Pressure limit evaluation codes for Spent Nuclear Fuel cask Submerged in deep Sea

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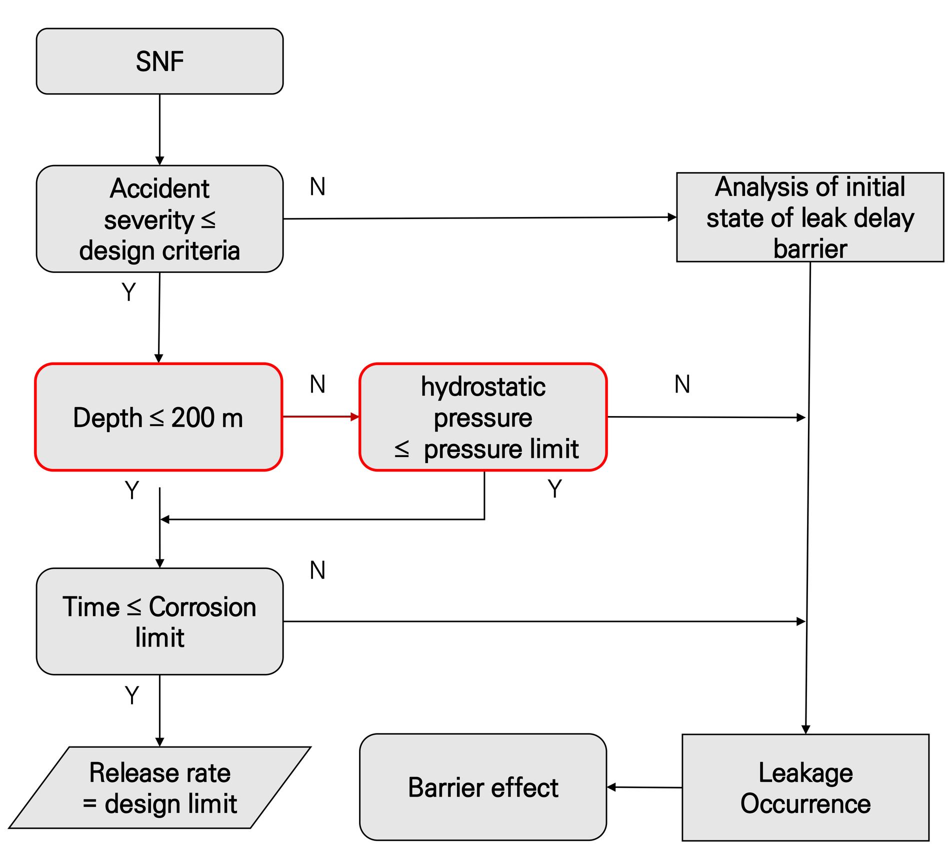
Spent Nuclear Fuel(SNF) is transported in a **type B transport cask**, and due to the geography of Korea, transportation by sea may be inevitable. The loss of a transport cask in an accident during marine time transportation is plausible. The containment boundary of the transport cask can be damaged due to high hydrostatic pressure if it is lost in the deep sea of more than 200 m depth. Therefore, evaluation of radioactive material release from a submerged transport cask should be conducted considering the condition of the cask. In this study, a **code** was developed to evaluate the pressure limit of a cask considering the loading conditions and design specifications of the cask. To develop the code, a simplified computational model was constructed based on the existing detailed design specifications of the cask. After obtaining training data for code development through computational experiments of a simplified transport cask, a meta-model was created using Gaussian Process Regression. The resulting **meta-model** can be used as a code to evaluate the pressure limit of transport casks without conducting additional computational experiments.

1. Background and research objective

1.1 Extended ocean release scenario from a marine accident

- SNF transport casks can be lost in the sea due to an accident during maritime transportation.
- A type B cask maintain its integrity under the hydrostatic pressure corresponding to 200 m depth.
- Damage to the containment can occur at depths greater than 200 m.

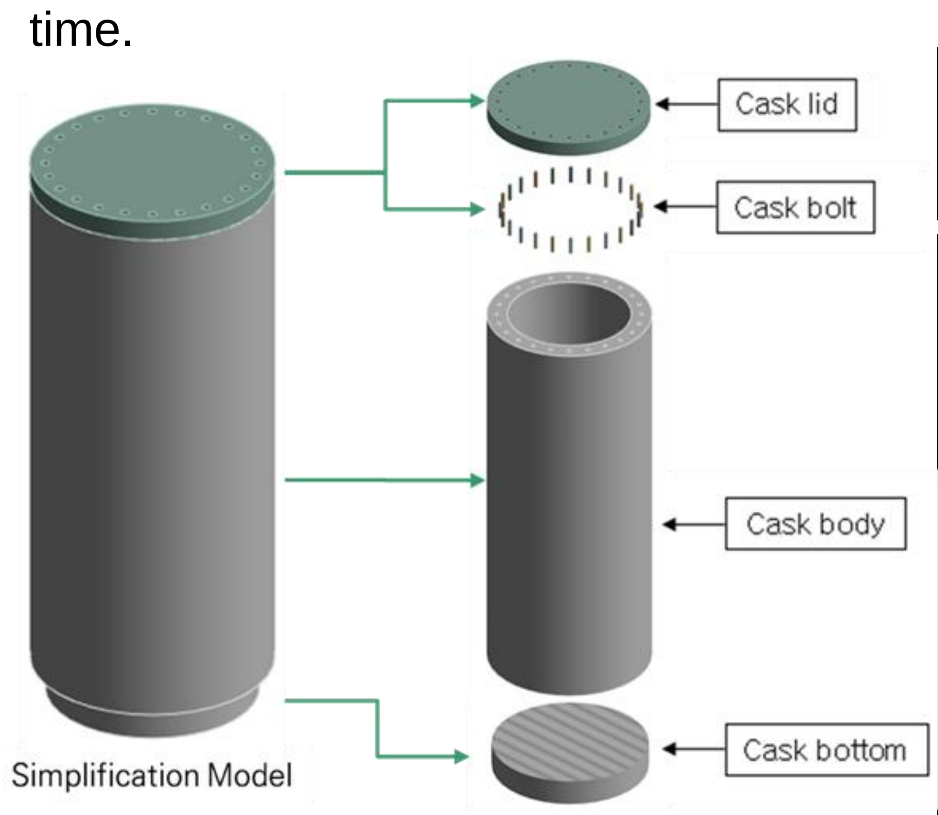


<High fidelity cask model >

2. Development of simplified cask model

2.1 Building a finite element computational model

- Simplified cask model is built using parametric modeling techniques for automatic model generation with change in loads and design specifications.
- The simplified model removes unnecessary geometric details from the detailed model, facilitating mesh generation and reducing computational time.

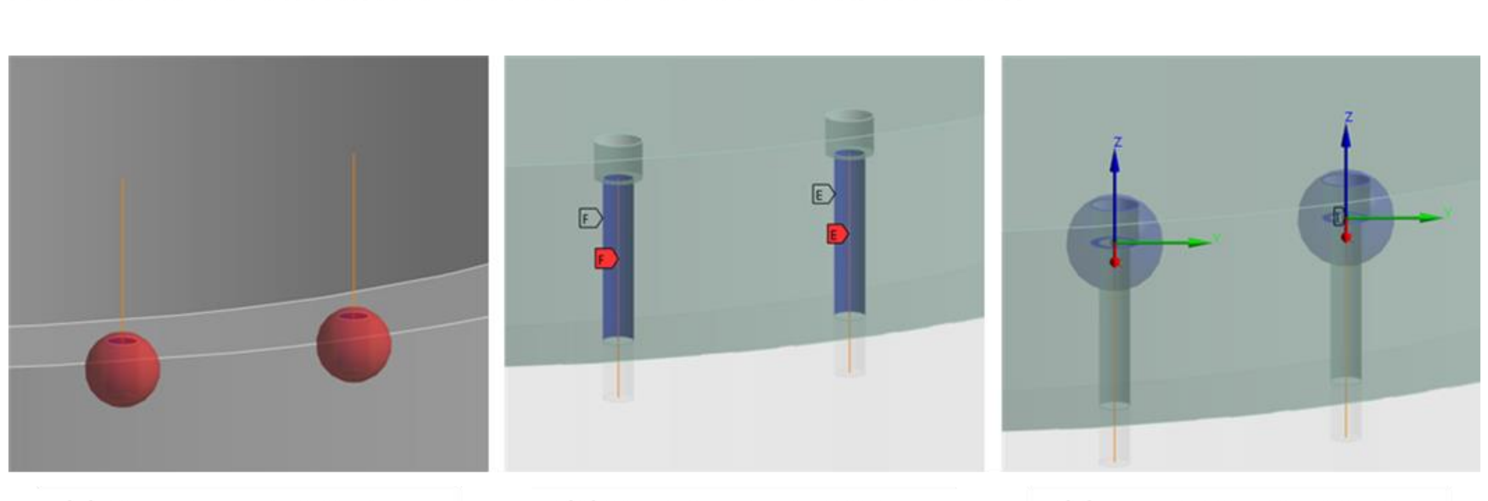


<Simplified cask model components>

Part	CASK_BODY	CASK_BOLT
Material	SA516 GR70	SA193 B7
Yield Stress	334.9 MPa	835.7 MPa

Parameters	Value
p_o (External pressure)	10.0 MPa
p_i (Internal pressure)	0.7 MPa
q $(p_o - p_i)$	99.3 MPa
R (Radius)	1033.5 mm
h_1 (Height of Lid)	189.0 mm
h_2 (Height of Bottom)	311.2 mm
E (modulus of elasticity)	$2.1e^5$ MPa
y (Radius of Bolt)	23.2 mm

- Bolts are simplified into beam elements so that bending and shear stresses are measured across the entire bolt cross-section.
- The bolt simplified to a beam requires different boundary conditions and constraints to simulate behavior of the real model.



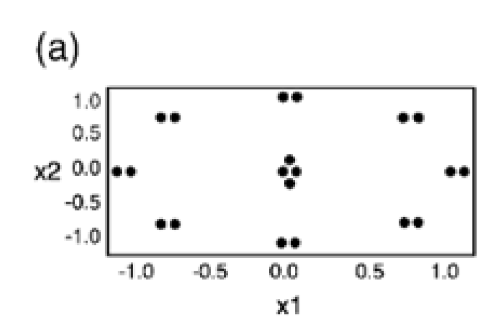
(a) Bonded-Bolt & Body (b) Frictional-Bolt & Lid (c) Joint_Fix-Bolt & Lid

<Constraints for simulating bolting>

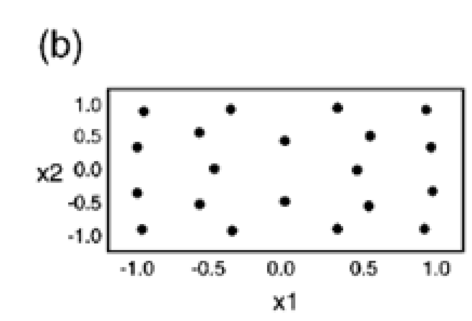
3. Development of meta model(surrogate model)

3.1 Computational experiments for developing pressure limit evaluation codes

- Optimal Space Filling Design technique of DACE Sampling is used to conducting computational experiments.
- The output is the maximum von-misses stress and intensity stress generated in the components(Lid, Bottom, Body, Bolt) of the cask.



<(a) Conventional Sampling>



<(b) DACE Sampling>

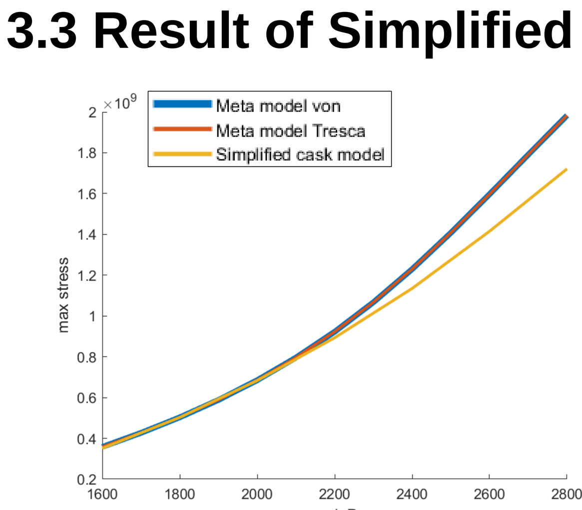
<Range of input variables>

Parameters	Max	Min
R (Radius)	3,000	1,500
h_1 (Height of Lid)	300	150
h_2 (Height of Bottom)	500	250
Th (Thick of cask Body)	400	150
p_o (External pressure)	150	1
N (Number of bolt)	28	12
E_body (modulus of elasticity)	2.4e05	1.6e05
E_bolt (modulus of elasticity)	2.4e05	1.6e05

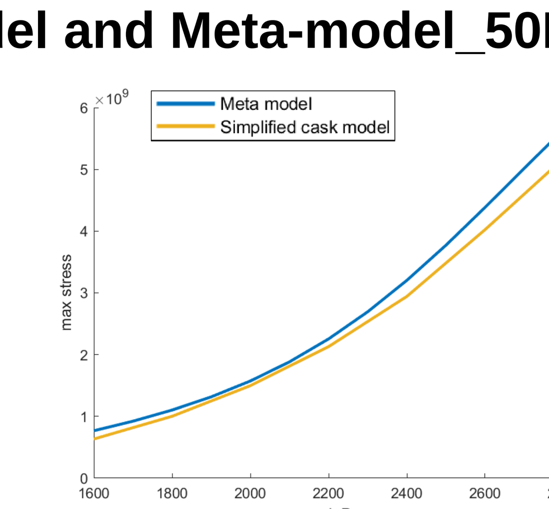
3.2 Development of Meta-model, Gaussian Process Regression(GPR)

- Create a metamodel using Gaussian process regression to build a model that can make high confidence predictions from a limited number of experimental points.
  - Gaussian Process Regression: $y(x) = f(x) + \varepsilon, \quad \varepsilon \sim N(0, \sigma_n^2)$
    $f \sim GP(m, k), \ y \sim GP(m, k + \sigma_n^2 \delta_{ii'})$
    (m: *mean function*, k: *covariance function*, σ_n: *Noise Level*)
  - Kernel (exponential) : $K(x, y) = \exp(-\|x - y\| / \lambda)$

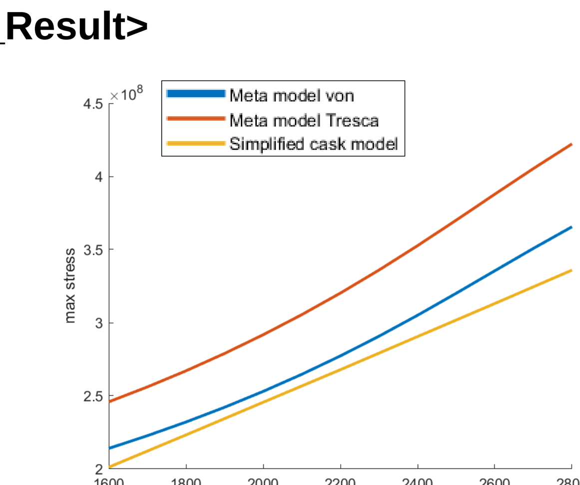
3.3 Result of Simplified cask model and Meta-model_50MPa(500m)



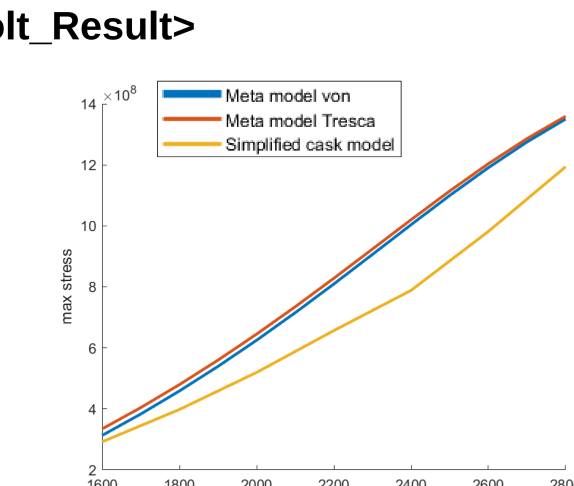
<Lid_Result>



<Bolt_Result>



<Body_Result>



<Bottom_Result>

4. Conclusions

- SNF transport casks can be lost in the deep sea due to an accident during maritime transportation.
- Integrity assessment of transportation cask in high hydrostatic pressure situations is required.
- A simplified finite element model was created using parametric modeling techniques for automated numerical experiments.
- A meta-model was developed by using Gaussian regression.
- The developed meta-model can be used as a code for evaluating the pressure limit of a transport cask.