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Calculation Methods of Small RCS Leakage Rate Through Related Measurements

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1. Introduction

Recently, a large amount of leakage event occurred from the steam generator lower drainage isolation valve welds of the Kori nuclear power plant (NPP). This study has been conducted to detect smaller leakage rate and more speedily than the existing reactor system leak monitoring system. Current leak detection methods in NPPs use the acoustic emission sensors [1].

The number of long-term aged NPPs has increased and NPPs piping has been aged due to flow accelerated corrosion and stress corrosion [2]. Leakage of the reactor coolant system (RCS) can cause serious accidents. In this study, we calculated the humidity and radiation dose amount in a measurement compartment of the containment by sucking the air from a leakage compartment. This study will be helpful in developing a new RCS leakage detection system

2. Calculation Methods

In order to calculate a small amount of RCS leakage rate, the gas is sucked in the leakage compartment and sent to the measurement compartment of the annular corridor of the containment. Calculations were made to predict leakage through humidity and radioactivity measurements. We assume environmental conditions in the containment to calculate the humidity. Fig. 1 shows the location of the measurement compartment and the leakage compartment in the containment. Fig 2 shows the mass transfer of the leakage compartment, the measurement compartment, and the heating, ventilation, & air conditioning (HVAC) system under assumed environmental conditions.

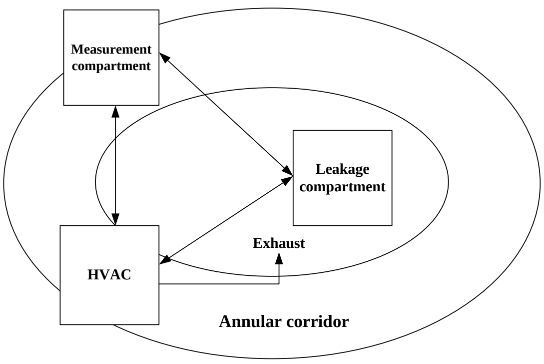

Fig. 1. Location of a measurement compartment and a leakage compartment in the containment

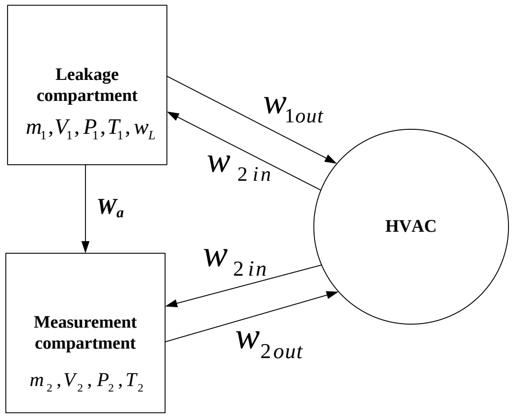

Fig. 2. Mass transit among the leakage compartment, measurement compartment, and HVAC system

2.1 Leakage Quantification Through Relative Humidity Measurement

The volume flowrates w_{in} and w_{out} in Fig. 2 are assumed to be proportional to each compartment size. w_a indicates the suction flowrate between the compartments. These related expressions are as follows.

$$w_{1out} = F_H V_1$$
$$w_{1in} = F_H V_1$$
$$w_{2in} = F_H V_2$$
$$w_{2out} = F_H V_2$$
$$w_a = F_a V_2$$

F_H = HVAC blower flow rate per unit volume (sec^{-1})
F_a = Suction flow rate per unit volume (sec^{-1})
w_L = RCS leak flow rate

The mass balance rate and the ideal gas equation due to RCS leakage are as follows.

$$\frac{dm_1}{dt} = w_{1out} - w_a + w_{1in} + w_L$$
$$\frac{dm_2}{dt} = -w_{2out} + w_{2in} + w_a$$
$$PV = nRT = \frac{m}{M} RT$$
$$m = \frac{MV}{RT} P$$

V, P, T = Volume, water vapor pressure, temperature
M = Molecular weight
R = Gas constant

The related equations for water vapor pressure are as follows.

$$\frac{V_1 M}{RT_1}\frac{dP_1}{dt} = -\frac{MF_H V_1}{RT_1}P_1 - \frac{MF_a V_2}{RT_1}P_1 + \frac{MF_H V_1}{RT_1}P_{in} + k_v w_L$$

$$\frac{V_2 M}{RT_2}\frac{dP_2}{dt} = -\frac{MF_H V_2}{RT_2}P_2 + \frac{MF_H V_2}{RT_2}P_{in} + \frac{MF_a V_2}{RT_1}P_1$$

$$\frac{dP_1}{dt} = -F_H P_1 - \frac{F_a V_2}{V_1}P_1 + F_H P_{in} + \frac{RT_1}{V_1 M}k_v w_L$$

$$\frac{dP_2}{dt} = -F_H P_2 + \frac{F_a T_2}{T_1}P_1 + F_H P_{in}$$

$$H_1 = 100 \times P_1 / P_s$$

$$H_2 = 100 \times P_2 / P_s$$

where k_v is a vaporization rate, P_s is a saturation pressure, and H_1 and H_2 indicate relative humidity in the leakage and measurement compartments, respectively.

We assumed environmental conditions to calculate the humidity according to the RCS leakage rate. The humidity of the HVAC system was assumed to be 50%, and the temperature of the leakage compartment and the measurement compartment was assumed to be 38℃.

Table I: Conditions for analyzing the leak rate effect

No	Leak rate	Other conditions
1	1.0gpm	Leakage compartment volume = 1.0*V10 Measurement compartment volume =0.5*V20 Intake amount=0.1*Fa0
2	0.5gpm	
3	0.3gpm	

*1gpm = 62.6479g/sec, *V10=5*5*10m^3, *V20 = 5*5*10m^3, *Fa0=27.348/41064.45

Table II: Conditions for analyzing the volume effect of the measurement compartment

No	measurement compartment volume	Other conditions
1	1.0*V20	Leak late = 0.5gpm Leakage compartment volume = 1.0*V10 Intake amount=0.1*Fa0
2	0.5*V20	
3	0.1*V20	

Table III: Conditions for analyzing the volume effect of the leakage compartment

No	Leakage compartment volume	Other conditions
1	1.0*V10	Leak late = 0.5gpm Measurement compartment volume = 1.0*V10 Intake amount=0.1*Fa0
2	0.5*V10	
3	0.1*V10	

2.2 Leakage Quantification Through Radiation Measurement

Considering the inventory of radioactivity in RCS, N-16 detection is expected to be the best choice. The calculation formulas of the leak amount using a radiation measurement are as follows.

$$V_1\frac{dA_1}{dt} = -(\lambda + k)V_1 A_1 - F_a V_2 A_1 + w_L A_c e^{-\lambda\tau_1}$$

$$V_2\frac{dA_2}{dt} = -(\lambda + k)V_2 A_2 + F_a V_2 A_1 e^{-\lambda\tau_2}$$

A_1 = Leakage compartment radioactivity concentration (Bq/cc)

A_2 = Measurement compartment radioactivity concentration (Bq/cc)

V_1 = Leakage compartment volume

V_2 = Measurement compartment volume

λ = Decay constant

A_c = Core radioactivity concentration (Bq/cc)

k = Volumetric removal rate

w_L = RCS leak flow rate (cc/sec)

τ_1 = Transit time from core to leakage

τ_2 = Transit time from the leakage compartment to the measurement compartment

3. Results of Small Leakage Calculation

Table I shows conditions for analyzing the effect of the change in the leak rate. The leak rate was assumed to be 1 gpm, 0.5 gpm, and 0.3 gpm, respectively. Figs. 3 and 4 show the relative humidity of each compartment according to the amount of leakage.

Table II shows conditions for analyzing the effect of the volume size of the measurement compartment. Figs. 5 and 6 show the relative humidity of each compartment according to the volume size of the measurement compartment.

Table III shows conditions for analyzing the effect of the volume size of the leakage compartment. Figs. 7 and 8 show the relative humidity of each compartment according to the volume size of the leakage compartment.

Figs. 9 and 10 show the specific activity of N-16 in the measurement and leakage compartments according to the leakage rate.

It is expected that the amount of leakage in an early time can be quantified using the results of the calculations.

4. Conclusions

In this study, the preliminary calculations have been conducted to develop an unidentified small RCS leakage detection system. Also, we analyzed the effects of several factors for quantifying the RCS leakage using the relative humidity and radiation level in the containment. It was confirmed that it would be possible to detect very small RCS leakage by measuring the relative humidity and radiation level in the measurement compartment.

REFERENCES

[1] S. O. Kim, H. S. Jeon, K. S. Son, and J. W. Park, Location Estimation Method of Steam Leak in Pipelines Using Leakage Area Analysis, Korean Society for Nondestructive Testing, Vol.36, p. 384-390, 2016.
[2] K. H. Yoo, J. H. Kim, M. G. Na, J. W. Kim, H. C. Jung, and K. S. Kim, Utilization of Heating Device Control for Wall-Thinned Defects Detection Using IR Thermography, presented at IEEE, NSS/MIC/RTSD Seoul, Korea, Oct. 27-Nov 2, 2013.

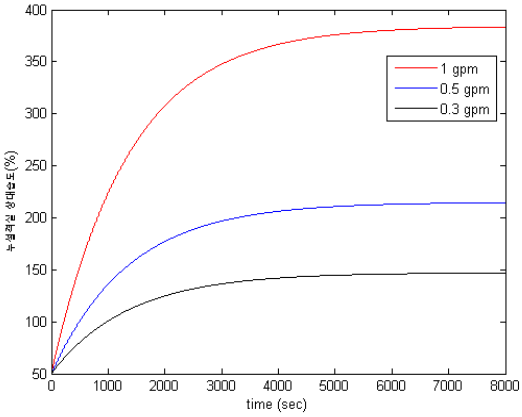

Fig. 3. Relative humidity of the leakage compartment (Leak rate change effect)

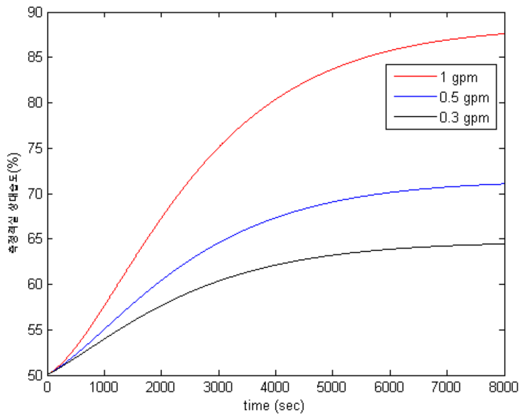

Fig. 4. Relative humidity of the measurement compartment (Leak rate change effect).

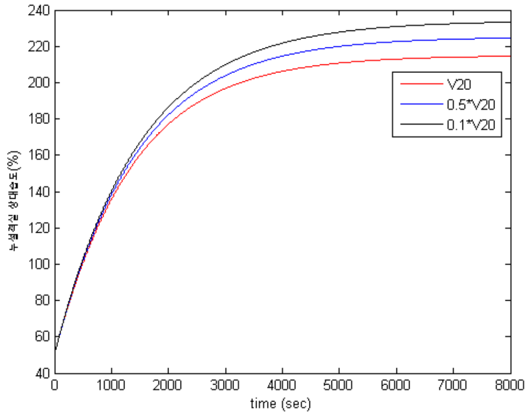

Fig. 5. Relative humidity of the leakage compartment (Volume size effect of measurement compartment)

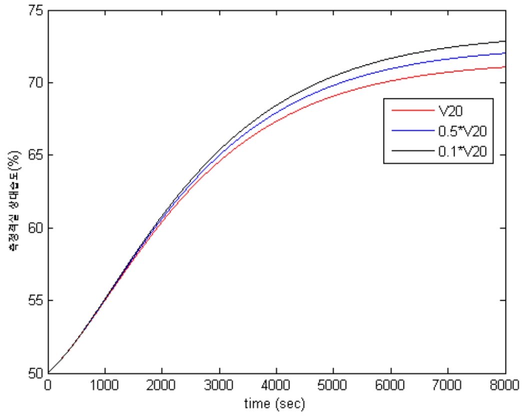

Fig. 6. Relative humidity of the measurement compartment (Volume size effect of the measurement compartment)

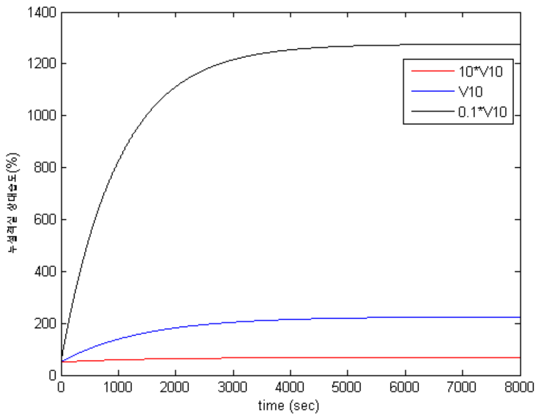

Fig. 7. Relative humidity of the leakage compartment (Volume size effect of the leakage compartment)

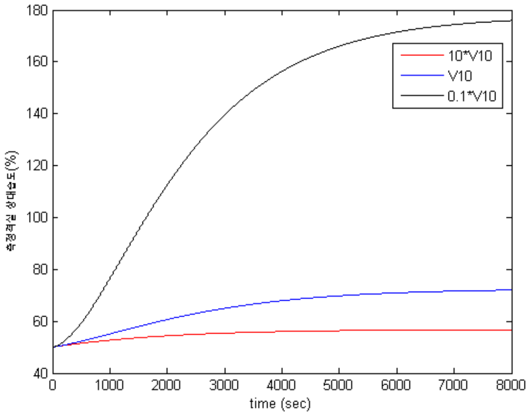

Fig. 8. Relative humidity of the measurement compartment (Volume size effect of the leakage compartment)

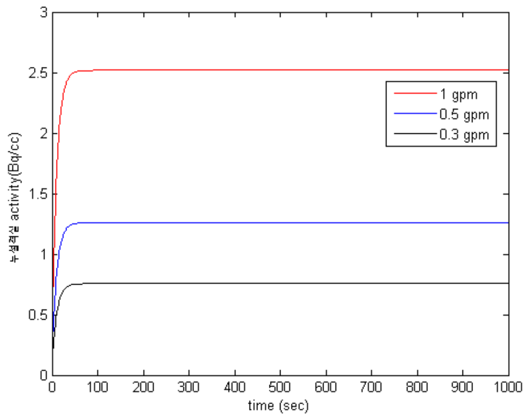

Fig. 9. Specific activity in the leakage compartment (N-16)

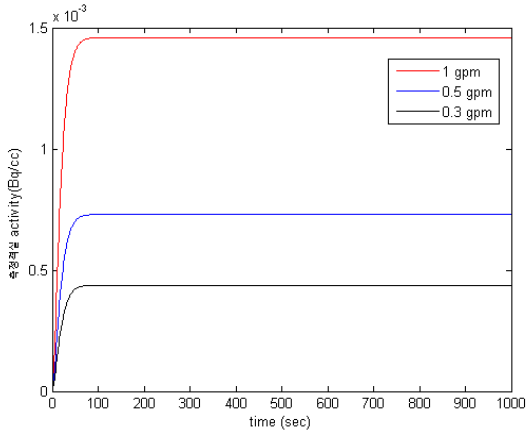

Fig. 10. Specific activity in the measurement compartment (N-16)