# REFURBISHMENT, MODERNIZATION AND AGEING MANAGEMENT PROGRAM OF THE 3MW TRIGA MARK-II RESEARCH REACTOR OF BANGLADESH


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## ABSTRACT


The 3 MW TRIGA MK-II research reactor of Bangladesh Atomic Energy Commission (BAEC) achieved its first criticality on 14 September 1986. The reactor has been used for manpower training, radioisotope production and various R&D activities in the field of neutron activation analysis, neutron radiography and neutron scattering. Reactor Operation and Maintenance Unit (ROMU) is responsible for operation and maintenance of the research reactor. During the past twenty seven years ROMU 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 port-1 leakage problem. All of these refurbishment activities were performed under an annual development project (ADP) funded by Bangladesh government.

BAEC research reactor (RR) was operated by analogue console system from its commissioning to July, 2011. Old analog based console has been replaced by digital console on June, 2012. Modernization program for the reactor control console due to obsolescence and unavailability of spare parts of I&C system was vital to restore the safe operation of the reactor. Considering these facts, installation of a digital control console and I&C system based on the state-of-the-art digital technology became necessary. Reactor digital console system installation tasks were performed under another ADP funded project by Bangladesh government. Now the reactor is operating with the digital control system. Besides this, the Neutron Radiography (NR) facility has been modernized 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 neutron powder diffractometer at the radial beam port-2 of the reactor.

Although preventive and predictive maintenance, periodic testing, in-service inspection and other mitigation measures were practiced in few systems of the BAEC RR facility, these were not enough to mitigate the ageing related degradation of N-16 decay tank, shell and tube heat exchanger and radial beam port-1. It was understood that if effective ageing management program were started effectively from the beginning of the reactor, refurbishment activities could be minimized. As well as life of the reactor could be enhanced without any hurdle tasks. Basis on these understanding ROMU submitted an IAEA TC Project (BGD1012) titled “Implementing an Ageing Management Program for RR”. Under this project an effective ageing management program has commenced on January, 2012 for the BAEC RR to enhance life and ensure safe operation of the reactor. This paper will describe chronologically refurbishment activities and experience for different affected systems, required resources & management and lessons learned from these tasks. It will also focus the modernization activities of the reactor facility. Moreover, it will describe ageing management activities that are planned for the BAEC TRIGA MK-II research reactor.

## 1. Introduction

The TRIGA Mark-II research reactor of BAEC is a light water cooled, graphite reflected reactor, designed for steady state and square wave operation up to a power level of 3 MW (thermal) and for pulsing operation with a maximum pulse power of 852 MW. The reactor achieved its first criticality on 14 September 1986. Since then, it has been used for manpower training, radioisotope production and various R&D activities in the field of neutron activation analysis (NAA), neutron radiography (NR) and neutron scattering.

During the period, operation of the reactor was interrupted several times due to various incidents encountered mostly in the cooling system of the reactor and the irradiation facilities. The most severe of these incidents are: The “N-16 Decay Tank Leakage Incident” that took place in 1997 and the leakage of the Radial Beam Port-1 (RBP-1) after removal of the broken graphite plug in January 2009.

As a consequence of the delay tank incident, full power operation of the reactor remained suspended for several years. During that period, the reactor was operated at 250 kW under natural convection cooling mode, so as to cater the needs of the experiments that require lower neutron flux (NAA and NR). Operation of the reactor at lower power level was made possible by establishing a temporary by pass connection across the decay tank which was done locally. To make the reactor operational again at full power, renovation and upgradation of the entire cooling system of the reactor were carried out. The renovated cooling system was successfully commissioned in June 2002.

For installation of the High Resolution Powder Diffractometer (HRPD) in RBP-1, it becomes necessary to remove all BP plugs from the RBP-1. During removal of the plugs, the inner graphite plug was broken. After removal of the inner 13 inches long broken part of graphite plug, the RBP-1 was found leaking at a rate of about 500 ml/day. To resolve the leakage problem, a Split Type Encirclement Clamp (STEC) was designed and fabricated locally and then installed around the RBP-1 on 26 February 2010.

The reactor was in operation with an analog I&C system for about 25 years. The old analog console spare parts became obsolesce and it was very difficult to get spare parts for the old analog system. So, it was necessary to replace the analog control system by a digital one. As such, a project was implemented in 2012 under the framework of Annual Development Program (ADP) of the government for procurement and installation of a digital control system involving the original reactor supplier, the General Atomics of the USA. Also as part of the modernization program of the reactor facility, digital neutron radiography facility at tangential beam port and High Resolution Powder Diffractometer (HRPD) at the RBP-2 have been installed.

At present ageing is a significant issue for the BAEC 3MW TRIGA Mark-II research reactor since the reactor is being operated for about 27 years. As a result of ageing, some of the reactor tank internals that are directly connected to the reactor core, such as the radial beam tube, rotary specimen rack (Lazy Susan) loading tube, etc. have developed corrosion damage. To extend the operational life of the reactor and its associated systems an ageing management program has been introduced. Under this program an IAEA TC project (BGD1012) titled “Implementing an Ageing Management program for the TRIGA Research Reactor” has been under taken to implement the comprehensive ageing management program.

## 2. Refurbishment of Reactor Cooling Systems

### 2.1 Replacement of N-16 Decay Tank and Heat Exchanger

A leakage was detected in the decay tank of the primary cooling system of the 3 MW TRIGA

Mark-II research reactor on 14 July 1997. The tank was isolated (Fig.1) and tested both non-destructively and destructively. Extensive corrosion and pitting were found in a particular area where rain water seeped in during the monsoon and remained logged for a long period. Upon inspection, corrosion and pitting were also observed on the inner walls/baffles of the decay tank.

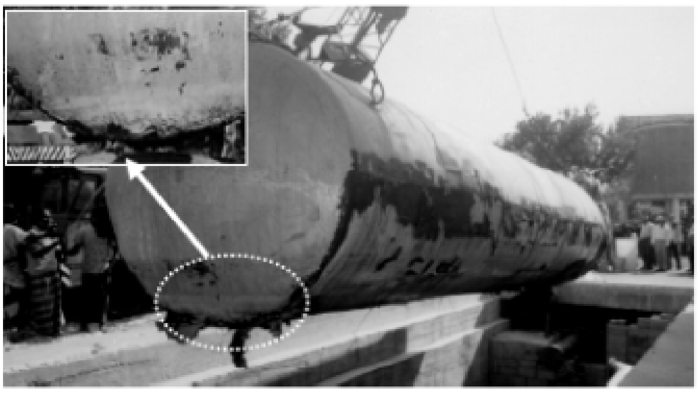

Fig.1 Removal of damaged N-16 decay tank

As a consequence corrosion damaged decay tank was replaced by a new decay tank with four aluminium saddles welded to its body. Each saddle was anchored to floor with four steel routed bolts (3.175 cm dia, 22.86 cm long). The saddles were bolted to the floor in a way such that one of the saddles remained fixed and the other three could slide on the floor. Sliding saddles were used in order to allow thermal expansion of the large decay tank having a length of about 10 m and a diameter of about 2.5 m. New decay tank with aluminium saddle is shown in Fig. 2. It is to be mentioned that the new decay tank was installed after modification of the shielding arrangement around the decay tank. A new plate type heat exchanger was also installed replacing the old shell and tube type heat exchanger, which got heavily fouled. The new heat exchanger required several changes in the piping layouts of both the primary and the secondary cooling loops. The new heat exchanger with modified piping arrangements is shown in Fig 3.

Fig. 2 New N-16 decay tank with aluminum saddle

Fig. 3 Piping arrangement around H/E

## 2.2 Modification of the Cooling System Piping Arrangements

A modified Y-connection (Fig 4) was introduced in place of the T-connection at the discharge side of the two 50-hp pumps, which are operated simultaneously to get the desired primary flow rate of 13,230 liters/minute (3,500 US gallons/minute). It is to be mentioned that a "T" connection in the discharge line of any pumps gives rise to "cavitations" like noise depending upon the degree of turbulence. The pumps in question had a history of vibration problems and one of the possible causes could have been this turbulence. The “Y” connection in the discharge resolved the matter to a great extent.

Fig. 4 Modified Y-connection

A butterfly valve was installed at the inlet of the decay tank. Two 25.4cm (10 in.) butter fly valves were installed in primary piping adjacent to the inlet and the outlet of the plate type heat exchanger. Design of the secondary cooling system piping arrangement at the inlet of the heat exchanger was changed so as to facilitate the maintenance of the Y-strainers. A paddle wheel type flow sensor with a digital readout panel was installed in the suction line of the secondary pumps to measure the flow rate of secondary cooling loop.

## 2.3 Modification of Pipe Supports

Necessary pipe supports were provided at different locations of the primary and secondary cooling loops in order to reduce the vibration of the piping to a minimum level. Three types of mild steel (M.S.) pipe supports were used for this purpose. The types used include adjustable floor mounted type, adjustable roof mounted type and wall mounted type. In addition to these, a few supports, which were connected simultaneously to the floor and the wall, were also installed (Fig 5). The above were essentially conventional steps taken to mitigate piping vibration. In most cases the inherent vibrations of the pump act as the forcing function. The pipe supports were placed at places of maximum amplitude.

Fig. 5 Modified pipe support

Conventional theoretical approach which is mainly used in the design stage is to see the spacing of supports and calculate the natural frequency “f”, for the piping section. If this is a multiple or sub multiple of the pump vibration, it can cause resonance. The remedial steps are to increase/decrease the support distance thereby changing the stiffness.

### 2.4 Modification of the Emergency Core Cooling System (ECCS)

It is essential that the ECCS should remain operational under all abnormal situations. One of such abnormal situation in the flooding of the decay tank and primary pump room by water leaked out from the primary cooling loop. The ECCS must not get under water in the event of such flooding. In order to remain unaffected in the event of the above mentioned flooding safe height of the base plate containing the pump form the primary pump room floor was calculated to be 3´- 6˝. Accordingly the wall mounted base plate was shifted at this height from its previous height of 3´- 0˝. The initial installation of the ECCS had several deficiencies, such as improper routing of the piping, defective installation of battery, battery-charger and pump motor unit, etc. Therefore, in order to improve the operational safety of the ECCS, several modifications were needed to be carried out on the system. These modifications were implemented after the installation of the new decay tank and associated components of the reactor cooling system. The modifications of the ECCS mentioned above include the followings:

1. Modification of the ECCS piping layout,
2. Shifting of the ECCS mounting block containing the ECCS pump-motor, battery and battery charger unit to a safe height,
3. Modification of the ECCS mounting block, and
4. Replacement of the old ECCS lead-acid battery by new Ni-Cd battery.

After satisfactory completion of all the above modification work, the ECCS was tested and commissioned on 8 April 2003.

Present set up of the ECCS pump, battery and charger is shown in Fig. 6.


Fig 6a: ECCS Pump-Motor unit

Fig 6b: ECCS Battery & Charger unit

## 3. Modernization of Reactor Instrumentation and Control (I&C) System

Digital instrumentation & control (I&C) system was installed in June 2012, replacing the old analog systems of the 3 MW TRIGA Mark-II research reactor, which had been in operation in BAEC since September 1986. The reactor I&C system include instrumentation for monitoring reactor parameters during all operational states and for recording all variables important to reactor operation. It also manages all control rod movements taking into account the choice of operating mode and interlocks. The I&C system is a computer-based system, but includes dedicated hardwired displays and controls so that safe operation can continue if the computer become unavailable. The system consists of three separate computer systems: the Data Acquisition and Control Unit (DAC), the Control System Console (CSC), and the User Interface Terminal (UIT). The CSC and DAC systems run under Linux operating system and the UIT runs on Windows. The Reactor Protection System (RPS) is contained within the

CSC and DAC. The RPS scrams the reactor by causing the control rods to insert into the core in response to certain abnormal reactor operating conditions. The scram circuits and components are completely hardwired and do not in any way depend on the CSC computer, the DAC, or any software to perform a scram. Furthermore, the reactor I&C system and RPS are designed such that there are no means available to the reactor operator to bypass the trips and operate the reactor at conditions that are beyond the limits defined by the trip set points. The UIT works as a display terminal and is not used in the control of the reactor. Reactor Operation and Maintenance Unit (ROMU) personnel, who are now operating and maintaining the digital I&C system, actively participated in the installation, testing and commissioning of the digital I&C system. ROMU's experience with the digital control system of BAEC TRIGA reactor is expected to be of use in understanding the I&C systems of the research reactors being designed by different technology developers. Photograph of the analog and digital control of BAEC TRIGA Research Reactor is shown in Fig. 7.

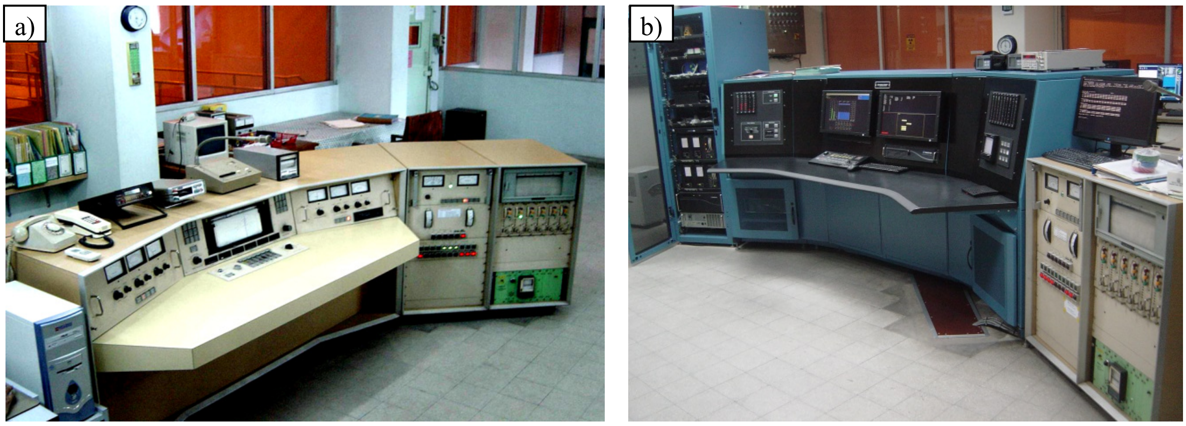


Fig. 7 Photograph of a) Analog and b) Digital Control Console

## 4. Modernization of Beam Port Facilities

The TRIGA Mark II has four beam ports namely tangential, piercing, radial-1 and radial-2. Two modern experimental facilities have been installed in the tangential beam port and radial-2 beam port under different annual development projects (ADP) of Bangladesh. Tangential beam port is used for digital neutron radiography facility and radial-2 is used for the high performance neutron diffractometer – SAND (Savar Neutron Diffractometer).

### 4.1 Installation of digital neutron radiography facility

Neutron Radiography Facility was used for nondestructive testing (NDT) of materials with an objective to utilize the reactor more potentially. The film neutron imaging method is being used from the beginning of the facility. Recently, digital neutron radiography set-up has been added to the facility along with a change in biological shielding arrangement. Introduction of digital neutron set-up has significantly reduced the experimental time and digitized images of the objects are obtained very fast and processed by software to improve the quality. The digital neutron radiography set-up has been procured under the ADP project of Bangladesh government. However, film technique is still used in parallel for some specific purposes. Fig. 8 shows the schematic diagram of the digital neutron radiography set-up.

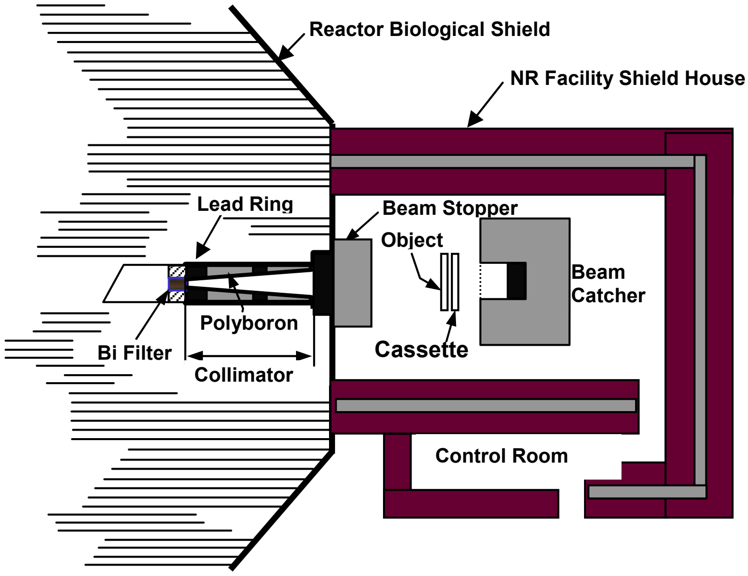


Fig. 8 Schematic Diagram of the Digital Neutron Radiography Facility.

## 4.2 Installation of high performance neutron diffractometer

The program of Reactor and Neutron Physics Division (RNPD) is entrusted with the responsibility to utilize the TRIGA Mark II research reactor which is the only one of its kind in Bangladesh. The high performance neutron diffractometer – SAND (Savar Neutron Diffractometer) has been installed on Radial Beamport-2.

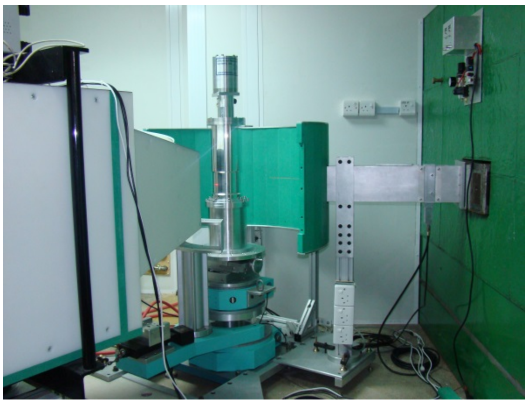

Fig. 9a Savar Neutron Powder Diffractometer

Fig. 9b System Control Electronics and Detector

Fig. 9 shows the Savar Neutron Diffractometer (SAND). Neutron Scattering (NS) experiments involve directing a beam of neutrons at a specimen and then detecting the energy of neutrons at which they are scattered at different angles after interacting with the atoms in the specimen. The NS experiment is mainly concentrated on elastic scattering or diffraction phenomena. Internal details of condensed matter such as its crystalline state, location of atoms in the crystal lattice, phase transitions and much other structural information can be determined by this technique. Neutron possesses magnetic moment and so it can interact with the atoms magnetically. Thus it can give the information about the position of the domain boundaries, their sizes and orientations. NS is an only technique that can divulge the magnetic architecture within materials.

## 5. Ageing Management Activities

At present ageing is an important issue for the BAEC 3MW TRIGA Mark-II research reactor although many modifications and refurbishment works at the reactor facility have been performed previously. As a result of ageing, some of the reactor tank internals that are directly connected to the reactor core, such as the radial beam tube, rotary specimen rack (Lazy Susan) loading tube, etc. have developed corrosion damage. The extent of corrosion damage caused to one of the radial beam ports (from its inner side) was so severe that through holes developed on the 6.8mm thick aluminum wall of the beam tube located inside the reactor pool liner at a depth of about 8m. Primary water started leaking out through these holes. Leakage of water was stopped by installing a split type encirclement clamp around the damaged part of the beam port by using locally developed remote handling tools. The rectification measure, which is semi-permanent in nature, needs to be reviewed and if felt necessary, has to be replaced by a permanent one. The other ageing issue of concern is with the Lazy Susan (rotary specimen rack). White powder-like substance is found to grow on the inner wall of the Lazy Susan. Repeated cleaning by mechanical means could not prevent it from growing. Besides these, yellowish spots are observed on many parts of the inner wall of the reactor pool liner when inspected by an underwater camera supplied by the IAEA under the TC project number BGD9011. The issues mentioned above seem to have potential safety concern and if they cannot be handled properly, might even limit the operational life of the RR. It is understood that these issues are to be addressed properly with the involvement of appropriate experts. However, such experts are not available locally. So it is expected that the ongoing IAEA TC project (BGD 1012) will be helpful in resolving the issues with the assistance of the IAEA expert services.

### 5.1 Beam port leakage problem

Reactor pool water was found to be leaking through the Radial Beam Port-1 (RBP-1) of the 3MW TRIGA Mark-II research reactor (RR) of Bangladesh Atomic Energy Commission (BAEC) when the graphite shield plug of the beam port (BP) was removed after about 23 years for installation of the collimator of the newly procured high resolution powder diffractometer (HRPD). The leak was found in the aluminium part of the RBP-1, which is located inside the reactor pool at a depth of about 8 m (Fig. 10).

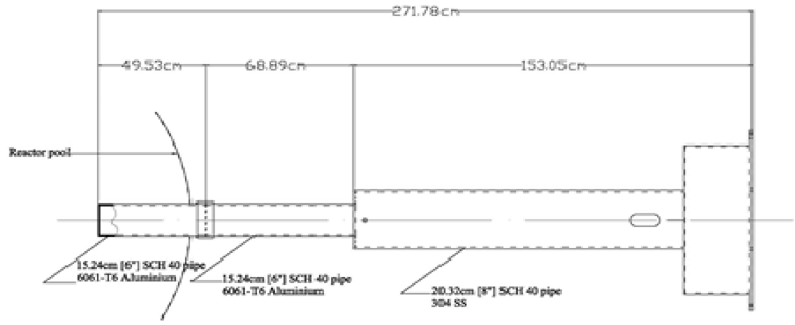


Fig. 10 Details of the radial beam port

Investigation showed that an installation defect caused moisture from the heavy concrete shielding to seep into beam port and initiate the corrosion. As a result of such corrosion, the 1.016m long graphite shield plug got jammed inside the BP very tightly. While trying to remove the plug, it got broken leaving a segment having a length of about 33cm inside the aluminium part of the BP. This segment of the BP plug was removed by using special hand tools designed and fabricated locally (Fig. 11).

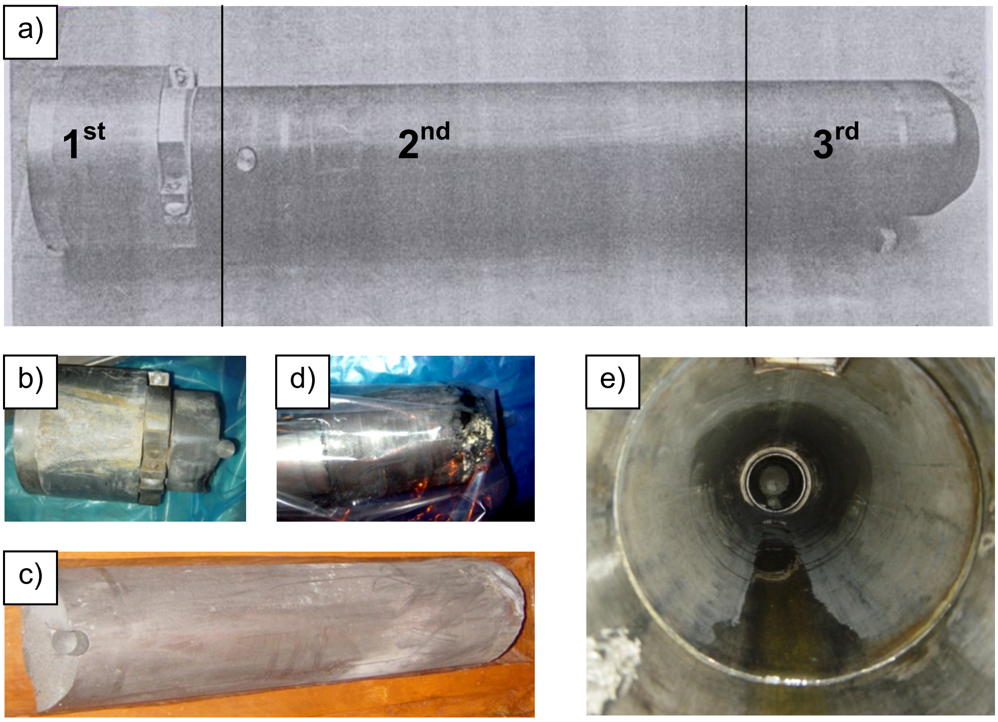


Fig. 11 Graphite plug of RBP-1; a) Graphite plug assembly, b)~d) 1st, 2nd and 3rd broken part of the plug, and e) Water leaking from RBP-1.

Leakage of water at a rate of about 500ml/day came to the notice of the reactor operators a couple of days after the graphite BP plug had been totally removed from the RBP-1. Immediately a rubber strap was installed around the leaking part of the BP by using a temporary arrangement so as to stop drainage of reactor pool water. Detailed investigations were carried out using remote handling cameras including an underwater camera supplied by the International Atomic Energy Agency (IAEA). Corrosion products were collected from the surface of the BP plug and analyzed using scanning electron microscopy and energy dispersive X-ray (EDX) analysis techniques. Results showed the presence of oxygen, carbon, lead, silicon and aluminum. The friable and porous nature of some of the samples indicated the presence of hydroxides in it. The investigation and analysis results were found to be useful in identifying the root cause of the leakage problem. Water leakage was eventually prevented by installing a split type encirclement aluminium clam (Fig. 12) around the damaged part of the RBP-1 by using innovative remote handling fastening devices, designed and fabricated locally.

Fig. 12 Split type encirclement clamp

## 5.2 Ageing problem of Rotary Specimen Rack (Lazy Susan) and Reactor Pool Liner

The lazy susan assembly consists of a stainless steel rack that holds specimens during irradiation and ring-shaped seal-welded aluminum housing. The rack rotate inside the housing and supports 41 evenly spaced aluminum tubes which are open at the top end. Recently white powder-like substance is found to grow on the inner wall of the Lazy Susan. Repeated cleaning by mechanical means could not prevent it from growing.

In the pool liner, yellowish spots are observed on many parts of the inner wall of the reactor tank during inspection by an underwater camera supplied by the IAEA under the TC project number BGD9011.

The issues mentioned above seem to have potential safety concern and if they cannot be handled properly, might even limit the operational life of the RR.

## 5.3 Future plan for ageing management activities

Under TC Project BGD1012 titled "Implementing an ageing management programme for TRIGA Research Reactor" ROMU has plan to perform the following ageing management activities:

i. Implementing an effective ageing management programme of the reactor facility following IAEA safety standards.
ii. Introduce an ISI programme for inspection of core internals specially pool liner using ultrasonic testing equipment.
iii. Establish an effective programme for cleaning of rotary specimen rack (lazy susan).
iv. Stress analysis of the modified primary and secondary cooling systems using CAESAR-II software.
v. Solve the vibration problems of the rotary parts of the different systems of the reactor using CSI Analyzer.
vi. Fix the leakage problem of the beam port and plan for proper maintenance of the beamport.
vii. Cleaning of the plate type heat exchanger and fix its high pressure problem.
viii. Confirm the design of fuel transfer cask and fuel storage pits and submission an annual development project (ADP) to establish these facilities in the reactor facility.

# 6. Conclusions

The BAEC reactor has been operated as per the technical specifications and procedures as laid down in the safety analysis report (SAR) of the research reactor. Moreover, special care was taken for routine check and surveillance activities for preventive and corrective maintenance of systems and equipment. Refurbishment works performed in the cooling system and rectification of BP leakage problem was really ensures 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 improves the cooling system parameters and reduces 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. Furthermore, the ageing related activities of the BAEC research reactor needs to be improved focusing on SSCs to enhance safe and more reliable operation of the reactor.

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