# 3-Dimensional Analysis of Hydrogen Behaviors in a Containment with PARs

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## 1. Introduction

During a severe accident with a core degradation in a nuclear power plant (NPP), hydrogen is generated by oxidation of the fuel-cladding and released into the reactor containment. NPPs are required to have hydrogen mitigation system (HMS) installed in the containments in order to protect them from a thermo-mechanical load generated by hydrogen explosion. The hydrogen mitigation system may include igniters, passive auto-catalytic recombiners (PAR), and venting or dilution systems. Recently PARs are commonly used to reduce a hydrogen concentration in a NPP containment because of it passive nature. Along with installation of the HMS in the containment, it is required to show the effectiveness of the system. For many years, the hydrogen safety analysis has been done by using a lumped-parameter code. But the lumped-parameter code analysis has a limitation in predicting the three-dimensional behavior of hydrogen transport and mixing within a full containment.

Currently, it is on-going to develop an analytical tool, containmentFOAM, for a turbulence-resolved detail analysis of hydrogen behaviors in a NPP containment based on OpenFOAM[1]. In order to evaluate efficiency of hydrogen depletion by PARs installed in a NPP containment, h2RecombinerFoam is proposed in the context of containmentFOAM development.

In this study, the h2RecombinerFoam code was implemented to evaluate thermal hydraulic behavior of hydrogen affected by activation of PARs installed in the SMART containment during a severe accident.

## 2. Modeling and Results

In this section analytical models used to simulate hydrogen behaviors with PAR's recombination are described. And results from its application to the SMART containment are presented.

### *2.1 Modeling of hydrogen behaviors*

The multi-component gas transport equations are used as governing equation, in which mass, momentum and energy conservation equations of the gas mixture and species mass conservation equations are solved. In order to resolve turbulence mixing of gas, a 2-equation turbulence model with buoyancy effect is considered. Chemical reactions in a PAR is modeling by a global 1-step mechanism with a vender-supplied hydrogen removal rate. In the application of h2RecombinerFoam to a SMART containment analysis, a correlation of AREVA's small PAR, FR-380T, is used.

### *2.2 Modeling of Hydrogen release in SMART*

A national regulation requires that hydrogen concentration in a compartment must be maintained below a detonable limit even in the case of 100% fuel cladding oxidation in view of equipment survivability. In order to evaluate hydrogen distribution and PAR performance in the SMART containment, 193 kg of hydrogen mass generated by 100% oxidation of the SMART fuel is used.

The total mass of hydrogen generated by 100% oxidation of the SMART fuel is 193 kg. In this study, a simple linear extrapolation of a hydrogen release rate from a MELCOR analysis result is used to get the maximum hydrogen mass. Fig. 1 shows the mass release rates of hydrogen during a loss-of-coolant-accident (LOCA) in SMART. The hydrogen release rate is multiplied by a certain factor to meet 100% oxidation of the active core of SMART. The total hydrogen mass by integrating the release rate along time is about 193 kg.

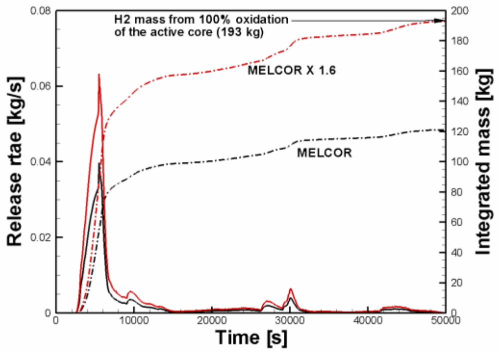


Fig. 1. Release rate and inventory of hydrogen during LOCA in SMART

In the containment design used for current analysis, hydrogen and steam in the SMART reactor are discharged to the lower containment area (LCA), and they move to in-containment-refueling-water-storage-tank (IRWST) by a pressure difference. Most of the steam released into the IRWST water pool is condensed but the hydrogen enters free volume above the pool and finally it is released into upper containment area (UCA) and mixed with atmosphere in the UCA. Initial condition of the containment and its free volume are summarized in Table 1.

Table 1. Containment free volume and hydrogen mass from 100% oxidation of active core

| | | |
|---|---|---|
| Initial containment pressure | 1.01 | [bar] |
| Initial containment temperature | 30 | [°C] |
| Initial containment humidity | 50 | [%] |
| Containment free volume | 51,920 | [m³] |
| Hydrogen mass | 193 | [kg] |
| Hydrogen concentration | 4.43 | [vol%] |

*2.2 Behaviors of hydrogen released into IRWST*

A simulation of hydrogen behavior in the SMART containment with 22 PARs installed was conducted by using the h2RecombinerFoam code. As mentioned above, AREVA's FR-380T was used for the current study. In this study, UCA and free volume of the IRWST are modeled with an assumption of full condensation of steam in the IRWST pool. Fig. 2 shows a mesh generated for the h2RecombinerFoam analysis. The total number of cells in the mesh is 179,430. PAR locations in the containment are schematically shown in the figure.

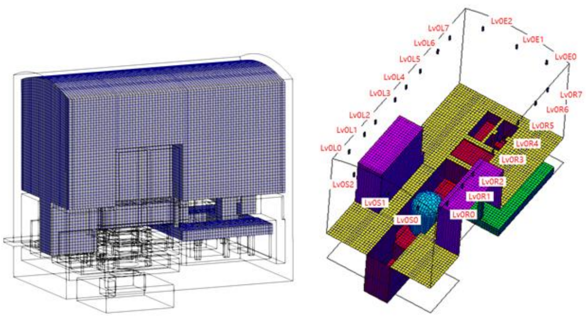

Fig. 2. Containment modeling, left: mesh for 3-D analysis, right: locations of PARs installed in the containment

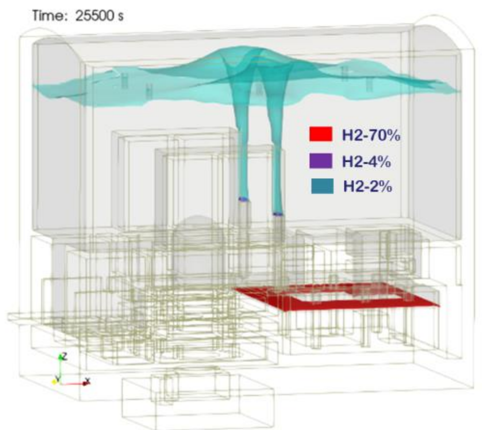


Fig. 3. Hydrogen behavior in the SMART containment without PARs activated.

In order to characterize the PARs installed in the containment, hydrogen behavior in the containment without PARs were simulated. As seen in fig. 3, hydrogen released from the IRWST through two vertical chambers moves upward continuously. In the case that the PARs installed in the SMART containment are operating, hydrogen mixture moves upwards to the containment dome at the beginning state. But after the exhaust gas of the PARs start to be accumulated in the upper region, it is found that hydrogen mixture does not move up to the dome and instead it spreads sidewise because of lighter density of the heated exhaust gas.

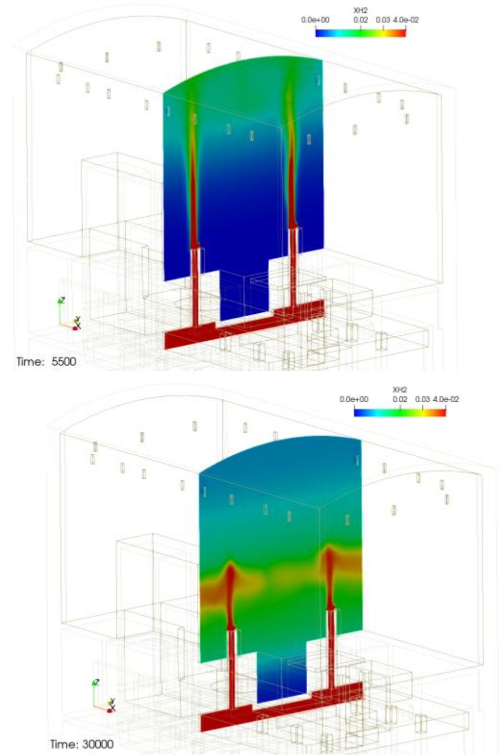


Fig. 3. Behaviors of hydrogen released from IRWST vent ducts, top: at 5500s, bottom: 30000s.

## 3. Conclusions

Simulation of hydrogen behaviors in a containment with PARS were conducted by using the h2RecombinerFoam code. It was found that PAR operation is strongly coupled with hydrogen behaviors in a containment.

## ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science, ICT) (No. 2017M2A8A4015277)

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