[2025 추계원자력학회]
2025.10.29-31

Preliminary Structural Integrity Assessment of the i-SMR Containment Vessel under a Hydrogen DDT Condition Using LS-DYNA

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1. Introduction

Background

- The containment vessel is essential for ensuring reactor safety and preventing the release of fission products.
- A structural integrity assessment should be performed for the metallic containment vessel of i-SMR under severe accident conditions involving hydrogen explosions.

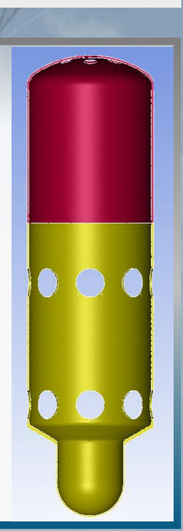
Objective

- To evaluate the i-SMR containment vessel's structural response to hydrogen DDT loads using dynamic finite element analysis and verify compliance with ASME safety criteria

2. Modeling of the i-SMR containment vessel

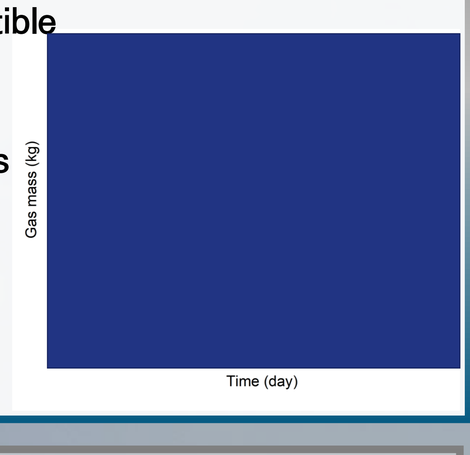
Finite element modeling of CV

- A 1/2 half-symmetry modeling (mesh size 0.2 m)
  - Upper-side 118,328 elements and 37,971 nodes
  - Lower-side 161,104 elements and 51,952 nodes
  - Internal reactor pressure vessel were excluded
- Properties of vessel materials were defined according to the ASME code
- LS-DYNA was applied for this analysis



Assumptions

- Hydrogen and oxygen were generated within the containment vessel over 72 hours after a severe accident
- For the conservative assessment, we considered total amount of hydrogen and oxygen is combustible
- In fact, for all accident scenarios, the atmosphere inside the CV does not reach flammable conditions due to large amount of steam



Calculation of DDT peak pressure

- DDT peak pressure can be calculated as follows :

$$P_{deflagration} = P_{initial} R_{CJ}$$

$$P_{detonation} = 2P_{deflagration}$$

$$P_{reflection} = P_{detonation} \Pi_{refelction}$$

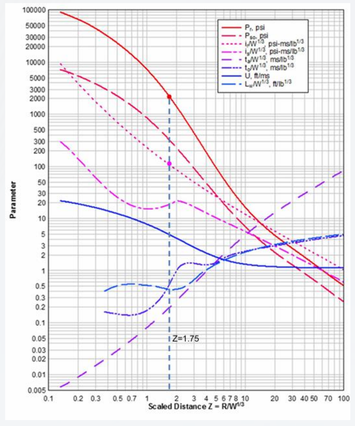
$$\Pi_{refelction} = \frac{5\gamma+1+\sqrt{17\gamma^2+2\gamma+1}}{4\gamma}$$

$$P_{DDT} = P_{reflection} F_{DDT}$$

- Where R_{CJ} is the ratio of the C-J pressure over the initial pressure, γ is specific heat ratio at the C-J conditions, F_{DDT} is DDT amplification factor

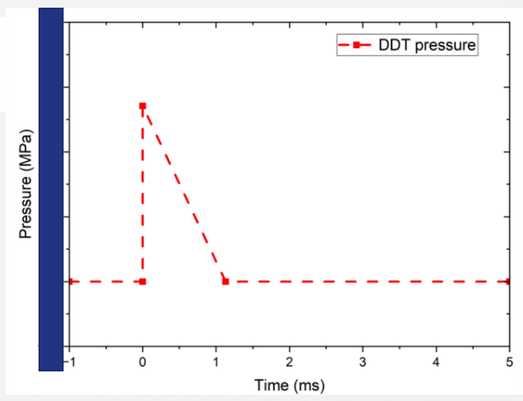
Calculation of duration time

- Using the scaled blast parameters for Trinitrotoluene equivalent load table, duration time can be calculated
- We assumed the explosion starts from CV centerpoint



Scaled blast table

$$i_s = \frac{1}{2} P_{\max} t_p$$



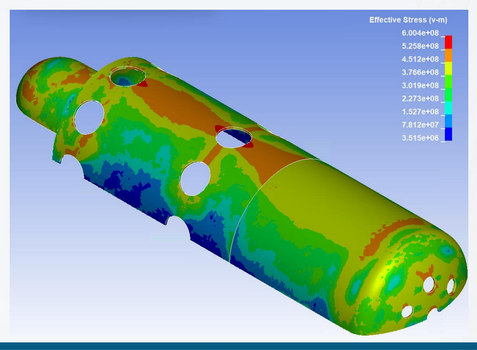
DDT load curve

4. Assessment result of CV structural integrity

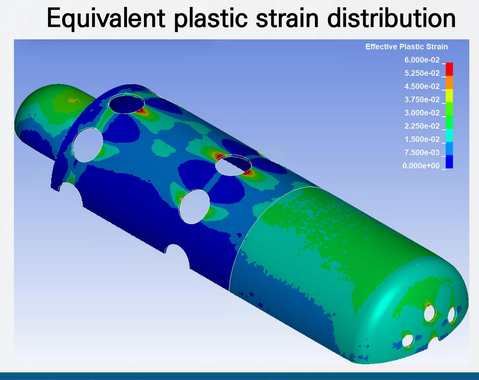
Calculation result

- The maximum stresses occurred at the top, bottom regions and near penetrations
- Plastic strain was up to 11%, near penetrations

Von Mises stress distribution



Equivalent plastic strain distribution



Assessment result

- Stress linearization was carried out in accordance with ASME Section III, NB-3200
- The resulting stresses remained allowable compared to the ASME's criteria for Service Loading Limit Level C

Stress	Criteria	Calculation result
Membrane	$\mathrm{Max}(1.2S_m, 1.0S_y)$ = 405 MPa	MPa
Local membrane	$\mathrm{Max}(1.8S_m, 1.5S_y)$ = 675 MPa	MPa
Local membrane + Bending		MPa
Triaxial	$4.8S_m$ = 988.8 MPa	MPa

5. Conclusions

Summary

- Analysis results showed the maximum stresses appeared at the vessel's top and bottom, remaining within ASME Section III allowable limits and ensuring sufficient safety margins
- Overall, the i-SMR CV preserves its structural integrity under conservative DDT scenarios

Calculation for CV bottom support

- Additionally, a detailed analysis including the CV bottom support was performed
- The results indicated that stress was concentrated at the lowest region of the CV bottom, yet the structural integrity remained sufficient.