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Development of the APR1400 model for countercurrent natural circulation in hot leg and steam generator under station blackout

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1. Introduction

In order to analyze severe accident phenomena, Korea Institute of Nuclear Safety (KINS) made a MELCOR model for APR1400 to examine natural circulation and creep rupture failure in the Reactor Coolant System (RCS) under station blackout (SBO).[1] In this study, we are trying to advance the former model to describe natural circulation more accurately. After Fukushima accident, the concerns of severe accident management, assuring the heat removal capability, has risen for the case when the SBO is happened and there are no more electric powers to cool down decay heat. Under SBO there are three kinds of natural circulation which can delay the core heatup. One is in-vessel natural circulation in the upper plenum of reactor vessel and the second is countercurrent natural circulation in hot leg through steam generator tubes and the last is full loop natural circulation when the reactor coolant pump loop seal is cleared and reactor coolant pump sealing is damaged by high temperature and high pressure. Among them this study focuses on the countercurrent natural circulation model using MELCOR1.8.6

2. Modeling of the RCS

Fig. 1 shows the nodalization of former MELCOR model.

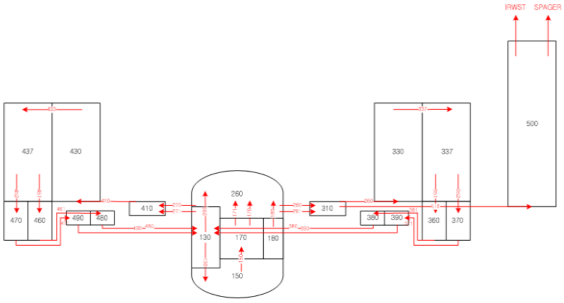

Fig. 1. Former RCS model of APR1400

In order to illustrate natural circulation in detail, we improved former model to see three kinds of natural circulation. This study concentrates on the countercurrent natural circulation between the hot leg and the steam generator. Fig. 2 describes the modified hot leg and steam generator modeling.

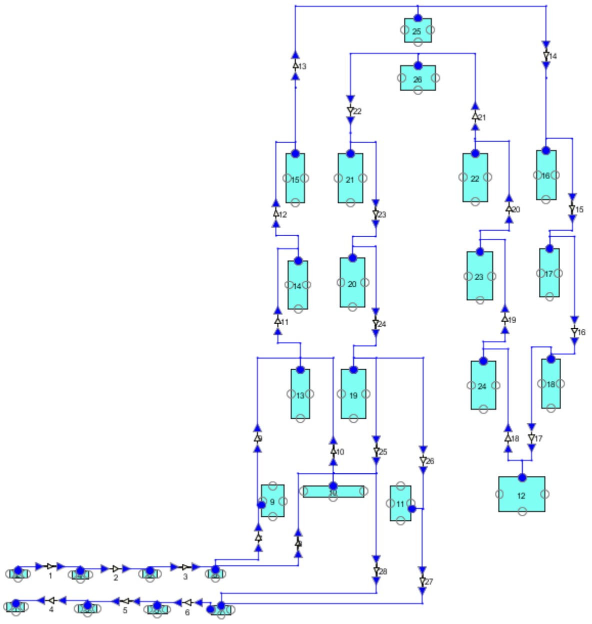

Fig. 2. Improved Hot leg and Steam generator modeling

3. Modeling of the hot leg

When coolant level is lower than the reactor vessel nozzle to the hot leg, the vapor from the reactor core goes to the steam generator through the hot leg. In this event high temperature vapor and condensed water will be developed along the hot leg with opposing directions each other. In order to model this stratified flow between gas and liquid, the hot leg is split into upper and down part for all the four nodes to represent temperature gradient, and changes of geometrical elevation and flow area of two phases along the hot leg.

3.1 Hot leg circumferential temperature gradient

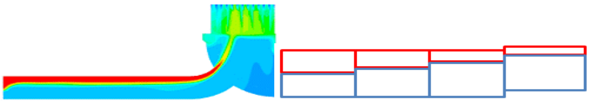

Fig. 3. Modified hot leg nodalization[2]

As in Fig. 3, accelerating superheated vapor exiting the reactor vessel is assumed to enter the half of the hot leg pipe and reach the steam generator inlet plenum occupying one-third of the hot leg flow area with cooler vapor. On the other hand condensed water travels along the bottom of the hot leg.[2] These flow will be developed stratified in the hot leg.

4. Modeling of the steam generator

Under SBO conditon steam generator has a major role as a heat sink and cool down the steam by mixing at the inlet plenum. In this case the steam generator tubes are vulnerable to creep rupture so we needed to model tubes with many nodes and heat structures to describe the Thermally Induced - Steam Generator Tube Rupture(TI-SGTR). The most important factor of countercurrent natural circulation is the mixing phenomena at the steam generator inlet plenum. In the inlet plenum, the hot and cold steam are mixed each other and exchanged their energy. This mixing event can lower the RCS temperature to delay the core heatup. The magnitude of the steam generator inlet plenum mixing is characterized by three parameters given by experiment and CFD analysis.[3],[4] These parameters are fraction of tubes carrying hot gases, recirculation ratio, and mixing fraction. In this improved modeling, we applied the CE reactor results to APR1400 modeling. Table 1 shows the several important parameters and Fig. 4 illustrates the relations between hot leg and steam generator inlet plenum and tubes using these parameters.

Table 1. Important parameters of mixing phenomena for the CE reactor[4]

% tubes carrying hot gases	36.9
T_h, hot leg hot temperature (K)	1284
T_c, hot leg cold temperature (K)	939
m, hot leg mass flow (kg/s)	12.5
T_{ht}, hot tubes temperature	1114
m_{ti}, hot mass flow entering the tube bundle (kg/s)	17.9
m_t/m, recirculation ratio	1.44
f, mixing fraction	0.58

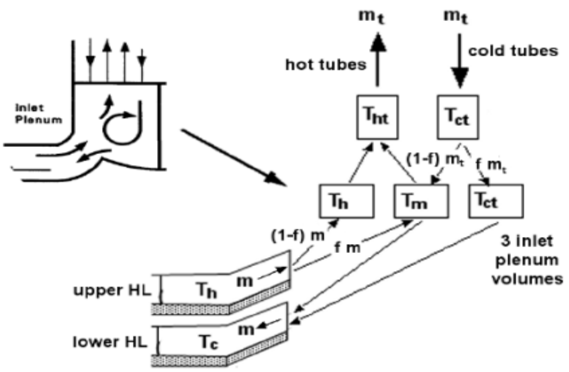

Fig. 4. Mixing phenomena in the improved modeling[2]

In modified modeling, steam generator is modeled by 3 inlet plenum volumes and 14 tubes including 6 hot steam tubes and 6 cold steam tubes, and 2 U-bends for hot and cold steam respectively.

4.1 Steam generator inlet plenum mixing phenomena

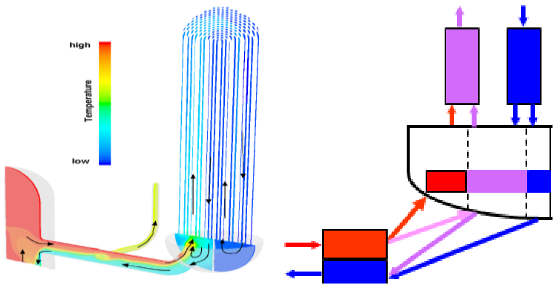

Fig. 5. Modified Steam generator nodalization[2]

Steam generator inlet plenum was divided to three volumes; the first one represents a no-mixing hot gas region and the second is for the mixing between hot and cold gases, and the last is given as a no-mixing cold gas region. All the data for the volumes and flow paths were calculated based on Table 1 and Fig. 4.

4.2 Steam generator tubes

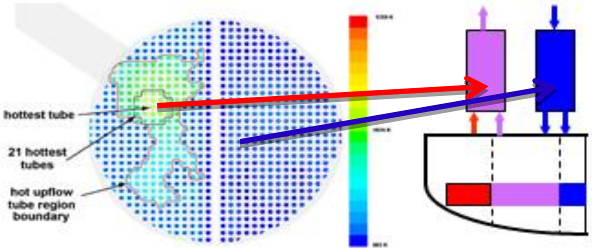

Fig. 6. Hot and Cold tube modeling[2]

Table 1 shows that the fraction of tubes carrying hot gas is 36.9%, from this value each tube volume was determined. Fig. 6 indicates the distinctive temperature difference in steam generator tube bundles so we divided whole tubes into hot and cold tubes.

5. Conclusions

To describe the severe accident phenomena under SBO, we are modifying the former MELCOR model. This study focusses on improved countercurrent natural circulation modeling by subdividing the hot leg and the steam generator sections into smaller volumes with phenomenological consideration.

REFERENCES

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