Evaluation on Wear Reliability for Delayed Neutron Tubing in Pressurized Heavy Water Reactors

Myung Ho Song [a*], Hong Key Kim [a], Woo Seog Ryu [b], Young Ho Lee [c]
[a] *Engineering Research Dept., Korea Institute of Nuclear Safety, Daejeon, 305-338, Korea*
[b] *Irradiated Material Examination Facility, Korea Atomic Energy Research Institute, Daejeon, 305-353, Korea*
[c] *Innovative Water Reactor Fuel Center, Korea Atomic Energy Research Institute, Daejeon, 305-353, Korea*
[*] *Corresponding author: k084smh@kins.re.kr*

1. Introduction

Wear defects of delayed neutron monitoring system tubing (on the other hand, DN tube was called) is one of causes that resulted in heavy water leakage accidents. So, the assessment on the wear degradation of this component was preformed for the aging management of the same one. Design specifications of DN tubes for pressurized heavy water reactors including Wolsong unit 1 and primary coolant leakage accidents of all pressurized heavy water reactors were summarized and causes of wear defect for DN tubes were reviewed. Simple wear growth rate equations based on the heavy water leakage history were made. The proper repairing time is possible to be expected if the continued operation was considered based on wear growth rate equations. Finally wear equation software items of DN tubes that were developed for the long term operation of Wolsong unit 1 are introduced.

2. Methods and Results

In this section, some of design data and the leakage history used to develop wear growth rate equations are described. Various wear growth rate equations and calculated results were produced and wear equation software program are presented [1].

2.1 Design Specifications and Operation Conditions

DN tubes are branched from feeder pipes and samples of primary coolant are transported to failed fuel location system through these tubes. The number of DN tubes is 380 and these are deigned, manufactured, and installed according to codes of ASME Section III Class 1 as Table 1. The material of DN tube is type 304L stainless steel.

Table I: Design Specifications of DN tubes

System Name	Design & Fabrication Code	Tubing Materials	No. of Tubing	O.D.	Thickness
Delayed Neutron Monitoring System	ASME Sec.Ⅲ, Class 1	SA213/450 TP304L	380	1/4", 3/8"	1.244㎜

DN tube endures the same temperature and pressure of the primary coolant inside the tube as shown in Table 2 and the high velocity air (8m/sec) is flowing surrounding the bundle of the tubes for air cooling and changing inside the reactor building.

Table 2: Operation Conditions and Environments of DN Tubes

System Name	Attached Line[1)]	Nuclear Grade	Materials	Fluid	Design Pre. (MPa)	Design Temp. (℃)
Delayed Neutron Monitoring System (63105)	Tubing connected to I&C Equipment	1	Stainless Steel	Heavy water (D_2O)	10.69	279

1) The non-safety grade pipe adjacent to the safety grade pipe includes the pipe of the first aseismatic anchor (equivalent anchor).

2.2 Accident History and Causes of D_2O Leak in DN Tubes

Leakage history of delayed neutron tubes was summarized in Table 3. Time to occur the leakage from commercial operation is 3.5 years to about 8 years.

Table 3: Histories of Wear Defect Occurrence on DN Tubes

Inspection Type	Plants	Occurrence Date	Degree of Defect	Commercial Date	Time to leak(Yr)
Leakage Accident	Wolsong unit 2	2004. 6. 18	100% pentration (Tk: 1.244mm)	1997. 7. 1	6.96
	Wolsong unit 3	2004. 5. 25	100% penetration (Tk: 1.244mm)	1998. 7. 1	5.92
	Wolsong unit 1	1986.10. 1	100% penetration	1983. 4.22	3.53
		1988. 8. 13	100% penetration		5.32
	Wolsong unit 4	2007. 9. 3	100% penetration (Tk: 1.244mm)	1999. 10. 1	7.92
Visual Inspection	Wolsong unit 2	2004. 9. 10	24~38% Wear (0.3~0.47mm)	1997. 7. 1	7.17

Note: Tube repair criteria (Wear depth: ≥ 50% of tube wall thickness or ≥ 0.622 mm)

In order to investigate the root cause of D_2O leak in DN tube, two failed tubes were pulled out from Wolsong unit 2 and unit 3 respectively and metallically examined. As results of these examinations, it was noted that the cause of contact was the thermal expansion of tubes and the cause of vibration was the operation of PHT pumps. Fig. 1 shows the pinhole and defective area of DN tube.

2.3 Wear Growth Rates of DN tubes in PHWRs

In general, wear growth rates were represented by Archard equation that included wear coefficient, contacting load, and sliding distance. But because there

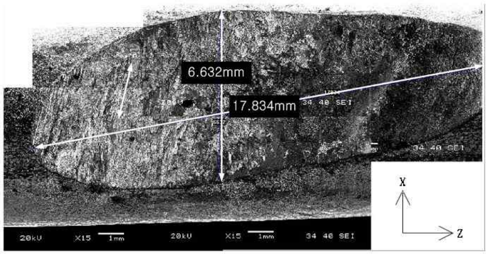

Fig. 1 The pinhole and defective area of DN tube

was no field data of contacting load and sliding distance, these variables were simply treated as single wear coefficient in the wear growth rate equation of DN tube.

That is, V = Kdn·t: Kdn is wear coefficient.

There are three wear types of DN tubes in PHWRs; Tube-Tube (TT), C wear ring-C wear ring (CC), and C wear ring-Tube (CT). Therefore if these parts were contacted across with 90°, correlation equations of for the wear volumes and the wear depth were calculated by simple 3-D code as follows:

- TT: V [mm^3]=$15\times d^2 - 0.8\times d^3$, **at** 1.244mm, V_{TT} = 21.67 mm^3
- CT: V [mm^3]=$15.7\times d^2 - 0.7769\times d^3$, **at** 1.244mm, V_{CT} = 22.80 mm^3
- CC: V [mm^3]=$16.55\times d^2 - 0.8039\times d^3$, **at** 1.244+ 0.5mm, V_{CC} = 46.07mm^3

The simplification of second order equation is well satisfied in the boundary of 1.24mm or 1.24+0.5mm of wall thickness. In order to determine wear coefficients, Kdn were calculate based on failure histories of DN tubes as shown in Table 3.

Table 4: Wear Coefficients (Kdn) of DN Tubes

Leak Occurrence Year	Tube to Tube Contact	C-ring to Tube Contact	C-ring to C-ring Contact
3.53 (WS-1)	6.189 mm^3/yr	6.459 mm^3/yr	13.051 mm^3/yr
7.92 (WS-4)	2.736 mm^3/yr	2.879 mm^3/yr	5.817 mm^3/yr
5.73 (Average)	3.782 mm^3/yr	3.979 mm^3/yr	8.040 mm^3/yr

Fig. 2 shows the correlation of the operating time and the wear depth using single wear coefficients in Table 4. And these figures also show three cases of wear growth rates of DN tubes; a) conservative case, b) non-conservative case, c) average case.

2.4 DTWAES (DN Tubes Wear Analysis Evaluation System)

The wear evaluation software for DN tubes that can calculate the wear depth increasing with the operating

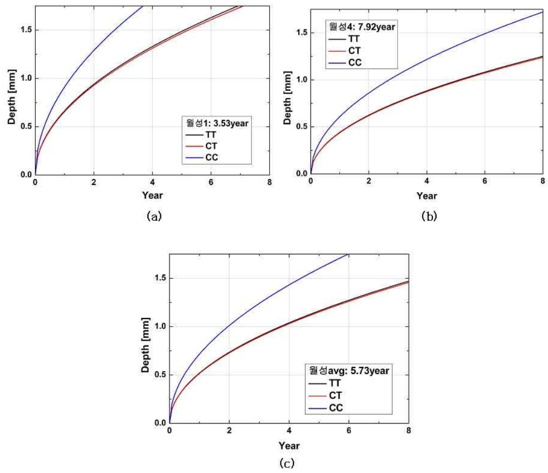

Fig. 2 Wear growth rates of DN tubes with contact types

time were developed as shown in Fig. 3 and the proper repairing time is possible to be expected provided that the continued operation is considered.

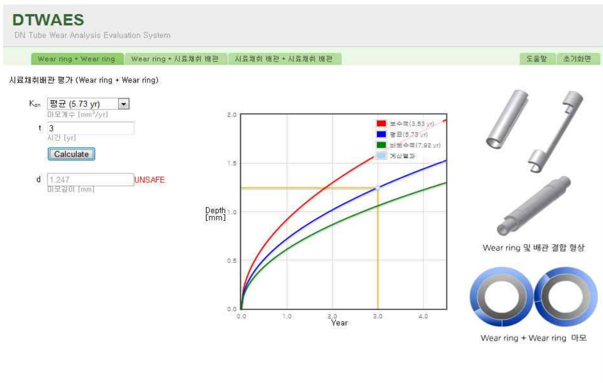

Fig.3 Initial screen of wear evaluation for C ring-C ring type

3. Conclusions

- The wear mechanism for delayed neutron tubes of domestic PHWRs is the abrasive wear and causes of wear are the contact by the tube thermal expansion and the vibration by the PHT pump operation.
- Equations for the wear growth rate were developed based on the failure histories of delayed neutron tubes for domestic PHWRs.
- Wear evaluation software for DN tubes that can calculate the wear depth increasing with the operating time were developed and the proper repairing time is possible to be expected if the continued operation is considered.

REFERENCES

[1] M.H.Song and H.K.Kim, The Study on Reliability Evaluation of Failed Fuel Location System Tube (Delayed Neutron Tube) for Continued Operation of Wolsong Unit 1, KINS/RR-797, p 92, 2010