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Evaluations of Explosions Postulated to Occur at Hydrogen Production Facilities near NPP

Young Hun Shin*, Sang-Jin Son, In Chul Ryu and Kyung-Tae Kim
KEPCO E&C, Nuclear Technology Research Department, 269 Hyeoksin-ro, Gimcheon-si, 39660
** dudgns391@kepco-enc.com*
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1. Introduction

When an industrial facility, such as a hydrogen production facility, is installed near a nuclear power plant, its potential explosion effects on nuclear safety should be evaluated. NRC RG 1.91 and KINS/RG 1.2 provide guidance for assessing postulated explosions at nearby industrial facilities. These guidelines indicate that no significant adverse impact on nuclear safety is expected when a sufficient separation distance is maintained. Therefore, an appropriate safety separation distance should be determined during the installation of a hydrogen production facility. This study proposes a methodology for determining the safety separation distance between a hydrogen production facility and a nuclear power plant (NPP).

2. Methodology

When a fixed facility, such as a hydrogen production facility, is installed near an NPP, the required safety separation distance is evaluated in accordance with the procedure specified in NRC RG 1.91, as shown in Fig. 1

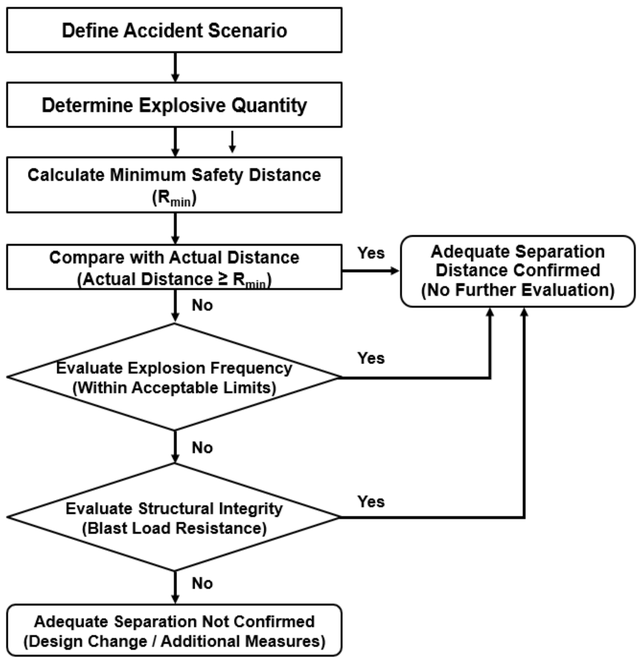


Fig 1. Evaluation Procedure for Safety Separation Distance.

2.1 Accident Scenario and Explosive Quantity

This study presents a methodology for estimating the mass of hydrogen participating in an explosion using Epstein's top-hat jet/plume model, as illustrated in Fig. 2.

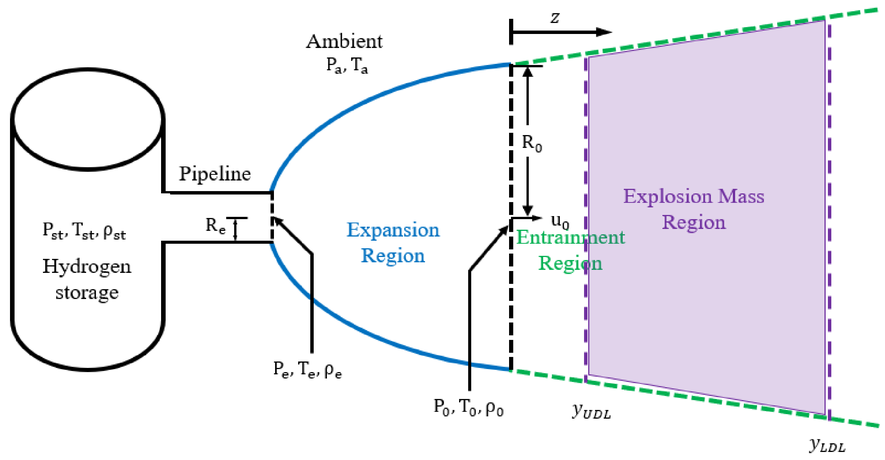


Fig 2. Epstein's top-hat jet/plume model for hydrogen release from a ruptured pipeline.

(1) $$R = \frac{R_0}{Y}\sqrt{\frac{T_a}{T_0}\left[Y + \frac{M_{H_2}}{M_{air}}(1-Y)\right]}$$

(2) $$m_{exp} = m_{det} = \int_{Z_{UDL}}^{Z_{LDL}} \pi R^2 \rho Y \, dz$$

(3) $$Y = \frac{u}{u_0} = \left[1 + \frac{2E_0}{R_0}\left(\frac{\rho_a}{\rho_0}\right)^{0.5} z\right]^{-1}$$

(4) $$y = \left[1 + \left(\frac{1}{Y} - 1\right)\frac{M_{H_2}}{M_{air}}\right]^{-1}$$

(5) $$y = \frac{d\lambda}{dz} < 0.1 \text{ (for detonation propagation)}$$

(6) $$\left(\frac{d\lambda}{d\phi}\right)\left(\frac{d\phi}{dY}\right)\left(\frac{dY}{dz}\right) < 0.1$$

(7) $$\ln\lambda = a + b\ln\phi + c(\ln\phi)^2 + d(\ln\phi)^3 + e(\ln\phi)^4$$

(8) $$\phi = \frac{M_a}{0.42\, M_{H_2}}\left(\frac{Y}{1-Y}\right)$$

(9) $$W_{TNT} = \frac{\Delta H_{comb}}{\Delta H_{TNT}} \times m_{exp}$$

2.2 Minimum Safety Distance Calculation

(10) $$\log P(\text{kPa}) = \sum_{i=0}^{n} c_i (a + b \log Z)^i, \quad (0.0674 \le Z \le 40)$$

(11) $$L_{min} = Z \times W_{TNT}^{1/3} = 18 \times W_{TNT}^{1/3}$$

Table I. Parameters for the CCPS overpressure correlation.

constant	value	constant	value
a	-0.214362789	c_5	-0.293912623
b	1.3503425	c_6	-0.026811235
c_0	2.780769166	c_7	0.109097496
c_1	-1.695898874	c_8	0.001628468
c_2	-0.154159377	c_9	-0.021463103
c_3	0.514060731	c_{10}	0.000145672
c_4	0.098855437	c_{11}	0.001678478

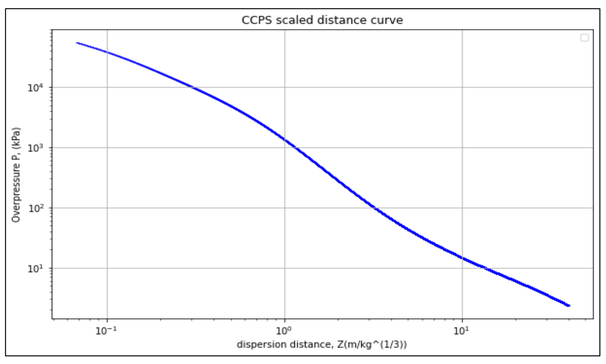


Fig 3. Plot of Explosion Overpressure versus Scaled Distance (CCPS).

3. Example Calculations and Results

Table II. Calculated Hydrogen Explosive Quantities for Different Rupture Opening Diameters. (Pst=7 MPa, Tst=20 ˚C)

D_e (mm)	Y_{LDL}	y_{LDL} (%)	λ_{min} (mm)	m_{det} (kg)	W_{TNT} (kg)
25	1.38×10^{-2}	16.86	128	0.32	0.43
40	1.29×10^{-2}	16.00	192	1.49	1.98
80	1.19×10^{-2}	14.91	356	14.02	18.70
100	1.16×10^{-2}	14.60	436	28.76	38.34

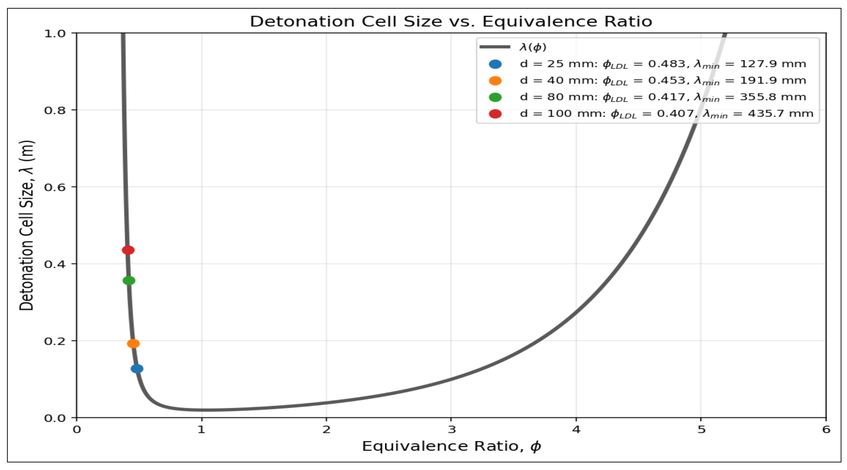


Fig 4. Minimum detonation cell size versus equivalence ratio for different rupture opening diameters.

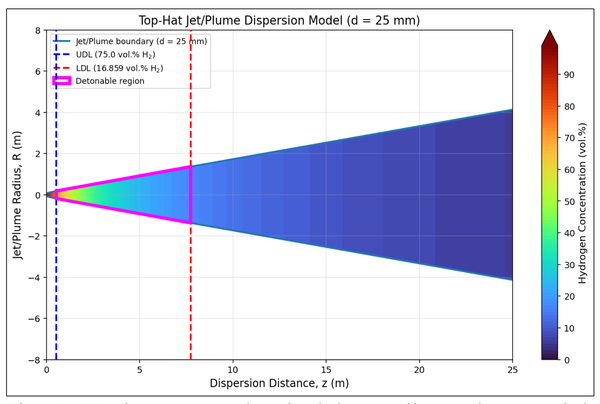


Fig 5. Hydrogen top-hat jet/plume dispersion model and explosive region (De=25 mm)

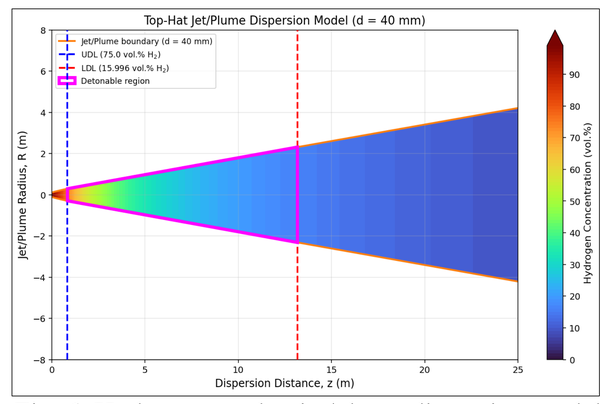


Fig 6. Hydrogen top-hat jet/plume dispersion model and explosive region (De=40 mm)

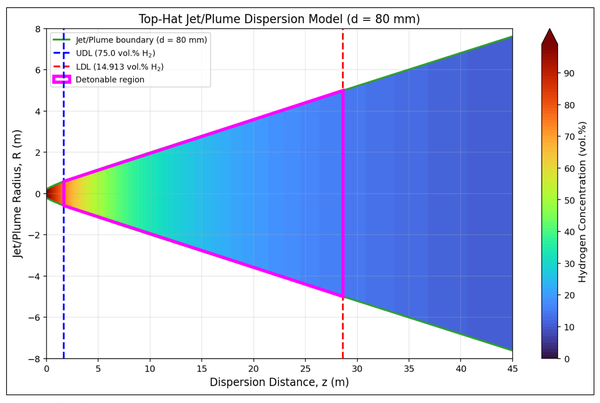


Fig 7. Hydrogen top-hat jet/plume dispersion model and explosive region (De=80 mm)

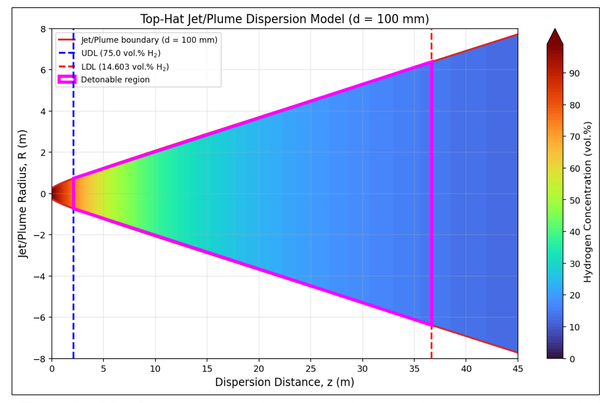


Fig 8. Hydrogen top-hat jet/plume dispersion model and explosive region (De=100 mm)

Table III. Minimum safe separation distance for each rupture opening diameter

D_e (mm)	L_{min} (m)
25	14
40	23
80	48
100	61

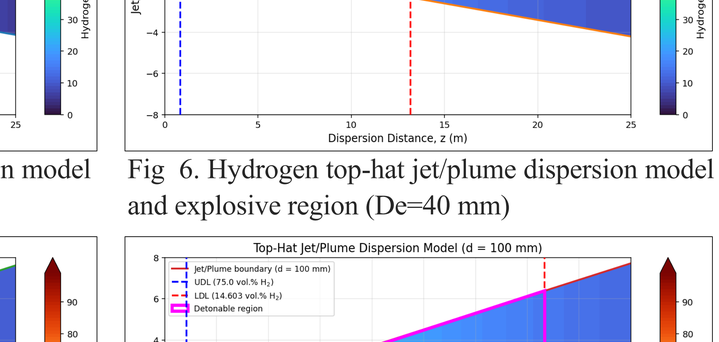


Fig. 9. Explosion overpressure versus separation distance for different rupture opening diameters.

4. Conclusions

This study presented a methodology for determining the safety separation distance between hydrogen production facilities and nuclear power plants for postulated hydrogen pipeline rupture accidents. The detonable hydrogen mass was estimated using Epstein's top-hat jet/plume model and the detonation cell-size criterion, converted into a TNT equivalent mass, and subsequently used to calculate the explosion overpressure and safety separation distance based on the CCPS correlation referenced in NRC RG 1.91. The evaluation methodology presented in this study can be applied to assess the potential impacts of postulated explosion accidents at hydrogen production facilities near nuclear power plants and to determine appropriate safety separation distances.