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Assessment of Mitigating Strategies Using CFVS and CVWM at CANDU Plant under Severe Accident Conditions

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1. Introduction

Under severe accident conditions where containment heat removal capability is lost as in Station Black-Out (SBO), the containment integrity can be challenged by gradual increase of the containment pressure. Therefore, it is important to maintain the containment pressure low during the accidents. As a mitigating action to control the containment pressure, venting using a Containment Filtered Venting System (CFVS) is considered. On the other hand, the containment of a CANDU plant can fail by rapid steam generation caused by the quenching of the corium as it relocates to the calandria vault after the failure of the Calandria Vessel (CV). Thus, it is required to maintain the water level in the calandria vault to prevent the failure of the CV and to maintain the containment integrity. During SBO, Calandria Vault Water Make-up (CVWM) using portable equipment is considered as an option to maintain the water level in the calandria vault.

In Korea, the CFVS and CVWM were first introduced in Wolsung Nuclear Power Plant (NPP) unit 1, which is a CANDU plant. If the mitigating strategies to use the CFVS and CVWM are well established, it will minimize the releases of the fission products into the environment. In this study, sensitivity analyses were performed by using MAAP (Modular Accident Analysis Program) - ISAAC (Integrated Severe Accident Analysis Code for CANDU plants) 4.03[1] to establish appropriate mitigating strategies to use CFVS and CVWM for reducing fission product releases to the environment.

2. Analysis Cases

Analysis cases evaluating the mitigating strategies using a CFVS and CVWM are presented in this section. First, the base accident sequence is selected, and then sensitivity analysis conditions are determined.

2.1 Base Accident Sequence

An SBO scenario is simulated as an initiating event for the analyses. The SBO in Wolsung NPP unit 1 causes a loss of active cooling systems, such as the Primary Heat Transport System (PHTS) and auxiliary feedwater system. Thus, the water in the PHTS and the steam generator dries out. Then, the water level in the CV decreases and fuel channel rows are uncovered. The uncovered fuel channels heat up and sag under gravity. The sagging process leads to disassembly of the fuel channels and results in the formation of suspended debris beds. As mass of the suspended debris builds up, the debris releases fission products into the containment through the CV rupture discs. When the load on the supporting channels exceeds a critical value due to the accumulation of the suspended debris, the core collapses in a short period of time, resulting in the suspended debris relocating to the bottom of the CV. After core collapse, CV bottom heats up rapidly if the calandria vault water level decreases below the bottom of the CV, and eventually, the CV fails from a creep rupture.

During the accident progression, a large amount of steam and non-condensable gases are generated, create pressure in the containment, and the generated fission products are released into the containment atmosphere.

2.2 Sensitivity Analyses Conditions

The base accident sequence is SBO-NE without the operation of the CVWM. This case is expected to progress as described in Section 2.1. For the sensitivity analyses regarding the CVWM, two additional cases, SBO-CVF and SBO-CVI, were considered for CVWM operation. In case of SBO-CVF, it is assumed that the CVWM operated for one hour after the CV failure. And, in case of SBO-CVI, the CVWM is operating when the water level of the calandria vault decreases below the top of the CV.

On the other hand, it is assumed that the CFVS is in operated for all analysis cases. However, two important parameters (vent initiating pressure and vent line size) regarding the vent flow characteristics are considered as sensitivity conditions. The vent initiating pressure is varied from 224 kPa(a) to 524 kPa(a) with 6 inch diameter of the vent line as listed in Table I. In addition, the vent line size (inner diameter) is varied from 6 inch to 12 inch with 224 kPa(a) vent initiating pressure. In this analysis, the closure pressure of the CFVS is set to 150 kPa(a).

3. Analysis Results

The effectiveness of the mitigating strategies using the CFVS and CVWM were assessed with the objective to reduce fission product releases into the environment. Thus, this study focuses on the vented radioactive aerosol mass in the CFVS, and the analyses results are summarized in Table I.

Table I: Results of Sensitivity Analyses

Accident Sequence	Vent Initiating Pressure (kPa(a))	Vent Line Size (inch)	Max. Venting Mass Flow Rate (kg/s)	Vented Radio-active Aerosol Mass (kg)
SBO-NE (Base)	224	6	7.7	5.57
		8	12.4	5.77
		10	20.4	4.81
		12	23.2	6.06
	324	6	8.9	6.24
	424	6	9.7	4.50
	524	6	11.4	1.05
SBO-CVF	224	6	7.7	5.57
		8	12.4	5.77
		10	20.4	4.81
		12	23.2	6.18
	324	6	8.9	6.31
	424	6	9.7	4.58
	524	6	11.4	1.05
SBO-CVI	224	6	6.1	5.50
		8	10.6	5.68
		10	16.5	4.71
		12	23.2	5.73
	324	6	7.8	5.88
	424	6	9.7	3.61
	524	6	11.4	0.37

Figure 1 shows the comparison of the vented radioactive aerosol mass between SBO-NE, SBO-CVF, and SBO-CVI where the vent initiating pressure is 224 kPa(a) and the diameter of the vent line is 6 inch. As presented in Fig. 1 and Table I, there is no remarkable difference whether the CVWM operates or not. And, the vented radioactive aerosol mass is not significantly affected according to the time of CVWM operation. Even though the CVWM is an effective measure to prevent the creep rupture of the CV by providing external cooling, the operation of the CVWM does not influence the progression toward core damage. Therefore, it did not contribute significantly in reducing the releases of fission products as the analyses results indicate. Since the CV failure can cause various severe accident phenomena such as steam explosion and Molten Core Concrete Interaction (CCI) in the calandria vault, current mitigating strategies to operate the CVWM before CV failure is appropriate regardless of the fission product releases.

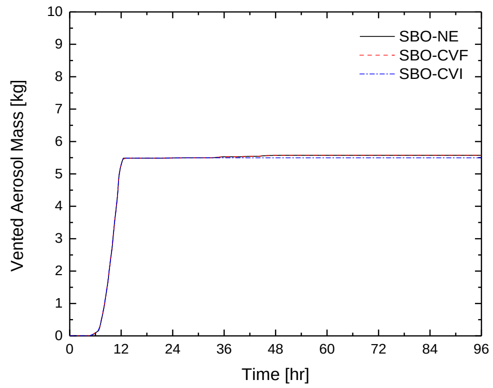

Fig. 1. Comparison of the vented radioactive aerosol mass (SBO-NE, SBO-CVF, and SBO-CVI).

On the other hand, the sensitivity analyses varying the vent line size were carried out. Figures 2 and 3 show the comparison of the containment pressure and the venting mass flow rate of SBO-NE case with the vent initiating pressure of 224 kPa(a), respectively. As illustrated in these figures, the vent line size influence the behavior of the containment pressure strongly due to the difference in the venting mass flow rate. However, it did not affect much to the vented radioactive aerosol mass as shown in Fig. 4 and Table I. Therefore, the current vent line size of the CFVS installed in Wolsong NPP unit 1 is appropriate for controlling the fission product releases.

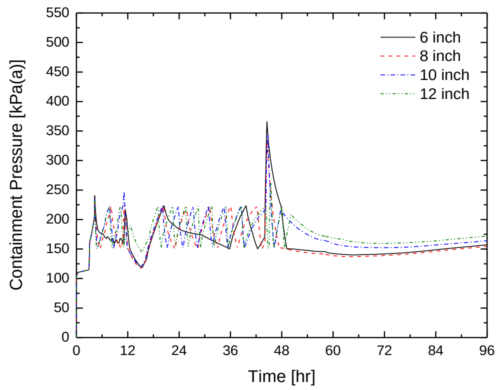

Fig. 2. Comparison of the containment pressure as vent line size (SBO-NE) varies.

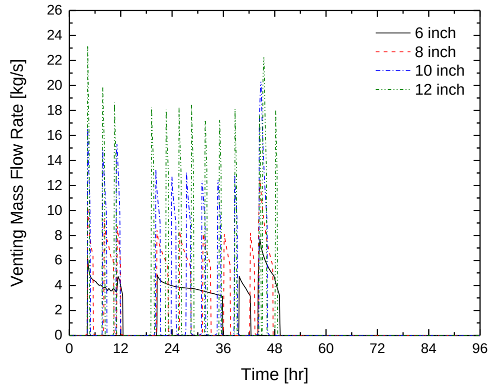

Fig. 3. Comparison of the venting mass flow rates with varying vent line size (SBO-NE).

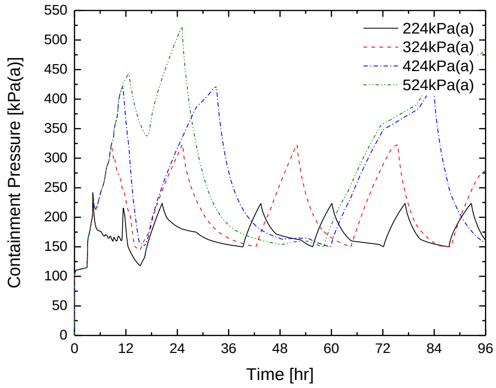

Fig. 5. Comparison of the containment pressures with varying vent initiating pressure (SBO-CVI).

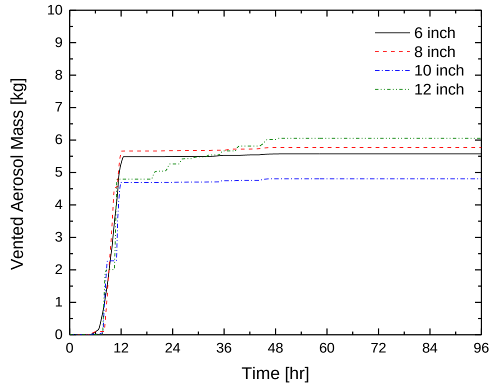

Fig. 4. Comparison of the vented radioactive aerosol masses with varying vent line size (SBO-NE).

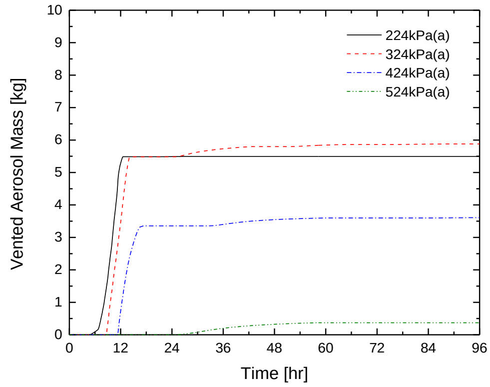

Fig. 6. Comparison of the vented radioactive aerosol masses with varying vent initiating pressure (SBO-CVI).

Finally, sensitivity analyses varying the vent initiating pressure to operate the CFVS were carried out. The comparison of the containment pressure of SBO-CVI case varying the vent initiating pressure from 224 kPa(a) to 524 kPa(a) by 100 kPa are presented in Fig. 5. As the vent initiating pressure increases, venting was delayed. Fig. 6 shows the comparison of the vented radioactive aerosol mass of each sensitivity case with varying vent initiating pressure. As presented in Fig. 6 and Table I, the quantities of the vented radioactive aerosol mass decreases as the vent initiating pressure increases. If the vent initiating pressure is sufficiently high to delay the actual venting, the suspended particles (i.e. aerosols) would be settled and deposited and the less amount of aerosol would be vented [2]. Therefore, in the point of view to minimize the fission product releases into the containment, the strategy to increase the vent initiating pressure of the CFVS can be an advantage related to the magnitude of the off-site consequence.

4. Conclusions

The CFVS and CVWM are effective measures to maintain the containment integrity against the gradual and rapid increase of the containment pressure. Since the operation of these measures can cause releases of a significant amount of radioactive materials, the mitigating strategies should be well established. Thus, in this study, various sensitivity analyses are carried out to evaluate the appropriateness of the current strategies.

According to the analysis results, CVWM operation in itself and the operation time does not contribute significantly in reducing the release of fission products. In addition, the vented radioactive aerosol mass is not affected by the vent line size strongly. Therefore, it can be concluded that the current strategy to use the CVWM before the CV failure and the current vent line size are appropriate to mitigate severe accidents.

However, it is understood that the increase in the vent initiating pressure gives positive effects to minimize the total releases of the fission products. The current vent initiating pressure of the CFVS installed in Wolsung NPP unit 1 is determined to be 224 kPa(a) [3], which is the design pressure of the containment for Design Basis

Accident (DBA). Considering that the CFVS is a severe accident mitigating feature and there are positive effects by increasing the vent initiating pressure, it is required to re-evaluate the current set-point of the CFVS operation carefully.

REFERENCES

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[3] KHNP, Wolsung NPP Unit 1 Operating Manual for Containment Filtered Vent System, 87-73160-7057-001-DM-A.