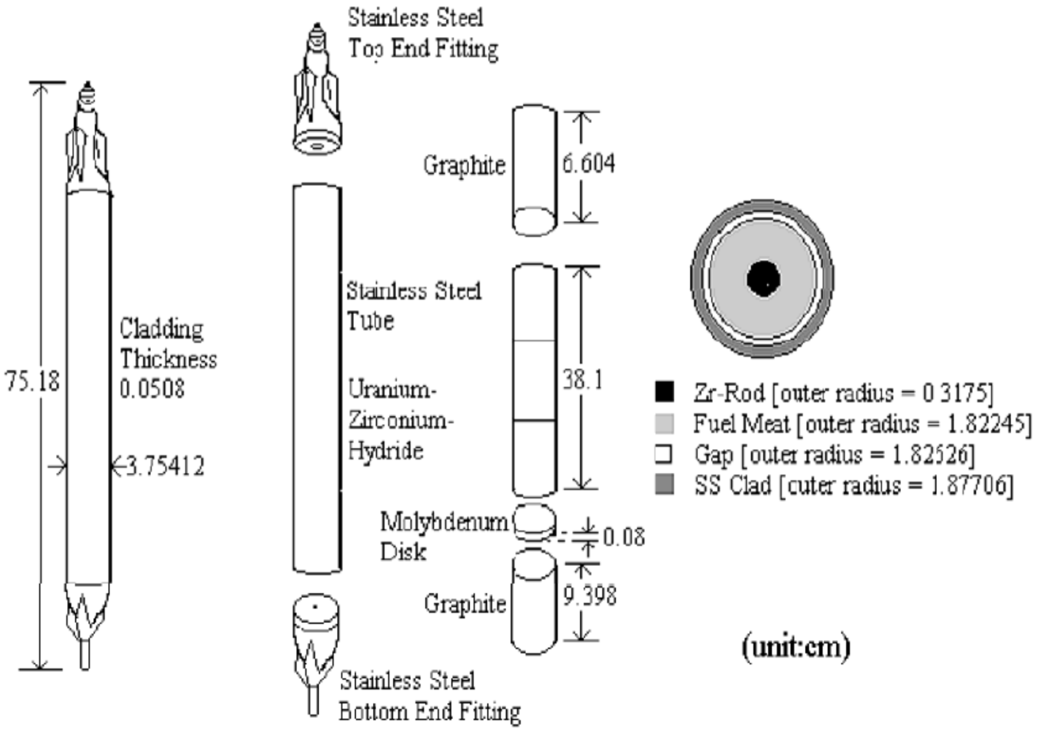


Fig. 4: TRIGA Fuel Element

2.2.2. Control Rods

Control rods (shown in Fig. 5) are used to control fission chain reaction in the core and the power level of the TRIGA reactor is controlled by six control rods, which contain Boron Carbide (B_4C) as the neutron absorber material. When these rods are fully inserted into the reactor core, the neutrons emitted continuously from the start-up source (^{241}Am-^{9}Be source) are absorbed by the rods and the reactor remains sub-critical. If the absorber rods are withdrawn from the core then the number of fissions in the core and the power level increases. The start-up process, which is accomplished by withdrawal of all control rods in steps, takes roughly about 10 minutes for the reactor to reach a power level of 3 MW from the sub-critical state. During the operation of the control rod, the electromagnet is activated by the current to the coil, then the link-latch is fixed in open-shape and holds the control rod..When coil current is cut off at reactor scram, the electromagnet is released and the link-latch is closed. The control rod detaches from drive mechanism and quickly drops by own weight and downward cooling water flow in the reactor tank. Then the neutron absorber is inserted into the core and fission chain reaction is terminated.

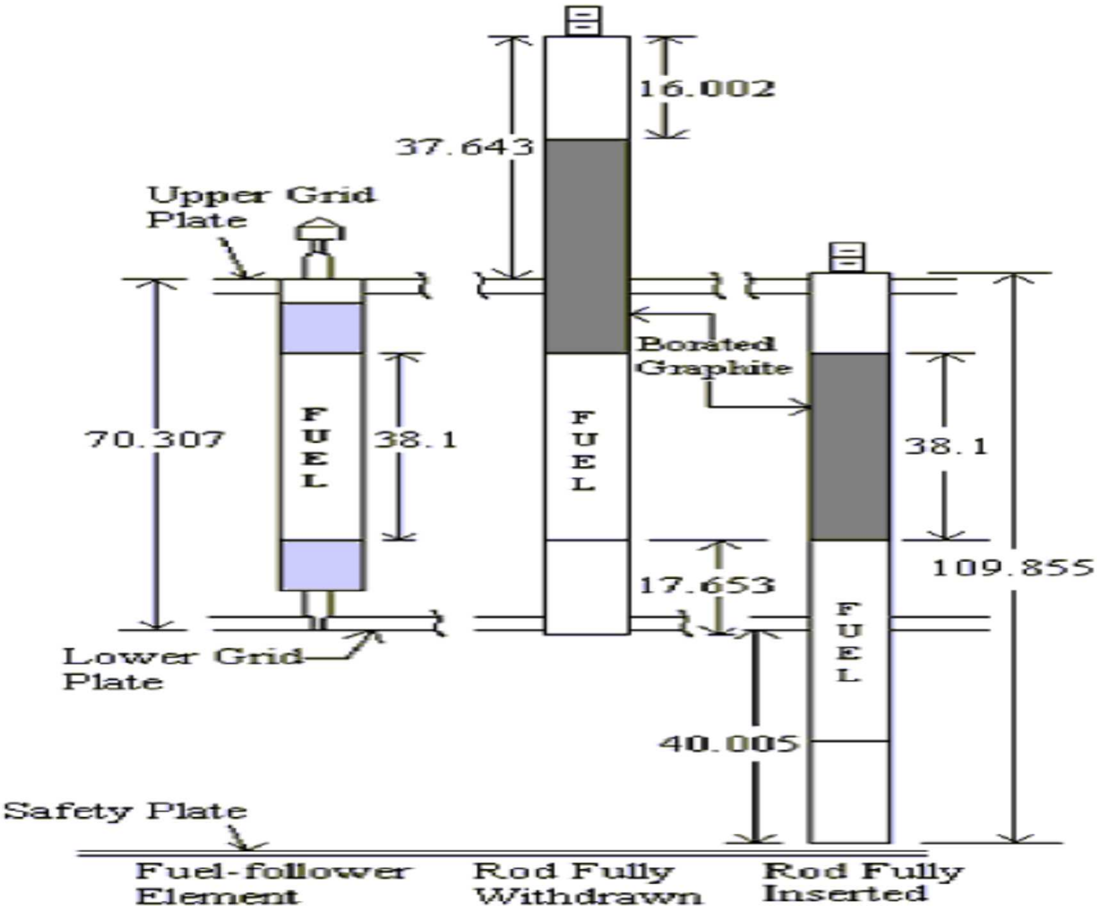


Fig. 5: Fuel Follower Control Rod

2.3 Reactor Cooling System

The steady state mode of operation of the reactor is performed under two cooling modes: Natural Convection Cooling Mode (NCCM) and Forced Convection Cooling Mode (FCCM). The NCCM is used to operate the reactor up to power level of 500 kW. During the NCCM of operation, generated heat in the reactor core is removed by the tank water through natural convection cooling mechanism. Meanwhile, for the operation of the reactor from 500 kW to 3 MW power level, FCCM is used. Heat generation during this mode of operation is dissipated into the atmosphere through a cooling system consisting of primary and secondary cooling circuits. Table 2 shows the specifications of the major components of the reactor cooling system.

Table 2: Major Specifications of the Reactor Cooling System

Primary Water System	Secondary Water System	Cooling Tower
Primary coolant: De-mineralized water	Primary coolant: Tap water	No. Cooling Tower: 2
No. of Pump: 2 (Centrifugal)	No. of Pump: 2 (centrifugal)	Flow Type: Counter Flow
Motor Power: 50 HP (each)	Motor Power: 40 HP (each)	Blower Capacity: 20 HP (each)
Flow Rate: 1750 gpm (each)	Flow Rate: 1650 gpm (each)	Temperature Drop, ΔT: 4 ^{0}C
Maximum Discharge: 35 Psi	Maximum Discharge: 34 Psi	

2.4 Loops for Testing Components of TRIGA Reactor Core.

In this case, the underwater camera was used for inspection of core components. The camera played a vital role during the repair of Radial Beam Port Plug of 3 MW TRIGA MK-II research reactor in 2010. It was also possible to inspect the reactor tank, core reflector assembly etc, at steady state condition.

2.5 Facilities for Investigation of Corrosion of TRIGA Reactor Materials.

- The concern with the Lazy Susan is that white powder like substances are growing on the inner wall of the Lazy Susan loading tube. Repeated cleaning by mechanical means could not prevent it from growing.
- In addition to that yellowish spots are observed on many parts of the inner wall of the reactor pool liner when inspected by underwater camera supplied by IAEA TC project number BGD9011.
- Corrosion spots as found on the inner wall of the Radial Beam Port #1 by an underwater camera. It is the only facility to investigate corrosion of TRIGA reactor materials through visualization of ageing issues regarding Reactor Tank and Beam Tube Plug, etc.

2.6 Devices for Capsule Irradiations/Tests

In capsule irradiation facilities specimens are inserted in a capsule and the capsule is inserted into an irradiation hole. About 41 irradiation holes (each hole contains two samples) are available in the rotary specimen rack (Lazy Susan), 1 hole in Dry central thimble and 1 hole in Rabbit system. These holes are used for non-instrumented capsules in TRIGA facility.

2.7 Devices for Investigation of Fuel and Structural Materials Behavior and Characteristics

The fuel element inspection tool is used to accurately inspect a fuel element for longitudinal growth and for bowing in excess of 0.062 inch. The bowing of a fuel element is detected by a carefully machined cylindrical (a go/no-go gauge) attached to the bottom of the tool. If a fuel element slides completely into the cylindrical, its bow, if any, is less than 0.062 inch. If the element passes through the cylinder, it comes to rest on the plunger in the lower end of the cylinder. The length of the fuel element is measured by pushing the indexing rod downward until the indexing plug rests on the reference plate.

A standard element is furnished with the inspection tool; it is a solid piece of aluminum with the same dimensions and the same top and bottom end fixtures as those on a regular fuel element. This standard element must be inserted to calibrate the tool. The amount of drive rod displacement caused by the standard element is used to zero the dial indicator. Every fuel element in the core can then be measured and its length compared with that of the standard. Instrumented fuel element can also be inspected with this tool. By using a longer go/no-go gauge and a dummy fuel-follower standard element, a fuel-follower control rod can also be inspected.

3. Related Engineering and Research Infrastructure

The following related engineering and research infrastructures are developed to perform the safe operation and the best utilization of 3 MW TRIGA Mark-II research reactor at steady state condition:

- Reactor physics and engineering division
- Nuclear and radiation chemistry division
- Health physics and radioactive waste management unit
- Reactor and neutron physics division etc,.

The functions of each division are different and to determine/evaluate safety parameters of TRIGA facility from the different safety viewpoints.

3.1 Experimental Material Logistic

Center for Research Reactor (CRR) is responsible for operation and maintenance of the research reactor. During the last twenty eight years CRR carried out several refurbishments, replacement, modification and modernization activities in the reactor facility. The major tasks carried out under refurbishment program were replacement of the corrosion damaged N-16 decay tank by a new one, replacement of the fouled shell and tube type heat exchanger by a plate type one, modification of the shielding arrangements around the N-16 decay tank & ECCS system and solving the radial beam tube-1 leakage problem. All of these refurbishment activities were performed under an annual development project (ADP) funded by Bangladesh Government [2-3].

The BTRR was operated by analogue control console system from its commissioning to July 2011. Old analogue based console has been replaced by digital console on June 2012. Besides this, the Neutron Radiography (NR) facility has been replaced by the addition of a digital neutron radiography set-up at the tangential beam port. The neutron Scattering (NS) facility also has been upgraded by the installation of a High Performance Powder Diffractometer (HPPD) at the radial beam port-2 of the reactor.

3.2 Hot cells

The purpose of radioisotope production laboratory (RIPL) is to produce short lived radioisotopes and radiopharmaceuticals for medical use in the country such as, ^{99m} Tc, ^{131}I, ^{131} I Capsule. In RIPL the following hot cell facilities are available:

^{99m} TC-Generator Hot Cell

Two shielded glove boxes with fume hood suitable for handling maximum 185 GBq of ^{99}Mo/batch for the production of ^{99m} Tc-Generator.
Dimensions of the shielded glove boxes: (23cm×120cm×140cm)×2
Specifications:
Containment: SS 304
Lead Shielding: 5 cm
Lead ball-brick: with manipulators (12 Nos.) and pantograph (2 Nos)
Lead glass window: Equivalent to 5 cm Lead (10 Nos.)
In-cell equipment: Trolly, Pantograph, Decrimper, etc.
Ventilation: Connected to the main exhaust of the ventilation system through HEPA filters.

^{99m} TC-Generator Hot Cell

Two GMP complaint hot cells with laminar flow module are suitable for handling 1110 GBq of ^{99}Mo/batch for the production of ^{99m}Tc-Generator.
Dimensions of the shielded glove boxes: (100cm×100cm×100cm)×2
Specifications:
Containment: SS Containment
Lead Shielding: 10 cm
Lead ball-brick: 10 cm Φ (No.4)
Lead glass window: 50 cm Thick
In-cell equipment: EDOS Dispasser, P^H meter, Vacuum pump, On-line dispasser, Pneumatic crimper, decrimper, griping device, close calibrator, etc.
Operating System: Computer controlled.
Ventilation: Connected with the central air handling system.

^{131}I Hot Cell

Suitable for handling a maximum of 370 GBq/batch
Dimensions of the shielded glove boxes: (495cm×115cm×140cm)
Specifications:
Containment: SS Container
Lead Shielding: 10 cm
Lead ball-brick: Φ 10 cm with manipulators (7 Nos.)
Lead glass window: Equivalent to 10 cm Lead (4 Nos.)
In-cell equipment: Quartz furnace, Can cutters, Separator, Absorber, Charcoal filter, Dispenser, etc.
ISEF: ^{131}I produced during sublimation is absorbed in buffer solution at P^H -9. Rest of the air containing ^{131}I is passed to air through the charcoal filter, to ISEF and subsequently the HEPA filter. Finally, it is released into the atmosphere through reactor exhaust stack.

^{131}I Capsule Hot Cell

Suitable for handling a maximum of 74 GBq/batch
Dimensions of the shielded glove boxes: (200cm×105cm×180cm)
Specifications:
Containment: SS Container
Lead Shielding: 5 cm
Lead ball-brick: with manipulators (4 Nos.)
Lead glass window: Equivalent to 5 cm Lead (2 Nos.)
Charcoal Filter: Shielded glove box air passes through activated charcoal filter and then released into the atmosphere through reactor exhaust stack.

3.3 Capabilities to Design and Manufacture Experimental Devices and Measurement Systems including Human Resource Development.

Neutron Activation Analysis (NAA), Neutron Radiography (NR) and Neutron Scattering (NS) techniques are being used to conduct various R&D activities. NAA technique is used to accurately determine trace elements in soils, rocks, water, air, particulate matter, vegetables samples, etc, and it is also used determine very low level (0.06 ppb) of arsenic in drinking water, human air, paddy, rice, urine and food staff. NR facility is used to detect of defects and corrosion in metals, alloys, aircraft spare parts, water absorption behavior of building materials, etc,. NS facility is used for neutron diffraction studies by using Triple Axes Spectrometer (TAS) at the piercing

beam port.
Some important reactor physics safety parameters were measured such as control rod worth, core excess reactivity, shutdown margin, loss of reactivity with power increases, power defect, fission product poisoning, fuel temperature reactivity coefficient, void coefficient and thermal power calibration of the reactor [4].
The High Performance Powder Diffractometer (HPPD) has been set up at the reactor to enhance the R&D facilities in the neutron scattering technique.
In case of training program, this facility is used to train-up the people in the different nuclear fields such as:

1. Training program of senior reactor operator and reactor operator
2. Basic nuclear orientation course
3. Reactor engineering course
4. Industrial attachment training program
5. Education program
6. Follow-up instructor training course

4. Recent Achievements

The BTRR has been operated as per the technical specifications and procedures as laid down in the safety analysis report (SAR). Moreover, special cares were taken for routine check and surveillance activities for preventative and corrective maintenance of systems and equipments. Refurbishment works were performed in the cooling system and rectification of beam port leakage problem was really ensured the sustainable, safe and reliable operation of the reactor.
After satisfactory installation of the plate type heat exchanger and modification of cooling system piping arrangements have significantly improved the cooling system parameters and reduced vibration level. Modification of ECCS has also enhanced the overall safety of the reactor. The digital I & C system will be helpful for the BAEC professionals to develop better understanding about the I & C systems of the reactor. After modernization of the beam port facilities, neutron based R & D activities have been increased significantly. Although BAEC has performed ageing management activities as per requirements; however, a systematic and structured ageing management program should be established based on IAEA safety standards. An IAEA TC project Titled “Implementing an Ageing Management Program for the TRIGA Research Reactor” has been taken to establish systematic ageing management program for BAEC RR. A few NDT equipments have been also procured under this project. It is expected that CRR will establish systematic ageing management program very soon which will be very much effective to extend the operational lifetime of the reactor. In addition, in order to support the radioisotope production the below facility was developed in RIPD:

- **Tc-99m Kit Production Facility (Clean Room):**

A pharmaceutical grade clean room facility for production of Tc-99m in-vivo kits has been established at RIPD in 2011. The clean room covering an area of 72 m^2 is equipped with necessary air handling equipment to achieve required clean classes for pharmaceutical preparation.
Tc-99m Kit Production Facilities Equipment:
The following equipment have been installed in the clean room:

- Laminar flow module with plastic tips around the module
- Laboratory freeze dryer.
- Deep freezer.
- Glassware washing machine.
- Hot air sterilizer with containers.
- Pyrogen free water production apparatus with glass internal.
- Balance with printer.
- Ultrasonifier: Capacity: 13.5L.
- Heating plate with magnetic stirrer.
- Dewar flask.
- Automatic dispenser.
- Manual dispenser.

5. Other Useful Information

The Fukushima Dai-ichi NPPs accident was occurred on 11 March 2011 in Japan due to natural disaster like earthquake and tsunami. This accident makes a serious impact for both commercial use and research & development of nuclear power in the world. After this event, the BTRR facility was upgraded to maintain the sustainable, safe and reliable operation of the reactor and the new regulatory requirements include the satisfaction of integrities for the updated earthquake forces, the consideration of natural phenomena and the management of the consideration in the DBA and BDBA to protect fuel damage and to mitigate impact of accidents. The major features of the new regulatory requirements for the BTRR are given below:

- Two sets of seismic switches were installed in the reactor facility which will turn off the UPS power of the new Digital console when seismic condition will trigger the set point.
- Reactor building was designed considering a seismic ground acceleration of 0.2 g. Reassessment of the integrity of the reactor

building is required considering largest possible earthquake at the nearest fault.

- BAEC research reactor facility has 250 kVA and 650 kVA diesel generators (DG). A portable 5 kVA petrol generator was also installed after FD NPP accident to provide power to the digital console.
- New fire detection & alarm system and fire hydrant system is installed in the reactor facility in March 2012.
- A 10 HP deep tube well is installed in the reactor facility for supplying water to the 20000 gallon underground storage tank which is used for makeup of secondary water and fire fighting.

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[3] A. Haque, M.M. Uddin, M.A. Salam, M.M. Haque, M.A. Zulquarnain," Report on Commissioning of the Cooling System of the BAEC 3 MW TRIGA Mark-II Research Reactor with the New Decay Tank and associated Components", 2003.

FNCA Research and Test Reactors Catalogue
Reactor Name: CARR (China Advance Research Reactor)
Organization: CIAE (China Institute of Atomic Energy)

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1. General information

Located in Fangshan District of Beijing, China, the China Advanced Research Reactor (CARR), composed of reactors, auxiliary systems and testing facilities, is a safe, reliable and multifunctional research reactor with high performance. The construction area of CARR is approximately 18,000m^2, about 2.3 hectar^{e}s of ground area occupied The CARR is a large-scale nuclear science project providing an important testing platform for nuclear science and research of China. For the aims of effective organization and management of the construction and commissioning of CARR, the China Institute of Atomic Energy (CIAE) established CARR Project Department and accredited it to control the quality and progress of the project, as well as its investment. CARR, started construction on 26th, August, 2002, successfully realized the first criticality on May 13, 2010.Initial full power operation for 72h has been finished in April, 2012. Up to now, all of the commissioning works on CARR have been finished.

CARR is an inverse neutron trap, multipurpose and high performance research reactor which is designed and built independently by China. Its rated power is 60MW. The plate-type fuel is adopted with U3Si2-Al dispersion as fuel pellet and aluminum alloy as cladding material. It provides strong neutron beams for NSE, NAA, NRG, etc., as well as has proper power and sufficient irradiation space for RIs production, fuel and material irradiation test, etc. Its main technical parameters and performance will reach or approach the level of advanced RR constructed currently in the world. There are many innovative designs, which are beneficial to improving main technical parameters and overall performance, and to improve advances, safety and reliability, and to reduce radioactivity dose level and effect on personnel and environment.

Its main technical parameters are listed in Tab.1.

The cross section view and exterior view are shown in Fig.1 to Fig.2.

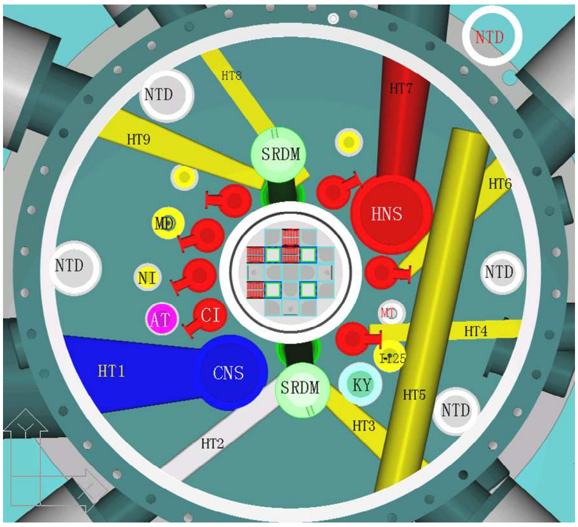


Fig.1 The Core layout of CARR

Fig.2 The exterior view of CARR

Technical Data

Reactor type	Tank in Pool
Thermal Power	60MW
Max Flux SS, Thermal	8.0E14(n/cm^2-s)
Max flux SS, Fast	6.0E14(n/cm^2-s)
Fuel material	U_3Si_2-Al
Cladding material	6061 Al
Moderator Material	Light Water
Coolant Material	Light Water
Reflector Material	Heavy Water
Control, Safety, Shutdown Rods Material/Number	Hf/6
Nat Convection/Direction	<900kW/Up
Forced Cooling/Direction	Yes/Down
Cool Velocity in Core	10m/s Nominal)

2. Reactor and Facilities

There are 21 square lattices in the core of CARR, the standard fuel assemblies are located in 17 lattices, and other lattices are for the follower assemblies.

The heavy water tank surrounds the reactor core, which diameter and height are same value, 2.2m. There are 9 horizontal tubes and 19 vertical tubes in the heavy water.

Whole reactor structure is immersed in the pool, which diameter is 5.5m and depth is 15m.

2.1 Experimental and testing facilities

A set of in-pile irradiation testing facilities is projected to be constructed in China Advanced Research Reactor (CARR) in 2014. The test loop can be used for steady state irradiation and transient test for nuclear fuel and material. It includes two parts: high temperature and high pressure test loop(HTHPTL) and helium-3 pressure control loop(He-3 Loop).By using thein-pile irradiation testing facilities, the performance tests (including steady and transient), high burn-up test, water chemistry activity transport and corrosion test, and fuel integrity and qualification test, etc., could be conducted.

(1) HTHPTL (Under construction)

HTHPTL is a separate pressurized water loop, connected with an in-pile tube. By use of HTHPTL, the fuel or material testing can be performed at different pressures, temperatures, flow rates, and water chemistry. The HTHPTL is connected to a computer control system. This control system controls, monitors, and provides emergency functions and alarms during operation of loop. HTHPTL consists of 10 sub-systems such as primary circuit system, safety injection system, purify and sampling system, component cooling system, etc. The sketch map of flow is shown in Figure 3.

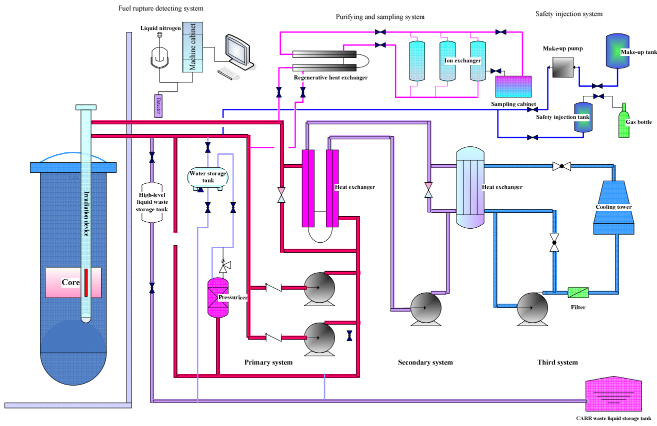


Fig.3 Sketch map of flow of in-pile HTHP test loop

The mainparameters are as following:

- Design pressure:17.2MPa
- Design temperature: 350℃
- Cooling power: 300kW
- Design volume flow: 30m^3/h

The operation parameters such as the pressure, temperature and hydrochemistry can be adjusted to satisfy different irradiation test needs by the cooperation of relative sub-systems.

(2) He-3 pressure control loop (proposed)

He-3 pressure control loop is used to change the pressure of helium around the test fuel assembly to adjust neutron flux, so that the power of the test fuel assembly is controlled. This loop adjusts the power rapidly, evenly and flexibly, and the irradiated parameters can be controlled accurately.

The main parameters are as following:

- Range of pressure change:05~4.0MPa
- Design temperature of tritium trap: 400℃
- Power ramping rate: 10kW/m· min
- Design volume flow: 1~2cm^3/s

The loop can be used to carry out power ramp test and power cycling test. It can also be used to control local neutron flux of irradiation samples during steady state irradiation.

(3) CIPITISE (Under construction)

The CIPITISE system consist of the irradiation facility including the pebble bed assembly (PBA) in CARR irradiation hole, and the tritium analysis and monitoring system (TAMS) in CARR operation hall as well as the monitoring system of the irradiation operational parameters in CARR operation control room. After irradiation, the irradiation will be dismantled in CARR operational hot-cell, and then irradiated PBA will be transferred to the 303# hot-cell for post-irradiation examination and some irradiation performances will be also carried out.

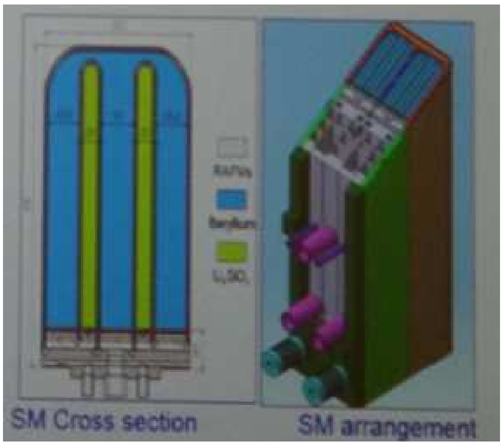


Fig.4 CIPITISE

The updated design was composed of twelve sub-module in the form of six lines and two columns with the breeder out of tube in order to simplify the sub-module structure, reduce mass of the RAFM structure materials and improve TBR performance. The tritium breeder zones would be packing of the lithium orthosilicate pebble with diameter of 1.0mm, and isotope abundance of 80% lithium-6.

The main parameters are as following:

- Maximum temperature for lithium breeder pebble bed:735℃
- Maximum temperature for the RAFM structure steel: 538℃

Its applying experiments and analysis are as following:

- ✧ Tests of effective thermal conductivity of the breeder pebble bed under In-pile irradiation
- ✧ Experiments of the tritium release behaviors of the breeder pebble bed under the conditions of reactor power operation
- ✧ Tests of the tritium release and retention performance of the breeder pebble bed by the electrically-assisted heating under the condition of reactor shutdown
- ✧ Experiments of the tritium permeation behaviors of the RAFM structural steel and the tritium permeation resistance and stability of the barrier coatings on the RAFM surface under In-pile irradiation
- ✧ Post-irradiation examination and study on irradiation swelling and/or damage performance of tritium breeder pebble after irradiation
- ✧ Evaluation and validation of the neutronics and thermo-hydraulic analysis of the HCCB pebble bed
- ✧ Comparison and assessment of the tritium production performance of the different lithium ceramics such as lithium ortho-silicate and meta-titanate pebble prepared by different methods.

2.2 Components of reactor core

(1) Fuel

Fuel element is an assembly of flat fuel plates with cooling channels between plates. Each plate contains a layer of uranium-silicide (U_3Si_2)-aluminum dispersion alloy covered with aluminum alloy cladding. Number of fuel plates per fuel element is 21 for standard element and 17for follower element which is connected with the control rod. The size of the fuel element is 76.2mm square for standard element and 63.6mm square for follower element in horizontal cross section, and about 850mm in height for both elements. Enrichment of the uranium in the fuel is 19.75wt%.

(2) Control rods

There are four control rods in the reactor core, each consists of the neutron absorber (square-tube of hafnium), fuel follower and shock section. During the operation of the control rod, the electromagnet is activated by the current to the coil, then the link-latch is fixed in open-shape and holds the control rod. When coil current is cut off at reactor scram, the electromagnet is released and the link-latch is closed. The control rod detaches from drive mechanism and quickly drops by own weight and downward cooling water flow in the pressure vessel. Then the neutron absorber is inserted into the core and fission chain reaction is terminated.

(3) Safety rods

There are two safety rods in the heavy water tank, each consists of the neutron absorber (circle tube of hafnium). During the operation of reactor, the safety rod is located on the top of reactor core, which is pushed by hydraulic driven mechanism. When accident happened, hydraulic driven mechanism is cut off, the safety rod quickly drops by own weight.

2.3 Investigation of Corrosion of reactor materials

Using HTHPTL and He-3 Loop, corrosion test of some structural materials could be conducted.

2.4 Device for Capsule tests

Specimens are inserted in a capsule, and the capsule is inserted into an irradiation hole. About 19 irradiation holes are available in the heavy water tank. Schematic drawing of Capsule is shown in Fig.5.

Requested specimen's temperature during irradiation is achieved by the selection of suitable irradiation holes as well as capsule design according to the irradiation purpose.

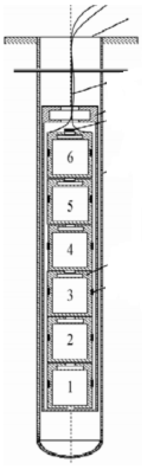


Fig.5 Capsule

3. Related engineering and research infrastructure

3.1 Experimental material logistic

Until now, these facilities mentioned above have not been considered.

3.2 Hot cell, PIE facilities

3.2.1 Hot cell

3.2.1.1 Description of the hot cell

There are three hot cells in CIAE, including the hot cell of CARR. The hot cell of CARR is a large non-destructive examination hot cell, shielded with heavy concrete and lined with stainless steel. A slope hole is installed inside the side wall of the cell which is connected with storage pool of the reactor. This hot cell is the first one in China which can perform full size non-destructive examination to the fuel rods from nuclear power plant. This facility was designed in April 2002 and operated in 2012.

The hot cell of CARR is the first one in China which can perform full size non-destructive examination to the fuel rods from nuclear power plant. Inside dimension of the hot cell is 7m×2.2m×4.1m（L×W×H）.The walls are made of heavy concrete of 4.2 g/cm^3. Thickness of the front wall is 1.3m, which allows a maximum activity of 3700TBq (10^5 Ci) for Co-60.This facility was designed in April 2002 and operated in 2012. Figure 4shows the front area of the hot cell. The main functions include non-destructive examination of fuel assembly, fuel rod and materials irradiated in CARR, full size fuel rods from PWR, Dismantling of radioisotope targets.

Fig.6 Front area of CARR NDT hot cell

3.2.1.2 PIE capabilities and main equipments

CARR hot cell provides the PIE capabilities to perform the following automated and remotely operated examination:

- Visual inspection and photograph of CARR fuel assembly and fuel plate
- Flow gap measurement of CARR assembly
- Dismantling of CARR fuel assembly
- Crude removal of fuel rod
- Non-destructive examination of fuel rods: including visual inspection, dimension measurement, eddy current testing, gamma scanning for relative burn-up measurement and Real time scanning X radiography
  Main equipments are list as follows,
- Cask for fuel rod and material transport
- Video and camera for visual inspection of fuel assembly
- Miller for dismantling of fuel assembly
- Multi-function bench for nondestructive examination of full size fuel rod and CARR fuel plate
- Video and Camera for visual inspection of fuel rod and CARR fuel plate
- Dimensional measurement device for measuring diameter and length of fuel rod
- Dimensional measurement device for measuring thickness of CARR fuel plate
- Flow gap measurement bench for CARR assembly
- Eddy current testing machine contains encircling coil and surface coil for measuring defects and oxide layer
- Gamma detector and Collimator for measuring relative burnup distribution of fuel rod
- Real time X radiography system for inspecting the defects, uniformity, structural integral of fuel

rod

3.2.2 Neutron beams facilities

3.2.2.1 Description of the neutron beams facilities

There are 9 horizontal beam tubes on CARR, including HT1: Cold neutron source beam tube, HT2: Multi-filtration neutron beam tube, HT3, HT4, HT6, HT8, HT9: Thermal neutron beam tubes, HT5: Long tangential beam tube, HT7: Hot neutron source beam tube.

Horizontal channels with associated equipment and instruments are installed in the heavy water reflector for various applications and make it possible for full use of the strong neutron source created by the reactor for neutron scattering experiments, study on nuclear power development and neutron activation analysis and so forth.

3.2.2.2 Capabilities and main equipments

With newly installed equipments such as the advanced cold neutron source and neutron guide tubes, are shown in Fig. 7, CARR will provide powerful capability for conducting a great deal of fundamental and engineering applied researches covering material science, life science, environment science, researches in physical-chemistry fields and in other important relevant areas.

Main equipments are listed as follows,

- CTAS：Cold Trip-Axes Spectrometer
- USANS：Ultra Small Angle Neutron Scattering
- CTOF: Cold Time of Flight
- PNR: Polarized Neutron Reflectometer
- CNR: Cold Neutron Radiography
- SANS: Small Angle Neutron Scattering
- NR: Neutron Reflectometer
- TNR: Thermal Neutron Radiography
- HIPD: High intensity powder diffraction
- TAS: Trip-Axes Spectrometer
- FCD: Four Circle Diffractometer
- NTD: Neutron Texture Diffractometer
- RSD: Residual Stress Diffractometer
- NPD: Neutron Powder Diffractometer

3.3 Simulator of materials testing reactors including HRD

There are four research reactors and ten zero power facilities in CIAE. Based on experiences of RR design, construction, operation and maintenance, a R&D group with rich experience has been developed. Now, one division in CIAE is in charge of experimental devices and measurement systems design including neutron physics, thermal-hydraulic, mechanism design and I&C design, the number of staff is about 60, most have attended the CARR design. The experimental factory in CIAE is in charge of manufacturing experimental devices, the number of staff is 100.

4. Recent achievement

At present, CARR is licensing for normal operation. Before normal operation, the work on CARR is to install devices and some measurement. Some R&D studies have been performed.

(1) Installation of CNS

- The Modification of CNS Design had been made through the optimized Calculations of LH2 and LD2 CNS for CARR.
- CNS with liquid deuterium is recommended for CARR as the best engineering solution.
- The alteration of Cryogenic Refrigeration System had been done through being replaced turbine, heat exchanger and helium gas loop.
- The cryogenic capacity tests of the Cryogenic Refrigeration System will be done in the final commissioning.

(2) Neutron texture diffractometer experiments

With relatively high neutron intensity and the performance, it has been proved to be efficient and suitable to pole figure measurements for simple structure materials in present stage. Up to now, a number of pole figures with satisfying quality have been obtained on this instrument for various research projects. A further improvement in its performance will be made in the near future by replacing the single ^{3}He detector with a two dimensional PSD.

(3) Sterile Neutrino Search

The feasibility study of a sterile neutrino search has been performed at the China Advanced Research Reactor by measuring $\bar{\nu}_e$ survival probability with a baseline of less than 15 m. Both hydrogen and deuteron have been considered as potential targets. The sensitivity to sterile-to-regular neutrino mixing is investigated under the “3(active) + 1(sterile)” framework. The result is founded that the mixing parameter $\sin^2(2\theta_{14})$ can be severely constrained by such measurement if the mass square difference Δm^2_{14} is of the order of ~1 eV^2.

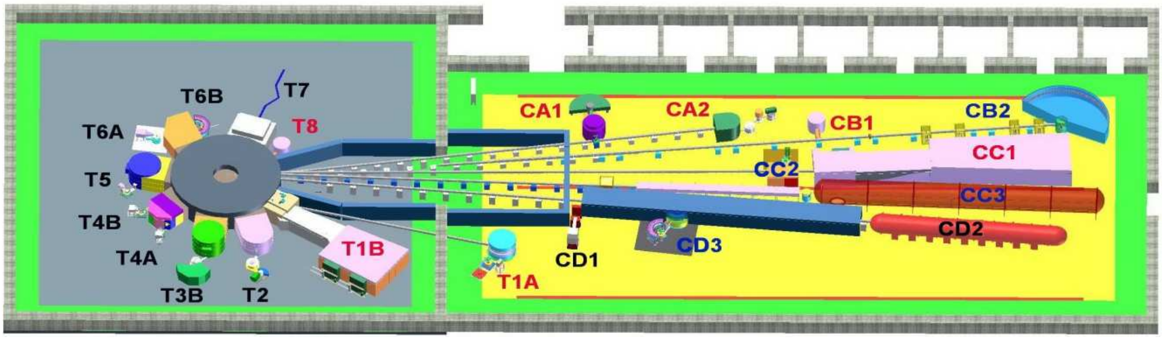


Fig7. The neutron physics and guide tube hall

FNCA Research and Test Reactors Catalogue
Reactor Name: RSG-GAS Reactor
Organization: BATAN (Indonesian Nuclear Energy Agency)

Centre for Multipurpose Reactor (PRSG)-BATAN,
Kawasan Puspiptek, Buliding No. 31, Serpong, Tangsel, Banten, Indonesia
Contact person : *Yusi Eko Yulianto,* ***e-mail:*** *yusi@batan.go.id*

1. General information

RSG-GAS reactor is a multipurpose research reactor operated by BATAN, Indonesia, located in Serpong, Southern of Jakarta, Indonesian capital. RSG-GAS reactor has power for 30 MW thermal. Configuration of MTR Type fuel elements, which are set up at a grid core in the deep of water pool. The reactor uses light water as cooling and moderator system.

Figure: RSG-GAS reactor

RSG-GAS reactor has been built in 1982, commissioned in 1985 and achieved first criticallity in August 20th 1987. Utilization of the reactor mainly is for radioisotope production, NAA, Experiments using neutron beams such as neutron spectrometry, neutron diffractometry and radiography, as well as a power ramp experiment on hight pressure in pile loop system.

General specification of the reactor is discribed in following Tabel:

Power	**30 MW**
Neutron Flux	2.10^{14} n/cm^2.s
Cooling Stoff	Light Water
Fuel Element Type	MTR
Fuel Material	U_3Si_2Al
^{235}U Enrichment	19.75 %
^{235}U Density	2.96 gr/cm^3
Neutron Absorber	AgIn-Cd
Number of Control Rod	8
Reflector	Beryllium
Number of Beam Tube	6
Radiation Protection	Warm Water Layer

2. Reactor and Facilities

The reactor core is a square grid from aluminium-magnesium. The core is configured by fuel elements, neutron absorbers, neutron source, reflectors and stringers for iradiation target. Around the core is installed utilization and exeriment facilities.

Figure Typical of Reactor Fuel Element

The existing utilization and experiment facilities in RSG-GAS reactor consist of facilities for radioisotope production, neutron beam experiments, rabbit system and in-pile loop system for power ramp test.

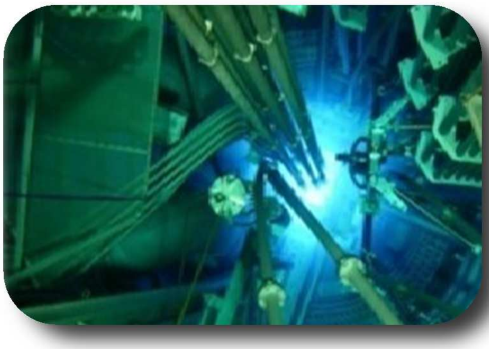
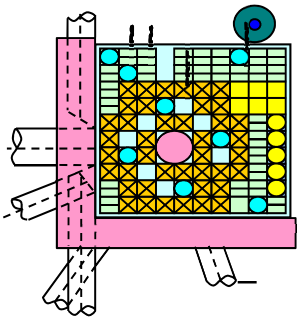


Figure Reactor Core

2.1 General description of experimental and testing facilities

In-core irradiation facility consist of 8 irradiation positions, which are completed by stringer with and without measurement instruments. RSG-GAS reactor has out-core irradiation facilites, which use a special design of capsules or containers. The capsules are loaded and un-loaded at irradiation positions manually by the operators



Rabbit system is the hydrolic and pneumatic tranports system for samples or irradiation targets, which are mounted at reactor rim. At irradiation position targets are exposured by neutron flux of 3.10^8 n/cm^2.s. Rabbit system consists of 4 hydrolic systems and 1 pneumatic system. Generally rabbit system is used for NAA, radioisotope production and radioactivation other specific targets, particularly for small and short time irradiation. Hydrolic system delivers capsules to the reactor core and let stay in the irradiation position under required irradiation time from 1 seconds until 5 hours. The target is placed inside Polyethilen and Aluminium capsules. The pneumatic system uses pressurized helium as the media to deliver capsules to the irradiation position in reactor core. The pneumatic system controls irradiation time for very short time in order to max of 30 seconds.

6 neutron beam tubes are installed radially from reactor core to the experiment instruments around the reactor vesel. The experiment facilities consist of neutron radiography, neutron spectrometry and neutron diffractrometry. Instrumentation for neutron beam experiments are very sophisticate in image processing for good accuracy.

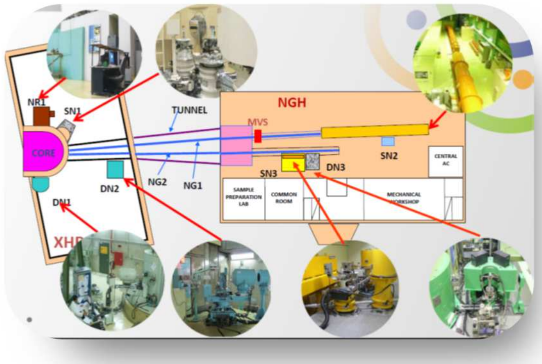


Figure 6 Beam tubes and its application

In-pile loop for power ramp manipulation is provided to test the characteristic of experimented pin of PWR type fuel element. This in-pile loop can generate pressure until 160 bar inside primary circulation loop as a simulation of condition in nuclear power plant.

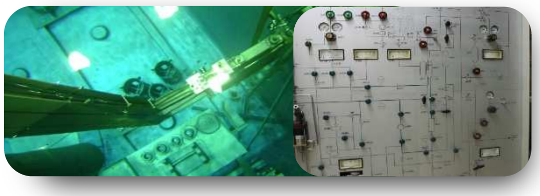


Figure Power ramp Facility

The future plan for experiment conducted in RSG-GAS reactor is to produce silicon semiconductor through irradiation and dopping method. Recently is going to study possible facilities be used for irradiation in light water circumstance and develop production procedures needed to achieve a good result.

2.2 Loops for testing components of reactor core

The RSG-GAS has no special loop for (fuel, control rods, structural materials, coolant technologies: lead, lead-bismuth, sodium, light and/or heavy water, molten salt, gas).

- At steady state conditions

- At transient conditions
- At accident conditions

2.3 Experimental facilities

Reactor operator of RSG-GAS reactor implements methodology to measure a case of un-balanced condition of neutron flux in core caused by un-expected reactivity changes at any position in the core. If system measures un-balanced measurement, the system will give the response on alarm and order the protection system to scram the operation or reactor is induced to shut down at one time.

The other manner of reactor control system, which has been well approved to limit the neutron flux acceleration is floating value limit system. The floating limit system restricts the neutron flux expansion and give information to the operator to adjust the reactor power in desired level.

2.4 Facilities for investigation of corrosion of reactor materials.

Corrosion is possible to attack the reactor structure and other auxiallary system. To measure the condition of reactor structure and facilities is carried out the inspection using corresponding water and radiation resist camera. The regulary inspection do to check the actual condition of structure againts corrosion. Conducting Study on images can complete information about the status of corrosion on structure corresponding to the activity of ageing and maintenance.

Through the analysis of water impurities can enrich the investigation the possible corrosion attacking on reactor structure.

2.5 Devices for capsule/ampule tests

Experiments carried out in RSG-GAS use two types of capsule material in differences dimensions. For hydrolic rabbit system uses polyethylene and Aluminium capsule. Both type of capsules have capability to bring the target to the irradiation position and back to the un-loading terminal.

To test the quality of capsule and ampule are used visual magnifying instruments and mechanical opener. Good condition and easyness to open and close are requirement for capsule and ampul

2.6 Devices for investigation of fuel and structural materials behavior and characteristics

RSG-GAS reactor has been facilitated with a Fuel Failure Detection (FFD) system. The FFD system has a function to detect fission product in small pieces, which is released in primary cooling system circulation. The detection system consists of detectors and instrument to display the counting system in control room. The operator regulary check the trend of it's counting rate at the recorder. Increasing of the counting can generate signal to shutdown the reactor completely and than let the operator do the failure analysis.

To check the condition of upsite surface of the reactor core according to the procedure is used the digital video camera and binocular before reactor started up. An other procudure requires rod drop test to ensure the capability of the control rod movement in and out of the reactor and the integrity of the fuel element shape.

Figure Visual inspection on reactor tank liner

The integrity of structure and material in the reactor container are inspected either visualy by water and radiation resist camera and also characteristicly by ultrasonic test for plate as well as eddy current test for tubes.

The operator carry out functional checking and testing of the isolation valves and natural convection flap to achieve their acceptance criteria. This activity is conducted before reactor started up to operate.

2.7 Other facilities

Facility in RSG-GAS reactor has been designed to produce Radioisotope such as ^{99}Mo, ^{131}Y for medic, ^{192}Ir for industry and others. Irradiation of target located in core positions and by using a specific designed capsule which place in a stable stringer.

3. Related engineering and research infrastructure

3.1 Experimental material logistic

Material used for supporting the operation and utilization such as material for isotope production, neutron activation analysis, experiment of characteristic material and neutron beam experiments are provided and prepared by the user under supervision of oficer in reactor operation safety section.

The RSG-GAS reactor operator than make sure the adequacy to meet procedure of reactor utillization. Material handling including transport to the processing facility and experimental facilities is a part of the safety and security action.

3.2 Hot cells, PIE facilities

RSG-GAS reactor is facilitated by Hot cells for handling high radiated material. Hot cells consists of 3 chambers, containing of working tool for preparation the radioactive target, before transporting out of the reactor building. The hot cells are completed by water channel to transport the target into processing hot cells in other building.

6 Beam tubes installed in RSG-GAS reactor are used for RI production and experiments. Beam Tube No.1 is used for istope Iodine ^{131}I. Beam Tube No.2 is used for Neutron Radiography. Beam Tube No.3 is unused. Beam Tube No.4 is used for Three Axis-Neutron Scattering. Beam Tube No.5 and No. 6 are used for measurement of neutron diffractometry.

Reactor facility is completed by gamma scanning to measure burn-up of fuel element. This measurement is important to validate the calculation in core management.

3.3 Capabilities to design and manufacture experimental devices and measurement systems including human resources development.

Management of RSG-GAS reactor has concerned to develope human resources capabilities in field of reactor operation and utilization, maintenance of facility, safety and security, as well as radiation protection. So, every 2 years has been conducted re-qualification program to improve the skill of the worker with examination and licensing by the authority.

Reactor manager creates a working group to design, manufacture and install special devices to support activities in experiments, such as manufacturing Irradiation Capsule, Container of Material Target auxilliared with cooling system, Temperature and Flow Measurement system in reactor core, instrumentation and control for automatic process in Rabbit and power ramp test facility.

4. Recent achievements

Publications related with operation and utilization of RSG-GAS reactor are:

1. Burn up calculation for RSG-GAS Reactor, Sembiring, Jakarta (in Indonesian)
2. Inspection on reactor vesel in RSG-GAS reactor, R. Himawan, Jakarta (in Indonesian)
3. Analysis of inspection on heat exchanger of RSG-GAS reactor, Santosa, Jakarta (in Indonesian)
4. Operation and Utilization of RSG-GAS reactor, Y.E. Yulianto, Jakarta (in Indonesian)
5. Minimizing the consequence of beam tube leak using the clamping, Y.E. Yulianto (in Indonesian)

5. Other useful/important information

Address of management of RSG-GAS reactor:

PRSG-BATAN
Building No.31 Kawasan PUSPIPTEK Serpong, Tangerang Selatan, 15310, Province BANTEN, Indonesia: Phone:+62.21.7560908 Fax: +62.21.7560573, Email: prsg@batan.go.id

REFERENCES

[1] “Safety Analysis Report of the RSG-GAS Reactor”, BATAN, 2010.

FNCA Research and Test Reactors Catalogue
Reactor Name: JMTR (Japan Materials Testing Reactor)
Organization: JAEA (Japan Atomic Energy Agency)

Neutron Irradiation and Testing Reactor Center,
Oarai Research and Development Center, Japan Atomic Energy Agency (JAEA)
4002Narita, Oarai-machi, Higashiibaraki-gun, Ibaraki, 311-1393, Japan
Contact person : *Masanori KAMINAGA,* ***e-mail:*** *kaminaga.masanori07@jaea.go.jp*

1. General information

Information of The Japan Materials Testing Reactor (JMTR) in Japan Atomic Energy Agency (JAEA) is as follows,

- ・Light water moderated and cooled
- ・Tank type reactor (Tank in pool type)
- ・Thermal power of 50000kW(50MW)
- ・Temporary shutdown

The JMTR is a testing reactor dedicated to the irradiation tests of materials and fuels. It achieved first criticality in March 1968. Currently the JMTR is being operated at thermal power of 50MW by about seven operation cycles a year, with about 30 operation days a cycle. Fig.1 shows outline of the JMTR, cross section of the core is shown in Fig.2. Specification of the JMTR is shown in Table 1. Outline of the JMTR and JMTR hot laboratory (JMTR-HL) is shown in Fig.3.

The JMTR was constructed to perform irradiation tests for LWR fuels and materials to establish domestic technology for developing nuclear power plants, and also to produce radio isotopes, and for the education and training.

In August 2006, operation of the JMTR was terminated. Then, there were user's strong requests for the JMTR reoperation from various fields, such as nuclear power industries, universities, radioisotope production companies. As a result of the national discussion, the JMTR was decided to be restarted after necessary refurbishment works. The refurbishment started from the beginning of JFY 2007, and after the replacement of primary and secondary cooling pump motors, nuclear instrumentation system, process control system, safety protection system among others. The refurbishment was finished after four years on schedule in March 2011 (JFY2010).

JMTR has some expected roles after refurbishment. First of all, JMTR contributes to aging management of LWRs and safety measure development for LWRs. Those results also will be utilized to higher burn-up fuels and soundness of materials. Also, contribute to solving the Fukushima NPPs accident. Secondly, JMTR is used to innovate in the field of science and technology, such as nuclear fusion research, materials/fuels for high temperature gas cooled reactors and to clarify damage mechanism of materials by neutron irradiation in the field of basic research for the nuclear energy. Thirdly, it is expected to expand industrial use including production of ^{99}Mo medical radioisotope used for diagnosis, or production of large dimension Si semiconductor. Finally, JMTR contributes development of nuclear human resources, not only in Japan, but also in Asian countries. It is expected to train next generation practical engineers through on the job training.

Table.1 Specifications of the JMTR

Reactor Power	50MWt
Fast Neutron Flux (Max.)	4×10^{18} n/m^2・s
Thermal Neutron Flux (Max.)	4×10^{18} n/m^2・s
Flow Primary Coolant	6,000 m^3/h
Coolant Temperature	49 ℃ / 56 ℃
Core Height	750mm
Fuel	Plate type, 19.8% ^{235}U
Irradiation Capability (Max.)	60(20*) capsules
Fluence/y (Max.)	3×10^{25} n/m^2・y
dpa of Stainless Steel (Max.)	4 dpa
Diameter of Capsule	30 - 110 mm
Temp. Control (Max.)	2,000 ℃
Average Power Density	425 MW/m^3

* : Capsule with in-situ measurement

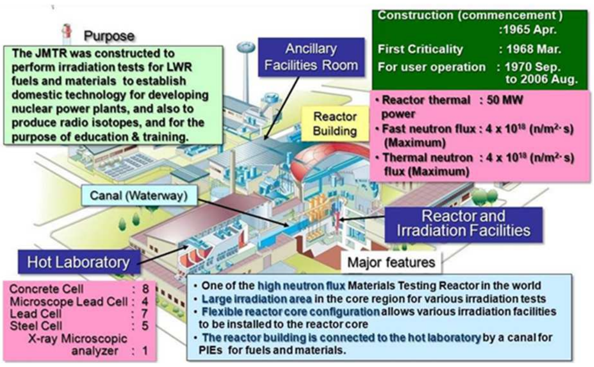


Fig.1 Outline of the JMTR

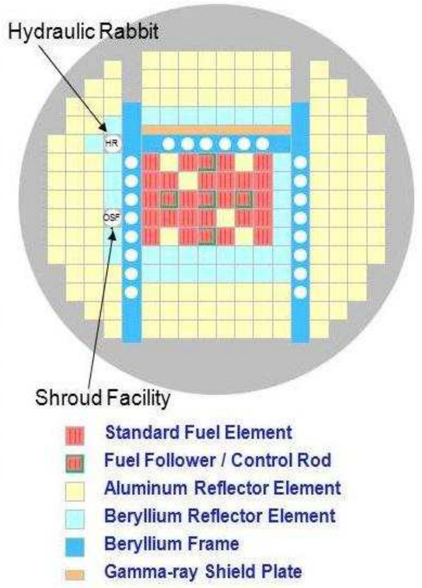


Fig.2 Cross Section of the Core

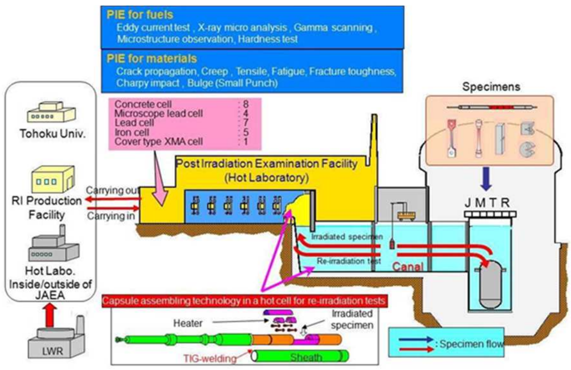


Fig.3 Outline of the JMTR and JMTR-HL

2. Reactor and Facilities

The reactor pressure vessel, 9.5m high, 3m in inner diameter, is made of low carbon stainless steel, 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 fuel in the core. The core of the JMTR is in a cylindrical shape with 1.56m in diameter and 0.75m high. It consists of 22 or 24 (for high burn-up core) standard fuel elements, five control rods with fuel followers, reflectors and H-shaped beryllium frame.

Cooling water in the primary cooling system is pressurized at about 1.5MPa to avoid local boiling in the core during rated 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 the secondary cooling system through heat exchangers. The heat transferred to the secondary cooling system is removed away into the atmosphere in cooling towers.

2.1 Experimental and testing facilities

The JMTR provides many kinds of irradiation facilities such as the capsule irradiation facilities, the shroud irradiation facility and the hydraulic rabbit irradiation facility for the irradiation tests of nuclear fuels, materials and radioisotopes production. Each capsule facility is installed into an irradiation hole where the neutron flux is suitable for irradiation purpose. Locations of the hydraulic rabbit irradiation facility and the shroud irradiation facility are fixed in the core, however the neutron fluence is controlled by moving the specimen into or take out from the core during reactor operation. Main irradiation facilities are follows.

(1) Capsule irradiation facilities

Non-instrumented, instrumented, Special (such as IASCC test capsule)

(2) Shroud irradiation facility

BOCA (Boiling Water Capsule) /OSF-1(Oarai shroud facility-1) irradiation facility for using power ramping test.

(3) Hydraulic rabbit irradiation facility

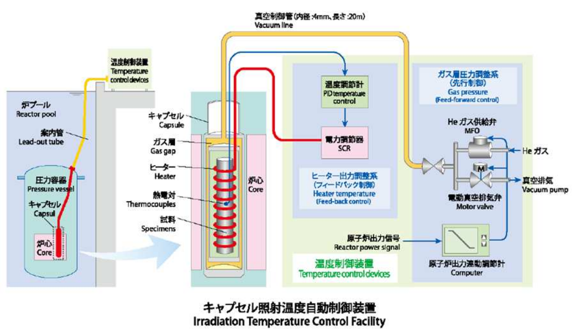
The hydraulic rabbit irradiation facility is a water loop system to transfer the small sized (150mm length) capsule, so called rabbit, into and take out from the core by the water flow in the loop. This facility is widely utilized mainly for the basic researches and for the production of short-lived radioisotopes.

(4) Advanced water chemistry controlled facility

This facility is used to carry out the irradiation test of materials under controlled conditions of temperature, radiation, and water chemistry aiming at irradiation tests for the IASCC (Irradiation Assisted Stress Corrosion Cracking) research. This facility is consists of SATCAP (Saturated Temperature Capsules) and Water Control Unit.

(5) Irradiation temperature controlled facility

Irradiation temperature controlled facility is composed of 14 temperature control devices and an operator station, and is possible to control simultaneously temperatures about 28 capsules in automatically, see Fig.4. Namely, constant temperature control during the reactor power change, cyclic temperature control with wide range and other complicated temperature control are possible to carry out in automatically.



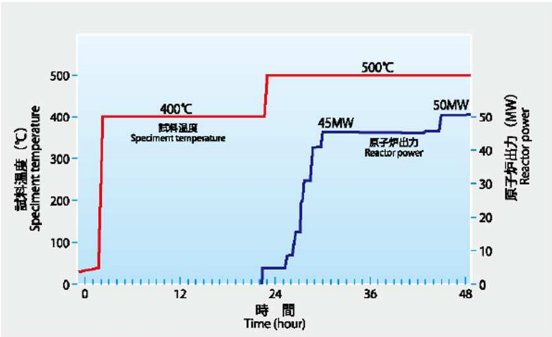


Fig.4 Irradiation temperature control facility

2.2 Components of reactor core

(1) Fuel

Fuel element is an assembly of flat fuel plates with cooling channels between plates. Each plate contains a layer of uranium-silicide (U_3Si_2) - aluminum dispersion alloy covered with aluminum alloy cladding. Number of fuel plates per fuel element is 19 for standard element and 16 for fuel follower which is connected with the control rod. The size of the fuel element is 76.2mm square for standard element and 63.6mm square for fuel follower in horizontal cross section, and about 1200mm and 890mm in height, respectively. Enrichment of the uranium in the fuel is slightly less than 20wt%. Fuel element contains thin cadmium wires as burnable absorbers.

(2) Control rods

Control rods are used to control fission chain reaction in the core. There are five control rods in JMTR, each consists of the neutron absorber (square-tube of hafnium), fuel follower and shock section. During the operation of the control rod, the electromagnet is activated by the current to the coil, then the link-latch is fixed in open-shape and holds the control rod. When coil current is cut off at reactor scram, the electromagnet is released and the link-latch is closed. The control rod detaches from drive mechanism and quickly drops by own weight and downward cooling water flow in the pressure vessel. Then the neutron absorber is inserted into the core and fission chain reaction is terminated.

2.3 Experimental facilities for Ramping Test

OSF-1 provides irradiation environments for the BOCA which is used to irradiate LWR fuel samples in the condition of BWR coolant. In-pile tube of the OSF-1 is penetrated into the core of the JMTR through the top lid of reactor pressure (about 7.3MPa) capsule made of stainless steel in which instrumented segment fuel is loaded, and is cooled by the pressurized water. The BOCA is inserted into the in-pile tube of the OSF-1, and power ramping test is performed by controlling ^{3}He gas (acting as neutron absorber) pressure in the ^{3}He gas screen of the in-pile tube. BOCA and OSF-1 are extensively used for the study on the integrity of the high performance fuels and high burn-up fuels of LWRs. These facilities are shown in Fig.5.

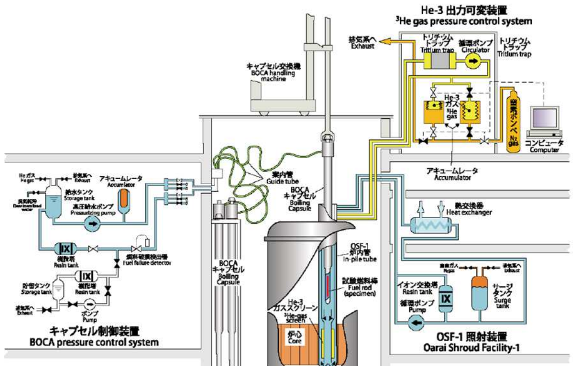


Fig.5 Shroud irradiation facility

2.4 Investigation of Corrosion of reactor materials

Material specimens are irradiated by the SATCAP in the high-temperature and high-pressure water, and temperatures of all specimens are controlled to be constant by the saturated boiling phenomena at the specimen surface. This system is shown in Fig.6.

(1) SATCAP

The SATCAP is designed to irradiate material specimens in the high-temperature and high pressure water. Temperatures of all specimens are kept almost equal over the inner loading space due to nucleate boiling of the cooling water.

(2) Water Control Unit

Water control Unit can supply the high-temperature and high-pressure water for saturated temperature capsule. According to the purpose of testing, feeding water’s temperature, flow, concentrations of dissolved oxygen and hydrogen, and electrochemical potential are controlled.

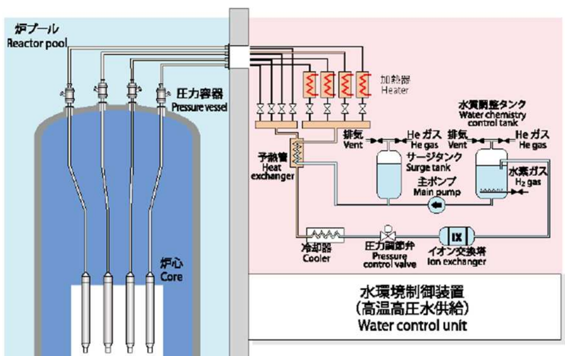


Fig.6 SATCAP and Water Control Unit

2.5 Device for Capsule tests

(1) Capsule irradiation facilities

Specimens are inserted in a capsule, and the capsule is inserted into an irradiation hole. About 60 irradiation holes are available in the reactor core, and about 30 irradiation holes can be used for instrumented capsules. Schematic drawing of Capsule and Capsule Controller are shown in Fig.7. Requested specimen's temperature during irradiation is achieved by the selection of suitable irradiation holes as well as capsule design according to the irradiation purpose.

Consequently, it is possible to select specimen's temperature with the range from 45 to 2000 deg-C corresponding to the irradiation purpose.

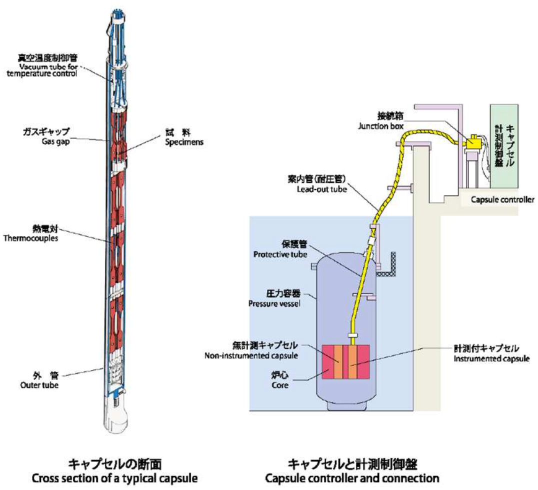


Fig.7 Capsule and Capsule Controller

(2) In-pile creep capsule with spectrum conditioning

Creep strain under irradiation condition, which is very important for nuclear materials to evaluate its lifetime, is influenced by not only fast neutron but also thermal neutron which generates He production in the material. This capsule enables to measure creep strain directly with controlled thermal neutron flux conditions. The capsule contains thermal neutron absorption material or breeder material.

3. Related engineering and research infrastructure

New JMTR is preparing its restart to be used as an important infrastructure for a safety research of fuels and materials for nuclear power plants, basic research for nuclear science, industrial utilization, and human resource developments of nuclear engineers as well as operators. In June 2010, the project named "Birth of the nuclear techno-park with the JMTR" was selected as one of projects of the Leading-edge Research Infrastructure Program by Japanese government. The new project is to install new irradiation facilities and PIE facilities to JMTR and JMTR-HL in order to promote basic as well as applied researches. This new installation of irradiation facilities and PIE facilities are shown in Fig.8 and Fig.9 respectively. In these facilities, such as BOCA capsules and manipulator in hot cell can be treated until 110GWd/t. And also, in the project, development of user-friendly environment especially for young and female researchers is highlighted.

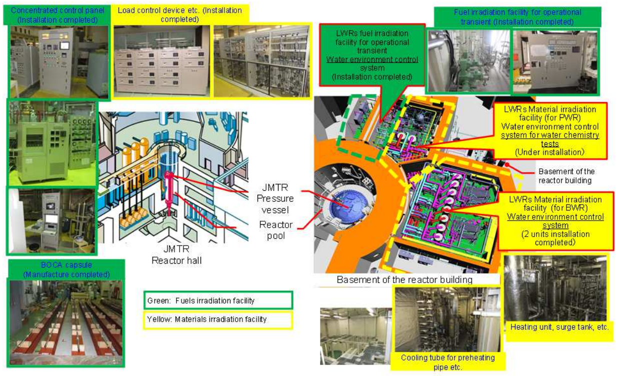


Fig.8 Installation of new irradiation facilities

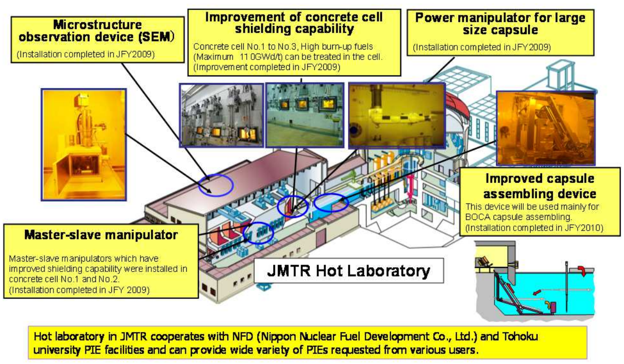


Fig.9 Installation of new PIE facilities

3.1 Experimental material logistic

The refurbishment project works of the JMTR was started from the beginning of JFY2007. The refurbishment project was promoted with two subjects; the one is the replacement of reactor components, and the other is the construction of new irradiation facilities.

The replacement work was finished at the end of Feb. 2011, according to schedule. The construction of new irradiation facilities is in progress as scheduled as shown in Fig.10.

Before the replacement of reactor components, an investigation of aged components (aged-investigation) was performed in order to identify integrity of facilities and components to be used for re-operation of JMTR. The equipment which needs replacing before the restart of the JMTR was selected after evaluated on its damage and wear due to aging significance in safety functions, past safety-related maintenance date, and the enhancement of facility operation. The replacement work of power supply system, boiler, radioactive waste facility, reactor control system, nuclear instrumentation system etc. was already carried out as scheduled. [1]

On the other hand, corresponding to the user's irradiation request, new irradiation facilities, such as irradiation test facilities for LWRs materials/fuels with a purpose of long-term and up-graded operations, production facilities for medical radioisotopes for Industrial Purpose, were planned to install in the JMTR.

(1) Replacement of reactor components

Based on criteria for selecting components, following items were reviewed and studied,

- Aging during 20 years during reoperation,
- Importance grade of reactor facilities/equipments,
- Conditions of facilities / equipments,
- Stable supply of spare parts in the maintenance activities during 20 years.

Replacement and renewal of the components were selected from evaluation on their damage and wear in terms of aging as shown in Table 2. Facilities whose replacement parts are no longer manufactured or not likely to be manufactured continuously in near future, were selected as renewal ones. Furthermore, replacement priority was decided with special attention to safety concerns. A monitoring of aging condition by the regular maintenance activity is an important factor in selection of continuous using after the restart. Taking also account of a continuous operation with safety, reactor facilities/equipments to be renewed were decided. [2]

As a result, aged or old-designed components of the control rod drive mechanism, primary cooling system, secondary cooling system, electric power supply system etc., were to be replaced by present-designed ones. Furthermore, the replacements and renewal were possible to carry out within the range of licensing permission of the JMTR.

For facilities which are not replaced, e.g. heat exchangers, pressure vessel, secondary cooling towers and so on, their safety was evaluated from a view point of aging. The long-term operation in future will be possible by maintaining the present condition in accordance with the periodic safety review of the JMTR. [3]

Renewal of the feed and exhaust air system is carried out at first, and also renewal of utility facilities of electric power supply system, boiler component, etc. is carried out at the same time. Then, facilities in the reactor building are to be finally renewed. Renewal of JMTR had been on schedule, and completed.

After restart of the JMTR, the maintenance activity will be carried out by the maintenance program based on the periodic safety review of the JMTR. By the replacement of reactor facilities, the failure possibility of each component will decrease, and this leads the improvement of the higher reactor availability-factor in future as shown in Fig.11. [4]

(2) Construction of new irradiation facilities

Corresponding to the user's irradiation request, new irradiation facilities, such as irradiation test facilities for materials/fuels, production facilities for medical radioisotopes, were planned to install in the JMTR as shown in Fig .12.

1) New Material and Fuel Irradiation Tests

[Facility for fuel development]

An irradiation facility of fuel behavior test at transient condition has been developed to evaluate the safety for the high burn-up light-water reactor fuels, uranium and MOX fuels in JMTR. The facility is capable of carrying out power ramping and boiling transition tests on light-water reactor fuels. The fuel irradiation test facility consists of shroud irradiation equipment, capsule control equipment and ^{3}He power control equipment. [5]

[Facility for material development]

The material irradiation test facility is developed to study the Stress Corrosion Cracking (SCC) under neutron irradiation for the light-water reactor in-core materials. This facility consists of a water environmental control system in the BWR material irradiation facility simulating the BWR environment and the water chemical test facility simulating the broad water environment such as the BWR, PWR. The BWR material irradiation facility consists of a water environment control system, weight-loading control unit and capsules.

2) New Irradiation Facility for Industrial Purpose

One of irradiation facilities is intended to provide the ^{99m}Tc for medical use. A hydraulic rabbit irradiation facility, which is well developed and already used for irradiation in the JMTR, can be applied to the production.

Table 2 Selection of components to be replaced

Criteria for selecting components to be replaced
1. Safety point of view
 (1)Aging of components
  (o: There is possibility)
 (2)Importance of safety feature
  (o: Importance is high level)
 (3)Maintenance experience
  (o: High trouble frequency or Short service life time etc.,)
2. Improvement of availability
 (4)Affordability of spare parts
  (o: Difficulty)

Facility, system	Components	Criteria (1)	(2)	(3)	(4)	
Reactor and process control system	Reactor control panel	O		O	O	Rep.
	Process control panel	O	O	O	O	Rep.
	Neutron instruments	O	O	O	O	Rep.
	CRDM	O	O	O	O	Rep.
Reactor cooling system	Main pump motors	O	O	O	O	Rep.
	Main heat exchangers		O			Cont.
	UCL circulation pump	O	O		O	Rep.
	Secondary cooling system main pipes					Cont.
Radiological waste disposal system	Emergency blowers	O	O		O	Rep.
	Regular blowers					Cont.
Power supply system	Power supply units	O			O	Rep.
	High voltage transformer	O		O	O	Rep.
Other system	Water demineralizer	O			O	Rep.
	Boiler units	O			O	Rep.

Rep. : to be replaced
Cont. : to be continuously used

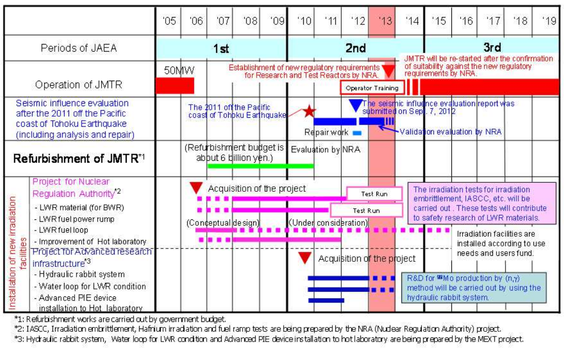


Fig.10 JMTR refurbishment work schedule

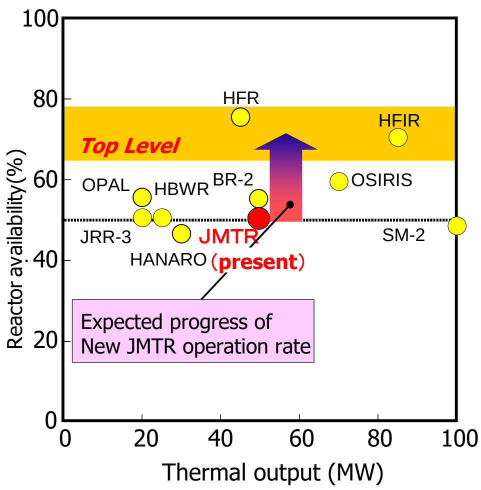


Fig.11 Expected reactor availability of JMTR

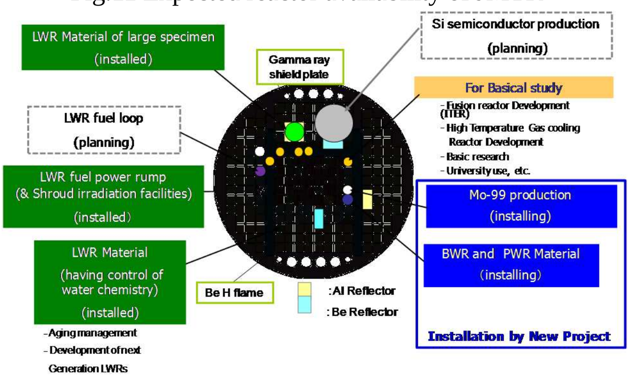


Fig.12 Outline of JMTR core irradiation facilities

3.2 Hot cell, PIE facilities

The JMTH-HL was founded to examine the specimens irradiated mainly in the JMTR, and has been operated since 1971. Post irradiation examinations (PIEs) for research and development in wide variety of nuclear fields such as nuclear fuels and materials are carried out in the JMTR-HL. The JMTR-HL is located adjacent to JMTR, and is connected to JMTR by a water canal, 6m in depth with 3m width. Irradiated radioactive capsules are transferred speedily and safely through the canal with the sufficient shielding capability of the water. High radioactive materials can be handled in the JMTH-HL, and various PIEs are performed treating high dose specimens.

The JMTH-HL consists of 8 concrete cells which attached 4 microscope lead cells, 7 lead cells and 5 steel cells. Dismantling of capsule, X-ray radiography, dimensional measurement etc. can be performed in the concrete cells as shown in Fig.13. The lead cells and steel cells are used for PIEs of materials, and PIEs for fuels can be carried out only in the concrete cells. In the lead cells, PIEs are carried out such as tensile test, instrumented impact test, Irradiation Associated Stress Corrosion Cracking (IASCC) tests, visual inspections, dimensional measurements. In the steel cells, PIEs for high temperature tensile/compression tests, fracture toughness tests, creep tests, fatigue tests, etc. are carried out. The specimens are transferred from the concrete cells using transport casks. Structure of the concrete cell and lead cell is shown in Fig.14.

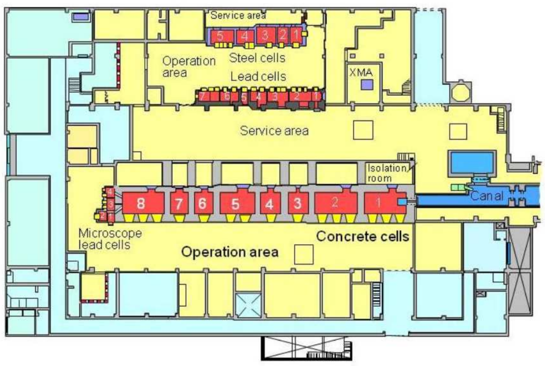


Fig.13 Horizontal view of JMTR-HL

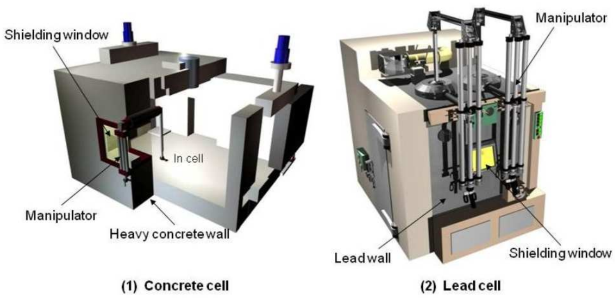


Fig.14 Structure of the concrete cell and lead cell

Taking four years from the beginning of JFY 2007 to March 2011, JMTR had carried out refurbishment works as mentioned in the previous section. [6]

During this period, advanced equipment/facilities have been developed and installed in the JMTR-HL. Obtaining high valuable technical data is requested as PIEs in order to contribute to safety management as well as lifetime expansion management of nuclear power plants and progress of science & technology. For that purpose, a three dimensional X-ray radiography system is developed and installed in the JMTR-HL. [7] Fig.15 shows the principle of the X-ray CT. A cone shaped radiation beam is emitted by the X-ray tube, and its intensity distribution, named "sinogram", is measured by the detector, which is composed of scintillator, CCD-array, data processing and host-PC. The radiation intensity is reduced depending on density and thickness of the inspection target in front of the detector. The CT image is obtained by restructuring of the sonogram. Fig.16 shows the three dimensional X-ray inspection system installed in JMTR-HL. The system consists of an X-ray generator, an X-ray detector, a machine for specimen movement, a control board and a data processing unit. Its specifications are summarized in Table 3. To get clear CT image, it is necessary to reduce the noise signal caused by the gamma-ray emitted by radioactive specimens. Then, the GOST (Gamma-ray Offset Scanning Technique) program has been developed, and installed in the system. Resolution performance test was carried out, and result is shown in Fig.17. X-ray CT measurements were carried out using platinum double wire specimens (diameter: 0.05 to 0.8mm, distance between wires: 0.05 to 0.8mm), and spatial resolution is confirmed up to 0.16mm. Performance test results using irradiated fuel rod, burn up at 25 GWd/t, is shown in Fig.18. From the test, we can see that the clear image is possible to obtain by the developed system.

Table3 Specifications of X-ray CT inspection system

Item	Specifications
1) X-ray system	
Target material	W (Tungsten)
Usable tube voltage	20 - 450 kV
Max. tube current	1.55 mA (at 450 kV)
2) Detector system	
Detector type	Line detector array (LDA)
Scintillator crystal	$CdWO_4$
Pixel size	0.254 mm
Number of Pixel	1984 pixels
Effective detector length	approx. 504 mm
3) Manipulator system	
Max. movement	1000 mm (Vertical)
Min. movement	0.1 mm (Vertical)
Min. rotation angle	0.025 degree

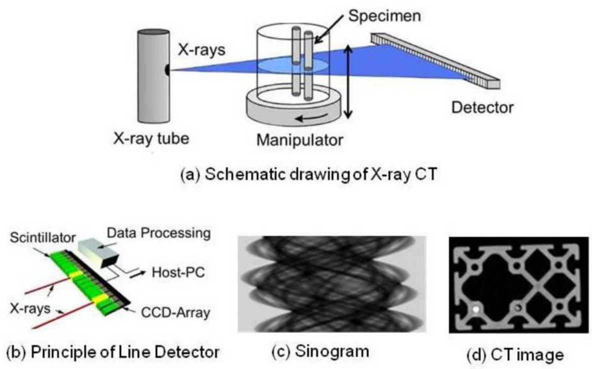


Fig.15 Principle of X-ray CT

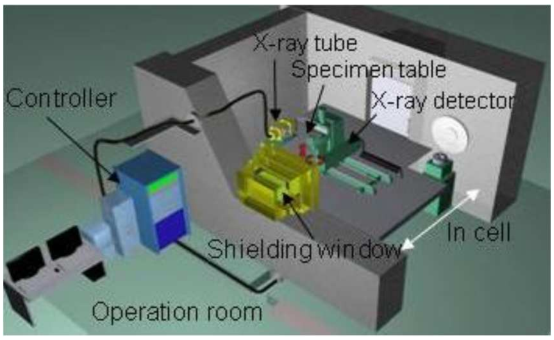


Fig.16 Schematic drawing of 3DX-ray CT

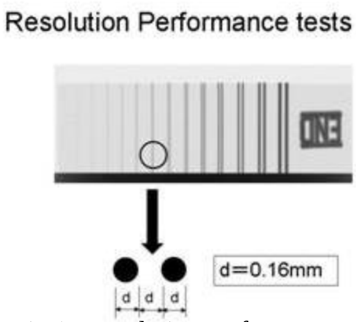


Fig.17 Resolution performance test

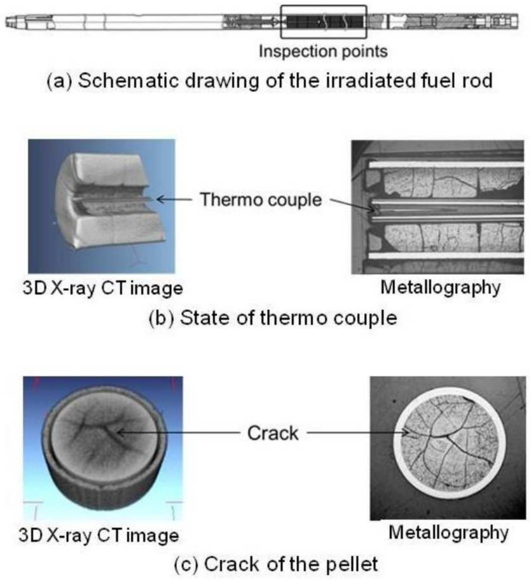


Fig.18 Performance test s using irradiated fuel rod

One key funding is the “Leading-edge Research Infrastructure Program” from the Japanese government in June 2010. From this funding, complex-type microstructure analysis equipment’s, which consist of TEM (Transmission Electron Microscope), FIB (Focused Ion Beam processing equipment) and XPS (X-ray Photoelectron Spectrometer), have been installed in the JMTR-HL.

(1) TEM

By electron beam irradiation to the sample and analyzing the scattered and transmitted electrons of the sample, an atomic level structural analysis is possible. The analysis will be applied to the research on irradiation damage from observation of irradiation defect and/or changes in metal structure. Three types of observation modes are available:

1) TEM mode: at 200kV accelerating voltage, it is possible to observe up to maximum magnification of 20,000,000 times, and the resolution is 0.1nm.

2) STEM (Scanning Transmission Electron Microscopy) mode: by combination with EDS (Energy Dispersed Spectroscopy) and EELS (Electron Energy Loss Spectroscopy), it is possible to carry out element analysis, element mapping etc.

3) SEM (Scanning Electron Microscopy) mode: it is possible to find the initial observation point, and to analyze the structure of sample which cannot transmit the electron beam.

Fig.19 shows the photograph of TEM and typical image obtained by the TEM. Moreover, specifications of TEM are summarized in Table 4.

Table4 Specifications of TEM

Item		Specifications
Accelerating voltage		200kV
Resolution	TEM	0.1nm
	STEM	0.2nm
Magnification	TEM	20,000,000 times
	STEM	20,000,000 times
Sample stage	Moving range	X,Y:-1 to 1mm, Z:-0.2 to 0.2mm
	Inclination angle	X: -25 to 25 degrees, Y:130 to 30 degrees

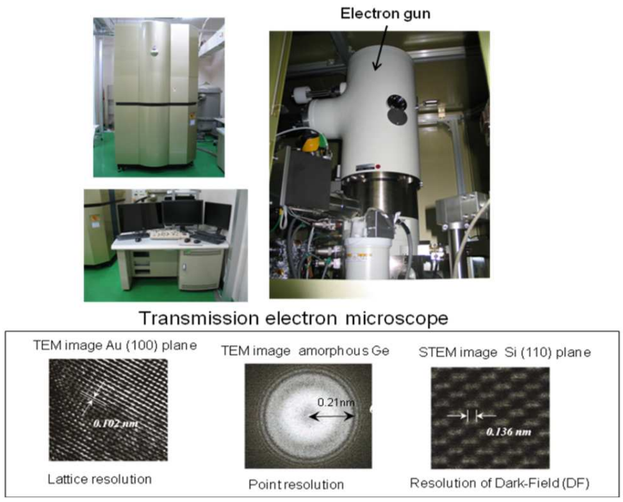


Fig.19 Photo of TEM and typical obtained image

(2) FIB

It is possible to prepare observation samples in micrometer order from irradiated bulk specimens by the Gallium (Ga) ion beam sputtering to the bulk specimen. From this, TEM samples can prepare directly from bulk irradiated specimens in the JMTR-HL. Moreover, by combining a Ga ion gun having a large current of 60nA with a scanning electron microscope (SEM), it is possible to prepare TEM samples in high-precision at a high speed. In addition, since the Electron Backscatter Diffraction (EBSD) is also installed in this system, it is possible to obtain the crystal orientation distribution of the sample surface by analyzing the Kikuchi patterns which are generated by inelastic scattered electrons when electrons are incident on the material. Specifications of FIB are summarized in Table 5.

Table5 Specifications of FIB

Item	Specifications
Current	Max. 60 nA
Resolution	10 nm
Beam current	0.5 pA to 60 nA
Accelerating voltage	1 to 30 kV
Accelerating voltage	30 times (Observation) 100 to 300,000 times (Processing & Observation)
Ion source	Gallium liquid metal ion source
Maximum processing	1.28 mm x 0.96 mm

range	
Irradiation time	0.4 microsec./point to 400 milisec./point

(3) XPS

Using the XPS equipment, it is possible to clarify the elemental analysis and chemical states of the sample surface by analyzing the emitted photoelectrons from an X-ray irradiated sample. This is useful for the assessment of the oxide layer composition in the Stress Corrosion Cracking (SCC) and/or analysis of the film formed on the surface of reactor materials. Measured photoelectrons are very near surface (at few nanometers) of the sample; however it is possible to carry out the high accurate analysis in depth direction (about ~ 1µm) in combination with Ar sputtering. Moreover, the surface analysis is possible at small area (Max. diameter 7.5µm) by the focused X-ray beam, and also possible maximum at 1.4 mm x 1.4 mm area by scanning of the X-ray beam. Specifications of XPS are summarized in Table 6.

Table6 Specifications of XPS

Item	Specifications
X-ray source	Al K□□Monochrome X-ray source
Resolution	Below 0.60 (eV) for X-ray beam diameter □ 10□□m to □ 20□m
Specimen size	70mm(X) x 70mm(Y) x 20mm(Z)
Sample stage	X: -40mm to 40mm Y: -40mm to 40mm Z: -25mm to 25mm Inclination: -45 degrees to 45 degrees Rotation: 360 degrees

3.3 Simulator of materials testing reactors including HRD

In June 2010, “Birth of the nuclear techno-park with the JMTR” was selected as one of projects of the Leading-edge Research Infrastructure Program by Japanese government. In this project, new irradiation facilities, post irradiation examination facilities, etc. will be installed up to JFY 2013 to build international research and development infrastructure. As a part of this project, a real-time simulator for operating both reactor and irradiation facilities of a materials testing reactor, “Simulator of materials testing reactors”, was developed by Japan Atomic Energy Agency (JAEA) with ITOCHU Techno-Solutions Corporation and GSE Power Systems.

It can simulate the behavior of the materials testing reactor under normal operation condition, anticipated operational transients and accident condition in order to utilize it for a nuclear human resource development and to promote partnership with developing countries which have a plan to introduce nuclear power plant and/or research reactor.

The JMTR of the JAEA had been stopped the reactor operation from August 2006, and then the refurbishment works were started in order to ensure safety and increase operating efficiency at the beginning of JFY 2007. In the refurbishment works, especially, the instrumentation and control system were completely upgraded. Therefore, the simulator is designed basically based on the refurbished JMTR, and treats systems/facilities of the JMTR, e.g. reactor core, primary cooling system, secondary cooling system, emergency cooling system, instrumentation and control systems, safety protection system and electrical system. The simulation model is developed by using the newest and various optimum techniques, codes and tools for real-time simulation with high precision. Furthermore, the simulation model can be modified for future demand by a developed support tool. The simulator had been designed in JFY 2010, fabricated from JFY 2011, and was successfully completed on May 2012. [8]

From JFY 2012, two courses will be held, and 20 trainees will be accepted in each course in the same way as JFY 2011. From JFY 2012, training of simulated operation of nuclear reactor will start using a simulator of irradiation test reactors. [9] The simulator was designed and fabricated based on the JMTR, and it can simulate operation, irradiation tests and various kinds of accidents in an irradiation test reactor. The hardware construction of the simulator is shown in Fig.20.

Fig.20 Overview of the simulator

4. Recent achievement

As one of effective uses of the JMTR, JAEA has a plan to produce ^{99}Mo by (n, γ) method ((n, γ)^{99}Mo production), a parent nuclide of ^{99m}Tc. ^{99m}Tc is most commonly used as a radiopharmaceutical in the field of nuclear medicine. In case of Japan, the supplying of ^{99}Mo depends only on imports from foreign countries. Therefore, the (n, γ) ^{99}Mo production was adopted from viewpoints of safety, nuclear proliferation resistance and waste management in JMTR. Advantages of JMTR are high neutron flux and direct connection to hot laboratory for RI productions. The (n, γ)^{99}Mo has several advantages compared to the fission Mo, but the extremely low specific activity makes its uses less convenient than the fission Mo. Fig.21 shows flow chart for the domestic production of ^{99}Mo-^{99m}Tc in JMTR. The R&D has been carried out with foreign organizations and relevant Japanese manufacturers under the cooperation programs and original R&D promotion program in Japan. The main R&D items for the (n, γ) ^{99}Mo production are as follows;

(1) Fabrication development of irradiation target as the high-density MoO_3 pellets,

(2) Separation and concentration development of ^{99m}Tc by the solvent extraction from Mo solution,

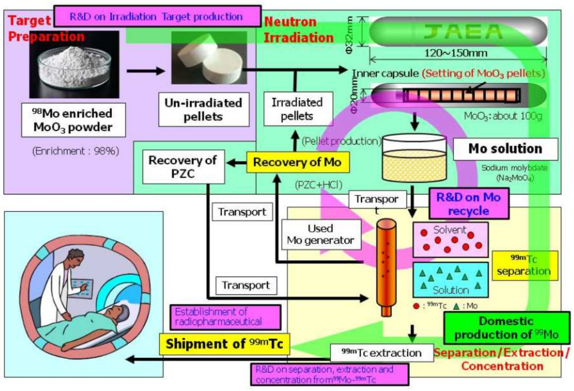
(3) Examination of ^{99m}Tc solution for a medicine, and

(4) Mo recycling development from Mo generator and solution.

Especially, the study of fabrication of high-density MoO_3 pellets is giving good results since it was started. As before, MoO_3 pellets produced by the Hot press were not able to obtain in high density owing to sintering temperature of the MoO_3 is at above 700˚C whereas low sublimation point(700˚C). Therefore, the plasma sintering methods were selected because of lower sintering temperature with less time consumption for the production of high density pellets. Then, prototypes of high-density MoO_3 pellets were tested taking account of "Mass production of pellets" and "Pellets solution for workability in hot laboratory". As a result, production technique of MoO_3 pellets was developed by plasma sintering method, and the method would be applicable to fabricate the high-density MoO_3 pellets.

The restart of JMTR will be achieved considering the safety as well as stable operation, then the in-pile test for ^{99}Mo production by the (n, γ) method will be carried out aiming at the domestic production of ^{99}Mo to realize so called "Life-innovation" safety and security of national health. This program is carried out under the Strategic Promotion Program for Basic Nuclear Research by the Ministry of Education, Culture, Sport, Science and Technology of Japan (MEXT).

Fig.21 Flow chart for the domestic production of ^{99}Mo-



^{99m}Tc in JMTR

5. New Regulatory Requirements

At the end of the JFY 2010 on March 11, ‘the off the Pacific coast of Tohoku Earthquake and Tsunami’ and the subsequence accident of Fukushima Dai-ichi NPPs occurred. JMTR was damaged by the earthquake. After the earthquake, integrity of the reactor building and equipment instrument was confirmed by equipment inspections and seismic response analysis. The repair work on places, such as cracks in concrete that were identified by the inspections has been completed.

However, the gigantic earthquake and tsunami and the accident of Fukushima Dai-ichi NPPs made a serious impact for both commercial use and research and development of nuclear power in Japan. Regulatory system was revamped and The Nuclear Regulation Authority (NRA) was established in September 2012. In 2013, NRA determined new regulatory standards based on the safety assessments considering the Great East Japan Earthquake in 2011. New regulatory requirements for research and test reactors have been established on Dec.18, 2013 by the NRA.

The new regulatory requirements include the satisfaction of integrities for the updated earthquake forces, Tsunami, the consideration of natural phenomena, the provision of manuals for full evacuation, and the management of consideration in the Beyond Design Basis Accidents to protect fuel damage and to mitigate impact of the accidents. Above analyses have intensively been performed, and an application to the NRA was submitted on March 27, 2015. Process toward reoperation of JMTR is shown in Fig. 22.

Major feature of the new regulatory requirements for the research and test reactors are shown as follows [10];

1) Accurate evaluation method on Earthquake and Tsunami. Define “Design Basis tsunami” that exceeds the largest in the historical records and require the protective measures. More precise methods to define

design basis seismic ground motion by the 3D observation of underground structure of the site.

2) Comprehensive consideration of natural hazards such as a volcano, tornado and forest fire in addition to earthquake and tsunami, etc.

3) Provision of equipment and measures to prevent fuel damage and to mitigate impact of the accidents (Beyond Design Basis Accidents).

4) Provision of full evacuation of the site in the event that the influence of accident may expand outside of the facility.

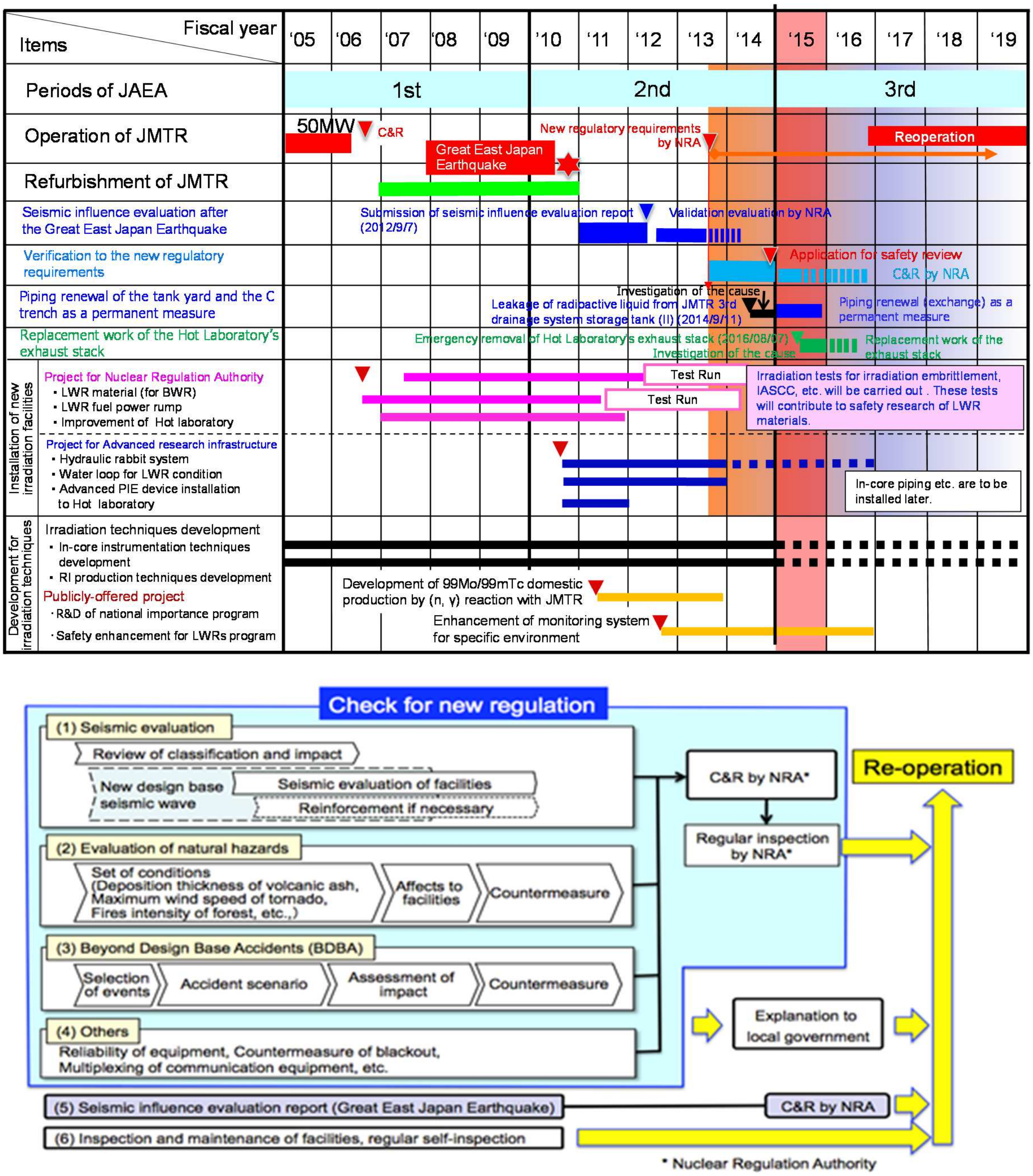


Fig. 22 Process toward the reoperation of JMTR.

5.1 Seismic evaluation

Review of safety classification had completed. Affects of the reactor building roof and crane to the “S” class facilities are under consideration. Building ground pressure and soil stability by the geological survey has been evaluated and the results meets the criterion. By the re-evaluation from the undersea fault and geological survey, an earthquake ground motion was estimated, and the design basis earthquake ground motion (DBEGM) Ss of about 0.7 G has been proposed. This value is larger than that of measured value (0.51G) in the reactor building at the Great East Japan Earthquake in 2011. The 3D calculation of reactor building and facilities are on going. Image of 3D calculation model is shown in Fig. 23.

As to the Tsunami, +16.9m high Tsunami from the sea level has been evaluated in case of similar scale with the Great East Japan Earthquake. However, it is no affect to the JAEA-Oarai because the location is +35 to +40m high from the sea level.

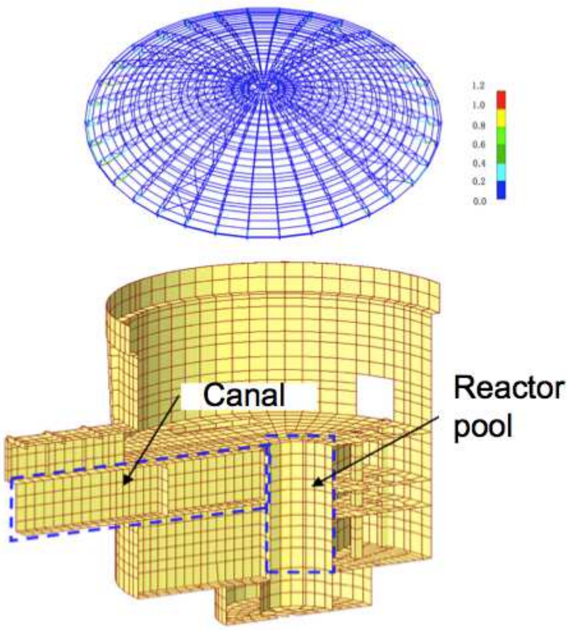


Fig. 23 Image of 3D calculation model.

5.2 Evaluation of natural hazards

1) Deposition of volcanic ash

11 volcanoes for 160km distance were evaluated by the geological survey. Eruption of Akagi Mountain (about 130km to west) at 45,000 years ago has been observed as a main source of the volcanic ash, and Akagi Mountain has been assumed as a source of the ash deposition. The thickness and density of volcanic ash have been estimated to be 50cm 1.5g/cm^3 by the geological surveys. In order to reduce the load of volcanic ash accumulated on the roof, the cleaning of roof is indispensable.

2) Fires

Fires form the forest, the heavy oil tanks and Aircraft (B747, KC-767, F-15, etc.) were evaluated. Temperature of reactor building surface is below 200 °C, and it is clear that no affect to the reactor building.

3) Tornado

F3 tornado of the Fujita scale and the maximum wind speed of 92m/s was assumed, and the steel pipes and plates, cars located near reactor building were assumed as the flying objects. To mitigate the collision of the flying objects by the tornado, a reinforcement such as covering the canal building with the protection wire-nets etc. are under designing. Image of wire-nets protection of canal is shown in Fig. 24.

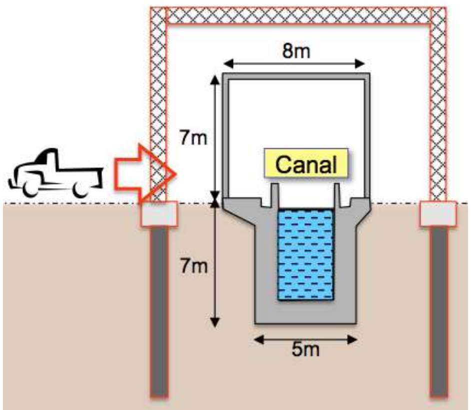


Fig.24 Image of wire-nets protection of canal.

5.3 Beyond Design Basis Accidents (BDBA)

9 events for the BDBA have been selected. All the events have been analyzed based on the each event’s scenario. And time margin for the BDBAs countermeasure have been confirmed. Based on the results, the operation manuals were prepared. Examples of BDBAs are shown in Table 7.

5.4 Others

The batteries, a tank truck (tanker) for blackout were prepared.

Under preparation items are shown as follows;

- Flame resisting of the walls and cables under the fire,
- Monitoring of the irradiation facility’s data in the reactor control room,
- Multiplexing of data transmission system for the radiation monitoring posts,
- Addition of the manual operation function for the siphon break valve to maintain fuels in the water.

The siphon break valves to maintain the fuels in the water in case of the LOCA is shown in Fig.25, and when the reactor protection system detects the LOCA (pressure of the primary cooling system decrease below 500 kPa), the valves are opened automatically . From the viewpoint of reliability improvement in a case of the automatic valves trouble, the manual operation function will be added.

Table 7 Examples of Beyond Design Basis Accidents

Abnormal events	Loss of additional safety function
Uncontrolled control rods withdrawal at reactor start-up	Two control rods stuck
Reactivity insertion by failure of irradiation facility	
Loss of primary coolant	
Reactivity insertion by failure of irradiation facility	Main pumps stop by loss of commercial electric power supply
Loss of commercial electric power supply	Failure of emergency generator
Loss of primary coolant	Flow rate reduction of recirculation facility
Flow blockage of fuel coolant channel or Fuel handling accident	Failure of emergency exhaust system

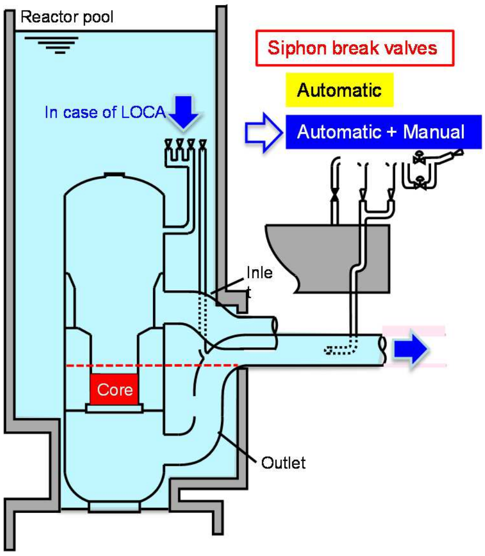


Fig. 25 Siphon break valves.

After taking measures for safety requirements and the permission by the NRA, the renewed JMTR will be operated for a safety research of LWRs, basic research for nuclear engineering such as HTGR and nuclear fusion research, industrial use such as high burn-up experiment of the LWR's fuel and production of Mo-99, and education & training of nuclear scientists and engineers.

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FNCA Research and Test Reactors Catalogue
Reactor Name: JRR-3 (Japan Research Reactor No.3)
Organization: JAEA (Japan Atomic Energy Agency)

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Nuclear Science Research Institute, Japan Atomic Energy Agency (JAEA)
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1. General information

JRR-3 achieved the first criticality in 1962 as the first research reactor constructed with homegrown technology and had been utilized in a lot of researches from the dawn of nuclear research and industry. In 1990, JRR-3 was modified for upgrade and resumed its operation as a high performance and multi-purpose research reactor with thermal power of 20MW. Since modified, JRR-3 has been utilized for neutron beam experiments, neutron activation analysis, production of radioisotopes, neutron transmutation doping of silicon, fuel and material irradiation, etc. JRR-3 has suffered the great earth tremor not previously experienced when the Great East Japan Earthquake with the seismic energy of magnitude 9.0 has occurred on March 11, 2011. At that time, JRR-3 was undergoing regular periodical inspection and the reactor was not operated. Reactor building and equipment for safety survived without getting serious damage and recovery works have already been completed.

The maximum thermal power of JRR-3 is 20MW. JRR-3 is a light water moderated and cooled, pool type research reactor using low-enriched silicide fuel (LEU: approximately 20% enriched uranium). Main specifications are summarized in Table1.

Table 1 Specifications of JRR-3

Reactor	Swimming pool type
Maximum thermal power	20MW
Maximum neutron flux	3×10^{18} m^{-2}sec^{-1}
Fuel	Plate-type silicide fuel (U_3Si_2-Al)
U-235 enrichment	20 %
Control rod	Hf
Reactor coolant	Light water
Primary coolant flow rate	2400 m^3/h
Primary coolant temperature	42°C
Reactor moderator	Light water
Reflector	Heavy water and Be

2. Reactor and Facilities

The reactor core is situated at the bottom of the reactor pool, (8.5 m in depth, 4.5 m in diameter, keyhole shaped horizontal cross section). A cylindrical reactor core is 60 cm in diameter and 75 cm in height. A heavy water tank, 200 cm in diameter and 160 cm in height, surrounds the reactor core. Cooling circuit systems are composed of a primary circuit, a secondary circuit and

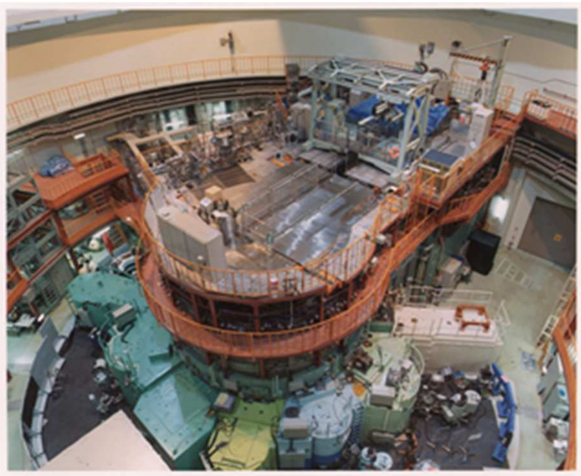

Fig.1 JRR-3's reactor room

heavy water circuit. Core heat is finally removed into atmosphere through the cooling tower.

Utilization facilities include irradiation facilities for using vertical irradiation tubes in the reactor core and the heavy water tank, and beam experimental facilities using horizontal experimental tubes in the heavy water tank. Both cold and thermal neutrons can be utilized as neutron beam. Neutrons are guided to the experimental building from the horizontal experimental tubes by the neutron guide tubes. The JRR-3's reactor room is shown in Fig.1.

2.1 Components of reactor core

The reactor core is composed of 26 standard fuel elements, 6 control rods with follower fuel elements, beryllium reflectors, and vertical irradiation holes. Fig.2

shows reactor core configuration.

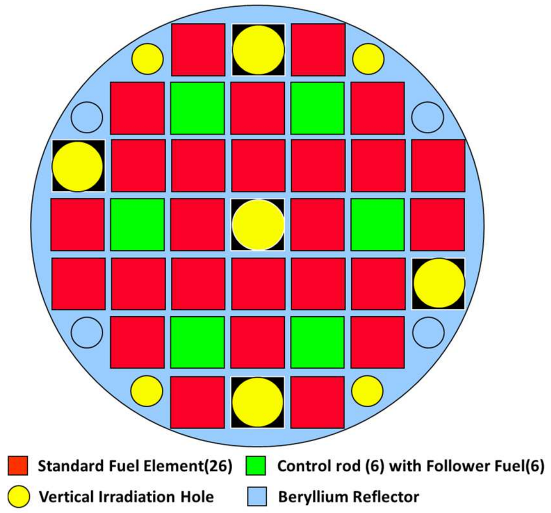

Fig.2 Core configuration

(1) Fuel

Plate-type uranium-silicon dispersion alloy fuels (U_3Si_2-Al) are used in JRR-3 as in other research reactors. Enrichment of U-235 in fuel is 20 %. JRR-3 adopts two kinds of fuels, standard fuel element and follower fuel element following the control rod (shown in Fig.3). Fuel elements composed of fuel plates, side plates, handle, nozzle, Cd wires etc. The thickness of fuel plate that is fuel meat materials (0.51 mm) sandwiched by Al alloy claddings is 1.27 mm. Burnable absorbers (cadmium wire) were introduced for decreasing excess reactivity. The number of fuel plates consisting fuel element is 21 for standard fuel and 17 for follower fuel element. The size of standard fuel element is 76.2 mm square in horizontal cross section and 1150 mm in height. That of follower fuel element is 63.6 mm square in horizontal cross section and 880 mm in height.

(2) Control rod

The control rod is composed of follower fuel, neutron absorber made of Hf and connecting shaft. There are 6 control rods in the core. Control Rod Drive Mechanism (CRDM) have the function of insertion and pulling up of a control rod. Control rods are attached to the CRDM by electromagnets as a safety measure. This means that in the event of emergency shut-down control rods are inserted automatically by cutting off coil current of CRDM. The time to scrum is no later than 1 second.

2.2 Experimental facilities

The JRR-3 provides various kinds of experimental facilities for neutron beam experiments and irradiation tests. Fig.4 shows the arrangement of vertical irradiation

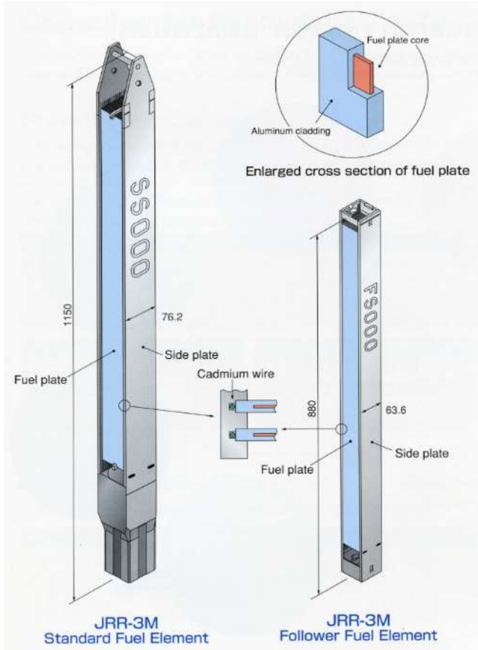

Fig.3 Fuel element

holes and horizontal beam tubes in the JRR-3. There are nine irradiation facilities for irradiation tests of nuclear fuels and materials, production of radioisotopes (RI) and high quality semiconductor grade silicon, and neutron activation analysis (NAA). In addition, there are total 31 instruments for neutron beam experiments including 16 and 15 instruments belonging to the JAEA and the external research institutions, respectively.

2.2.1 Irradiation Facilities

Table 2 summarizes the specification of irradiation facilities of JRR-3. Main irradiation facilities are described as follows:

(1) Hydraulic irradiation facility (HR-1/2)

There are two circuits of the hydraulic irradiation facility that allow materials to be exposed high neutron fluxes of 1.2×10^{14} (n/cm^2/s) for the production of radioisotopes and NAA. Small sized capsules called rabbits are transferred through the hydraulic irradiation facility by the water flow in the circuit. This facility generally uses aluminum rabbits with an outer diameter of 32 mm and a length of 150 mm. The rabbits are irradiated for up to 9 cycles in this facility.

(2) Pneumatic Transfer Facility (PN-1/2)

The configuration of this facility is essentially the same as that of the hydraulic rabbit facility. There are two circuits of pneumatic irradiation facility that allow materials to be exposed high neutron fluxes of 6.0×10^{13} (n/cm^2/s) for the production of radioisotopes and NAA. The rabbit

Table 2 Summarizes the specification of irradiation facilities of JRR-3

Irradiation facilities		Irradiation times	Irradiation capsule		Thermal neutrons flux
			Material	Profile (mm)	($n/cm^2 \cdot s$)
HR-1, HR-2		10 minites ~1 cycle	Aluminum, Stainless steel	Φ 32×150 L	1.2×10^{14} 1.0×10^{14}
PN-1, PN-2		1~20 minites (~150 hours)	Polyethylene (Polyether resin)	Φ 33×95 L	6.0×10^{13} 5.0×10^{13}
PN-3		5 seconds ~20 minites	Polyethylene	Φ 17×30 L	1.9×10^{13}
SI-1		1 hour ~ 1 cycle	Aluminum	———	2×10^{13}
DR-1		1 cycle ~	Aluminum, Stainless steel	Φ 130×1000 L Φ 34×150 L	3×10^{13}
Capsule irradiation facilities	VT-1	1 cycle ~	Aluminum, Stainless steel	Φ 55×900 L Φ 34×150 L	3×10^{14}
	RG-1~RG-4				2×10^{14}
	BR-1~BR-4			Φ 40×900 L Φ 34×150 L	2×10^{14}
	SH-1			Φ 90×1000 L Φ 34×150 L	4×10^{13}

is transferred by nitrogen gas and air in primary system and secondary system, respectively. This facility generally uses polyethylene rabbits with an outer diameter of 33 mm and a length of 95 mm. The rabbits are irradiated for up to twenty minutes.

(3) Activation Analysis Facility (PN-3)

This facility allow to be exposed the neutron flux of 1.9×10^{13} ($n/cm^2/s$) for single purpose of the NAA. In order to examine the short-lived nuclides of up to ten minutes, such as ^{28}Al, ^{51}Ti, ^{52}V, the rabbits need to be ejected from the core through the circuit at short times. Therefore, the laboratory for PN-3 is located close to the reactor and equipped the transferred system and analytical instruments. This facility generally uses polyethylene rabbits with an outer diameter of 17 mm and a length of 30 mm. The rabbits are irradiated for up to twenty minutes.

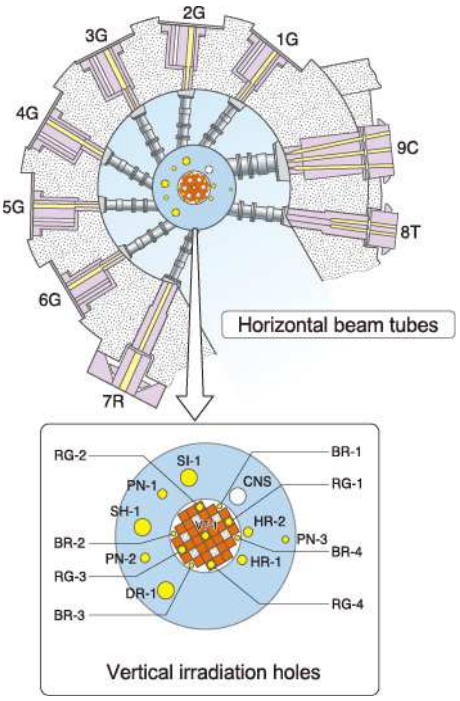

Fig.4 Arrangement of vertical irradiation holes and horizontal beam tubes in the JRR-3

(4) Uniform Irradiation Facility (SI)

The uniform irradiation facility (SI) is designed to uniformly irradiate large sized samples such as a silicon ingot for Neutron Transmutation Doping (NTD) that is instrumental in the semiconductor industry. The NTD process takes place when the thermal neutron is captured by the ^{30}Si atom, which constitutes about 3 % of the naturally occurring silicon. And the ^{31}Si atom is produced and transmutes to a stable ^{31}P atom with a half-life of 2.6 hour. In order to achieve a homogeneous doping, the large sized capsules called holders is axially rotated during irradiation. The JRR-3 uses holders made from high-purity aluminum (1050) for silicon irradiation. The annual production for doped silicon is about 3.5 tons at the JRR-3.

(5) Capsule Irradiation Facility (VT, RG, BR, SH)

The capsule irradiation facilities are suitable for material testing and fuel research using the

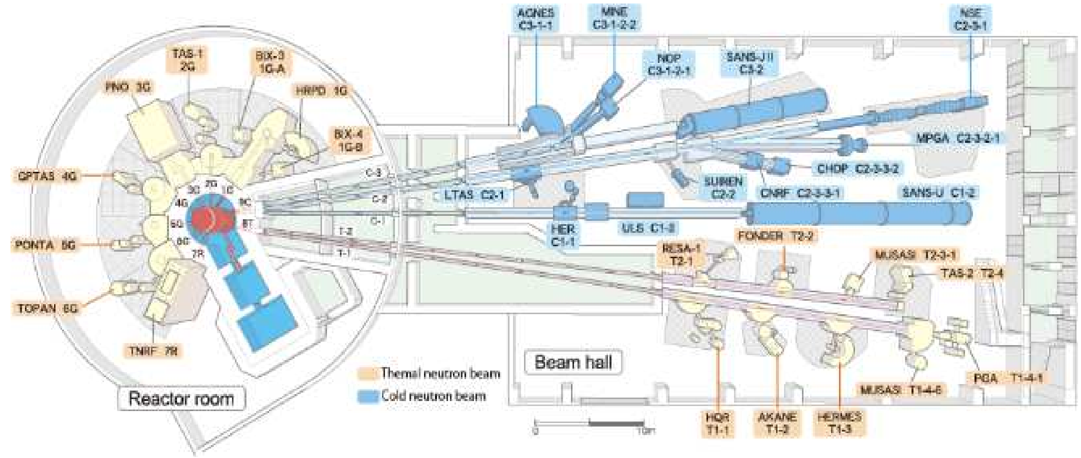

Fig.5 Arrangement of beam experimental facilities in the JRR-3

capsule with and without instrumentation system. There are nine irradiation facilities in the core region (VT, RG-1, RG-2, RG-3, RG-4, BR-1, BR-2, BR-3, BR-4) and one irradiation facilities in the heavy water tank (SH). These facilities allow materials to be exposed high neutron fluxes; the thermal neutron flux is up to 3.0×10^{14} (n/cm^2/s) and the fast neutron flux is up to 2.0×10^{14} (n/cm^2/s) at VT facility in core region. VT facility generally uses stainless steel capsule with an outer diameter of 55 mm and a length of 900 mm. The capsules are irradiated for up to nine cycles for every capsule irradiation facilities.

2.2.1 Irradiation Facilities

Fig.5 shows the arrangement of neutron guide tubes in the JRR-3. The reactor has nine horizontal neutron guide tubes and a liquid hydrogen cold neutron source (CNS) for neutron beam experiments. The seven horizontal neutron guides (1G – 6G and 7R) lead the thermal neutrons to experimental instruments in the reactor building. The other two horizontal neutron guide tubes lead thermal and cold neutrons to experimental instruments in the adjacent experimental building. Two thermal guide tubes (T1 and T2) are 60 m long and designed with supermirror guides in order to deliver a higher neutron flux than the nickel ones. Three cold guide tubes (C1, C2 and C3) are 31 m – 51 m long, of which parts are designed with supermirror guides.

(1) Cold Neutron Source Device (CNS)

Fig.6 shows the schematic illustrations of the CNS device and neutron guide tube. The CNS is equipped with a moderator cell filled with liquid hydrogen at a temperature of about 20 K inside the heavy water tank. The moderator cell, which is located in the maximum thermal neutron flux area, is flask shape vessel made of stainless steel and has a height of 20 cm, width of 13 cm and thickness of 5 cm.

(2) Neutron Beam Experiments

Unique properties of neutrons (such as high penetration, high sensitivity to light elements, possession of magnetic moment) make neutron scattering as a versatile probe to explore matter. A wavelength of neutron ranging from nano- to sub-micro meter is ideal to study structures of various states such as liquid, soft to hard matter including biological materials and thin-films, and to measure strains and textures in structural materials as well. Furthermore, another superiority of neutron scattering is its power to study dynamics in materials, such as thermal and diffusive motions, phonons and magnons etc. The neutron beam is also utilized for neutron radiography which is a nondestructive method to inspect the inside of materials, using the advantage that neutrons easily penetrate materials. The radiography image has sharp contrast between heavy element materials and hydrogen containing materials. Furthermore, neutron beam is used for elemental analysis by measuring prompt gamma-rays which are immediately emitted after neutron irradiation. Utilization of neutron beam at JRR-3 has been dedicated to various fields of researches and developments, including materials and life science, nondestructive analysis, materials engineering and neutron device development, in not only academia but also industry. The neutron beam application of the JRR-3 is described as follows:

(i) Biological Molecular and Structural Analysis (BIX-3, 4)

Detailed analyses of crystal structure, including hydrogen atomic positions, are available for chemical substances and proteins.

(ii) Powder Structural Analysis (HRPD)

Crystal structural analyses are available for

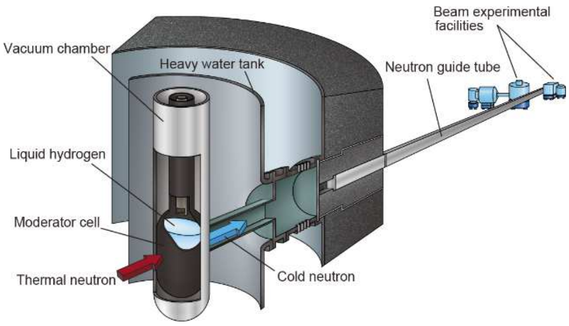

Fig.6 Schematic illustration of the cold neutron source device and neutron guide tube in the JRR-3

powder materials that contain light mass elements, such as hydrogen and lithium, which are difficult to be detected by x-rays.

(iii) Residual Stress Analysis (RESA-1)

Residual stress analyses are available by measuring the distortion deep inside the material, which is difficult to be measured by x-rays.

(iv) Elementary Analysis (PGA)

Multi-element analyses for products and materials are available in nondestructive manner. This is suitable for analyses of light mass elements, such as hydrogen and boron.

(v) Imaging (TNRF, CNRF)

Observation of the inside of a product and materials is possible in nondestructive manner. This is particularly useful for observation of hydrogen and the water inside products. Taking animation and tomogram is also available.

(vi) Characteristic Examination of Devices (CHOP, NOP, MUSASI)

It is available to perform characteristic evaluation of neutron detectors and optical devices, as well as proof examination for development of beam experimental instruments.

(vii) Laminated Structure Analysis (SUIREN, SANS-J/Ⅱ, PNO)

Analyses of the surface of materials are available by reflectometer, and structural analyses of macromolecules and multilayer films are available by small angle scattering measurements.

(viii) Dynamical behavior Analysis (TAS-1/2. LTAS)

Analyses of dynamical behavior of atoms and molecules in a material are available using triple axis-spectrometers.

3. Recent information

JRR-3 has suffered strong shock not experienced previously by the Great East Japan Earthquake registered a magnitude of 9.0 on March 11, 2011. At that time, JRR-3 was undergoing regular periodical inspection and the reactor was not operated. Reactor building and equipment for safety survived without getting serious damage and recovery works have already been completed.

JRR-3 had been confirmed conformation to new regulations on research and test reactor facilities which came into force on 18th December 2013. The application has been submitted to NRA on 26th September 2014.

FNCA Research and Test Reactors Catalogue
Reactor Name: HANARO (High Flux Advanced Neutron Application Reactor)
Organization: KAERI (Korea Atomic Energy Research Institute)

Contact person's organization name Korea Atomic Energy Research Institute
111 Daedoek-daero 989 beon-gil, Yuseong-gu, Daejeon,34057, Republic of Korea
Contact person :** Junsig Lee,* ***e-mail: *jlee15@kaeri.re.kr*

1. General Information

The High-Flux Advanced Neutron Application Reactor (HANARO) is a 30 MW multi-purpose research reactor located in Daejeon, Republic of Korea. It was designed by KAERI as a facility for research and development on the neutron science and its applications. HANARO has been playing a significant role facility in the area of neutron science, the production of key radioisotopes, material testing for power reactor application, serving as a regional and international facility for neutron science.

▣ Design specifications
- ▸Reactor type: Open-Tank in pool
- ▸Thermal Power: 30 MW
- ▸Fuel: U_3Si, 19.75%
- ▸Max. thermal neutron flux: $4x10^{14}$ n/cm^2/sec
- ▸Max. Fast neutron flux: $2x10^{14}$ n/cm^2/sec
- ▸Coolant/Moderator/Reflector:H_2O/H_2O, D_2O/D_2O
- ▸Core cooling: forced up-ward direction
- ▸Control/Shut off Rod: Hafnium
- ▸Beam port: 7
- ▸Vertical Irr. Holes: 36

▣ Auxiliary experimental facility
- ▸Cold Neutron Laboratory (CNL)
- ▸Radioisotope Production Facility (RIPF)
- ▸Irradiated Materials Examination Facility (IMEF)

Fig 1. HANARO research reactor complex (PH: Pump house, CT: Cooling tower)

2. Reactor and Facilities

2.1 General description of experimental and testing facilities

The neutron beam research facility consists of the cold neutron beam research facility in the cold neutron guide hall and the thermal neutron beam research facility in the reactor hall. The former consists of 9 instruments. In the reactor hall, there are 10 instruments.

Neutron irradiation is done by inserting the test material into one of the vertical holes of the reactor and pulling it out. The materials are encased in rabbits or capsules in labs, either instrumented or non-instrumented. Only when doping silicon by neutron transmutation, the silicon ingot is encased in a container. Once irradiated, the material properties are measured in hot cells at other facilities. Activation analysis can be done in-house with a few gamma spectrometers.

There are two types of neutron activation analysis that are carried out at HANARO. One is delayed neutron activation analysis, which requires pneumatic transfer system to send the sample to the reactor. The activation is measured after the sample in rabbit is recovered from the reactor. The other is the prompt gamma activation analysis, which requires neutron beam and gamma spectrometers to measure the activation on the fly.

Radioisotopes are produced by irradiating the raw materials and extracting useful radioisotopes in hot cells. The radioisotope production facility has 4 banks of hot cells.

2.2 Thermal and cold neutron science

The HANARO neutron beam research facility consists of the thermal neutron beam research facility in the reactor hall and the cold neutron beam research facility in the cold neutron guide hall. High Resolution Powder Diffractometer (HRPD), Four Circle Neutron Diffractometer (FCD), Bio Camera(Bio-C), Bio Diffractometer (Bio-D), Residual Stress Instrument (RSI), Neutron Radiography Facility (NRF) and Excore Neutron Irradiation Facility (ENF) are operating at the HANARO reactor hall. The Thermal neutron Triple Axis Spectrometer (Thermal-TAS) is in the commissioning stage at present. 40M-Small Angle Neutron Scattering Instrument (40M-SANS), 18M-Small Angle Neutron Scattering Instrument (18M-SANS), KIST-Ultra Small Angle Neutron Scattering (KIST-USANS), Vertical-type REFlectometer (REF-V), Bio-REFlectometer (Bio-REF) and Disk Chopper-Time of Flight spectrometer (DC-ToF) are operating in in the cold neutron guide hall. The Cold neutron Triple-Axis Spectrometer (Cold-TAS) and the Guide-Test Station (G-TS) are commissioning stage at present.

With HRPD, people investigate the magnetic structures, multi-ferrroic materials in which ferroelectric and magnetic properties coexist. In addition because neutron only can see the light atoms such as Hydrogen, Lithium and Oxygen, the energy storage materials such as Li-ion battery is studied using HRPD. Bio-C and Bio-D are dedicated to a crystal structure investigation on the biological macromolecules. A single crystal neutron diffraction method using FCD can deliver the atomic displacement parameters which provide crucial information on properties such as zero-point vibrational motion, phase transitions, diffusion profiles and ionic conductivity.

The RSI is an engineering neutron diffractometer dedicated to stress measurements in polycrystalline metals and alloys. This RSI enables us to investigate in-situ material behavior under load and the temperature using the loading auxiliary equipment. NRF provides the transmission image with neutrons

The small angle neutron scattering (SANS) technique is one of the most powerful tool to study nano sized inhomogeneity. At HANARO, three SANS instruments, 18m and 40m SANS (conventional pinhole type), and USANS (Bonse-Hart-type double crystal diffractometer) are installed. A neutron reflectometer is a tool for studying the properties of interfaces. The reflectometry technique is highly demanded and finds its application in a wide range such as surfactants adsorbed at solid/liquid interfaces, Langmuir-Blodgett, polymer films, lipid bio-layers in biological cell membranes and magnetic ultrathin films.

The DC-ToF can provide wide dynamic range by adjusting incident neutron energy and instrument resolution. Triple-axis spectroscopy is best applied to single crystalline samples of magnetic materials. Neutrons as well as some atoms have magnetic moments and interact with each other 'magnetically' and exchange energies in the process. This allows one to deduce how the magnetic moments are interacting in the material and gives us clues to the mysteries of exotic magnetic behavior such as quantum spin liquids.

Fig 2. Thermal neutron instruments

Fig 3. Cold neutron instruments

2.3 Irradiation services and neutron activation analysis

NTD irradiation holes are vertical irradiation holes with D2O reflector: NTD1 and NTD2. Thermal neutron flux without target is ~5.2×10^{13} $cm^{-2}s^{-1}$. Longitudinal length of hole is 120 cm, and diameters are 220 cm (NTD1) and 180 cm (NTD2). Diameters of the accessible irradiated materials are 6/8 inch (NTD1) and 5/6 inch (NTD2), respectively. NTD irradiation time is 0.2 ~ 9.5 hours. Way of rotation is done with stepping motor. Way of cooling for irradiation object is natural convection and semi-forced pumping by lower floater. Way of monitoring the irradiation fluence is with SPND for real time monitoring, and with Zr foils for actual fluence. Capacity per year is 20 tons using NTD2 only. Accumulated production from 2003 to 2007 was 45 tons.

Table 1.Irradiation hole of HANARO

Name (Position)	Utilization field	Flux [$cm^{-2}s^{-1}$] (thermal/fast)	Status
CT (Inner core)	Material test, RI production	4.4×10^{14}	In service
IR1 (Inner core)	FTL	3.9×10^{14}	Commissioning
IR2 (Inner core)	Material test, RI production	3.9×10^{14}	In service

OR (Outer core)	Material test, RI production	3.4×10^{14}	In service
CN (Reflector)	Cold neutron Source	9×10^{13}	Developing
NTD-2 (Reflector)	Silicon doping	5×10^{13}	In service
NTD-1 (Reflector)	Silicon doping	5×10^{14}	Testing
HTS (Reflector)	RI production	1×10^{11}	In service
IP-4, 5, 15 (Reflector)	RI	$\sim\times10^{13}$	In service
NAA-1, 2, 3 (Reflector)	NAA	6×10^{9}~ 1.5×10^{14}	In service

2.4 Radioisotope production

At HANARO, medical (^{131}I, ^{99m}Tc, ^{99}Mo, ^{166}Ho, ^{153}Sm, ^{177}Lu) and industrial (^{192}Ir) radioisotopes are manufactured, and their applications are performed for increasing the medical usage 'The development of radiolabeled compounds' and for industrial diagnosis 'The development of RI tracking technology by using Radiotracers'.

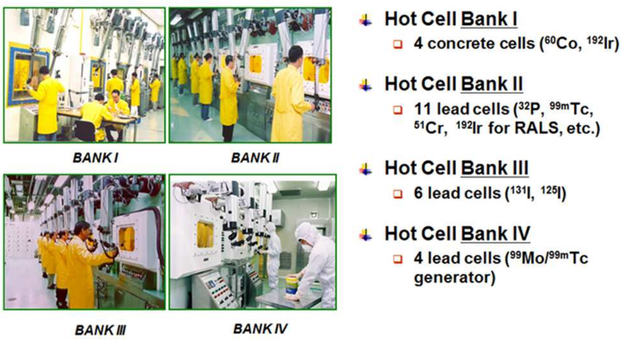

Fig 4. Radioisotope Production Facility

Among the various outcomes, 'Holmium-166 chitosan (Millican injection)' as the 3rd new drug, 'Re-188 generator' nominated as the nation's one of the 100 outstanding research and 'Water treatment plant diagnosis technology with RI' obtained ministry of Environment's certification are representative. In addition, Radioisotope Research Division provides RI supporting and application service for both industry and medical facilities in domestic and foreign countries to enhance the better welfare for the people of the world.

2.5 Irradiated materials experimentation facility

IMEF (Irradiated Material Examinations Facility) conducts post-irradiation examination (PIE) for irradiated materials at the HANARO reactor and specimens from power plant reactors:

- Integrity and life estimation of the structural parts in an operating reactor.
- Irradiation behavior evaluation of developing fuels and structural materials for next-generation and future reactors.
- Back-end fuel cycle demonstration tests.

IMEF is devoted to supplying high-quality PIE data to R&D projects on nuclear fuel and materials. It has contributed to South Korea becoming a world-leading nuclear technology nation.

IMEF building has three stories and one basement with 4,000m^2 of total floor space. The hot cells, which are the main facilities, has 31 work units with a total length of 71m. The maximum wall thickness of the hot cells is 1.2 m to shield a radiation source with a maximum radioactive level of 3.7 x 10^{16} Bq. In addition, a pool with a depth of 10 m is located in the service area to handle transporting casks.

The hot cells in the ground floor consist of 6 concrete cells (M1~M6) and 1 lead cell (M7) with a U shape line arrangement. One hot cell (M8) was placed in the basement and called as ACPF.

▣ M1~M4 Line: Non-destructive testing, Capsule dismantling, Specimen Preparation, and Storage

▣ M5 Line: Mechanical tests (Impact, Tensile, Fracture, Fatigue), Dimension measurement

▣ M6 Line: DUPIC Experiments (Powdering, Oxidation-Reduction, Sintering)

▣ M7 Line: Microscopy, Hardness, Density, SEM analysis

▣ M5 Line: Pyroprocessing, Demonstration

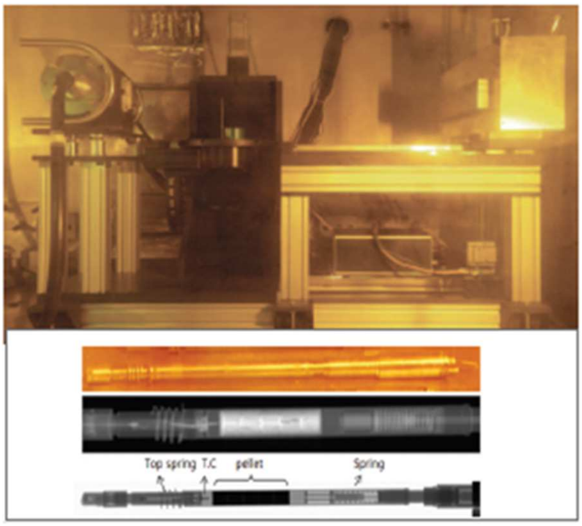

Fig 5. X-ray inspection of fuel pellets and components in fuel rig

3. Recent Achievements

3.1 Finalization of cold neutron research facility

The finalization of the cold neutron research facility was the most ambitious task at HANARO since the reactor itself was built. The purpose of the project were to insert a new cold neutron source into the existing vertical hole that was originally designated for the cold source in the reactor, to construct the Cold Neutron Laboratory Building (CNLB), to set up guides from the horizontal cold neutron beam tube to the guide hall, to build 3 new scattering instruments, and to relocate 3 existing instruments. The project started in 2003 and lasted until early 2012 [1,2].

3.2 Neutron beam research on structural materials and helping industries

Residual stress instrument (RSI) installed at the ST-1 beam port, HANARO, is a wide-angle neutron diffractometer optimized for strain/stress scanning and deformation behavior studies in various polycrystalline metals and alloys. For years high-impact papers and research activities were performed for materials science and helping industries using RSI: (i) Basic neutron science: developed unprecedented strong neutron penetration capacity passing through the 80 mm thick steel plate based on selected wavelength and beam focusing technology [3] (ii) Engineering applications: observed the deformation behavior for an new automobile alloy (DP980) and determine residual stresses in extra thick welds for large container ship building [4].

3.3 Fission Mo-99 process development

KAERI is developing LEU-based fission ^{99}Mo production process which is connected to the new research reactor (Kijang New Research Reactor, KJRR), which is being constructed in Gijang, Busan, Korea. [5] Radioisotope division is developing LEU-based ^{99}Mo production process to be implemented for the KJRR. In KAERI's fission ^{99}Mo process, plate-type LEU target is used. KAERI's uranium powders were prepared by the unique centrifugal atomization technology. In the overall scheme of the KAERI's fission ^{99}Mo process, LEU targets are dissolved in alkaline solution to extract ^{99}Mo into the solution. Other fission products including unreacted uranium and actinides are removed from the solution. Medical-grade ^{99}Mo can be extracted after proper chemical treatments and multi-step separation and purification process.

Pre- and post-irradiation tests of the fission ^{99}Mo target will be done in 1st quarter of 2017. For the fission Mo production process development, hot experiments with irradiated LEU targets will be done in 1st quarter of 2017. Then, verification of the production process with quality control will be followed until the commercial production of fission ^{99}Mo scheduled in 2019. In the future, weekly productivity of 2000 Ci fission ^{99}Mo from the KJRR will cover 100% domestic demand (~150 Ci/wk) of Korea, as well as about ~18% of international market.

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FNCA Research and Test Reactors Catalogue
Reactor Name: RTP (The Reactor TRIGA PUSPATI)
Organization: Malaysian Nuclear Agency

Reactor Technology Division, Malaysian Nuclear Agency,
Ministry of Science, Technology and Innovation,
43000 Kajang, Selangor, Malaysia
Contact person :** Zarina Masood* ***e-mail: *zarina@nm.gov.my*

1. General information

The Reactor TRIGA PUSPATI (RTP) is a light-water moderated and pool-type research reactor with 1 MW(th) capability. It was built in 1979 and attained the first criticality on 28 June 1982. The RTP was designed mainly for neutron activation analysis, small angle neutron scattering, neutron radiography, radioisotope production, education and training purposes. It uses standard TRIGA fuel developed by General Atomic in which the zirconium hydride moderator is homogenously combined with enriched uranium. The RTP core has a cylindrical configuration surrounded with an annular graphite reflector and enclosed in the aluminum casing tank. The fuel-moderator element is approximately 3.65 cm in diameter and 38.1 cm long. The fuel is a solid, homogeneous mixture of uranium-zirconium hydride alloy containing about 8.5% to 20% by weight of uranium enriched of U-235. The hydrogen- to-zirconium atom ratio is approximately 1.6. The specification of RTP is tabulated in Table 1.

Table1: RTP Specification

Items	Specification
Name	RTP
Type	TRIGA MARK II; pool type reactor
First Criticality	28 June 1982
Maximum Thermal Power	1 MW
Average Power Density	22.8 w/cm^3
Typical Maximum Thermal Neutron Flux	1 x 10^{13} n/cm^2/s
Shape and Size of Reactor Core	Cylindrical, 55cm in ∅ x 59cm in H
Coolant	Light water
Moderator	Light water
Control Rod	B_4C
Reflector	High Purity Graphite
Shape of Fuel Element	Rod Type
Enrichment of U-235	Approx. 20%

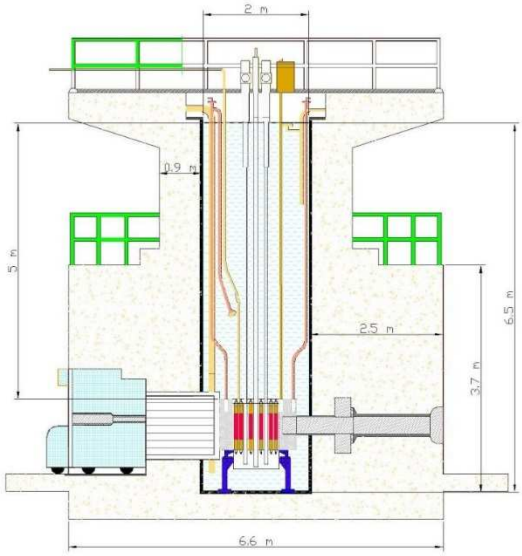

Fig. 1 Vertical view of RTP

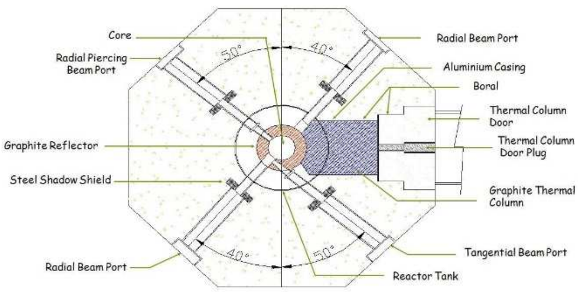

Fig. 2 RTP Cross section

2. Reactor and Facilities

The reactor core is a cylinder approximately 1.09 m in diameter and 0.89 m high. The reactor core consists of a lattice of fuel-moderator elements, graphite dummy elements and control rods. The core is surrounded by a graphite reflector. The entire assembly rests on the bottom of the reactor tank and is supported by the reactor support structure. Shielding above the core is provided by approximately 5.18 m of water. Core cooling is provided by natural convection of pool water, circulating through the core. Heat rejection is achieved through two cooling loops; the coolant flow rate is 80 m^3/h in the primary loop and ~160m^3/h in the secondary loop. By thermal conductivity, heat generated in fuel is transferred to the fuel cladding surface, from which heat is removed by the coolant circulating around. For steady-state natural convection, the core coolant flow rate is calculated based on the balance of the buoyancy force to the friction pressure drop across the core.

The RTP can be operated in the steady-state and square wave modes. The power level of the reactor is controlled with four control rods: a regulating rod, a shim rod, a safety rod, and a transient rod. For safety concerns, transient tests at General Atomic have proved conclusively that the large prompt negative temperature coefficient of the fuel-moderator material provides a high degree of self-regulation without the assistance of external control devices. The water cooling and purification systems maintain low water conductivity, remove impurities, maintain the optical clarity of the water, and provide a means of dissipating the reactor heat. It consists of a water surface skimmer, pump, filter, demineralizer, heat exchange unit, associated piping and valves, and miscellaneous instrumentation.

2.1 General description of experimental and testing facilities

The experimental and irradiation facilities of the RTP are extensive and versatile. Physical access to the core and observation of it are possible at all times through the vertical water shield. Four beam ports extend from the reactor assembly through the water and concrete to the outer face of the shield structure. A rotary specimen rack in an annular well in the top of the graphite reflector provides for the large-scale production of radioisotopes as well as for the activation and irradiation of small specimens. All 40 positions in this rack are exposed to neutron fluxes of comparable intensity. The RTP is also equipped with a central thimble for conducting experiments or irradiating small samples in the core at the point of maximum flux. A high-speed pneumatic transfer system (PTS) permits the use of extremely short-lived radioisotopes. The in-core terminus of this system is located in the outer ring of fuel element positions, a region of high neutron flux. Experimental tubes can easily be installed in the core region to provide additional facilities for high level irradiation or in-core experiments. In addition, a dry tube, isotope pneumatic system and delayed neutron activation system were also installed in-core. The space in the water around the reflector can also be used for irradiation experiments.

2.2 In-Core Experimental facilities

2.2.1 Rotary Specimen Rack

The rotary specimen rack assembly consists of a ring-shape, seal-welded aluminium housing containing an aluminium rack mounted on special bearings. The rack supports 40 evenly spaced tubular aluminium containers that serve as receptacles for the specimen containers. Each receptacle has an inside diameter of 3.17 cm and height of 27.4 cm and can hold two specimen containers, with the exception of position number 1 which can only hold one specimen container. The specimen removal tube, located 180 degrees from the tube and shaft assembly, terminates at the top of the reactor in a funnel located just below one of the top plates of the centre channel assembly. The tube has an internal diameter of 3.39 cm and an axial offset of approximately 45.7 cm between the top and bottom of the tube to avoid direct-beam radiation from the core. Loading and unloading of the 40 specimen positions in the rack takes place through this tube.

2.2.2 Pneumatic Transfer System

Production of very short-lived radioisotopes is accomplished by a pneumatic transfer system, which rapidly transfers a specimen to and from the reactor core.

2.2.3 Central Thimble

The central thimble in the centre of the core provides space for the irradiation of samples at the point of maximum flux. It also provides a highly collimated beam of neutrons and gamma radiation when the water is pneumatically expelled from the section of the thimble above the core. The thimble is an aluminium tube with an inside diameter of 3.38 cm. It extends from the top of the reactor tank through the central hole in the top and bottom grid plates and terminates in a plug below the bottom grid plate.

2.3 Out-Core Experimental facilities

The beam ports provide tubular penetrations through the high density concrete shield and the reactor tank water, making beams of neutrons and gamma radiation available for a variety of experiments. They also provide an irradiation facility for large (up to 15.2 cm diameter) specimens in a region close to the core. There are two beam ports (Figure 3) that has been utilized for experimental equipment currently, while the other two are available to equip with other beam experiment.

2.3.1 Graphite Thermal Column and Door

The thermal column is a large boral-lined, graphite-filled aluminium container embedded in the concrete shield. It penetrates the reactor tank wall and extends to the graphite reflector, where it matches the contour of the reflector over an angle of 100 degrees. In the vertical plane, the column extends approximately 30.5 cm above and below the reflector with the centreline of the column coinciding with the reflector centreline. Its basic overall dimensions are 1.2m by 1.2 m in cross section and approximately 1.7 m long. Access to the centrally located stringer in the thermal column is provided by the stringer access plug. The plug is a steel tube, stepped to reduce radiation steaming and filed with heavy aggregate concrete.

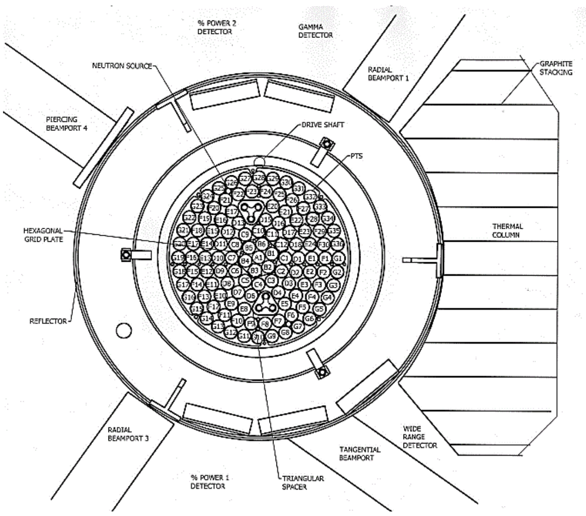

Fig.3 In-Core and Out-Core Experimental Facilities

2.3.2 Neutron Radiography-1 (NuR-1)

NuR-1 was first installed in 1983 at radial beamport No.1 to study its suitability for neutron radiography work and the efficiencies of the biological shielding. It was made of small concrete blocks, beam-stopper and collimator and various materials were tested and radiography work carried out. A results from the previous studies showed that beamport No.1 was not suitable for neutron radiography due to its neutron beam quality and gamma radiation profile. This facility was dismantled in 1984.

2.3.3 Neutron Radiography -2 (NuR-2)

Construction of the neutron radiography facility NuR-2 at the radial beamport No.3 was started in 1984 and completed in 1985. This facility was dismantled in 2013 and upgrading activities is currently being carried out.

2.3.4 Small Angle Neutron Scattering (SANS)

The Small Angle Neutron Scattering (SANS) facility at beamport No.4 was installed in 1990 and subsequently refurbished in 1995 (Fig. 4). This facility consists of a coarse collimator, beryllium filter assembly (cryostat), monochromator assembly, biological shielding, main collimator, sample irradiating area, secondary flight-tube and position sensitive detector (PSD).

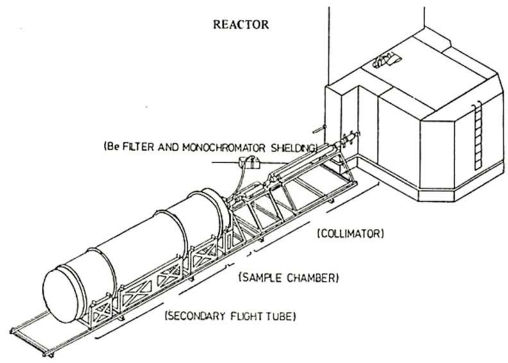

Fig. 4 Small Angle Neutron Scattering (SANS) Facility

3. Related engineering and research infrastructure

3.1 Hot cells, PIE facilities

In nuclear medicine, radioisotopes are used as diagnostic as well as radiotherapeutic agents. Radioisotopes such as I-131, Sm-153 and Ho-166 are used as radiotherapy agents while Tc-99m is mainly used for diagnostic application. Irradiation facilities for radioisotope production in the RTP are Dry Tube (DT), Isotope Production System (IPS), Rotary Rack (RR) and Central Thimble (CT). The radioisotope facility is equipped with hot-cells and glove boxes for handling and labelling compounds and complexes. The radiopharmaceutical kits produced are sent to various nuclear medicine centres in Malaysia.

The radioisotope Production Laboratory was established to carry out the production and distribution of radioisotopes, radiopharmaceuticals and radiopharmaceutical kits to hospitals around Malaysia and other users. The laboratory is equipped with an extensive range of facilities including:

- Hot-cells for the production of Tc-99m generator
- Hot-cell for the production of miscellaneous radioisotopes

- Hot-cell for the production of I-131
- Clean room and freeze dryer for aseptic preparation of radiopharmaceutical kits
- GMP certified clean room for aseptic preparation of Tc-99m generator and radiopharmaceutical kits

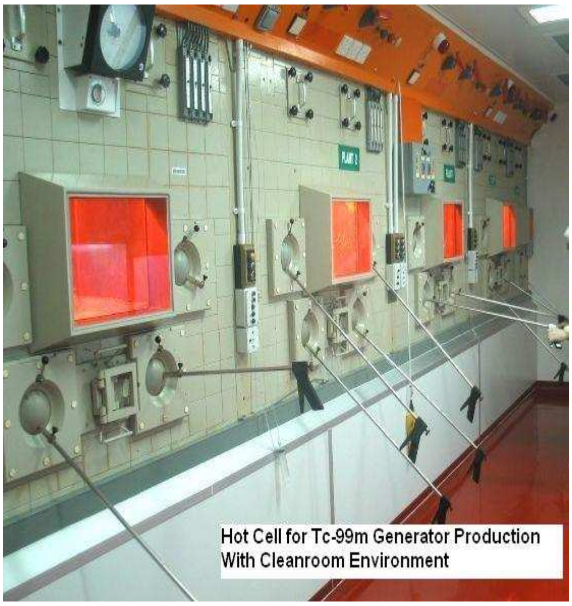

Fig. 5 Hot Cell for Tc-99m Generator Production with Cleanroom Environment

Equipment for quality control such as Multi-Channel Analyzer, Automatic Gamma Counter, High Performance Liquid Chromatography (HPLC), Dose Calibrator, Polarography Equipment, Pyrogen Test Equipment and Sterility Test Equipment.

4. Recent achievements

4.1 New Digital Console

Newly digital console has been installed to replace the ageing console and was commission in 2014. The main inherent safety feature of the I&C system design is such that any failure in the electronic or its associated components, does not lead to an uncontrolled rate of reactivity. The RTP I&C system provides means of monitoring and displaying all reactor parameters such as, neutron flux or reactor power, fuel temperature, water temperature for bulk, inlet and outlet, control rods position, period or rate of power increase and recording of power. It also provides a means of protecting the reactor from undue conditions or abnormal circumstances that could result in an accident. In case of any abnormality, the protection logic will generate a reactor trip signal that releases all control rods into the core. The reactor power was controlled by withdrawal and positioning the control rods as well as maintaining and regulating the power to a 'set' value.

The reactor can be operated in two operation modes namely NORMAL and SQUARE-WAVE. An operation mode is selectable by setting operation mode switch on reactor operating console. All functions essential to operation of the reactor are controlled by the operator from a desk-type console that contains the electronics of the instrumentation and control system.

Fig. 6 The old reactor console
Fig. 7 The new digital console of RTP

5. Education and Trainings

Besides facilitating research and development in nuclear and related technologies, the RTP are also was designed to be used as a tool for education and training purposes. The RTP is being used to provide undergraduate as well as postgraduate students hands-on experience in their field of studies especially in reactor physics and engineering and reactor operator training. The R&D projects in reactor utilization are also being incorporated into teaching modules for undergraduates as well as post graduates studies.

Fig. 8 RTP Education and Training Program

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FNCA Research and Test Reactors Catalogue
Reactor Name: Thai Research Reactor 1/Modification 1 (TRR-1/M1)
Organization: Thailand Institute of Nuclear Technology (TINT)

Reactor Center, Jatujak Office, Thailand Institute of Nuclear Technology (Public Organization)
16 Vibhawadee-rungsit Road, Ladyao, Jatujak, Bangkok 10900 THAILAND
***Contact person :**Suthipong BOONMAK* ***e-mail:** suthipong@tint.or.th*

1. General Information

TRR-1/M1 is located in Bangkok, the capital of Thailand. The reactor site is next to Kasetsart University and the total area of the site is about 13,000 m^2. The TRR-1/M1 core utilizes approximately 20% enriched UZrH fuel which is loaded into two types of fuel elements: 8.5% wt and 20% wt uranium. The TRR-1/M1 fuel element is clad with 304 stainless steel. The 20% wt fuel element also contains about 0.5% wt Erbium as burnable poison which is intended to extend the operation lifetime of TRIGA fuel and provides significant fraction of the prompt negative temperature coefficient for reactivity feedback.

The fuel elements are positioned in a grid plate forming hexagonal configuration. The TRR-1/M1 uses five control rods, i.e., a safety rod, a regulating rod, two shim rods and a transient rod. The regulating, shim and safety rods are sealed in 304 stainless steel tubes while the transient rod has aluminum clad. The TRR-1/M1 can be operated in manual or automatic modes. The reactor power levels can be varied up to 1.3 MW (thermal).

The core cooling is maintained by natural convection. A circulation coolant system provides a sufficient heat removal capacity for 1.3 MW thermal through a primary coolant system and transferred heat through heat exchangers, i.e., a shell and tube type and a plate type. The extracting pipe of the primary cooling system is installed at the reactor pool about 1 meter below the pool water surface. The extracted water coolant is passed through the heat exchangers prior to be fed back to the bottom of the reactor pool. The pool water in the primary cooling system is absolutely isolated from the coolant water in the secondary system.

2. Reactor and Facilities

The TRR-1/M1 experimental facilities include beam ports, horizontal thermal column with graphite blocks, vertical tube in thermal column, rotary rack specimen, high-speed pneumatic transfer system, and several in-core and out-core irradiation facilities. The beam port is the facility which transports the neutron from the reactor core to the irradiation zone outside the reactor pool. Most uses of the beam ports are for neutron radiography, neutron computed tomography and neutron scattering experiments. The other irradiation facilities are in-core and out-core irradiation facilities which are being used for radioisotope production, neutron activation analysis (NAA), gemstone irradiation for gemstone colorization and other experiments upon requests.

2.1 Out-core Irradiation Facility

The out-core irradiation facilities are attached to the reactor bridge. They consist of 3.81 cm (1-1/2 in) OD aluminum tubes that extend from the reactor bridge straight down to the flux region out-core. The end of the tubes are located in the relatively high flux region out-core. There are three categories of out-core facilities, one is the bare tube, another is cadmium covered tube (in order to obtain the neutron in epithermal and fast energy range) and the other is the graphite covered tube (in order to obtain high thermal-to-fast flux ratio). The location of each out-core irradiation facility can be moved depending on the utilization. Figure 1 shows the drawings of the out-core irradiation facilities (A1, A4, CA2, CA3 and TA).

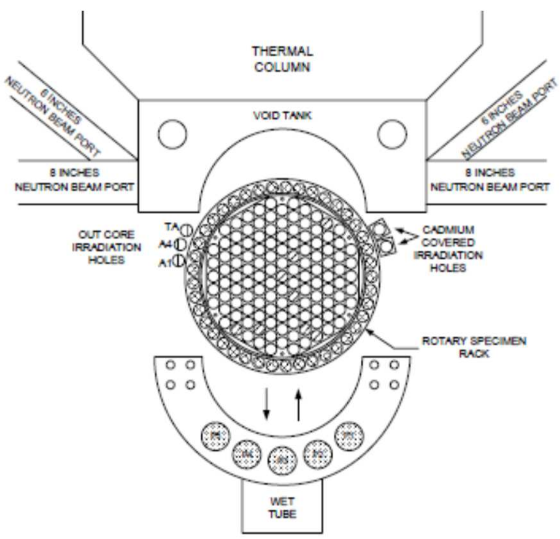

Figure 1 Out-core irradiation facility

2.2 In-core Irradiation Facility

Several in-core irradiation facilities are installed in the reactor core to conduct experiments or to irradiate small samples in the core at the points of respectively high flux. Essentially, the in-core irradiation facility is a 3.81 cm OD aluminum tubes inserted straight down through the hole of the upper grid plate to bottom grid plate. A specimen in a capsule of a maximum diameter of 3.50 cm can be inserted in through these in-core irradiation facilities. The location of the in-core irradiation facility can be varied for each core loading. Typical use of these in-core irradiation facilities is for radioisotope production. Figure 2 shows the drawing of the typical in-core irradiation facility.

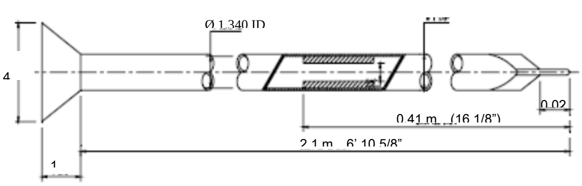

Figure 2 In-core irradiation facility

2.3 Neutron Beam Experimental facilities

Neutron beam ports are installed with utilization facilities including neutron scattering, prompt gamma neutron activation analysis (PGNAA) and neutron radiography. For each beam port in operation, a shutter made of high neutron absorbing material (i.e., borated plate) is provided to shield neutron exposure. When the shutter is closed, the radiation dose at the working area in front of the beam is typically less than 1 mSv/hr. To protect working personnel, additional shielding is put in place using heavy concrete and lead blocks as needed. The radiation level behind this shield is generally less than 10 μSv/hr. Figure 3, 4 and Figure 5 show beam port arrangements for neutron radiography, PGNAA and neutron scattering experiments respectively.

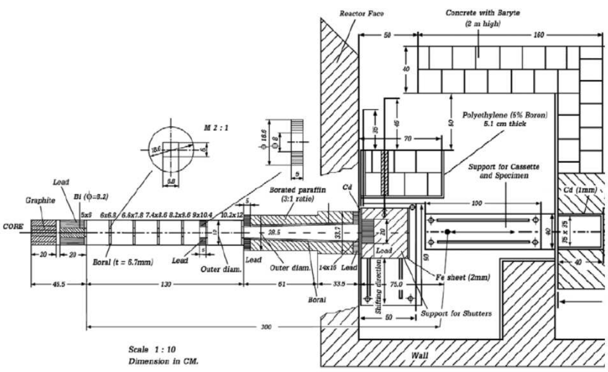

Figure 3 Beam port for neutron radiography experiment

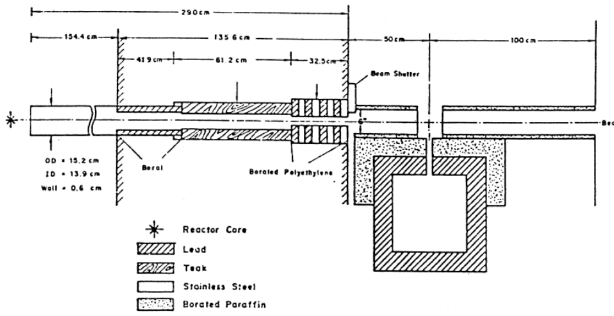

Figure 4 Beam port for PGNAA experiment

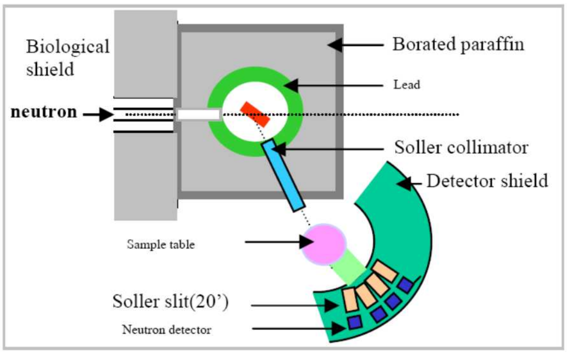

Figure 5 Beam port for neutron scattering experiment

The reactor provides a broad range of irradiation services for TRR-1/M1 researchers and other governmental and private sectors. The experimental programs conducted include: production of radioisotopes for nuclear medicine, agricultural, industrial and research applications; neutron beam experiments such as Neutron Scattering experiments; neutron radiography; Neutron Activation Analysis; experiments for training in nuclear technologies; other experiments for research and development in the nuclear field; training of reactor operation and education for nuclear technology.

2.4 Pneumatic sample transfer system

Short-lived radioisotopes are produced in a pneumatic transfer system, which rapidly conveys a specimen capsule (rabbit) to and from a position in the outer ring of the reactor core. The system includes a specimen capsule, a blower and filter assembly, a valve assembly, a core terminus assembly, a receiver/sender assembly, a control assembly, and such items as tubing, flexible hoses and fittings.

Tubing from the blower extends both to the terminus in the core and to the receiver/sender unit in the laboratory. The tubing extends through a switching transfer box to three positions along the travel of the reactor bridge. A quick disconnect on the bridge permits the pneumatic system to be operable at any of core positions at either end or in the center of the pool. Injection and ejection of the specimen capsule are by means of a vacuum maintained by the blower.

The system is controlled from receiver/sender assembly in the laboratory and may be operated either manually or automatically. With automatic control, the specimen capsule is ejected from the core after a predetermined length of time. A solenoid operated valve controls the airflow direction. All the air from the pneumatic system is drawn through a filter before it is discharged into the building exhaust system for venting radioactive argon.

2.5 Wet tube

The wet tube is a special irradiation facility, semicircular in shape, comprising of several irradiation positions. When in use, it surrounds half of the reactor core. The wet tube is held by the holding structure mounted to the auxiliary bridge in order to support the weight of the assembly. The wet tube has 5 large irradiation positions with the diameter of 12 cms and 8 smaller irradiation positions with the diameter of 6 cms. Figure 6 shows the wet tube configuration.

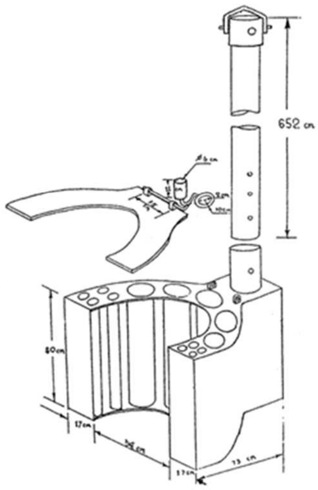

Figure 6 Wet tube configuration

2.6 Standard Neutron Irradiation Facility (SNIF)

The standard neutron irradiation facility (SNIF) is a cylindrical aluminum container which is typically used neutron mutation breeding. The SNIF is held by the same holding structure of the wet tube; thus, it replaces the wet tube when in use.

2.7 Rotary specimen rack

The rotary specimen rack (also known as "Lazy Susan") is a doughnut-shaped watertight that rotates around the core support shroud. It can be used for isotope production or neutron activation analysis. Samples loaded in the 41 holes of the rotary specimen rack can be simultaneously irradiated. The facility consists primarily of six components, that is,

- The rotary specimen rack assembly, which surrounds the core;
- The specimen removal tube;
- The tube-and-shaft assembly;
- The drive-and-indicator assembly on the reactor bridge;
- The buoyancy chambers for vertical movement of the rotary specimen rack;
- The specimen-lifting assembly, which is used for the insertion and removal of specimen containers.

The picture of the rotary specimen rack assembly is shown in Figure 7 below.

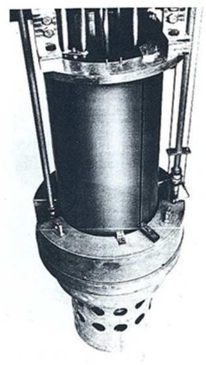

Figure 7 Rotary specimen rack assembly

3. Recent Achievements

3.1 Upgraded and Modified Instrumentation and Control System

TRR-1/M1 is currently under the Instrumentation and Control System (I&C) upgrade - from the original analog type to a modern semi-digital system. The new I&C system comprises of two independent sub-systems which are Reactor Protection System (RPS) and Reactor Regulating System (RRS). The RPS, which functions to trip the reactor, is fully analog in order to protect against software-error vulnerability. The RPS has two redundant and independent channels to assure high system reliability. The RRS, on the other hand, is based on modern control system which uses industrial programmable controllers to enhance the reactor operation. The new I&C system is equipped with a graphical interface for the reactor operator to easily operate the reactor. The user interface software allows the reactor operator to operate either in the manual mode via control buttons or in the automatic mode where the programmable controllers regulate the reactor power using the embedded control algorithm. The new I&C system is expected to provide highly reliable reactor operation and promote effective reactor uses. The new I&C system is shown in Figure 8

Figure 8 New I&C system

The new I&C system has been successfully installed and the cold commissioning of the new system is complete. TINT is currently waiting for the regulatory approval to commence the hot commissioning of the new I&C system which is expected in December 2016. Normal schedule operation of the reactor with the new I&C system is expected in March or April 2017.

3.2 Seismic Analysis of TRR-1/M1

After Fukushima accident, the seismic analysis and ageing management were considered for TRR-1/M1. Non-destructive tests, using rebound hammer and ultrasonic pulse velocity measurement, were performed on the reactor pool and the building to obtain an upper bound estimate of the concrete compressive strength. The tests indicated an in-situ compressive strength ranging from 30 to 50 MPa, the value used in the analysis was conservatively taken as 20.5 MPa, the same value specified in the original design drawing.

The structures were analyzed using a combination of equivalent static and dynamic procedures. The dynamic procedure involved time-history analysis of spring-mass models capable of simulating the behavior of contained water in the reactor pool, as shown in Figure 9. It shown that the maximum tensile stress of the concrete reactor pool obtained from the analyses was lower than the allowable tensile strength. Therefore, the reactor pool can withstand the seismic-induced loading that might occur.

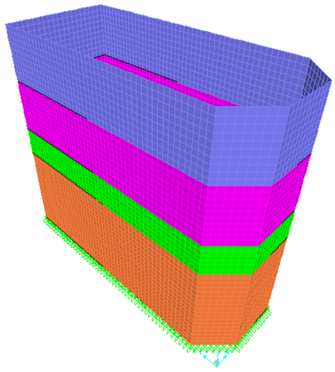

Figure 9 Reactor Pool Model

To capture the interaction of the reactor pool and its building, a model comprising of the reactor pool (with contained water) attached to the building with flexible foundation was developed. The finite element model is shown in Figure 10.

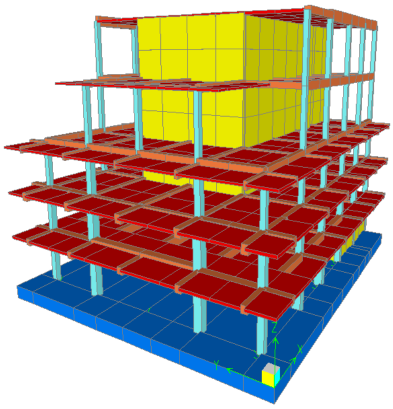

Figure 10 Building - Reactor Pool Interaction Model

The analytical results, under different critical combinations of dead load, live load and seismic load, indicated that the maximum stress that will develop in the beam and column is significantly lower than the member strength. This can be explained by the interaction of the reactor pool and its building, which effectively shorten the overall structure period and reduces the member forces. It can be concluded that both the reactor pool and its building structure are safe from earthquake loading and consequently no strengthening measure is required for the structures under consideration.

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FNCA Research and Test Reactors Catalogue
Reactor Name: DNRR (Dalat Nuclear Research Reactor)
Organization: DRNI, VINATOM (Dalat Nuclear Research Institute, Vietnam Atomic Energy Institute)

Center for Research and Production of Radioisotope
Dalat Nuclear Research Institute
Vietnam Atomic Energy Institute
01 Nguyen Tu Luc, Dalat City, Vietnam
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1. General information

Dalat Nuclear Research Reactor (DNRR) was reconstructed and upgraded from the USA made 250 kW TRIGA reactor with nominal power 500 kW. The DNRR is pool-type research reactor using light water as both moderator and coolant. Since March 1984, the reactor has been officially put into operation for the purposes of radioisotope production, neutron activation analysis, fundamental and applied research, and manpower training. From 1984 to 2011, the DNRR has been operated with HEU working core and mixed core. In December 2011, the reactor was converted to LEU fuel and, 92 LEU fuel assemblies were loaded in the reactor core.

The reactor is installed on the floor at ground elevation in the center of the reactor hall. The reactor tank and major components are surrounded by a thick concrete shielding structure.

High-Enriched Uranium (HEU) fuel assemblies of 36% utilized in the reactor core are of the VVR-M2 type, manufactured in the former USSR. Each fuel assembly consists of three coaxial annular tubes (fuel

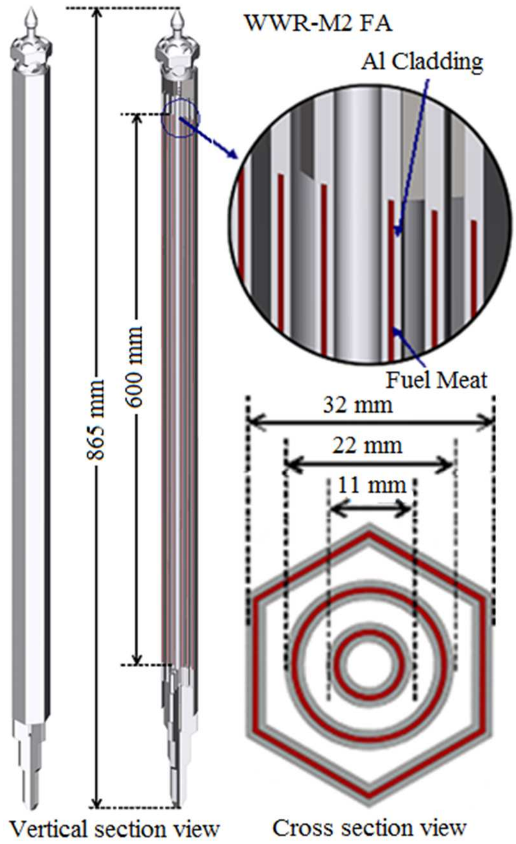
Table.1. Summary description of the DNRR

Parameter	**Description**
Reactor	Swimming pool type
Nominal power	500 kW
Neutron flux (thermal, max.)	2.2×10^{13} neutrons/cm^2.s
Fuel	VVR-M2 type, tube form
Fuel meat	Mixed UO_2-Al, 19,75% enrichment
Fuel cladding	Aluminium alloy
Moderator	Light water
Reflector	Graphite, beryllium and water
Coolant	Light water
Core cooling	Natural convection
Heat rejection	Two-loop cooling system
Shielding	Concrete, water and steel cover
Control rods	2 safety, 4 shim and 1 regulating
Safety and shim rod material	B_4C
Regulating rod material	Stainless steel

elements), as well as a header and a tail. The outermost fuel element has a hexagonal shape of 32 mm in width across parallel sides and the other two inner ones have a circular shape of 22 mm and 11 mm in outer diameter, respectively. Each fuel element is composed of three layers; the fuel meat, in aluminum-uranium alloy with 35wt-% of uranium and 36% enrichment, has a thickness of 0.7 mm and is cladded by two aluminum alloy layers of 0.9 mm each in thickness. In average, each fuel assembly contains about 40.2 g of U-235. The space of 2.5-3 mm in thickness between the fuel elements serves as the passage for water flow. The total length of the fuel assembly is 865 mm, of which the fuelled part (active height) is 600 mm long; the remaining non-fuelled parts are made of aluminum alloy. Low-Enriched Uranium (LEU) fuel assemblies of 19.75% of the VVR-M2 type used in the reactor core consists of 49.7 g U-235 in average with the composition of UO_2-Al. In geometry, two types of HEU and LEU fuels have the same dimension, but there is a difference in the fuel meat and fuel cladding thickness.

Table.2. Characteristics of a VVR-M2 fuel assembly with 36% and 19.75% enrichment

Parameter	HEU Fuel	LEU Fuel
Number of fuel elements in an assembly	3	3
With hexagonal shape (outermost element)	1	1
With circular shape (inner elements)	2	2
Thickness, mm		
Fuel element (fuel meat and cladding)	2.5	2.5
Fuel meat (Al-U alloy)	0.7	0.94
Cladding (Al)	0.9	0.78
Spaces for water flow	2.5-3	2.5-3
Cross section area, cm^2		
Fuel cell	10.61	10.61
Water flow	5.85	5.85
Length, mm		
Total fuel assembly	865	865
Active height (fuelled part)	600	600
U-235 content		
Enrichment, %	36	19.75
Weight, g	40 (approx.)	49.7 (approx.)



The critical core configuration with 72 LEU fuel assemblies with neutron trap and 12 beryllium rods around neutron trap was established in November 30, 2011 and U-235 mass was about 3.6 kg. The working core with loading 92 LEU fuel assemblies and 12 partial burnt LEU fuel assemblies using before in mixed core from 2007. Table.3 lists main physics parameters from the obtained results of experiments or calculations for the working core using LEU fuel assemblies.

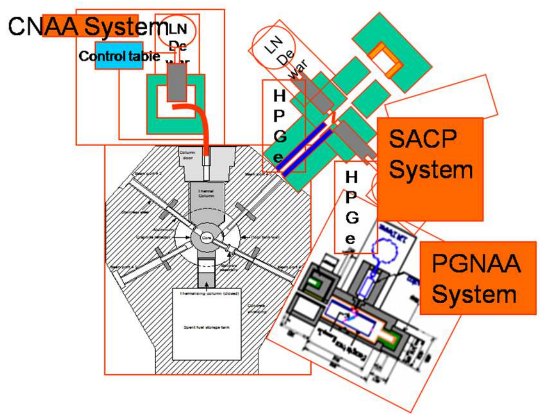


Table.3. Technical parameters of the working core configuration with 92 LEU fuel assemblies and the central neutron trap

Parameter	Value
Core dimensions (diameter by active height), cm x cm	44.2 x 60
Core volume, litters	91
Fuel cell volume, litters	0.6365
Density of U-235 in a cell, g/l	78.68
Total fuel volume in the core, litters	59.8
Water fraction in the core, %	55.2
Infinite multiplication factor k_∞	1.63
Effective delayed neutron fraction β_{eff} ($1\beta_{eff}$ = 1\$), %	0.745
Effective worth of control rods, %	
2 safety rods	4.682
4 shim rods	11.533
1 regulating rod	0.495
Excess reactivity (fresh core), %	6.9
Xenon poison ($\Phi = 4\times10^{12}$ n/cm^2.s), %	
Equilibrium	0.89
Maximum	0.97
Temperature reactivity coefficients, %/^{o}C	
Coolant/moderator	-1.26×10^{-2}
Fuel	-1.86×10^{-4}

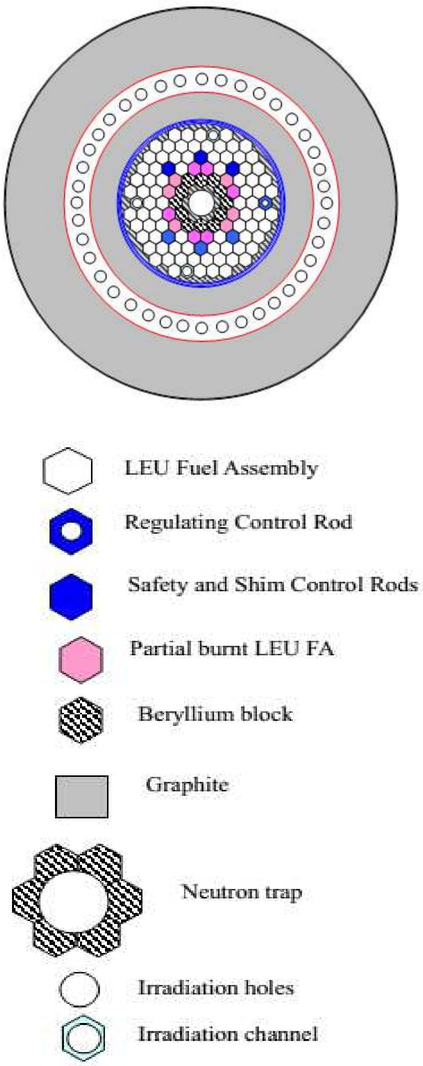


Fig.2. Working core of the DNRR with 92 LEU FAs

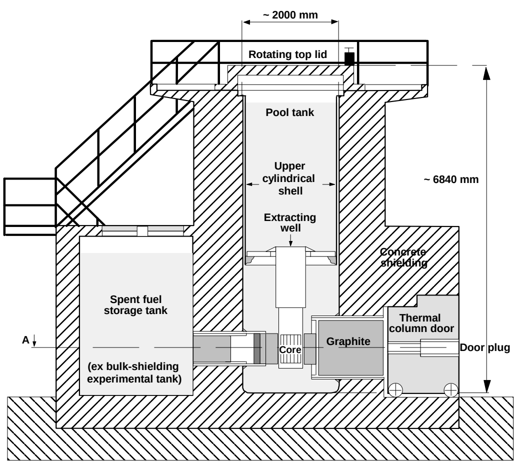


Fig.1. Vertical and horizontal of the DNRR

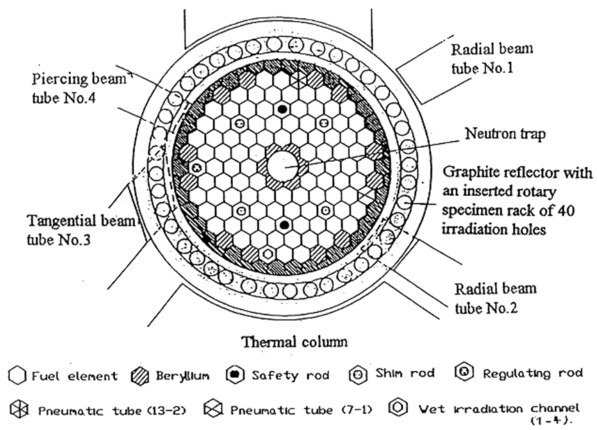


Fig. 3: Cross-section view of the reactor core

2. Reactor and Facilities

Experimental facilities or irradiation channels of the DNRR include:

- wet channels:
  - neutron trap at the core center: cylindrical hollow filled with water, surrounded by beryllium blocks; all these occupy 7 cells in the center of the core;
  - channel 1-4 at the core periphery with an inner diameter of 30 mm occupies;
  - rotary specimen rack with 40 holes at the graphite reflector: located in a circular well of 30-cm depth within the upper part of the graphite reflector, consists of an aluminum rack for holding specimens during irradiation inside a ring-shaped, seal-welded aluminum housing.

The wet irradiation channels are used for radioisotope production, neutron activation analysis and research experiments. Targets requiring long-term irradiation (more than 30 minutes) are placed in aluminum containers and then are put in the wet channels inside or around the reactor core. The wet irradiation channels have shown no failure after many years of operation.

- Dry channels:
  - Channels 7-1 and 13-2 on the core periphery are mainly used for neutron activation analysis. Samples requiring short-term irradiation (from some seconds to 30 minutes) are placed in polyethylene capsules and can be inserted into these dry channels thanks to the pneumatic transfer systems;
  - Thermal column with dimensions of 1.2 x 1.2 x 1.6 m has waterproofed walls, made of aluminum and covered with boron. Graphite blocks with dimensions of 10.2 x 10.2 x 127 cm fulfill the volume of the column.
- Four horizontal beam-ports, but only the following two ready for utilization:
  - Tangential beam-port No.3;
  - Radial piercing beam-port No.2 and No.4.

These horizontal beam tubes provide beams of neutron and gamma radiation for a variety of experiments. At present, three horizontal beam-ports No.2, No.3 and No.4 are utilized for nuclear data measurements, prompt gamma neutron activation analysis, transmission experiments, and for other applications.

Table. 4. Characteristics of the wet irradiation channels.

Characteristics	Neutron Trap	Channel 1-4	Rotary Specimen Rack
Thermal neutron flux, $n/cm^2.s$	2.23×10^{13}	1.07×10^{13}	$3\div4\times10^{12}$
Channel dimensions (Diameter by Height, mm)	∅42÷65 × H600	∅30 × H600	40 holes of ∅31.75 × H274
Irradiation time	From several to hundred hours		

Table. 5. Characteristics of the dry irradiation channels

Characteristics	Channel 7-1	Channel 13-2	Thermal Column
Thermal neutron flux, $n/cm^2.s$	4.1×10^{12}	4.2×10^{12}	1.3×10^{11}
Fast neutron flux, $n/cm^2.s$	3.8×10^{12}	3.3×10^{12}	5.2×10^{8}
Loading capacity, g	20	4	6
Irradiation time (max.)	20 min.	30 min.	4 hrs
Sample moving speed, m/s	10	2.5	2.5

Table.6. Characteristics of the utilized beam-ports

Characteristics	Piercing Beam-port (No.2)	Tangential Beam-port (No.3)	Piercing Beam-port (No.4)
Thermal neutron flux, $n/cm^2.s$	1.0×10^{6}	3.0×10^{5}	4.5×10^{7}
Cadmium ratio (R_{Cd})	230	240	140
Gamma dose, R/h	<0.1	<0.1	<2.0
Beam section, mm^2	30×30	20×20	30×30

The reactor is operated mainly in continuously extended runs of 130 hrs with the full power of 500 kW once every 3 or 4 weeks, for radioisotope production and neutron activation analysis. Between two consecutive extended runs, there are short runs from a dozen of minutes to several hours at varying power up to 500 kW, for research experiments and other purposes.

- Radioisotope and radio-pharmaceutical production. This program has been mainly concentrated on the production of the following radionuclides:
  - P-32 in orthophosphate solution for injections and P-32 applicator for skin disease therapeutics;
  - I-131 in NaI(I-131) solution and capsule;
  - Tc-99m generator;
  - Cr-51 in sodium-chromate solution for injections and solution of chromium-chloride and Cr-EDTA;
  - Others by the end-user's requirements.
- Nuclear analytical techniques. The following nuclear analytical techniques (NAT) have been developed at DNRI:
  - Instrumental neutron activation analyses (INAA),
  - Radio-chemical neutron activation analyses (RNAA),
  - Prompt gamma neutron activation analyses (PGNNA), and
  - Delayed neutron activation analyses (DNAA).

Samples to be analyzed for element determination are approximately as follows:

  - Geological samples for precious metals, rare earth elements, natural radionuclides and others;
  - Biological samples, soil and agriculture materials for microelements;
  - Environmental samples for toxic elements, heavy metals and radionuclides;
  - Food stuff for minerals, heavy metals and toxic elements; etc.
- Nuclear Physics research: The reactor is an intense source not only of thermal neutrons, but also of intermediate and fast neutrons. The horizontal beam-ports of the reactor provide beams of neutron and gamma radiation for a variety of nuclear physics experiments.
- Reactor Physics and Thermal Hydraulics research: This program allows for acquisition of reactor information and data, such as:
  - Core effective dimensions (e.g. radial extrapolated length),
  - Perturbation effects in the neutron field,
  - Vertical and radial neutron flux distributions,
  - Neutron spectra,
  - Delayed photo-neutron effects,
  - Minimum critical power level,
  - Differential and integral worth of control rods (i.e. control rod calibration) and their interference effect,
  - Response time of the reactor protection system and drop time of control rods,
  - Reactivity feedback (due to temperature and power changes and xenon poisoning),
  - Fuel burn-up distribution,
  - Temperatures of coolant and fuel cladding,
  - Behaviour of fuel temperature during a reactor transient due to insertion of allowable reactivity,
  - Thermal power calibration, etc.

Results obtained from the reactor physics and thermal-hydraulic research are to aim at verifying the designed values of reactor parameters, estimating the variation of reactor physical characteristics during the core life, and ensuring the safe, reliable and efficient operation of the reactor.

3. Capabilities to design and manufacture experimental devices and measurement systems including human resources development

Set up experimental devices for basic research in horizontal beam tubes No.2, No.3 and No.4. The tangential beam-port (No.3) is used for nuclear data measurements by (n, 2γ), (n, 3γ) reactions using the two-detector spectrometry system. This beam-port is also used for transmutation doping study and other experiments when requested. The radial piercing beam-port (No.4) with filters of silicon mono-crystal, aluminum, iron, etc. in combination with additional filters such as of B-10, S, or Ti provides quasi-mono-energetic neutron beams. This beam-port is utilized for reaction cross section measurements, prompt gamma neutron activation analysis (PGNAA) and for other applications such as measurement of hydro index in oil samples. Beam port No.2 was used for nuclear data measurement, neutron activation analysis with Compton suppression spectrometer system and serving for training. Filter system also was installed in this beam-port and can be used when having demands.

In reactor physics and thermal hydraulics research, many experimental equipment have been designed and installed to use for research, education and training. Two independent neutron detection systems use for critical approach experiment, noise technique to determined kinetics parameters. Neutron activation method including gamma spectrometry system and many irradiation metal foils is applied to evaluate neutron flux distribution and neutron spectrum at irradiation positions, outside fuel assemblies. An on-line gamma spectrometry system together with collimator and axillary devices is used for measurement of gamma spectrum of burnt fuel assembly spectrum as well as burn-up evaluation by gamma scanning method. Since 1990, by using the HEU instrumented fuel assembly, the measurements of fuel cladding temperatures have been frequently carried out.

User manuals of neutronics (WIMS-ANL and REBUS system, SRAC system, MCNP5 code) thermal hydraulics (PLTEMP, COOLOD, COBRA codes) and safety (RELAP5 code) computer codes provide detailed instructions, numerical solution techniques, description modal input parameters and input examples of the DNRR. These user manuals have been prepared by Vietnamese. All these codes were validated by comparing with experimental data on the DNRR when using HEU and LEU fuel assemblies.

4. Recent achievements

To upgrade in the overall, an IAEA VIE/4/014 project and the national self-sustained projects have been implemented in the period 2005-2007. The main upgrade in this period was renewing almost all of the neutron flux measuring system, the digital processing system, the control panel, and control console. However, the principles and basic functions are in compliance with the old system as before but performed on the state-of-the-art electronic components to enhance the flexibility and reliability. SNIIP Systematom Corp., Republic of Russian Federation, which has previously designed, manufactured and installed the old I&C system, was selected as contractor for designing and manufacturing the new I&C system. The new I&C system was put into trial operation since April 2007 and officially licensed for operation of No. 2144/GP-BKHCN on 03 October 2007.

Physics and energy start-up of the Dalat Nuclear Research Reactor (DNRR) for full core conversion to use low enriched uranium (LEU) fuel were performed from November, 24th, 2011 until January, 13th, 2012 following a prepared program that was approved. The program provides specific instructions for manipulating fuel assemblies (FAs) loading in the reactor core and denotes about procedures for carrying out measurements and experiments during physics and energy start-up stage to guarantee that loaded LEU FAs in the reactor core in accordance with calculated loading diagram and implementation necessary measurements to ensure for safety operation of DNRR.

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