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Effect of Mass Transfer on Iodine Concentration under Evaporative Condition in Containment Building of SMR

K.J. Kang, Y. I. Kim, K.K. Kim
SMART Development Division, Korea Atomic Energy Research Institute
989-111 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea
kkj@kaeri.re.kr,

1. Introduction

The fission products that can be released in the environment during accidents such as LOCA or severe accidents, iodine causes great concern because of its volatility and of its potential radiological impact on population. Several methods are developed to prevent releasing of iodine such as iodine filter venting system. Figure 1 shows the radioactive material reduction facility for applicable to SMR. The facility largely consists of radioactive material reduction facility, water tank, and outer containment building. In accident such as LOCA, large amount of iodine of gaseous and aerosol forms are released from the reactor with steam into radioactive material reduction facility. And then, temperature and pressure of radioactive material reduction facility increased due to released high energy steam. So, steam and radioactive material of radioactive material reduction facility are discharged into water pool through discharging pipe installed between radioactive material reduction facility and water pool. The steam and radioactive material are released through discharging part which submerged in bottom of water pool into water pool.

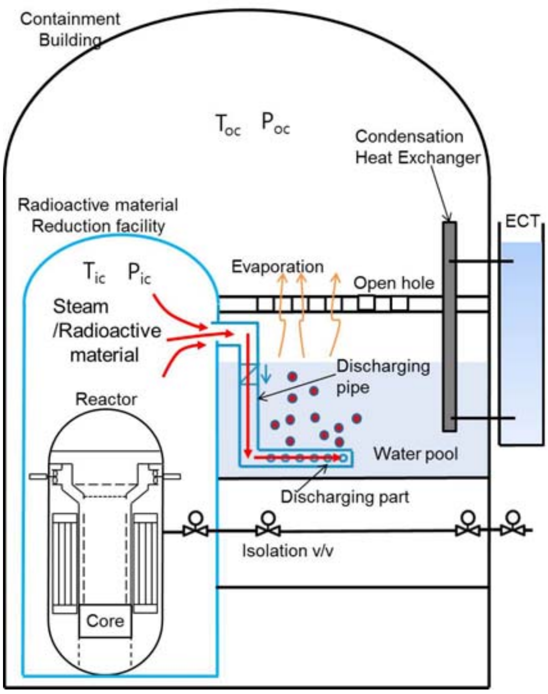

Figure 1. Iodine reduction facility in containment building

The water pool can be considered as IRWST. The radioactive material, especially element iodine, can be dissolved in floating up in the water pool. The radioactive material solved in water is evaporated in the top surface of water pool. The evaporated gas flows out through open hole connected between water pool and outer containment building. The paper is to evaluate the effect of performance of the suggested radioactive reduction facility on water pool temperature under evaporative condition.

2. Iodine behavior in containment building

In the radioactive material reduction facility, possible released path of iodine and steam from reactor is water pool. In the server accident, it is assumed half of the iodine fuel inventory reached the inner containment under aerosol and gaseous forms. Most of the iodine released into the inner containment was supposed to be in the form of volatile molecular iodine (I_2) form (91%) and the rest were almost equally distributed in particulate form (5%) and organic species (4%). In this study, it is focused on the volatile iodine transferred through interface. Figure 2 shows chemical formation by hydrology of molecular iodine and concentration profile between water pool and atmosphere of containment. In the water pool, $H^+(aq)$ will be generated and make aqueous pH to be changed. Volatility of iodine in water pool depends on aqueous pH and temperature. Volatility of iodine increases as aqueous pH in the water pool decreases and temperature increases. The volatile iodine within water pool is transferred to the atmosphere by diffusion owing to difference of iodine concentration and mass transfer.

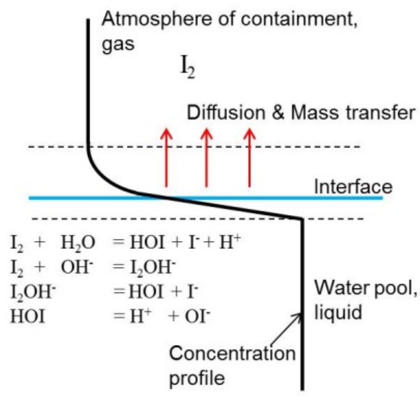

Figure 2. Iodine chemistry and mass transfer between water pool and atmosphere [1]

3. Evaluation of iodine gas in containment

In this section, gas iodine transferred from water pool to atmosphere in containment building will be evaluated by two-film model. [1] It is assumed that pH in water pool is not considered because volatility of aqueous iodine is dramatically decreased and negligible. There is no iodine path transferred to containment except path through water pool. The containment initial conditions are shown in Table 1.

Table 1 Containment condition

Element	Feature
Interfacial area between liquid and gas(A_{int})	411(m^2)
Initial pressure	1.1 bar
Initial temperature of containment	48.9℃
Initial temperature of water pool	48.9℃
Initial relative humidity	5 %
Free volume	3.24×10^4 m^3

It is assumed that half of iodine inventory in reactor, 32.19×10^{17} Bq, is corresponding to total activity with 8.6×10^{-3} mol/㎥ solution of iodine. The concentration of gas iodine was calculated by the follows.

The partition coefficient, H is given as function of temperature in water pool. [4] In this here, H is defined by ratio of aqueous to gaseous iodine concentration at the interface as shown in Fig. 2.

$$H = \frac{C_{liquid}^{int}}{C_{gas}^{int}} = 231 \cdot \exp\left(1.65 \times 10^{-4} \times (T - 571.24)\right) \qquad (1)$$

Under evaporative conditions, the iodine concentration at between water pool and atmosphere of the containment is defined by the follows equation. [1]

$$\frac{C_{liquid}}{C_{gas}} = \frac{H}{1+\left(\frac{\dot{m}_{ev}}{A_{int}\rho_{sat}(T_l)k_{gas}}\right)} \qquad (2)$$

Here, $\dot{m}_{ev}$is evaporation flow rate. A_{int} is interfacial area. $\rho_{sat}(T_l)$ is saturation density at given water pool temperature. k_{gas} is the gas mass transfer coefficient.

$$Gr = \frac{g(\rho_{bulk}-\rho_s)L^3}{\rho v^2},\ \mathrm{Sc} = \frac{\nu}{D_{liquid-gas}},\ k_{gas} = D_{gas}/\delta_{gas}$$

By assuming that heat and mass transfer analogy may be applied, the *Sh* number may be estimated as natural convection.

$$\mathrm{Sh} = 0.15(\mathrm{GrSc})^{1/3} \qquad (3)$$

The *Sh* number is applied to calculation for the mass transfer coefficient as shown in equation (5).

The evaporation flow rate is calculated by equation (3).

$$\dot{m}_{ev} = h_{mass}A_{int}(\rho_{v,s} - \rho_{v,bulk}) \qquad (4)$$

$$h_{mass} = \frac{ShD_{liquid-gas}}{L} \qquad (5)$$

Here, L is characteristic length which is corresponded to interface area over peripheral length of water pool. D is diffusion coefficient at interface region.

Figure 3 shows the mole fraction of gaseous iodine transferred from aqueous solution (water pool) to the atmosphere in containment. The cause of main transferring is dragging by the evaporation flow from the liquid-gas interface. From Fig.3, liquid-to-gas iodine concentration ratio is linearly increased as temperature of water pool increases.

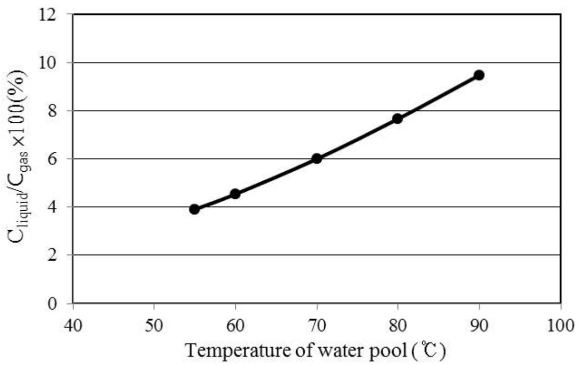

Figure 3. Liquid-to-gas iodine concentration ratio with temperature variation of water pool

This result means the gas iodine concentration transferred from aqueous iodine is more about than two times than it of at 90℃.

4. Conclusions

The objective of this paper was to assess the impact of temperature of water pool on the iodine mass transfer phenomenon. It can be concluded that the impact of evaporating conditions on the iodine gas concentration is increased as temperature of water pool increases. The iodine gaseous concentration under evaporative condition at 90℃ water pool temperature increases more than 2～3 times than it of at initial containment.

ACKNOWLEDGEMENT

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