Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

CFD analysis of steam flow at TI-SGTR accident induced by MSSV stuck-open faults

Wung Jae Wang[a], Man Sung Yim[a*]
[a]*Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, 305-701, Guseong-dong, Yuseong-gu, Daejeon, Korea*
*Corresponding author: msyim@kaist.ac.kr

1. Introduction

When a severe accident occurs at a nuclear power plant, the leakage of radioactive materials from the reactor core can occur in several ways: 1) Leakage of the containment building 2) Steam generator tube rupture (SGTR) 3) Interface system loss of coolant accident (ISLOCA), etc. There is containment filtered venting system (CFVS) to prevent overpressurization of containment building. However, in the rare case of a containment bypass accident, there is no barrier like CFVS to prevent leakage to atmosphere. There could be an external leak of radioactive material which poses a high risk to the public.

To mitigate consequence of this accident, in a previous researches, a radioactive material mitigation system was proposed [1-3]. In this study, the thermally-induced steam generator tube rupture (TI-SGTR) accident was selected as representatives and their release characteristics were analyzed in previous research [4,5]. TI-SGTR can occur with loss of electrical power and main steam safety valve (MSSV) stuck-open. When the MSSV is stuck open with TI-SGTR, radioactive materials can be released with high pressure and high flow rates. In order to reduce consequence of this situation, the behavior of the fluid through the MSSV should be analyzed.

In this study, we considers the case where radioactive material is released through MSSV in TI-SGTR accident. The inlet flow inside the MSSV was analyzed by ANSYS Release 18.1 program [6]. This study shows the physical properties in fluid behavior before and after the valve.

2. CFD analysis preparation

2.1 Release characteristics

For TI-SGTR scenario, release characteristics should be analyzed to evaluate the mitigation system. Based on the literatures, in the TI-SGTR scenario the core will start to melt after 3.45 hours with loss of electrical power and MSSV stuck open at 3 hours [4,5]. The valve stuck open lead sudden pressure gradient and a temperature gradient, which causes the tube break. Leakage of radioactive material can occur about 3.45 hours with the accident. The flow rate of released gas is 4.8kg/s. After 15 minutes, the flow rate is reduced to 0.25 kg/s. Less than 0.1% of the total released gases is radioactive material the rest is dry steam.

2.2 Modeling of vent pipe and suction pipe

The model of MSSV is shown in Figure 1. This valve model has an inlet diameter of 249mm and an outlet diameter of 254mm. This model is assumed as stuck-open. The disk of valve is lifted and distance between the valve disk and the inlet nozzle is 29.4mm. The inlet gasses are released to the environment through the vent pipe. Although these dimension are not an exact match to those of a nuclear power plant (NPP), the analysis of this system is representative as all the components are similar to those in an actual NPP.

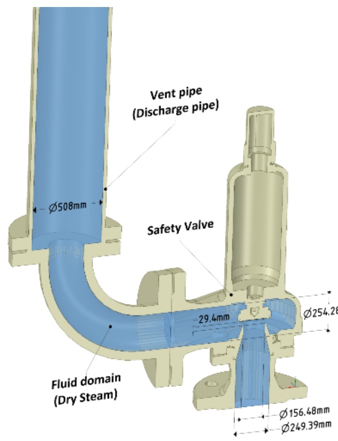

Fig. 1. Schematic main steam safety valve

For the CFD analysis, commercial software ANSYS was used and meshed are modelled with tetrahedral elements. For CFD analysis, commercial software ANSYS was used, and meshes were modeled with tetrahedral elements. Realizable K-Epsilon turbulence model and Total energy equation was used and Inlet fluid (dry steam) and air were considered as ideal gases for compressibility effect.

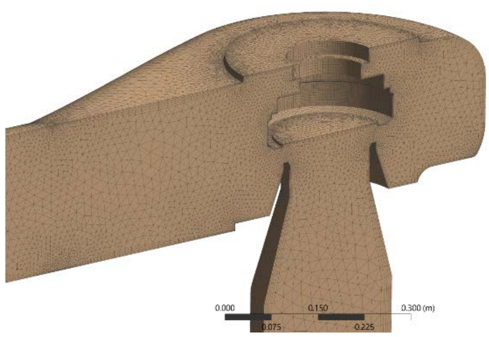

Fig. 2. Computational mesh on symmetry plane for CFD analysis.

2.3 Boundary conditions

Boundary conditions for CFD analysis are based on release characteristics of the TI-SGTR scenario. A summary of the boundary conditions is listed below:

(i) Safety valve disk is stuck open,
(ii) The inlet fluid is dry steam at 823 Kelvin,
(iii) The inlet pressure is 0.5MPa, 2MPa, 8.7MPa,
(iv) The outlet and opening absolute pressure is 1 bar,
(v) Symmetry conditions is used (half model),
(vi) No slip wall conditions for inner surfaces.

3. Result and discussion

The flow from the MSSV was analyzed for the transient condition. The figure 3 shows the stream line inside the MSSV. The velocity of gases released through the gap between the disk and the inlet nozzle decreases as entering into the exhaust pipe.

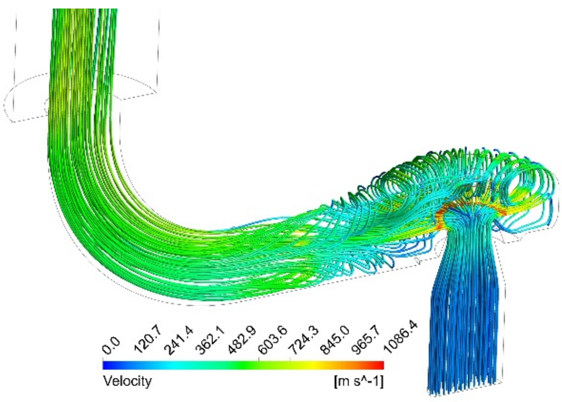

Fig. 3. Flow Streamline from inlet in MSSV and mitigation device

The velocity and pressure distributions in the pipe were also examined. Figure 4 shows the distribution of velocity and static pressure over time in MSSV. The velocity was 1000m/s in gap between disk and inlet nozzle. However, as the gas releases to the outlet, the velocity drops sharply to 300m/s or less. For static pressure, the trend of distribution was similar with typical safety valve's result. Before gap between disk and inlet nozzle, static pressure is 500kPa which is initial condition. However, after release, pressure distribution was quite low compared to initial value. Because reference pressure is 1atm, pressure near outlet nozzle is similar atmospheric pressure.

For the specific value, velocity and total pressure was measured in horizontal line (figure 5). First, for the total pressure, solid line, the pressure near disk is about 550kPa, and as the flow is discharged to the gap between disk and inlet nozzle, the pressure is reduced sharply. And it decreases to about 120kPa. In the case of velocity, it shows the smallest velocity at the center of the disk, but it has a peak value of about 850 m/s near the throat area. And after the peak, it decreases to a value of about 300 m/s.

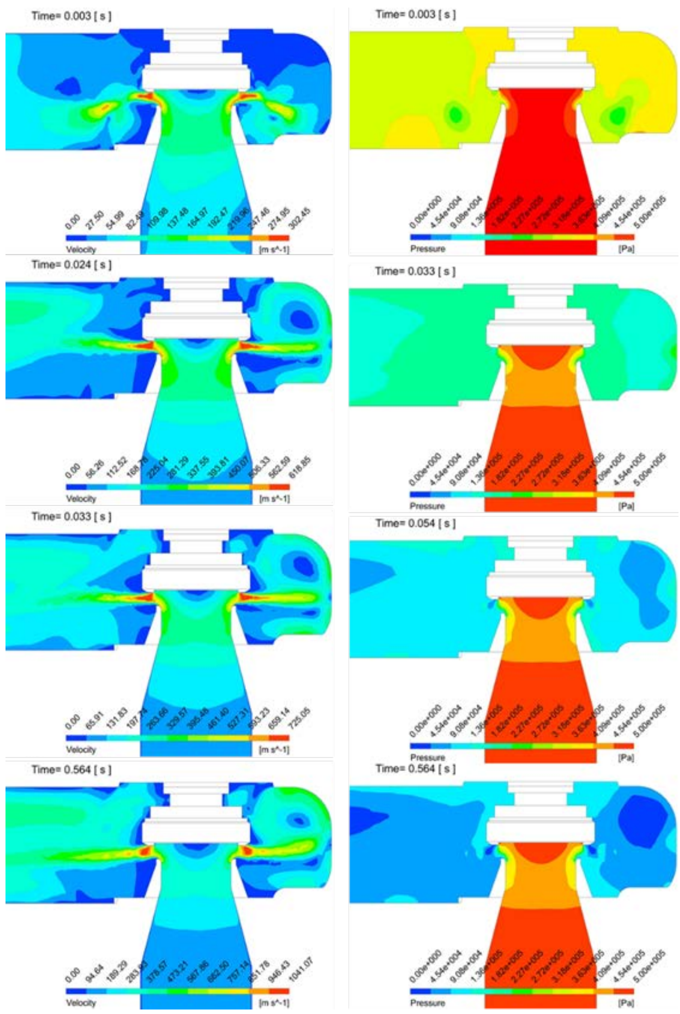

Fig. 4. Velocity and static pressure contours on the symmetrical plane in MSSV.

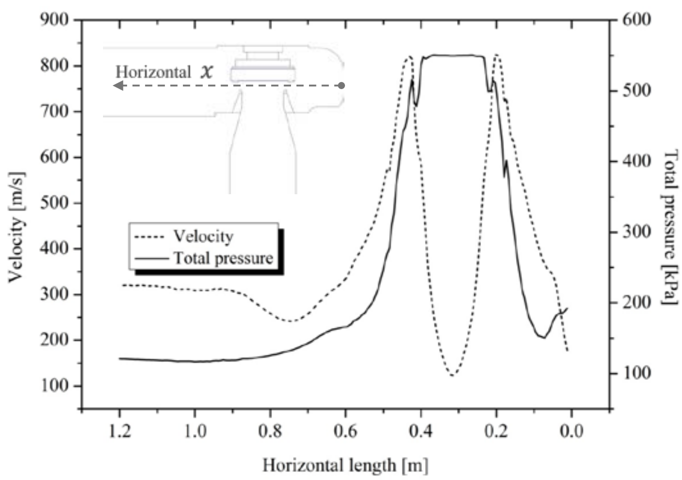

Fig. 5. Physical properties in horizontal line (x line)

4. Conclusions

In this study, we investigated the feasibility of a mitigation system that minimizes leakage to the environment when radioactive gas release through the MSSV in a TI-SGTR accident scenario.

The results of this study are summarized as follows.

1. Analysis of steam emitted to the outside through MSSV in case of TI-SGTR accident due to failure of main steam safety valve. Flow characteristics were analyzed through CFD analysis in MSSV.

2. Both the speed and the pressure showed a sharp decline in the MSSV when it was discharged from the disk, as shown in the general valve. The pressure was similar to atmospheric pressure just after the narrow gap, and the velocity was 300m / s.

Acknowledgement

We would like to acknowledge the technical support from ANSYS Korea.

REFERENCES

[1] SW Kang, MS Yim, “Defining Design Limits of a Portable Radiation Dispersion Prevention System”, Transactions of the Korean Nuclear Society Spring Meeting, 2016.
[2] S Ullah, MS Yim , “Suppression of Radioactive Material Dispersion in the event of a Radioactivity Release Accident at a Nuclear Power Plant”, GLOBAL 2017
[3] Sana Ullah, S.W. Kang, W.J Wang, H.H. Byun, M. S. Yim, Transactions of the Korean Nuclear Society Spring Meeting, 2018
[4] SW Kang, MS Yim, “Analysis of the Radioactive Release Characteristics for Development of the Containment Bypass Mitigation System”, Transactions of the Korean Nuclear Society Autumn Meeting, 2017.
[5] Nuclear Regulatory Commission. State-of-the-Art Reactor Consequence Analyses (SOARCA) Report. Nuclear Regulatory Commission; NUREG-1935, 2012 Nov 29.
[6] ANSYS Mechanical, Release 18.1, ANSYS Inc.