Operating Experiences and Utilization Programmes of the BAEC 3 MW TRIGA Mark-II Research Reactor of Bangladesh

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Abstract

The 3 MW TRIGA Mark-II research reactor of Bangladesh Atomic Energy Commission (BAEC) has been operating since September 14, 1986. The reactor is used for radioisotope production (^{131}I, ^{99m}Tc, ^{46}Sc), various R&D activities, manpower training and education. The reactor has been operated successfully since it's commissioning with the exception of a few reportable incidents. Of these, the decay tank leakage incident of 1997 is considered to be the most significant one. As a result of this incident, reactor operation at full power remained suspended for about 4 years. However, the reactor operation was continued during this period at a power level of 250 kW to cater the needs of various R & D groups, which required lower neutron flux for their experiments. This was made possible by establishing a temporary by pass connection across the decay tank using local technology. The reactor was made operational again at full power after successful replacement of the damaged decay tank in August 2001. At that time, several modifications of the reactor cooling system along with its associated structures were also implemented and then necessary testing and commissioning of the newly installed component/equipment were carried out. The other incident was the contamination of the Dry Central Thimble (DCT) that took place in March 2002 when a pyrex vial containing 50g of TeO2 powder got melted inside the DCT. The vial was melted due to high heat generation on its surface while the reactor was operated for 8 hours at 3 MW for trial production of Iodine-131 (^{131}I). A Wet Central Thimble (WCT) was used to replace the damaged DCT in June 2002 such that the reactor operation could be resumed. The WCT was again replaced by a new DCT in June 2003 such that radioisotope production could be continued.

The facility has so far been used to train up a total of 27 personnel including several foreign nationals to the level of Senior Reactor Operator (SRO) and Reactor Operator (RO). The reactor is operated 4 days a week at a power level of 3 MW for production of Iodine-131. During the other one weekday, the reactor is operated at lower power levels (250 – 500 kW) to cater the needs of NAA and NR groups. At present the total burn-up of the core stands at about 549 Megawatt Days. BAEC has a plan to increase the production of Iodine-131 to install more dry tubes in the core so as to meet the total demand of RI in the country. There is also plan to develop unused experimental facilities such as, thermal column and radial beam ports for strengthening the R& D activities around the reactor. A total of 1147 irradiation requests (IRs) have been catered so far for different reactor uses. The total amount of RI produced stands at about 4200 GBq. The total amount of burn-up-fuel is about 13180 MWh. An ADP project already been taken by BAEC to convert the analog console and I&C system of the reactor into digital one. The paper summarizes the reactor operation, maintenance experiences and utilization programmes focusing on troubleshooting, rectification, modification, RI production, various R&D activities and training program being conducted at the facility.

Keywords: Reactor, Dry Central Thimble (DCT), Wet Central Thimble (WCT), demineralize water, irradiation request (IR), pyrex vial, TeO2 powder, radioisotope, burn up.

1. Introduction

The TRIGA Mark-II research reactor is a light water cooled, graphite reflected reactor, designed for steady-state and square wave power level of 3 MW (thermal) and for pulsing with maximum power level of 852 MW. The reactor is designed for multipurpose uses like training, education, radioisotope production and various R&D activities in the field of nuclear science and technology. The reactor was first made critical at 50 W on September 14, 1986 and was commissioned to steady state power of 3 MW in October 1986. During 1987-1990, the reactor use was mainly limited to operator training and various R & D activities in the area of radioisotope (RI) production and Neutron Activation Analysis (NAA). For better and safe utilization of the maximum flux, a Dry Central Thimble (DCT) was placed in the core center replacing the water filled CT in 1988.

After the instillation of the DCT, reactor operation increased significantly for RI production. Subsequent to this operation, the primary cooling system pipe supports failed at a weld joint and one of the two exit check valves cracked due to excessive vibration. The whole primary cooling system support was then changed and the reactor was returned to full power operation in the mid of 1992. In 1994, three butterfly valves were installed in the pipeline of the secondary cooling system. One of these valves was placed in the return pipeline of the cooling tower sump. To facilitate cleaning of the cooling tower as well as heat exchanger, two other valves were also installed in the return pipeline of the heat exchanger. Two modifications were made in the electrical control circuit of the ventilation system in September 1995 and in March 1997.

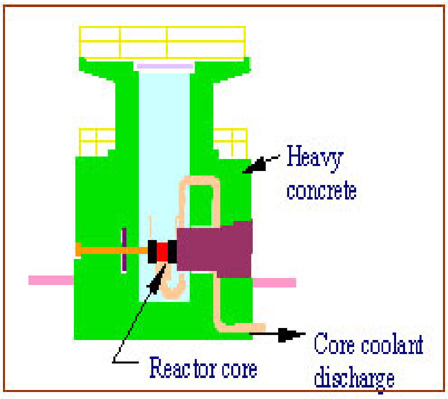
In July 1997, the decay tank was found damaged due to pitting corrosion on the tank bottom that was in direct contact with the concrete saddle. This put the reactor again into a prolonged shut down. Mean while a bypass connection was established across the N-16 decay tank with the help of local expertise, and the reactor was brought to operation on August 1998 with a maximum power level 250 kW under natural convection. The reactor was made operational again at full power after successful replacement of the damaged decay tank by a new one supplied by GA/Sorrento Electronics Inc. (SEI) in August 2001. In addition, the shell and tube heat exchanger was replaced by a new plate type heat exchanger. At that time, several modifications of the reactor cooling system along with its associated structures were also implemented and then necessary testing and commissioning of the newly installed component/equipment were carried out. Several modification works of the Emergency Core Cooling System (ECCS) were also implemented.

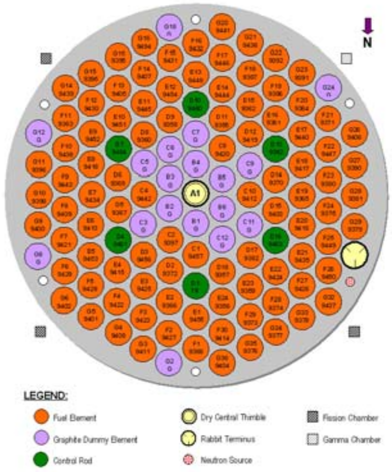
In March 2002, the DCT got contaminated due to melting of a pyrex vial with 50g TeO_2 powder in it. The objectives of this paper are to brief about the experiences of operation and maintenance of the TRIGA research reactor, various R&D activities and training programs being conducted in the facility.

2. Brief Description of the Reactor

2.1 Reactor Core

The reactor core is located near the bottom of the reactor tank. The reactor 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, respectively. The tank is filled up with 24,865 liters of demineralized water. The reactor core consists of 100 fuel elements (including 5 fuel follower control rods and 2 instrumented fuel elements), 1 air follower control rod, 18 graphite dummy elements, 1 DCT, 1 pneumatic transfer system irradiation terminus (Rabbit system) and 1 Am-Be neutron source (strength: 3 Ci). Figures 1 & 2 show the sectional view and core configuration of the TRIGA reactor, respectively. Figure 1 shows the location of the reactor core surrounded by coolant and shielding structure of heavy concrete wall. Figure 2 shows the core configuration comprises fuel elements and control rod.





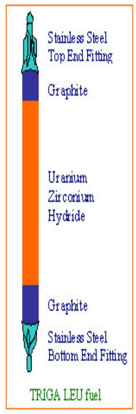


Fig.1 Sectional View of the TRIGA

Fig. 2 Core Configuration of the TRIGA Reactor

2.2 Reactor Operation Mode:
BAEC 3MW TRIGA Research Reactor can be operated in Automatic, Manual, Square wave, Pulse HI and Pulse Low mode of operation.

2.3 Irradiation Facilities
In accordance with its purpose as a research reactor, the BAEC 3MW TRIGA Mark-II reactor is equipped with a number of irradiation facilities. The name of these facilities and corresponding neutron flux are given below:

i) Dry Central Thimble (DCT): In the DCT, samples may be exposed to a maximum neutron flux density of 9.12×10^{13} n/cm^2/sec. The DCT is used for radioisotope production and various R&D purposes.

ii) Beam Tubes**:** There are four neutron 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/cm^2/sec. The piercing BT is being used for neutron scattering studies by using Triple Axes Spectrometer (TAS). Two radial beam tubes are not yet used.

iii) Rotary Specimen Rack (Lazy Susan): The rotary specimen rack/Lazy Susan is a donut shaped watertight device placed in the upper part of the graphite reflector assembly around the reactor core. This rack facilitates 41 sample-holding tubes. Each of these tubes (except the 1st one) can accommodate two standard specimen containers. The dimension of the each specimen container is 13.9 cm long and3.18 cm dia. Sample is loaded into the rotary specimen rack through the 3.3 cm dia loading tube, which extends up to the top of the reactor shield structure and terminate at the center channel. A position control mechanism allows loading of samples in different chambers of the Lazy Susan. This facility is used for neutron activation analysis as well as isotope production. The neutron flux in this facility is 1.23×10^{13} n/cm^2/sec.

iv) Pneumatic Transfer System (PTS): The PTS is also called the Rabbit System. It is used for the production of very-short-lived radioisotopes. It transfers the sample to be irradiated into the reactor core or out from the reactor core in about 4.6 sec. The neutron flux in this facility is

1.91×10^{13} n/cm^2/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 yet used.

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

2.4 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.

3. Operation & Maintenance Experience

3.1 Operation Statistics

The reactor has so far been operated about 6545 hrs for isotope production, various experiments and training purposes. This includes a total of about 2201 hrs of operation at full power. A total of 1147 irradiation requests (IRs) have been catered up to July 2007. The total burn up of the fuel stands at about 13180 MWh. A graph showing operational statistics is shown in fig 3.

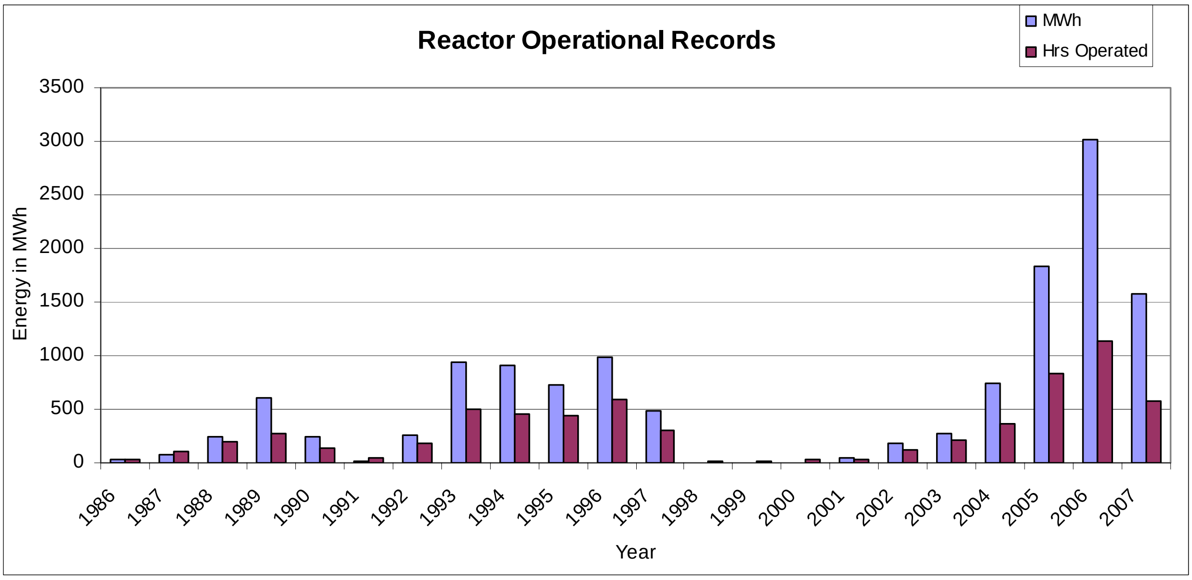


Fig.3 Operational Statistics of BAEC TRIGA Research Reactor (up to July 2007)

3.2 Reactor Incidents

So far five reportable incidents took place in the BAEC TRIGA reactor facility. These are as follows:

Incident-1: A small aluminum pipe of the emergency core cooling system (ECCS) having a diameter of 2.5 cm developed a leakage on 3 January 1990, due to constructional defects. This was studied and rectified.

Incident-2: A crack was developed in the welding joint of the exi-check valve of the primary cooling system on 4 September 1990. The failure was thoroughly studied. The crack developed primarily due to faulty primary pump foundation and the pipe support system. The design of the system also contributed partly to the excessive vibrations. The system was rectified, tested and cleared for normal operation.

Incident-3: In July 1992 a fuel element, while carrying out the routine dimensional checks, dropped inside the reactor tank. There was no apparent damage to either the fuel element or to the reactor tank. The fuel element was, however, replaced by a new one. This incident occurred due to safety procedure violation and lack of QA measures.

Incident-4: In February 1993 an Aluminum specimen container used for irradiating samples cracked inside the dry central thimble (CT) while undergoing 12 hour long irradiation at 3 MW. The incident was reviewed and studied. The CT was appropriately (1993) cleaned and decontaminated. This incident occurred again due to safety procedure violation and lack of QA measures.

Incident-5: 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. About 45,000 liters of de-mineralized water with an activity concentration of about 28 Bq/liter due to the presence of ^{58}Co, leaked out from the primary cooling loop. The water was collected and contained in a special storage and in plastic containers.

3.3 Decay Tank Incident

On 14 July 1997, water was found to be leaking out of the 32000 liter capacity decay tank of the primary cooling system of the reactor while carrying out the routine inspection of the facility. About 34000 liters of de-mineralized water with an activity concentration of about 28 Bq/liter (mainly due to the presence of ^{58}Co) leaked out from the primary water system. The water was collected and stored in several polyethylene containers.

A number of independent investigations and assessments on the cause of leakage and possible remedies were carried out. The tank was isolated, removed and corroded areas were tested by NDT techniques. Extensive corrosion and pitting were found in a particular area where rain water seeped in during monsoon and accumulated for a long period, perhaps over a number of sensors. Corrosion and pitting were also observed on the inner walls/baffles of the decay tank.

Fig 4 shows the pitting corrosion of the decay tank bottom and fig.5 shows the decay tank saddle. Fig.6 shows the new decay tank supplied by General Atomics, USA. To protect rain water, a room has been constructed over the new decay tank.

3.4 Problem with the Reactor Cooling System

3.4.1 Problem with the Vibration in the Discharge Line of the Primary Pump

A fault at the weld-joint in the form of a crack having a circumferential length of about 25 cm in the exi-check valve of the primary cooling system was detected in September 1990. It was found that vibration induced stress in the primary pipes was one of the reasons for this failure. Design defects such as pipe supports, layout, couplings spacers and hubs; misalignment of pump and motor, defective motor bearings, static imbalance of pump impeller, and undesirable throttling of discharge valves of the pumps were identified as some of the possible reasons leading to the fault. The exi-check valve was duly repaired and reinstalled. Pipe supports and pump foundations were modified so as to reduce stress and vibration by incorporating some additional valves, replacing a "T" joint with a modified "Y" joint. Impeller and shaft of the primary pumps were also balanced statically to reduce vibration.

Fig. 4 Pitting Corrosion of the Decay Tank Bottom

Fig. 5 Decay Tank Saddle

Fig. 6 New Decay Tank

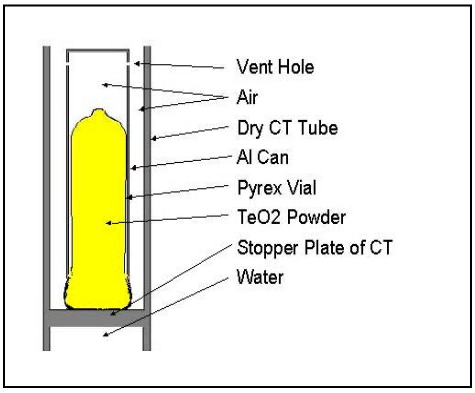


Fig. 7 Damaged Pyrex Vial inside the DCT

3.4.2 Problem with the Primary and Secondary Pumps

Electrical phase changed by Rural Electrification Board (REB), local electricity supply authority, the impeller of primary cooling system pumps were found to get stack with volute casing due to reverse rotation. This caused the snap ring (retainer ring) to be damaged. ROMU`s Mechanical Maintenance Group replaced the damaged snap ring with a new one. Bearings of the pumps & motors of the primary and secondary cooling pump-motor set replaced by new ones.

3.4.3 Problem with the Heat Exchanger

The efficiency of the shell and tube heat exchanger was seriously degraded due to fouling on the surfaces of the tubes. A new plate type heat exchanger with cooling capacity of about 4 MW (extendable up to 7 MW) was installed replacing the old shell and tube heat exchanger. With the introduction of the high performance plate type heat exchanger, the cooling rate of the primary water has noticeably improved. As a result, it has been possible to operate the reactor at full power with comparatively lower core inlet temperature.

3.5 Problem with the Emergency Core Cooling System (ECCS)

ECCS is the single most important engineered safety system of the reactor that plays the key role for protecting the reactor fuel in the event of a Loss Of Coolant Accident (LOCA). 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. In order to improve the operational safety of the ECCS, several modifications were implemented after the installation of the new decay tank and associated components of the reactor cooling system which comprises the plate type heat exchanger, modified Y-connection, new isolation valves, etc. The modifications of the ECCS include ECCS piping layout, shifting & modifications of the ECCS mounting block containing ECCS pump-motor, battery and battery charger unit to a safe height.

3.6 DCT Incident

DCT is mostly used for production of RI. In March 2002, the reactor was operated at full power for 8 hours to irradiate 50g of TeO_2 powder in the DCT for trial production of ^{131}I. The TeO_2 powder was filled in a pyrex vial, which was again placed inside a standard aluminum specimen container. The aluminum specimen container was then placed in the DCT. When the irradiated aluminum container was attempted to take out from the DCT after 3 days cooling, it was found that its lower part was got melted. Further investigation revealed that the lower part of the pyrex vial was also got melted and about 30g (out of 50g) of the irradiated TeO_2 powder was left over the DCT. Figure 7 shows the contaminated DCT with partial melted pyrex vial (bottom part) in it. This was happened due to excess heat generation over the surface of the pyrex vial. After the incident, the contaminated DCT was removed from the reactor core and in its place the old Wet CT (WCT) was installed. The WCT was again replaced by a new DCT in June 2003 such that radioisotope production could be continued.

3.7 Problem with the Instrumentation and Control System

The Instrumentation and Control (I&C) system of the reactor uses mostly analog system and devices, which are getting backdated and obsolete. However, BAEC engineers and scientists have so far been operating and maintaining the I&C system quite successfully. Several modifications and upgrading of the system were carried out so as to operate the reactor with safety. This included, among others, development of a PC-based Data Acquisition System (DAS), incorporation of digital flow measuring system in the secondary cooling loop, High Pool Water Level Scram System, Instrument Air Interlock System, etc. Efforts are now on to upgrade the analog I & C system using state of the art digital technology.

4. Project related to BAEC 3MW TRIGA Mk-II Research Reactor

4.1 ADP Project for upgrading the TRIGA Mark-II research reactor for increased isotope production and other uses

An ADP project has been completed to upgrade the research reactor for strengthening isotope production program and other uses. The main objective of the project is to renovate and refurbish the TRIGA MARK II Research Reactor for increased Isotope production and other uses in different research areas. Components and spares are needed to keep it operational. BAEC has 13 (thirteen) on going Nuclear Medicine Centers and one Institute through which nuclear diagnosis and treatment services are being given to the general mass using radioisotopes. Several equipment /items were purchased under this ADP project which includes 650 kVA Diesel Generator, 600 kVA Automatic Induction Voltage Regulator (AIVR), Vibration measuring equipment, computerized PCB maker, Fission chamber, UPS (1000 VA), Fuel handling tool, RTD transmitter, Dry Irradiation Tube (DIT), Continuous Air Monitor (CAM), Hand and Foot Monitor, Digital Pocket Alarm Dosimeter and Wireless communication equipment for ROMU facility and Compact Control System for Iodine-131 isotope production plant along with necessary backup equipment and spares, Cold Tc-99m generators with necessary kits, furnace for Iodine-131 production plant, Quality Control equipment for RIPD of INST. These equipment have been successfully installed in the reactor facility and isotope production lab.

4.2 Installation of Digital Control System for the TRIGA Mark-II Research Reactor

The present analog console can be kept operational for next 3-4 years with the help of the present stock of the spare parts, but after that it would be very much difficult to keep it operational as a consequence of the shortage and unavailability of spare parts. The manufacturer and supplier of the 3MW TRIGA reactor informed that, it would not be possible for them to supply or provide any service relating to the old technology based analog control system in future. On the other hand, it is very much essential to ensure the nuclear radiation safety as far as the growing uses and especially repair and maintenance of the reactor are concerned. Needless to say that, Control and Instrumentation system is the key to manage nuclear safety of the reactor.

Considering the above mentioned points an ADP project on “Strengthening the Control System of TRIGA Mark II Research Reactor by installing Digital Control Console” has been taken for installation of a digital control console and instrumentations based on the state-of-the-art-technology is being proposed by changing the analog based console and instrumentations. With the installation of PC based Digital Control Console including data acquisition and control unit, reactor protection system, wide range log power channel, multi range linear power channel, safety power channel, three fuel temperature channels, four control rod drives, three reactor pool water level float switches and Side Cabinet systems for monitoring and measuring different process parameters/variables like flow rate, pressure, temperature, electrical conductivity, p^H of all air conditioning, ventilations, cooling and other systems of the reactor will be developed under this project.

5. Utilization of the Reactor

5.1 Radioisotope Production

The reactor facility is now being used routinely for production of Iodine-131 (^{131}I) for medical uses. Scandium-46 (^{46}Sc) was also produced once for isotope hydrology research. A total of 1147 irradiation requests (IRs) were completed for radioisotope production and different R&D activates so far. The total amount of radioisotope produced stands at about 4200 GBq. The current demand of ^{131}I in the country is about 1 Ci per fortnight.

5.2 R & D Activities

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. NAA technique is also used to determine very low level ($\cong$ 0.06 ppb) of arsenic in drinking water, human hair, paddy, rice, urine and food staff. It is to be mentioned here that arsenic contamination in drinking water is a serious problem that is prevailing throughout the country. NR facility is used to detect voids, cracks, internal continuity in materials and 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. Students from different Universities of Bangladesh are working for M.Sc., M. Phill and Ph. D. degrees using reactor facilities at different laboratories of INST. An ADP project is now going on namely “Strengthening the Utilization of the TRIGA Mk-II Research Reactor” funded by the Govt. of Bangladesh. Under this project a Neutron Powder Diffractometer will be installed at the Radial Beam Port-1 of the reactor.

5.3 Training Program

The facility has so far been used to train up a total of 27 personnel including several foreign nationals to the level of Senior Reactor Operator (SRO) and Reactor Operator (RO). Of them, only two licensed SROs and nine ROs are working at the facility. The other personnel have either left the organization or have moved to some other places within the organization with new assignments. About 30 students of 4th year B.Sc. Engineering (Mechanical) from Engineering Universities received their industrial training from ROMU. To increase the strength of SRO / RO pool, seven personnel are now being received training at the facility.

6.1. Safety documents

BAEC TRIGA has following important Safety documents:

- 2nd version of BAEC TRIGA Reactor Safety Analysis Report (SAR) has already been completed.
- Preparation of 25 BAEC TRIGA Reactor Operating Procedures (BTROP) are now under process.

6.2. Safety Committees

a. AERE Radiation Safety and Control Committee (RS&CC)

- To strengthen and implement radiation safety and control activities in accordance with the NSRC-Law-21/1993 and the NSRC Rules 97 (SRO No. 205-Law/97)
- Implementation of applicable safety standards, codes and guides adopted by the Competent Authority.

b. AERE Nuclear Safety and Safeguards Committees (NSSC)

- To audit, review, evaluate, recommend and approve all programs, actions and issues involving inventory accounting and safeguards of all nuclear materials including spent fuels stored and/or used in AERE as per the Safeguards Agreement and it’s Subsidiary Arrangements between the Govt. of People’s Republic of Bangladesh and the IAEA under the NPT signed in September, 1979.
- These activities shall be carried out in accordance with the Guides, and Standards prescribed/adopted by the Regulations/Bangladesh Atomic Energy Commission.

c. AERE Research Reactor Operation and Utilization Committee (RROUC)

- To promote the safety in operation and use of research reactor.
- To review, evaluate, recommend and approve experiments, programs, actions and issues involving safety, operation and use of the 3 MW TRIGA Mark-II Research Reactor in accordance with the FSAR and other Safety Standards prescribed/adopted by the Regulations based on the Nuclear Safety and Radiation Control Act of 1993.
- RROUC will also audit the activities of the authority responsible for operation and maintenance of the research reactor.

7. Knowledge Management

The management of nuclear knowledge has emerged as growing challenge in recent years. The need to preserve and transfer nuclear knowledge is compounded by nuclear trends, such as ageing of the nuclear workforce, declining student numbers in nuclear related fields, and the threat of losing accumulated nuclear knowledge. Developing both guidance documents for nuclear knowledge management in Reactor Operation & Maintenance Unit (ROMU), Institute of Nuclear Science and Technology (INST) and other institutes of Atomic Energy Research Establishment of knowledge management system are the key activities.

In recent years, a number of trends have drawn attention to the need for better management of nuclear knowledge. The nuclear workforce is ageing as more nuclear workers approach retirement age without a compensating influx of appropriately qualified younger personnel to replace them. Fewer young people are studying nuclear science, nuclear engineering and related fields at university level, and a growing number of universities have given up their nuclear education programmers altogether. If the efficient transfer of nuclear knowledge from one generation to the next is constrained by an ageing workforce and fewer university program that only increases the importance of maintaining accessible, clear and comprehensive technical information and documentation.

Bangladesh Atomic Energy commission (BAEC) is interested to set up a Nuclear Safety Network Center under the umbrella of Asian Nuclear Safety Network (ANSN) at AERE, Savar, Dhaka. BAEC has a plan to preserve and enhance nuclear knowledge and to ensure the availability of qualified manpower vital to the continued, safe and secured utilization of nuclear technologies for peaceful purposes.

8. Conclusion

The reactor has been operated safely for various peaceful applications of nuclear technology without few incidents as presented in the paper. The modification, rectification and upgrading works of the facility were carried out locally. The reactor is being utilized for producing RI for its medical uses, conducting various R&D activities and manpower-training program of the country. There is a plan to install more dry tubes in the core so as to meet the total demand of RI in the country. There is also plan to develop unused experimental facilities such as, thermal column and radial beam ports for strengthening the R& D activities around the reactor and to preserve nuclear knowledge and to ensure the availability of qualified manpower for safe and secured utilization of nuclear technologies for peaceful purposes.

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