Root Cause Analysis of Swelling Problem in *Kartini* Reactor

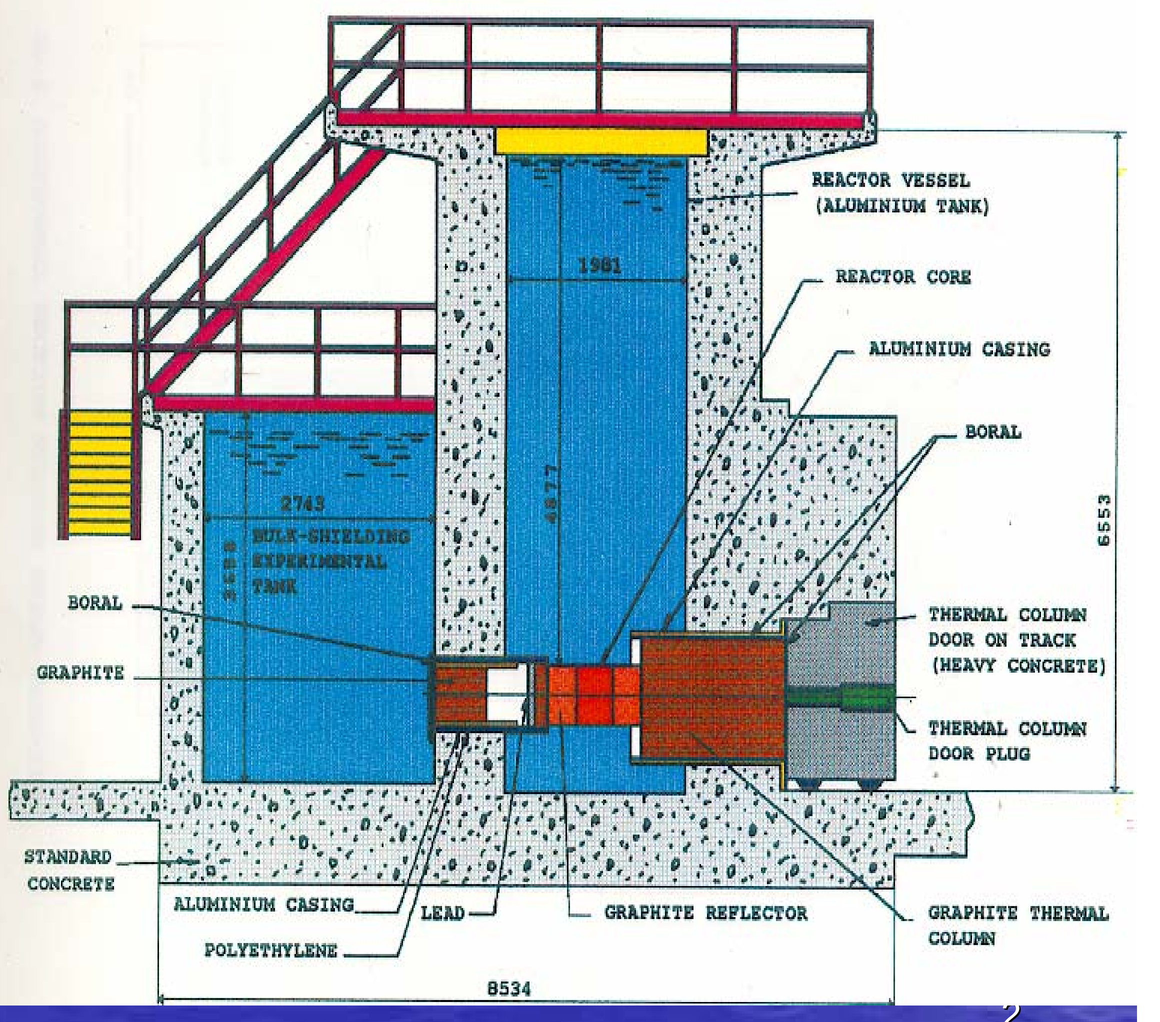
Syarip, Sri Nitiswati, Y. Sardjono,
Tegas Sutondo, T.W. Tjiptono
BATAN (Indonesian National Nuclear Energy Agency)

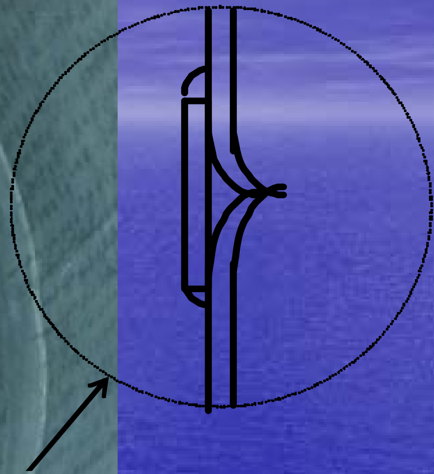
Paul Stathers, Richard Blevins, Kevin Thorogood
ANSTO, Australia

Introduction

Description of KARTINI reactor

- TRIGA Mark II
- Aluminium Pool liner (1050 grade Al)
- Pool liner thickness 6 mm
- Pool liner construction – four flanged 2m diameter cylindrical section which have been assembled into a reactor pool approximately 6 m deep.





The pool liner was fabricated by BATAN

Al- ‘belts’ (300mm) were *fillet welded* over the joins in each section.

Functions of the Aluminium Pool Liner

- To maintain the integrity of the reactor pool for both cooling and retention of radioactive products.
- There are research reactors still in service that do not rely on a metal liner – they rely on a sealed concrete or tile surface to maintain pool integrity.

Inspection History

- In 2001 the Pool was emptied of fuel and control system to enable a complete inspection of the pool liner, the following test were conducted;
  - A comprehensive visual examination
  - A comprehensive hardness survey
  - A thorough dye penetrant examination
  - A comprehensive ultrasonic thickness survey
  - Replication of features of interest

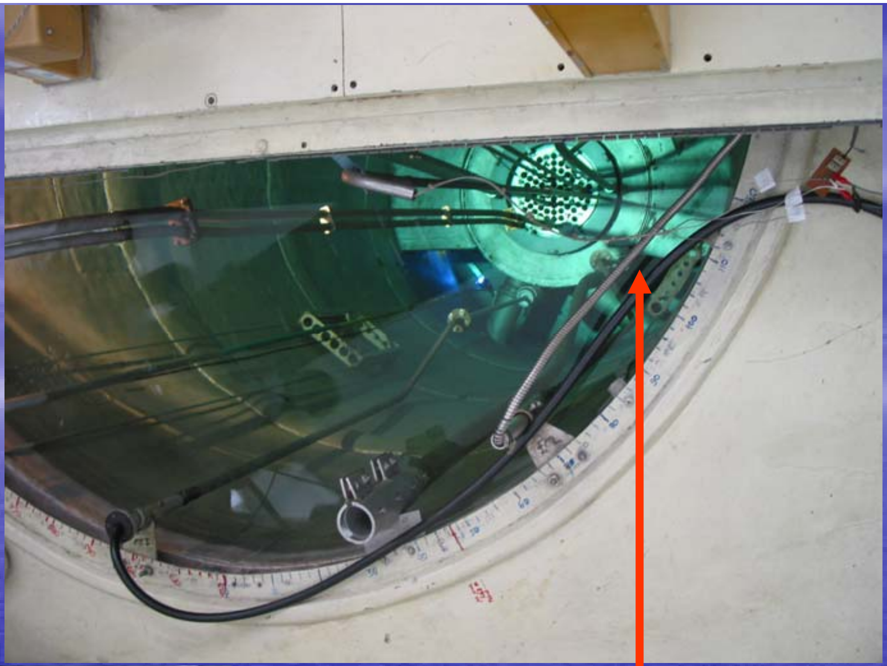
Inspection history (2)

In general : the pool liner was in good condition, thickness and hardness survey were consistent with the service history.

3 areas of interes were observed :

- A small area with apparent thinning
- A small crack (analysed as an original manufacturing defect)
- Two small areas of bulging under the thermalyzing column (S1 and S2).

Location of the Bulges



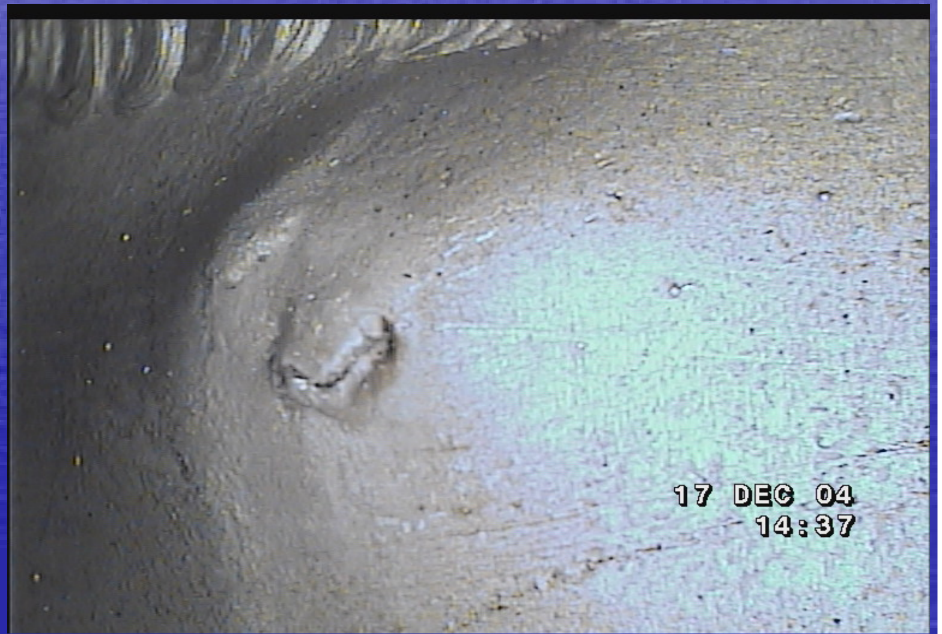
near the curved transition between the wall and the pool liner bottom under the thermal column

Inspection History (3)

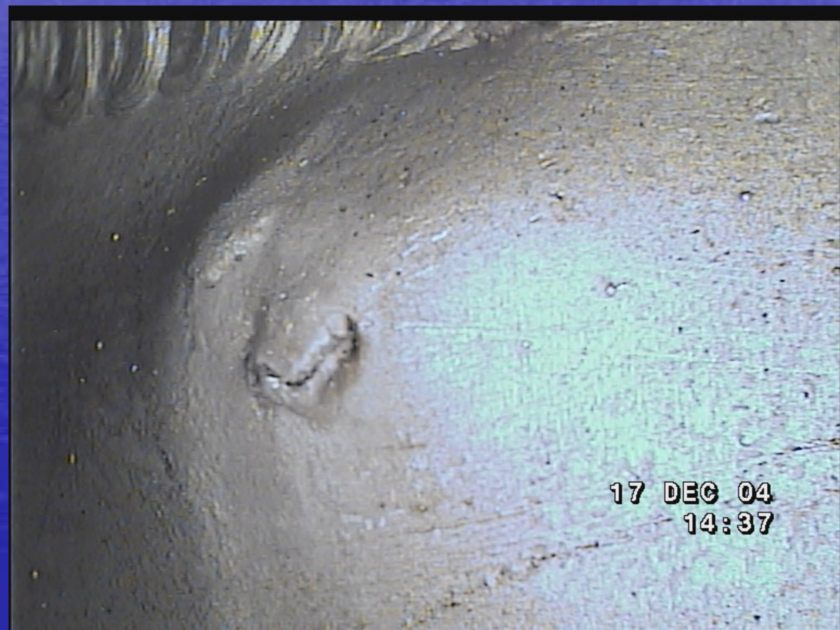
- The bulges re-examined in 2003, 2004 and 2005, the bulges had increased in size over this period.
- The increase of height and area of S1 and S2 were :
  - 7.72 mm and 7 mm (2004), and the areas were 1365 mm^2 and 1083 mm^2 respectively.
  - 7.78 mm and 7.56 mm (2005), and the areas were 1389 mm^2 and 1839 mm^2 respectively.
- Recent examination (Sept 2006 and Aug 2007) shows that the size of bulges relatively constant.
- The peak of the bulges appears to contain tears (cracks) in the metal.

Images from the video inspection equipment April 04 (S1 & S2)

Image with Scale (1mm divisions) Taken December 2004 – S1 & S2

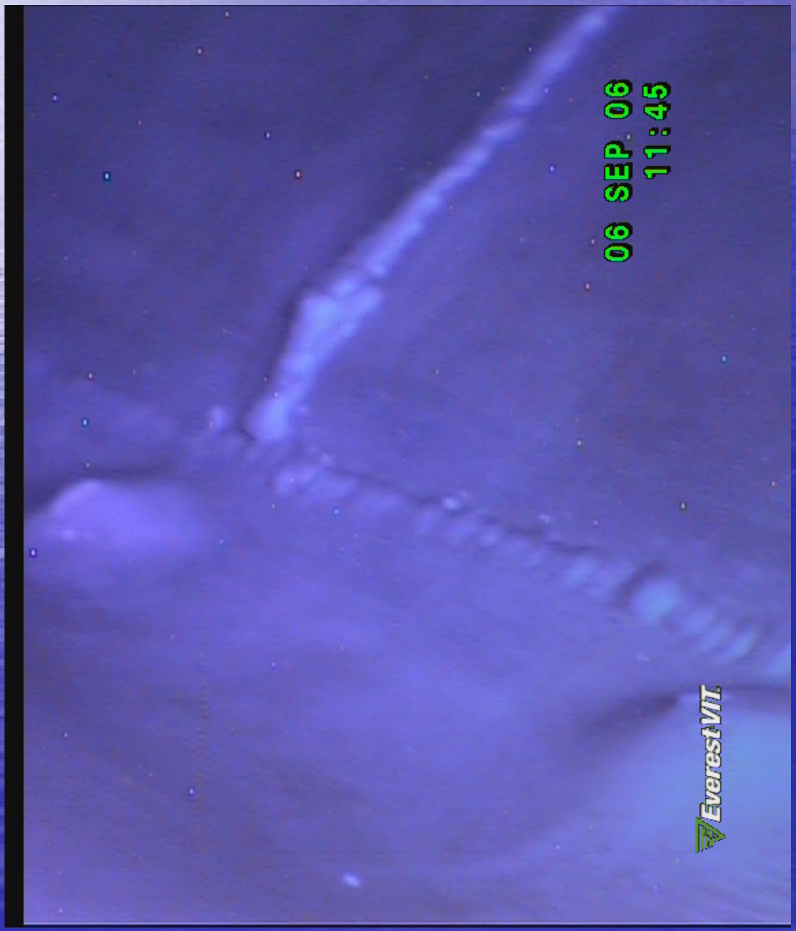


Comparative images of April and December 2004 Inspections – S2



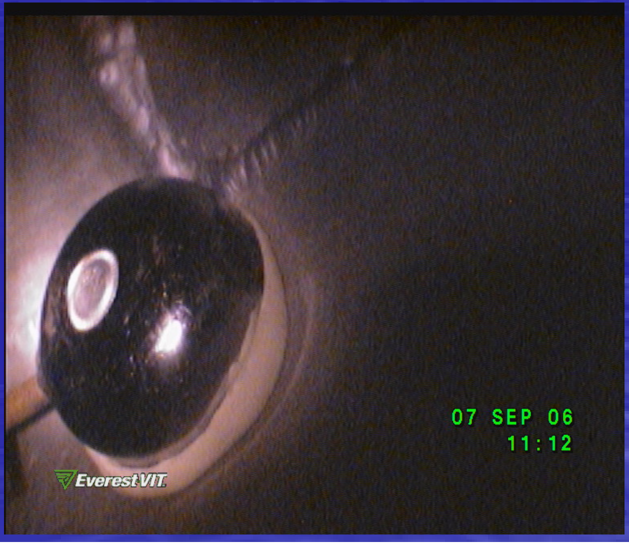
Replicas of bulges

Swellings S1 & S2 September 06 images.



Ultrasonic thickness measurement of tank wall.

Replication of bulge to allow accurate measurement of size.



Root Cause Analysis (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.

The following observations have been made regarding the swelling

The swellings have increased slowly in size over several years.

The Al thickness is still substantial, measurements shows that the Al 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.

Observation (Cont'd)

Two possibilities have been put forward : corrosion of the steel reinforcement bars that were located close to the inside surface of the concrete pool backing, and the possible incorporation of clay nodules into the concrete mix. This can result in volume expansion and fracture of the overlaying concrete that can result in the pool liner protruding into the pool.

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.

Bulk Shielding Facility (BSF-service pool)

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

Fig. 7. Showing white deposits formed by water seepage through the BSF wall

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 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.

There is no evidence that operation issues have contributed to the root cause. The internal condition of the Al liner is good indicating that effective control of water chemistry has been maintained and no significant physical damage is evident.

The remedial actions that are under implementation are as follows:

- To dry the concrete block to attempt to remove the conditions that are causing the defects. The BSF 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.

- 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.

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.

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.

Lessons Learnt (Cont'd)

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.

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.

CONCLUSION

The 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

Conculsion (Cont'd)

- 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
- Every effort should be made to ensure that the area behind the pool liner remains dry
- 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.


Thank you

Effect of pH on Corrosion rate of Iron

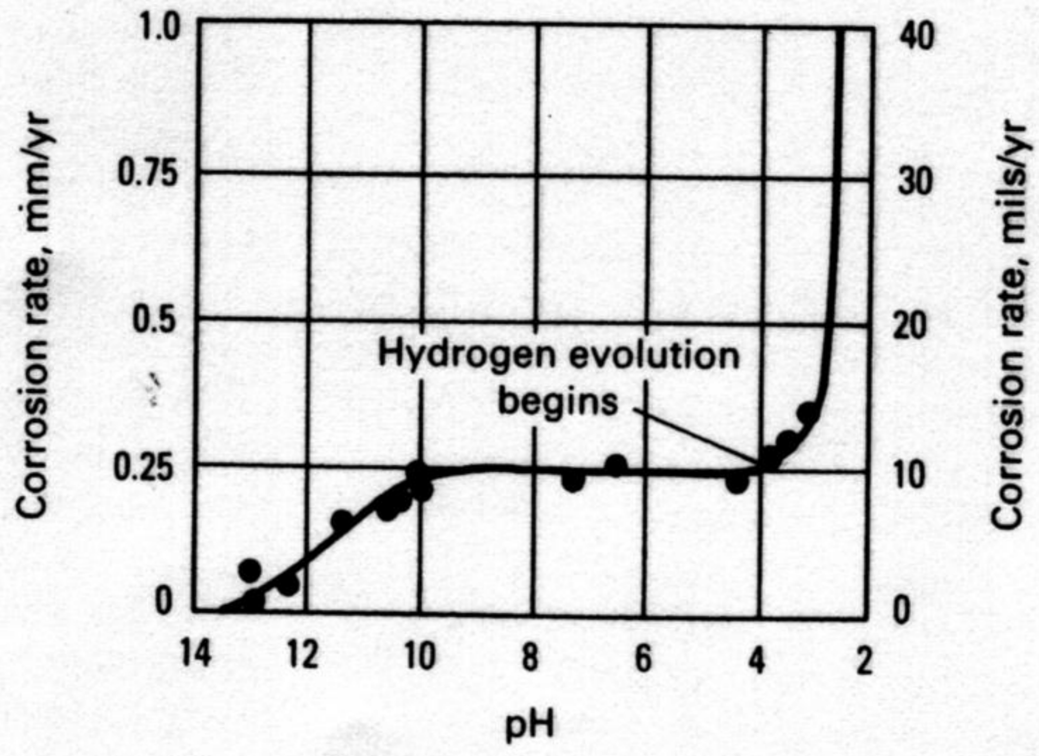


Fig. 2 Effect of pH on the corrosion rate of iron in aerated soft water at room temperature

Intentinally Blank!

Potential Long Term Corrosion Issue for Aluminium

- Water in contact with both concrete and aluminium has the potential to corrode the aluminium liner due to increases in the pH of the water trapped between the aluminium liner and the concrete.
- Other core structures such as the thermal column are also at risk from corrosion if water has entered the thermal column – less of a problem due to probable lower pH (not in contact with concrete).

There are two issues

- The mechanism for the creation of the bulges – Dominated by Iron corrosion – Highest corrosion at low pH <4
- The potential for corrosion of aluminium – dominated by the pH of water in contact with the aluminium – dependant on the pH changes due to concrete – corrosion is worst at low pH and also at High pH. See graph.

Weight Loss for 3004-H14 in distilled water – various pH values

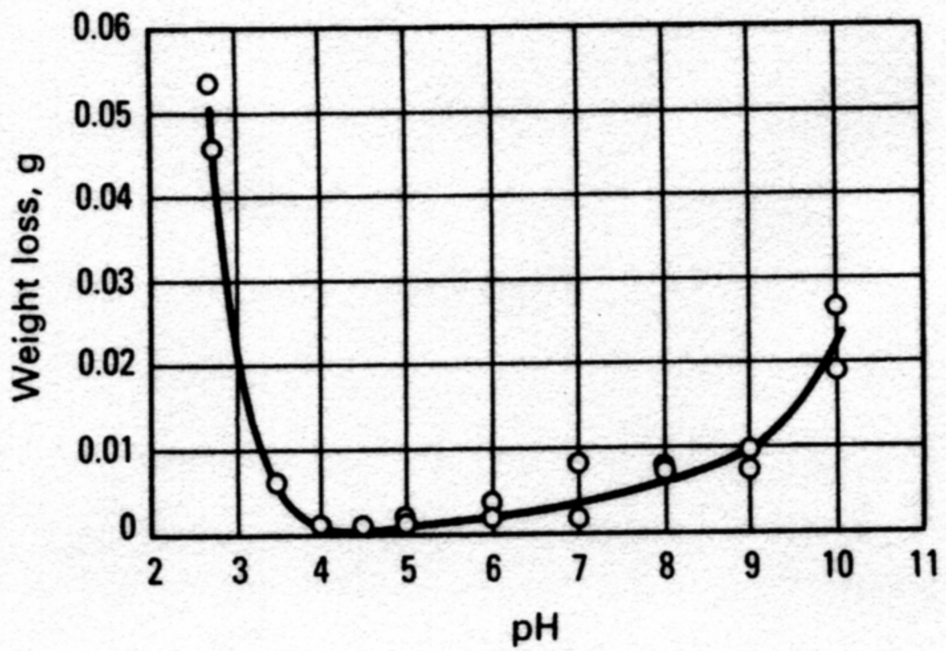


Fig. 2 Weight loss of alloy 3004-H14 exposed 1 week in distilled water and in solutions of various pH values. Specimens were 1.6 × 13 × 75 mm (0.06 × 0.5 × 3 in.). The pH values of solutions were adjusted with HCl and NaOH. Test temperature was 60 °C (140 °F).

Issues to be addressed in considering remedial actions

- Safety
- Public perception
- Cost
- Loss of facility time
- ALARA principles for remedial action
- Ease of repair
- Expected future length of service

Pool Liner Repair Options – Replace Pool Liner

- Advantages
  - New pool liner will last a long time
  - It can be done BATAN
- Challenges
  - Prohibitive cost
  - Unnecessary ‘overkill’
  - Out of scale to the issue
  - Loss of facility for long period

Pool liner repair options – weld a patch over affected areas

(Photo - R.Mazon (ININ), IAEA-SR-190/29)

- Advantages
  - Relatively low cost
  - Solid repair
  - Long lasting

  Photo of repairs to Mexican TRIGA III reactor pool liner

Reactor wall after the repair

- Challenges
  - Access is a major problem
  - An automated welding process would be needed
  - A complex patch would need to be accurately manufactured and placed
  - Space would need to be allowed for future growth of the defect

Potential repair – patch with waterproof adhesive

- Advantages
  - Low cost
  - Relatively easy to install
- Successful Epoxy repairs have been made to reactor pools (W. Krull - IAEA-SR-190/10)

- Challenges
  - A complex patch would need to be manufactured
  - Potentially shorter life of repair than welding

Iron Corrosion

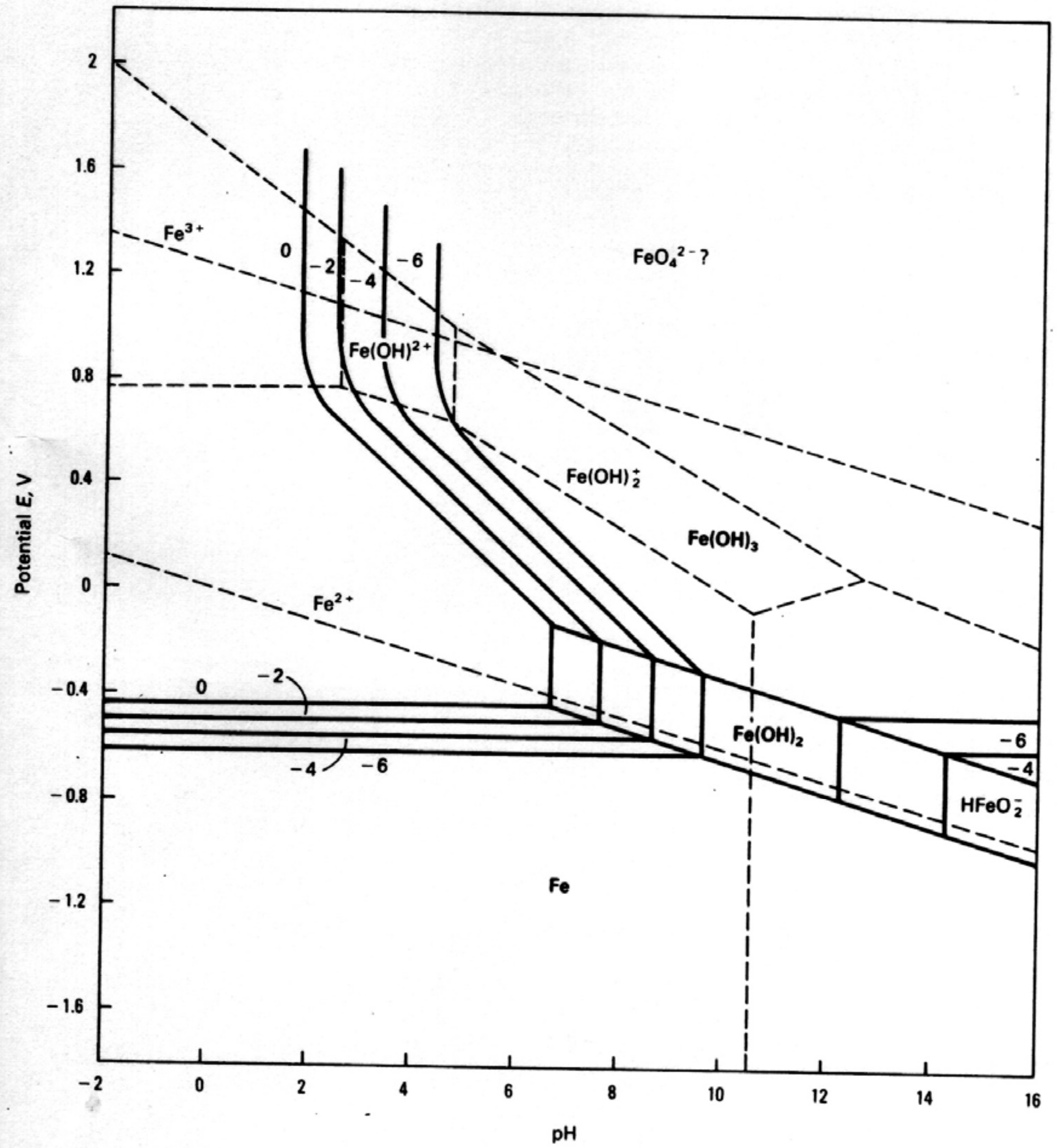


Fig. 1 Pourbaix (potential-pH) diagram for the system iron-water at 25 °C (75 °F). Source: Ref 4

Reactor Water sample

Si	0.027 mg/L
Mg	0.011 mg/L
Ca	0.037 mg/L
Fe	0.007 mg/L