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Spray effect on the Hydrogen behaviors during Severe Accidents in the Containment of the APR1400 NPP

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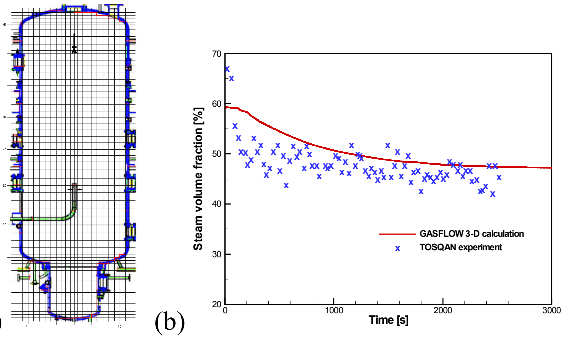
1. Introduction

A spray system in a containment of a nuclear power plant is required to be installed in order for the integrity of the containment by its heat removal functionality during an accident. It is known that the spray system can affect the behaviors of the hydrogen generated by an oxidation of a fuel cladding and released in the containment during a severe accident, which must be considered for the hydrogen safety. The spray effects can be described as follows in view of the hydrogen safety. The good point of the effects is to help the mixing of the hydrogen and finally reduce its concentration. But the bad point is that the spray can also reduce the steam concentration by condensing it, and increase the hydrogen concentration locally. Those spray effects on the hydrogen behaviors are dependent on the specifications of the spray system and accident scenarios. So, it is necessary to quantify the spray effects on the hydrogen behaviors during a severe accident for an interesting containment.

The GASFLOW[1] code has been used to study the hydrogen behaviors and the effectiveness of the hydrogen mitigation system in the APR1400 during a severe accident[2]. As a continuous work, the effects of the spray system of the APR1400 are evaluated by the GASFLOW analysis during LOCAs in view of the hydrogen safety. For the validation of the spray model included in the GASFLOW code, the TOSQAN experiment is analyzed with the code.

2. Spray modeling and validation

For the two-phase flow with a gas mixture and spray droplets, GASFLOW solves basically homogeneous two-phase model with the assumption that the liquid droplets are dispersed in a gaseous medium. The spray model of GASFLOW assumes that there is a mechanical equilibrium between the phases but thermally non-equilibrium. The assumption of equal velocities between the phases has a limitation to resolve well the flow structure of the two fluids. But the model is popularly used for the engineering problems with very large flow domains because of the computational efficiency with reasonable accuracy. To evaluate the spray model of GASFLOW, the TOSQAN experiment[3] is analyzed with the GASFLOW code. TOSQAN test 101 was modeled three dimensionally in cylindrical geometry. Total 5,760 nodes were applied for the GASFLOW simulation. For the spray actuation, nomal water of 293 K was introduced at the rate of 30 g/s and the droplet size was about 0.02 cm.



(a) (b)

Fig. 1 GASFLOW simulation of the TOSQAN experiment, (a) computational mesh, (b) comparison of the time variation of the steam volume fraction at z6 location.

Fig. 1(a) shows the r-z plot of the computational mesh used for the GASFLOW simulation, and fig. 1(b) is the time history of the steam volume fraction at height 2.045m (named as Z6). It depicts that GASFLOW resolves well the steam condensation rates by the sprayed droplets.

3. Analysis of APR1400

In this study, the effects of the spray system of the APR1400 have been evaluated by the GASFLOW analysis during LOCAs in view of the hydrogen safety.

The main components of the spray system are pump, heat exchanger, valve, and nozzle. The containment spray pump is activated by a Containment Spray Actuation Signal (CSAS). The CS pump takes a suction of the water from the IRWST and pushes the water to the spray nozzles after reducing the temperature at the heat exchanger. CSAS can be generated by a pressure signal in the containment automatically or by an operator in the control room manually. The main spray nozzles are attached to four spray rings on the dome wall. And the auxiliary spray nozzles are attached to the 2 spray rings around the annular compartment below the operating deck. The spray rate per nozzle is 0.86kg/s and the droplet size is about 1mm. In a recirculation mode of the CS system, the exit temperature of the heat exchanger is set to 74^{o}C.

Fig. 2 shows the modeled nozzle rings of the APR1400 spray system. The two nozzle rings at the uppermost of the dome are merged into one because of the limited mesh resolution used for this study.

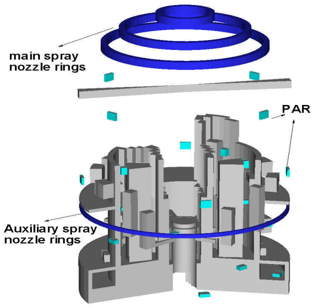


Fig. 2 Perspective view of the modeled APR1400 containment with nozzle rings.

As a first case for the simulation of the spray effects on the hydrogen safety in the APR1400 containment, the SBLOCA was simulated with the released hydrogen source from MAAP analysis. In that case, the spray system is not activated automatically because of the lower increase of the containment pressure. It is assumed in this study that the spray system is manually activated by an operator. Three scenarios are postulated as follows.

·Base case: Spray system is not activated

·Spray-case1: Spray system is activated for 500s from 5000s at which the hydrogen is not yet released.

·Spray-case2: Spray system is activated for 1000s from 5500s at which the hydrogen is starting to release.

By the GASFLOW analyses for the proposed cases, it was found that the hydrogen behaviors are heavily affected by the spray activation.

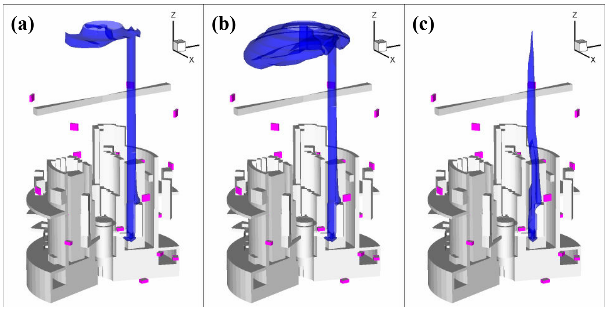


Fig. 3 Sigma clouds developed in the containment, (a) base-case, (b) spray-case1, (c) spray-case2

Fig. 3 shows the sigma cloud developed in the containment at T=6,275s when the release rate of the hydrogen is maximized. It is found that the time of the spray activation affects on the hydrogen behaviors especially its concentration.

During the LBLOCA, the containment pressure rises quickly because of the amount of the released water and steam from the cold-leg break which is two times as much as that for the SBLOCA. By the high pressure developed in the containment above the set point of the CS system, the CS activation signal is automatically generated and the CS system is activated. For the LBLOCA, the alteration of the hydrogen concentration in the containment by the spray activation along the following proposed cases is studied.

·Base-case: the spray system is not activated

·Spray-case: the spray system is activated by the over-pressure above the set point of the CS system and it operates continuously.

In the case of the LBLOCA, the amount of the steam released into the containment is very high compared to the SBLOCA and other accidents. The concentration of the hydrogen in the containment was very low in the base-case as shown in fig. 4(a). It is seen in fig. 4(b) that the hydrogen is much more dispersed in the spray-case, which means the decrease of the hydrogen concentration by the mixing from the spray droplets is much higher than its increase by the steam condensation

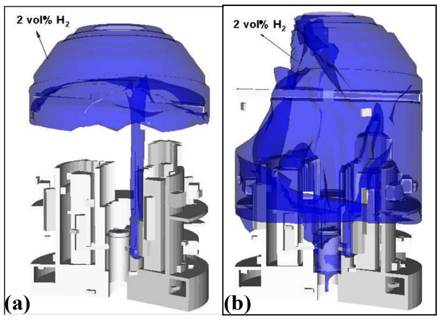


Fig. 4 Hydrogen distributions, (a) base-case, (b) spray-case

For the base-case of the LBLOCA where the spray was not activated, the steam concentration in the dome region is above 60 vol%, and because of that, the hydrogen mixture cloud is in the non-flammable condition. For the spray-case, the steam concentration in the dome region was lowered to about 20 vol% by the spray effect which condenses the steam in the region. Even with the reduced concentration of the steam for the spray-case, it was found that the sigma index was lower than 1, which means that there is no possibility of the flame acceleration in the dome region from the hydrogen combustion.

4. Conclusion

The GASFLOW analysis has been conducted for the evaluation of the spray effects on the hydrogen behaviors in view of the hydrogen safety in the APR1400 containment during the selected severe accidents. It was found in this study that the spray system can affect the hydrogen distributions in the containment and it is important to control the spray system carefully during an accident for the hydrogen safety.

REFERENCES

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