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Generation of Quantitative Information for Risk-Informed Decision Making on the Containment Liner Plate Corrosion Issue

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1. Introduction

Containment liner plate (CLP) corrosion was firstly discovered at a nuclear power plant (NPP) in U.S. In 2016, similar phenomena were also reported in an NPP in Korea. Risk informed decision making (RIDM) process can be used to determine whether this issue needs additional safety enhancement activities and how safety enhancement activities should be done [1]. To apply the RIDM process, it is essential to generate quantitative information in terms of deterministic analysis and probabilistic assessment. The present study performs quantitative evaluation for the CLP corrosion issue to support RIDM process. As the deterministic analysis, CLP corrosion depth estimation is performed based on the corrosion rate. Containment performance degradation is then estimated using the corrosion depth in terms of design pressure, which is mainly used to evaluate safety margin and risk insight in the RIDM process. Also, risk assessment is performed based on the deterministic analysis, which has central role of RIDM process.

2. Deterministic Analysis

Deterministic analysis is focused on the corrosion rate of the CLP. To understand the corrosion process, underlying mechanism is described using simple chemical reaction process. Although theoretical corrosion rate calculation method is proposed [2], historical data was used to estimate the corrosion rate because there are significant uncertainties in the parameters used in the theoretical calculation method.

2.1 Corrosion Mechanism

Most of CLP corrosion event observed was initiated by embedded foreign materials. Macro-cell accelerated localized corrosion [2] is known as the most likely mechanism for through-wall penetration of CLP. The acidity of foreign material prevents the formation of a passive film on the steel liner when contacted with concrete and dissolve carbon steel according to Eq (1).

$$Fe \rightarrow Fe^{2+} + 2e^{-} \quad (1)$$

The Fe^{2+} cations are hydrolyzed in the aqueous environment to produce $Fe(OH)_2$ as shown in Eq. (2)

$$Fe^{2+} + 2H_2O \rightarrow Fe(OH)_2 + 2H^{+} \quad (2)$$

Chloride ions can increase the acidity of the electrolyte which accelerate the corrosion rate. Outside of the pitting or crevice, the steel passivated by alkaline concrete environment is semi-conductive and the cathodic reduction reaction can readily occur on its surface as in Eq. (3)

$$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \quad (3)$$

Since the CLP is electrically connected with multiple rebar using tie-bars, the reaction is not limited in the vicinity of the pitting or crevice. As a result, this creates macro-cell which support cathodic reaction to occur over a large area, by which the rate of corrosion rate is not decreased.

2.2 Corrosion Rate Estimation

The theoretical corrosion depth prediction method uses variety of parameters which are uncertain in their application to a specific pitting corrosion case. So, the experience data from USNRC was used to estimate the corrosion rate. Table I shows the experience data of U.S. and Sweden NPP pitting corrosion events.

Table I: U.S. CLP corrosion experience

NPP	Max. Penetration	Average Corrosion rate
Barsebeck-2 Sweden	7 mm	0.44 mm/yr
Brunswick-2 North Carolina	8 mm	0.33 mm/yr
North Anna-2 Virginia	10 mm	0.5 mm/yr
D.C. Cook-2 Michigan	4.8 mm	0.22 mm/yr
BeaverValley-1 Pennsylvania	5.8 mm	0.19 mm/yr
	10 mm	0.29 mm/yr
Koeberg-1 South Africa	6 mm	0.23 mm/yr

Considering domestic environment, the data used was limited to PWR type plant, by which the average corrosion rate was estimated as follows:

$$Corrosion\ rate = \frac{0.5 + 0.19 + 0.29 + 0.23}{4} = 0.3025\ mm/yr \quad (3)$$

2.3 CLP Performance degradation

Pitting Corrosion of CLP mainly induces the degradation of containment performance in terms of internal design pressure. Since the containment performance is based on tendon, reinforced concrete, and CLP, the containment performance degradation should be estimated with the overall consideration of the structure. The containment performance degradation was estimated from the sensitivity analysis of a computer aided simulation using finite element method [3]. The containment design pressure degradation was expected to be decreased by 0.6% for 10% thickness thinning.

3. Probabilistic Assessment

The effect on risk by CLP corrosion is described in this section. The possibility of effect on core damage and large release of nuclear materials are separately inspected and quantified when there is a relationship between CLP corrosion and the risk change.

3.1 Effect on Core Damage of an NPP

CLP corrosion can affect the safety functions for the prevention of core damage by introducing two events. One is the leakage of coolant through the pitting hole in the phase of coolant recirculation from the containment sump and the other is the decrease of net positive suction head (NPSH) by containment pressure drop caused by pitting hole. It was estimated that there is little possibility of such an event from the ignorable leakage rate for expected pitting hole size and safety margin for NPSH respectively.

3.2 Effect on Containment failure of an NPP

There can be an effect on the risk of severe accident progression by the weakened containment design pressure caused by pitting corrosion. The containment performance decrease can be quantified in terms of level 2 PSA risk measure. The weakened containment design pressure affects the early and late containment failure scenario of an NPP. To assess the effect on the risk of an NPP by pitting corrosion, the following 4 analyses should be performed.

- Corrosion rate and CLP corrosion depth
- Containment design pressure degradation quantification
- Level 2 PSA accident scenario analysis caused by containment degradation
- Containment failure frequency quantification

First and second analysis was performed from the deterministic analysis in Section 2. According to Eq. (3), CLP average corrosion rate was estimated by about 0.3mm/year. Considering 5 operating years in a pilot NPP, pitting corrosion depth will be estimated to be 1.5 mm. From the computer-aided sensitivity analysis of structural simulation, this depth of CLP corrosion can weaken the containment design pressure by about 2%. The weakened containment performance can affect the leakage and rupture probability of containment in the severe accident progression scenarios in a Level 2 PSA. Table II shows the effect of containment performance weakening in terms of large release frequency (LRF) in the pilot NPP. The resulting containment failure risk of a pilot NPP was below 1.5% for any initiating event.

Table II: change of risk according to containment performance change

measure	Internal Event	Seismic Event	Internal Flooding
Rate of change	1.13%	1.5%	0.8%

4. Conclusions

Quantitative information for RIDM of CLP corrosion issue was generated using deterministic analysis and probabilistic assessment. Corrosion rate was estimated using history data of U.S. NPPs CLP corrosion events. The containment performance change was evaluated using sensitivity analysis of structural simulation of containment. Risk change effect was also assessed using level 2 PSA model of a pilot NPP. The information generated may be used to check the 5 principles of RIDM. Especially, in the assessment of safety margin and defense in depth, this quantitative information may have major role of a judgement.

REFERENCES

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