Evaluation of sealing performance of metal gasket used in dual purpose metal cask subjected to an aircraft engine missile

CRIEPI

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These works have been carried out under the contract from former NISA/METI.

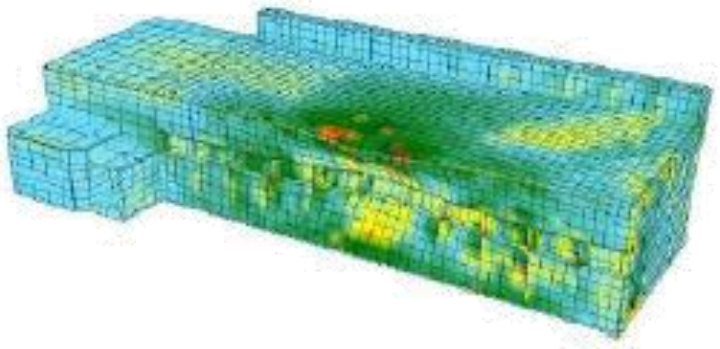
Current State of the art

- **Credible external accident, such as Aircraft crash**
  - **Taken into account in the design**

    if its probability exceeds 10^{-7} /facility/year
- **Japanese New Regulatory Requirements for Light-Water NPP enhanced in 2013**
  - **Tightening measures to prevent or deal with severe accidents and acts of terrorism**
  - **Establishment of the rational and reliable corresponding numerical approach to assess the inherent safty is highly expected**
  - ✓ **e.g. US/NEI 07-13, Methodology for performing aircraft impact assessments for new plant designs**
  - ✓ **Technical basis for issuing this methodology is not disclosed by now,.**

Objective

- ***Important to establish the methodology to assess the inherent safety in an interim NSF storage facility***
- ***Ascertain whether a forced aircraft crash event could lead to a significant release of radioactive substances into the environment***
- ***A civilian airplane is assumed to crash on a storage facility as a severe accident of credible external event***



Example by BAM, Germany

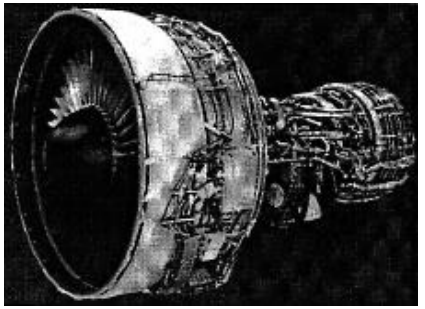
Objective (cont'd)

Execution of Aircraft Crash Test and Analysis

- Technical data basis to inform
  - ✓ Robustness of the lid structure under extreme loads
  - ✓ Applicability of the numerical approach by impact analysis code to clarify the dynamic mechanical behavior and sealability of the lid system

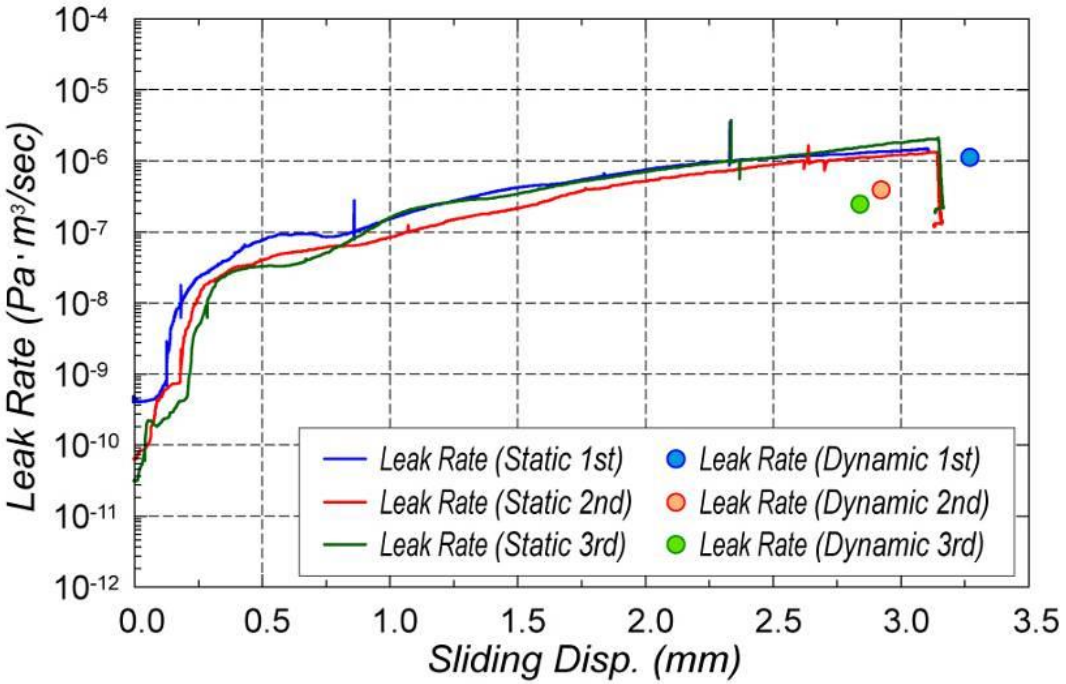
Contents

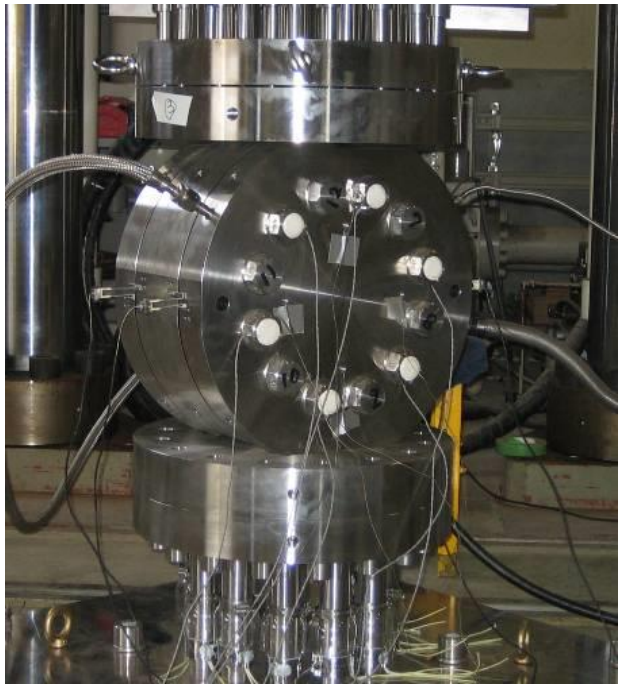
- Leakage criteria for cask lid structure using metal gasket
- Airplane crash test with reduced engine missile and full-scale lid structure of the dry cask
- Missile Impact analysis by impact code, LS-DYNA
- Possibility to assess the sealing performance of the cask lid structure by numerical approach



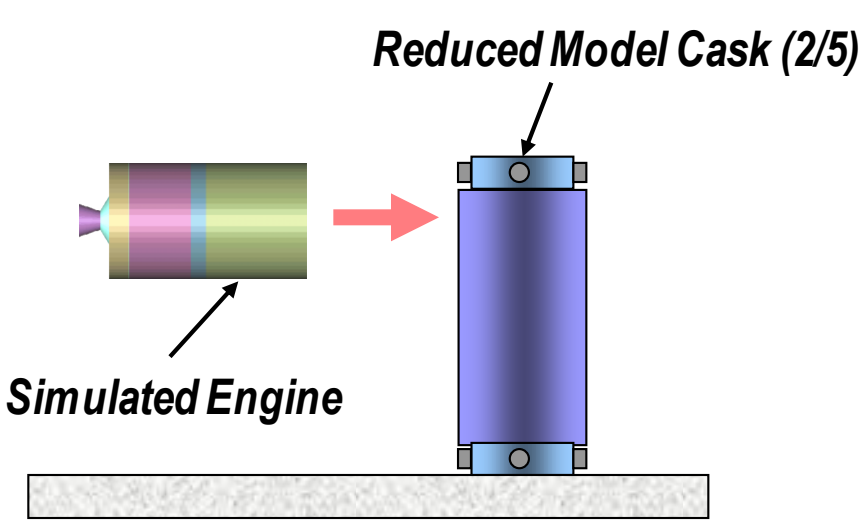
Leakage Criteria for Cask Lid Structure

- ***Leak tightness of the metallic gasket is very sensitive to lid movements***
- ***Leakage test with 1/10 scale cask lid sructure under impulsive loads***
  - ***Double aluminum metal gasket (C.S. Dia.=10mm)***
  - ***Aging Effect : 20hours at 180°C inside an oven***
- ***Instantaneous leak rate for aged metal can be evaluated by the relationship between the leak rate and the accumulated sliding displacement.***

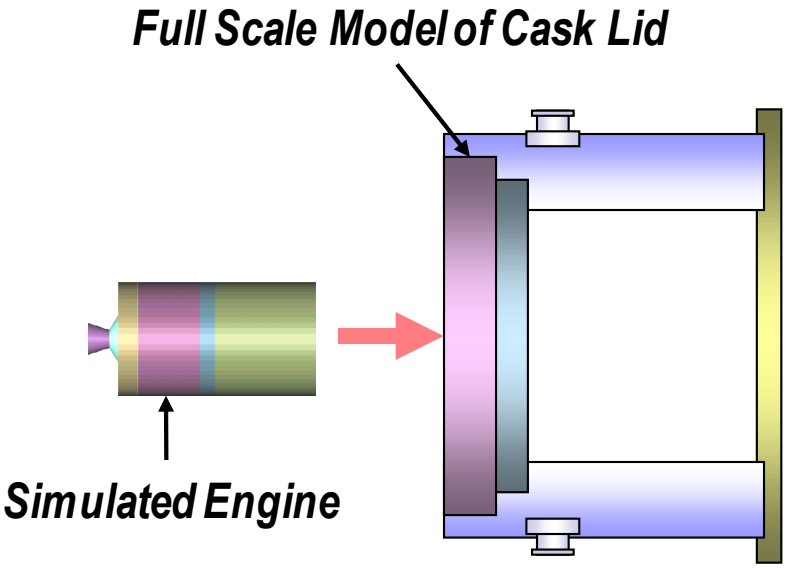




Airplane Crash Tests



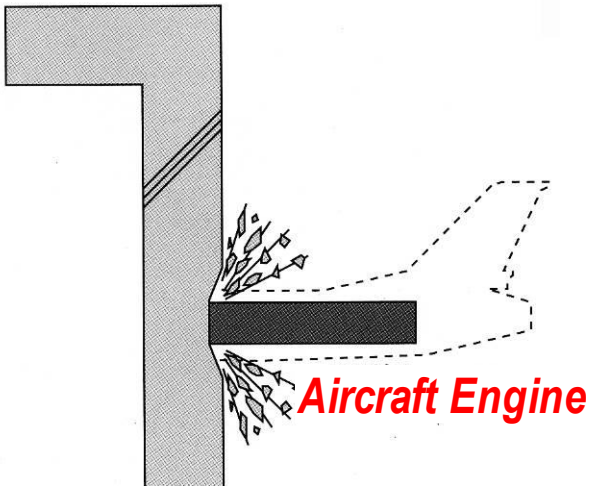
Horizontal impact test of 2/5 reduced cask model crashed by a simulated engine



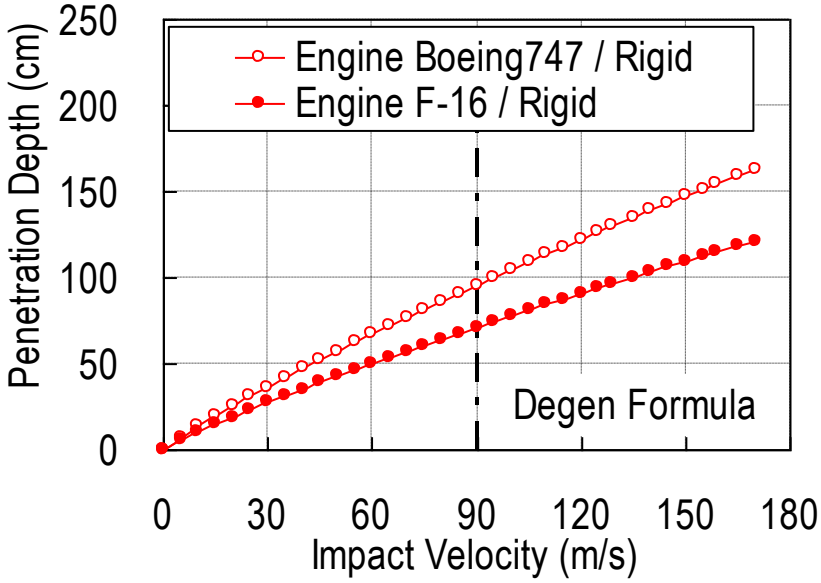
Vertical impact test of full scale model cask lid crashed by a simulated engine

Impact Velocity

- **Local penetration damage of the interim storage facility building against a relevant aircraft engine crash**
  - **Impact Velocity 90m/sec**
    - ✓ **Taking-off, landing speed of the passenger aircraft**
    - ✓ **Type C package test conditions in the IAEA Transport Regulation**

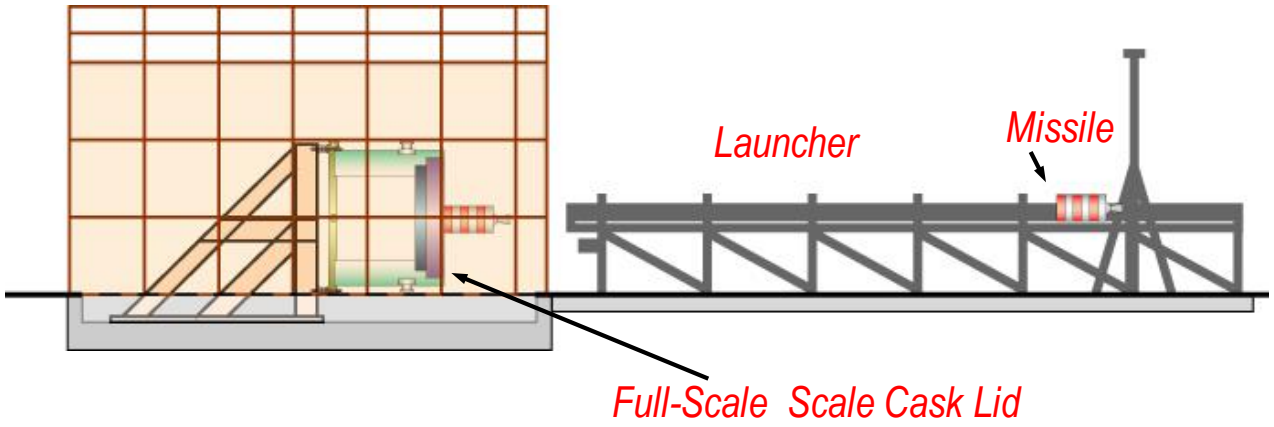


- **Penetration depth**
  - **Degen formula with rigid missile**
  - **Min. 96cm for impact velocity 90m/s**
- **Residual velocity of the engine missile**
  - **Design concept of the storage building**
  - **Wall thickness from 0.7m to 1.2m**
    - ✓ **after 70cm wall thickness penetration**
    - ✓ **Residual velocity about 60m/s**

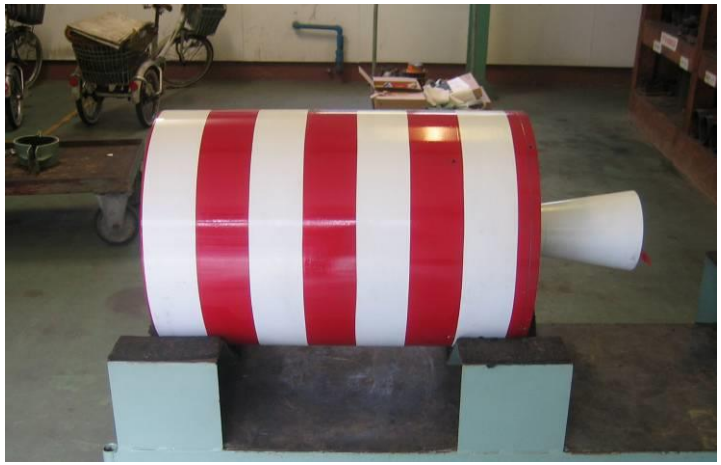


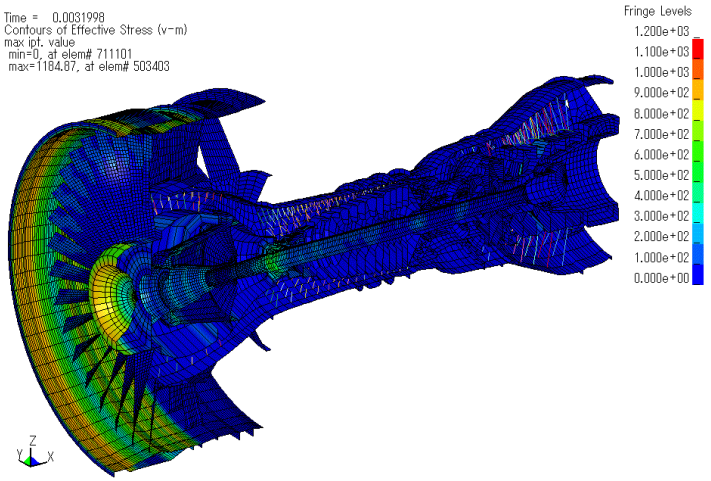
Vertical Impact Test

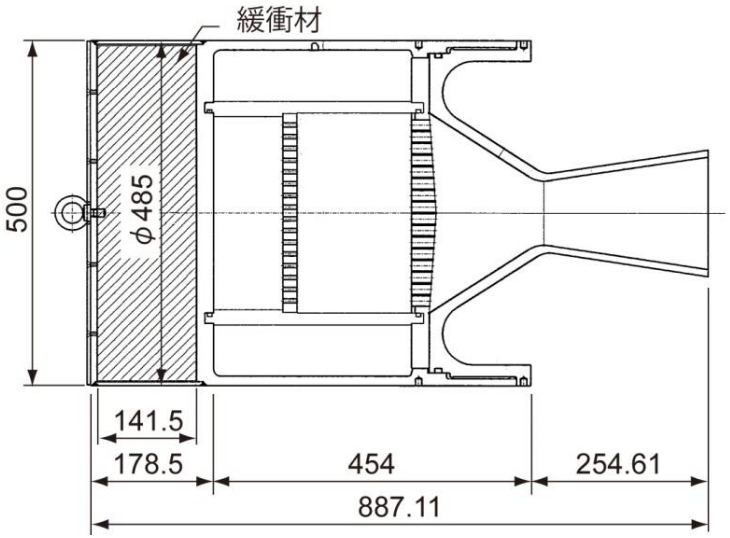
- ***Test Apparatus***
  - ***Full-scale metal cask lid structure for vertical impact test***
  - ***Deformable engine missile***
  - ***Test apparatus in the open air***



Engine Missile







Example of Aircraft Engine

- ***Weight***
  - ***302.5kg***
- ***Velocity (measured Value)***
  - ***65.0 m/s***
- ***Impact load adjusted by shock absorber to induce the equivalent damage to the 2nd lid***

Full-scale metal cask lid structure

- The lid model was cut from a full-scale transport/storage cask for 69 BWR spent fuel assemblies
- Specification
  - Double lids
  - Outer Diameter 2.5m, Height 2m
  - Weight : Body 28ton
    Primary lid 4ton, Secondary Lid 4ton
  - Metal gasket : Double Al Gasket
- Measurement items
  - Impact Load
  - Lid Bolt Stress
  - Sliding/Vertical Lid Disp.
  - Inner body Strain
  - Acceleration
  - Leak Rate
  - Inner Pressure between two lids

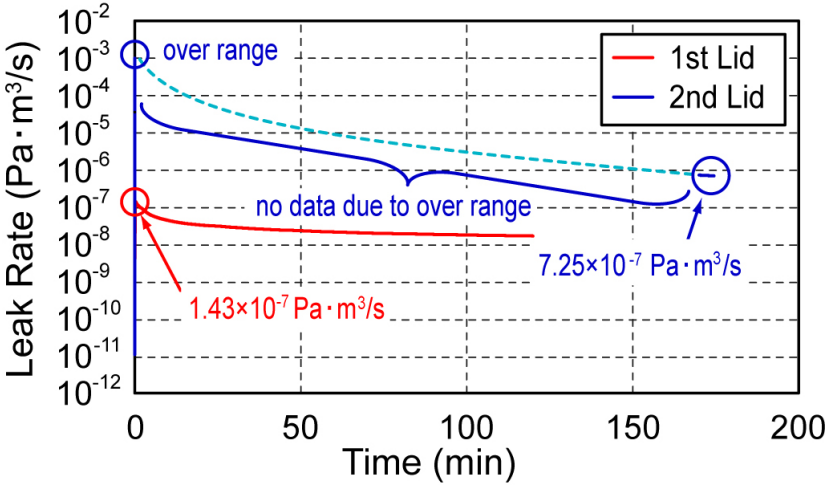
(Full-Scale Cask)

(Test Model)

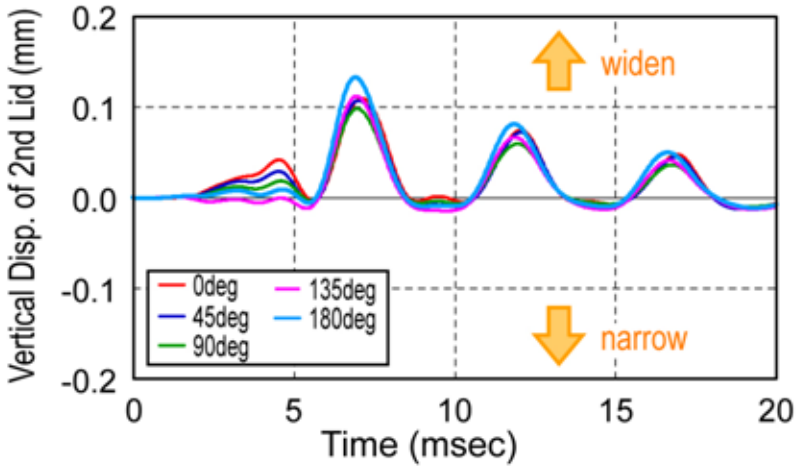

FRAME NO
00150
REC RATE
500
ID NO 1
DISPLAY
RATE 2
PLAYBACK
PLAY
LIVE
BLOCK
S
E
MULTI
REC MODE
START
READY
REC

Vertical Impact Test Results

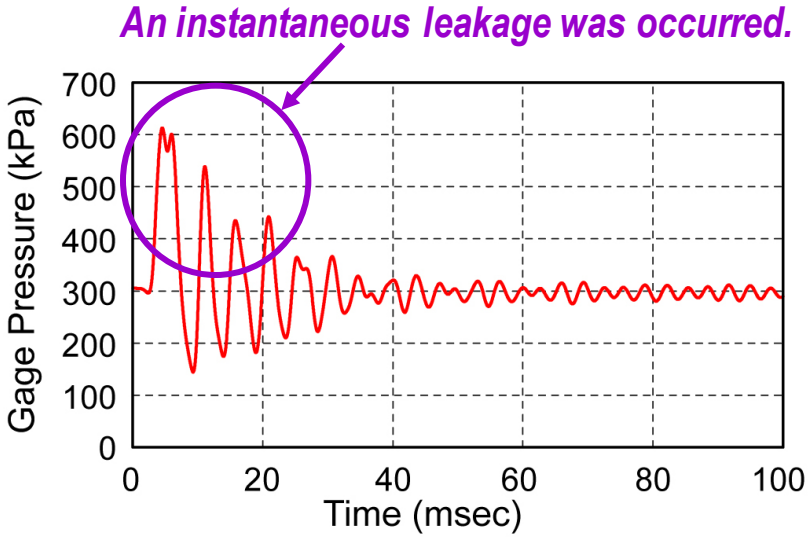
- Leak rate was over-ranged due to the opening displacement which leaded an instantaneous leakage
- After loading, the leak rate recovered to less than 1.0×10^{-6}



(He Leak Rate)



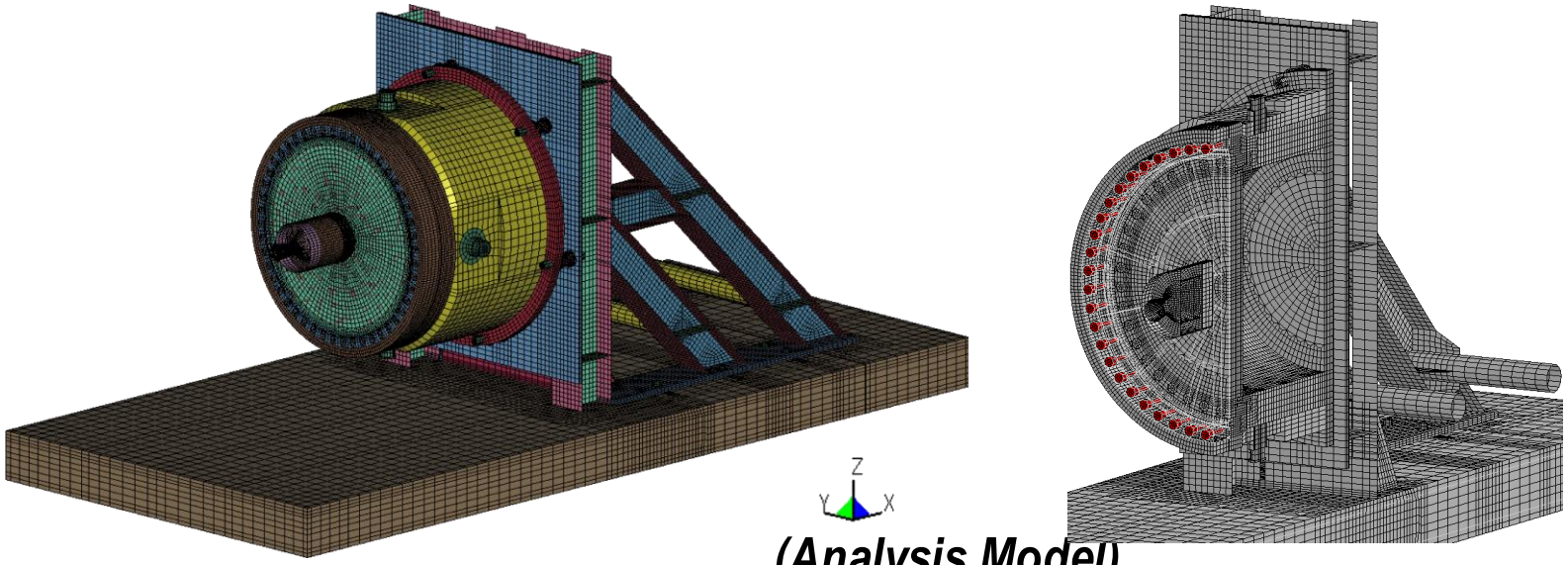
(Lid Displacement :2nd lid)



(Inner Pressure)

Applicability of Numerical Approach

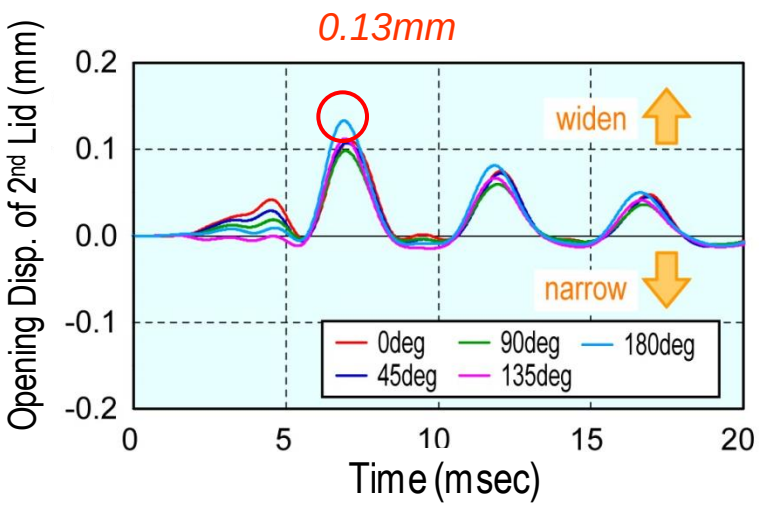
- ***Benchmark to simulate dynamic lid behavior during impact load***
  - ***LS-DYNA Ver.970***
  - ***Analytical condition***
    - ✓ ***Friction coefficient***
    - ✓ ***Initial tightening lid bolt force***
    - ✓ ***Gasket reaction force***
    - ✓ ***In-house Concrete and Neutron Absorber Material Model***



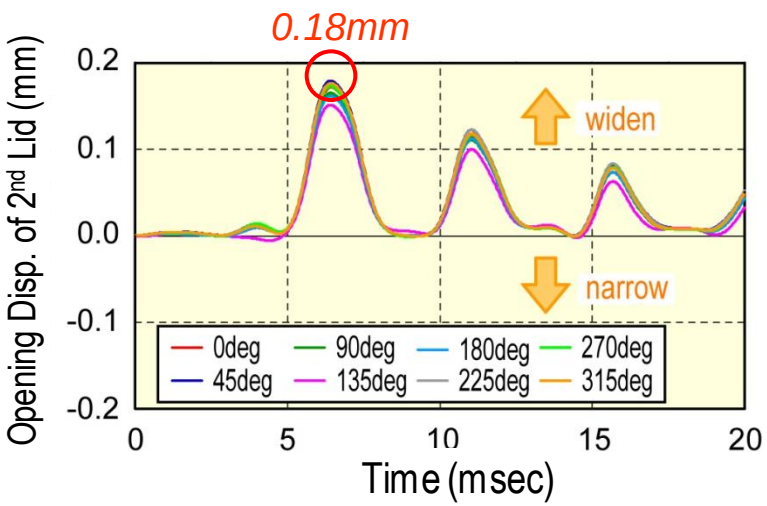
(Analysis Model)

Applicability of Numerical Approach (Cont'd)

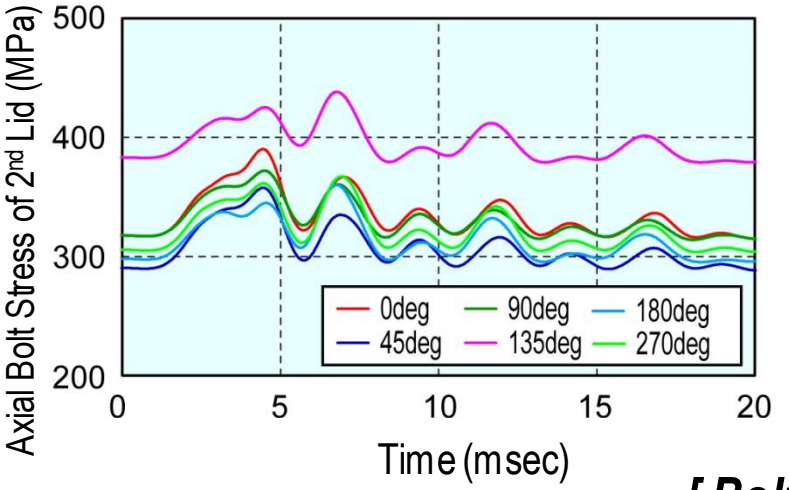
Experiment

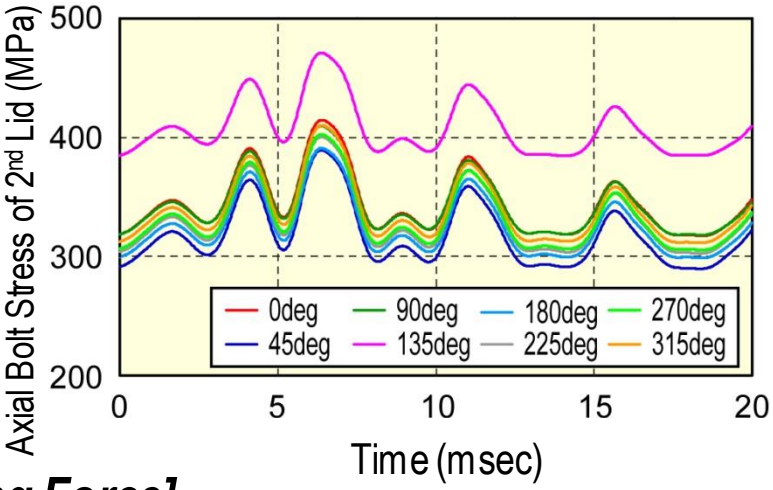


Analysis



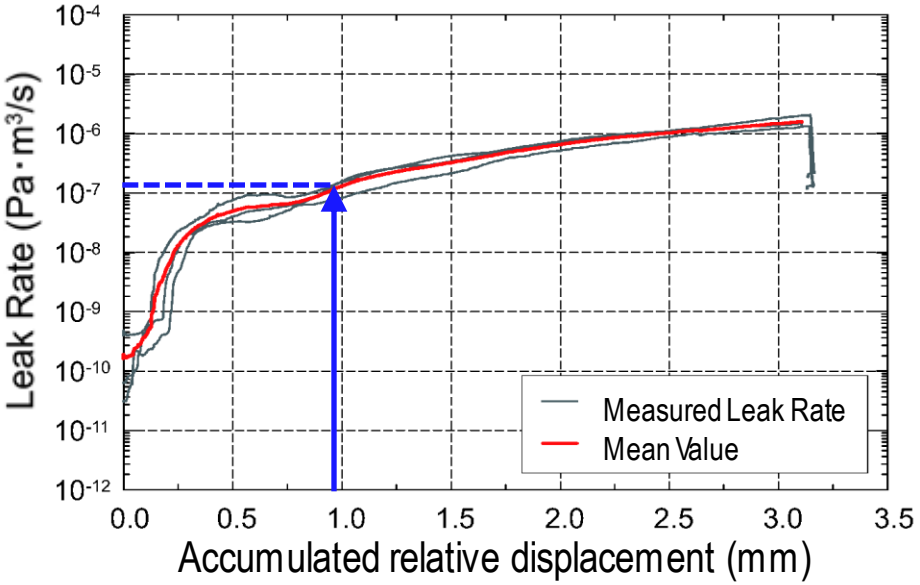
[Opening Displacement]

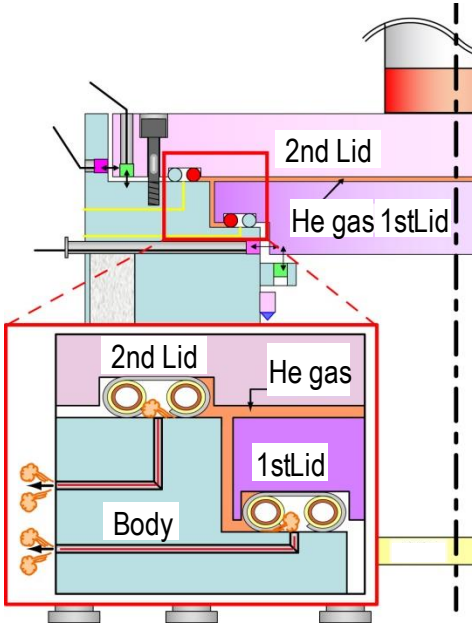




[Bolting Force]

Sealing Performance Evaluation





[Evaluation Results of 2nd Lid]

Parameter	Experiment	Analysis
Sliding (accumulated)	1.02 mm	0.96 mm
Opening	0.13 mm	0.18 mm
Bolt Stress	438 MPa	471 MPa
Leak Rate	7.25×10^{-7} Pa·m³/s	1.15×10^{-6} Pa·m³/s

Summary

- *The experimental study for aircraft engine crash onto the metal cask without impact limiters has been executed to clarify the extent of reducing the cask integrity and the leakage increase.*
- *After the lid behaviours have been evaluated, it was found that the leakage rate from the lid would be low and release of radioactive substances in the cask would be avoided in the extreme impact loading conditions.*
- *The impact analysis code LS-DYNA could reproduce the impact behavior and the containment performance of the metal cask sealing system under the extreme impact loads due to aircraft crash. Therefore, numerical approach is possibly feasible for the sealing evaluation.*