Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

Hydrogen Safety Analysis of the OPR1000 Nuclear Power Plant during a Severe Accident by a Small-Break Loss of Coolant

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1. Introduction

A huge amount of hydrogen can be generated in a nuclear reactor and released into the reactor containment if a hypothetical severe accident happens. Even for the accident, the hydrogen concentrations must be safely controlled. In order to prove a nuclear power plant (NPP) safe from hydrogen, a simulation of hydrogen distributions in the containment are usually conducted by using a 1-dimnetional thermo-hydraulic system code. If there exists a possibility of a hydrogen explosion in the containment, it is required to install a hydrogen mitigation system such as igniters or hydrogen recombiner.

For a licensing of NPP construction and operation, the hydrogen combustion and hydrogen mitigation system in the containment is one of the important safety issues. In Korea, two OPR1000 NPPs by the name of Shin-Wolsung 1&2 are under construction. The hydrogen safety and its control for the new NPPs will be evaluated in detail until a licensing of the operation.

Until now, simulations of the hydrogen behaviors in the OPR1000 have been conducted by a lumped method for each compartment in the containment using CONTAIN [1] or MAAP. This 1-dimensional method is very efficient for a long-term simulation of an accident because of its fast running time, and it is very effective for establishing the averaged hydrogen concentrations in each compartment. But a 3-dimentional flow structure developed by a discharged mass from a reactor vessel and local concentrations of hydrogen are difficult to be resolved by the lumped method.

In this study, hydrogen distributions and characteristics of hydrogen mixture cloud such as a possibility of flame acceleration in each compartment of OPR1000 containment were evaluated by using GASFLOW [2]code.

2. Nodalization for the OPR1000 containment

The containment of the OPR1000 is cylindrical with a hemi-spherical dome. The height from the bottom of the reactor cavity to the top of the dome is 75.3 m and the inner radius of the containment wall is 22 m. For an analysis of OPR100 with the GASFLOW code, a cylindrical coordinates were used. The number of grid points in each coordinate direction used in this study is 21×61×53. Fig. 1 shows the generated mesh on the surfaces of the structures and main equipments such as a reactor vessel and steam generators in the containment. In this study, steel gratings built in an annular compartment were also modeled to consider the effect of a steam condensation on the surfaces. A free volume occupied by a gas phase in the containment is about 78,439 m^3 in the GASFLOW model which is very similar to the CONTAIN model of 76,978 m^3 and the MELCOR model of 77,433 m^3.

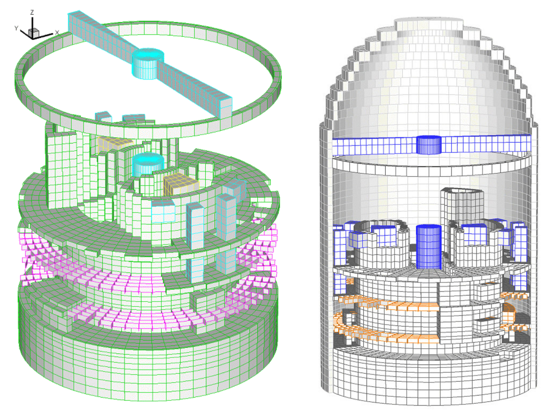

Fig. 1. Nodalized containment of OPR100 for a GASFLOW analysis

3. SBLOCA analysis

3.1 Released mass rates

The SBLOCA that is chosen in this study is one of the hypothetical severe accidents in the OPR1000, where an auxiliary feed water, high pressure, and low pressure pumps are not working. It was assumed that the accident is initiated by a 2-inch break in a cold-leg of the primary cooling system.

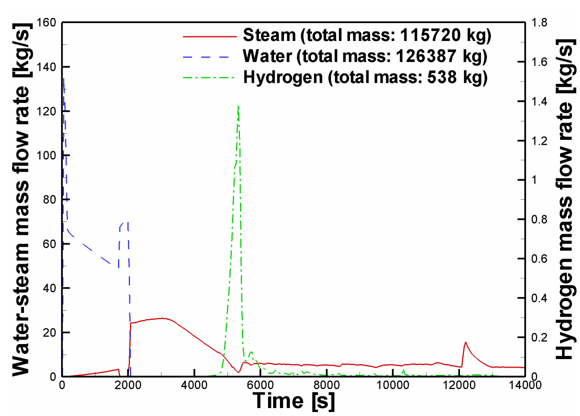

Fig. 2. Mass rates released from the cold-leg break by a MAAP calculation for the SBLOCA.

In order to evaluate the hydrogen safety in the OPR1000 containment during the accident by using the GASFLOW code, the mass rates of hydrogen and steam-water released through the break are required.

Fig. 2 shows the release rates during the SBLOCA which was obtained from a MAAP calculation. Hydrogen concentration in the containment during an accident is very affected by its release pattern and its total mass. For the SBLOCA, the total amount of hydrogen accumulated in the containment until 14,000 s is 539 kg which is very large. But it can be expected that the steam and water released before the hydrogen release starts preconditions the atmosphere very humidified.

3.2 Results of GASFLOW analysis

In this study, the steam and hydrogen distributions during the SBLOCA in the OPR1000 containment were calculated by using the GASFLOW code. Fig. 3 shows the steam and hydrogen clouds developed in the containment at 5,300s after the SBLOCA initiated. The left figure is the case when the side of the cold-led is assumed to be broken. In that case, the released steam and hydrogen make a horizontal jet. Because of the jet impingement on the walls near the cold-leg, the jet can be easily mixed with the ambient gas before it flows upward by buoyancy. On the contrary, if a vertical jet is made by a top rupture of the cold-leg as shown in the right figure, the jet flows upward directly with little mixing. Fig. 3 depicts that the hydrogen cloud with more than 10 % hydrogen volume concentration appears in the dome region only in the case of cold-leg top rupture. It could be thought from the figures that the case of cold-leg top rupture is more conservative than the side rupture in view of the hydrogen safety.

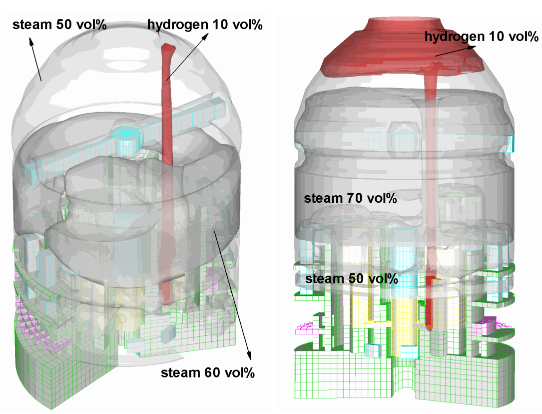

Fig. 3. Distributions of the hydrogen and steam in the containment at 5,300s for the SBLOCA, left: cold-leg side rupture, right: cold-leg top rupture

Two most important compartments in the containment for the hydrogen safety during a SBLOCA are the steam generator compartment where the hydrogen is released and the dome where it is accumulated. Fig. 4 and 5 show the averaged hydrogen concentrations along time in the compartments. In the S/G compartment, the averaged hydrogen concentration increases up to around 30%. Event with the high value of the hydrogen concentration, the d/7λ index which indicates the possibility of DDT is lower than 1.0 because of dense steam mixed with hydrogen.

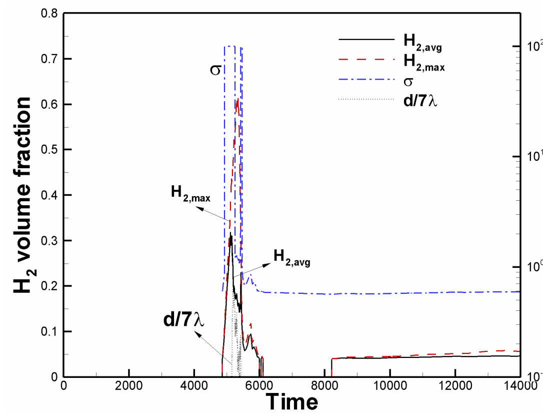

Fig. 4. The characteristics of the hydrogen mixture cloud in the steam-generator compartment.

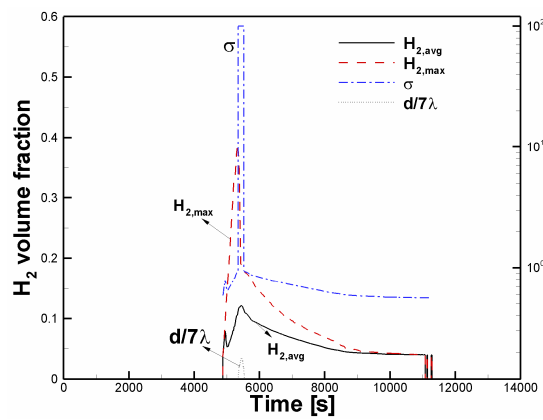

Fig. 5. The characteristics of the hydrogen mixture cloud in the dome region.

5. Conclusion

In this study, hydrogen distributions in the OPR1000 containment were analyzed 3-dimentionally by using the GASFLOW code. It was found that a vertical release from the top rupture of the cold-leg is more conservative in view of the hydrogen safety. And it is concluded that there is no possibility of DDT in the OPR1000 containment because of the huge amount of steam during the SBLOCA

REFERENCES

[1] KHNP, Ulchin 5,6 Final Safety Analysis Report, 2002.

[2] J. R. Travis, et al., GASFLOW: A Computational Fluid Dynamics Code for Gases, Aerosols, and Combustion, LA-13357-M, FZKA- 5994, 1998.