Sensitivity Study on Hydrogen Detonability in IRWST under Station Blackout Accident

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1. Introduction

When a high-pressure accident occurs in APR1400, large amount of steam-hydrogen mixture may be released to the in-containment refueling water storage tank (IRWST) through the pilot-operated safety relief valves (POSRVs). If the heat removal is not successful, core melt may proceed and massive hydrogen will be generated by zirconium-water reaction. The hydrogen concentration in the atmosphere of IRWST is supposed to be very high and a detonable condition can be formed.

This paper introduces the results of sensitivity study executed by KINS on the IRWST hydrogen issue. The station blackout (SBO) accident scenario was selected as the result of a comprehensive consideration based on the probabilistic core damage frequency (CDF) [1] and the deterministic engineering judgment.

2. Methodology and Considerations

2.1 Assessment Methods

In this study, the mass and energy release data from the utility's MAAP calculation were applied as an input for MELCOR 1.8.5 where 51-control volumes (CVs) have been modeled for containment including IRWST. Based on hydrogen distribution analysis, possibilities for flame acceleration (FA) and deflagration-to-detonation transition (DDT) were assessed with the methodologies introduced in OECD/NEA report [2]. The containment integrity was decided by the assessment of σ and 7λ criteria for FA and DDT, respectively. FA criterion is expressed as $\sigma_{index}=\sigma/\sigma^*$, and DDT criterion as $R=L/7\lambda$, where σ is ratio of densities of reactants and products, σ^* is the critical value of σ, which is expected to be function of β (Zeldovich number) and Le (Lewis number), L is a characteristic geometrical size, and λ is detonation cell size. We judged the possibility of detonation by these criteria, i.e. it is detonable when $\sigma_{index}>1.0$ and $R>1.0$, at the same time.

2.2 Uncertain Parameters in Consideration

The effects of phenomenological uncertain factors (1. assumptions on creep rupture at a hot leg; 2. the mixture release ratio into IRWST; 3. the operator's action to manually open the relief valves) and the effects of some user-dependent modeling factors (4. the modeling of control volumes in IRWST for both assessments of hydrogen distribution and detonability; 5. the value of a user parameter in mechanistic model; and 6. the assumption on characteristic length for DDT) have been investigated. Table 1 shows the analysis matrix in which the numbers correspond to each uncertain factor.

Table I: Analysis Matrix

Case ID	Uncertain Factors in Consideration			
	Creep Rupture (1)	Release into IRWST (2)	Loss Coeff. at IRWST Vents (5)	Char. Length of DDT (6)
S1-1	Yes	50%	1.0	L1(I)*
S1-2			2.0	
S1-3		20%	1.0	
S1-4A			2.0	L1(I)
S1-4B				L2(I)
S1-4C				L3(I)
S1-4D				L1(C)**
S1-4E				L2(C)
S1-4F				L3(C)
S1-5	No	50%	1.0	L1(I)
S1-6			2.0	
S1-7		20%	1.0	
S1-8			2.0	

* I: individual CV model in Fig. 2(b)
** C: combined CV model in Fig. 2(b)

3. Results

3.1 Effect of Uncertain Factors with L1

Fig. 1 compares the detonability of each case (S1-1 to S1-8) where the uncertain factors 1, 2 and 5 are considered. The results are based on the characteristic length L1 shown in Fig. 2. The results show that the atmosphere of IRWST would be in detonable conditions during SBO sequence at any considered situation.

From the results, DDT index is relatively high in CVs 36 and 37 where the sparger assemblies are located, and CV 23, the central space between the release locations, also has high values. In turn, we can say that there is the possibility the detonation to occur at least in the region near the sparger locations.

Effect of creep rupture (factor 1)

When comparing upper results (S1-1 to S1-4A: creep rupture assumed) with lower ones (S1-5 to S1-8: no creep rupture assumed) in Fig. 1, the cases without creep rupture assumption give more severe results from the viewpoints of duration and number of locations. This is why the amount of mixture released into IRWST is considerably reduced because of the phenomenon like blowdown at ruptured location.

Effect of release ratio into IRWST (factor 2)

The release ratio also affected the possible duration of detonation as well as the location. In case the amount

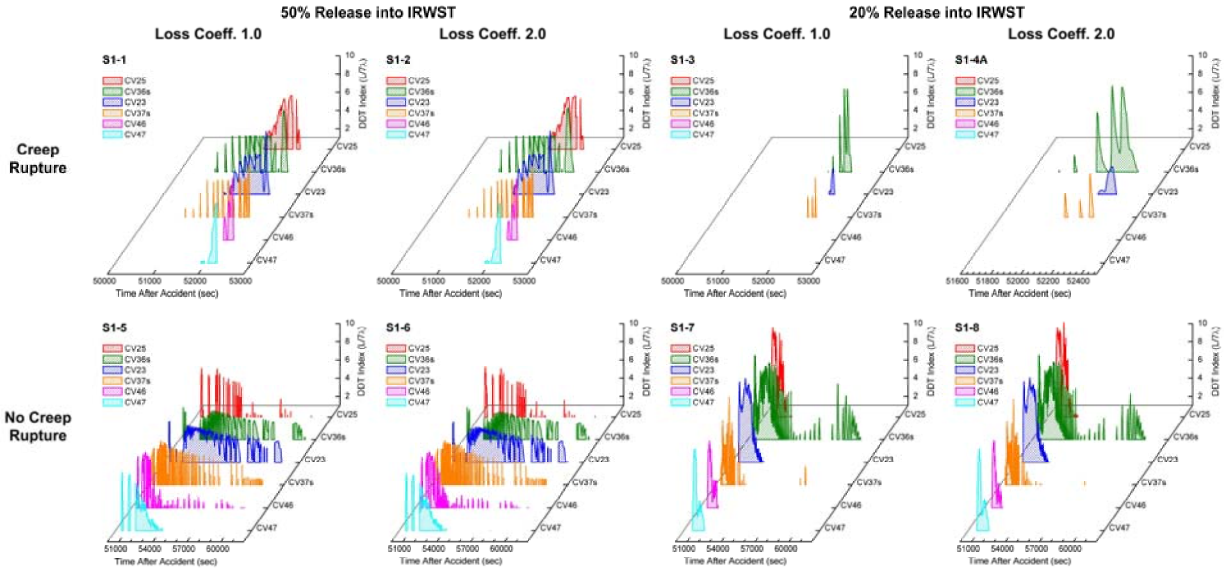


Fig. 1. Detonability comparison with characteristic length L1

of releasing mixture in IRWST is small (20%), the absolute amount of hydrogen transported to IRWST will also become small. It is easy to find by comparing S1-1 vs. S1-3 or S1-2 vs. S1-4A, and the same for lower figures. It can be inferred that the installation of branch lines to the steam generator compartment may be effective, but it does not eliminate the detonability in IRWST.

Effect of loss coefficient at IRWST vents (factor 5)

Comparing four couples of results shown in Fig. 1, variation of the user specified loss coefficient between 1.0 and 2.0 did not show large difference in the results.

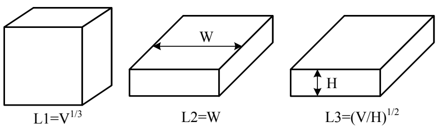
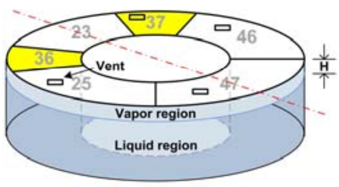
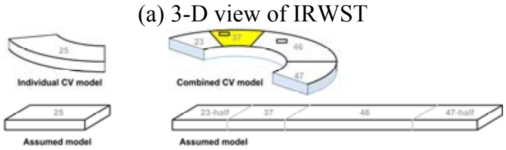


Fig. 2. Definition of characteristic length of DDT



(a) 3-D view of IRWST



(b) Assumptions for shape of vapor region

Fig. 3. Geometries considered in DDT assessment

3.2 Effect of the Definition of Characteristic Length

Individual CV model for DDT

Additional analysis done on the effect of the characteristic length of DDT (not shown in this paper) showed that the possibility of detonation might be obviously affected by the assumption of geometrical shape of compartment and the definition of characteristic length. Comparing the results using L1 to L3 (see Fig. 2), the meaningful comparison would be made between the cases for individual CV model and those for combined CV model. Definition of L1 gave the most non-conservative result. In viewpoint of the reality, it is up to the engineering judgment and it can be said that the L3 case is the realist definition in the application to IRWST.

Combined CV model for DDT

The combined model was introduced since the space of IRWST is physically a unique volume. Each combined CV in Fig. 3(b) includes one sparger assembly and two IRWST vents. Considering the combined CV model as realistic approach, the detonability could greatly be reduced (not shown in this paper). However, there still exists the possibility of a detonation in IRWST.

4. Conclusions

The methodology for FA and DDT assessments has shown large uncertainties. In this study, we investigated the uncertain parameters that may affect the FA and DDT assessment for the IRWST under a SBO accident. With a large spectrum of assumptions on the uncertain factors, it was confirmed that the detonability in IRWST was high. For this issue, a design change, through a deep discussion, was recently decided not to release steam and hydrogen mixture into IRWST during severe accident condition.

REFERENCES

[1] KHNP, APR1400 Standard Safety Analysis Report, Ch.19, 2000.

[2] NEA/CSNI/R(2007)7, "Flame Acceleration and Deflagration-to-Detonation Transition in Nuclear Safety," State-of-the Art Report by a Group of Experts, OECD/NEA, 2007.