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An Analysis of FCVS operation strategy as a severe accident mitigation system using MELCOR

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1. Introduction

The Containment Filtered Venting System (FCVS) has the main objectives; the depressurization in the containment building and decontamination of fission products generated under a severe accident. The FCVS is engineered safety features (ESF) to be used as a last resort for preventing containment overpressure damage under severe accident.

Korea will be completed or installed as a follow-up management after the Fukushima accident, so it is necessary to evaluate the systematic integrity and severe accident management guidelines (SAMG) for FCVS in case of a severe accident. The Korea Institute of Nuclear Safety (KINS) published a report on safety issues for FCVS in 2014(KINS/RR-1108). The contents of the report are divided into three main categories. First, FCVS operation strategy including decompression capability, fission product load, Second, the hydrogen integrity in the piping and the system in the case of filtration and containment of containment buildings, Third, it is FCVS operation as a severe accident mitigation system. Third, FCVS operation strategy means FCVS operation as an available system. For example, a typical containment building in the PWR and PHWR typically has a large dry structure that can withstand a significant amount of steam and other gases from damaged reactors. The FCVS itself does not prevent severe accidents, but it can alleviate the accidental consequences. Thus, if the FCVS is available, it is also possible to release it prematurely when the uncontrolled containment damage is unlikely to occur.

In this paper, we evaluate the early opening strategy based on the FCVS integrity and the amount of radioactive materials released by normal pressure and early opening.

2. Methods

The nuclear power plant to conduct the analysis is OPR-1000(Optimized power plant), a KSNP (Korea Standard Nuclear Power plant) which has 2,815 MW thermal power and 77,220 m^3 free volume of containment building. The code used for the analysis is MELCOR version 1.8.6, It is a severe accident analysis code developed by US. NRC.

2.1 Simulation conditions

A computer codes simulated that one of the severe accident scenarios, a Station Black out (SBO), occurred in nuclear power plants. For the conservative analysis were selected if all active Emergency Safety Features (ESF) does not operate in an accident (e.g. high pressure safety injection, low pressure safety injection, containment spray system, containment fan cooler and so on.). In order to observe the decompression rate, FCVS system integrity, and external radioactive material release due to the FCVS opening pressure under the above assumptions, the following scenario is assumed.

Table I: Simulation conditions

NAME	Early venting/ Pressure	Normal venting/ Pressure	Comments
CASE1	No	No	No venting
CASE2	Yes/2bar	Yes/5bar	Early and late venting
CASE3	Yes/2bar	Yes/9bar	Early and late venting
CASE4	No	Yes/5bar	Normal venting
CASE5	No	Yes/9bar	Normal venting

2.2 FCVS Modeling

Generally FCVS consists of two major components. It is cylindrical vessel combining dry filter and wet scrubbing systems. Primarily physical method such as venture nozzle and impact plate crush an aerosols and chemical reaction such as additive solutions are maximize decontamination, secondly remove re-entrainment aerosol by the moisture separator or zeolite filter. MELCOR FCVS model consists of cylindrical vessel of diameter 3m and 6.5m height, and it includes dry filter and a scrubbing solution (4m heights) with scrubber systems which consists of multi-hole sparger. System is linked with the top of the upper compartment, inlet and outlet pipe is stainless steel pipe with a diameter of 15cm. Scheme of the model is shown in Figure 1

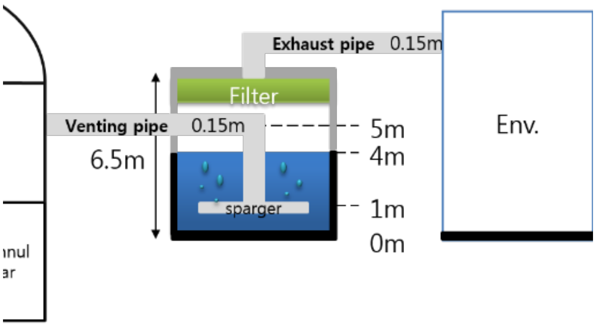

Figure 1. Scheme of the FCVS mode

3. Results

3.1 Depressurization of the containment

After the SBO, if there is no action by the operator, the containment building will be gradually pressurized due to PSV opening and failure of the reactor vessel. Thereafter, non-condensable gases and vapors accumulate due to a ex-vessel severe accident phenomena such as MCCI, DCH, and the pressure in the containment building gradually increases. It takes about 10 hours to reach 2 bar and 55 hours to reach 5 bar. If no action was taken, the containment building was failed by reaching the design pressure in about 120 hours. Figure 2 shows the pressure inside the containment building. In Case 2 and 3, the venting operation was performed at 5 bar and 9 bar, respectively, after the containment building pressure reached 2 bar and the venting operation was performed to lower the atmospheric pressure. The early depressurization took about 7 hours, which is caused by the pressurization of the containment building due to ex-vessel phenomena after the reactor vessel failure and the low flow rate due to the low containment pressure. There was an effect of about 10 hours of relaxation time when the accident occurred, and when the pressure was reduced to 5 bar and the valve was not opened early.

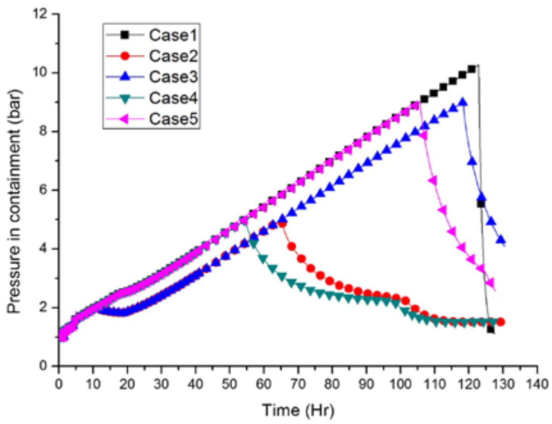

Figure 2. Pressure of the containment

3.2 Integrity of the FCVS

As described in Section 2.2, decontamination is carried out through adsorption or crushing with water through an FCVS filter nozzle. At this time, if there is no coolant, the radioactive material discharged from the containment building will pass through without being decontaminated. This should be observed sufficiently because it does not achieve the function of FCVS aiming to maintain the integrity of containment buildings and to reduce leakage of alienated radioactive materials. Figure 3 shows the amount of residual coolant in the FCVS. The overall water level was found to be maintained after increasing the amount of coolant due to the condensation of the venting from the initial mass of 28 tonnes. Case 2 and 3, which were subjected to early venting operation, decreased gradually with time after the coolant was increased by about 6 tons after the early opening, and gradually decreased by about 12 tons with the influence of reopening. Figure 4 shows the temperature of the coolant. Boiling occurred due to the heat accumulated by the steam vented from the containment building, the water level gradually decreased but the integrity of the system could be maintained until end of the depressurization. Therefore, it is analyzed that the integrity of the FCVS is maintained by early exhaust and normal exhaust.

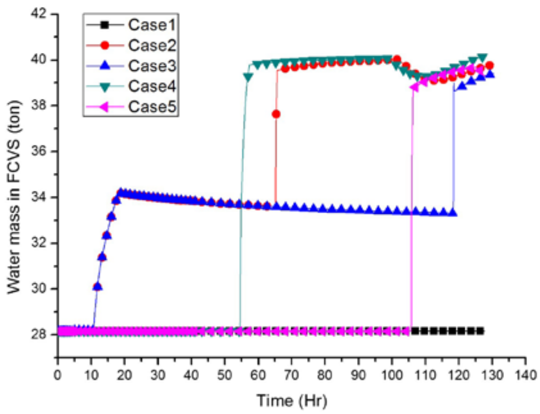

Figure 3. Water mass in the FCVS

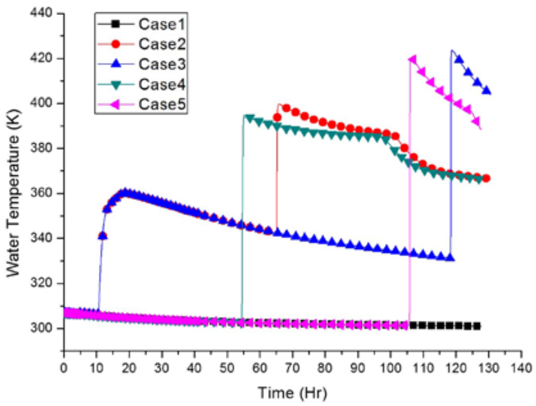

Figure 4. Water temperature in the FCVS

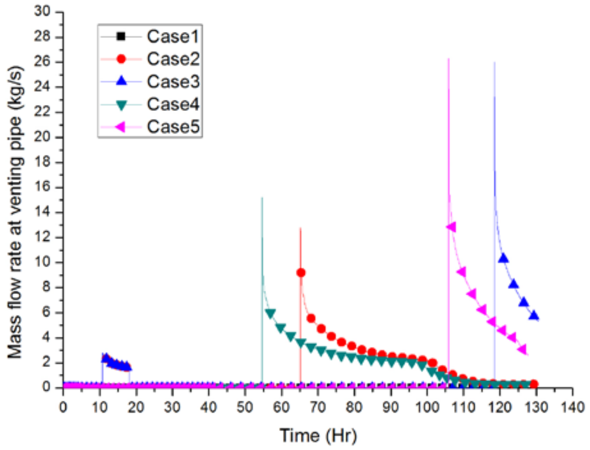

Figure 5. Mass flow rate at the venting pipe

The venting flow rate is shown in Figure 5. The maximum flow rate of FCVS venting pipe at early venting was about 3 kg / s, and the maximum flow rate at 5 and 9 bar was 15 kg / s and 26 kg / s, respectively.

3.3 Amount of leaked radioactive material

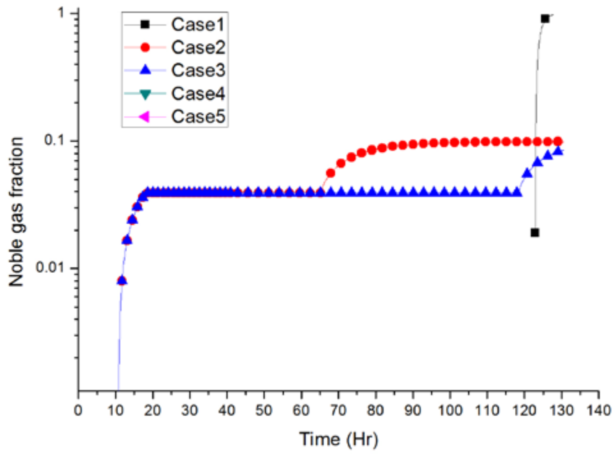

Figure 6. Amount of leaked noble gas

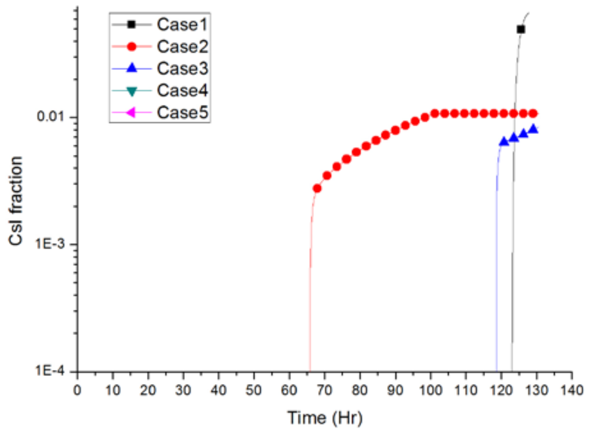

Figure 7. Amount of leaked CsI

Figures 6 and 7 show the emissions of alienated radioactive materials according to the venting strategy. It was confirmed that all the radioactive materials leaked in the case 1 where the containment building was damaged. Noble gas did not reflect the effect of FCVS operation. Because of the noble gas, both the scrubbing and the dry filter were passed through, so the amount was constant throughout. CsI is a standard nuclide for the evacuation of residents, and the amount of CsI emission according to the FCVS operation strategy is analyzed to be insignificant.

4. Conclusions

The analysis of decompression rate, system integrity and leakage of radioactive materials according to FCVS operation strategy at OPR-1000 nuclear power plant SBO accident was analyzed using MELCOR. According to the early opening, the operator action time for the containment building pressure was secured about 10 hours. The remaining coolant in the FCVS was maintained, confirming that the FCVS maintained integrity according to the operating strategy. Also, the early open strategy did not show any significant difference from the normal open strategy in terms of radioactive emission amount. Therefore, early opening strategy is reasonable from the viewpoint of ensuring operator action time for mitigating severe accidents such as Fukushima dai-ich nuclear power plant accident. Future works are to analyze the effects of early venting and normal venting due to accidents such as MSLB and LOCA.

ACKNOWLEDGEMENTS

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