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The Development of Evaluation Model for Component Aging in CANDU-6 Reactor

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1. Introduction

In Korea, there are 4 CANDU reactor units which have been operating more than 10 years. Hence, the aging of components become to be an importance issue for its safety margin and operating integrity. CANDU reactor consists of a lot of components, including pressure tube, reactor pump, steam generator, feeder pipe, and so on. The aging phenomena of these components lead to the change of operating parameters, and it finally results to the decrease of the operating safety margin. As the reactor experiences the aging, the reactor operators should reduce the reactor power level in order to keep the minimum safety margin, and it results to the deficit of economical profit [1]. Therefore, in order to establish the safety margin for the aged reactor, the aging characteristics for components should be analyzed and the effect of aging of components on the operating parameter should be studied.

In this study, the aging characteristics of components are analyzed and revealed how the aging of components affects to the operating parameter by using NUCIRC code. Finally, from the variation of operating parameter with operating time, the evaluation model for the components aging has been developed.

2. Magnetite Corrosion and Deposition in a loop

For a CANDU reactor, one of the important aging phenomena is the flow accelerated corrosion (FAC), together with the pressure tube creep [1]. The magnetite transport in the primary system, specifically the magnetite dissolution at the outlet feeder pipe and the magnetite deposition at the inlet feeder pipe, has an effect on a pressure drop in the primary system.

The magnetite corrosion occurs on an outlet feeder pipe by the flow accelerated corrosion. The dissolved magnetite is deposited on the cold side of steam generator & inlet feeder pipe having a low temperature in a loop because the magnetite solubility at this cold temperature is lower than the amount of magnetite dissolved in a coolant.

3. Numerical Analysis

The thermal-hydraulic analysis of a CANDU-6 reactor fuel channel was performed with an inlet header temperature of 262°C, an outlet header pressure of 9.99 MPa, and a header-to-header pressure drop of 1282 kPa by using NUCIRC code [2]. In the present calculation, the circuit analysis has been conducted by using the ITYPE 6 among NUCIRC calculation options. The detailed calculation procedure for the circuit analysis is well documented in the reference [3].

The main aging components are firstly defined and the effect on the operating parameter, such as inlet header temperature and pressure, has been analyzed. The values of aging parameter for the 15, 30 EFPY (Effective Full Power Year) is predicted from the historical operating data of Wolsung units. In order to reveal the independent effect of the aging parameter, the reference values has been used for the plant operating condition except the considered aging parameter. In this study, the aging effect has been analyzed for the main aging components of pressure tube, feeder pipe, steam generator, orifice degradation factor. The feeder pipe roughness for 15, 30 EFPY is predicted from the operating data of Wolsung unit 4 in 11 EFPY by extrapolating from the present data sets.

4. Evaluation model for the components aging

In order to develop the evaluation model for the components aging, lots of calculation was conducted for the various operating condition. Figure 1 and 2 shows the effect of feeder pipe roughness on the inlet header temperature and pressure, respectively. It is revealed from the figure that the feeder pipe roughness tends to increase the inlet header pressure, while it has small effect on the inlet header temperature. The inlet header temperature tends to increase with the creep ratio of pressure tube, while the inlet header pressure decrease with the creep ratio because the pressure drop in the reactor core decrease with the creep ratio and the outlet header pressure is kept to a constant value by the pressurizer. Based on the calculation results, the aging model for the feeder pipe has been developed for the fresh pressure tube condition.

$$T_{InletHeader} = 2.1\times10^{8}(FR)^{4} - 5.2\times10^{6}(FR)^{3} + 4.3\times10^{4}(FR)^{2} - 221\times FR + 264.26$$
$$T_{OuletHeader} = -4.1\times10^{8}(FR)^{4} + 9.1\times10^{6}(FR)^{3} - 9.2\times10^{4}(FR)^{2} + 517\times FR + 301.3$$
$$P_{InletHeader} = -9.7\times10^{7}(FR)^{4} + 2.6\times10^{6}(FR)^{3} - 2.3\times10^{4}(FR)^{2} + 95.2\times FR + 11.16$$
$$P_{OutletHeader} = 9.5\times10^{7}(FR)^{4} - 3.4\times10^{6}(FR)^{3} + 279.1\times(FR)^{2} - 1.6\times FR + 9.95$$

Figure 3 and 4 shows the effect of steam generator fouling factor on the inlet header temperature and pressure, respectively. It is revealed from the figure that the steam generator fouling tends to increase the inlet header temperature, while it has small effect on the inlet header pressure. As the steam generator fouling increases, the heat transfer between primary and secondary RCS is decreased due to the low heat conductivity in steam generator, which results to increase the inlet header temperature. Since the steam generator fouling factor is only related to the heat transfer rate, the inlet header pressure and RCS flow rate is nearly unaffected by the steam generator fouling factor. Based on the calculation results, the aging model for the steam generator fouling has been developed for the fresh pressure tube condition.

$$T_{InletHeader} = -2.2\times10^{15}(FR)^4 + 4.5\times10^{12}(FR)^3 - 3.3\times10^{9}(FR)^2 + 1.2\times10^{9}FR + 118.0$$
$$T_{InletHeader} = -3.5\times10^{15}(FR)^4 + 4.5\times10^{12}(FR)^3 - 3.6\times10^{9}(FR)^2 + 1.2\times10^{9}FR + 167.7$$
$$P_{InletHeader} = 5.2\times10^{12}(FR)^4 - 9.2\times10^{9}(FR)^3 + 6.6\times10^{6}(FR)^2 - 2.3\times10^{3}FR + 11.45$$
$$P_{OutletHeader} = 1.2\times10^{10}(FR)^4 - 4.4\times10^{6}(FR)^3 + 3.4\times10^{4}(FR)^2 - 15.6\times FR + 9.95$$

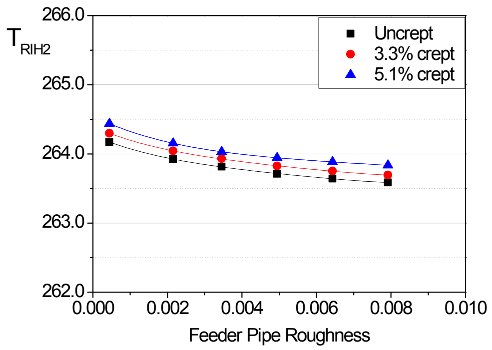

Fig.1 The effect of feeder pipe roughness on the inlet header temperature.

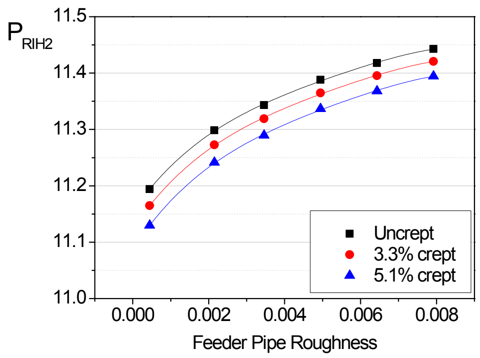

Fig.2 The effect of feeder pipe roughness on the inlet header pressure.

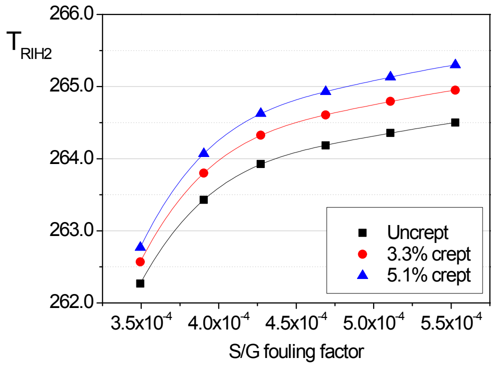

Fig.3 The effect of steam generator fouling on the inlet header temperature

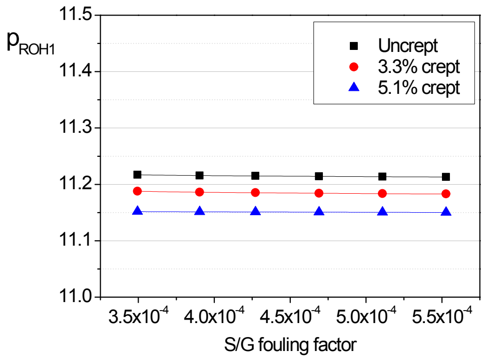

Fig.4 The effect of steam generator fouling on the inlet header pressure

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