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Analysis of specific factors causing RCS pressure boundary cracking

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1. Introduction

As nuclear power plants become aged, pressure boundary integrity has become so important issue in domestic and foreign nuclear industry that many related research projects are on-going.

KEPRI is going to embark a new research project for managing and preventing these kinds of cracks in nuclear power plants (NPPs).

Many nuclear power plants experienced pressure boundary stress corrosion cracking (SCC) and shut-downed because of it. In USA, V.C. Summer plant experienced reactor coolant pipe SCC near reactor outlet nozzle and Davis Vesse plant experienced reactor head crack around penetration pipe which is used to control rod drive mechanism [1].

In this paper, RCS pressure boundary cracking cases and corrosion potential have been studied to find out what are the specific factors that have affected crack initiations in the reactor coolant pressure boundaries.

2. Cracking Cases study

2.1. CRDM(control rod drive mechanism) cracks

In 1991, France Bugey-3 nuclear power plant has found that RPV upper head leakage during reactor coolant system pressure test by acoustic monitoring.

As a result of the investigation into the leakage, it was found that there was a through-wall crack at the Alloy 600 CRDM head adapter nozzle.

In 1992, at Sweden Ringhals-2 nuclear power plant, 25 % through-wall crack has been found. It was also considered PWSCC(primary water stress corrosion cracking) at the Alloy 600 CRDM head adapter nozzle.

After these accidents, inspections have been made at the location of the CRDM head adapter nozzles. And as a result of these inspections, at other NPPs in France some cracks have been found.

In USA, inspections at the CRDMs indicated some cracks. The plants that have found these kinds of cracks are D.C. Cook, Ginna, Millstone and Oconee-1.

In recent years, Davis-Basse and Oconee NPP unit 1, 2, &3 have experienced CRDM head adapter nozzle through-wall crackings.

In 2002, severe damage at the location of number 3 CRDM head adapter nozzle were found during the refueling stage at Davis-Basse plant which is B&W type NPP.

Up to now, PWSCCs have been found at the Base Metal.

2.2 Boric Acid Corrosion and replacement of the studs

In 1985, some leakage was found at the location of RPV flange in Ringhals NPP unit 2. After disassemble the flange, it was found that O-ring contanct area was slightly damaged.

In 1987, 230 kg Boric Acid crystals were found at the location of RPV closure head at Turkey Point NPP unit 4 and Salem NPP unit 2. After clearing these boric acid crystals, it was found that severe corrosion damages had been developed at some locations. This corrosion damage was turned out to be caused by boric acid leakage through instrumentation tube seal (Conoseal). Corrosion damage location was under this Conoseal. By this corrosion damage, 3 stud bolts and nuts were replaced and vent shroud support rings were also replaced. It was found that minimum thickness of Upper head closure of RPV required by design specification had been maintained despite of this corrosion damage.

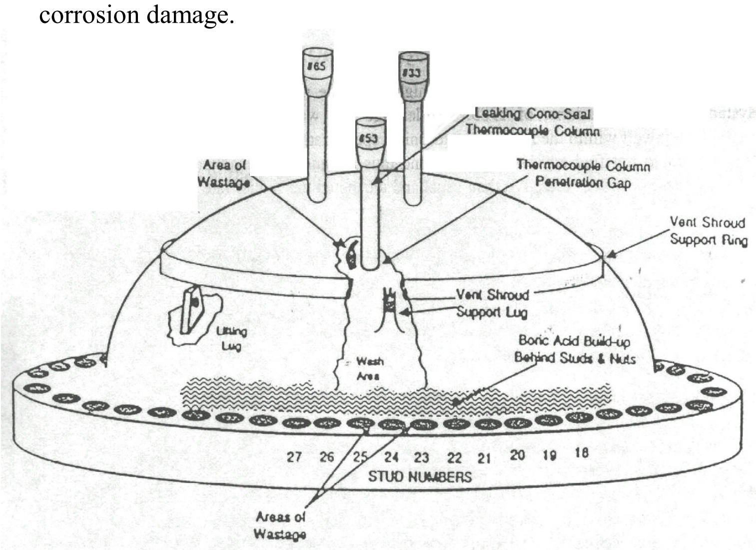

Fig 1. CRDM leakage and Boric Acid Corrosion

As shown in figure 1, Davis-Besse has experienced CRDM head adapter nozzle leakage and as a result of this leakage boric acid had been built-up behind studs and nuts. As a result of this build-up of boric acid, upper head material was corroded and considerable wall thinning was measured when the damage was found. However, RPV rupture didn't happen.

2.3. V.C. Summer NPP RPV outlet nozzle SCC

As shown in figure2, boric acid crystal was found at the RPV outlet nozzle of V.C. Summer NPP during visual examination in the year of 2000. After investigating leakage monitoring history docket, it was found that coolant leakage must had been continued below 0.3 gpm (gallon per minute) which amount is technical specification requirement.

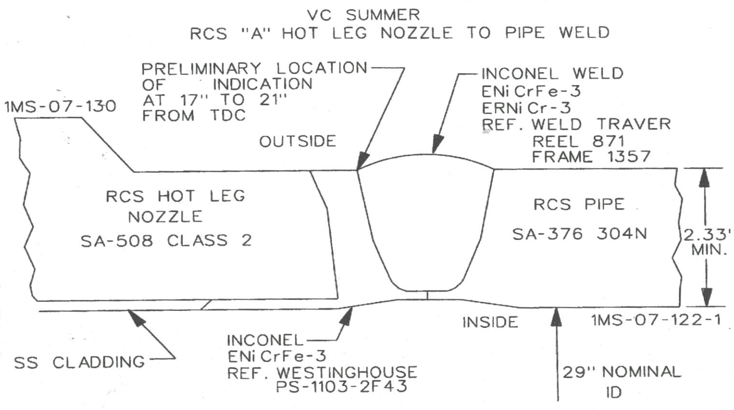

Fig 2. V.C. Summer Outlet Nozzle SCC

After this finding, PT, UT and ECT examinations were made to ensure the pressure boundary integrity. As a result of this examination, circumferential and axial cracks were found. With Metallurgical structure examination, it was found that crack had been developed between Inconel buttering and weld. It was considered that high residual stress arising from welding could be the main reason to cracking. Because of through wall cracking, nozzle welding parts were replaced. Other welding places were examined by UT and ECT. Some flaws were found. However, through pressure boundary integrity study such as fatigue, PWSCC and fracture mechanics analysis (including LBB), pressure boundary integrity was assured and the plant was restarted again.

3. Corrosion Potential Analysis in RPV

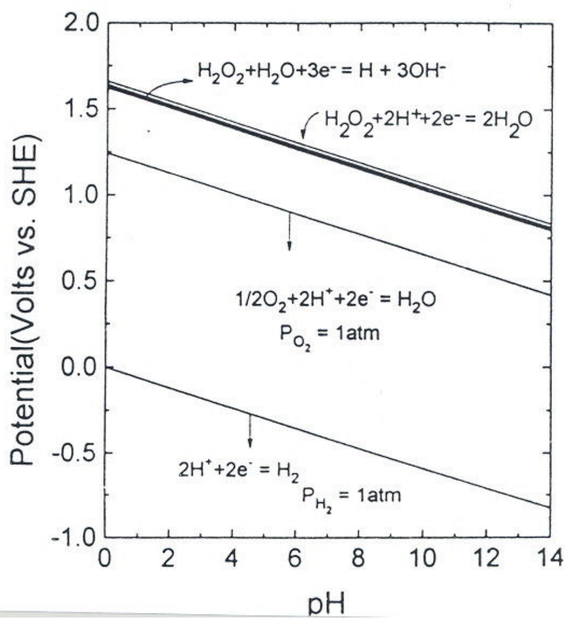

Fig. 3. Corrosion Potential Analysis

In figure 3, three oxidant reactions are shown, hydrogen reaction line, oxygen reaction line and hydrogen peroxide reaction line.

First of all we can consider high radiation at the reactor region.

Hydrogen peroxide can be produced by gamma-ray reaction with water, which is very unique factor in reactor area[2,3].

There are four lines in figure 3. Each line has been calculated using following chemical theory. For this, four possible chemical reactions in the coolant have been used.

$$H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O \quad E^o = 1.76\ V$$

$$\triangle G = \triangle G^o + RT \ln \frac{1}{[H_2O_2][H^+]^2}$$

$$\triangle G = \triangle G^o + RT \ln[H_2O_2] + 4.606\ RT\ pH$$

Where $\triangle G^o$ = 339,634 joules/mole

R = Gas Constant

T = temperature

$pH = -\log [H^+]$

Corrosion Potential $E = \triangle G/-2F$

Where F = 96487 coulomb/mole

As shown in the above equations, Corrosion potential can be higher with hydrogen peroxide reaction.

4. Conclusion

In this paper, RCS pressure boundary cracking cases have been studied to find out what are the specific factors that have affected crack initiations in the reactor coolant pressure boundaries

Through corrosion potential analysis in RPV, it was found that high corrosion potential can be formed by hydrogen peroxide which is produced by gamma ray interaction with water.

In addition to this high corrosion potential, initial defect (formed at the time of construction such as welding defects) could be very harmful. For, localized corrosion attack can grow to the size that could become fatigue crack initiation size.

In brief, the following specific factors have been found through various case studies and corrosion potential analysis.

(1) High corrosion potential
(2) Initial welding defects and high residual stresses
(3) Galvanic corrosion(localized attack or pitting)
(4) Boric acid corrosion
(5) Fatigue load by plant transients such as plant heat up and cool down.

REFERENCES

[1] KEPRI, "Kori Unit 2 Periodic Safety Review" 2004.
[2] A.O. Allen, "The Radiation Chemistry of Water and Aqueous Solution. 1961.
[3] T.H.Song, "Effect of H_2O_2 on the corrosion behavior of 304L Stainless Steel", 1995.