Evaluation of the sealing performance of a metal cask subjected to vertical and horizontal impact load due to aircraft engine crash

*CRIEPI*
(Central Research Institute of Electric Power Industry)

K. SHIRAI, K. NAMBA and T. SAEGUSA

Background

- *After the terrorist attacks from 11th September 2001*
- *Accident scenarios exceeding the design requirements, e.g. Forced aircraft crash*
- *Corresponding analysis have been executed with regard to <u>the assessment of the inherent safety</u> in an interim NSF storage facility*


~ 23 m
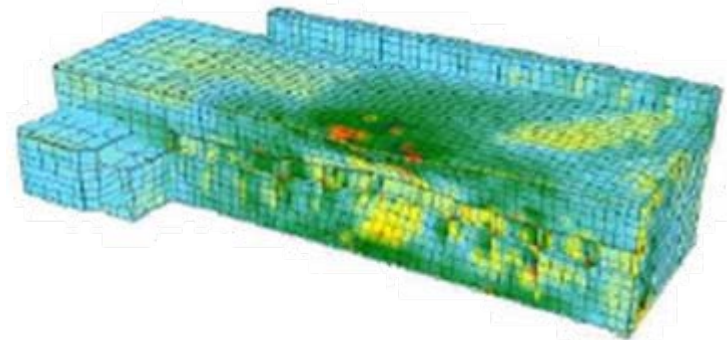
Example by BAM, Germany

- *It is important to ascertain whether a forced aircraft crash event could lead to a significant release of radioactive substances into the environment.*

Aircraft Crash Test

- *To evaluate integrity of a metal cask under a hypothetical airplane crash accident.*
- *Dynamic mechanical behavior of the metal cask lid closure system under extreme impact loads*
- *Key issue "Leak tightness of the metallic gasket is very sensitive to <u>lid movements</u>"*
- *Study Flow*
  - *Assume a <u>big passenger aircraft engine crash into a cask storage facility, its engine penetrates the facility and hit the cask.</u>*
  - *Estimate the reduced velocity of the penetrating engine.*
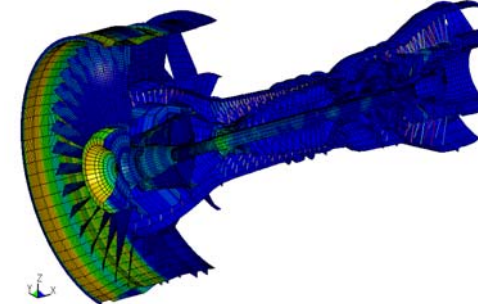
  - *Determine the impact load vs. time function of the engine crash on cask.*
  - *Choose the most critical scenarios for the metal cask.*
  - *Execute the Impact Test and Analysis by LS-DYNA.*
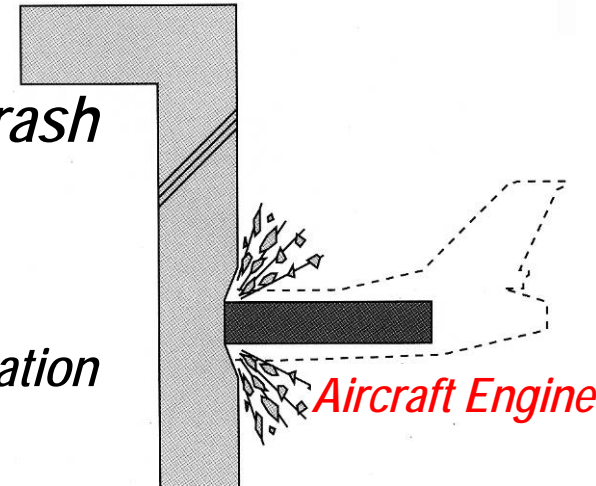 - *Estimate the maximum leakage rate from the metal gasket of the cask lid.*

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*
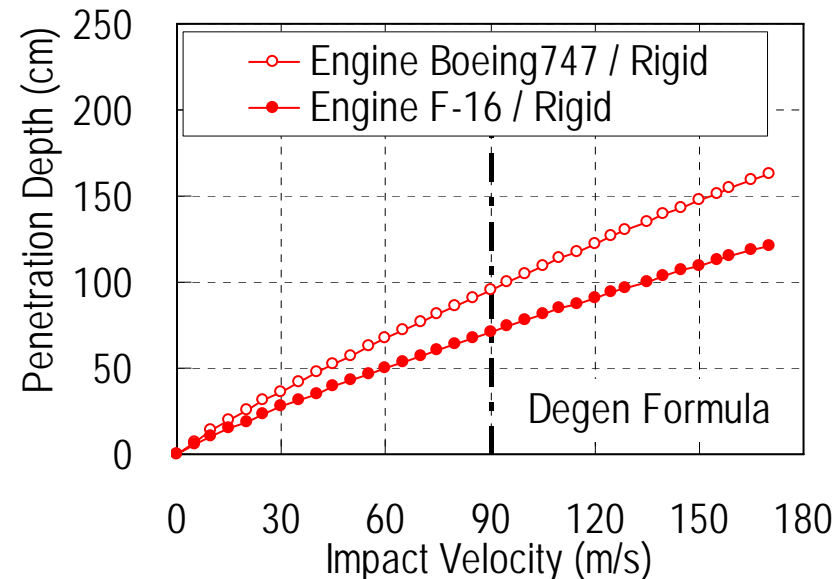   *in the IAEA Transport Regulation*

- Penetration depth
  - Degen formula with rigid missile
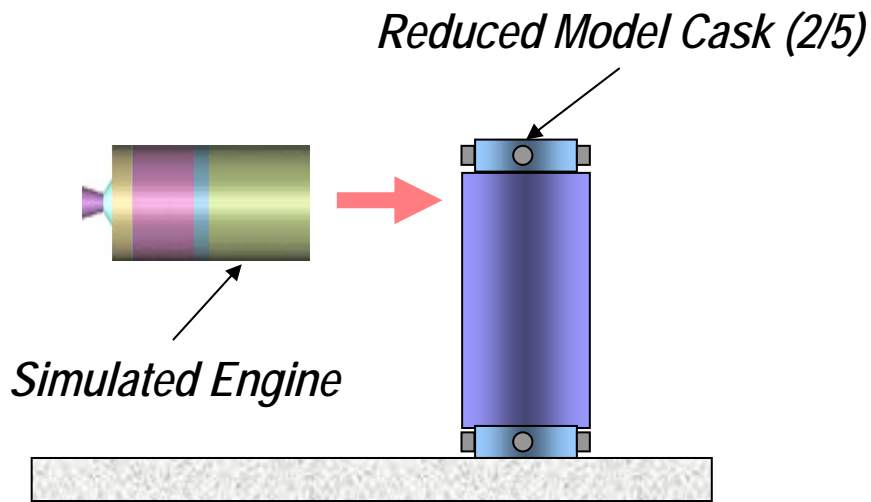   - *In case of the impact velocity 90m/s*
    - *Over 96cm*

- Reduced velocity of the engine missile
  - *Design concept of the storage building*
  - *Wall thickness from 0.7m to 1.2m*
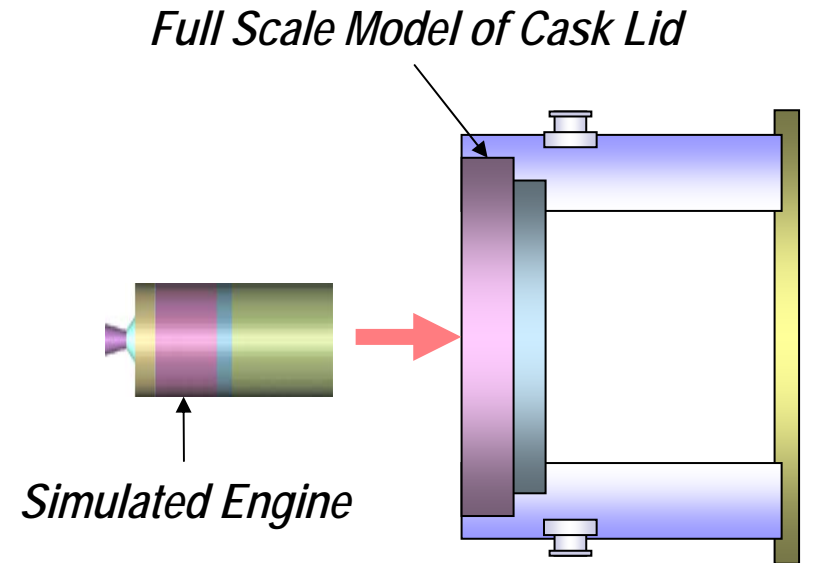   *e.g. after 70cm wall thickness penetration*
    Reduced velocity about 60m/s

Aircraft Engine

Test Plan for Airplane Crash Tests

Reduced Model Cask (2/5)

Simulated Engine

Horizontal impact test of 2/5 reduced cask model crashed by a simulated engine (Jan. 2008)

Full Scale Model of Cask Lid

Simulated Engine

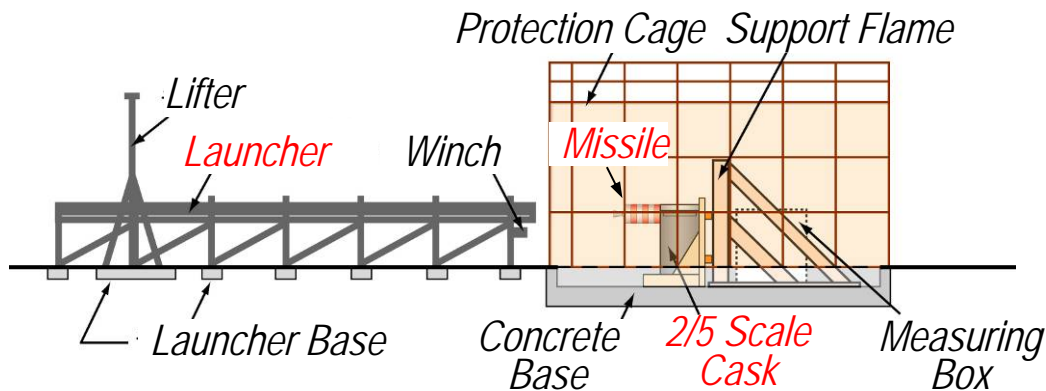Vertical impact test of full scale model cask lid crashed by a simulated engine (Nov. 2008)
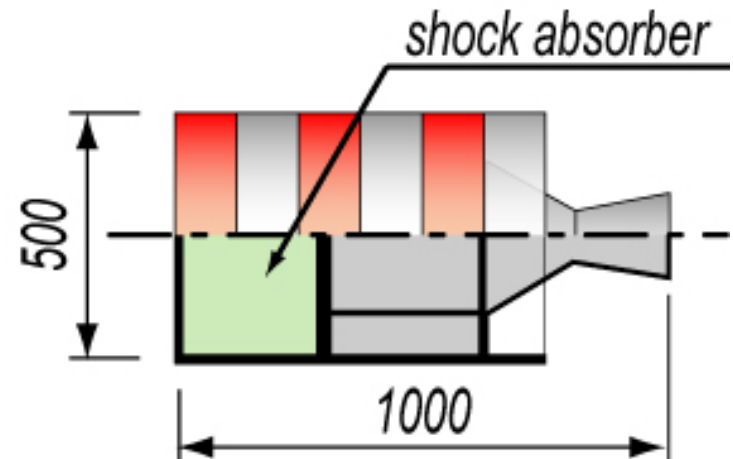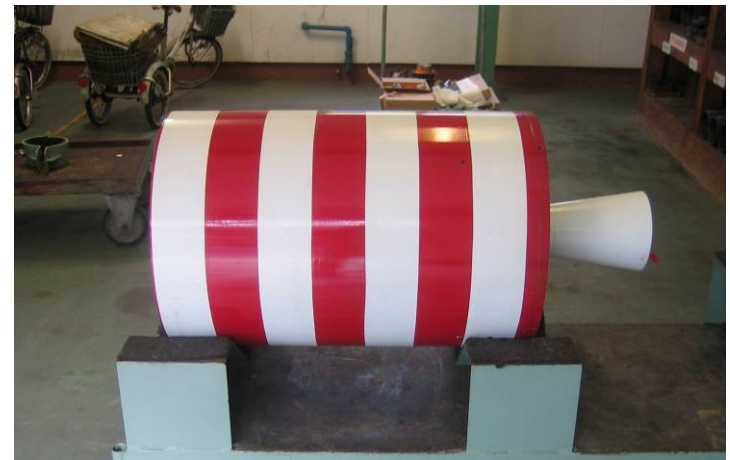
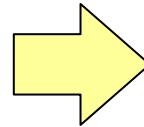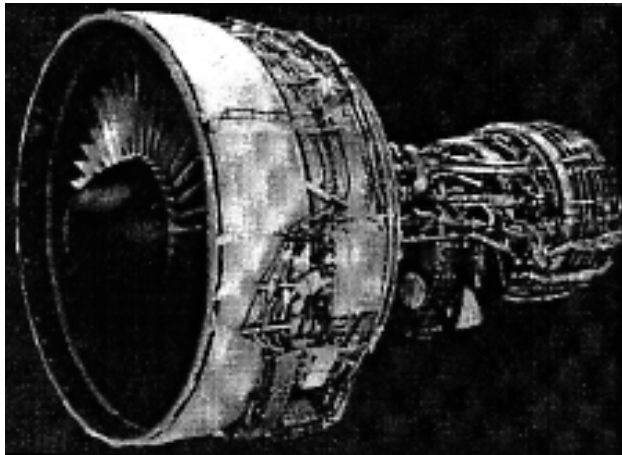# *Horizontal Impact Test*

- *Objective*
  - *Verification of simulation code to estimate the behavior of a cask under extreme impact load*
- *Test Apparatus*
  - *2/5 scale metal cask for horizontal impact test*
  - *Full-scale metal cask lid structure*
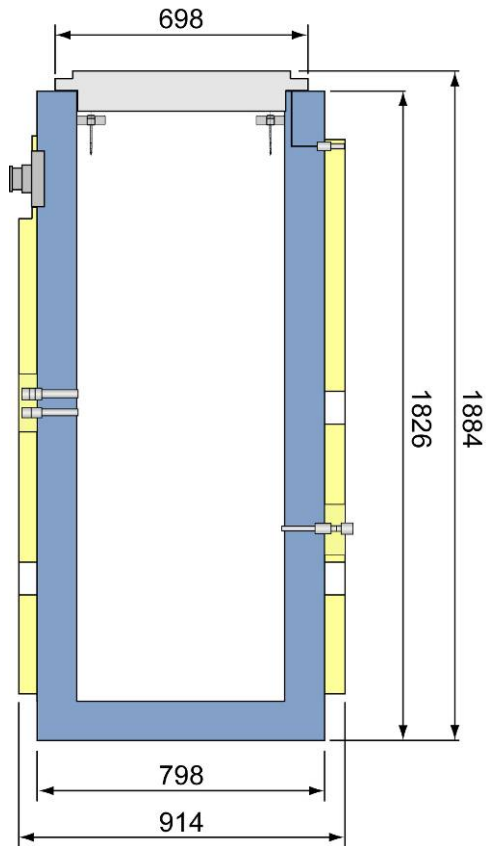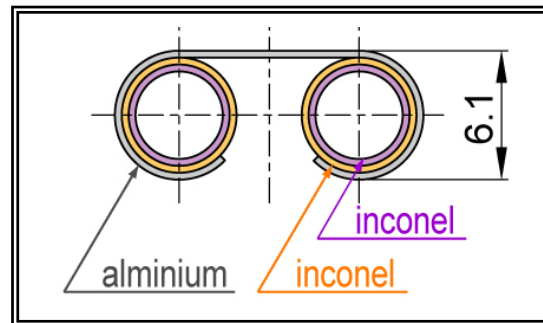 - *Deformable missile*
  - *Test apparatus in the open air*

Protection Cage   Support Flame

Lifter

Launcher   *Winch*   *Missile*

Launcher Base   *Concrete Base*   *2/5 Scale Cask*   *Measuring Box*

Missile

shock absorber

500

1000

- *Weight*
  - *4400kg*
- *Velocity*
  - *60m/s*

- *Weight*
  - *316kg*
- *Velocity (measured Value)*
 - *57.3 m/s*

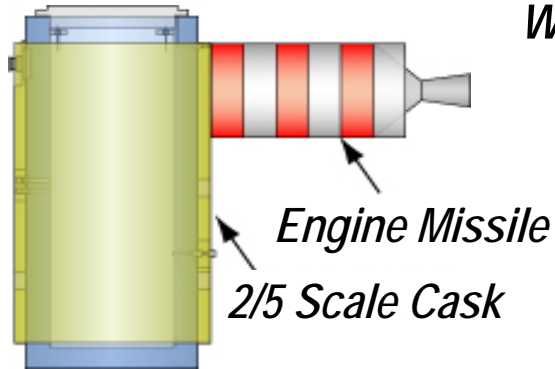# 2/5 scale cask

Body

Lid

- *Structure*
  - *2/5 scale metal cask*
  - *Single lid*
- *Weight*
  - *Body : 4.17 ton*
  - *Lid : 0.29 ton*
- *Gasket*
  - *Double Aluminum Metal Gasket (C.S.Dia. 6.1mm)*
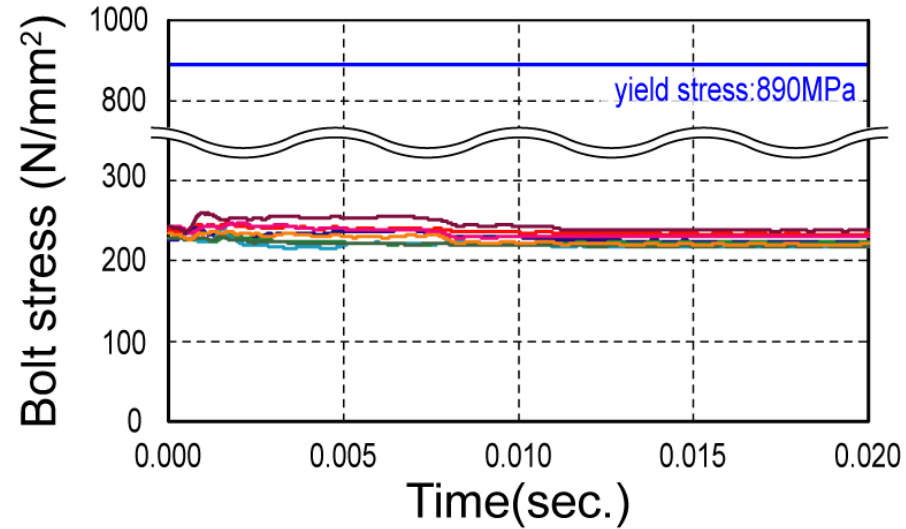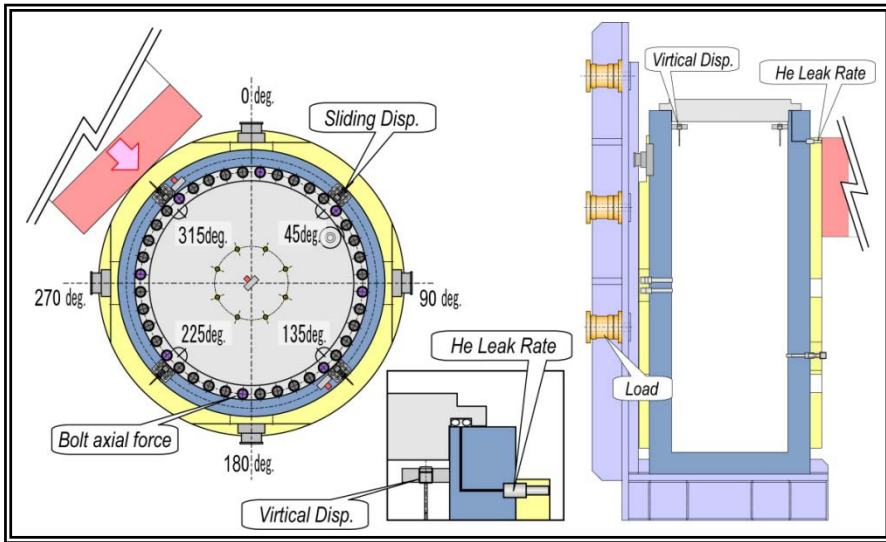 - *Aging effect (over 30hours under 175ºC*

alminium / inconel / inconel / 6.1

Impact Test Results (1)

- *The peak value of total reaction forces was 485kN*
- *Measured leak rate was under 1.0×10^{-5} Pa·m³/s*
  within the permissible value for a transport cask.

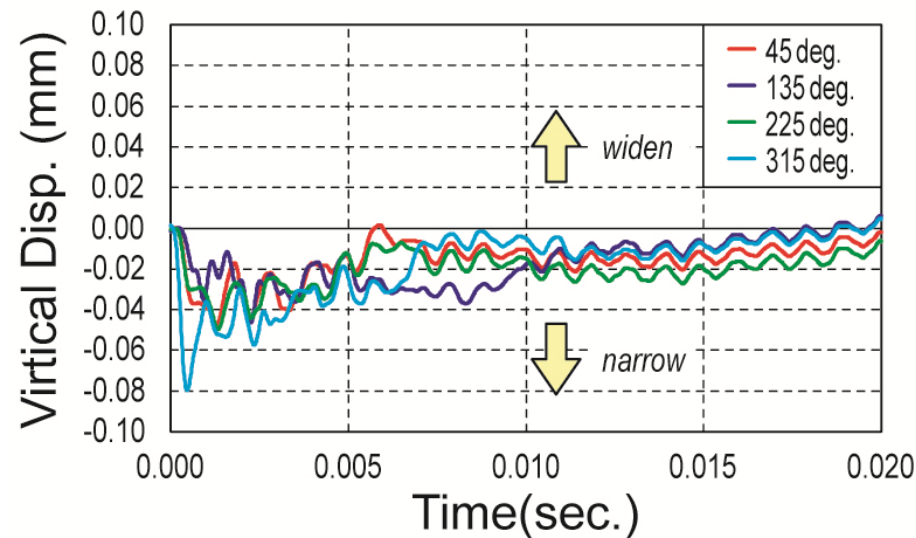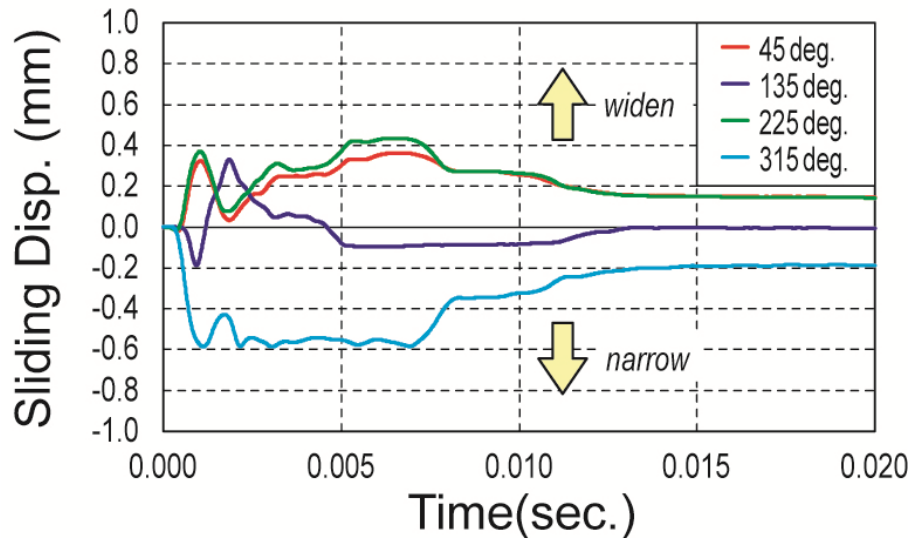Engine Missile
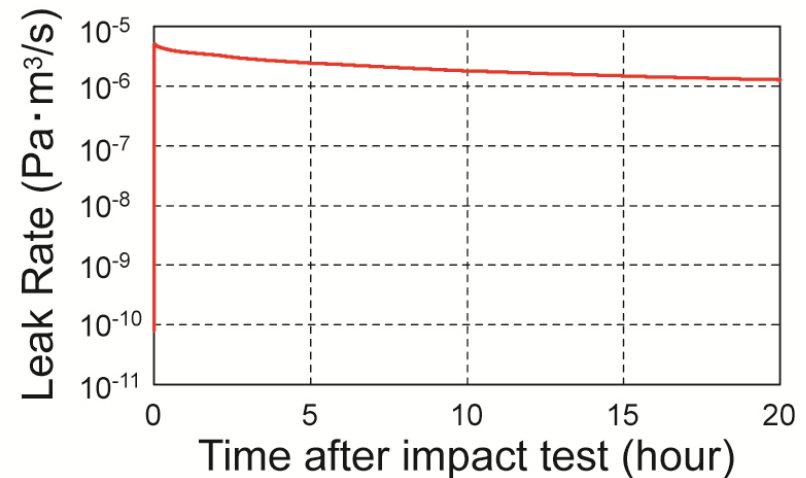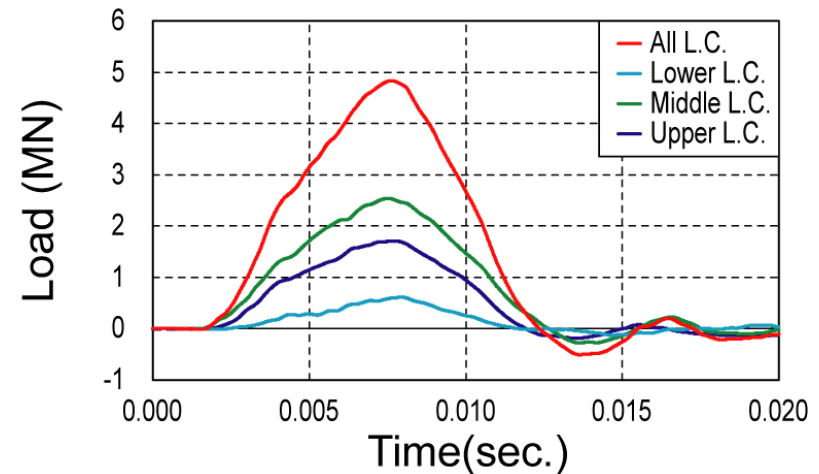
2/5 Scale Cask

◁▦ *Video*   ◁▦ *High Speed Camera*

Impact Test Result (2)

(Measurement)

Similarity Law Employed in the Scale Model Test

Parameter	Dimension	Ratio	Typical quantities
Length	L	$L_m/L_p = 1/s$	Missile/Cask dimension
Mass	M	$m_m/m_p = 1/s^3$	Missile/Cask mass
Time	T	$T_m/T_p = 1/s$	Impact Duration Time
Velocity	LT^{-1}	$v_m/v_p = 1$	Missile velocity
Force	MLT^{-2}	$F_m/F_p = 1/s^2$	Impact force Reaction force
Sealability	ML^2T^{-3}	$Q_m/Q_p = 1/s^2$	He Leak Rate

s: geometrical scale factor, p: prototype, m: scale model

from Leakage Characteristic Test
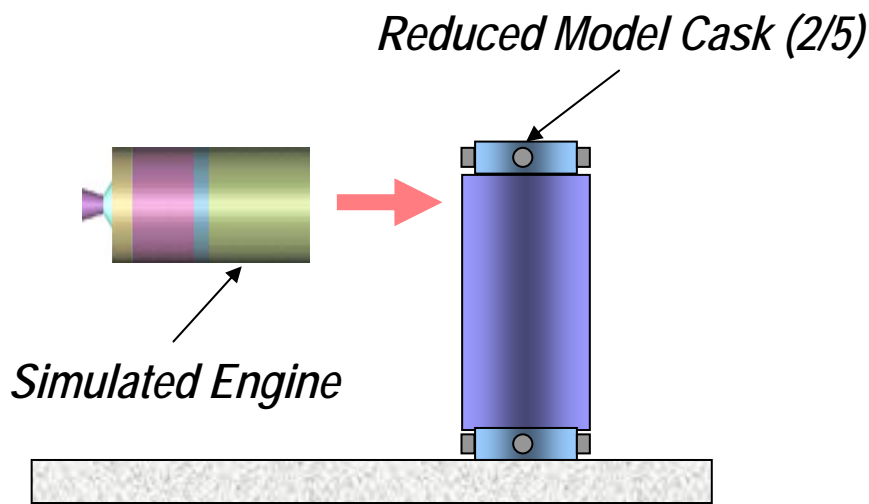
$$7.9 \times 10^{-6} \ Pa \cdot m^3 / sec$$
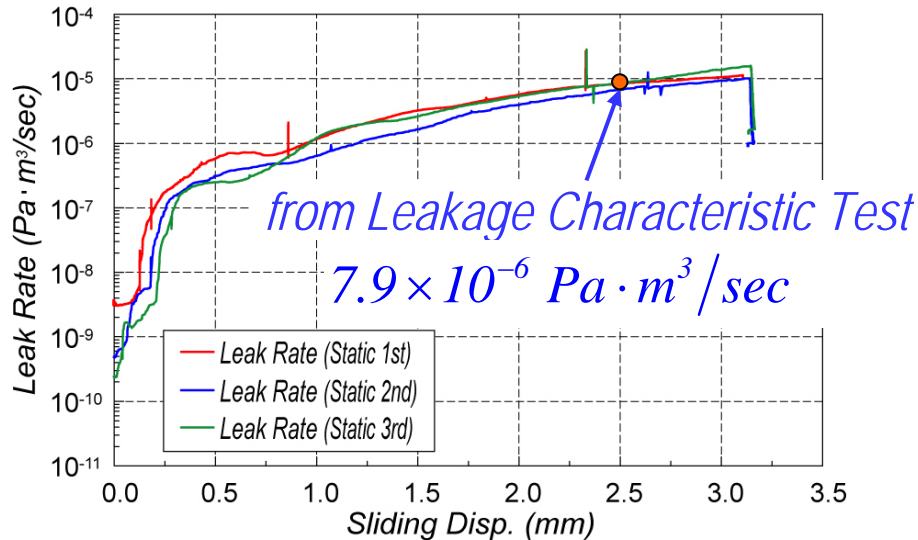
Estimated Leak rate of Prototype Cask

From Similarity Law
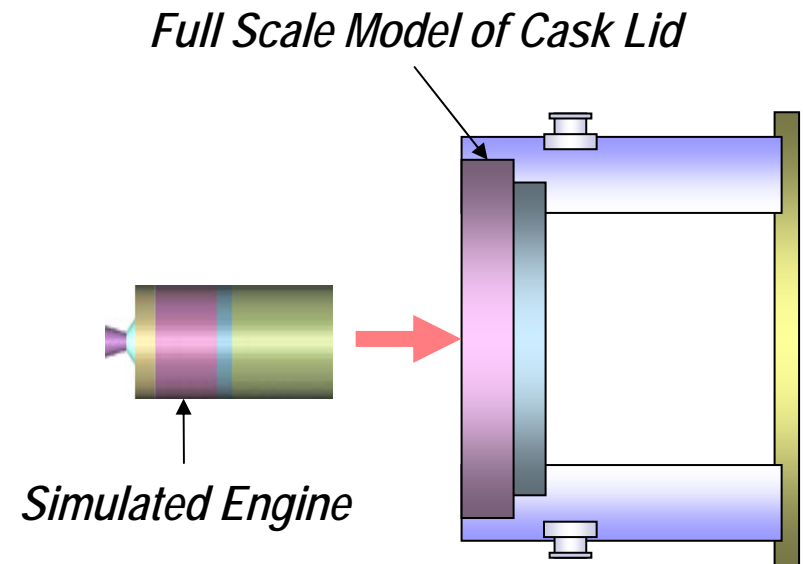
$$Q_p = \frac{Q_m}{(1/s^2)} = \frac{4 \times 10^{-6}}{(2/5)^2}$$

$$= 2.5 \times 10^{-5} \ Pa \cdot m^3 / sec$$

The applicability of the similarity law was confirmed through this test.

Test Plan for Airplane Crash Tests

Reduced Model Cask (2/5)

Simulated Engine

Horizontal impact test of 2/5 reduced cask model crashed by a simulated engine (Jan. 2008)

Full Scale Model of Cask Lid

Simulated Engine

**Vertical impact test of full scale model cask lid crashed by a simulated engine (Nov. 2008)**

Vertical Impact Test

Objective

- *Verification of simulation code to estimate the behavior of a cask under extreme impact load*
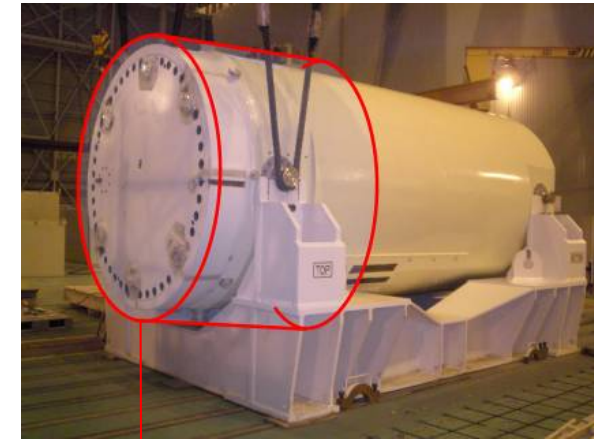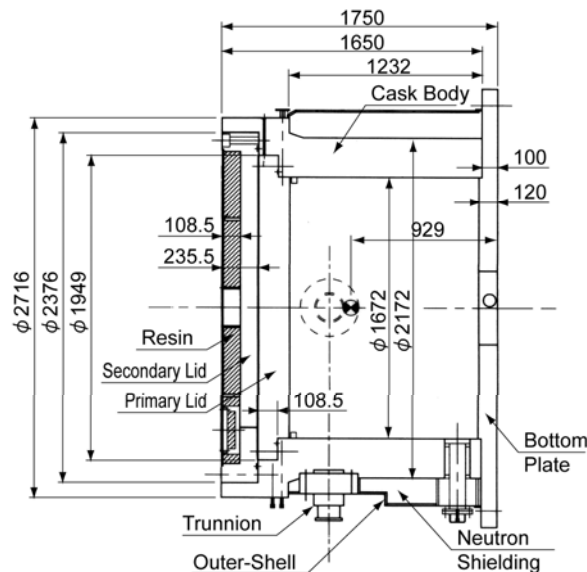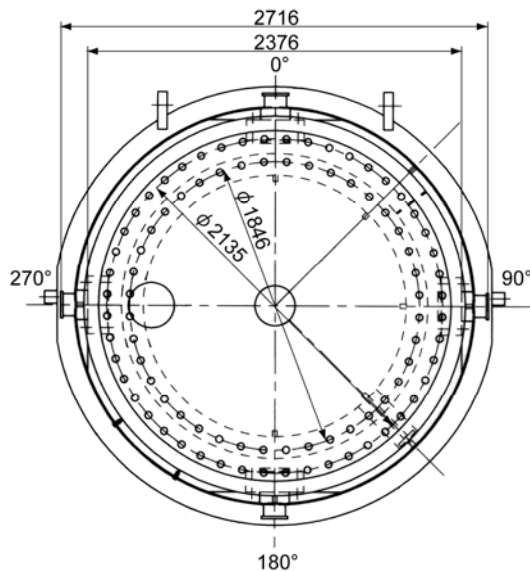
Test Apparatus

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

Launcher

Missile

Full-Scale Scale Cask Lid
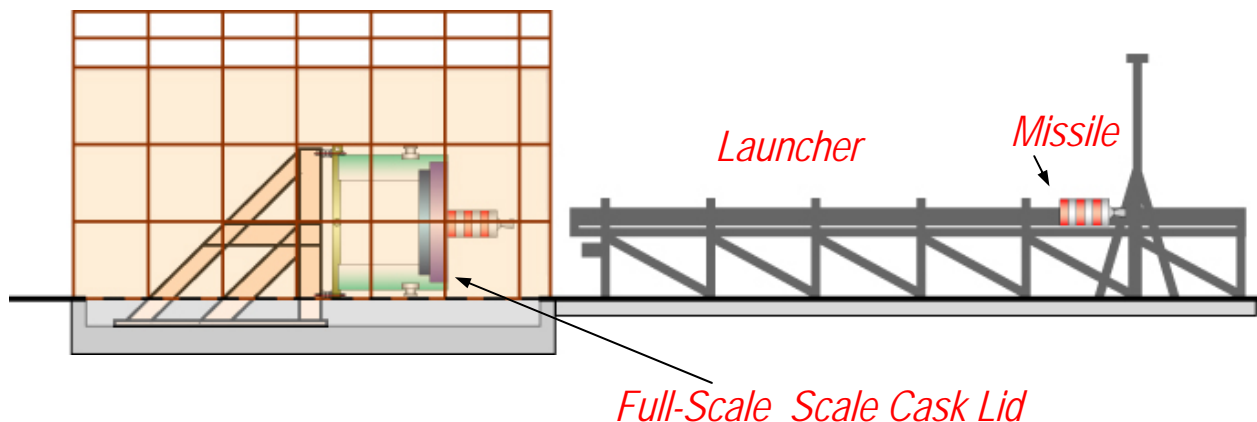
Full-scale metal cask lid structure

■ *Specification*

- ☐ *Double lids*
- ☐ *Outer Diameter 2.5m, Height 2m*
- ☐ *Weight：Body 28ton*
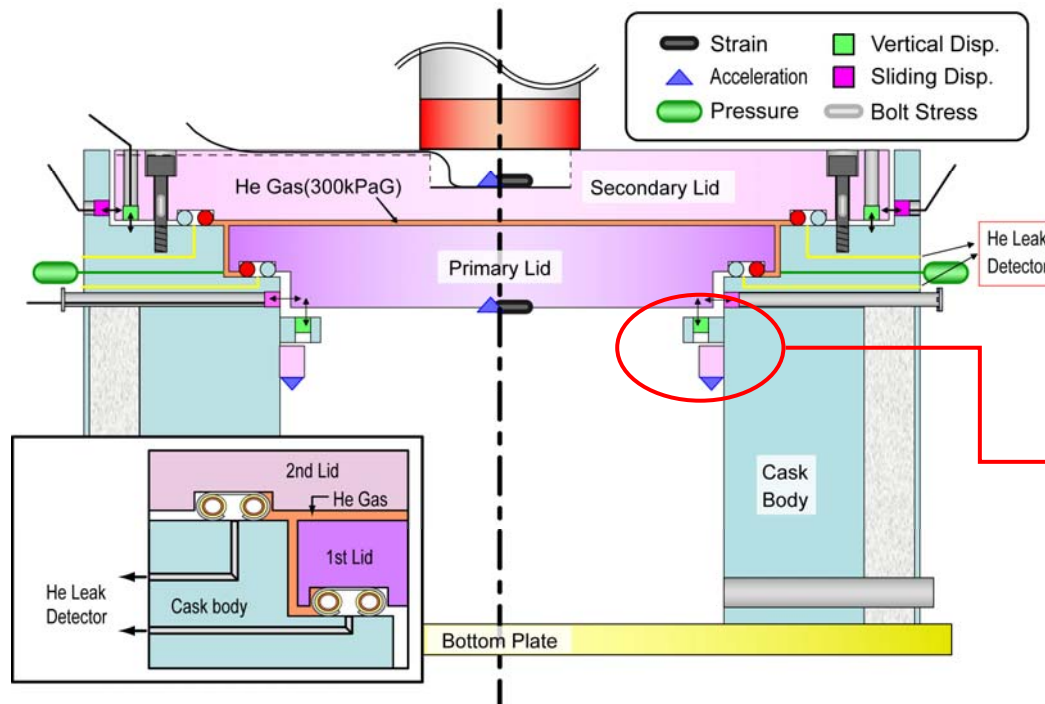   *Primary lid 4ton, Secondary Lid 4ton*
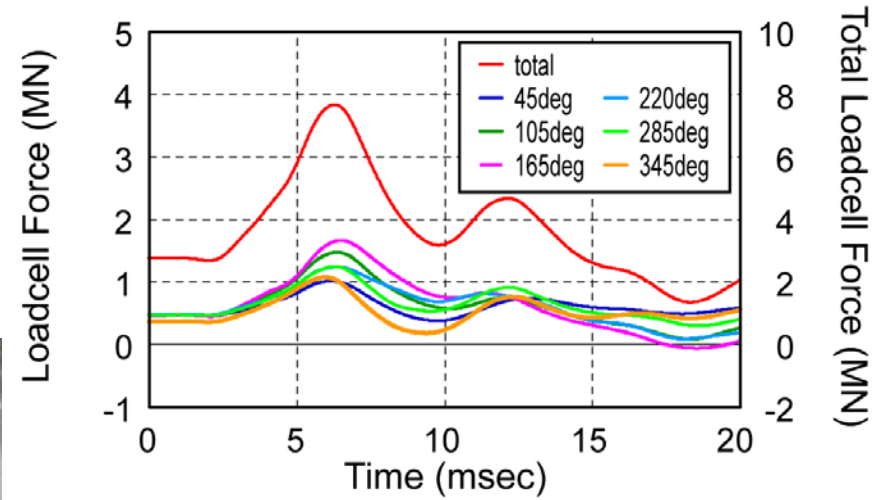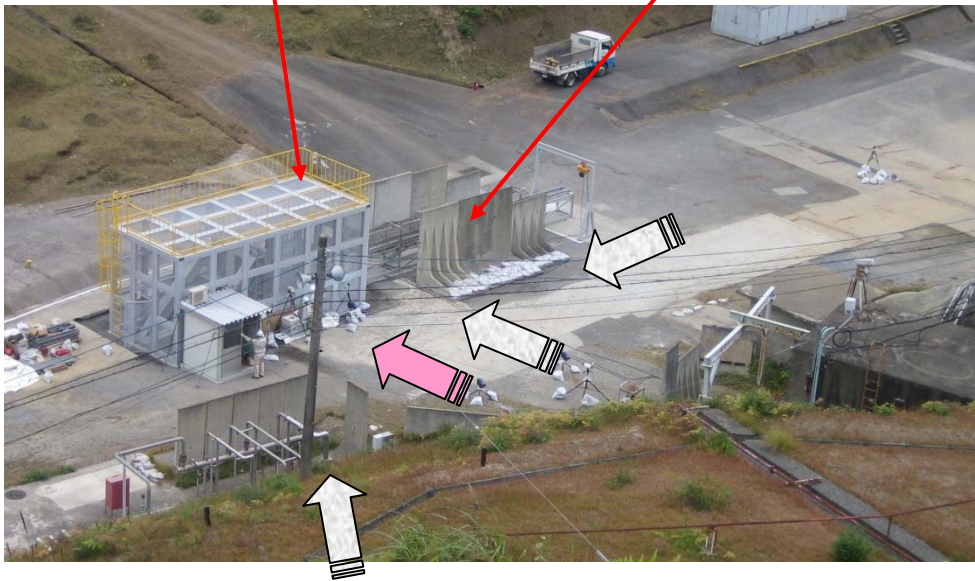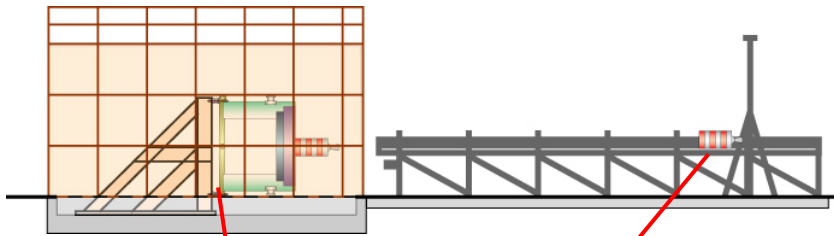- ☐ *Metal gasket ：Double Al Gasket*

(Full-Scale Cask)

(Test Model)

Measurement items

- Impact Load
- Lid Bolt Stress
- Sliding/Vertical Lid Disp.
- Inner body Strain

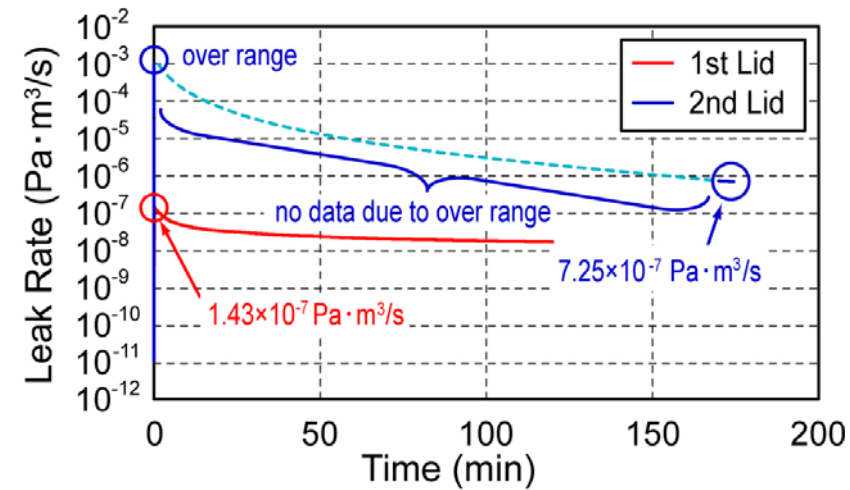- Acceleration
- Leak Rate
- Inner Pressure between two lids
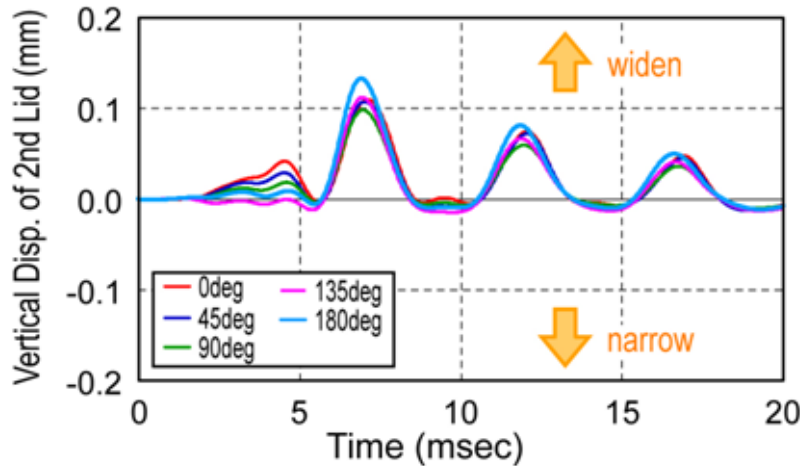

(Eddy Current Sensor)
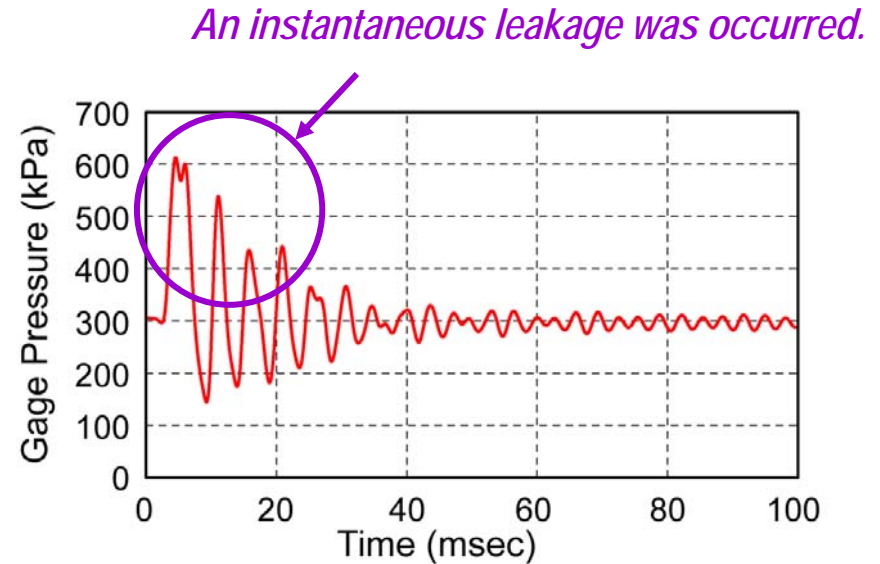
Vertical Impact Test

(Impact Force :Load Cell)

(He Leak Rate)

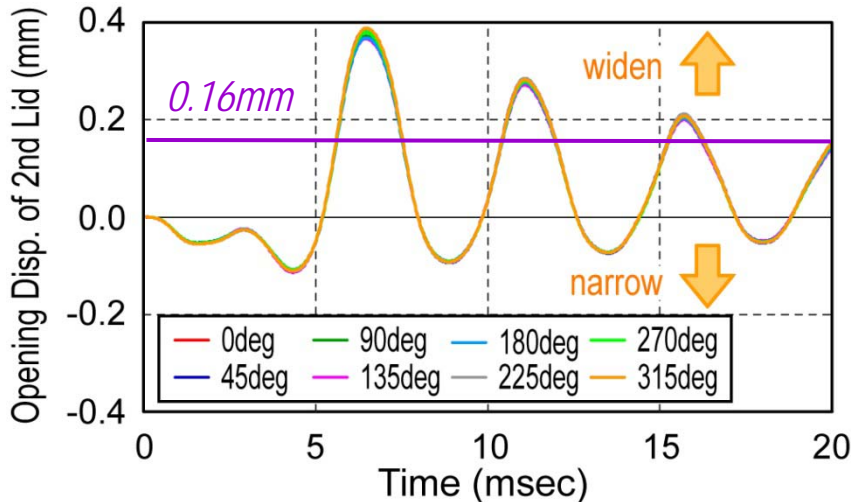# *Vertical Impact Test Results*

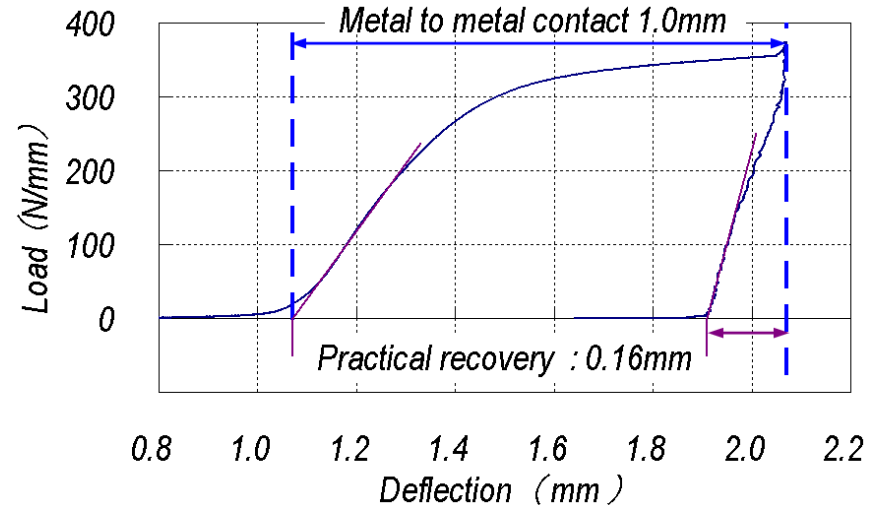*An instantaneous leakage was occurred.*

(Lid Displacement :2nd lid)

(Inner Pressure)

(Gasket Opening by LS-DYNA)

(Metal Gasket : Load vs. Deflection Curve)

Summary

■ *The experimental studies for aircraft engine crash onto the metal cask without impact limiters, using lid structure and engine missile, have 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.*