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Applicability of 7λ DDT Criterion in the IRWST of APR1400

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1. Introduction

Evaluation of hydrogen risk during a severe accident is important to ascertain the safety of nuclear power plant. Standard way of evaluation is first to calculate the distribution of hydrogen in the containment and then apply some criteria to see whether a flame acceleration (FA) or a deflagration-to-detonation transition (DDT) is possible to occur in a specific containment volume. Here FA means a rapid increase in flame speed due to generation of large and small eddies - turbulence – as flow ahead of flame passes over objects or through orifices. And in certain circumstances a flame may accelerate to high velocities (greater than 1,000m/s) and suddenly become a detonation instead of a deflagration which means DDT has occurred. Direct path to hydrogen detonation is known to be very difficult, thus normally we evaluate whether a DDT is possible to occur. The one criterion generally used to check the DDT is the 7λ criterion of Dorofeev [1].

During the safety review of APR1400, it was assessed that the hydrogen in the In-containment Refuelling Water Storage Tank (IRWST) of APR1400 could possibly accumulate to somewhat high level during a station black out (SBO) accident scenario. To assess whether a DDT is possible in the IRWST, we have applied the 7λ criterion and it gave us that the DDT is possible. But since the criterion was deduced from all the hydrogen experimental data available on the market, we found that it is more than fair to doubt whether the criterion is really applicable in the steam rich IRWST specific condition. In this paper we present our evaluation result on the applicability of 7λ criterion in the steam rich IRWST condition, comparing with the available experimental data.

2. Analysis of Applicability

In this section we will introduce briefly what is the 7λ criterion, how it is applied to assess the DDT and how we have analysed the applicability of this criterion in the IRWST.

2.1 Detonation Cell Size λ

Previous studies show that for a detonation to occur it is necessary that a local distribution of mixture properties in a sensitized region should provide coupling of chemical and gas dynamic processes that result in the formation of an explosion wave. The minimum size of this sensitized region is given by the detonation cell size λ and it was used to characterize the sensitivity of the mixture to detonation initiation. Dorofeev et al. [1] has deduced the following λ equation from the available detonation experimental data

$$\log(\lambda) = \left(a - m + \left(b/(A - k/B)^f + h\cdot(A - g\cdot B)^2 + i\cdot(A - g\cdot B)\right)\cdot (1 + d\cdot C + e\cdot B\cdot C^2)\cdot j/B\right)\cdot(D - c)\cdot\left(1/(0.1 - c) + n\cdot(D - 0.1)\right) + m$$

$a = -1.13331E+00$ $b = 4.59807E+01$ $c = -1.57650E-01$ $d = 4.65429E-02$
$e = 3.59620E-07$ $f = 9.97468E-01$ $g = -2.66646E-02$ $h = 8.74995E-04$
$i = -4.07641E-02$ $j = 3.31162E+02$ $k = -4.18215E+02$ $m = 2.38970E+00$
$n = -8.42378E+00$

2.2 7λ DDT Criterion

A detailed study of DDT in tubes conducted at McGill University [2,3] showed that a size of the unobstructed passage, d, of more than 1λ is necessary for transition to detonation. This criterion can be used as the necessary condition for DDT in obstructed channels. But this is only applicable for a very long channels and long channels with or without obstacles are not typical of the geometry of containment buildings. One criterion formulated [1,4,5] to be applicable in the containment building is L>7λ criterion, where L is defined as a characteristic size of a room filled with combustible mixture. This means if the value of 7λ is smaller than the characteristic length of the compartment the DDT is possible to occur. This criterion was supported by fig.1 below. In the figure, black straight line represents

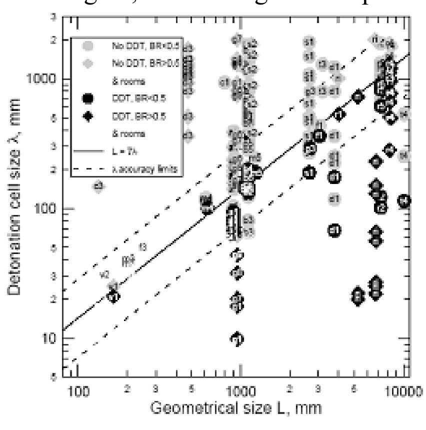

Figure 1. Experimental Data Supporting L>7λ Criterion

L=7λ line. The black points represent the experimental data having DDT. Thus from this figure we can understand that the most experimental data having DDT lie in a region where L>7λ

2.3 Applicability of 7λ criterion in the IRWST

From fig.1, we saw that if a characteristic length is larger than 7λ the DDT might be possible, though it is not a sufficient condition. But the problem of figure 1 is that all the experimental data available on the market are used in deducing the criterion. This means in the real IRWST atmosphere we will have hydrogen, air and steam, but the data of figure 1 includes all the other mixture compositions. So to evaluate the applicability of 7λ criterion in IRWST, we have tried to remove the data points with irrelevant mixture compositions.

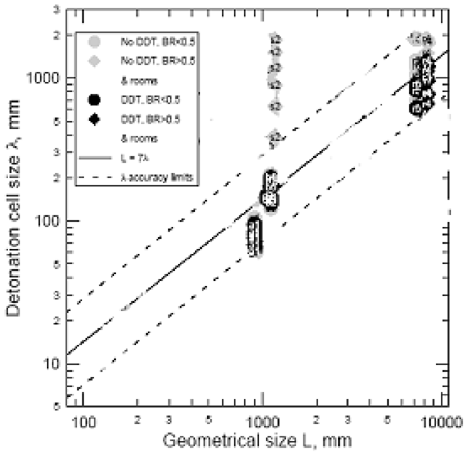

Figure 2. Experimental Data having H^2/Air/Steam Mixture

Fig.2 shows the result. In the figure, the black points are marked by a1, b4, b6, r4 and these letters show from what experiment the data are retrieved. For example a1 is an AECL test, b4 and b6 are data from HTCF(High Temperature Combustion Facility) of BNL(Brookhaven National Laboratory). Even among these 4 experiments, the data which conforms with the IRWST atmospheric condition are provided only by b4 and b6. The raw data from these experiments are given in table 1 below.

Table 1. BNL's HTCF Experimental Data

Temp.(K)	Steam(%)	H2(%)	λ(cm)
400	25	30	15~20
650	20	18	~10
650	30	30	~5
650	35	28	~17
650	40	28	~50

On the other hand , the IRWST atmospheric conditions and the λ we have calculated during the selected SBO accident scenario using MELCOR code and the above Dorofeev equation is given in the table 2 below.

Table 2. IRWST Condition and the Calculated λ

Time(sec)	Temp.(K)	Steam(%)	H2(%)	λ (cm)
55,771	392	44.62	17.27	14.8
56,139	388	42.74	20.48	12.33
63,110	374	33.17	19.87	7.52

Because we are using a node of 2.9m long, L is always higher than 7λ in our assessment and thus we should say that DDT is possible in the IRWST. But if we compare the HTCF experimental data and our calculation results, the situation becomes different. For example, in Table-1 λ is ~ 50cm for a condition of H^2: ~28%, steam:40% and T:650K while in Table-2, λ = 12.33 cm for H^2 :~20.48%, steam:42.74% and T:388 K. Knowing that the λ decreases when T increase or H^2 concentration decreases , the λ calculated in Table-2 is too short compared to the experimental data. The λ for this case should be much longer than 50cm and then L> 7λ condition will not be satisfied. If this is true then we should say that the DDT is not possible in the IRWST of APR1400, which contradicts our previous prediction.

3. Conclusion

To assess whether a DDT is possible in a containment we normally refer to 7λ criterion. But comparing the calculated λ with the experimental data, we found that the calculated λ is too short compared with the experimentally measured value. This means that the assessment of DDT possibility based on the 7λ is too conservative or even not reliable at all.

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