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Evaluation of Performance and Safety Issues in FCVS with MELCOR code

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1. Introduction

Adoption of Filtered Containment Venting System (FCVS) installation in Pressurized Water Reactor (PWR) causes safety issues even though it has many beneficial features. Also, the effect of FCVS differs depending on operation strategies, type of Nuclear Power Plants (NPP) and accident scenarios, etc. [1]. Therefore, many researchers studied about FCVS.

Bracht et al. [2] proposed an idea of hydrogen issue using Shapiro diagram in German nuclear power plants depending on the opening time of FCVS. Late venting could not avoid entering detonation region while early venting could avoid it.

Y. S. Na et al. [3] analyzed the thermal-hydraulic issue of FCVS using MELCOR computer code. He focused on the evaporation time of FCVS pool depending on diameter of venting/exhausting pipes. When the diameter of exhausting pipe is smaller, the pool exists for a long time so that the performance of FCVS can be kept.

S. Y. Park et al. [4] compared the fission product behavior for OPR1000 and CANDU6 using MAAP and ISAAC code depending on opening and closing pressure of FCVS. The decontamination factors were defined depending on the aerosol size.

The FCVS can significantly reduce the release amount of fission products to the environment. Also, the containment over-pressurization can be prevented by releasing steam and fission product gases to the FCVS vessel. However, it may have negative features also. For example, as soon as the FCVS is actuated, the hydrogen burning can be occurred in the FCVS vessel because the hydrogen is discharged to the FCVS and steam condensation starts, simultaneously.

In this paper, these beneficial and negative features of FCVS are analyzed with regard to the integrity of FCVS by using MELCOR code.

2. Methods and Results

To analyze the features related with FCVS, the MELCOR ver. 1.8.6 is used [5]. The MELCOR code is a severe accident code to predict the thermal-hydraulic behavior of NPP and release of fission products under the severe accident.

The Optimized Power Reactor 1000 MW_e (OPR-1000) was modeled to assess the performance of FCVS and the station blackout (SBO) accident was chosen as an accident which can induce the over-pressurization of containment. The purpose of this paper is to evaluate the radiation release to the environment and hydrogen risk in the FCVS vessel with respect to the containment pressure which is the criteria for FCVS operation. Therefore, the safety injection tank (SIT) is only considered in accident scenario.

The FCVS model is composed of venting pipe, vessel and exhausting pipe [3]. The diameter of each pipe is set as 0.15 m. The vessel is modeled as a cylindrical vessel with 3 m diameter and 6.5 m height consisting of pool and atmosphere. The filter exists in the top of FCVS vessel and the sparger is modeled at the end of the venting pipe which is submerged in the pool.

2.1 SBO Accident Sequence

Figure 1 shows the pressure behaviors in reactor vessel and containment under SBO accident. When SBO occurs, systems connecting with AC power cannot be actuated at all. Also, failure of turbine driven auxiliary feedwater system is assumed so that the steam generator (S/G) dryout occurred at 52 minutes after SBO occurred. After S/G dryout, the reactor coolant system (RCS) pressure increased and the pressurizer safety valve (PSV) was opened due to high pressure in pressurizer. Through the PSV, the hot coolant and steam were discharged to the containment and it induced the increase of containment pressure. The core water level decreased continuously because the emergency core cooling systems were not available. Therefore, the core dryout occurred at around 3 h. Vessel failed at 4 h after the accident initiated. After the reactor vessel failed, the containment pressure increased due to generation of steam, hydrogen and other non-condensable gases from RCS and molten core-concrete interaction. When the containment pressure reached at containment failure pressure, then it failed and the fission products in the containment released to the environment.

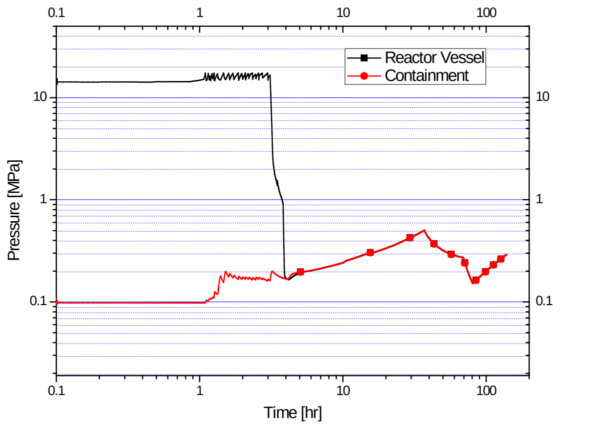

Figure 1. Pressure of reactor vessel and containment. Note that log-log scales are used.

2.2 Performance of FCVS

The pressure of containment and FCVS vessel are shown in Figure 2. When the FCVS was not installed, the containment pressure increased until it reached containment failure pressure which was set 1.027 MPa at 90 h in this paper. On the other hand, when the FCVS was installed, if the containment pressure reached valve opening set-point (0.5 MPa), the valve was opened at 37 h and the containment pressure decreased until it reached valve closing set-point (0.15 MPa) at 80 h. The FCVS could prevent over-pressurization and failure of containment.

To simulate the decontamination of aerosol and fission product vapor, the FCVS model has two factors; pool scrubbing and filter. There are sparger with small holes in the pool and filter with decontamination factor (DF). The value of DF is assumed as 10. Release fraction to the environment of each RN class during accident are shown in Figure 3 and 4 without/with FCVS installation, respectively. Due to the pool and filter effect, the fraction of radionuclides released to the environment at 140 h reduced (Figure 5). The details about radionuclide (RN) class in MELCOR are described in Table I [5].

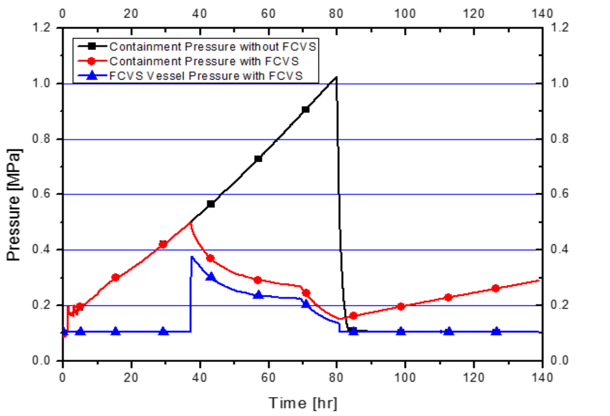

Figure 2 Pressure behaviors in containment and FCVS vessel without/with FCVS installation

Because the noble gas is chemically inert so it releases to the environment. Almost 100% of noble gas, class 1, released into the environment regardless of FCVS installation. On the other hand, the fraction of radionuclides except the noble gas in case of FCVS operation were smaller than the values for FCVS non-installation. Roughly, the fraction of radionuclides reduced two or three orders of magnitudes in case of FCVS installation compared to non-installation.

Table I. Radionuclide (RN) class in MELCOR

Class	Name	Represen-tative	Member Elements
1	Noble Gas	Xe	Xe, He, Ar, Kr, Rn, H, N
2	Alkali Metals	Cs	Li, Na, K, Rb, Cs, Fr, Cu
3	Alkaline Earths	Ba	Be, Mg, Ca, Sr, Ba, Ra, Es, Fm
4	Halogens	I	F, Cl, Br, I, At
5	Chalcogen	Te	O, S, Se, Te, Po
6	Platinoids	Ru	Ru, Rh, Pd, Re, Os, Ir, Pt, Au, Ni
7	Early Transition Elements	Mo	V, Cr, Fe, Co, Mn, Nb, Mo, Tc, Ta, W
8	Tetravalent	Ce	Ti, Zr, Hf, Ce, Th, Pa, Np, Pu, C
9	Trivalent	La	Al, Sc, Y, La, Ac, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Am, Cm, Bk, Cf
10	Uranium	U	U
11	More Volatile Main Group	Cd	Cd, Hg, Zn, As, Sb, Pb, Tl, Bi
12	Less Volatile Main Group	Sn	Ga, Ge, In, Sn, Ag

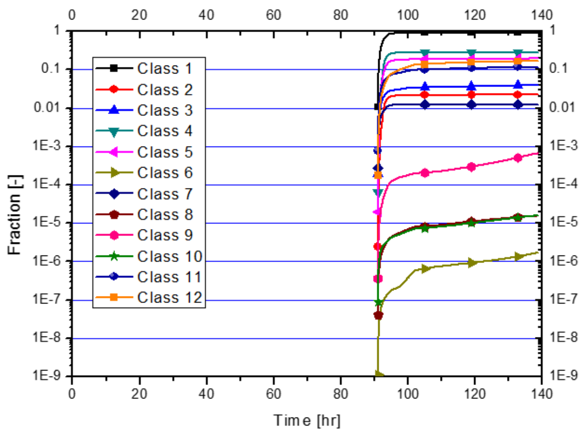

Figure 3. Release fraction to environment without FCVS

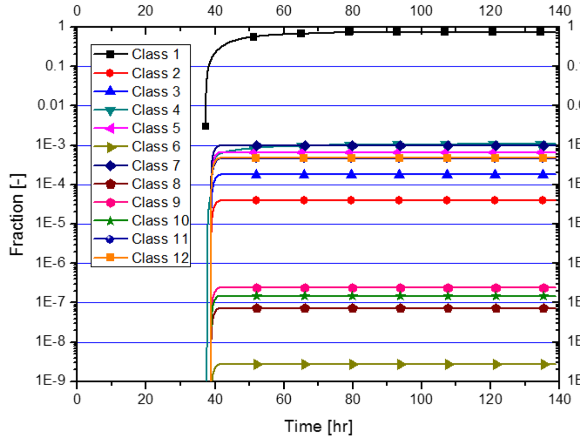

Figure 4. Release fraction to environment with FCVS

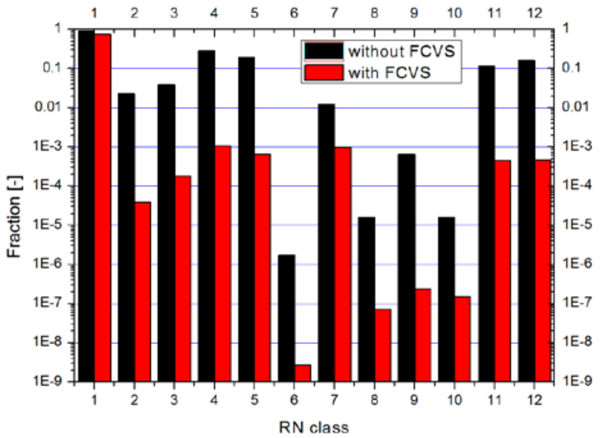

Figure 5 Fraction of radionuclides released to the environment at 140 h

2.3 Risk of Hydrogen Burning

Figure 6 shows the mole percent of steam, air and hydrogen in FCVS vessel from 37.2 h to 37.6 h (during 25 minutes). The valve between containment and FCVS was opened at around 37.3 h. The time points in Figure 4 are drawn as Shapiro diagram in Figure 7. Time between each point is about 6 minutes.

(A point) Just before opening of the valve, the atmosphere of FCVS vessel is composed of air and a little steam.

(B point) As soon as valve operated, the mole percent of hydrogen increased from 0 to 27 %. The mole percent of steam increased more slowly than that of hydrogen. Therefore, soon after the opening of valve, there is a possibility for hydrogen detonation in the FCVS vessel. If the hydrogen concentration is more than 20 % and the steam concentration is less than 40 %, then this region is called detonation region. At this point, the hydrogen is 27 % and the steam is 4.6 % so that it corresponds to the detonation.

(C point) Right after sudden increase of hydrogen, hydrogen released to the environment via exhaust pipe. At this point, the hydrogen concentration is 17 % and the steam concentration is 41 %. Because the concentration of steam is less than 55 % and that of hydrogen is between 10 and 20 %, this point belongs to flammability region. Through point B to C, it passes from the detonation region to the flammability region and it takes about 6 minutes.

(D-E points) At these points, because the steam concentration increased more than 55 %, these are corresponding to safety region. When FCVS is operated, it takes about 12 minutes to avoid the flammability region. After the E point, the amount of steam is more than that of hydrogen and the concentrations have steady values.

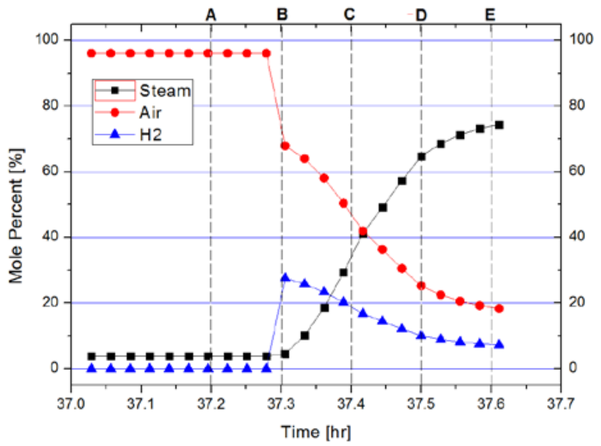

Figure 6 Mole percent of steam, air and hydrogen in FCVS vessel

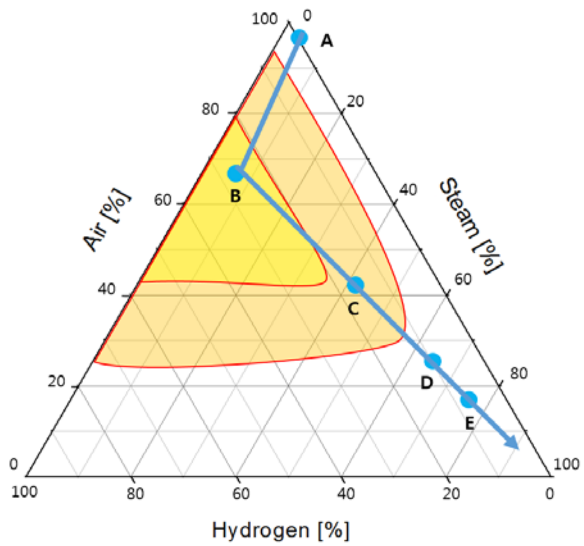

Figure 7 Shapiro diagram for FCVS vessel during 37.2 to 37.6 h

3. Conclusions

The performance and safety issue of FCVS were studied in this paper. If the FCVS is actuated under sever accident, then the steam and fission product gases are released through the venting pipe so that the pressure of containment decreases. In addition, the amount of fission products released to the environment decreases due to pool and filter in FCVS. However, when the valve which is connected with containment and FCVS is opened, the concentration of hydrogen in the FCVS increases rapidly compared with steam and air concentration. It takes about 12 minutes to avoid the detonation and flammability region.

FCVS can prevent over-pressurization of containment and reduce the amount of radioactive material release to the environment. However, the risk of hydrogen explosion at instant time when FCVS is actuated may exist so that the further work related with safety issue of FCVS should be performed.

ACKNOWLEDGEMENT

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