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Three-dimensional Numerical study on Hydrogen Behavior in CANDU Reactor Building in a Severe Accident

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1. Introduction

If a severe accident occurs in a nuclear power plant, large amount of hydrogen can be generated by reaction between hot steam and Zr metal of a fuel in reactor core. Then, hydrogen, steam and other gas species can be released into the reactor building (or containment building) through possible gas-release locations. The gas-release location can be at break position of reactor coolant system or in the primary circuit depressurization system.

If the hydrogen is locally accumulated in the reactor building's atmosphere up to the possible concentration causing energetic hydrogen combustion, the integrity of the reactor building may be threatened so that the reactor building might lost its function as a final barrier for fission product release.

In this study, three dimensional geometry of CANDU reactor building was used to analyze the hydrogen behavior for postulated large break loss of coolant accident (LLOCA) scenarios in the CANDU reactor building with a loss of emergency core cooling (LOECC). The specialized CFD codes for a containment analysis developed by KIT, GASFLOW-MPI was used to simulate the hypothetical severe accident. The gas release sources from the break location were given by severe accident analysis by using the ISAAC code. The gas release sources consist of the release of superheated steam and hydrogen from the break and from rupture valves of depressurization system.

2. Methods and Results

2.1 3D Mesh Generation

A Cartesian GASFLOW-MPI geometry model has been built with a specially developed automatic mesh generator tool based on the three dimensional CAD CANDU containment model. The mesh generation procedure using the automatic mesh generator tool.

In the GASFLOW-MPI CANDU geometry model, there are 80, 80, and 90 cells in x, y, and z direction respectively. The z direction represents the direction from the reactor cavity floor to the top of the containment dome. The CANDU containment is modeled with a single block grid applying a total of 618,608 mesh cells including boundary cells. Figure 1 gives an outline of the generated mesh. The total computational volume is around 48,000 m^3.

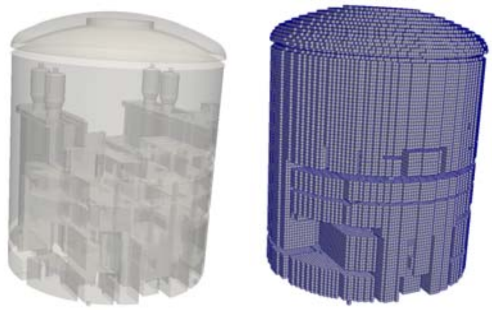
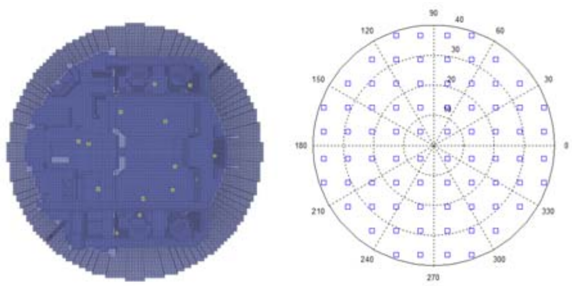


Figure 1. 3D CAD model and computational mesh

2.2 Models of Accident Mitigation Systems

There are 27 PARs in the CANDU's reactor building. Their positioning is shown in Figure 2(a). The PAR model in GASFLOW-MPI calculate mass sources and sinks of gas species which are related to recombination in the computational cells where the PAR models are imposed.[1] For the calculations of mass sources and sinks, the performance correlation of the PARs installed in the CANDU plant is used. The correlation can be found in the FSAR. [2]

The containment spray system is activated when the overpressure reaches 1.14 bar. In the GASFLOW-MPI model the spray nozzles are assumed to be uniformly distributed as shown in Figure 2(b). The water spray rate was assumed based on the accident analysis result using the ISAAC code. The temperature is set to 305.3 K and the droplet diameter is assumed as 1 mm.



(a) PARs (b) nozzles

Figure 2. Positions of mitigation systems

2.3 Initial conditions and boundary conditions

The inlet boundary conditions for gas release rate and locations are based on severe accident analysis of CANDU power plant using the ISAAC code. There are four gas release locations, the first inlet is the break in the reactor inlet header of which break size is assumed to be 0.213 m^2 (100% break size of the reactor inlet header). The second inlet is the break through Calandria vault's rupture disk to boiler room. The third inlet is the break is from the degasser condenser tank to the fuel machine room. The last inlet is the break through the Calandria tank rupture valve to boiler room. The gas release mass flow rates obtained from the accident analysis using the ISAAC are depicted in Figure 3.

The initial temperature is 314 K and the initial pressure is 1.01 bar. The initial flow velocity is zero in all directions. The LES turbulent model and wall function are used to consider the large scale convection in the reactor building.

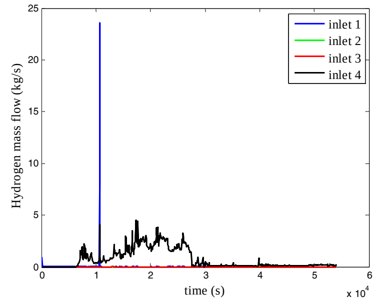


Figure 3. Release rates of hydrogen

3. Results

In the loss of coolant accident, hydrogen released from the break location flows upward and accumulated in the dome region of the reactor building by buoyancy force. By the continuous accumulation, hydrogen is distributed to the mid-region of the reactor building. For the period of 0 to 28,000 seconds when hydrogen and steam are continuously released, the volume fraction of hydrogen at the upper part of the reactor building is higher than that at the lower part of the reactor building. During this period, the local maximum hydrogen volume fraction in the reactor building is about 6.5%. Figure 4 shows the local volume fraction of hydrogen at the different elevations. Figure 5 shows the distributions of volume fraction of hydrogen in the reactor building. Hydrogen distributed in the reactor building is effectively removed by the PARs and the volume fraction of hydrogen is kept lower than 5%. Therefore, the CANDU plant will be able to reduce the hydrogen risk sufficiently by effectively removing hydrogen from severe accidents by the PAR installed in the reactor building.

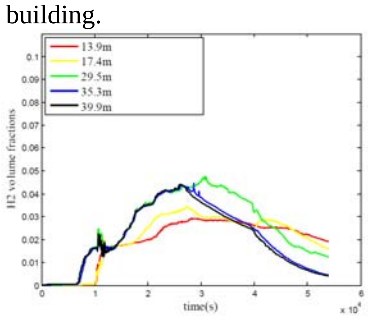
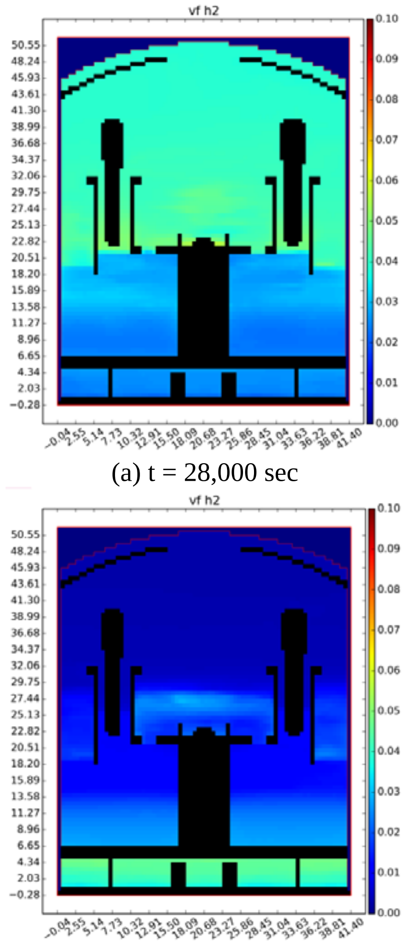


Figure 4. Local volume fraction of Hydrogen at different elevations



(a) t = 28,000 sec

(b) t = 56,000 sec

Figure 5. Hydrogen distributions

4. Conclusions

In this study, the hydrogen mitigation capability of CANDU was investigated by performing a three-dimensional numerical analysis in the CANDU reactor building in the event of a severe accident. According to the analysis, hydrogen released into the reactor building is effectively removed by the PARs, and mixed by a large amount of steam. It is expected that flame acceleration which is able to threaten the integrity of the reactor building could not occur. Therefore the CANDU plant can mitigate the hydrogen risk sufficiently through the PARs installed in the reactor building.

REFERENCES

[1] Jianjun Xiao, J. R. Travis and Thomas Jordan, GASFLOW-MPI: A Scalarable Computational Fluid Dynamics Code for Gases, Aerosol and Combustion Volume1: Theory and Computational Model (Revision 1.0), KIT, 2016

[2] Wolsung unit 1 Final Safety Analysis Report, Rev 207, 2012