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Preliminary Analysis for U-Tube Degradation in CANDU Steam Generator Using CATHENA

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1. Introduction

The interest in plant safety and integrity has been increasing due to long term operation of nuclear power plants (NPPs) and lots of efforts have been devoted to developing the degradation evaluation model for all the Structure, System, and Components (SSCs) of NPPs in these days. The efforts, however, were mainly concentrated on pressurized light water reactors (PWRs) in domestic. In contrast, the study for the aging degradation of counterparts of CANDU (CANada Deuterium Uranium) reactors has been rarely performed, even though Wolsong unit 1 (WS1), that is a CANDU 6 NPP in Korea, has been operating for almost 30 years. Therefore, the assessment of the aging degradation is required and the proper and exact evaluation model for the aging degradation of SCCs of CANDU, especially WS1, is urgently needed.

In this study, the aging degradation of steam generators (SGs) in WS1 was mainly discussed. Based on cases of the aging degradation of SGs in overseas CANDU reactors, the major potential aging mechanisms of SGs were estimated since there has been no case of accident due to degradation in CANDU NPPs in Korea [1]. Some core parameters which are indicators of the degree of degradation were calculated by CATHENA (Canadian algorithm for thermal hydraulic network analysis) [2]. In the result of comparing two calculation cases; core parameters for only aged SGs in fresh plant and those for all the aged component, it can be concluded that aging of SGs is a main component in the degradation assessment of CANDU NPPs, and keeping the integrity of steam generator (SG) tubes is important to guarantee the safety of the NPPs.

2. Methods

To assess the impact of aging degradation in CANDU SGs, the major degradation mechanisms and the susceptible parts to degradation were investigated. And then, a sensitivity study was performed to investigate the impacts of the degradation mechanisms by a CATHENA model.

2.1 Degradation Mechanisms Which Can Occur in CANDU SGs

Based on damage assessments or maintenance records which were reported from the domestic and the overseas CANDU NPPs, the major degradation mechanisms of the SGs in WS1 were estimated.

The tubing material of WS1 is alloy 800, which is less susceptible to various types of degradation than mill annealed Alloy 600, 690 and Monel 400. Any abnormal signal due to a specific defect has not been found in service inspection of SG tubes. The reasons of rupture events related to aging degradation in overseas CANDU NPPs using alloy 800 tubes are as follows. Fretting in the primary side of U-bends, Small-scaled pitting in the secondary side and Fouling on both primary side and secondary side were reported. According to plugging records of overseas CANDU NPPs, the fretting wear at U-bend was the major reason of plugging tubes. From these results, the fretting wear and the fouling can be mainly generated in WS1.

2.2 Susceptible Parts to Aging Degradation in CANDU SGs

The susceptible parts to aging degradation in the SGs of WS1 are the U-bend region, the cold leg side and the tubing expansion transition zone. At the U-bend region, FIV (Flow Induced Vibration) generated by high circulated flows can cause the aging degradation at contact points between tubes and the anti-vibration bars (AVBs). If intervals between tubes and AVBs are long, the large scale vibration will occur. In WS1, the intervals between them are short because there are much more AVBs in WS1 than in other plants. Thus, the effect of the vibration is not supposed to be big. However, it is possible to generate fretting wear and denting in the secondary side of the U-bend region because AVBs were made of carbon steel unlike other support structures made of stainless steel. Also, if there is an inflow of impurities in tubes, fretting wear and denting will occur in the primary side of the U-bend region, because the water flow is rapidly changed in that region. Besides, loosing parts, which are caused by the fretting wear, can be accumulated in both primary and secondary sides at the U-bend. Also, if some sludge such as the oxidized iron melted from AVBs due to FIV-induced FAC (Flow Accelerated Corrosion) in the secondary side, or impurities in the primary side accumulates in both sides at the cold leg, fouling will occur in that region. Meanwhile, the degradations such as pitting and denting can occur at the tubing expansion transition zone in WS1 which was expanded by rolling expansion method unlike that in unit 2, 3, 4 expanded by hydraulic expansion method, because the former method makes a higher residual stress than the latter.

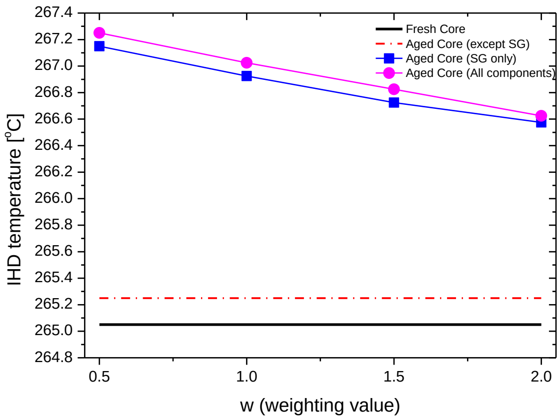
2.3 Sensitivity Study Using a CATHENA Aging Model

The 11 core parameters of WS1 were estimated by the CATHENA aging model. The core parameters for only aged SGs and those for all the aged components were calculated. Table I shows that the differences between them are very small. The additional estimation of the core parameters for all the aged components except SG was also performed. These values are very close to the counterparts of fresh one. From these results, it is concluded that the aging of SGs is a critical factor of the aging degradation of WS1 plant.

A sensitivity study was performed with changing the aging parameters of 3 nodes in the primary side of SGs head to cold leg, and those nodes are susceptible to the aging degradation. The changed aging parameters were flow area, hydraulic diameter and roughness in SG U-tubes. The correction factor which affects fouling factor was also modified. The first three parameters related to the heat transfer coefficient of tubes are dependent on each other. The output data for the aged core values were calculated by giving different weightings to three parameters of input data through multiplying each differential percent by 0.5, 1.5 and 2.0. Figure 1 shows the trend of IHD (inlet header) temperatures according to weighting values. They were changed according to the degree of changing aging parameters at the primary side flow into cold leg. It was indicated that the core parameters for only aged SG were almost same as those for all the aged components regardless of the degree of weighting. The differences between fresh core results and those of only aged SGs took about 95% of the differences between the fresh core results and those of all the aged components. This result also definitely shows that the aging of SGs is a major component for the aging degradation of the CANDU NPPs.

3. Results

As a result of comparing the three calculation cases; input parameters for only aged SG, for all the aged components and for all the aged components except SGs, it was investigated that the aging of SGs is the most important part of the aging degradation assessment of NPPs. As a result, a sensitivity study for the degradation of SGs was performed by changing the aging parameters which cause phenomena of degradation at the sensitive part of SGs. Changing these values affected the core parameters which are important to the reactor safety. It was shown that the safety of CANDU reactors depends highly on the degree of the aging degradation of SGs. This result also means that the aging degradation factors should be accurately measured and calculated.



Fresh input value: $\boldsymbol{x}$, Aged core input value: $\tilde{\boldsymbol{x}}$
Aged core input value (weighted): $\hat{\boldsymbol{x}}$, Weighting value: w
$\tilde{\boldsymbol{x}} - \boldsymbol{x} = \text{d}$, $\hat{\boldsymbol{x}} = \boldsymbol{x} + \text{wd}$

Fig 1 Trends of IHD Temperatures According to the Weighting Values on Aging Parameters

REFERENCES

[1] KINS (Korea Institute of Nuclear Safety), Study on assessment of the integrity of steam generator in Wolsong 1, in KINS/RR-766, 2010 (in Korean).
[2] AECL (Atomic Energy of Canada Limited), CATHENA MOD-3.5d theory manual, 153-112020-STM-001, 2005.

Table I. Sensitivity Study Results Using a CATHENA Ageing Model

Parameters	Fresh Core		Aged Core (except SG)		Aged Core (SG only)		Aged Core (All)
	value	Diff.	value	Diff.	Value	Diff.	value
IHD Pressure [Mpa]	11.26	-0.09	11.24	-0.07	11.20	-0.03	11.17
OHD Pressure [MPa]	10.03	0.00	10.03	0.00	10.03	0.00	10.03
SG Dome Pressure [Mpa]	4.69	0.00	4.70	0.00	4.70	0.00	4.70
IHD Temperature [°C]	265.05	1.97	265.25	1.77	266.93	0.10	267.03
OHD Temperature [°C]	310.60	-0.05	310.60	-0.05	310.60	-0.05	310.55
SG U-Tube Inlet Temperature [°C]	309.80	0.00	309.80	0.00	309.80	0.00	309.80
SG U-Tube Outlet Temperature [°C]	264.60	1.98	264.80	1.78	266.45	0.13	266.58
OHD Quality	0.0137	0.01	0.0116	0.02	0.0302	0.00	0.0282
OHD Void Fraction	0.1442	0.12	0.1247	0.14	0.2743	-0.01	0.2604
Pump Flow [kg/sec]	2101.0	-63.75	2129.3	-92.00	2013.8	23.50	2037.3
Pressurizer Level [m]	13.624	-1.03	11.246	1.35	13.999	-1.41	12.594
Turbine Flow [kg/sec]	983.5	-0.30	983.5	-0.30	983.0	0.20	983.2