Analysis on the effect of risk from containment failure by over-pressurization during the operation of containment filtered venting system

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1. Introduction

After the Fukushima accident, SBO becomes one of the most important initiating event in nuclear power plant. According to the recent report of the PSA review of the APR-1400, SBO represents the largest portion of the total core damage frequency not only in APR-1400 but also in other advanced PWRs. Thus, passive safety systems which are operated without power source are suggested as a solution SBO. For containment protection system, Containment Filtered Venting System (CFVS) is suggested. CFVS controls the containment pressure by releasing the containment gas through filter passively without any power source. But because still small amount of radioactive material have no choice but to release to the environment, starting time and operation method of CFVS have to be determined carefully. Later starting time brings not only lower release but also higher risk from containment failure by over-pressurization, so it is a problem. In this research, the effect of risk from containment failure by over-pressurization during the operation of containment filtered venting system was analyzed.

2. Research Methods

2.1 Risk Analysis

Risk is the product of consequence and probability. To calculate the risk, amount of release from containment failure and containment over-pressurization failure probability according to the containment pressure has to be determined.

Two kinds of containment failure modes are considered: leak and rupture. Failure area of each mode are suggested as 0.1 ft^2 and 1.0 ft^2 from OECD/NEA standard. Containment pressure and mass flow rate in each failure areas are expressed in equation. The mass flow rate in each failure areas which is function of containment pressure are divided by mass flow rate of CFVS, and it is multiplied to release rate from simulation data to calculate amount of release from containment failure.

Design pressure of PWR is considered as 0.67 MPa, and the fragility curves of leak and rupture are used from the recent research by Daegi Hahm et al. Failure probability of both leak and rupture are calculated based on general equations between containment pressure and failure probability from fragility curves.

2.2 Decontamination Factor (DF) as a function of time

The aerosols are captured by pool scrubbing in CFVS, and the efficiency of aerosol capture can be expressed in Decontamination Factor (DF). DF is defined as the mass entering the pool divided by the mass leaving the pool, and it is influenced by properties of containment and CFVS according to time. In pool scrubbing, hydro-dynamic behavior can be divided in three zones: injection, break up, and bubble rise. Total DF in pool scrubbing can be obtained from the product of injection zone DF (1) and rise zone DF (2).

$$\mathrm{DF(Injection\ Zone)} = \frac{1}{\exp(-\mathrm{Kn}\sqrt{\varphi})},\ \ \varphi = \frac{C\rho_d d^2 v_0}{18\mu D} \quad (1)$$

$$\mathrm{DF(Rise\ Zone)} = \frac{1}{\exp\left(-\frac{653.33 t_b \rho_p r^2}{\eta_B R_B}\right)} \quad (2)$$

Among these variables, Cunningham factor(C), undisturbed upstream fluid velocity(v_o), rise time(t_b), viscosity of fluid(η_B) are used as a function of time from the table values and calculation based on simulation data. The rest variables are assumed as a constant.

2.3 Operation Method

There are two ways to operate CFVS, with closing set-point or without. Cyclic venting which has closing set-point is considered for CFVS operation in this study. Because the containment pressure reaches 0.1 MPa without closing set-point, then pressure becomes unstable and sub-atmospheric pressure can occur by a small amount of steam condensation.

Three variables are considered to determine operation method of CFVS: open pressure, pressure interval (close pressure), and vent pipe diameter (mass flow rate). All the variables are determined based on DF as a function of time and risk calculation. Pressure interval and vent pipe diameter, is determined from the sensitive studies with constant open pressure (0.67 MPa, design pressure). Test matrix for operation method is on table I. The effect of risk from containment over-pressurization failure was analyzed by open pressure in cases of 0.50, 0.67, 0.80 MPa based on the selected pressure interval and vent pipe diameter.

Table I: Test matrix for operation method
(open pressure: 0.67 MPa, design pressure)

Pressure Interval (MPa)	Vent Pipe Diameter (cm)
0.1	8
0.2	9
0.3	10

2.4 Simulation Method

MAAP 4.0.3 is used as a simulation code. Modular Accident Analysis Program (MAAP) is an integral analysis code which is based on Fortran for assessing off-normal transients and severe accident. This code covers the level 2 PSA. MAAP 4 has a reasonable prediction capability in the range of containment analysis comparable to those of MELCOR and SCDAP.

The reference reactor is APR-1400, the recent major model of advanced PWR in South Korea. Code analysis model for containment is shown in figure 1.

Integrated Passive Safety System (IPSS) is used as a reference system. IPSS is the integrated passive safety system which uses two large water tanks placed on the top of the auxiliary building and the volume is about 2,000 ton each. This system performs many safety functions passively such as Direct Vessel Injection (DVI), Passive Containment Cooling System (PCCS), CFVS and so on.

Initiating event is SBO. SIT (4/4) and 8 hours of Turbine Driven Auxiliary Feed-Water Pump (TDAFW) are successfully operated to save reactor vessel. But reactor vessel is failed after the operation of TDAFW. Cavity Flooding System (CFS) starts to operate when Core Exit Temperature (CET) reaches 1200˚F which is the SAMG entry condition. PAR assumed to be operated successfully in all of the simulation time, so the hydrogen problem is not considered in this research. The simulation time is 7 days, almost same with duration of Fukushima accident.

11 kinds of fission product groups are analyzed for radioactive material release: CsI, TeO2, SrO, MoO2, CsOH, BaO, La2O3, CeO2, Sb, Te2, UO2. Noble gas is not considered in this research, because noble gas is not influenced by filter in CFVS.

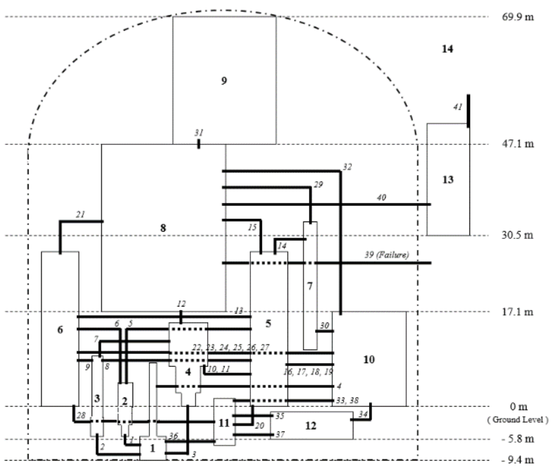

Fig. 1. MAAP 4.0.3 code analysis model for containment in APR-1400

3. Results and Discussion

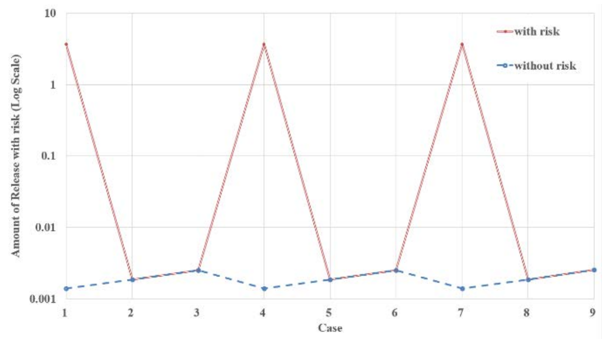

Fig. 2. Amount of release in log scale by cases

Results of test matrix for operation method with constant pressure is shown in figure 2. DF as a function of time and risk from containment failure is considered to calculate amount of radioactive material release. Case 1 to 3, 4 to 6 and 7 to 9 have same pressure interval, and have each 8 to 10 cm of vent pipe diameter. Release without risk get lower values with lower vent pipe diameter. However, release with risk get sharply high values in lowest vent pipe diameter. It is because release rate is lower than the increasing rate of containment pressure, so the containment pressure exceeds design pressure which is influenced by containment failure probability in some range of simulation time. Release with risk in 0.1 MPa of pressure interval shows the lowest value, but the values are almost same with all range of pressure intervals in case of 9 cm of vent pipe diameter. It is because of vent pipe diameter. If vent pipe diameter has larger value, then CFVS will have more operation times. In other words, pressure interval is a secondary variable for CFVS, and lower pressure interval gets lower release, but 0.1 MPa is considered as a minimum value in this research because value of pressure interval which is lower than 0.1 MPa has problems with operation realistically.

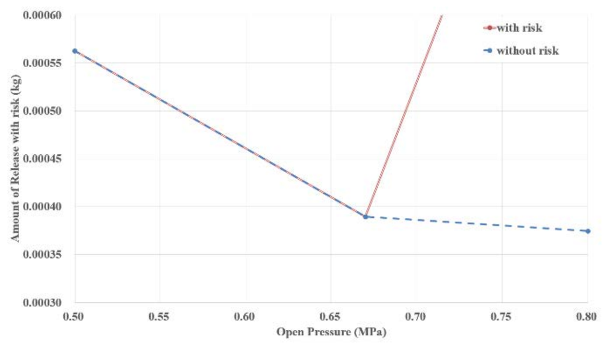

Fig. 3. Amount of release by open pressure

Results of release by open pressure in cases of 0.50, 0.67, 080 MPa which are each represented the pressure lower than design pressure, the design pressure, larger than design pressure with 9 cm of vent pipe diameter and 0.1 MPa of pressure interval. Release without risk get lower values with higher open pressure. However, release with risk get sharply high values in highest open pressure. It is because open pressure exceeds design pressure which is influenced by containment failure probability. Release with risk in 0.67 MPa, design pressure, gets the lowest value.

4. Conclusions

In this research, optimized values for variables of the CFVS operation method are found as 0.67 MPa, 9 cm, 0.1 MPa each for open pressure, pressure interval, and vent pipe diameter when DF as a function of time and risk from containment over-pressurization failure are considered. Generally in this research, release without risk get lower values in higher pressure, and lower vent pipe diameter. Also the lower value for pressure interval get lower release without risk, but because 0.1 MPa is the lowest value in this research, additional research with other considerations are needed to determine the pressure interval as a general expression. Release with risk get sharply high values when the containment pressure exceeds the design pressure because of the effect of risk from containment failure by over-pressurization. In conclusion, highest pressure, and lowest vent pipe diameter which are not influenced by risk is the optimized values for CFVS operation method because amount of risk is much larger than release through the CFVS.

ACKNOWLEDGEMENT

This work was supported by the KUSTAR-KAIST Institute, Korea, under the R&D program supervised by the KAIST.

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