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A Review of Steam Generator Tube Plugging Effects on Design Base Events

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1. Introduction

Nuclear power plants experience steam generator (SG) tube degradation in the course of operation. If the repaired tubes by sleeving and plugging exceed the licensing level, replacement of SGs should be considered. The tube degradation is not a new issue in the nuclear industry. However, the information which comprehensively explains the effect on the safety analysis of non-LOCA events is rare, even though there is relatively abundant information regarding to the tube's integrity, in-service inspection or chemical environment of the secondary side of SG. In this paper, the initialization procedure of the computer code (CESEC-III) used for safety analysis and the heat transfer effects on the design based events are thoroughly reviewed with SG tube plugging levels.

2. Effects on Safety Analysis

The operating conditions may change according to the SG tube plugging levels. How it is considered in safety analysis and whether the effects of the tube plugging are dependent on event characteristics are reviewed in this section. The computer code used for this purpose is CESEC-III which has been licensed to analyze non-LOCA events for OPR1000 and APR1400.

2.1 Effects on Initial Condition

As tube plugging level increases, RCS mass flow rate will decrease. If we maintain the core inlet temperature and the core power, core outlet temperature will rise correspondingly. In addition, due to the reduced heat transfer area, the overall heat transfer coefficient multiplied by area (UA) will decrease. Consequently, secondary temperature would slightly decrease to compensate the reduced UA to maintain the same heat rate. If there are enough margins in system design and operating conditions are within the safety analysis ranges, SG tube plugging will be allowed to a certain extent with maintaining current core power and RCS mass flow rate. To cover the degradation of SG tubes and crud in the RCS pipes during the plant life time, conservative ranges of RCS flow rate and core temperature have been already considered in safety analysis. The procedure to consider them in the analysis is as follows. In the CESEC code, the heat load of steam generator primary side nodes at each time step is computed by the following relationship:

$$Q = UA(T_{pri} - T_{\sec})$$

As tubes are plugged, UA will decrease. Based on heat balance between primary and secondary side, the tube plugging reduces the initial steam generator pressure. Next, the CESEC flow model calculates the mass flow rate by solving the one-dimensional momentum equation for the each pump loop. The one-dimensional equation is written as follows.

$$\frac{dW}{dt} = \frac{g\sum_{i=1}^{n}\rho_i Z_i - \sum_{i=1}^{n} W_i^2 \left[\frac{\phi_f f_i R_{fric,i}}{\rho_{is}} + \frac{R_{geo,i}}{\rho_{in}}\right] + \Delta P_{pump}}{\sum_{i=1}^{n}(L_i / A_i)}$$

The second term represents the total pressure change around the loop due to the friction loss and the geometric expansions and contractions. These factors are constants and are determined by the initial conditions. SG tube plugging will increase these values while RCS flow rate decreases. Then, at a given RCS flow rate, the code finds pump head from the RCP H-Q curve and adjusts the system resistances at the same rate. To see the effect of the tube plugging, two cases, no tube plugging and 10% tube plugging, are arbitrarily determined and the results are compared.

2.2 Effects on Design Based Events

Two events have been chosen to examine the heat transfer effects of the tube plugging. Those are the loss of condenser vacuum (LOCV) and the steam line break (SLB) which stands for the decrease in heat removal by the secondary systems and the increase in heat removal by the secondary systems, respectively.

<u>LOCV event</u>

Three cases are analyzed to see the heat transfer effects of the LOCV event. The initial conditions of the cases are shown in Table 1.

Table 1. Initial Condition of LOCV event

Case	Tin (F)	PZR Press. (psia)	RCS Flow Rate, per loop (gpm)
1	564.5	2250	82500
2	560.	2250	95700
3	572	2250	78375

The cases are divided based on the RCS mass flow rate. As mentioned earlier, the SG secondary pressures of 10% plugging case are initialized as lower than those of no tube plugging cases as shown in Fig.1. The UAs of plugging cases are lower than those of no plugging cases; however, the trends of UAs vs. time are not changed so much. The difference of heat rate between them is negligible. Accordingly, the tube plugging by itself has no significant effect on the results of LOCV event.

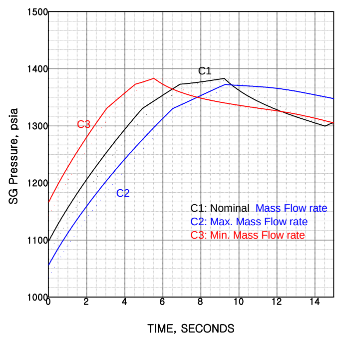

Fig.1 SG Pressure (LOCV)

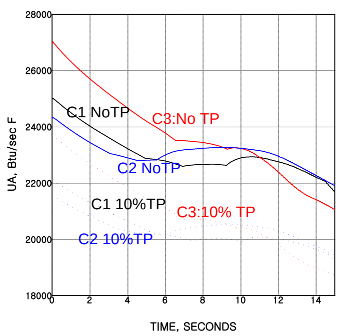

Fig.2 UA (LOCV)

<u>SLB Accident</u>

The effects of tube plugging are shown from Fig.3 through Fig.5. SG U-tubes are divided by hot and cold nodes in the CESEC-III model. The plugging case's primary nodes temperatures are a bit higher than those of no plugging case while secondary temperature is reversed. The heat rate as shown in Fig.5 can be obtained by the product of UA and primary to secondary temperature differences. The heat rates of the plugging case at the hot sides are a bit smaller but those at the cold side are slightly larger, which results in similar total amount of heat rate. Therefore, the tube plugging by itself has no significant effect on the results of SLB like LOCV event.

3. Conclusion

The rate of heat rate before and after tube plugging has not changed significantly without dependency of event characteristics, if the safety ranges are maintained. The differences at the initial condition due to the plugging somewhat exist but the effects are not significant.

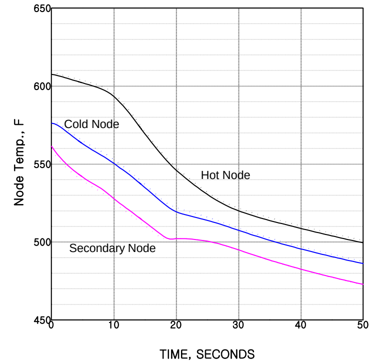

Fig.3 SG U-tube Temperatures (SLB)

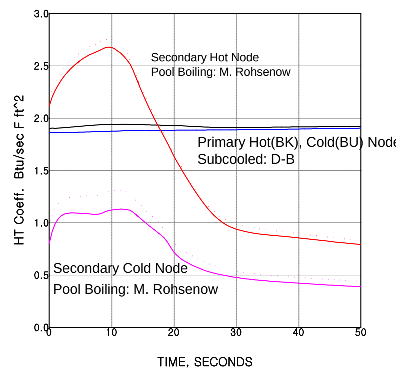

Fig.4 U-tube HT Coeff. (SLB)

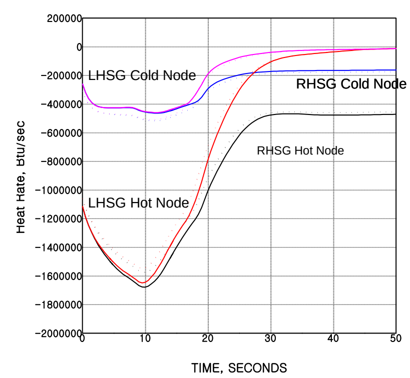

Fig.5 Heat Rate (SLB)

REFERENCES

[1] CE-CES-78-Rev.0-P, "CESEC-Digital Simulation of a Combustion Engineering Nuclear Steam Supply System" May 1987.