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Analytical Study of Joule-Thomson Effect on Aerosol Retention during SGTR accident

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1. Introduction

A lot of studies related on aerosol retention inside steam generator during steam generator tube rupture (SGTR) accident have been conducted. In ARTIST project started at 2003, it was found that aerosol type fission products could be removed inside the steam generator and decontamination factors (DF) were evaluated quantitatively [1, 2]. Similar studies were conducted in Korea by experimental and analytical methods [3, 4], and it was confirmed again that the aerosol removal mechanism by the SG tube collision had a significant effect. During the SGTR accident, high pressure almost over than 1000 bar is maintained in the primary side and the secondary pressure is the atmospheric pressure level with assumption of atmospheric dump valve (ADV) or main steam safety valve (MSSV) opening. In this condition, the gas temperature could be reduced in a process of involving expansion below a certain temperature and pressure, which is Joule-Thomson effect. In this study, the effect of Joule-Thomson during the SGTR accident was evaluated analytically, and preliminary results were presented.

2. Analysis Method

2.1 Pressure behavior

SGTR accident analysis was conducted using MELCOR, and the target plant was OPR1000. Major assumptions and results can be found in the reference [3]. Nodalization of the plant is presented in Fig. 1 and major thermal-hydraulic results are indicated in Figs. 2. Major events with occurrence time are also presented in Table 1. The thermal-hydraulic conditions between SGTR occurrence and lower head failure time are focused to analyze the Joule-Thomson effect in this study. The pressure and temperature conditions were summarized and major points were indicated in Figure 3 using temperature-entropy (T-S) diagram of steam.

2.2 Joule-Thomson(J-T) effect

When a compressed gas releases occurred through a small hole, it then expands to a low pressure and the gas temperature falls on account of the performance by the gas of internal work in expanding against the forces of attraction between the molecules, and it is called Joule-Thomson effect. The Joule-Thomson effect is generally employed in gas liquefaction system. In such an expansion process, there is no in kinetic energy of the gas, and the enthalpy of the gas before and after expansion remains constant since the process takes place adiabatically. When the pressure of a gas changes by an amount dp on passing a throttle or expansion valve, the temperature is changed by an amount of dT, and it can be expressed as equation below [5].

$$\frac{dT}{dp} = \frac{1}{C_p}\left[T\left(\frac{\partial v}{\partial T}\right)_p - v\right] = \frac{T^2}{C_p}\frac{\partial}{\partial T}\left(\frac{v}{T}\right) = -\frac{1}{C_p}\left(\frac{\partial H}{\partial p}\right)_T$$

After occurring of SGTR accident, high pressure gases inside SG tubes are released to SG shell. At that time, the pressure difference is high enough to consider the Joule-Thomson effect. Gas composition could be different with time due to hydrogen generation, and it could affect the gas temperature variation because the Joule-Thomson coefficients of steam and hydrogen are different.

2.3 Vapor pressure of radionuclides

The gas temperature can be decreased right after

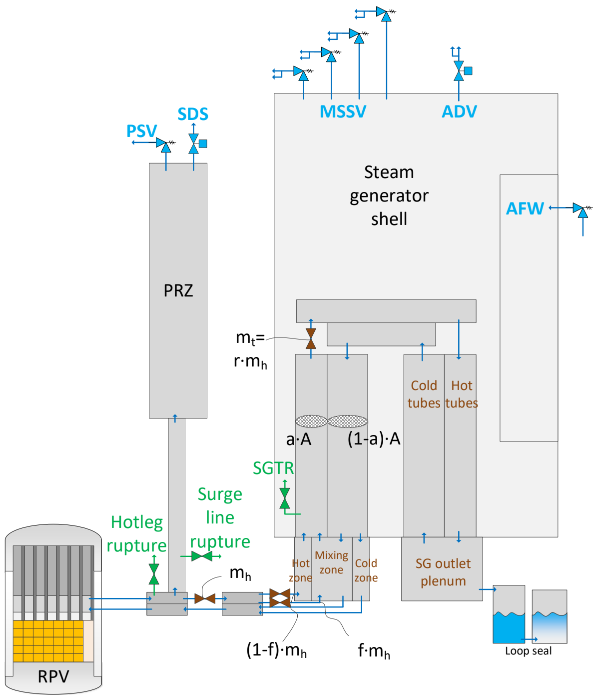

Fig. 1. Nodalization of OPR1000 plant for SGTR accident analysis

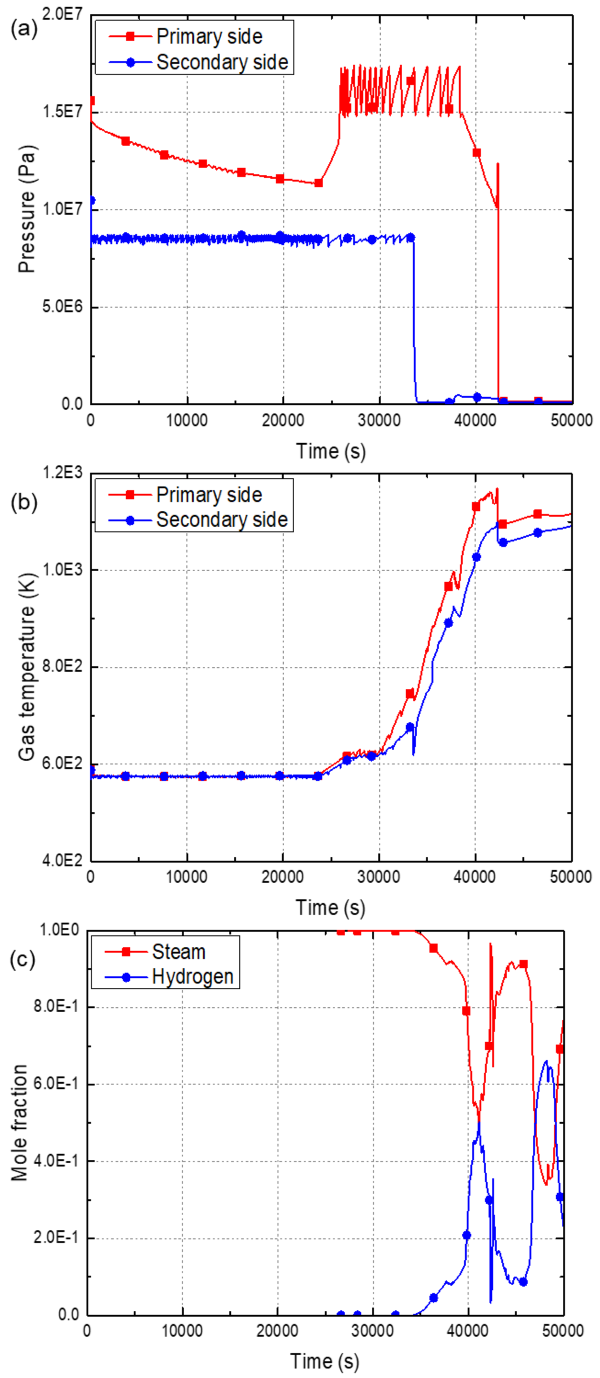

Fig. 2. Major thermal-hydraulic behavior during SGTR accident: (a) pressures, (b) gas temperatures, and (c) gas mole fraction

throttling expansion process after the SGTR occurrence. Although the amount of temperature variation can be lower than 100 K, it could be important in a point of view of fission product release to environment. The gas temperature can affect the amount of aerosol type fission products because the vapor pressure of radionuclides is increased with temperature as shown in Fig. 4. The amount of aerosol type radionuclides variation can affect the total amount of released fission products to environment. From the previous researches, it was found that

the aerosol type fission products retention inside steam generator contributes to the decrease of the amount of fission product in environment [1, 2, 4]. After the SGTR accident, when gas containing fission products is released through the tube break point, it

Table I: Major event in the SGTR accident analysis

Event	Time (s)
SBO accident	0.0
Reactor trip, RCP trip, MSIV close	0.001
AFW pump operation start	1,897.0
AFW pump operation end	16,297.0
Water mass of both SG shell< 1000.0 kg	23,808.7
PSV first open	26,008.6
SAMG entry condition (Core exit temperature = 923.0 K)	31,690.0
ADVs of both SGs open	33,490.2
Fuel gap release	34,553.7
SGTR accident occurrence	37,692.3
UO2 relocation to lower head	40,927.9
Lower head failure	42,265.8
SIT injection	42,283.4
End of calculation	50,000.0

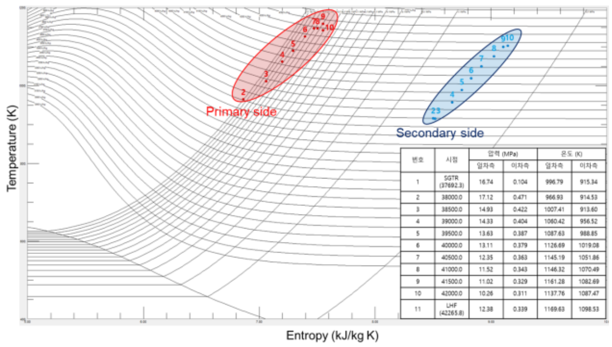

Fig. 3. T-S diagram of steam during the SGTR accident

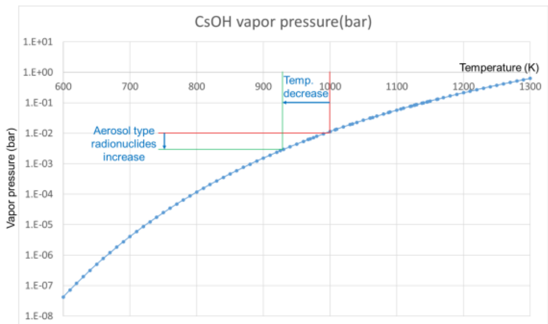

Fig. 4. Saturation vapor pressure of CsOH

collides with a lot of peripheral tubes. The amount of decontamination factor varies greatly depending on whether the phase of the fission product is a gas or an aerosol.

3. Preliminary Results

Gaseous type fission products can change their phase from gas to aerosol with decreasing peripheral gas temperature, then the aerosol type fission products mass can be increased. The increased aerosol mass was calculated from the ideal gas equation. (n: mole number, R: universe ideal gas constant, T: temperature, P: vapor pressure, V: volume, M: molecular mass, m: mass)

$$n_a = \frac{P_a \ V}{R \ T}$$
$$\Delta m_i = \left(n_{initial} - n_{final}\right) M_i$$

It was found that the aerosol type CsOH mass in the case 2 of the Fig. 3 was increased with the CsOH saturation vapor pressure decrease. The number of mole of CsOH molecule in gas phase before and after passing the tube break point were 0.077 and 0.027 per unit volume, respectively. The increased aerosol mass was around 7.39 g per unit volume considering the molecular weight of the CsOH. The increased aerosol mass could be changed with thermal-hydraulic conditions of primary and secondary side with accident progression. For instance, in case of 6 of the Fig. 3, the increased aerosol mass was around 104.6 g per unit volume. More fission product could be removed in the aerosol phase compared to the gas phase inside the steam generator because of impaction, deposition, and other aerosol removal mechanism.

The amount of released CsOH masses in the environment are calculated using MELCOR and the results are shown in Fig.5 with the result considering Joule-Thomson effect. In this calculation, it was assumed that all of the aerosol generated from the throttling effect were eliminated inside SG with aerosol removal mechanism. It can be seen that the J-T effect is noticeable at the beginning of the radionuclides release. As the amount of released CsOH increased from the fuel, the portion of the aerosol mass generated from the J-T effect is smaller. However, it was found that it should be considered when evaluating the amount of fission product at the early stage of the accident.

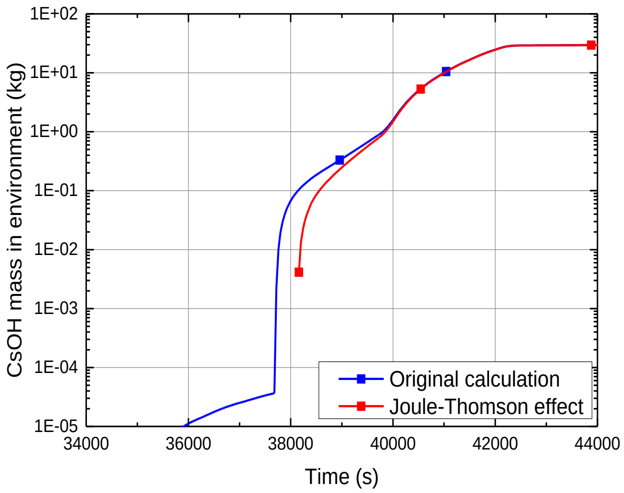

Fig. 5. CsOH mass in environment with considering J-T effect

3. Conclusions and Plans

Joule-Thomson effect on the released fission product mass into environment was analyzed using MELCOR and analytical method. The effect could be changed depending on the thermal-hydraulic conditions, and the effect is more important at the initial stage of the accident. In the future, more analysis will be conducted under the various thermal-hydraulic conditions that could be occurred in the accident period and more effort will be put on the quantification of the generated aerosol mass. It is expected that the temperature behavior will vary depending on the mole fraction of gas species (hydrogen or steam) because they have different J-T coefficient, and the results will also be analyzed.

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