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The Characteristics of Hydrogen Generation and Combustion during Severe Accidents in the CANDU-6 Plants

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1. Introduction

This paper provides an evaluation of hydrogen characteristics during severe accidents in the Wolsong plant which is a typical CANDU-6 type. The evaluation includes the following sub-topics: (1) In-vessel/Ex-vessel hydrogen generation (2) In-vessel/Ex-vessel hydrogen combustion (3) Igniter effects (4) Reactor building challenge from hydrogen burn. The tested scenario is a loss of coolant accident with a small out-of-core break, and the thermal hydraulic and severe accident phenomenological analyses are done by using the ISAAC 2.0.2(Integrated Severe Accident Analysis Code for CANDU Plant) computer program[1].

2. Analysis and Results

2.1 Description of Analyzed Cases

Selected cases are small LOCA scenarios. The break size considered is a 2.5% reactor inlet header with a discharge rate of about 460 kg/s. All the emergency core cooling (ECC) systems, the moderator cooling system, the end-shield cooling system, and the dousing spray are assumed to be inoperable to simulate the severe core damage cases. Table 1 shows calculation cases. The cases are classified by availability and operation time of the local air coolers (LAC) and the igniters.

Table 1. Analyzed Cases

	LAC status	Time of LAC ON	Igniter status	Time of Igniter ON
Case 1	OFF	N/A		
Case 2	ON	SAMG entry condition	OFF	N/A
Case 3	ON	Just before R/B fail		
Case 1-A	OFF	N/A		
Case 2-A	ON	SAMG entry condition	ON	R/B High Pressure
Case 3-A	ON	Just before R/B fail		

2.2 Hydrogen Generation

When severe accidents occurs in the CANDU-6 plants, hydrogen can be generated by two mechanisms, i.e. the zircaloy oxidation in the calandria vessel during a fuel degradation and the combustible gas generation during a molten core-corium interaction (MCCI) in the calandria vault. Figure 1 shows an amount of hydrogen produced in the vessel and the vault for the Case 1- Case 3.

ISAAC calculation shows that the amount of in-vessel hydrogen generation is strongly dependent on the LAC availability. When the LAC operation initiated at severe accident management guidance (SAMG) entry condition (3.1 hours) (Case 2), the produced hydrogen mass is about 230 kg. On the other hand, if the LAC is not operated (Case 1) or delayed to the time of just before a reactor building(R/B) failure (Case 3), the hydrogen amount reaches to 620 kg. The major reason is that the lower steam temperature in the calandria due to the LAC operation causes a decrease of hydrogen generation.

The sharp increase of hydrogen generation after 47 hours in the Figure 1 is resulted from the MCCI in the calandria vault. The produced mass is about 1,100-1,200 kg until 72 hours after the MCCI.

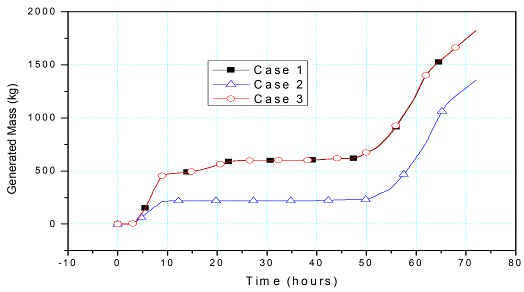

Figure 1. Total Amount of Hydrogen Generated in the Calandria Vessel and Calandria Vault

2.3 Hydrogen Combustion

Figure 2 shows the hydrogen combustion behavior for Case 1-Case 3 in the reactor building without the igniter operation. Before the MCCI initiation, there is no hydrogen combustion for the Case 1 and Case 2 since the hydrogen concentration is not high enough to exceed flammability limit. However, if the LAC is working just before the reactor building failure (Case 3) the hydrogen concentration will be increase because of a steam condensation. Accordingly, about 300 kg of hydrogen burn occurs at the time of the LAC operation.

The sharp increase of hydrogen combustion after 47 hours in the Figure 2 is resulted from the MCCI in the calandria vault. The gas temperature of the calandria vault is so high that an auto-ignition burn can occur at this compartment. Furthermore, after an oxygen is consumed in the calandria vault the combustion takes place in the steam generator room by the hydrogen-laden jet burn. This is the circumstance in which relatively hot, hydrogen rich gases are transported into cooler, oxygen-rich regions.

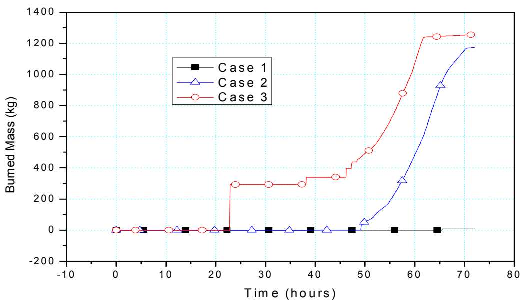

Figure 2. Total Amount of Hydrogen Burned in R/B

2.4 Igniter Effects

Wolsong plant 2, 3&4 have a hydrogen control system. The system consists of 44 hot surface igniters and distributed in the two fuel machine vaults and the R/B vault. The system is intended to mitigate the effects of a post-Accident hydrogen accumulation. Figure 3 shows hydrogen concentrations in the upper dome region for the all cases of Table 1.

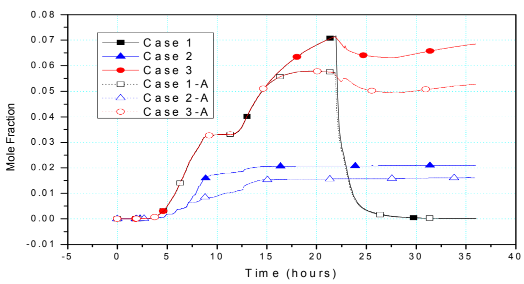

Figure 3. Hydrogen Mole Fraction in Upper Dome

When the LAC is working from the time of a SAMG entry condition (Case 2, Case 2-A), the igniter reduces the concentration about 0.5 mole fraction. In the other cases, the concentrations are reduced about 1.5-1.8 mole fraction. The sudden decrease in the Case-1 and Case 1-A represents a hydrogen release into an environment due to the R/B failure at 22 hours.

2.5 R/B challenge from Hydrogen Burn

If the reactor building is inerted and a significant hydrogen is accumulated within the building, using the LAC or dousing spray will reduce the steam mole fraction and increase the likelihood of a hydrogen burn. The calculation of Case 3-A is intended to investigate this negative effect of a 'R/B control strategy' in the Wolsong SAMG[2]. The hydrogen mass reaches to about 620 kg at just before R/B failure and about 400 kg of hydrogen is burned as soon as the LAC operation has initiated. Figure 4 shows that a R/B pressure is still decreasing due to a steam condensation in spite of the significant hydrogen combustion. Therefore, this negative effect of hydrogen burn by a operation of LAC or spray is not a issue in the decision process of SAMG.

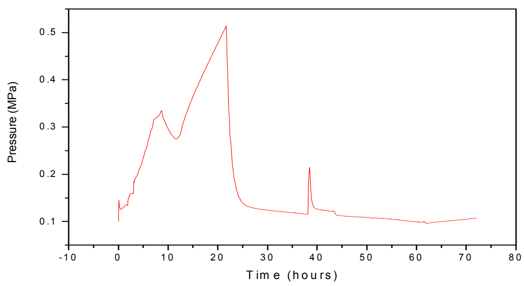

Figure 4. Pressure in Upper Dome for the Case 3-A

Acknowledgements

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REFERENCES

[1] FAI, "ISAAC Ver. 2.0.2 New Features and Improvement," FAI/05-109, 2005

[2] KAERI, " Severe Accident Management Guidance for Pressurized Heavy Water Reactor," KAERI/TR-3284/2006, 2006.