Study on the Impacts of Adverse Effects in SAMG focused on the Hydrogen Concerns

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1. Introduction

In the current SAMG (Severe Accident Management Guidelines) based on the WOG (Westinghouse Owners Group) SAMG published in 1994, the adverse effects for some mitigation actions should be evaluated before the initiation of mitigation actions and, if the benefits for those actions are judged to be greater than the cost due to the unperformed mitigation actions, those mitigation actions are performed with contingency plans to minimized the adverse effects. [1] However, there have been so many issues that these procedures are not practicable and the proper decision-making is impossible during the situation for responding the severe accident in nuclear power plants.

In the newly developed DPG (Diagnosis Process Guideline) based SAMG representing the PWROG (Pressurized Water Reactor Owners Group) SAMG published in 2016, the impacts of adverse effect and cost-benefit analysis for mitigation actions are pre-evaluated during the SAMG developing phases. So, the processes and guidelines for identification and evaluation of adverse effects and for making the contingency plans are disappeared in the performance phase of each mitigation strategies. [2][3]

The project for upgrading the domestic SAMG based on the WOG SAMG to DPG based SAMG have been proceeding from 2022. In this project, all the adverse effects for mitigation strategies are identified, and some items required the specific quantitative analysis are classified.

In this paper, the evaluation results for the impact of the adverse effect focused on the hydrogen concerns can be occurred by the some mitigation actions, such as containment spray for control the containment over-pressurization, in the Westinghouse type nuclear power plants were described. For these analyses, MAAP 5.06 code was utilized. The insights and results from those evaluations were utilized in the SAMG technical background documents.

2. Analysis Methodologies

2.1. Accident Scenarios

The adverse effects related to the hydrogen in the containment can be occurred when several mitigation strategies are performed. Most of them are related with unintended hydrogen production due to the injection of emergency cooling water and successive entrance into the hydrogen threat region (or Severe Challenge region) for containment integrity. Other threats are the occurrence possibilities of the flame acceleration due to hydrogen combustion or the flame acceleration in the duct.

Generally, the deterministic accident scenarios for evaluation of adverse effects are conservatively selected because the impact of adverse effects are maximized. In this analysis, the 5 deterministic accident scenarios, such as large, medium, and small loss of coolant accident (LOCA, MLOCA, SLOCA) and loss of feedwater (LOFW) and station black out (SBO), are selected. And the target plant type is the Westinghouse (WH) 3 loop nuclear power plant.

2.2. Major Assumption for Analysis

The major assumptions for system availabilities used in these analyses were described In Table I.

Table I: Assumption for system availabilities

System	Assumption
Motor Driven Aux.Feedwater	Not Available
Turbine Driven Aux.Feedwater	Not Available
Safety Injection Pump	Not Available
Accumulator	3
Safety Depressurization	2 PORVs Open 30 min. after SAMG entrance in SAG-02 1)
Mobile Pump (MACST)	2 hours after SAMG Entrance in SAG-03 2)
Containment Spray	High-High setpoint reached in the Containment in SAG-05 3) and SAG-06 4)
Forced Limitation for Hydrogen Analysis	PAR Capacity = 0 % RCFC Operation, 100% MWR, Limiting the Auto-Ignition

1) SAG-02: Depressurize the RCS
2) SAG-03: Inject into the RCS
3) SAG-05: Reduce Fission Product Release
4) SAG-06: Control Containment Condition

Specifically, it is noted that the too much conservative assumptions have to be used, such as intentional increase of hydrogen production and exclusion of passive control system, in order to maximize the adverse effects for hydrogen.

3. Results

3.1. Accident Progression

In Table II, the major events calculated by MAAP 5.06 for each accident scenarios are shown.

Table II: Major event for each accident scenarios

EVENT	hours				
Initiating Event	LLOCA	MLOCA	SLOCA	LOFW	SBO
Reactor Trip	0.01	0.01	0.01	0.01	0.01
Core Uncover	0.02	0.05	0.52	0.98	2.01
SAMG Entrance	Not Yet	Not Yet	Not Yet	Not Yet	2.52
CV Spray (H-H Pressure)	0.03	0.10	Not Yet	Not Yet	2.72
SAMG Entrance	0.51	0.94	0.80	1.23	Done
RCS Depressurization	N/A	N/A	1.30	1.73	3.02
Core Relocation	1.32	1.90	1.36	Not Yet	Not Yet
CV Spray (H-H Pressure)	Done	Done	1.47	1.75	Done
Mobile Pump Operation	Not Yet	Not Yet	2.88	3.31	4.60
Max.Flooding Water Level	Not Yet	Not Yet	48.27	31.18	32.52
Core Relocation	Done	Done	Done	35.22	36.45
RV Fail	1.95	2.66	56.94	36.97.	38.39.
Mobile Pump Operation	2.59	2.94	Done	Done	Done
Max.Flooding Water Level	34.42	34.83	Done	Done	Done
Containment Fail	N/A	67.57	N/A	N/A	N/A

3.2. Hydrogen Behavior

3.2.1 LLOCA

The hydrogen concentration in containment is rapidly increased when the reactor vessel is failed. And it is continuously increased with the interaction of external emergency cooling water to RCS and molten corium in the cavity. It is decreased when the hydrogen production is stopped due to the termination of MCCI. The general change of hydrogen concentration is shown in Figure 1.

The condition of hydrogen combustibility did not enter the hydrogen threat region even in the conservative assumption, also temporarily stepped in and out in the possible region for flame acceleration. Figure 2. shows the hydrogen behavior on the CA-07 (Calculational Aid-07) used in the decision-making for hydrogen control strategies in SAMG. And, Figure 3. shows the possibility of flame acceleration in this case.

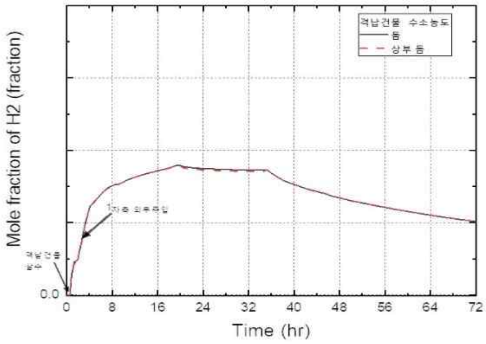

Fig. 1. LLOCA Hydrogen Concentration

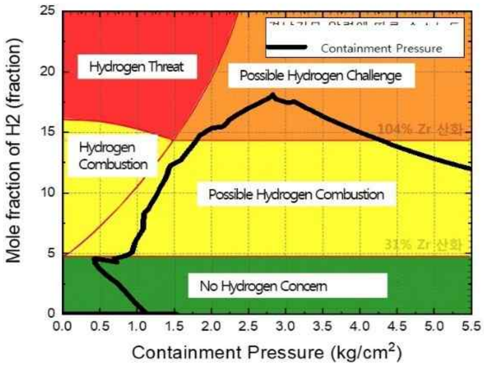

Fig. 2. LLOCA Hydrogen Behavior in CA-07

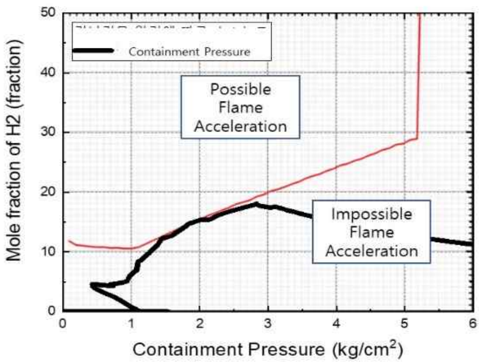

Fig. 3. LLOCA Flame Acceleration possibilities

3.2.2 MLOCA

The hydrogen concentration in containment is very similar to that of LLOCA case and the general change of hydrogen concentration is shown in Figure 4.

The condition of hydrogen combustibility also similar to that of LLOCA case. It did not enter the hydrogen threat region even in the conservative assumption, also temporarily stepped in and out in the possible region for flame acceleration as shown in Figure 5. and Figure 6.

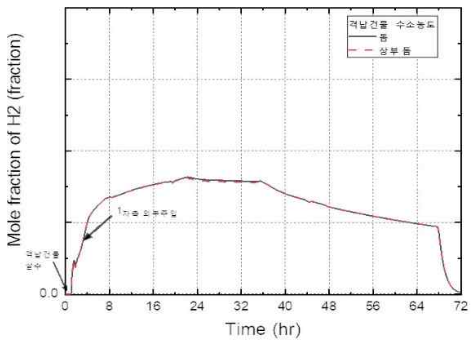

Fig. 4. MLOCA Hydrogen Concentration

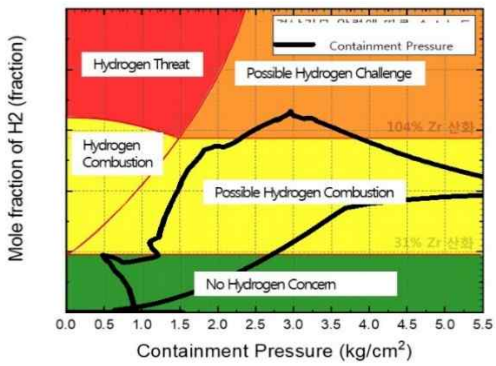

Fig.5. MLOCA Hydrogen Behavior in CA-07

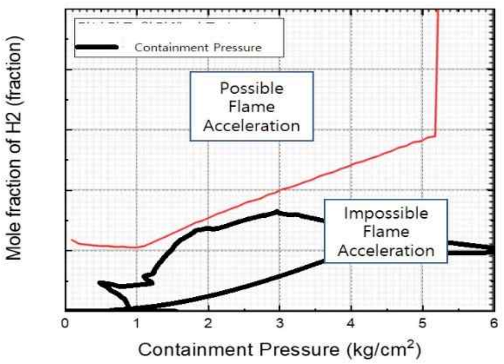

Fig. 6. MLOCA Flame Acceleration possibilities

3.2.3 SLOCA

The hydrogen concentration in containment is rapidly increased when the PORV is opened and the containment spray is activated. It is decreased when the recirculation is initiated. After that, when the reactor vessel is failed, the hydrogen concentration is increased again due to MCCI. The general change of hydrogen concentration is shown in Figure 7.

The condition of hydrogen combustibility did not enter the hydrogen threat region even in the conservative assumption, also temporarily stepped in and out in the hydrogen combustion region. Also, it did not enter the possible region for flame acceleration. Figure 8. shows the hydrogen behavior on the CA-07 used in the decision-making for hydrogen control strategies in SAMG. And, Figure 9. shows the possibility of flame acceleration in this case.

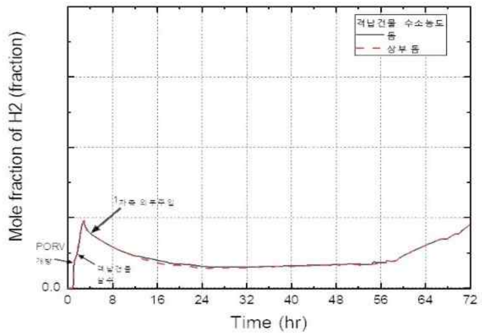

Fig. 7. SLOCA Hydrogen Concentration

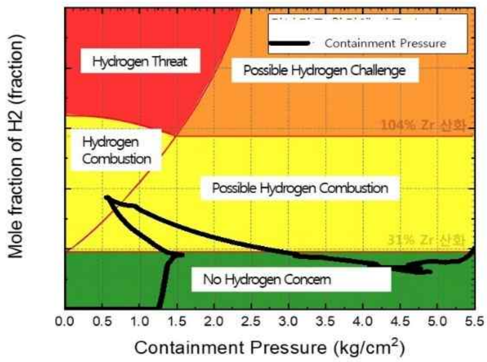

Fig.8. SLOCA Hydrogen Behavior in CA-07

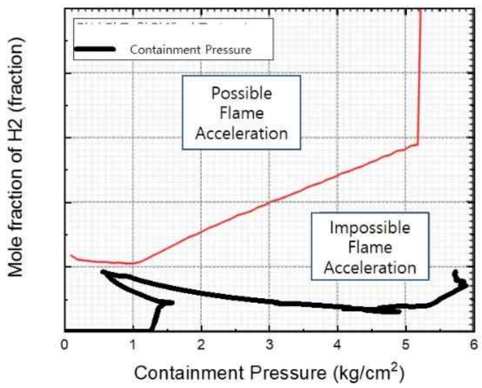

Fig. 9. SLOCA Flame Acceleration possibilities

3.2.4 LOFW

The hydrogen concentration in containment is very similar to that of SLOCA case and the general change of hydrogen concentration is shown in Figure 10.

The condition of hydrogen combustibility did not enter the hydrogen threat region even in the conservative assumption, it entered only in the possible hydrogen challenge and combustion region. Also, it did not enter the possible region for flame acceleration. Figure 11. shows the hydrogen behavior on the CA-07 used in the decision-making for hydrogen control strategies in SAMG. And, Figure 12. shows the possibility of flame acceleration in this case.

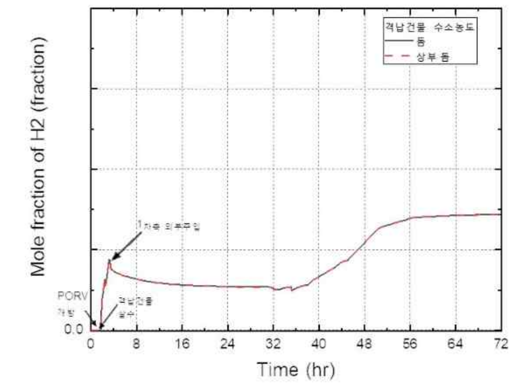

Fig. 10. LOFW Hydrogen Concentration

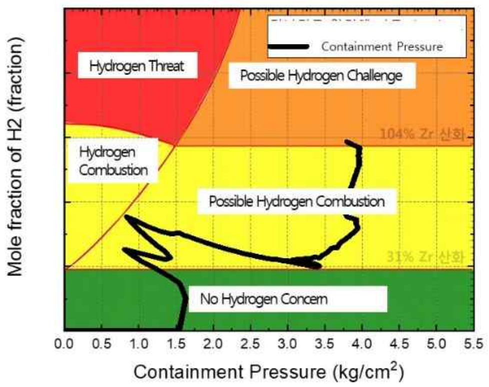

Fig. 11. LOFW Hydrogen Behavior in CA-07

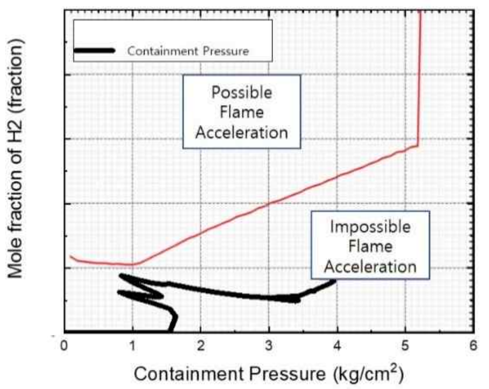

Fig. 12. LOFW Flame Acceleration possibilities

3.2.5 SBO

The hydrogen concentration in containment is very similar to that of LOFW case and the general change of hydrogen concentration is shown in Figure 13.

The condition of hydrogen combustibility did not enter the hydrogen threat region even in the conservative assumption, it entered only in the possible hydrogen combustion region and hydrogen combustion region. Also, it did not enter the possible region for flame acceleration. Figure 14. shows the hydrogen behavior on the CA-07 used in the decision-making for hydrogen control strategies in SAMG. And, Figure 15. shows the possibility of flame acceleration in this case.

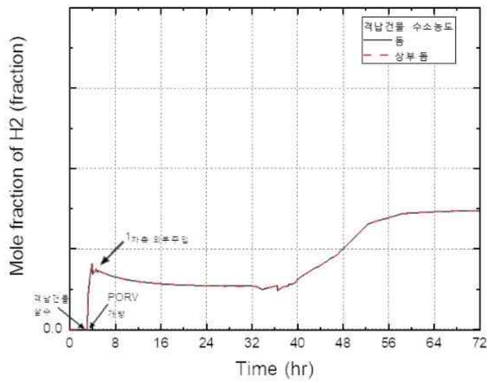

Fig. 13. SBO Hydrogen Concentration

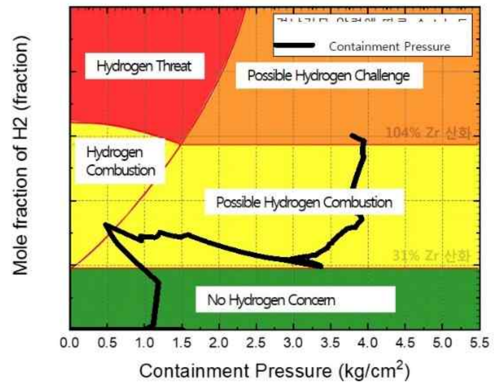

Fig. 14. SBO Hydrogen Behavior in CA-07

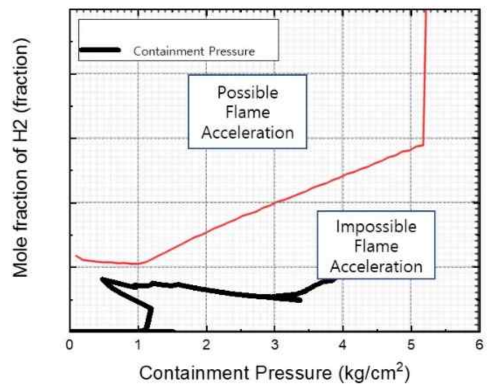

Fig. 15. SBO Flame Acceleration possibilities

3.3. Conclusion for Possibilities of Adverse Effects

According to results of hydrogen behavior based on the conservative deterministic accident scenarios and more conservative assumptions, there are no cases that the hydrogen concentration enters the hydrogen threat region. It is judged that the one of the major reasons is the design limitation of spray system of WH type plants that do not have heat exchanger. This limitation cannot maintain the containment pressure at low pressure.

So, in the WH type plants, when the TSC consider the mitigation actions for SAG-02 “Depressurize the RCS”, SAG-03 “Inject into the RCS”, SAG-05 “Reduce Fission Product Release” and SAG-06 “Control Containment Condition”, it is judged that the consideration of adverse effect for hydrogens is unnecessary.

4. Conclusion

In the current SAMG, the identification of adverse effect and the decision-making based on the cost-benefit analysis, and preparing the contingency plan should be prepared before the performance of all mitigation actions. These tasks had been a great burden to the TSC and it is the great obstacles to the proper and timely actions for response in the urgent situations. In the recent DPG based PWROG SAMG (2016), these processes for the considerations of adverse effects are disappeared since the evaluations for the possibilities and impacts are already made in the developing stages.

In this paper, the occurrence possibilities and the impacts of the adverse effects focused on the hydrogen threat was evaluated for the Westinghouse type nuclear power plants using MAAP 5.06 code.

According to the results, it is judged that the considerations of adverse effects for hydrogen are unnecessary in the mitigation actions, such as SAG-02, 03, 05, and 06. These insights and results will be represented in the technical background of Korean DPG based SAMG.

REFERENCES

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[2] PWROG-15015-P Revision 0, “PWROG Severe Accident Management, Guidelines”, February 2016.
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