CORROSION INDUCED LEAKAGE IN THE RADIAL BEAM PORT OF THE 3 MW TRIGA MARK-II RESEARCH REACTOR OF BANGLADESH

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Abstract

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. 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 1.016 m 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 33 cm inside the aluminium part of the BP. This segment of the BP plug was removed by using special hand tools designed and fabricated locally. Leakage of water at a rate of about 500 ml/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 around the damaged part of the RBP-1 by using innovative remote handling fastening devices, designed and fabricated locally. The paper presents details of the leakage problem, root cause analysis and the corrective measures implemented so as to prevent any further leakage of pool water through the beam port and thus make the reactor ready again for normal operations.

1. INTRODUCTION

BAEC TRIGA Mark-II research reactor (RR) is a light water cooled, graphite reflected reactor, designed for steady state and square wave operation up to a power level of 3MW (thermal) and for pulsing operation with a maximum pulse power of 852MW. The reactor achieved its first criticality on 14 September 1986, and was commissioned at full power of 3MW on 01 October, 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, neutron radiography and neutron scattering. The RR has four beam ports, namely tangential BP, radial piercing BP, radial BP #1 (RBP-1) and radial BP #2 (RBP-2). Figure 1 shows the locations of the BPs in the reactor shield structure and Figure 2 shows details of the radial beam port, RBP-1.

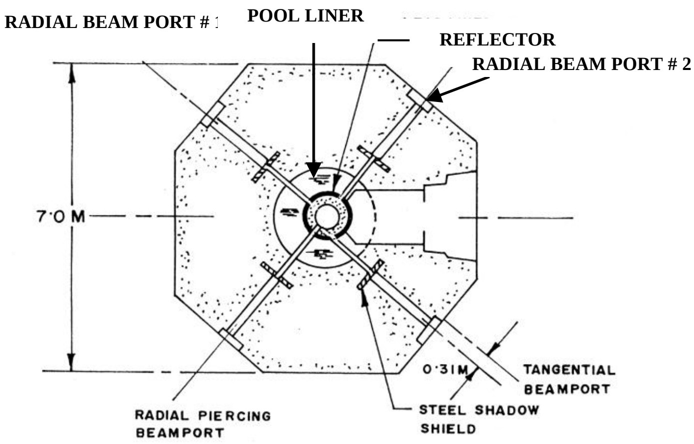


FIG. 1. Location of the beam ports.

It is to be mentioned that the parts of the BP located inside and immediate outside of the reactor pool liner are made of Type 6061-T6 aluminium alloy and its remaining part is made of Type 304 stainless steel. The tangential BP and the radial piercing BP have been in use for neutron radiography and neutron scattering respectively since early 90s. But RBP-1 and RBP-2, which have never been used for any purpose, remained plugged with various types of removable shield plugs provided by the reactor supplier since their commissioning in mid 80s. The BP plugs, mainly consist of (1) an outer plug, made of high density (HD) polyethylene; and (2) an inner plug, made of stainless steel, lead and graphite layers. The BP plugs are shown in *Fig. 3* and their dimensions are given in Table 1. The outermost ends of the BPs are shielded by sliding lead shutters each having a diameter of 25.4 cm and a thickness of 24.14 cm. The lead shutter slides in the rectangular box shown at the rightmost end of Figure 2.

In 2009, i.e., almost 23 years after the commissioning of the RR, it became necessary to remove the BP plugs from inside the RBP-1 so as to facilitate installation of the collimator of the high resolution powder diffractometer in it.

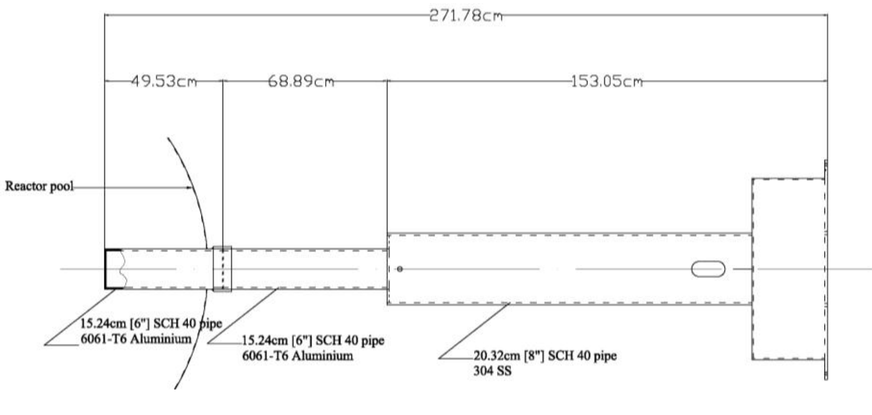
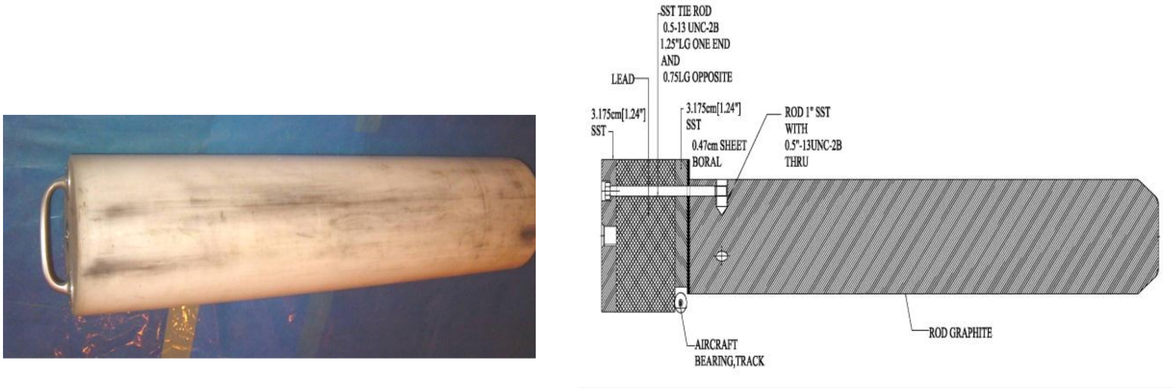


FIG. 2. Details of the radial beam port.

The HD polyethylene plug is a lightweight device (weight: 21.8 kg) and as such it was removed easily by hand. But for removing the inner plug, a special shielded handling equipment called, cask & carriage, and the over head crane of the reactor hall were used. While doing the removal operation, the graphite part of the inner BP plug got broken at the point where three punches, each 120^{o} apart, were made for fixing the anchor bolts. With the approval of the local safety committee, efforts were made to take out the 93.98cm long broken graphite plug. A scoop-like device (Figure 4) was used for this purpose. But unfortunately the plug got broken again into two parts. The outer part having a length of about 60.96cm could



(a) Outer plug assembly *(b) Inner plug assembly*

Fig. 3. Beam port plugs.

TABLE 1: DIMENSION OF INNER AND OUTER SHIELD PLUG ASSEMBLIES OF RBP-1

Shield plug assemblies	Materials	Dimensions (diameter x length)
Outer plug assembly	HD polyethylene	ϕ 20.02cm X 109.22cm
Inner plug assembly	Stainless Steel (SS)	ϕ 20.02cm X 05.72cm (2 pieces)
	Lead	ϕ 20.02cm X 12.70cm
	Graphite	ϕ 14.94cm X 101.60cm

be taken out easily with the help of the scoop mentioned above, but the inner part of the graphite plug (length 33.02cm; diameter: 14.94cm) remained stuck inside the aluminium section of BP tube. The plug was pulled by a mechanical tension application device after installing a rowel bolt on it (plug), but could not be moved. Then, with the approval of the regulatory authority, the sticking graphite plug was trimmed off by using an auger (circular-saw like cutting tool) and then taken out of the BP.

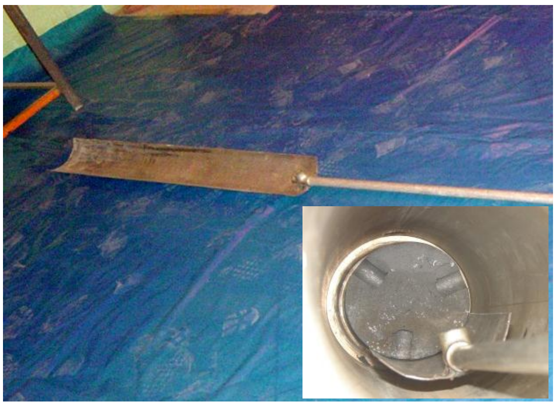


Fig. 4. Scoop used for graphite plug removal.

2. REMOVAL OF THE BROKEN GRAPHITE PLUG

Operations for removal of the 33.02 cm long broken part of the graphite plug was undertaken after getting formal approval of the regulatory authority. Before that Reactor Operation & Maintenance Unit (ROMU), the authorization holder of the reactor facility, had to submit to the regulatory authority detailed work plan, emergency response preparedness plan and QA program to be implemented in connection with plug removal work. While performing the removal operation, extreme care was taken such that the corroded aluminum BP pipe did not get damaged and also that the amount of graphite dust produced could be kept at minimum. The stainless steel auger, designed and fabricated mainly by ROMU personnel, was found to be very effective in this regard. A picture of the auger and associated fixtures used are shown in Figure 5. It is to be mentioned that the auger was operated manually so as to be sure that it was not cutting the wall of the aluminium BP tube. It took about 12 working days to complete the cutting operation. The picture of the last segment of the graphite plug is given in Figure 6. In this picture clear corrosion marks are seen on the surface of the graphite plug that was not trimmed off by the auger.

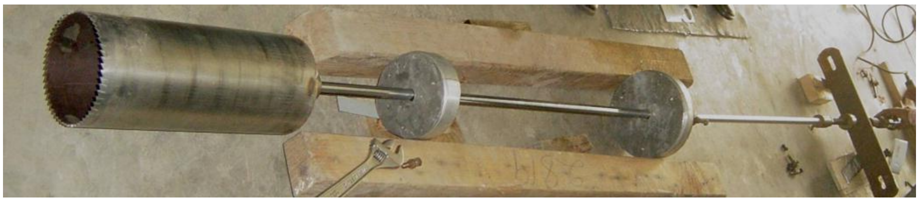


Fig. 5. The augur and associated fixtures.

3. PROBLEM INVESTIGATION

As the leakage of water through the beam port came to the notice of the operators, it was stopped by putting a rubber strap around the leaking part of the RBP-1 (see *FIG. 7*). Efforts were then made to carry out visual inspection of graphite plug and the inner part of the beam port using a digital camera. At the same time initiatives were taken to develop a device that could be used to prevent leakage of reactor pool water.

Fig. 6. Last segment of the graphite plug.

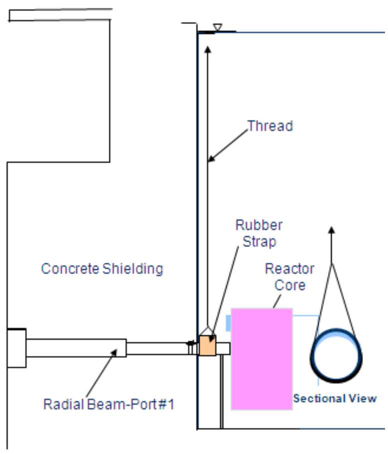


FIG. 7. Installation of the rubber strap

3.1. Visual inspections

The graphite plug removed from the RBP-1 was wrapped with a polyethylene sheet and stored in a wooden box. Upon visual inspection, water condensate was visible inside the polyethylene sheet. This clearly indicated that the corroded part of the graphite plug absorbed moisture from the condensate that had accumulated in the annular space between the plug and the beam port tube. Deposits or scales were found on the outer surface of the lead plug and these deposits consist of species resulting from the corrosion. Photographs obtained from a digital camera inserted into the RBP-1 clearly showed the corrosion damages in the form of metal removal and pits on the inner bottom surface of the aluminium pipe. It also revealed that the damage in the form of pits had initiated at the interface between the stainless steel and aluminium. Brown stain marks were observed on the stainless steel surface but no pits or metal removal was found on the stainless steel surface as shown in Figure 8.

3.2. Location of the leaks

As shown in Figure 2, the aluminium part of the RBP-1, which has a length of 48.26cm, pierces the reactor pool liner and terminates near the outer surface of aluminium liner of the reactor core. The end of the beam port tube is closed with a 6.125 mm thick aluminum disc. The graphite plug occupied about 34.29cm of the aluminium pipe. Therefore about 15.24 cm of the aluminium pipe of the beam port from its dead end remained void. The leaks that developed from corrosion damage mainly took place on the inner bottom surface of the aluminium pipe located at distances from 15.24 cm to 35.56 cm from the dead end of the RBP-1. Corrosion damage also occurred to some extent on the stainless steel pipe and at the aluminium-steel interface. These were confirmed by visually inspecting the inner walls of the beam tube with a digital camera that was inserted inside the beam tube and operated remotely.

3.3. Scanning electron microscopy and EDX analysis

Samples of corrosion products, debris, deposits, etc. were collected from inner surface of the aluminium part of RBP-1. The specific radio activities of these samples were found to be quite high, and as such, these could not be examined. However, scanning electron microscopy and energy dispersive X-ray (EDX) analysis of the deposits collected from the surface of the lead part of the inner shield plug [see Figure 3(b)] were performed. The results showed the presence of oxygen, carbon, lead, silicon and aluminium. The friable and porous nature of some of the debris indicated the presence of hydroxides in it.

Fig. 8. Corrosion at the Al-SS junction.

Fig. 9. Split type encirclement clamp.

4. ROOT CAUSE ANALYSIS

Detailed analysis pointed out that the aluminium (Al) pipe of the RBP-1 suffered extensive damage as a result of corrosion caused due to the presence of air and moisture inside the beam tube. It also attributed that damages in terms of corrosion had been initiated at the Al-SS interface where a SS sleeve had been used to cover the circumferential gap between the SS and Al pipes (see *FIG. 2*). It is to be noted that the interface sleeve was not wrapped with sealant during installation. As a result water vapour from the surrounding concrete found its way to condense into the gap between the graphite plug and aluminium pipe. Later these moistures initiated the corrosion process onto the aluminium pipe. The continual presence of moisture transformed the otherwise protective aluminium oxide layer into aluminium hydroxide, which is porous and cannot prevent seepage of air and moisture through it and attack the fresh aluminium underneath. The cracks and/or pits resulted from corrosion went through the aluminium pipe inter-granularly and allowed water from reactor tank to seep through and drain out of the beam port. The rubber sleeve used underneath the aluminium pipe temporarily sealed the mass flow of water from reactor tank and stopped water seepage through the beam port.

As already mentioned, the BP plugs were never removed in 23 years for inspecting the condition of the beam tubes. The mechanical maintenance manual did not have any instruction in this regard. The matter was also not addressed by the INSARR mission conducted in the RR facility in 1996 or the local safety committee or by the regulator. It is understood that if periodic inspection would have been performed at certain intervals, the corrosion problem, which developed gradually, could have been averted. The deficiency just mentioned is also one of the root causes that led to the corrosion leakage problem.

5. RECTIFICATION MEASURES IMPLEMENTED

Experts involved in the problem investigation recommended several actions including installation of an outside aluminium sleeve so as to protect the outer surface of the aluminium pipe and seal the flow of water from the reactor tank into the beam port. In line with the recommendation, a split type encirclement clamp (STEC) with silicon rubber lining as shown in Figure 9, was designed and fabricated locally using Type-6061 aluminium alloy. The STEC was then installed around the segment of the RBP-1, which is located inside the reactor pool at a depth of about 8m, by using innovative remote handling fastening devices, designed and fabricated locally. The STEC has been designed and fabricated with provision such that it can be dismantled for replacement of the silicone lining and reinstalled again. About 48 hours after installation of the STEC, the inner part of the RBP-1 was inspected with a camera and no trace of water was found.

It is to be noted here that approval of the regulatory authority was undertaken before implementing the above mentioned rectification measures, and also that several fuel elements had been removed from the part of the reactor core that was in the line of sight with the RBP-1 such that radiation streaming from the core could be minimized. The job was implemented under constant supervision of the Radiation Control Officer responsible for the research reactor and the Reactor Supervisor/Reactor Manager.

6. CONCLUSIONS

The beam port leakage problem of the BAEC research reactor posed significant threat to the safety of the reactor. The problem could eventually lead to a situation like LOCA. The matter was, therefore, handled very carefully taking all measures so that such a thing could be prevented from happening. Assistances of agencies such as IAEA, BUET, BITAC, etc. were taken for solving the problem. It is understood that the silicon rubber lining of the encirclement clamp may get damaged because of neutron irradiation. Therefore, while designing the clamp, provisions were kept such that it can be dismantled and reinstalled again with the lining replaced by a new one. After solving the leakage problem, the reactor was made operational again after about 16 months.

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