Evaluation of structural Integrity of HIC container based on the technical standards of Type A transport package

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Radiation poses serious risks to human health and the environment, necessitating strict control measures at sites with potential radioactive exposure, such as nuclear power plants and waste management facilities. The High Integrity Container (HIC) discussed in this study was originally developed as a packaging container for the disposal of radioactive material drums, but it was designed to meet the requirements of a Type A transport package to ensure safe handling and operation. Type A packages must satisfy specific requirements stipulated in IAEA regulations, including limiting radiation dose rates to below 2 mSv/h, providing sufficient shielding performance, and preventing the release of radioactive substances. Structural integrity must be verified under four key scenarios: stacking, lifting, dropping, and penetration. This study focuses on assessing the structural safety of the container under drop conditions using finite element analysis. The current analysis utilizes elasto-plastic material models for the components of HIC and does not consider detailed cracking pattern of the concrete. For more accurate evaluations in future studies, it is necessary to incorporate nonlinear concrete models capable of simulating crack initiation and propagation in regions experiencing maximum stress.

1. Outline

1.1 Evaluation of structural integrity of HIC container

- For safe operation, HIC is designed to meet the type A package requirements.
- Type A transport package must satisfy following technical standards under normal condition of transportation
  - Radioactive contents must not be lost or dispersed.
  - The radiation dose rate should not exceed 20% to maintain shielding capability.

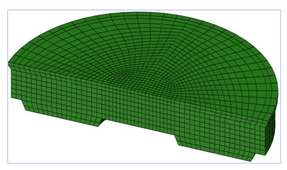
1.2 Safety tests of Type A transport package

- In this study, structural analysis was performed for a total of 5 cases:
  - ➢**Free drop tests :** 3 cases (vertical drop, horizontal drop, corner drop)
  - ➢**Penetration** : 2 cases (Lid penetration, Lateral penetration

2. Finite Element Modeling

2.1 Finite Element Analysis model

Materials	Color
MATERIAL	
PE	
POLYCON	
RUB	
SS275	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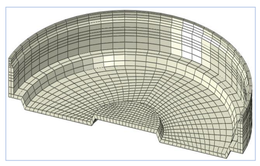
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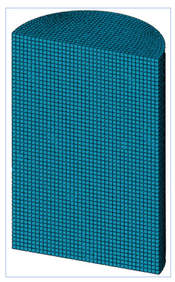
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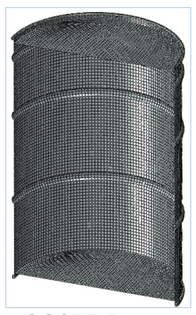
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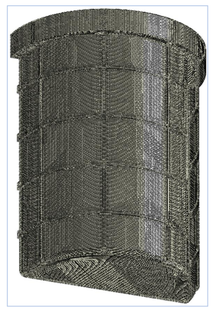
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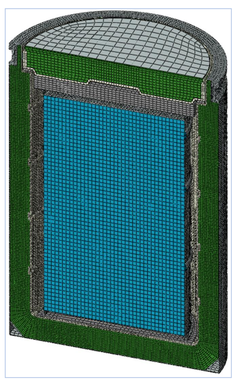
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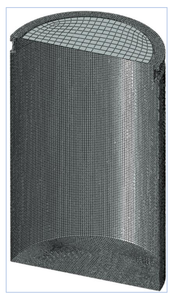

<SS275 Outer Shell>


<Polymer Concrete Shield>

Total Elements	Total Nodes	Solid	Shell
585,721	691,911	C3D8R	S4R

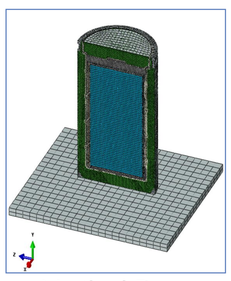
<Material Property>

Property	Density [kg/m^3]	Young's Modulus [MPa]	Yield Strength [MPa]	Tensile Strength [MPa]
Material	737	1,000	-	-
SS275	7,690	210,000	275	400
Poly Ethylene	940	820	-	-
Polymer Concrete	2,300	32,161	-	-

2.2 Boundary condition

- Since the HIC has a symmetric geometry, only half of the full model was constructed to reduce the analysis time.

  : Drop heights transformed into the initial velocity : $mgh = \frac{1}{2}mv^2, v = \sqrt{2gh}$
- The HIC was positioned such that the line connecting the center of gravity(COG) and the impact point is orthogonal to the ground surface in corner drop.
- A steel rod with a diameter of 3.2 cm and mass of 6 kg was dropped from a height of 1 m to simulate penetration.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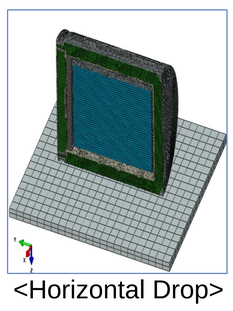
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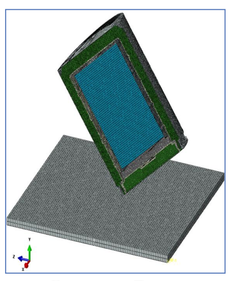
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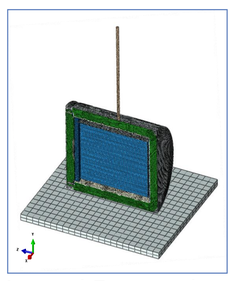
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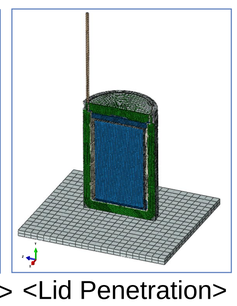
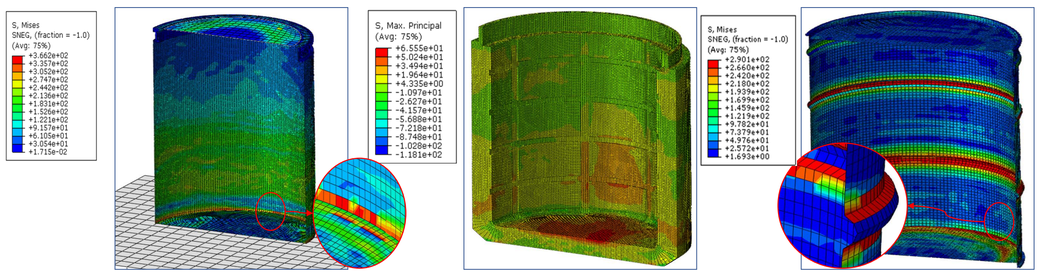

<Lid Penetration>

3. Analysis result

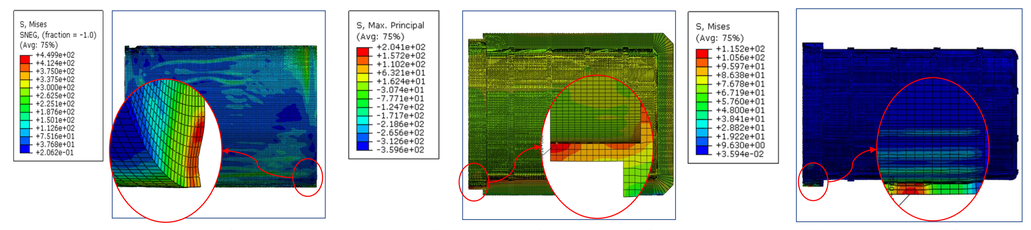
1) Vertical drop

- The lid and shields are expected to maintain its structural integrity, whereas permanent deformation occurs in the outer shell and the drum.


<Outer Shell> <Polymer Concrete Shield> <Drum>

2) Horizontal drop

- There is a high possibility of damage occurring in the polymer concrete shield. Permanent deformation of outer shell is predicted.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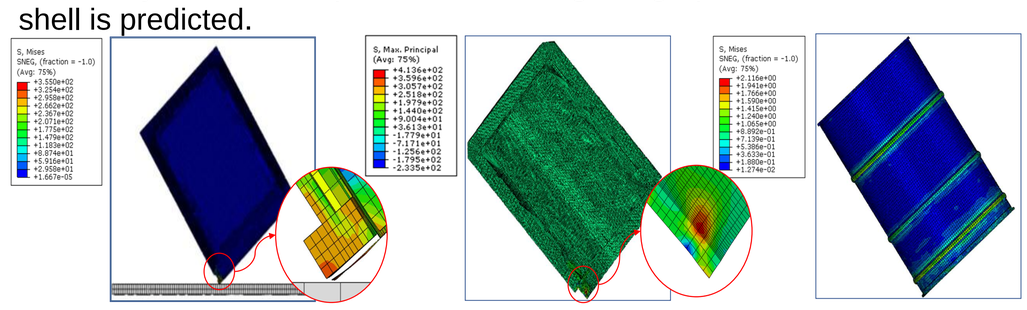
3) Top-corner drop

- Structural damage is anticipated in the polymer concrete shield. A more detailed assessment incorporating crack prediction will be necessary to accurately evaluate its pattern of cracking. Large plastic deformation of outer shell is predicted.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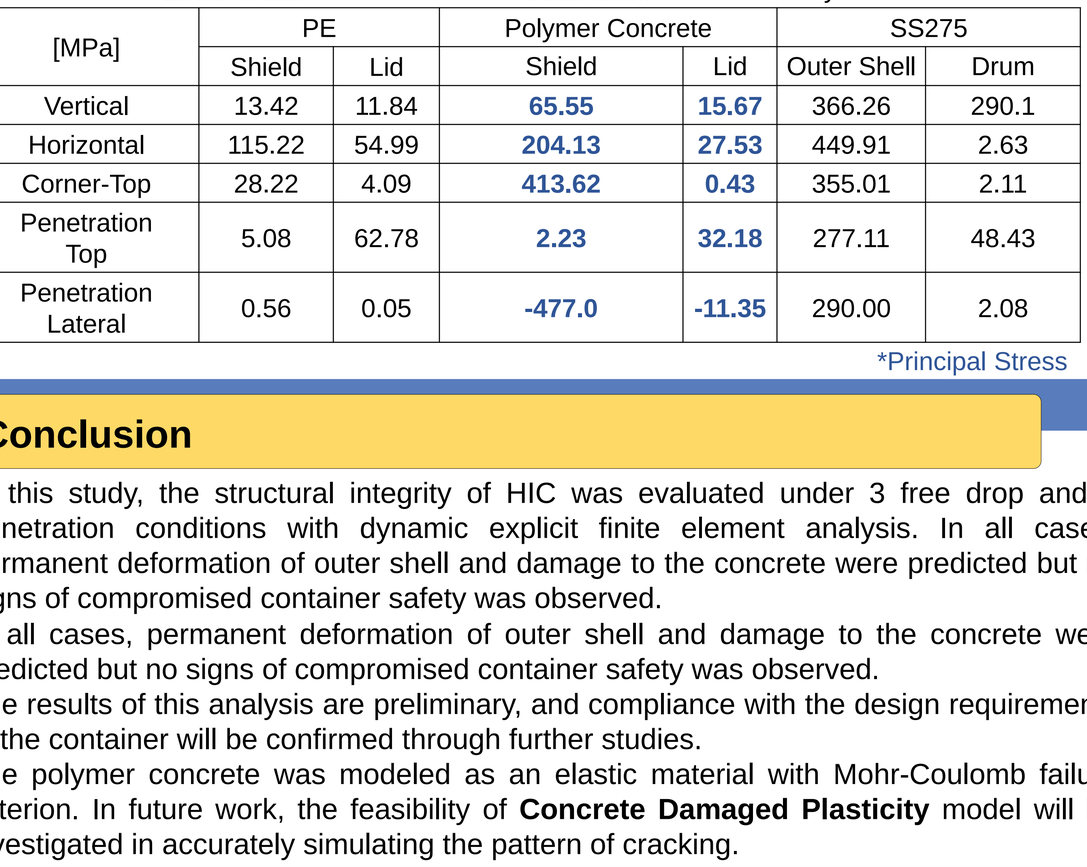
4) Penetration

- Permanent deformation occurs in the outer shell under all penetration scenarios, and crack may occur in the polymer concrete shield during lateral penetration.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[MPa]	PE		Polymer Concrete		SS275	
	Shield	Lid	Shield	Lid	Outer Shell	Drum
Vertical	13.42	11.84	**65.55**	**15.67**	366.26	290.1
Horizontal	115.22	54.99	**204.13**	**27.53**	449.91	2.63
Corner-Top	28.22	4.09	**413.62**	**0.43**	355.01	2.11
Penetration Top	5.08	62.78	**2.23**	**32.18**	277.11	48.43
Penetration Lateral	0.56	0.05	**-477.0**	**-11.35**	290.00	2.08

*Principal Stress

4. Conclusion

- In this study, the structural integrity of HIC was evaluated under 3 free drop and 2 penetration conditions with dynamic explicit finite element analysis. In all cases, permanent deformation of outer shell and damage to the concrete were predicted but no signs of compromised container safety was observed.
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- The results of this analysis are preliminary, and compliance with the design requirements of the container will be confirmed through further studies.
- The polymer concrete was modeled as an elastic material with Mohr-Coulomb failure criterion. In future work, the feasibility of **Concrete Damaged Plasticity** model will be investigated in accurately simulating the pattern of cracking.