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REFURBISHMENT OF THE COOLING SYSTEM OF THE 3 MW TRIGA Mk-II RESEARCH REACTOR OF BANGLADESH

M. A. Zulquarnain[1], M. M. Haque[1], M. A. Salam[1], M. A. Sarder[1], M. A. M. Soner[1], A. Haque[1], M. M. Uddin[1], M. M. Rahman[1], M. Haque[2] and T. Q. Choudhury[2]

[1]Reactor Operation and Maintenance Unit, Atomic Energy Research Establishment (AERE) Bangladesh Atomic Energy Commission (BAEC), Dhaka, Bangladesh
[2]Central Engineering Facility, AERE, BAEC, Dhaka, Bangladesh

ABSTRACT
The 3 MW TRIGA MK-II research reactor of Bangladesh Atomic Energy Commission (BAEC) achieved its first criticality on 14 September 1986. Since then 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. During the last 21 years, full power operation of the reactor had to be suspended a couple of times because of various problems of the primary cooling system. Of these, the leakage problem of the N-16 decay tank in 1997 is considered to be most serious one. Full power operation of the reactor had to be suspended for a long period of about 5 years. The decay tank was replaced by a new one in 2001 and some modification and upgrading works were carried out in the cooling system of the reactor such that operational safety of the reactor could be strengthened. After successful completion of all these modification work, the reactor was made operational again at full power of 3 MW in August 2001. The paper focuses on the experience with the modification of the cooling system of the 3 MW TRIGA Mark-II research reactor of Bangladesh.

Keywords: N-16 decay tank, cooling loops, plate type heat exchanger, loss of cooling accident (LOCA)

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 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 achieved its first criticality on 14 September 1986, and was commissioned at the full power of 3 MW in the same year. 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. The most severe of these incidents was the “N-16 Decay Tank Leakage Incident” that took place in 1997. As a consequence of this 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 upgrading of the entire cooling system of the reactor were carried out. The renovated cooling system was successfully commissioned in June 2002 and through this, it was possible to restore the full power operation of the reactor after a long period of about five years.

From July 2004, the reactor is being used for the production of Iodine-131 (I-131) for all the nuclear medicine centres of the country on routine basis. After the replacement of the damaged central dry irradiation tube by a new one in June 2003, a total of 160 batches of I-131 with a cumulative activity of about 2,574GBq have been produced until July 2007. The reactor is now also being operated for about 1000 hours per year for radioisotope production and for irradiation of different samples under various programs in the areas of NAA, NR and neutron scattering. Annual operation data of the reactor are shown graphically in Fig 1.

2. N-16 DECAY TANK LEAKAGE INCIDENT
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 litres of de-mineralized water with an activity concentration of

about 28 Bq/litre 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. The tank was isolated and then removed (Fig 2), and tested both non-destructively and destructively.

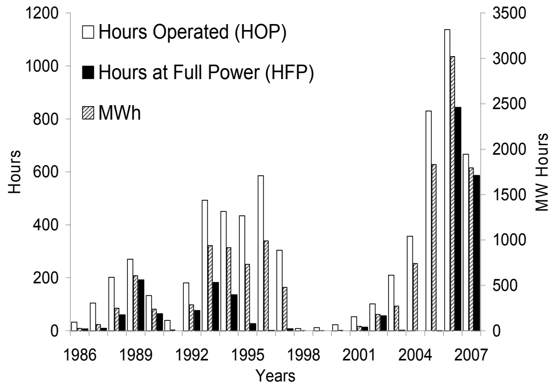

Fig 1: Operation data of the reactor (Sept '86-Aug '07)

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 of perhaps a number of years. Upon inspection, corrosion and pitting were also observed on the inner walls/baffles of the decay tank. It is to be noted that a leakage in the primary cooling loop of the reactor could have caused loss of coolant accident (LOCA) to occur. However, in the case presented here, it was possible to avoid LOCA because of the passive safety system which had been incorporated into the design of the primary cooling loop through the use of anti-siphon vent line at appropriate location of the outlet piping of the primary cooling loop (Fig 3).

On 27 July 1998, a jumper connection was installed in place of the decay tank. With this jumper or decay tank bypass connection, the reactor was made operational at a power level of 250kW (high power operation was not possible without a N-16 decay tank). During 2000 – 2001, a new decay tank was installed and at the same time several modifications in the primary cooling loop such as, replacement of the tube-shell type heat exchanger with a plate type heat exchanger, replacement of the 'T' connection at the discharge of the pumps with a modified 'Y' connection, etc. were implemented so as to make the reactor operational again at full power.

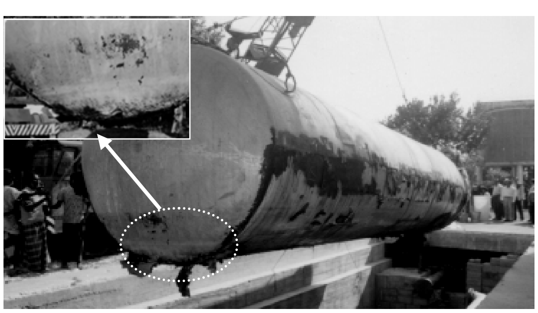

Fig 2: Removal of the damaged N-16 decay tank

2.1 Feasibility for Local Fabrication

An attempt was made to see if the fabrication of the decay tank could be done locally. A committee was formed with members from within and outside BAEC. Various local organizations like BITAC, MAWTS, Biman Hangar Complex etc. were visited to see the sort of facilities available

It may be mentioned that the services required for such a fabrication job includes plate rolling, edge preparation, plate cutting, and TIG welding and marking and fitting. Though some facilities were available in some organizations, a comprehensive service could not be obtained from any one. This vessel was a four pass vessel and though rated at atmospheric pressure, welding and general design was to be carried out based on Pressure vessel Code.

Quotations from suppliers of the special alloy aluminum plate were received. Considering the time constraint the absence of a consolidated service and the estimated cost, a purchase decision was made. However, if a mild steel vessel was considered, it could have been fabricated here. The non availability of expert TIG plate welder was a big factor in this decision to procure.

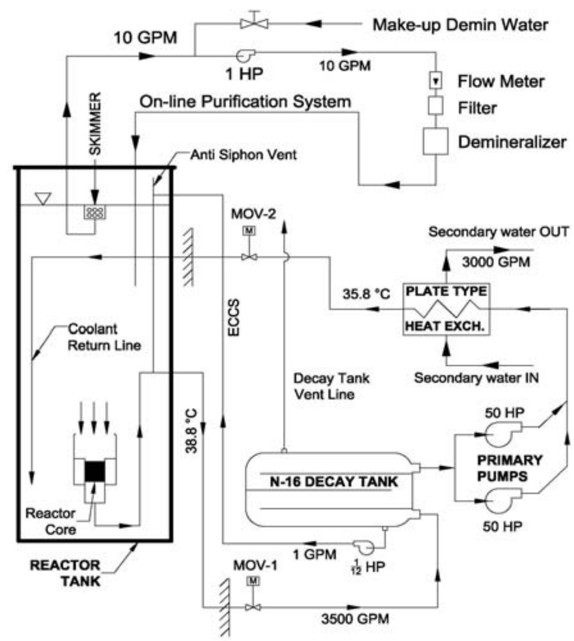

Fig 3: Primary cooling system of the research reactor

3. CAUSES OF THE INCIDENT

The decay tank leakage problem was thoroughly investigated to identify the causes of the incident. Recommendations of the local experts (from within and outside BAEC) were taken for rectification/ refurbishment measures/work to be implemented. Major causes of the incident as identified through various investigations are as follows:

(1) Improper design of the decay tank concrete saddle.
(2) Improper routing of the decay tank vent line.
(3) Improper design of the shielding wall between the decay tank room and the primary pump room.
(4) Weakness in Quality System (QS).

4. REFURBISHMENT OF THE COOLING SYSTEMS

Cooling system of the reactor was refurbished during 2000-2001 based on the recommendations of the expert committees. Some of the modifications carried out are described in the following sections.

Fig 4: New decay tank with aluminium saddle

4.1 New Decay Tank and Plate Type Heat Exchanger

A new decay tank with four aluminium saddles welded to its body was installed in the decay tank room. 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. 4.

A new plate type heat exchanger was 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 shown Fig 5.

4.2 Chemical Injection System for the Secondary Cooling Loop

A microprocessor based chemical controller was installed for secondary cooling loop. The controller injects three chemicals into the secondary loop water so as to maintain the secondary water chemistry parameters (conductivity, total alkalinity, chlorides, total hardness, silica, phosphonate) within permissible limits.

4.3 Modification of the Cooling System Piping Arrangements

A modified Y-connection (Fig 6) 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 may 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

Fig 5: Plate type H/E with modified piping arrangements

causes could have been this turbulence. The "Y" connection in the discharge resolved the matter to a great extent.

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.

Fig 6: Modified Y-connection replacing T-connection

4.4 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 7).

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.

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.

4.5 Modification of the Shielding Arrangements around the Decay Tank

A concrete shielding wall having a thickness of about 1.12m (44 in.) was constructed between the decay tank room and the primary pump room in order to protect the personnel working in the primary pump room and adjacent areas from radiation hazard. A mild steel door (203.2 cm x 63.5cm x 3.175 cm) was provided in the shielding wall to facilitate periodic inspection of the decay tank room. Decay tank room top shielding was also raised by 58cm (20 inches) compared to its previous position. A room with corrugated iron (C.I.) sheet roof was constructed on the top of the decay tank room, such that rainwater cannot enter into the decay tank room. Before this modification, rain water could fall directly on the top of the vertical shielding blocks placed over the decay tank.

Fig 7: Modified pipe supports

4.5 Modification of the Emergency Core Cooling System (ECCS)

ECCS is the single most important engineered safety system of the BAEC 3 MW TRIGA 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. 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.

5. OUT COME OF THE REFURBISHMENT WORK

The refurbishment work was performed to sustain safe and reliable operation of the reactor. After satisfactory installation of the plate type heat exchanger and Y-connection some of the parameters of the secondary systems were found to improve. Table 1 & 2 show the improvements.

Table 1: Cooling System Parameters

Parameters	Old system	New system
Flow Rate	13,230 l/min.	13,230 l/min.
Core Inlet Temp.	40 ^{0}C	35.8 ^{0}C
Core Outlet Temp.	43 ^{0}C	38.8 ^{0}C
Fuel Temp.	620 ^{0}C	520 ^{0}C

Table 2: Vibration Data of Primary Pumps & Motors

Location	Vertical component of vibration velocity (cm/s)	
	T-connection	Y-connection
Top of motor (non-drive end)	0.53	0.35
Top of motor (drive end)	0.6	0.33
Pump (suction end)	0.4	0.3
Pump (coupling end)	0.96	0.5

From Table-1 it is observed that after installation of the plate type heat exchanger reactor core inlet, outlet and fuel temperatures have dropped down compared to their corresponding previous values. This indicates that the safety margins have improved after the modification work. It is to be mentioned that the old shell and tube type heat exchanger got fouled seriously and as such it was not being possible to operate the reactor at 3 MW during the hot and humid days.

From Table-2 it is observed that after installation of Y-connection and appropriate pipe supports, the vibration level of the primary pumps & motors have minimised significantly and thus ensured safer operation of the reactor cooling system.

Besides these, the other modification work that were implemented in the reactor cooling system (ECCS, decay tank, etc.) have also enhanced the overall safety of the reactor.

6. CONCLUSIONS

The reactor has been operated safely for last 21 years for various peaceful applications in the field of nuclear science and technology. During this period a couple of modifications and upgrading work were carried out, mostly in the cooling system of the reactor. Most of the modification, rectification and upgrading work were carried out with local resources to the extent possible. The reactor is now being utilized for producing I-131 radioisotope, conducting various R&D activities and manpower-training program of the country. Initiatives have been taken to install additional dry irradiation tubes in the core such that radioisotope production could be increased significantly. There is also plan to develop neutron instrumentations around the unused beam facilities such as, thermal column, radial beam ports, etc. for strengthening the neutron based R& D activities of BAEC. Measures have also been taken to strengthen the Quality Management System (QMS) of the reactor facility.

7. REFERENCES

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8. NOMENCLATURE

Symbol/ Acronym/	**Meaning/Full Construction**
AERE	Atomic Energy Research Establishment
BAEC	Bangladesh Atomic Energy Commission
BITA C	Bangladesh Industrial & Technical Assistance Centre
ECCS	Emergency Core Cooling System
GBq	Giga Becquerel
H/E	Heat Exchanger
hp	Horsepower
I	Iodine
LOCA	Loss of Coolant Accident
MAW TS	Mirpur Agricultural Workshop & Training School
MS	Mild Steel
N	Nitrogen
Ni-Cd	Nickel-Cadmium