Root Cause Analysis of Swelling Problem in *Kartini* Reactor

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ABSTRACT

Root Cause Analysis of Swelling Problem in Kartini Reactor. A root cause analysis (RCA) related to the swelling problem in Kartini reactor have been done. Three areas of interest were observed from the inspection of Kartini reactor tank liner conducted in 2001 i.e.: a small area with apparent thinning, a small crack that was analysed as an original manufacturing defect, and there were two areas of swelling (bulges) observed under the thermal column. The visual inspections each year by the video equipment and replication indicate that the swelling parts observed in 2001 had grown in size. Recent examination 2006-2007 showed that the size of bulges relatively constant, and the peak of the bulges appears to contain tears (cracks). Therefore, RCA has been conducted to evaluate the problem and the result shows that probable root cause of swelling are as follows: it is probable that the seal on the cover plate in the service pool has deteriorated and allowed water to enter both the thermal column and the space between the aluminium reactor pool liner and the concrete. The water will also saturate the concrete and has the potential to corrode the steel reinforcement close to the surface of the concrete. It is believed that water leakage from the bulk storage facility (BSF) has entered the area behind the aluminium pool liner and has saturated the concrete, and also believed the carbon steel reinforcement close to the inner surface of the reactor block has corroded. The expanding corrosion product (rust) has the forced layer of concrete covering the steel reinforcement and subsequently pushing the aluminium pool liner inwards, causing the swelling. As the evidence, it has been shown that water has penetrated the concrete block of the service pool, and this is supposed to be a probable cause of the swelling. As a remedial action is to dry the concrete block to attempt to remove the conditions that are causing the defects, and the BSF would then be lined to prevent future water penetration of the concrete.

INRODUCTION

Kartini research reactor is a TRIGA Mark II type, provided with an aluminium pool liner (1050 grade Al, ex IRT-2000 reactor) with 6 mm in thickness. Pool liner construction consists of four flanged 2 m diameter cylindrical section which was assembled into a reactor pool approximately 6 m deep. To facilitate mechanical strength and watertight construction 300 mm wide ‘belts’ of 5 mm thick aluminium were fillet welded over the joins in each section. The reactor has been in operation since 1979.

In 2001 the pool was emptied of fuel and control system to enable a complete inspection of the pool liner, at that time the following test were conducted; a comprehensive visual examination, hardness survey, a thorough dye penetrant examination, a comprehensive ultrasonic thickness survey, and replication of features of interest. In general the inspection revealed that the pool liner was in good condition and the results of the thickness and hardness survey were consistent with the service history. Three areas of interest were observed; a small area with apparent thinning, a small crack that was analysed as an original manufacturing defect. There were two areas of swelling (bulges) observed under the thermal column and these were assigned as S1 and S2 for identification purposes [1]. These features were difficult to observe at the 2001 inspection due to the lack of specialised visual inspection equipment available at the time. New inspection equipment was acquired by BATAN through the IAEA TC Project No. INS 9022, and the features re-examined in 2003, 2004, 2005, 2006 and 2007.

A review of the above features have been undertaken, starting with a root cause analysis related to the above swelling problem. Root cause analysis (RCA) is a method that can be applied to identify the root cause of an event or adverse trends associated with corrective actions to a set of events. Fig.1. below shows the general area of interest and Fig. 2. shows the swellings S1 and S2.

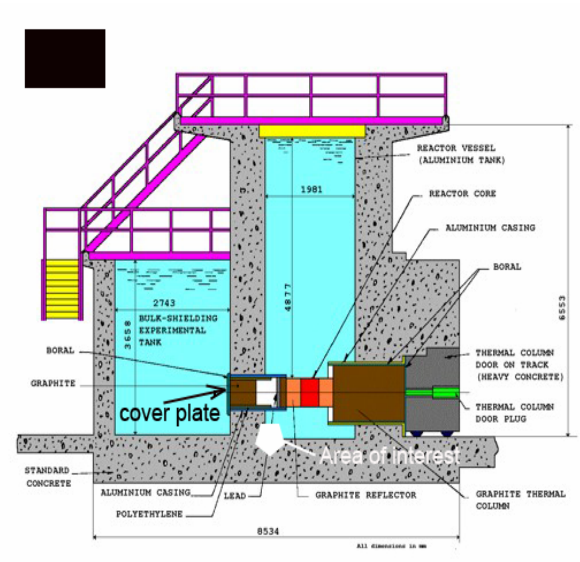

Fig 1. Vertical Section of Kartini Reactor with the area of interest indicated.

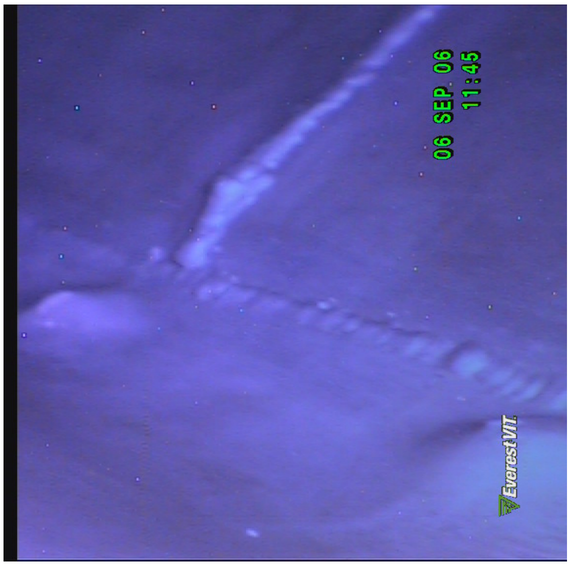

Fig. 2. Swellings S1 & S2 September 06 images.

METHODOLOGY

Root cause analysis (RCA) is a class of problem solving methods aimed at identifying the root causes of problems or events. The practice of RCA is predicated on the belief that problems are best solved by attempting to correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms. By directing corrective measures at root causes, it is hoped that the likelihood of problem recurrence will be minimized. However, it is recognized that complete prevention of recurrence by a single intervention is not always possible. The RCA is often considered to be an iterative process, and is frequently viewed as a tool of continuous improvement [2,3].

To be effective, RCA must be performed systematically, and conclusions must be backed up by evidence. There is usually more than one root cause for any given problem. General process for performing RCA :

- define the problem
- gather data/evidence

– identify issues that contributed to the problem
– find root causes
– develop solution recommendations
– implement the recommendations
– observe the recommended solutions to ensure effectiveness.

RESULT AND DISUSSION

The periodic inspection revealed that the swelling had increased in size over this period. Visual inspections by the video equipment and replication indicate that the swelling parts observed in 2001 had grown in size. In 2004 the dimension of S1 and S2 were observed to have 7.72 mm and 7 mm of height, and 1365 mm^2 and 1083 mm^2 of area, respectively. While in 2005, the heights of S1 and S2 were seen to increase to 7.78 mm and 7.56 mm, and the areas to be 1389 mm^2 and 1839 mm^2 respectively [4]. Recent examination (Sep. 2006 and September 2007) showed that the size of the swelling has remained relatively constant since 2005, and the peak of the bulges appears to contain tears (cracks). Fig. 3. below shows an ultrasonic thickness probe measuring the metal thickness at the swelling and Fig. 4. shows relication of the swelling using replication putty.

Fig. 3. Ultrasonic thickness measurement of tank wall.

Fig. 4. Replication of bulge to allow accurate measurement of size.

The following observations have been made regarding the swelling.

- The swellings have increased slowly in size over several years.
- The aluminium thickness is still substantial, ultrasonic measurements of the aluminium thickness using equipment provided by funding under IAEA TC INS 9002 shows that the aluminium thickness is predominantly at original values and still greater than 4mm in the area of the bulges. This indicates that the aluminium pool liner has not corroded significantly.
- It is apparent that some element of the reactor block structure is expanding and forcing the pool liner into the reactor pool. Two possibilities have been put forward. The first is corrosion of the steel reinforcement bars that were located close to the inside surface of the concrete pool backing, the second is the possible incorporation of clay nodules into the concrete mix. Both possibilities can result in volume expansion and fracture of the overlaying concrete that can result in the pool liner protruding into the

pool. The evidence for both the clay nodule and corroded reinforcement mechanisms can be observed on the external surface of the reactor block, particularly in areas around the base of the BSF Figures 5 and 6 shown photos of the fractured external surface of the reactor block. The brown material in the centre if the fractured area has been analysed at ANSTO using SEM analysis and indicates a composition typical of clay. Examination of sand in the Yogyakarta region, used to make concrete, shows that clay nodules can be observed in the sand mix.

Fig. 5. Showing reinforcement (painted over) that had corroded and fractured concrete

Fig. 6. Showing a clay nodule that had expanded and fractured the concrete

- Concrete Standards make recommendations for the minimum over-cover thickness of concrete depending of the environment Recommendations area also made that corrosion protection, such as galvanising or in extreme cases the use of stainless steel reinforcement be considered where moisture penetrate on of the concrete is a possibility.
- The external surface of the bulk shielding facility (BSF) shows evidence of water leakage. The white deposits on the side of BSF shown in Figure 7, which were originally thought to be Ca(CO3), were analysed as Sodium carbonate. This indicated that water has been slowly seeping though the concrete wall and carrying with it dissolved material from the concrete which has reacted with CO_2 from the air to form the carbonate. The presence of Sodium poses the possibility that the water used to make the concrete contained salt, which suggests to the possibility of chlorides in the concrete that could lead to corrosion issues.

Fig. 7. Showing white deposits formed by water

seepage through the BSF wall

Therefore, it is wise to undertake a review of the above features, starting with a root cause analysis (RCA) related to the above swelling problem. The RCA result shows that probable root cause of swelling are as follows:

Several aspects of the root cause analysis need to be considered, these are:

- The original design.
- The construction and supervision methods.
- Operational issues.

The design aspects have contributed to the development of the issue by incorporating a potential for water to act on deficiencies in the construction supervision of the reactor concrete block. The particular aspect in the design is the potential for water from the bulk storage to activate the construction deficiencies by penetrating the area behind the reactor pool liner.

The construction and supervision aspects of the reactor block have contributed to the issue by allowing reinforcement steel to be placed too close to the concrete surface and this has allowed contact with water and corrosion to occur. The volume expansion of the corrosion product has fractured the concrete and distorted the pool liner. Another aspect that could have contributed to the cause is the use of water containing impurities such as salt that increase conductivity and assist corrosion processes. Analysis shows that clay nodules have been incorporated into the concrete and these have fractured the external concrete surface and the same processes are likely to be occurring in the concrete behind the aluminium pool liner.

These is no evidence that operation issues have contributed to the root cause. The internal condition of the aluminium liner is good indicating that effective control of water chemistry has been maintained and no significant physical damage is evident. Regardless of the which of the proposed mechanisms is active, steel reinforcement corrosion or clay impurity expansion, the root cause involves the penetration of water to areas behind the aluminium pool liner in combination with design and construction deficiencies.

- The seal on the cover plate in the BSF has deteriorated after >25 years of service and allowed water to enter the thermal column. In August 2007 the sealing plate over the thermal column was removed and approximately 200 litres of water was drained from the thermalising column, see Fig. 8. below. The first 200 mm thick layer of graphite was removed to allow inspection of the aluminium behind the Boral layer separating the graphite and thermal column liner. Examination of the condition of the inside of the thermal column indicates that uniform corrosion has occurred on the inside of the thermal column. It can reasonably assumed that the condition of the areas examined are typical of general corrosion within the column. From the examinations conducted on the accessible internal and external surfaces there are no concerns regarding the integrity of this component.
- The surface of the reactor block wall in the BSF contained cracks that could have allowed water penetration. Water could be observed to be seeping from the bottom corner of the BSF and probing allowed brown mud to flow from the area behind the painted surface, see Figure 9 below.

Fig. 8. Showing water leaking from the thermal column

Fig. 9. Showing water and 'mud' seeping from the reactor block wall.

The condition has been slowly advancing and could possibly result in a loss of pool liner integrity, this does not present a safety hazard due to the multiple barriers in the design. The aluminium liner is backed by a bituminous layer between the aluminum and the concrete. The situation is not urgent at this time because a loss of cooling accident (LOCA) is not credible from the defects observed. The issue is one of maintenance not safety. Seepage of pool water behind the liner could accelerate corrosion behind the pool liner. It has been shown that water has penetrated the concrete of the BSF. This has caused moisture penetration into the concrete and also the inside of the thermal column (see Figure 1). The inspection results evidence from the 2001 major shutdown indicate that the aluminium thickness is close to original thickness and no through-thickness corrosion was observed. This layer provides and addition barrier to both water leakage and can protect the aluminium from coming in contact with low pH water [6].

Remedial Actions

Up until this time a program of periodic inspection of the defects has been maintained. This program has involved close-up video examination, replication of the defects and ultrasonic thickness measurement. Details of these inspections and analysis of the data from this series of inspections has been reported elsewhere [1,4,5]. The remedial actions that are under implementation are as follows:

- The first course of action is to dry the concrete block to attempt to remove the conditions that are causing the defects. The bulk storage facility would then be lined to prevent future water penetration of the concrete. If continued monitoring of the swelling indicates that some repair action should be taken the reactor pool will need to be emptied of fuel and control systems and the BSF would be required for storage.
- The second course of action is to maintain the program of periodic inspection to monitor the rate of progression and take action to repair to the areas involved.

Lessons Learnt

Periodic examination of reactor pool liners are essential to detect issues at an early stage. Early intervention is important to minimise the effect of any issues found. Degradation processes that occur in the structural elements behind the pool liner can affect the pool liner integrity. In the current context it is important to ensure that the reinforcement has sufficient cover of concrete to prevent corrosion of the reinforcement. A judgement should be made at the construction phase of any new reactors to assess if better corrosion protection of reinforcement should be provided, considerations could include;

- Use of galvanised reinforcement steel.
- Use of stainless steel reinforcement in critical location.
- Control of depth and placement of steel reinforcement.
- Assessment of any corrosive elements in the make up of the concrete.

The quality of the concrete from both a constituent viewpoint and the quality of water used to make the concrete are important. Particular attention should be given to exclude and clay material that can expand and damage the concrete under wet conditions. Also the water should be assessed to ensure that salt or other element that could influence the corrosion rate of the steel reinforcement in the concrete.

Every effort should be made to ensure that the area behind the pool liner remains dry. One potential source of water ingress to the area behind the pool liner is the BSF attached to the reactor block. Any cracks caused by concrete shrinkage or by seismic events can provide a water leak path. Many of the BSFs in this design of reactor are sealed and painted concrete. A metal liner in the BSF can provide a superior waterproof design. In future reactor designs consideration should be given to the incorporation condition-monitoring behind reactor pool and bulk storage liners, for example, moisture monitors or drain points could be used to detect the presence of water behind areas that are difficult to inspect.

The BSF incorporated in this design of reactor has a thermalising column that provides a neutron path for experiments that can be conducted in the BSF. In the as-supplied reactor the beam outlet is usually blanked off with a plate bolted onto the reactor block and a seal is incorporated to prevent water ingress into the thermalising column. Experience with another reactor of similar design shows that the seal can leak and allow water to penetrate into the thermalising column and also provide a potential leak path between the BSF and the area behind the reactor pool liner. It was established in September 2007 that the thermalising column contained a substantial quantity of water.

In order to preserve the thermalising column facility and also provide a fully sealed BSF a neutron transparent window (e.g. aluminium or reactor grade zirconium) could be incorporated over the beam outlet. It is the view of the authors that future designs of this type of reactor should incorporate a metal liner in the BSF to prevent water penetration of the reactor block.

One very important lesson that can be gained is that quality control and inspection processes are vital during every stage of construction to ensure the long-life success of reactor assets. As an example take the case of concrete elements in the design. At every stage of the manufacture of the concrete it is important to assure the water is clean and free from elements that could leach from the concrete and affect metal components of the design. It is also important to maintain control of the purity of the sand and cement to ensure that unwanted contaminants are kept out of the concrete.

CONCLUSION

The root cause analysis result shows that probable root cause of swelling in Kartini reactor are as follows: it is probable that the seal on the cover plate in the service pool has deteriorated and allowed water to enter both the thermal column and the space between the aluminium reactor pool liner and the concrete. The water will saturate the concrete and has the potential to corrode the steel reinforcement close to the surface of the concrete. It is believed that water leakage from the bulk storage facility has entered the area behind the aluminium pool liner and has saturated the concrete, and also the carbon steel reinforcement close to the inner surface of the reactor block has corroded. The expanding corrosion product (rust) has the forced layer of concrete covering the steel reinforcement and subsequently pushing the aluminium pool liner inwards, causing the swelling. As the evidence, it has been shown that water has penetrated the concrete block of the service pool. Every effort should be made to ensure that the area behind the pool liner remains dry. Any cracks caused by concrete shrinkage or by seismic events can provide a water leak path. Many of the BSFs in this design of reactor are sealed and painted concrete. A metal liner in the BSF can provide a superior waterproof design. A loss of cooling accident is not credible from the defects observed, the issue is one of maintenance not safety. In future reactor designs consideration should be given to the incorporation condition-monitoring behind reactor pool and bulk storage liners, for example, moisture monitors or drain points could be used to detect the presence of water behind areas that are difficult to inspect.

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