Transactions of the Korean Nuclear Society Autumn Meeting
PyeongChang, Korea, October 30-31, 2008

Analysis of Hydrogen Control Strategy Using Igniter during Severe Accident

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1. Introduction

The Severe Accident Management Guidelines (SAMGs) for the operating pressurized water reactor (PWR) have been completed within 2006. Among the SAMG strategies, mitigation-07 is the most important strategy for managing a severe accident of a PWR in order to reduce containment hydrogen. The fastest way to reduce the containment hydrogen concentration is to intentionally ignite the hydrogen. For this strategy, igniters exist in Optimized Power Reactor 1000 (OPR 1000) to burn hydrogen for a severe accident. For using the igniters during a severe accident, the adverse effects such as the explosion of the hydrogen mixture should be considered for containment integrity. However, an applicable discrimination method to activate the igniters does not exist, so that the hydrogen control strategy using the igniters cannot be chosen during a severe accident.

Thus, this study focused on suggesting an applicable discrimination method to carry out the strategy of using the igniters. In this study, the specific plant used for this analysis is Ulchin Unit 5&6, OPR 1000 plant, in Korea.

2. Analysis Methodology

Hydrogen combustion potentials could be evaluated with two well-defined criteria; σ-criterion for Flame Acceleration (FA) and λ-criterion for Deflagration-to-Detonation Transition (DDT). In this study, σ-criterion for FA was used to determine conservatively the criterion of intentionally burning the hydrogen with the igniters.

The possibility of occurrence of FA could be evaluated by value "sigma" as following:

If σ/ σ*<1 ; no FA occurrence,
If σ/ σ*>1 : possibility of FA occurrence

The value σ means expansion ratio, which is defined as the ratio of densities of reactants and products. And the value σ* is sigma critical as a function of Lewis number (Le) and Zeldovich number(β) [1,2,3]. The sigma critical could be calculated by linearly interpolating experimental data [1] as shown in Table 1.

In order to determine the criterion of FA occurrence from σ-criterion, the following assumptions have been made.

◦ The atmosphere environment is assumed to be a homogeneous mixture of air, steam and hydrogen for which the ideal gas law applies.

◦ Hydrogen igniters have not been used, and there have been no previous hydrogen burns.

◦ The containment atmosphere is assumed to be at 100% humidity when the igniters is activated.

◦ The volume, initial temperature and initial pressure of containment are assumed to be within Final Safety Analysis Report (FSAR) [4] as listed in Table 2.

Table 1. List of critical sigma as a function of temperature for hydrogen lean and rich oxygen mixture

Temperature	Critical Sigma $[h_2] < 2[O_2]$	Critical Sigma $[h_2] \geq 2[O_2]$
300	3.75	3.75
400	2.80	3.75
500	2.25	3.75
600	2.10	3.75

Table 2. Plant-specific input data from FSAR

Variable	UCN 5&6	Unit
Initial containment temperature	120	^oF
Initial containment pressure	16.1	psia
Volume of containment	2.727×10^6	ft^3

3. Results of Analysis

The analyses were carried out by the following three steps to determine the criterion of FA occurrence. In the first step, the criterion of FA occurrence was discriminated by hydrogen concentration, steam concentration and temperature of containment. In the second step, steam concentration and temperature of containment as containment pressure could be predicted by the assumptions mentioned in Section 2. In the third step, finally, the criterion of FA occurrence was determined by hydrogen concentration and pressure of containment from using the results of the first and second steps.

3.1 The possibility of FA occurrence as hydrogen concentration, steam concentration and temperature of containment

According to the analysis methodology by σ-criterion for FA in Section 2, the possibility of FA occurrence depends on hydrogen concentration, steam concentration, and temperature of containment. Fig. 1 shows the possibility of FA occurrence.

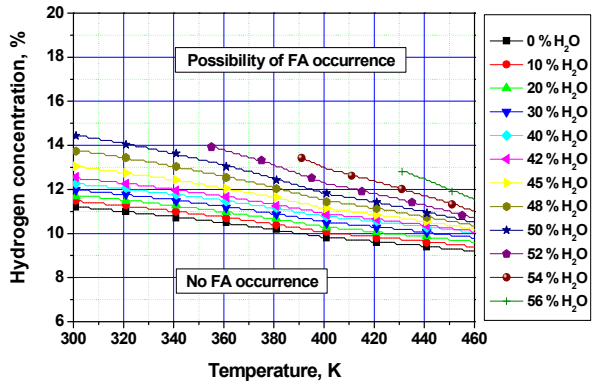

Fig. 1. The possibility of FA occurrence as hydrogen and steam concentration and temperature of containment

3.2 The prediction of containment temperature and steam concentration as containment pressure

In order to estimate the possibility of the FA occurrence from Fig. 1, the operators and the Technical Supporting Center (TSC) staff should check steam concentration and temperature of containment. However, the instruments to measure temperature of containment could be damaged during a severe accident. Moreover, steam concentration in containment cannot be measured with the plant instruments. Therefore, it is required to predict steam concentration and temperature of containment from other parameters. Thus, in this study, steam concentration and temperature of containment as pressure of containment were calculated based on the assumptions listed in Section 2 as illustrated in Fig. 2 and Fig. 3.

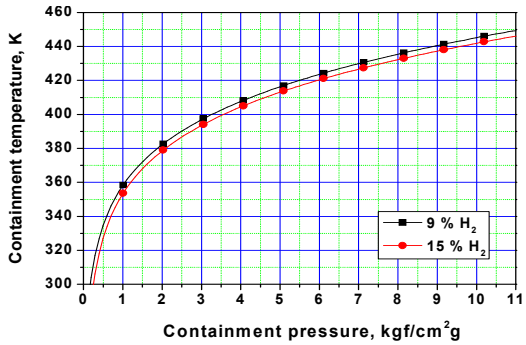

Fig. 2. The containment temperature as containment pressure

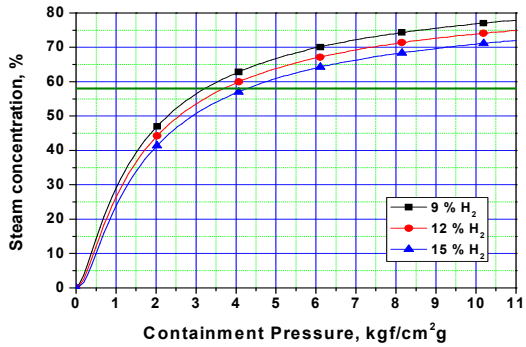

Fig. 3. The steam concentration as containment pressure

3.3 The possibility of FA occurrence as hydrogen concentration and containment pressure

The criterion of FA occurrence as hydrogen concentration and pressure of containment could be determined by using Figs. 1 to 3. Thus, Fig. 4 was illustrated by combining Figs. 1 to 3 for the convenience of the operators and the TSC staff during a severe accident. According to Fig. 4, FA is not occurred under the containment condition of 11 % hydrogen concentration. And the possibility of FA occurrence is quite low when the containment pressure is over 3.3 kgf/cm^{2}g.

The operators and the TSC staff can confirm the criterion of FA occurrence by using Fig. 4, and determine to whether activate the igniters or not.

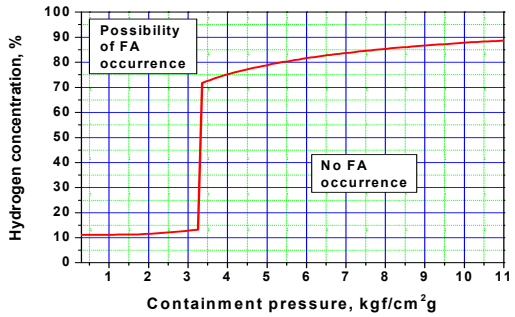

Fig. 4. The possibility of FA occurrence as hydrogen concentration and containment pressure

4. Conclusions

In this study, the discrimination method for using the igniters to reduce containment hydrogen via an intentional burn was suggested. According to the discrimination, the operators and the TSC staff can confirm the possibility of FA occurrence with values of containment hydrogen concentration and containment pressure. According to the confirmation, they can decide to whether activate the igniters or not. This discrimination will be reflected as a potential hydrogen control strategy in SAMGs, when the igniters is incapable in the early stage of the accident.

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