CORROSION PROBLEM IN THE C.R.E.N.K. TRIGA MARK II RESEARCH REACTOR.

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1. ABSTRACT

In August 1987, a routine underwater optical inspection of the aluminum tank housing the core of the CRENK Triga Mark reactor, carried out to update safety condition of the reactor, revealed pitting corrosion attacks on the 8 mm thick aluminum tank bottom. The paper discuss the work carried out by the reactor staff to dismantle the reactor in order to allow a more precise investigation of the corrosion problem, to repair the aluminum tank bottom, and to enhance the reactor overall safety condition.

2. INTRODUCTION

The Centre Régional d'Etude Nucléaires de Kinshasa (C.R.E.N.K.) Triga Mark II reactor, located in Kinshasa (Zaïre), went critical on March 24, 1972. It is a 1 Mw(th) machine with a pulsing capabilities up to 1.600 MW(th). The reactor core is located in a 8 mm thick, 7 m height cylindrical aluminum tank with a diameter of 2 m, [1] .

In August 1987, a routine underwater optical inspection of the aluminum tank housing the reactor core, carried out to update safety condition of the reactor, revealed pitting corrosion attacks on the 8 mm thick aluminum vessel bottom.

Twelve pits were identified using an above water telescope. The corrosion problem seemed serious, one of the pits having an apparent depth of 5 mm, as could be estimated using long distance measurements from the top of the reactor, [2].

Concerning pitting corrosion one must know something of the probability of pitting, the rate of penetration , the shape of the pit depth distribution curve in order to tell whether repair is necessary, or worth while, or whether general failure is impending, [3].

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In order to gain these knowledges and to identify the causes of the pitting corrosion it was necessary to dismantle the reactor in order to investigate more fully the corrosion problem.

2. DISMANTLING THE REACTOR CORE

To dismantle a reactor core is always a difficult, and at time, dangerous task. It was carried out in two months time by a 5 men local team, fortunately without serious incident but with some difficulties.

Two serious problems were encountered. The first one was the presence of a cocked fuel element which was very difficult to disengage. The team had to lower the water level to approximately 1 m above the core to have a better grip on the fuel element.

The second problem was related to the rotary rack assembly, which turned out to be hotter than anticipated , posing a serious radiological hasard to the staff.

3. STATE OF THE ALUMINUM REACTOR TANK

If the reactor has been in service since 1972, the tank housing the core was in fact manufactured in 1965 in Austria using 6061-T67 aluminum. The tank was coated on the outside with a layer of pitch followed by a layers of tar paper. It was then embeded in an above ground high density concrete structure, 7,7 m height. It contains about 22 cubic meter of demineralised water, [1]. Figure 1 gives the CRENK Triga Mark II reactor cross section.

The inspection of the aluminum tank carried out after the removal of the core structure showed a less serious corrosion problem than was anticipated. Only 8 pits were identified as resulting from the corrosion of the aluminum plate. The most advanced corroded spot has a depth of 2,5 mm. The range of the depths of the 8 pits was between 1 mm and 2,5 mm. The pit shape vary somewhat but the mouth of a pit tended to be circular, while the cross section was roughly hemispherical. Figure 2 gives the location of the 8 pits that were identified, relative to the ground position of some elements of the core structure.

To ascertain that no corrosion was taking place from the exterior of the tar coated aluminum tank, its thickness was determined ultrasonically from the bottom up to a height of 2 m above the core structure. The result of the ultrasonic survey indicated that the area

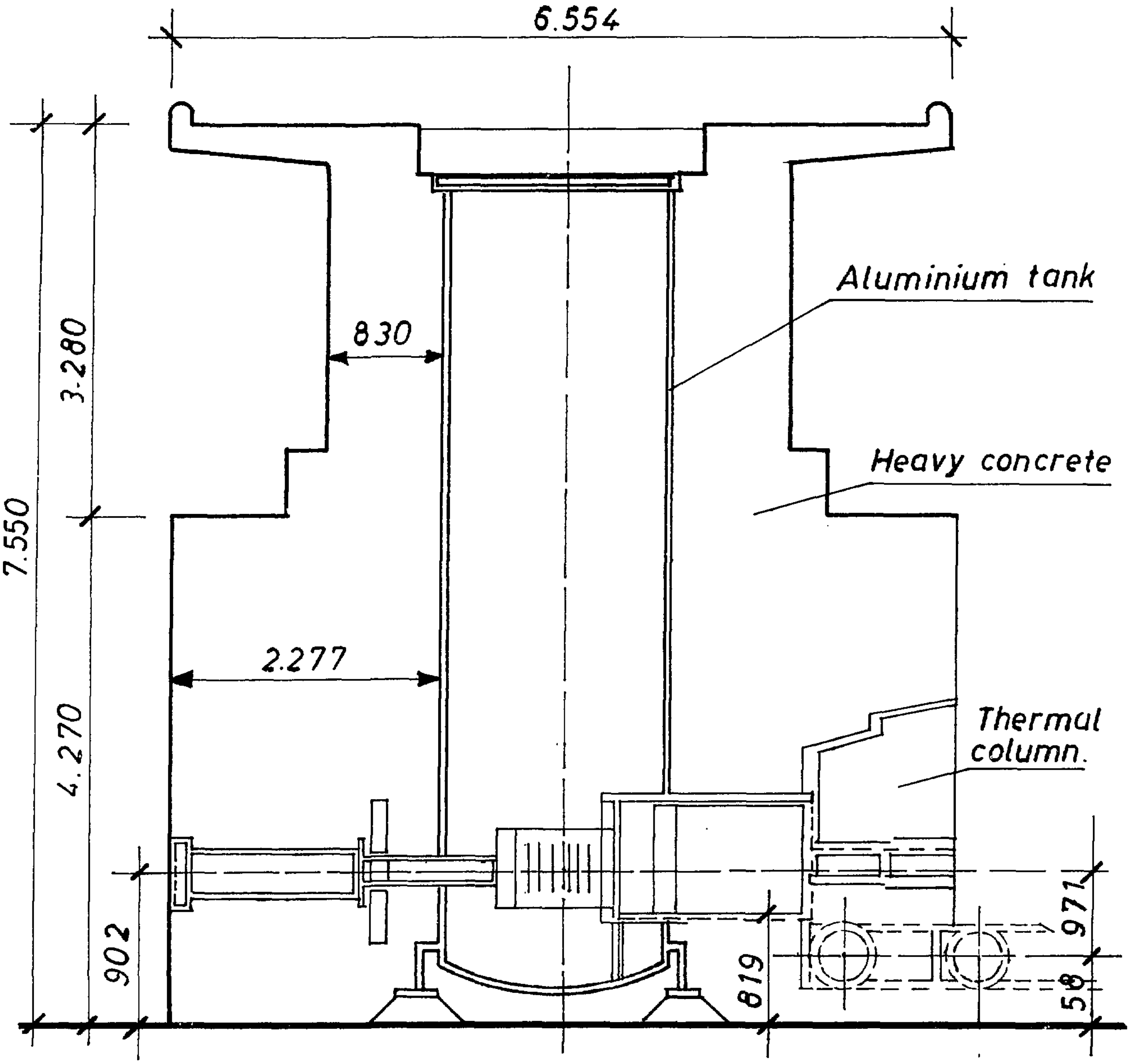

Fig.1 Vertical cross section of the C.R.E.N.-K. Reactor. (Figure in mm)

covered was free of any corrosion problem. It was discovered however that the area covered by the thermal column has a thickness a bit less than the standard 8 mm.

4. EVALUATION OF THE CAUSES OF THE CORROSION PROBLEM

To really enhance the safety of the reactor it is important to know the causes of the corrosion of the aluminum tank bottom.

Many factors can be at the origin of pitting corrosion of aluminum alloy. It is difficult to distinguish their respective importance in a given case, such as the one under investigation.

One has to take into consideration the structure of the metal, water chemistry, absorption of impurities or gases to explain the propagation process of the pitting. However the initiation of the process is normally due to one particular reason, [3].

As far as the initiation of pitting corrosion of aluminum is concerned the factors to be considered fall into three categories, [3], [4] :

a) Chemical factors : Chloride, Calcium Bicarbonate, Copper, Mercury, Chromium, Lead, Oxygen;

b) Metallurgical factors : wrong thermal treatment; intermetallics compounds such as (Fe Al3), (Al Cu2), (Al Fe Si) which create cathodic areas with respect to pure aluminum, while the compound of aluminum with Zinc or Magnesium produce anodic area with respect to pure aluminum; difference in reaction rate between crystals of different orientation.

c) Microbiological factors : bacteria, such as desulfovibric desulfuricans acting in the presence of cations or anions as cathodic depolarising agents to reduce sulphate to sulphide.

As far as the corrosion of the CRENK aluminun tank is concerned one has to take into account the fact that the aluminum plate used to fabricate the bottom of the reactor tank is different from those used to manufacture the reactor tank wall. Indeed, during the installation of the aluminum tank it was discovered that its bottom has a small crack. The original bottom of the tank was thus cut out and replaced by a new one fabricated in Belgium using what was supposed to be the same quality of aluminum, [5].

Since all the corrosion pits that were identified are located on the tank bottom, it is likely that the initiation of the corrosion process is due essentially to metallurgical factors; either :

a) to impurities in the original aluminum plate used to make the bottom of the tank; or

b) to impurities incrustrated in the plate during the machining process; or

c) to impurities dropped into the tank bottom during the eighteen years of operation of the reactor.

Taking into account the fact that all the pits are located outside the area covered by the core, that is outside the reflector, (see 'fig.' 3), it is likely that the corrosion process was initiated by galvanic couples, with impurities dropped into the aluminum tank during the operation of the reactor playing the cathodic role. If the pit created survives the initiation phase, it propagates by galvanic reaction with the aluminum being anodic and the impurities being cathodic.

5. RATE OF PENETRATION OF PITS IN ALUMINUM

It is important to evaluate the rate of penetration of pits in aluminum. It allows one to determine if the repair of the aluminun tank botton is necessary.

One can use the following formula to evaluate the rate of penetration, ([3], p. 60) :

$$d = K\,(t)^{1/3} \qquad (1)$$

where :

d = maximum pit depth; t = time; K = constant that depends on the alloy and the environment.

Since 17 years separate the time of the manufacture of the tank bottom and the time that the maximum pit depth of 2,5 mm were measured, it follows from relation 1 that in the case of the CRENK aluminum tank the constant K is in the range :

$$K_1 = 0{,}981 < K < K_2 = 2{,}5 \qquad (2)$$

If the same rate of penetration holds for the future the deepest pit will go through the aluminum tank botton at a time, t, such that :

$$\left(\frac{8 - d'}{K_2}\right)^3 < t < \left(\frac{8 - d'}{K_1}\right)^3 \quad (3)$$

with d' = 2,5mm; that is :

$$10 \text{ years} < t < 177 \text{ years.} \quad (4)$$

Tanking into account the lower value of, t, one can wait for 10 years before carrying out the repair of the aluminum tank bottom. We thought it advisable, however, to repair the tank bottom right away.

6. THE REPAIR OF THE CORROSION DAMAGE

To remedy the corrosion problem one has to fill the cavities created by the pits. Three solutions can be considered.

The first solution is to fill the pits with aluminum by welding procedure. The second solution is to use concresive epoxy resins. The third solution is to use silicone rubber.

The filling by welding procedure was deemed unfit because one has to heat the aluminum tank to such a high temperature as to cause local defects. The filling of the pits with epoxy resins was discarded because it was felt that under hard and intensive radiations epoxy will not remain stable in the long run. Before using the third solution, that is filling the cavities with silicone, a sample made of aluminum pieces binded together with silicone was irradiated at the BR2 Material Testing Nuclear Reactor in Mol (Belgium) to an integrated flux equivalent to a 1 Mw(th) reactor working full time for 20 years. No damage of the sample was recorded. The repair was thus carried out using silicone covered by small pieces of 1 mm aluminum to act as a protective barrier, ('Fig.' 3).

7. SAFETY UPGRADING OF THE CRENK NUCLEAR REACTOR

After the repair work the reactor was brought in full working condition without any problem.

To avoid the recurrence of the corrosion problem, the following measures were taken :

a) The top of the aluminum tank was sealed more tightly than before to avoid the drop of foreign objects into the the reactor:

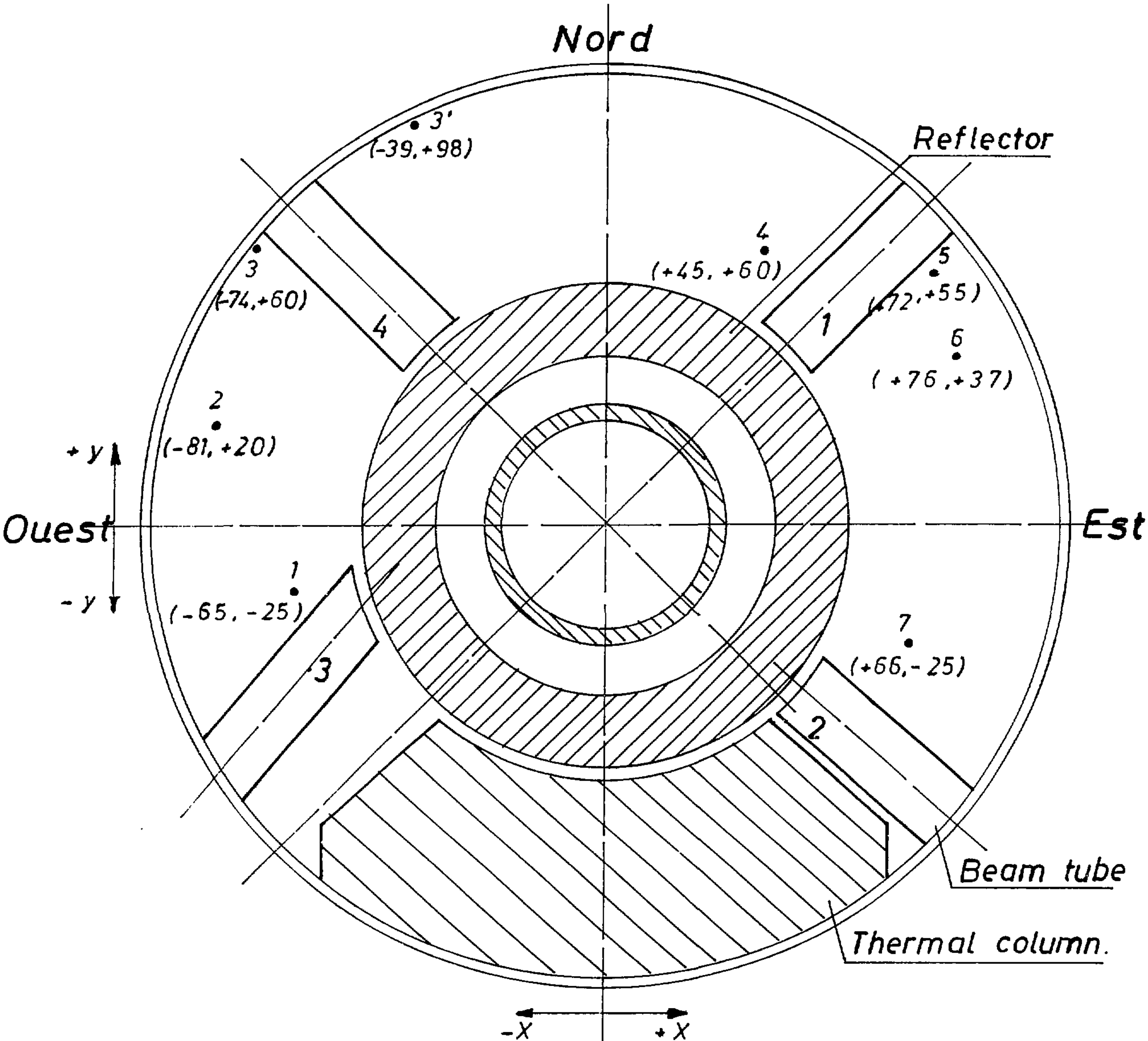

Fig. 2 Approximate location of pits in the tank bottom. Figures in bracket give the coordinates of pits relative to the centre. (in cm.)

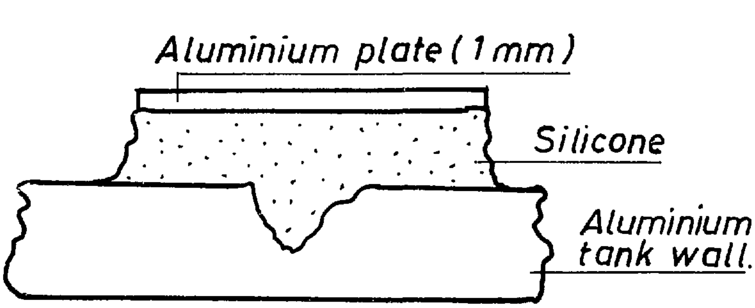

Fig. 3 Filling of pits

b) to improve the water chemistry, and to reduce bacteriologial growth in the water, frequent and intensive stirring of the water in the reactor tank is carried out using the primary circuit water pumps;

c) More precise monitors of the pH and resistivity of the deminarelized water was installed;

d) A careful control of Chlorine in the water in the tank is now carried out on routine basis;

e) Since corrosion af aluminium may be noticed by peak values of some elements, such as Fe, Cu, SO2, in the water, chemical analysis of the water is now carried out every week;

f) An underwater telescope using a flexible endoscope is being manufactured to monitor constantly the bottom of the aluminum tank, particularly the area under the core which is not visible from the top of the reactor.

8. CONCLUSION

It is our conclusion that the corrosion process of the CRENK reactor aluminun tank bottom was due to galvanic couples initiated by the drop into the reactor tank of materials being cathodic to the aluminum, such as Iron, Titanium, Vanadium, Nickel or Copper. It was not possible to determine the exact galvanic couple but the most likely candidate is "Iron-Aluminum".

Although care was taken to insure that the pH of the water in the reactor tank was always close to neutral as possible, it should be mentionned that the tap water in Kinshasa is strongly acidic in nature, which make it a good electrolyte for the galvanic couple. At all events other factors than metallurgical one, such as bacteria, can intervene to make a pit propagates once it has survived the initiation stage, [3].

With the most advanced corroded pits having a depth of only 2,5 mm out a possible maximum of 8 mm the safety of the reactor was certainly not a short term issue. Besides, since the rate of penetration in pitting corrosion usually diminishes with time, perforation may not occur for a considerable time if the metal thickness is adequate, as is the case for the CRENK aluminum tank. Thus we could have waited, possibly for the remaining life of the CRENK reactor. However we thought it worthwhile to meet the challenge and dismantle the reactor in order to gain a better insight of the causes of the corrosion problem. Besides it is a good exercice to dismantle and re-assemble a nuclear reactor, in preparation for the final shutdown of the reactor at the end of its life cycle.

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