2024 KOREAN NUCLEAR SOCIETY

# Evaluation of Standoff Distances for NPP-Linked Hydrogen Production Facilities Through Analysis of Hydrogen Flammable Mass and Explosion Overpressure

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*Keywords : Hydrogen, Jet, Flammable Mass, TNT-equivalent Mass, Overpressure, Standoff Distance*

## 1. Introduction

When hydrogen production facilities are integrated with nuclear power plants, significant quantities of high-pressure hydrogen may be produced and temporarily stored onsite, necessitating a thorough risk assessment of the associated storage facilities. This paper focuses on assessing the risks associated with hydrogen facilities within nuclear power plant premises. We employ scenario-based analysis to model hydrogen gas leakage and determine the flammable mass of leaked hydrogen. Additionally, we calculate the effective TNT equivalent mass to evaluate explosion overpressure scenarios. Our study culminates in the derivation of standoff distances that comply with the regulatory guidelines, particularly US NRC R.G 1.91 based on the calculated hydrogen explosion overpressures.

## 2. Methodology

### *2.1 Leakage Source Model*

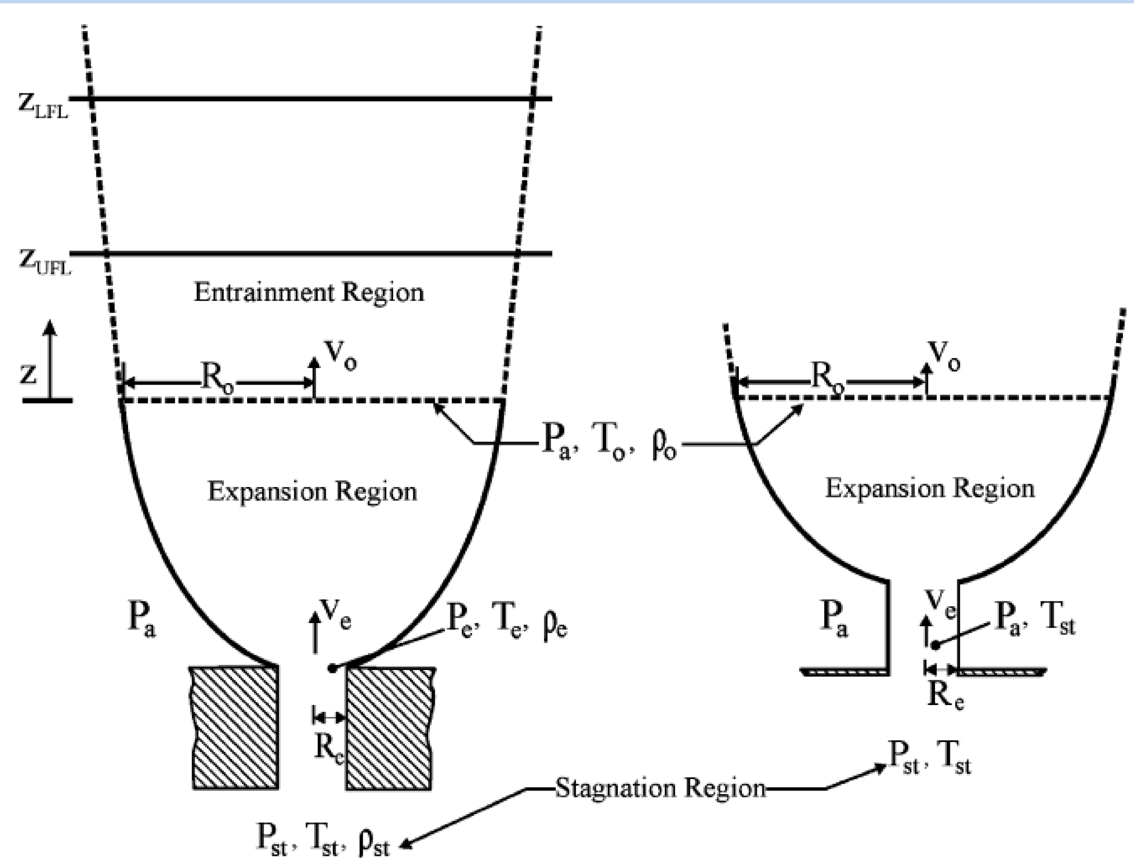


Fig 1. Jet/plume leak model of hydrogen gas

$$(1)\ G = C_D\left[\gamma P_{st}\rho_{st}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}\right]^{1/2}$$

$$(2)\ P_e = P_{st}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

$$(3)\ \rho_e = \rho_{st}\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}}$$

$$(4)\ T_e = T_{st}\left(\frac{2}{\gamma+1}\right)$$

$$(5)\ v_0 = \frac{G}{\rho_e} + \frac{P_e - P_a}{G}$$

### *2.2 Hydrogen Flammable Mass*

$$(6)\ m_{flam} = \left(\frac{\pi R_0^3 \rho_0 Y_0}{2E_0}\right)(Fr)^{\frac{3}{5}}\left(\frac{\rho_0}{\rho_a}\right)^{1/2} I_{flam}$$

$$(7)\ I_{flam} = \frac{5}{4}\left[\left(\frac{Y_0^2}{Y_{LFL}^2} + Fr - 1\right)^{2/5} - \left(\frac{Y_0^2}{Y_{LFL}^2} + Fr - 1\right)^{2/5}\right]$$

$$(8)\ Fr = \frac{8E_0\, v_0^2(\rho_a/\rho_0)^{1/2}}{5g\, R_0\, (\rho_a/\rho_0 - 1)}$$

### *2.3 TNT-Equivalent Mass*

$$(9)\ m_{TNT,eff} = \alpha\frac{\Delta H_{comb}\, m_{flam}}{\Delta H_{TNT}}$$

### *2.4 Hydrogen Explosion Overpressure*

$$(10)\ \frac{P_s - P_a}{P_a} = \frac{808\left[1 + \left(\frac{X}{4.5}\right)^2\right]}{\left[1 + \left(\frac{X}{0.048}\right)^2\right]^{1/2}\left[1 + \left(\frac{X}{0.32}\right)^2\right]^{1/2}\left[1 + \left(\frac{X}{1.35}\right)^2\right]^{1/2}}$$

$$(11)\ X = \frac{x}{m_{TNT,eff}^{1/3}}$$

## 3. Analysis

### *3.1 Initial Conditions*

Table I. Initial condition of hydrogen jet

| Symbol | variable | initial data |
|---|---|---|
| $\gamma$ | Specific heat | 1.41 |
| $P_{st}$(Pa) | Storage pressure | 7.00E+06 |
| $T_{st}$(K) | Storage temperature | 293 |
| $R_{id}$ (J/kgmole K) | Ideal gas constant | 8314 |
| $P_a$(Pa) | Ambient pressure | 1.01E+05 |
| $T_a$ (K) | Ambient temperature | 293 |
| g(m/sec$^2$) | Gravitational constant | 9.8 |

### *3.2 Calculation Results*

Table II. Calculation results of hydrogen jets

| Symbol | variable | initial data |
|---|---|---|
| G(kg/m$^2$ sec) | Mass flux of hydrogen | 3521.3 |
| $P_e$ (Pa) | Pressure at the failure opening plane | 3.693E+06 |
| $\rho_e$ (kg/m$^3$) | density at the failure opening plane | 3.645 |
| $T_e$(K) | Pressure at the failure opening plane | 243.8 |
| $\mu_0$ (m/sec) | Velocity of depressurized jet | 1986.198 |

Table III. Effective TNT equivalent mass with respect to failure opening radius

| Failure opening Radius (m) | Effective TNT equivalent mass (kg) | Standoff Distance (m) |
|---|---|---|
| 0.04 | 166.58 | 74.0 |
| 0.06 | 513.91 | 107.7 |
| 0.08 | 1130.25 | 140.1 |

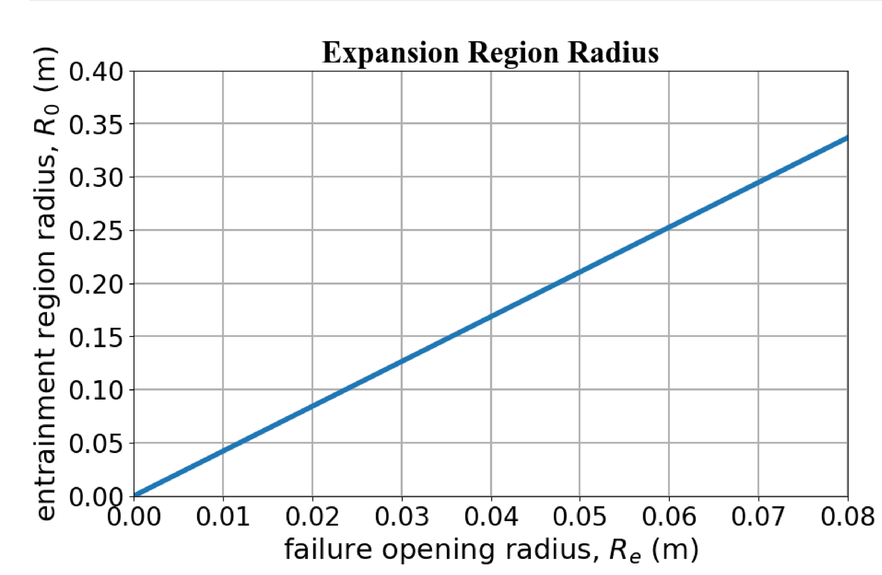


Fig 2. Radius of the expansion region

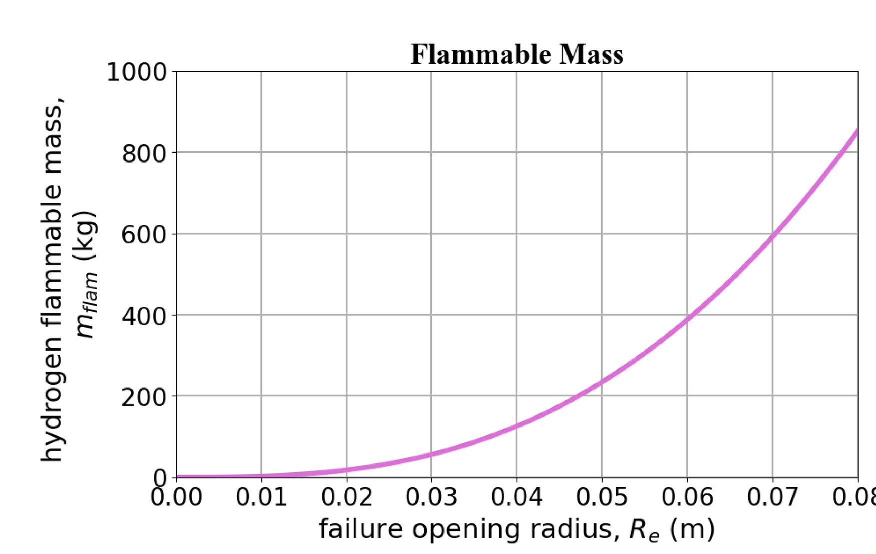


Fig 3. Hydrogen flammable mass curve

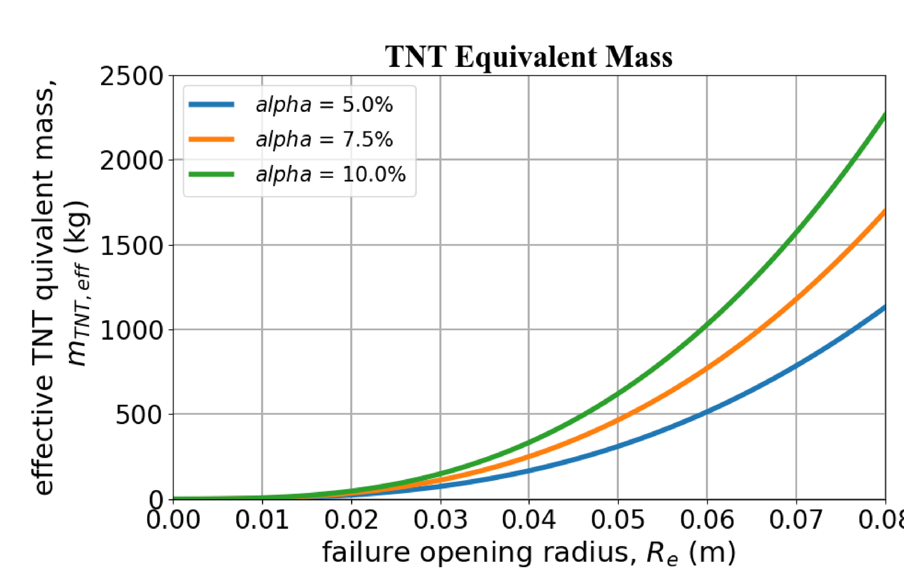


Fig 4. Effective TNT equivalent mass curve

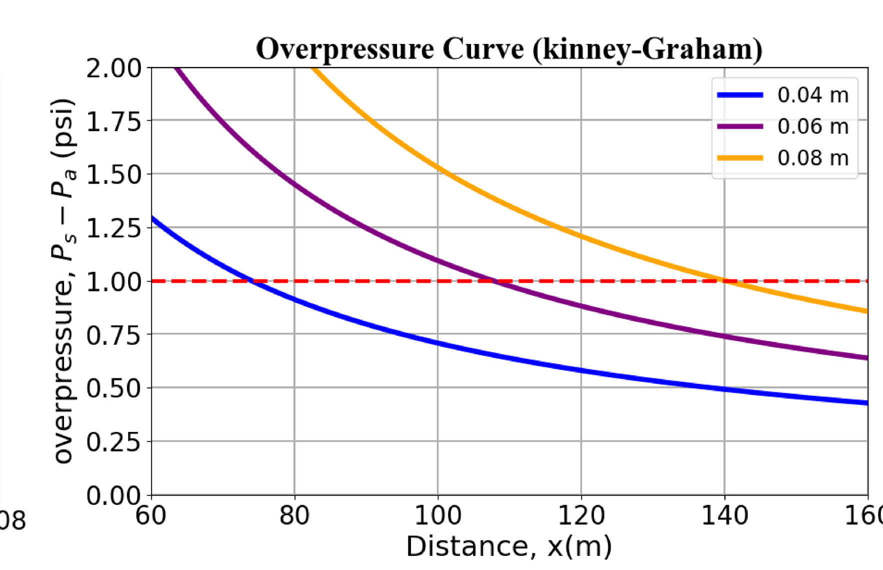


Fig 5. Explosion overpressure curve

## 4. Conclusions

Accordingly, the paper proposes employing the distance at which the overpressure from an explosion reaches 1 psi (6.9 kPa) as the safety standoff distance. The methodology presented in the paper facilitates the calculation of the hydrogen flammable mass within a hydrogen gas jet and determines the effective TNT equivalent mass based on parameters such as temperature, pressure, and failure opening radius of the hydrogen storage facility. By defining the effective TNT equivalent mass, it becomes feasible to calculate the explosion overpressure as a function of the distance from the explosion origin. This approach is anticipated to contribute to the advancement of clean hydrogen production from nuclear power plants by establishing a rational safety standoff distance that accurately reflects the properties and behavior of hydrogen.