<Short Note>

HYDROGEN BEHAVIOR IN THE IRWST OF APR1400 FOLLOWING A STATION BLACKOUT

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In order to confirm the integrity of IRWST following a severe accident, the hydrogen behavior inside and around the IRWST has been investigated for an SBO accident. A detailed containment model, including 18 control volumes for IRWST, has been developed. Analysis results show that the peak hydrogen concentration is about 57% during the core melting period. The combustion regime shows that flame acceleration and DDT are possible in the IRWST. The flame acceleration criterion is met when the peak hydrogen concentration occurs; the 7λ-DDT criterion is also met during some periods. These results show certain measures may be required to assure IRWST integrity against an SBO accident.

KEYWORDS : APR1400, Station Blackout, Hydrogen, IRWST, Containment, Flame Accelration, DDT

1. INTRODUCTION

The Hydrogen Mitigation System (HMS) for the APR 1400 is designed to preclude detonations in the containment which might jeopardize the containment integrity or damage essential equipment. The system consists of 26 Passive Autocatalytic Recombiner (PAR) units and 10 glow plug igniters of which four PARs and two igniters are installed in the In-containment Refueling Water Storage Tank (IRWST) [1-3].

The applicant of the Design Certification for APR1400 evaluated the capability of HMS against those of Loss of Coolant Accident (LOCA), Station Blackout (SBO) and Loss of Feedwater (LOFW) using MAAP4. The accident sequences were selected using a screening review of the Probabilistic Safety Assessment (PSA) Level 1 results. The results show that for most accidents the hydrogen concentrations in the containment lie outside of the flammability limit or in a region of mild deflagration. However, as hydrogen and steam are discharged from the Pilot Operated Safety and Relief Valves (POSRVs) of the pressurizer into the IRWST through spargers, the hydrogen concentration could reach 55% in the IRWST for an SBO accident [3]. Another analysis using GASFLOW showed that the accumulated hydrogen could be released into the annular compartment through the IRWST and result in flame acceleration and Deflagration-to-Detonation (DDT) [4]. In the GASFLOW calculation, the source of the hydrogen and steam was obtained from a MAAP4 calculation and the analysis was based on the assumption that dry hydrogen is released into the atmosphere of the IRWST. Therefore, a confirmation analysis has been performed as part of the review process using an integrated code, i.e. MELCOR 1.8.5 [5], to investigate the hydrogen behavior inside and around the IRWST following an SBO accident.

This paper introduces the status of KINS's (Korea Institute of Nuclear Safety) on-going independent analysis of hydrogen behavior inside and around the IRWST following an SBO accident.

2. ANALYSIS METHODOLOGY

2.1 Selected Accident Sequence

The selected accident sequence consists of the loss of offsite power with a concurrent demand failure of both the emergency diesel generators and the alternate combustion turbine/generator. The secondary heat is removed over 8 hours through turbine-driven auxiliary feedwater (AFW) pumps. Rapid depressurization is possible through the POSRVs. The recovery of offsite power is not assumed, but the PARs are available at all times. The Cavity Flooding System is assumed to be non-operational. The sequence is SBO-25 in the Standard Safety Analysis Report for APR 1400. The accident sequence is considered to be one with relatively high frequencies that result in relatively large contributions to radiological releases [3].

2.2 System Modeling

The reactor coolant system (RCS) model includes the core, primary, and secondary coolant systems. The core is modeled as 5 radial rings and 16 axial levels including top- and bottom-end fittings. The RCS model includes 2 steam generators, 4 reactor coolant pumps, and direct vessel injection from the Safety Injection System to the RCS (see Figure 1). The 51-cell containment model consists of 32 subcompartments, 1 environment, and the 18-cell IRWST with 3 axial levels in which 6 cells are azimuthally separated (see Figures 2 and 3).

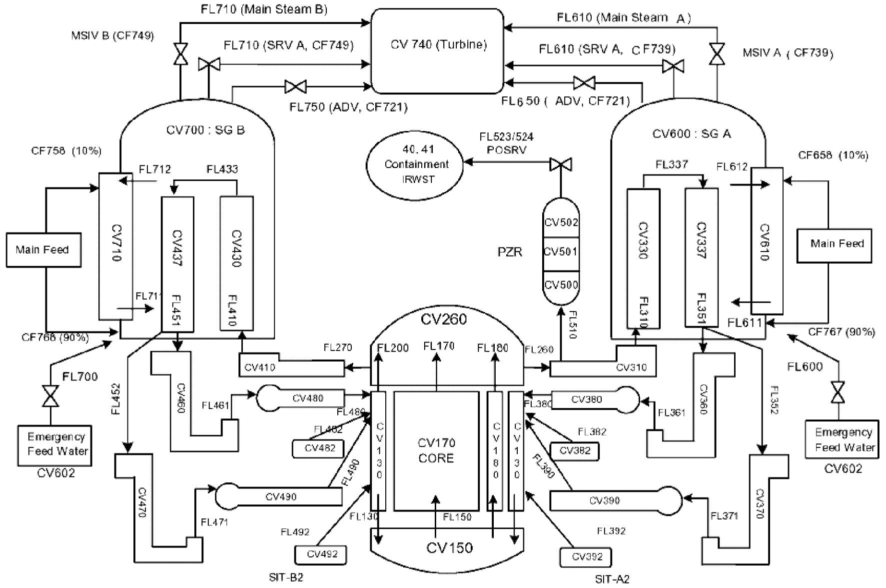


Fig. 1. Reactor Coolant System Model for APR1400

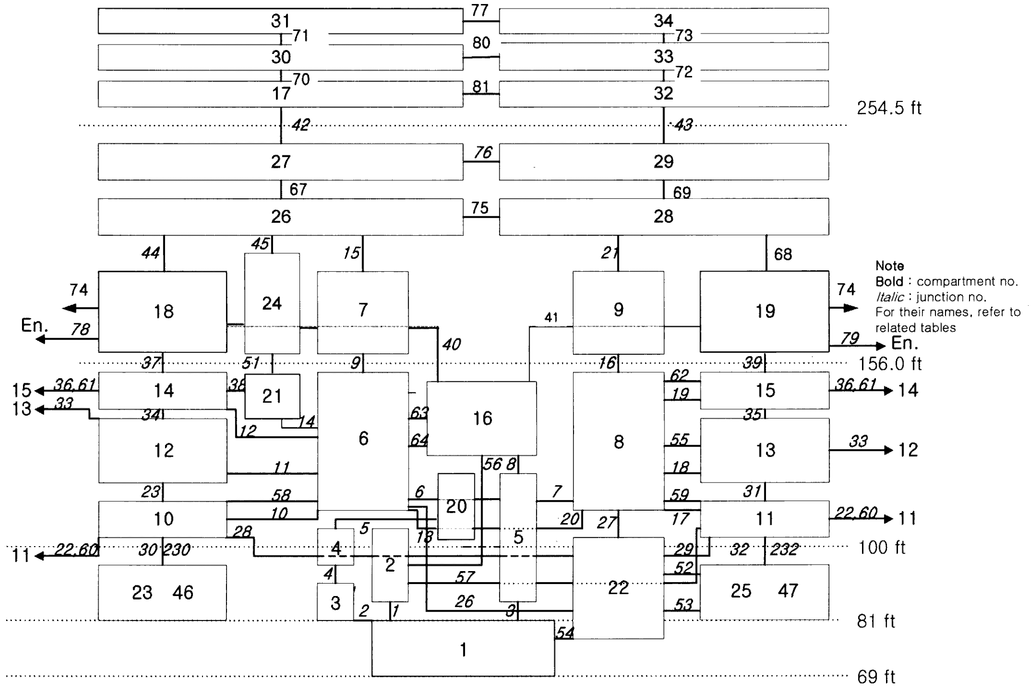


Fig. 2. Containment Model for APR1400

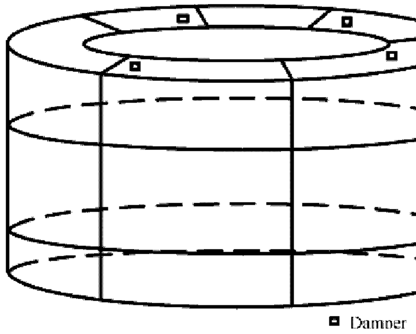


Fig. 3. 18-cell IRWST Model

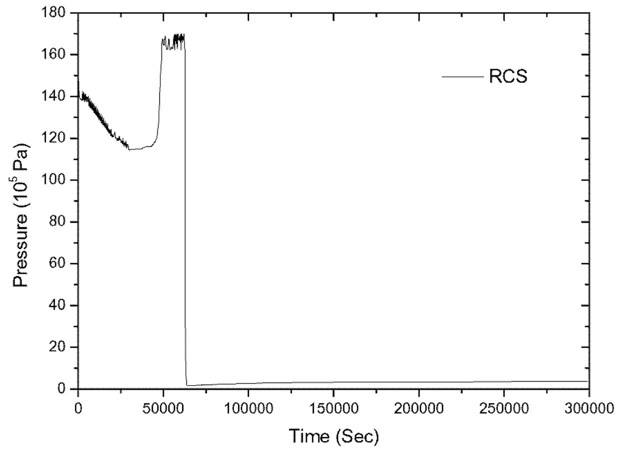


Fig. 4. Reactor Coolant System Pressure

3. ANALYSIS RESULTS

3.1. Primary and Containment System Responses

This SBO scenario makes all active safety systems unavailable, except the AFW system. Approximately 4.6 hours after all AFW are lost, the steam generators dry out and the heat removal from the RCS is lost resulting in a repressurization of the RCS, and the POSRVs cycle opens, which leads to loss of RCS inventory and core uncovery at approximately 15 hours. The fuel rapidly heats up and melts, and then relocates to the lower plenum and the lower head of the reactor vessel fails. A summary of the predicted sequence of the key events and their timing is presented in Table 1; Figures 4 and 5 show the pressure of the RCS and the containment following the accident.

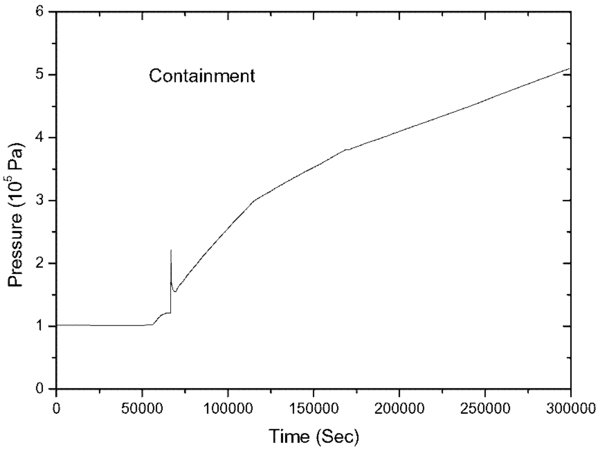


Fig. 5. Containment Pressure

Table 1. Key Event Timing

Key event	Time (sec.)
Accident initiation (Auxiliary Feedwater start)	0
Auxiliary Feedwater off	28,800
Steam Generator Dryout	45,184
Core uncovery 52,836	
Relocation into lower head	65,687
RPV Failure	66,729
Start SIT Injection	66,756

3.2 Hydrogen Production and Release into the IRWST

The hydrogen generation is estimated to be 880 kg from the in-vessel and 3,004 kg from the ex-vessel reactions until 300,000 seconds after the initiation of the accident. Figure 6 shows the cumulative hydrogen production. The maximum hydrogen generation rate from the in-vessel reaction is 2.0 kg/sec.

Figure 7 shows the hydrogen and steam release into the IRWST. Although the pool water is subcooled, the SPARC model of the MELCOR code simulates a vapor rise into the atmosphere of the IRWST.

Hydrogen is removed by two PARs in the IRWST. Figure 8 shows the accumulated amount of hydrogen removed.

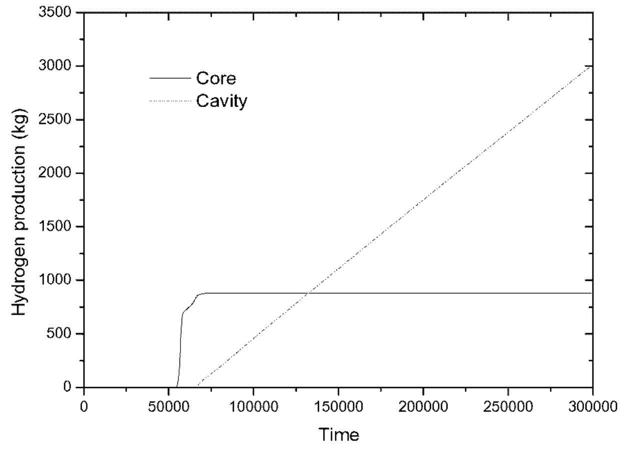


Fig. 6. Cumulative Hydrogen Production in the Core and Cavity

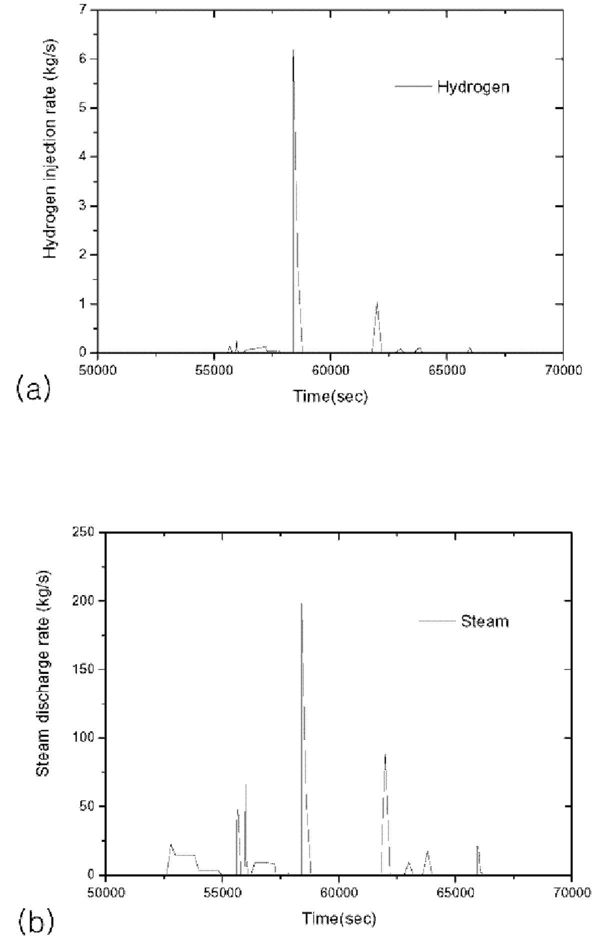


Fig. 7. Hydrogen (a) and Steam (b) Release Through the IRWST Sparger.

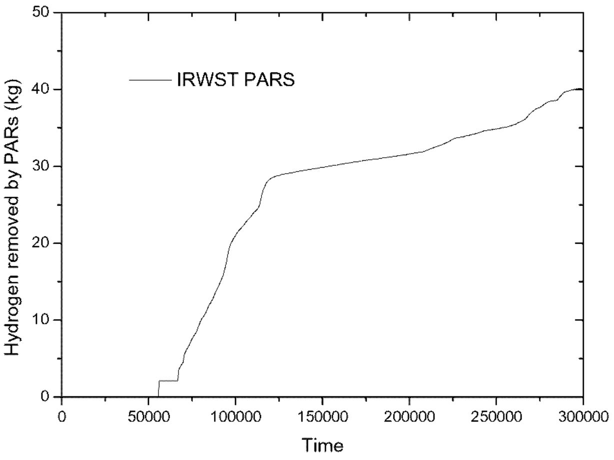


Fig. 8. Cumulative Hydrogen Removal Quantity

3.3 Gas Composition in the IRWST

The amount of hydrogen in the IRWST atmosphere increases rapidly during and shortly after release, and then decreases due to the removal operations of the PARs, as shown in Figure 9. The amount of steam also increases during the release period, and then decreases due to condensation on the tank wall. The oxygen concentration remains above 5% until 115,000 seconds after the initiation of the accident. Therefore, the gas composition could provide flammable conditions in the atmosphere during that period. From 55,700 seconds, the products of the molten core-concrete interaction, carbon monoxide, and carbon dioxide enter the atmosphere.

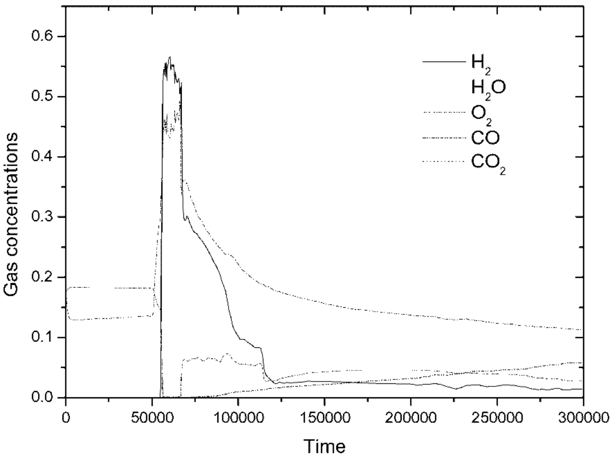


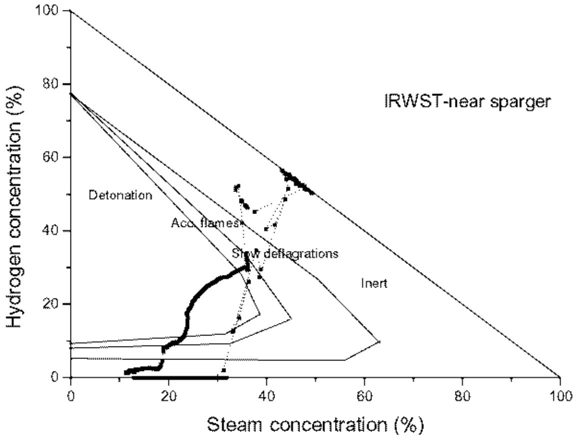
Fig. 9. Gas Composition of the IRWST Atmosphere

3.4 Evaluation of Flame Acceleration and DDT Possibilities in the IRWST

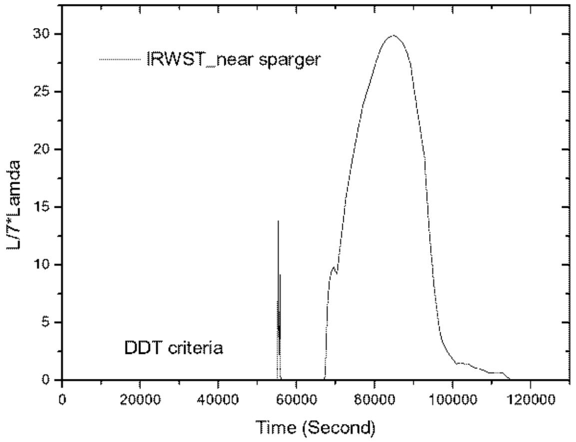
A rough estimation of the combustion regime for the calculated gas composition shows that flame acceleration and DDT are possible near the sparger and in the rest region of the IRWST, as shown in Figures 10(a) and 11(a). Figure 12 shows that flame acceleration and DDT are not possible in the bottom region of the annulus, just above the IRWST.

A more detailed analysis of flame acceleration and DDT also showed the same results. The flame acceleration criterion ($\sigma/\sigma^*>1$, where σ is the ratio of densities of the reactants and products, i.e. the expansion ratio and σ^* is a critical value determined by Le, the Lewis number and β, the Zeldovich number) is met in the IRWST when there is an active release of hydrogen produced in the reactor vessel (at approximately 56,000 seconds after the initiation of the accident). Applying Dorofeev et al. 's analytic function shows that the DDT criterion ($L/7\lambda>1$, where L is the characteristic geometrical size, and λ is the detonation cell size) is met in the IRWST (see Figures 10(b) through 11(b)).

However, the bottom region of the annulus may not have the condition of DDT and flame accelerationwithout opening of dampers (see Figure 12). Furthermore this analysis covers the period over which the fraction of CO gas in the IRWST is not significantly high [6].

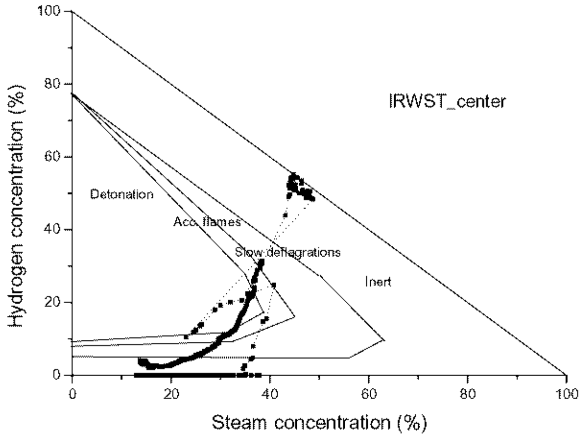


(a) Combustion regime

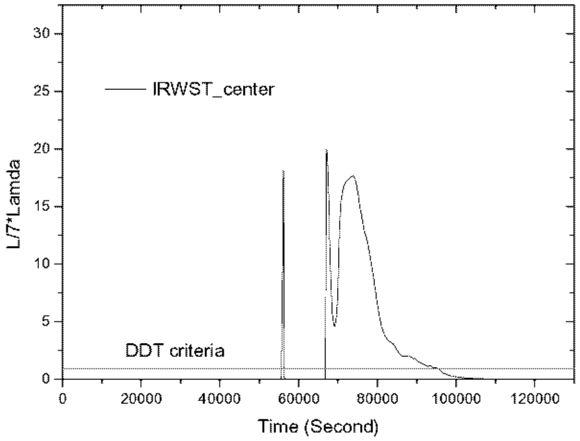


(b) DDT criterion

Fig. 10. Flame Acceleration and DDT Possibility for the IRWST-sparger Region

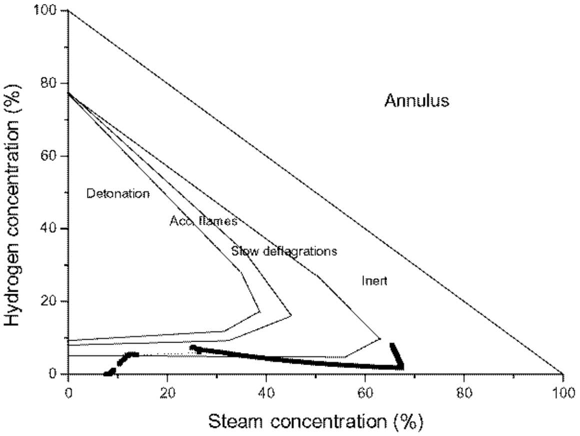


(a) Combustion regime

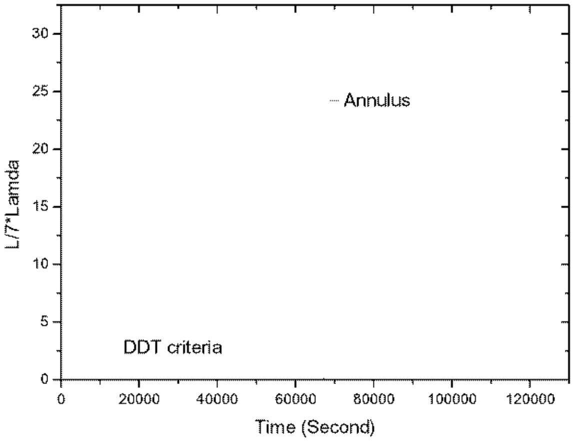


(b) DDT criterion

Fig. 11. Flame Acceleration and DDT Possibility for the IRWST-central Region



(a) Combustion regime



(b) DDT criterion

Fig. 12. Flame Acceleration and DDT Possibilities for the Annulus Regions

IV. CONCLUSIONS

Hydrogen behavior inside and around the IRWST has been investigated for an SBO accident. The peak hydrogen concentration is estimated to be approximately 57% during the core melting period. The combustion regime shows that flame acceleration and DDT are possible in the IRWST. The flame acceleration criterion, i.e. the sigma criterion, is met when the peak hydrogen concentration occurs. As for the possibility of DDT, the 7λ criterion is met during some periods, based on the detonation cell width calculated by Dorofeev et al.'s analytical function. These results show that certain measures may be required to assure IRWST integrity against an SBO accident.

ACKNOWLEDGMENTS

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