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Safety Assessment, Vulnerability Analysis and Remedial Measures for different Systems of the BAEC TRIGA Research Reactor

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Abstract

BAEC TRIGA Research Reactor (BTRR) has been in operation since 1986 and utilizing for peaceful applications of nuclear science and technology like experimental research on reactor safety, various R&D activities in the field of neutron activation analysis, neutron radiography, neutron scattering and manpower training & education. During the operation period of about 38 years some of its systems, structures and components (SSCs) were subjected to performance degradation. Therefore, to assess the residual life of the reactor the detailed ageing studies were carried out to identify aging effects and appropriate remedial actions. Based on this study some modernization, refurbishment and extension of reactor safety related systems with the objective of design life extension for about 15-20 years was performed. During refurbishment, additional safety features were incorporated in various systems to qualify them for the current safety standards. This paper gives the details of the refurbishment and upgradation works to extent BTRR design life ensuring operational safety.

Keywords: BTRR, Safety assessment, SSCs, Ageing study, Remedial measure, Life extension, and Safety.

1. Introduction

The BAEC TRIGA Research Reactor (BTRR) with a capacity of three megawatts (3 MW) (Safety Analysis Report (SAR), 2005) was purchased from the US General Atomics Company and installed at the Atomic Energy Research Institute in Savar, Bangladesh. It is the country's only nuclear research reactor having 100 erbium-uranium-zirconium hydride fuel elements in a circular grid array, 6 boron carbide (B_4C) control rods and 1 Am-Be neutron source of 3 Ci strength (General Atomics, 1984). On 14 September 1986, the reactor started operating after achieving criticality. The research reactor plays a key role in the production of radioisotopes, research activities (neutron activation analysis, neutron radiography, neutron scattering and other studies related to reactor safety) (Islam *et al.*, 2004) and the development of human resources in nuclear science and engineering. The knowledge and experience gained through operating the research reactor has been directly and indirectly instrumental in the development of the nuclear power programme of the country. BTRR provides educational and training support to students of nuclear science and engineering departments of various universities. Also the specialized knowledge gained through operating the reactor is playing a significant role in nuclear safety, human resource development, environmental protection, emergency preparedness, physical security, waste management, fuel handling and conservation.

The design life of TRIGA reactors is about 30 years but many countries extended the life by replacing essential parts, adding new systems, modernizing safety systems, repairing and maintaining reactors. Therefore, it is expected that BTRR operating life time can also be extended for 15 to 20 years through a comprehensive ageing management, refurbishment and modernization program. Pre-OMARR and main OMARR (Operational and Maintenance Assessment for Research Reactors) mission was conducted to provide recommendations and suggestions for preparation of action plans for ensuring long term operation of the reactor with enhanced performance and reliability.

According to OMARR mission recommendations as core structure and reactor tank appears in good condition, operational lifetime can be extended by replacing, refurbishing some associating systems. Considering the above, an Annual Develop-ment Program (ADP) project has been implemented to extend the life of BTRR by 15 to 20 years through aging management.

The most significant upgradation and modernization actions in this project are: installation of new digital I&C system, refurbishment of the primary and secondary cooling system and ventilation system, upgradation of radiation monitoring and protection system, modernization of fire detection, suppression and alarm system, installation of new plate-type heat exchanger etc. As a result of these upgradation and refurbishment the reactors nuclear and physical safety measures have been enhanced.

I&C system of Digital Console

Initially the reactor was operated by an analog control console but due to scarcity of necessary spare parts, the main part of the console was replaced by a digital console in 2012 by General Atomics-ESI, the supplier of the reactor. Later, with the remaining analog parts of the control system, field instruments and insufficient spare parts of digital consoles, failure rate of the instrumentation and control (I&C) system escalated. This resulted in frequent reactor shutdowns and extended repair durations, thereby creating uncertainty regarding the safe operation of the reactor.

In addition, after the Fukushima-Daiichi NPP accident in 2011, IAEA's latest Safety Standard (IAEA Safety Standards Series No. SSR-3, 2021) No. According to SSR-3, Reactor Protection System (RPS) needs to be Redundant, Physically Separated and Independent which was not included in the partial digital console installed in 2012. Therefore, the complete control system of the reactor with all field instruments replaced by state-of-the-art technology digital instrument & control System has been installed. This fully-digitalized I&C systems capable to control and monitor variables and parameters of physical and other processes, component and system statuses considering safety conditions. The new I&C systems also able to perform all the functions in standard or abnormal conditions, including emergency scenarios. The I&C systems are equipped by appropriate control and safety devices to keep critical variables within the pre-defined limits specified in the Safety Analysis Report. The main inherent safety feature of the new 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 functions of the BTRR I&C system can be clustered into three main categories. Firstly, BTRR I&C system provides means of monitoring (Final Safety Analysis Report (SAR), 2020) 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. Secondly, it provides a means of protecting (Soner *et al.,* 2022) 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. Finally, it provides means of controlling the reactor power by withdrawal and positioning the control rods as well as maintaining and regulating the power to a 'set' value. To execute all these functions, the new reactor operating console consists of the following systems:

- Data Acquisition and Control System (DACS)
- Reactor Protection System (RPS) Cabinets
- Wide range Neutron Measurement System (WR-NMS)
- Operation Workstation (OWS)

Apart from RPS, Data Acquisition System and Thermal Power Calculator (TPC) have been kept redundant in the system. As a result, it will be possible to operate the reactor with greater safety. Human-Machine-Interfacing (HMI) is also emphasized during the design of Digital I&C System and it is tested and deployed at various levels. Successful completion of Factory Acceptance Test (FAT) before shipment of new Digital I&C System and after installation Site Acceptance Test (SAT), System Performance Test (SPT), Commissioning Test and Reactor Performance Test (RPT) through continuous 24 hours reactor operation. It may be noted that the above tests were successfully completed by CRR engineers/scientists in the presence of experts from the supplier. It is also noted that the required number of spare parts for the new Digital I&C System has been procured through this project.

Fig. 1: Reactor Shield Structure (1a, left) and Reactor Digital I & C System (1b, right).

Modernization of the reactor's primary and secondary cooling systems

The reactor's primary and secondary cooling systems have two pumps each, driven by two electric motors of 37.5 kW and 30.0 kW, respectively. The reactor's primary cooling system requires a water flow of 3,500 gallons per minute (Ajijul Hoq *et al.,* 2017). To achieve this, previously, two pumps had to be operated with the valves in the pump discharge line closed by about 50%. This would have created additional vibration in the pump and discharge line and consumed additional power in the motors. To reduce vibration in the discharge line, some pipe supports were installed in 2001 to bring the vibration to a tolerable level. Four Variable Frequency Drives (VFDs) have been installed to drive and control the frequency of the motors to maintain a flow of 3,500 gallons of water per minute in the primary cooling system through control logic of the new Digital I&C System. As the two valves in the discharge line of the primary cooling system are fully open, the vibration of the discharge line has been further reduced and the two pumps are consuming about 50% less electricity. This has resulted in a reduction in overall reactor power consumption by about 20%. In addition, new Plate Type Heat Exchanger and Cooling Tower have been installed to increase the cooling performance of the reactor's primary and secondary cooling systems. It is also worth noting that the field instruments of the reactor's Primary and Secondary Cooling Systems, On-line Purification System, Emergency Core Cooling System have been replaced with digital instruments and connected to the reactor's Digital I&C System. As a result, it is possible to monitor all parameters from the control room during reactor operation.

Fig. 2: Primary Cooling System Pumps (2a, left), VFD (2b, middle), and Heat Exchanger (2c, right).

Reactor Hall Ventilation System

The Reactor Hall Ventilation System is one of the most important systems of the reactor facility for ensuring radiation safety. With the system a 0.08 inch-of-water negative pressure is maintained inside the reactor hall and airborne radioactive substances are monitored by the Stack Monitor, filtered if necessary, and released to acceptable levels through the Building Stack. Beforehand, the reactor hall ventilation control system was manually operated analogue system. Under the said project, negative pressure was maintained inside the reactor hall by installing a Programmable Logic Controller (PLC), the Air-tight Door Control. Moreover, Inflation System was renovated, a Biometric Access Control System was added, and the Stack Monitor and Continuous Air Monitor were replaced.

Construction of 1250 KVA electrical sub-station

The former electrical sub-station and 250 kVA emergency diesel generators were located on the ground floor of the building adjacent to the reactor building. A new 1250 KVA sub-station has been constructed under the project to reduce extreme external hazards (fire accidents) as per IAEA guidelines. The 250 KVA diesel generators are placed side by side in the 650 KVA generator room.

Radiation Monitoring System

To enhance radiation monitoring and protection system of the reactor facility new Continuous Air Monitor (CAM) and Area Radiation Monitoring (ARM) Systems have been installed. The previous monitors reached the end of their lifetime and the efficiency of them begun to decline from the standard level. New area radiation monitoring system monitors the radiation level of specific points of the facility for 24 hours. New ARM is fully digitalized and consists of seven detectors (reactor top, four beam ports, heat exchanger room and primary pump room) with two local display units to monitor the radiation levels from the reactor hall and control room. The previous ARM system was analogue and had detectors on six locations which became faulty over the time. Moreover, two new hand foot monitors have been installed in the facility to enhance personal radiation safety for the radiation workers and avoid contamination.

Physical Protection System

To increase the physical security of BTRR, a 10 feet high security wall with 2 feet barbed wire placed on top has been constructed. Inner Security Fence has been installed around the reactor building which is protected by Perimeter Protected Camera. Biometric Access Control System has been installed inside the reactor building. A new Vehicle and Personnel Portal has been set up to access the CRR. Archway Gate, X-ray Bag Scanner, Full-height turnstile/Flap Barrier, Hand held Metal Detector, Vehicle inspection mirror and Boom Barrier has been installed at both places. Besides, the entire facility has been brought under the cover of CC cameras.

Fig. 3: 1250 kVA Electrical Sub-station (3a, left), and Outside View of CRR (3b).

2. Conclusion

In the light of the long practical experience of operating the BAEC TRIGA Research Reactor, it has been possible to eliminate the identified problems of reactor safety and other supporting systems through successful completion of repair, renovation and modernization work. It is expected that the BTRR will be able to run for another 15 to 20 years ensuring operational safety. If new TRIGA fuel can be acquired, it may be feasible to restart the production of radioisotopes alone with extensive research in several scientific and engineering disciplines and training of personnel to ensure its best use.

3. Author Contributions

A.H.: Conceptualization, methodology, writing the manuscript. N.J.; M.O.R.; and M.A.M.S.: Contributed in investigation, visualization. M.R.H.; M.A.S.; and M.M.U.: Finally checked the manuscript and editing, and funding acquisition. All authors who are involved in this research read and approved the manuscript for publication.

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5. Conflicts of interest

The authors sincerely admitted no conflicts of interest to declare.

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