Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Sensitivity analysis for aging degradation of SG tubes in CANDU NPPs

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1. Introduction

Wolsong unit 1(WS1), which is one of CANDU(CANada Deuterium Uranium) nuclear power plants(NPPs) in Korea has been operating for its design life of 30 years. Nevertheless, there are little attempts to assess the aging effect of components in the aspect of safety analysis. Even though there has been no case of accidents due to aging degradation in CANDU SGs[1], the prediction of aging degradation for steam generators(SGs) among all components is very important[2] since none of the steam generators in the reactor has been refurbished.

The fouling is generally known as a major degradation mechanism of SGs. It means that unwanted materials are deposited on inside surface of the SG tube. The magnetite deposition in SG tubes is a main cause of the fouling. The magnetite is originated from thinning of feeders which are made of carbon steel. The magnetite deposition in SG tubes contributes to a loss heat transfer efficiency and increase the RIHT(Reactor Inlet Header Temperature) which is used as the representative value for aging degradation. To reduce this effect, the mechanical cleaning of inside surface of the SG tube was carried out in 2003. The removal of magnetite by cleaning is effective to decrease the RIHT. To set the date for the cleaning of inside surface of the SG tube, it is important to estimate the inside diameter of the SG tube according to SG aging degradation.

Meanwhile, refurbishment of components of WS1 without SGs was carried out in 2009. In the previous study for the safety analysis of CANDU NPPs by CATHENA(Canadian algorithm for thermal hydraulic network analysis), using the newly refurbished WS1 NPP in 2009 as a starting point, the fresh model at 2009 was referred as the 0 EFPY model. And, 11 EFPY model was created from the 0 EFPY model after refurbishment. Because SG tubes were neither replaced nor cleaned during the refurbishment outage, the site data at 2004 after cleaning in 2003 was used. It is possible that the aging degradation parameters were underestimated since the magnetite from aged feeders before retubing might have been deposited in SG tubes from 2004 to 2009.

In this study, in the aspect of the maintenance of SGs, the more conservative safety analysis with the consideration of SG aging degradation from 2004 to 2009 was suggested. 0 EFPY(SG 4.6 EFPY) model and 11 EFPY(SG 15.6 EFPY)model which considered the effect of SG aging degradation from 2004 to 2009 after retubing were estimated. And then, it was identified whether there is the crucial difference between results of this new analysis and the previous analysis or not.

2. Methods

To analyze the sensitivity for aging degradation of SGs in CANDU NPPs, first, the major reason of aging degradation and trends of aging parameters in SGs were investigated. And then, the sensitivity study was performed to identify impacts of the discrepancy between the starting points of aging degradation of SGs and that of other components by CATHENA.

2.1 Trends of Aging Parameters in CANDU SGs

In the result of comparing SG input data of 0EFPY and those of 11EFPY, the SG aging parameters such as flow area, hydraulic diameter and roughness at the primary side flow into cold leg were changed from 0 EFPY to 11 EFPY. The hydraulic diameter and the flow area were decreased, and the roughness was increased as WS1 ages. Meanwhile, the changed RIHT by CATHENA should be corrected by the correction factor since the RIHT is estimated not by CATHENA but by another method. Thus, the correction factor was modified to square the RIHT which is one of output data of CATHENA with the one which had been estimated before carrying out the analysis by CATHENA. It seems that the changed SG aging parameters reflected the fouling mechanism which contributes to a loss heat transfer efficiency and increasing the RIHT. Since feeders in WS1 were made of carbon steel, it is possible that the oxidized iron melted from those parts due to FAC(Flow Accelerated Corrosion)is easily deposited in the primary side flow into SG cold leg in the form of the magnetite. That is, thinning of feeders is a major reason of aging degradation in SGs. As WS1 ages, depending on the degree of thinning at feeders, accumulation of the magnetite on inside surface of the SG tube affects the aging parameters of SGs. It makes the diameter and the flow area decreased, the roughness increased.

The 11 EFPY post-retubing model in a previous analysis was created by using a linear interpolation. The aging trends obtained before and after refurbishment should be treated separately. Using the trends of SG aging degradation between 0 EFPY and 14.45 EFPY at 2000 before retubing, the aging parameters at the 11 EFPY after retubing were estimated from those at the 0 EFPY after retubing. That is, the change rates for each SG aging parameter of pre-retubing models and those of post-retubing models were almost same.

Meanwhile, the RIHT has the tendency to increase with age. According to PSR report of WS1[3], the RIHT of WS1 has increased at a constant rate with time.

2.2 Sensitivity Study Using CATHENA

The 0 EFPY post-retubing at 2009 was set as the starting point of aging degradation for WS1 in the previous analysis by CATHENA. Tubes such as feeders and pressure tubes were replaced at 2009, whereas SG tubes were cleaned not at 2009 but at 2003. Thus, the site data at 2004 after cleaning SGs was used only for SG input data. In other words, the SG condition of the 0 EFPY post-retubing was set to be same as that of the 2004 data. Fig. 1 shows that the starting point of aging degradation for SGs was different from that for feeders at the 0 EFPY post-retubing. Although the magnetite transport effect might have been eliminated by installing new feeders at 2009, it is possible that the aging degradation parameters for SGs were underestimated because post-retubing models didn't consider the effect of magnetite deposition which caused by aged feeders from 2004 to 2009 before retubing.

Thus, the SG condition at 2009 which was estimated by using a linear interpolation with 2004 data was applied to the 0 EFPY post-retubing model. In other words, the SG aging parameters such as flow area, hydraulic diameter and roughness in the previous 0 EFPY post-retubing model were replaced by the estimated SG data at 2009. At this time the RIHT was supposed not to be changed because the RIHT which had been estimated before carrying out the analysis by CATHENA. Thus, CATHENA calculation continued to be carried out, by modifying the correction factor, until the changed RIHT by CATHENA was same as the original RIHT of the previous aging model. In this way, 11 EFPY(SG 15.6 EFPY) model as well as 0 EFPY(SG 4.6 EFPY) model was created.

3. Results

Table I shows the result of sensitivity analysis according to considering SG aging degradation for 4.6 years which is a time gap between aging models of SGs and feeders. In the result of comparing output of analyses before and after considering SG aging degradation for 4.6, it was investigated that there was a slight difference between results of two cases by CATHENA. The differences in the OHD Quality and the OHD Void Fraction between SG 0 EFPY model and SG 4.6 EFPY model account for approximately 27% and 23% of the previous SG 0 EFPY model results. Therefore, it is suggested that the more conservative safety analysis considering SG aging degradation for 4.6 years be used to assess the safety of NPP in the aspect of the maintenance of SGs.

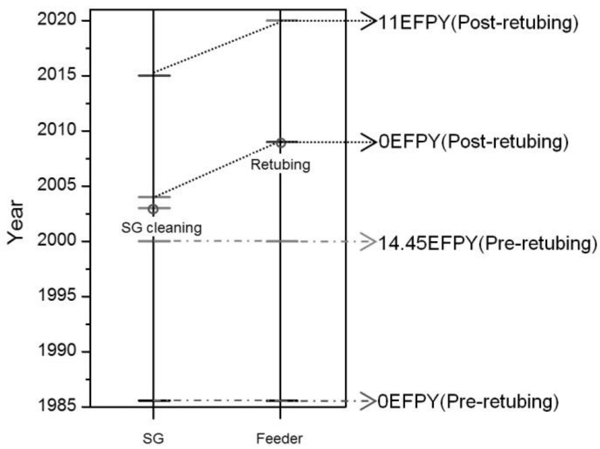

Fig. 1. Points of time for aging models of SGs and feeders.

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] S. E. Shin, J. H. Lee, T. K. Park, S. H. Hwang, and J. Y. Jung, Preliminary Analysis for U-Tube Degradation in CANDU Steam Generator Using CATHENA, Transactions of the Korean Nuclear Society Autumn Meeting, p11-12, Gyeongju, Korea, October 25-26, 2012.

[3] PSR(Periodic Safety Review) of the Wolsong unit 1, 2003(in Korean).

Table I. Sensitivity Study Results Using CATHENA

Parameters	0 EFPY(Post-retubing)		11 EFPY(Post-retubing)	
	SG 0 EFPY	SG 4.6 EFPY	SG 11 EFPY	SG 15.6 EFPY
IHD Pressure [Mpa]	11.27	11.23	11.17	11.15
OHD Pressure [MPa]	10.03	10.03	10.03	10.03
SG Dome Pressure [Mpa]	4.70	4.70	4.70	4.70
IHD Temperature [^{o}C]	265.05	265.05	267.03	267.03
OHD Temperature [^{o}C]	310.60	310.58	310.55	310.58
SG U-Tube Inlet Temperature [^{o}C]	309.80	309.70	309.80	309.80
SG U-Tube Outlet Temperature [^{o}C]	264.60	264.68	266.58	266.58
OHD Quality	0.0138	0.0175	0.0282	0.0307
OHD Void Fraction	0.1448	0.1773	0.2604	0.2777
Pump Flow [kg/sec]	2101.0	2067.3	2037.3	2014.0
Pressurizer Level [m]	13.634	13.683	12.594	12.605
Turbine Flow [kg/sec]	983.7	983.6	983.2	983.3