Probabilistic Evaluation of Failure Time of a Hot Leg of APR1400 Following a SBO accident

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1. Introduction

During a severe accident, under a high temperature and pressure condition, hot leg nozzles, pressurizer surge line or steam generator tubes could fail by creep rupture following natural circulation in the Reactor Coolant System (RCS) if depressurization of the system is not performed at a proper time.

The capability of depressurization with POSRVs at APR1400 was analyzed using the MELCOR code [1]. A RCS natural circulation model was also developed in previous study [1] and used for evaluation of the creep rupture possibility of the hot legs, SG tubes and pressurizer surge line selected for vulnerable parts during a severe accident. The calculation results for various points of the hot leg, etc. were used as the input for the CREC calculation, which estimated the creep rupture time and occurrence frequency. From the cumulative distribution function of the rupture time, the appropriate time of depressurization using POSRVs was determined.

The aim of this study is to evaluate the creep rupture time due to high temperature and pressure conditions following a station black out (SBO) accident in order to determine the appropriate opening time of POSRVs.

2. Models for Creep Rupture Evaluation

2.1 Modeling of Natural Circulation in the RCS

To estimate the creep rupture time, the existing MELCOR 1.8.5 model [1] for the RCS of APR1400 was used as shown in Fig. 1. It consists of the reactor core, the reactor vessel and the RCS of two loops with two steam generators, four reactor coolant pumps (RCPs) and a pressurizer. In addition, the safety depressurization system is modeled as two trains.

When the accident is occurred at APR1400, two-phase flow is set up in the RCS and then the SG can act as both a heat source and a heat sink. At this time, the flow directions of steam and water could be reverse. In order to simulate this counter-current flow, the MELCOR model has two nodes for each hot leg and four nodes for the SG tubes.

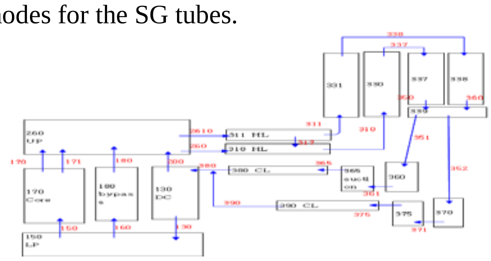

Fig. 1. Detailed RCS model for APR1400 (NAT case).

2.2 Creep Rupture Evaluation Code (CREC)

Creep Rupture Evaluation Code (CREC) [2] based on MS Visual Basic program was developed by FNC technology corporations. It chooses possible failure locations such as SG tubes, hot leg nozzles or pressurizer surge line and estimates their failure probability and the time to creep rupture due to high temperature induced from a core melt accident with high pressure and has the accuracy of creep rupture time through thermal hydraulics analysis according to accuracy of the temperature and pressure condition. CREC performs random sampling of the probability variables such as the pipe thickness and its size, and the depth and length of the crack. Then it repeats calculation of the rupture probability for each location using the creep rupture correlations based on OPR1000 plant materials, as shown in Table I. The materials for the RCS pipes are the same for APR1400 except the SG tubes which are made of Inconel 690 instead of Inconel 600. Therefore, with the assumption that they have the similar mechanical characteristics, the same rupture model was applied to this analysis. And the required pressure and temperature data were provided by the MELCOR calculation.

Table I: Creep rupture failure model

RCS elements	Structure material	Time to creep rupture
SG tubes	Inconel®600	Larson-Miller Model $p = -11333\log(\sigma) + 43333$ $t_R = 10^{(p/T-15)}$
Pressurizer surge line	SS-316 Stainless Steel	Larson-Miller Model $p = -11320\log(\sigma) + 54870$ $t_R = 10^{(p/T-25)}$
Hot leg nozzle	A508 carbon steel	Manson-Haferd Model $p = -158.233\log(\sigma) - 255.346$ $t_R = 10^{[(T-1503.69/p+3.499)}$

3. Analysis Results

The station blackout (SBO) accident was analyzed using the MELCOR model for the RCS of APR1400. The calculated pressure and temperature history for the selected heat structures, i.e., hot leg nozzle, pressurizer surge line or SG tubes were used for the CREC estimation of their failure probability and the time to creep rupture.

Fig 2 shows the frequency distribution of the rupture time of the hottest pipe 311-331 with 10,000 iterations. Creep rupture failure occurs first at about 6,100 sec.

Then failure appears more frequently but still the frequency does not increase rapidly until 11,000 sec. After that it rises quickly, which means failure becomes more certain.

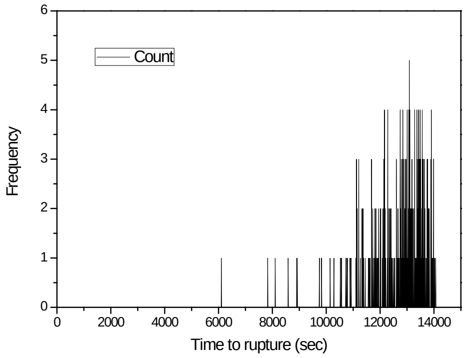

Fig. 2. Frequency distribution of the rupture time for the hottest pipe 311-331 (10,000 iterations)

The cumulative distribution function was used to determine the opening time of POSRVs because the creep rupture time does not follow the normal distribution in this study. In order to obtain the reasonable safety margin, the rupture time at P=0.025 was chosen as the appropriate opening time of POSRVs. The cumulative distribution function of the rupture time for the hottest pipe 311-331 with 10,000 iterations is shown in Fig 3. In this figure the creep rupture time with the failure probability of 0.025 corresponds to 8,925sec.

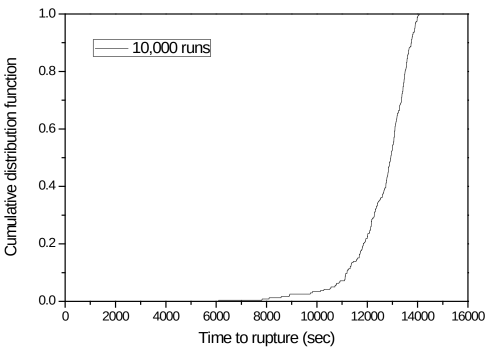

Fig. 3. Cumulative distribution function of the rupture time for the hottest pipe 311-331 (10,000 iterations)

In addition, 50,000 iterations were performed to examine the dependency of the CREC calculation results on the number of iterations. The calculation results revealed that the distribution of the creep rupture time was slightly different from those of 10,000 iterations. Fig. 4 shows the frequency distribution of the rupture time for the hottest pipe 311-331 with 50,000 iterations. The creep rupture failure occurs first at about 5,500 sec and then a lot of creep rupture follows over 11,000 sec. That is, the possibility of creep rupture increases after 11,000 sec, which is similar to the case of 10,000 iterations.

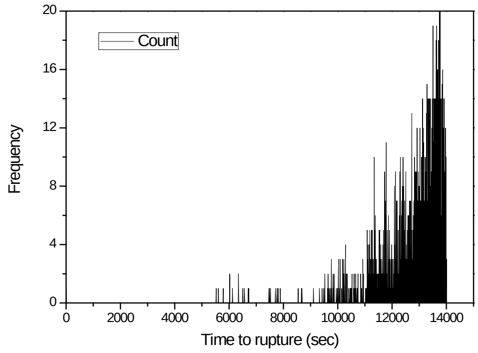

Fig. 4. Frequency distribution of the rupture time for the hottest pipe 311-331 (50,000 iterations)

In Fig 5, the cumulative distribution function of the rupture time for the hottest pipe 311-331 with 50,000 iterations is presented. The possibility of creep rupture obviously increases after 11,000 sec. Also, the creep rupture time–with the failure probability of 0.025 was estimated to be 9,645 sec. This is about 700 sec later than that of the 10,000 iteration.

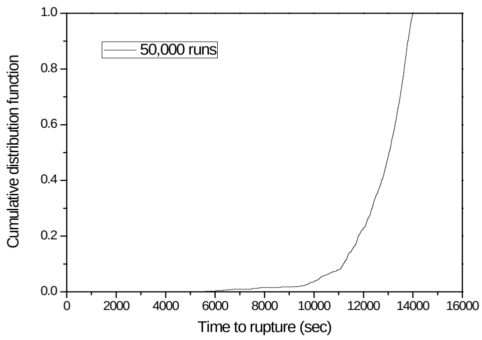

Fig. 5. Cumulative distribution function of the rupture time for the hottest pipe 311-331 (50,000 iterations)

4. Conclusion

Creep Rupture Evaluation Code (CREC) was used for evaluation of the creep rupture time for the hot leg pipes of APR1400 after a SBO accident. Calculations for estimating the creep rupture time were performed with both 10,000 and 50,000 iterations. As a result, the frequency distribution and the cumulative distribution function of the creep rupture time for the hottest pipe 311-331 were obtained. Based on this distribution, the appropriate opening time of POSRVs could be estimated. Further work is needed to evaluate the development of the consequential effects of the RCS depressurization at this time.

REFERENCES

[1] H.-C. Kim, Y.-J. Cho, J.-H. Park, S.-W. Cho, Analysis of a Natural Circulation in the Reactor Coolant System Following a High Pressure Severe Accident at APR1400, May 26-27, 2011, Transactions of the Korean Nuclear Society Spring Meeting, Taebaek, Korea.
[2] CREC Users Guide Manual, FNC technology, Nov 2010.