AGEING MANAGEMENT AND PREVENTIVE MEASURES FOR REACTOR POOL LINER AND BEAM TUBES AT THE DALAT RESEARCH REACTOR

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ABSTRACT

The 500-kW Dalat Nuclear Research Reactor (DNRR) was reconstructed from the original 250-kW TRIGA Mark II as named of VN-001. In the framework of the reconstruction project during the years 1982-1984, some structures of the TRIGA reactor which was constructed in the early sixties, such as the aluminum tank, graphite reflector, thermal column, four horizontal beam tubes, etc. have been remained. Such components are more than 50 years old and facing with ageing issues.

The structural materials of the pool liners and other components of the TRIGA reactor were made of aluminum alloy 6061. Some other parts, such as reactor core, irradiation rotary rack around the core, vertical irradiation facilities, etc. were replaced by the former Soviet Union's design with structural materials of aluminum alloy CAV-1. The reactor core was loaded with HEU VVR-M2 fuel assemblies of 36% enrichment from 1983. The core HEU fuel was converted and since Nov. 2011, the 19.75% enriched LEU fuel has been used. Both fuel types of U-Al alloy 36% and of UO_2 19.75% enrichment use aluminum as fuel cladding.

For ageing management and preventive measures of corrosion, an underwater high-resolution video camera system was designed for visual inspections and a cleaning system was also designed for cleaning the reactor pool liners and other inside components. Water chemistry of the reactor pool and spent fuel storage pool has been monitored regularly. During Sept. – Nov. 2011, all four horizontal beam ports were cleaned inside and visual inspection was done using a special camera system. It was the first time from beam ports installation during TRIGA reactor construction such activity could be done. Based on the results obtained we could conclude that the inside of all horizontal beam ports is in good condition and leakage could not be occurred.

1. Introduction

Originally the Dalat Nuclear Research Reactor (DNRR) was a 250-kW TRIGA MARK II reactor, started building from early 1960s and achieved the first criticality on Feb. 26, 1963. During the years 1982-1984, the reactor was reconstructed and upgraded to 500 kW, and restarted operating on March 20, 1984.

In its original version, the reactor core was setting upon an all-welded aluminum frame supported by four legs attached to the bottom of the pool. After the modification made, the new core is now suspended from the top of the reactor pool by means of three aluminum concentric cylindrical shells. This shell prevents from any visual access to the upper part of the pool liners, but is provided with a series of holes to facilitate water circulation in the 4-cm gap between itself and the aluminum pool liner. The lower cylindrical shells act as an extracting well for water circulation (Fig. 1) [1].

As the reactor has been operated at low power of 500 kW, there were no any problem with degradation of core structural materials due to neutron irradiation and thermal heat, but there are only some ageing issues with aluminum pool liner and other in-pool structures such as corrosion of tightening-up steel bolt in the neutron beam tube No #4 and on surfaces of other components. Countermeasures with reactor water leakage through horizontal neutron beam ports are also important issues and need to be considered.

In this report, experiences on ageing management and preventive measures of corrosion for the reactor pool liner and horizontal beam ports are given and some recent results of the visual corrosion observation are presented.

2. Brief description of the reactor [1, 2]

The DNRR is a pool type reactor, moderated and cooled by light water. Main specifications of the reactor are listed in Table 1.

Table 1. Specifications of the DNRR.

Reactor type	TRIGA Mark II, modified to Russian IVV-9 type
Nominal thermal power	500 KW, steady state
Coolant and moderator	Light water
Core cooling mechanism	Natural convection
Reflector	Beryllium and graphite
Fuel types	WWR-M2: + HEU core: U-Al alloy with 36% enrichment, aluminum cladding (before Sept. 2007). + HEU and LEU mixed core of U-Al alloy with 36% enrichment and UO_2+Al with 19.75% enrichment (Sept. 2007 – Aug. 2011). + LEU core of UO_2+Al with 19.75% enrichment, aluminum cladding (from Nov. 2011).
Number of control rods	7 (2 safety rods, 4 shim rods, 1 regulating rod)
Materials of control rods	B_4C for safety and shim rods, stainless steel for automatic regulating rod
Neutron measuring channels	6 combined in 3 housings with 1 CFC and 1 CIC each
Vertical irradiation channels	4 (neutron trap, 1 wet channel, 2 dry channels) and 40 holes at the rotary rack
Horizontal beam-ports	4 (1 tangential - No #3 and 3 radial - No #1, #2, #4)
Maximum thermal neutron flux	2.2×10^{13} $n.cm^{-2}.s^{-1}$ (in the neutron trap at core center)
Main utilizations	RI, NAA, PGNAA, NR, basic and applied researches, manpower training

The reactor pool is a cylindrical aluminum tank of 6.26 m high and 1.98 m diameter of the original TRIGA Mark II reactor. This tank is surrounded by a thick concrete wall of 1.5 m in average for biological shielding (Fig. 1).

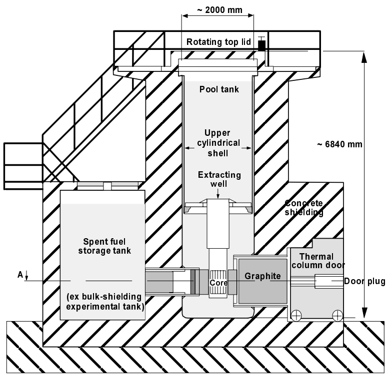


Fig. 1. Vertical section of the DNRR.

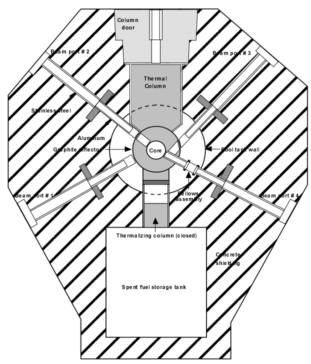


Fig. 2. Horizontal section of the DNRR.

A number of experimental irradiation facilities consisting of one in-core vertical wet and two in-core dry (pneumatic transfer) irradiation channels, a rotary specimen rack with 40 irradiation holes at the graphite reflector, a graphite thermal column, and four horizontal beam ports are installed inside and around the reactor core.

Three of the beam tubes (No #1, #2 and #4) are oriented radially to the center of the core, and the fourth tube (No #3) is tangential to the outer edge of the core. Two of the radial tubes (No #1 and #2) terminate at the outer edge of the graphite reflector. The third radial tube (No #4) penetrates into the graphite reflector and terminates at the inner surface of the reflector, just at the outer edge of the core. The tangential beam tube (No #3) terminates at

the outer surface of the reflector, but it is also aligned with a cylindrical void, which intersects the piercing tube in the reflector graphite (Fig. 2).
The reactor pool tank and inner sections of the components are waterproofed by continuous welded joints. For corrosion protection from the concrete shielding, the outside of the tank has been coated with a hot application of bituminous coating reinforced with felt.
The chemical compositions of two aluminum alloy types used in the reactor pool are slightly different (Table 2).

Table 2. The chemical compositions of alloys used in the DNRR tank.

Materials	Cu %	Cr %	Mg %	Si %	Al %	Impurities
6061	0.25	0.25	1	0.6	> 97.7	
CAB-1	0.0058	-	0.48	0.8	> 98.5	Ti, Fe, B, Ni

3. Visual inspection of the reactor pool liner and in-pool structures

The pool tank itself and almost in-pool structure materials were made of aluminum with high purity. Despite excellent properties of aluminum in nuclear engineering such as temperature and radiation stability, mechanical strength, low neutron absorption, high corrosion resistant, etc., after long operation in underwater and nuclear radiation condition, the corrosion attack and radiation damage must be regularly checked.
The first time in 1982, during the reconstruction and upgrading work, the general survey of the status of the reactor pool tank was done by a Russian-Vietnamese joint group and it may be concluded that no corrosion effect was observed on the aluminum pool liner and associated components. The reactor tank was good enough for further long exploration.
The second time in 1989, the inspection was undertaken by the IAEA expert team. At that time, only about 20% of the tank surface was possible to examine by an underwater telescope. The signs of corrosion attack were firstly detected. According to the expert conclusion, some of corrosion attacked areas were estimated seriously and the penetration of water through the aluminum tank to the concrete shielding would happen.
Because of that, the corrosion issue has been more carefully considered and investigated. A new telescope was designed for observation. The third examination was conducted at the beginning of 1993. It was really found out that the corrosion areas had not been due to corrosion attack, but mechanical defects.
To respond to such situation, an ageing management programme for extending of the lifetime of the rector pool tank and its in-pool structures was set-up with regular inspection, surveillance and assessment of pool tank and in-pool components every 3-4 months. In order to enhance quality of visual inspection, some high-resolution underwater camera systems were designed and used. The system can create significant pictures and is really powerful tool for visual examination in underwater condition.
The main results of visual inspections in 2011 and 2012 showed that [3, 4]:

- As previous results, the most concerns were with the beam port No #4 because two of four steel bolts to tighten-up the flexible joint (the bellows assembly flange of beam port) were rusted and the results indicated that this rust was slowly developed and the electrochemical corrosion may happen with these bolts. However it was difficult to explain clearly because only two of four bolts are rusted, but other two bolts still have a shining color of stainless steel (Fig. 3).
- There were some pitting corrosions with 2-3mm in diameter on the outside surface of beam port No #3. It may be due to surface scratches or mechanical defects happened when the re-installation of reactor structures done during the years of 1982-1983. Based on the pictures taken during last five years, it can be concluded that corrosion phenomenon still happens but slowly develops (Fig. 4).
- There are pitting corrosions on the pool tank liner, thermal column, beam ports, and weld line, where corrosion products of $Fe(OH)_3$ have been watched. However, no abnormal phenomenon has been seen.

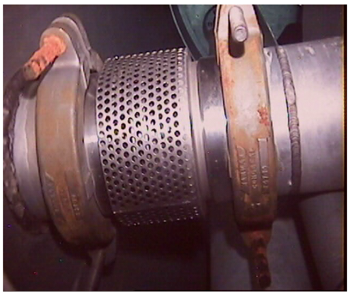


Fig. 3a. Four bolts to tighten-up the flexible joint of the beam port No #4 (down side).

Fig. 3b. One steel bolt at beam port No #4 (reactor pool wall side).

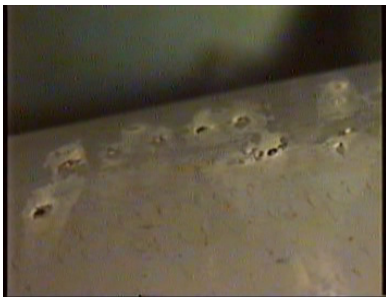


Fig. 4a. Pitting corrosion on the upper surface of beam port No #3.

Fig. 4b. Pitting corrosion on the side surface of beam port No #3.

4. Cleaning and visual inspection inside of the horizontal beam tubes [4]

For conversion of the reactor core from HEU to LEU fuel, in Oct. 2011, the transfer of all 106 burnt HEU FAs from interim storages in the reactor pool to spent fuel storage pool was safety completed. This is to permit visual inspection of four horizontal beam ports as gamma and neutron radioactive doses in the beam ports were significantly reduced. During Sept. – Nov. 2011, the inside surface cleaning and visual inspection of all four beam tubes were done using a special camera system which can store data into PC. The system consists of a small rotated camera of 3cm x 3cm with LED lamps around for lighting, stainless steel tube of 3 cm in diameter and 5m long for rotated camera installation, a special supporting stand for keeping the stainless steel tube with the capability of moving and rotating the camera to any position inside the beam tubes.

It was the first time from TRIGA reactor construction, all its four beam tubes have been carefully opened, cleaned and visually examined by the designed camera system. Some pictures are shown in Fig. 5 and Fig. 6. Based on the results obtained it can be concluded that the status of all four beam tubes of the DNRR are still in good condition and the reactor can be continuously safely operated without water leakage happened.

Fig. 5a. Inside surface of beam tube No #1 before cleaning.

Fig. 5b. Inside surface of beam tube No #1 after cleaning.

Fig. 6a. Inside surface of beam tube No #2 before cleaning.

Fig. 6b. Inside surface of beam tube No #2 after cleaning.

5. Countermeasures with water leakage through horizontal beam ports

Lost of coolant accident (LOCA) is one of postulated initiating events (PIE) which may lead to reactor fault sequences or accident scenarios. In case of the DNRR, failure of beam tubes or other penetrations will cause the excessive loss of reactor pool water. Analyzed results shown that in the case of loss of the core cooling water, damage of fuel cladding could not happen to release a significant amount of fission products into environment. However, decrease of pool water level also leads to decrease the radiation protection function [2]. Because of that prevention of reactor water leakage through beam ports has been carefully considered in the ageing management programme of the DNRR.

For the above-mentioned purposes, during the last ten years, some proposals and designs were taken, tested and installed at the beam ports, for example, a manual open-close system with humidity sensor generated alarm signal, resin probes manually used in case of serious leak of the beam port, an on-line system for monitoring the reactor pool water level with alarm signal transferred to the facility entry where security guards on duty, etc. The last design is a watertight instrument which was directly installed inside the beam tube together with other components such as neutron filters, gamma and neutron shielding and collimators, etc. in order to prevent the loss of shielding water if the beam tube should develop a serious leak. Fig. 7 shows the watertight instrument and the full components of the beam tube No #2 are shown in Fig. 8.

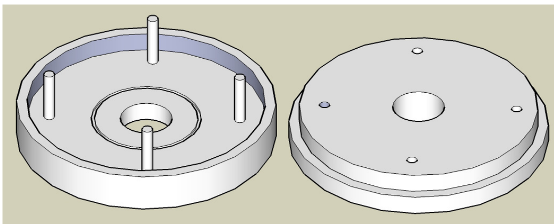
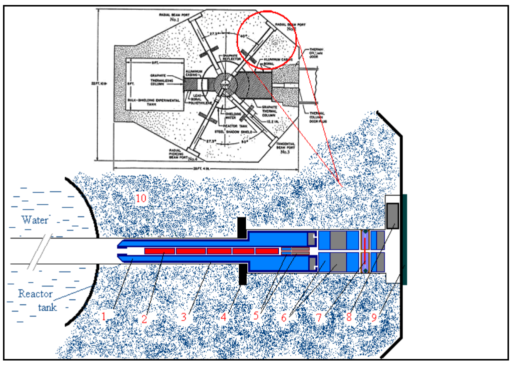


Fig. 7. Watertight instrument for neutron beam tubes at the DNRR.



Note: 1- beam shielding for neutron filters, 2- neutron filters, 3- aluminum cover, 4- gamma shielding plate, 5- pre-collimators, 6- gamma and neutron shielding and collimator, 7- watertight collimator, 8- lead-filled shutter, 9- lead-lined door, 10- concrete shield structure of reactor.

Fig. 8. Watertight instrument was installed in the beam tube No #2.

6. Conclusion

It is well known that aluminum is a very reactive material but it is covered itself with an oxide layer of hydrated aluminum oxide $Al_2O_3\,nH_2O$. This layer may usually vary between 40 and 100A^o. Because of good water chemistry control in the DNRR, pH maintains from 5.5 to 6.0, this layer is practically stable, well resists the corrosion attack.

For the DNRR, two main types of localized corrosion that must be carefully considered are pitting corrosion and crevice corrosion.

Pitting corrosion is a corrosion attack that was mainly found out during the examination on the pool tank wall, thermal column, beam ports, and weld lines. Most of them stopped developing because of their big enough space for oxygen penetration.

If the crevice corrosion exists, it may be dangerous corrosion. So, during inspection, the crevice corrosion in the reactor pool tank was much attractive to our attention, especially mainly along the weld lines and confined or stagnant areas, but the signs of crevice corrosion have not been detected.

Of course, beside two types of localized corrosion mentioned above, the other corrosions such as inter-granular corrosion, stress corrosion cracking or exfoliating corrosion and radiation damage were also considered, but no signs of their effects have been seen at present.

As mentioned above, almost corrosions detected in the DNRR pool tank are pitting corrosion, which initiated from surface scratches or mechanical defects during the re-installation of reactor structures, and slowly develops. The results of visual inspection revealed that at the beginning pitting corrosion develops but it seems to stop at the end. The results obtained also show that the status of reactor pool liner, inside components and four beam tubes of the DNRR are still in good condition and the reactor can be continuously safely operated.

7. References

[1] Safety Analysis Report (SAR) for the Dalat Nuclear Research Reactor, Dalat Nuclear Research Institute, 2009.

[2] Safety Analysis Report (SAR) for the Dalat Nuclear Research Reactor, Dalat Nuclear Research Institute, 2012.

[3] Report on visual inspection and cleaning of the reactor pool tank and inside components of Dalat Nuclear Research Reactor, Dalat Nuclear Research Institute, 2012.

[4] Report on programme and results of visual inspection of neutron beams and components of Dalat Nuclear Research Reactor by video cameras, Dalat Nuclear Research Institute, 2011.