EVALUATION OF THE SEALING PERFORMANCE OF A METAL CASK SUBJECTED TO VERTICAL AND HORIZONTAL IMPACT LOAD DUE TO AIRCRAFT ENGINE CRASH

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ABSTRACT

In Japan, there are plans for the first interim spent nuclear fuel storage facility away from a reactor site to go into commercial operation in around 2012, featuring the use of dual-purpose metal casks and in the northern Honsyu island and with a business license examination for safety design approval underway since March, 2007. To demonstrate the more scientific and rational implementation of safety regulation activities during each phase for the initial license procedure, CRIEPI executed demonstration tests with full scale casks, such as drop tests onto real targets without impact limiters [1] and seismic tests subjected to strong earthquake motion [2]. Moreover, it is important to develop knowledge to ensure the inherent security of metal casks subjected to extreme mechanical impact, especially given the enhanced interest since the terrorist attacks of 11 September, 2001 [3]-[6]. To evaluate the potential damage to casks from an aircraft crashing at the storage facility, a numerical evaluation was performed for two impact scenarios, a vertical impact onto the lid structure and a horizontal impact hitting the cask [7]. Moreover, according to these scenarios, two impact tests by aircraft engine missiles onto the metal cask without impact limiters were executed, during which the leak rate from the metal gasket in the cask was also measured on impact [8]. This paper presents the dynamic mechanical behavior and confinement integrity of the metal cask lid closure system as obtained in the impact tests.

INTRODUCTION

Following the terrorist attacks on 11 September, 2001, accident scenarios exceeding design requirements, such as forced aircraft crashes, were considered, and corresponding analyses have been executed in order to assess the inherent security in an interim nuclear spent fuel storage facility with combined transport and storage casks. With this in mind, it is important to ascertain whether a forced aircraft crash event could lead to a significant release of radioactive substances into the environment [7]. In this study, to investigate the integrity of the lid structure of the metal cask during extreme impact loads caused by an aircraft crash, two impact tests involving aircraft engines crashing into the metal cask without impact limiters were executed in the form of a horizontal impact hitting the cask [8] and a vertical impact onto the lid structure, as shown in Fig. 1. This paper presents the dynamic mechanical behaviour and confinement integrity of the metal cask lid closure system (in particular, the leak tightness based on relative dynamic displacements between metallic seals) as obtained in the horizontal and vertical impact tests.

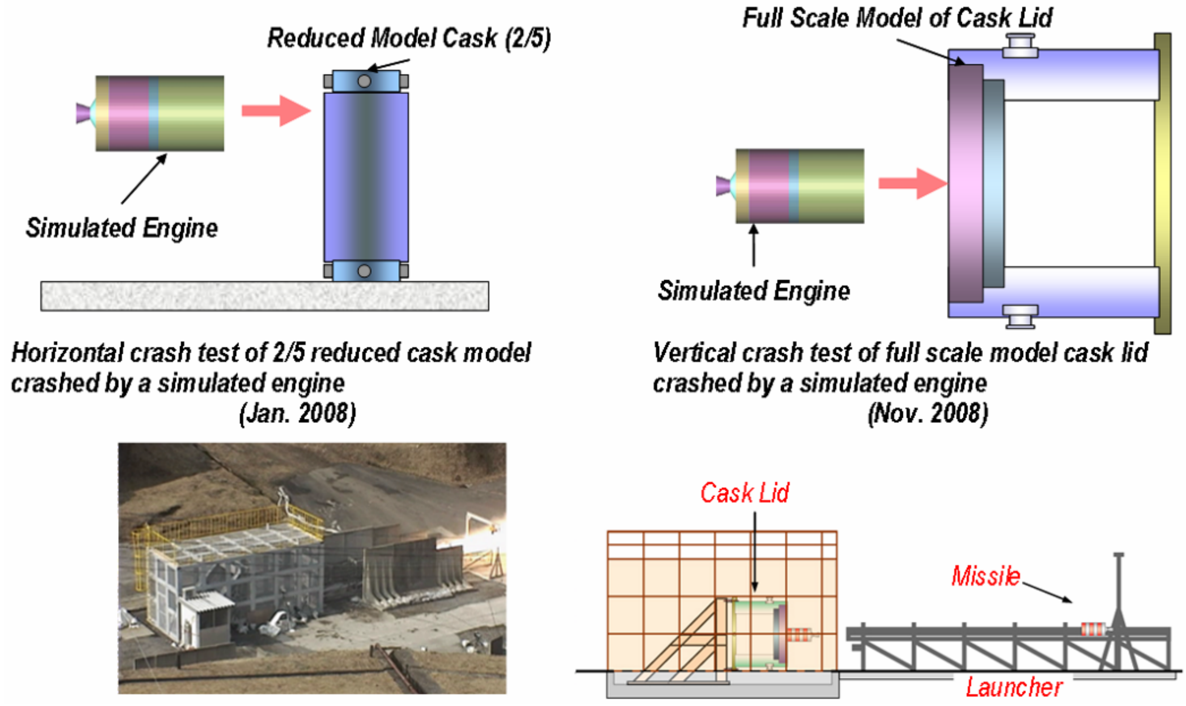

Fig. 1 Outline of Aircraft Engine Crush Test

LEAKAGE CHARACTERISTIC OF THE CASK LID STRUCTURE

With the aim of evaluating any instantaneous leakage on impact, a series of leakage tests were conducted using a 1/10 scale model of a cask lid structure. The scale model consists of three flanges bolted together and helium gas installed in a groove of one of the outer flanges. The containment is maintained by an aluminum metal gasket (Dia. 10mm). To simulate the aging effect, these scale models were heated for 20 hours at 180˚C inside an oven prior to the tests. Fig. 2 shows the relationship between the amount of lateral sliding of the lid and the leak rate. Based on these results, it was determined that the relationship between the maximum sliding displacement and leak rate was not significantly dependent on the loading rate.

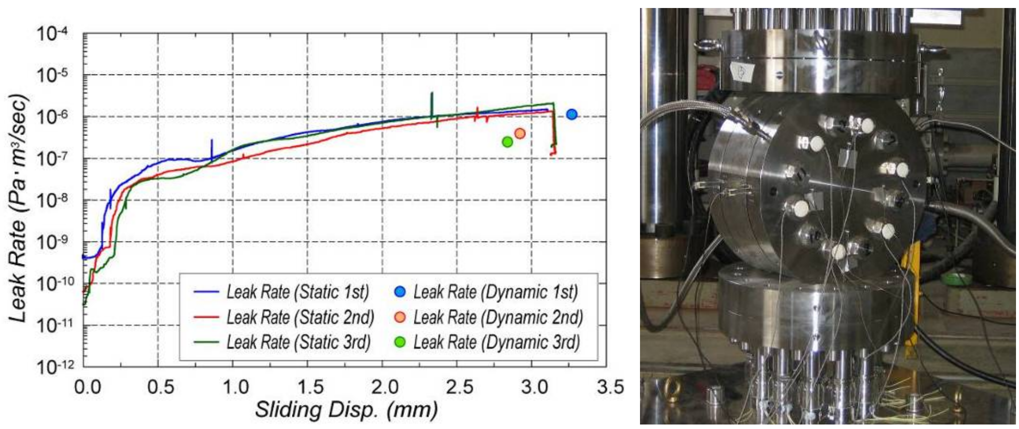

Fig. 2 Relationship between Leak Rate and Sliding Displacement of Scale Model

HORIZONTAL IMPACT TEST

Test condition

As a relevant aircraft engine, a turbofan engine, as used on major passenger planes, such as the Boeing 747 and Airbus 300, was chosen. Its length, outer diameter and weight are 2.7m, 4.3m and 4.4 tons respectively [7]. The local penetration damage of the interim storage facility building when exposed to a relevant aircraft engine crash was examined. The impact velocity was set at 90m/s considering the take-off and landing speed of the passenger aircraft, and the Type C package test conditions in the IAEA Transport Regulations [9]. The penetration depth can be calculated by a local damage formula, such as the Degen formula [10] for concrete structures. Considering the design concept of the storage building (wall thickness 80cm), the reduced velocity of the engine missile after penetration of the wall was estimated at about 60m/s [7].

Test description

The geometry scale factor for the test was set at 1/2.5, based on the constraints of the testing facility [8]. The lid gasket of the scale model cask is a double-type aluminum-coated metal gasket. To simulate the aging effect, the lid part was heated for over 30 hours under 175˚C. As the missile, a simplified deformable missile was used considering the rigidity of the actual aircraft engine. Figs. 3 and 4 show an overview of the missile and the scale model cask used in the horizontal impact test. The missile weight is 316kg with the deformable nose filled with shock absorbent material (foam aluminum) to control the impact load. The size of the scale model cask is about 900 mm in outer diameter, 1800 mm in height and gross weight of 4.4 tons.

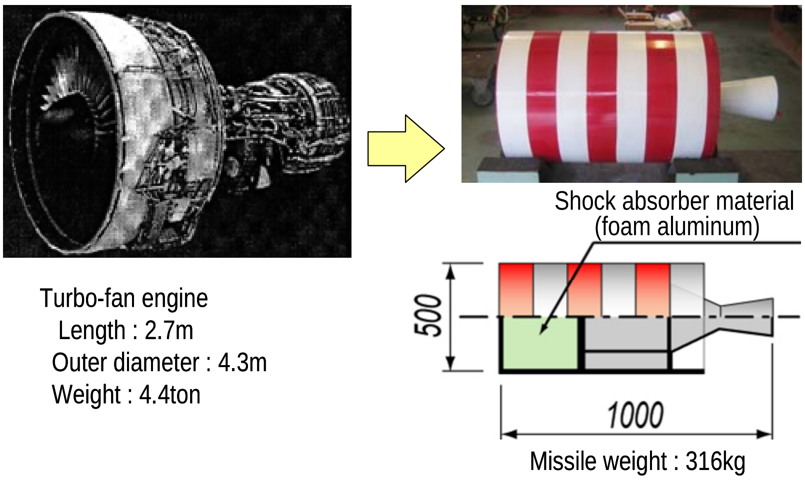

Fig. 3. Overview of the Missile

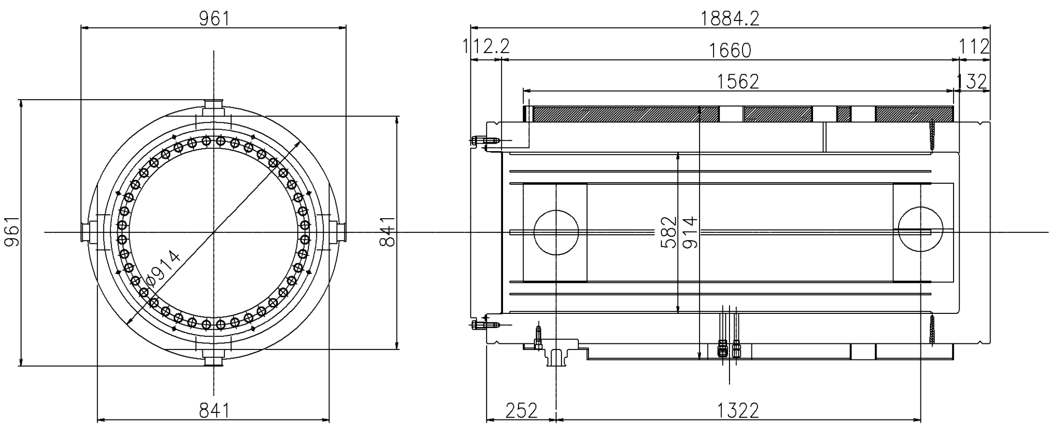

Fig. 4. Overview of the Scale Model Cask

Fig. 5 shows the test view for horizontal impact. For safety reasons, this apparatus was constructed in the open air. The missile was accelerated to the specified impact velocity by driving force of the explosion of gunpowder inserted in the tail of the missile. The velocity was controlled by the amount of powder and the travel distance of the missile. To measure its impact velocity, fine carbon pins were installed at four points near the front face of the cask. Its velocity (57.3m/sec) was calculated from the time differences when the missile cut the pins in passing. The scale cask was mounted on a supporting frame structure by the specific panel, while the reaction forces were measured by six load cells installed between the panel and supporting frame.

Fig. 6 shows the measuring items. During the missile impact test, the acceleration and displacement of the lid and cask body, and the leak rate of the metal gasket were all measured. The measured data was processed using the 2kHz low-pass filter.

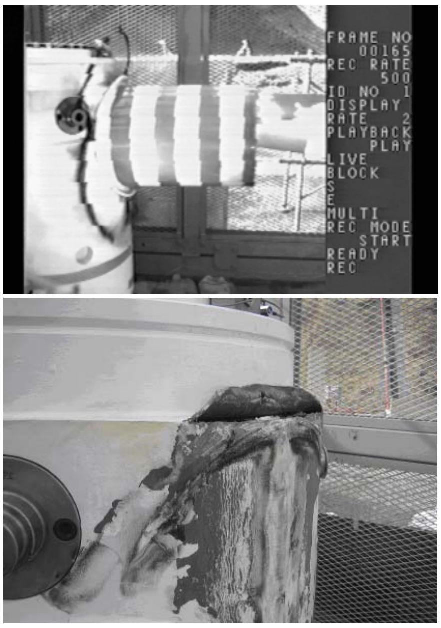

Fig. 5. Aircraft Engine Crash Test : Horizontal Impact

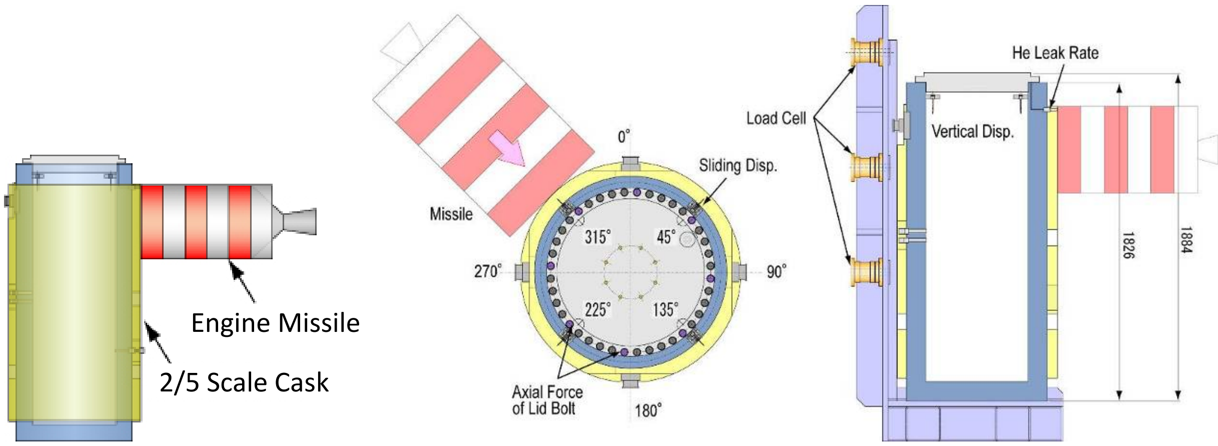

Fig. 6. Measuring Items for the Horizontal Impact Test

Test results

Fig. 7 shows the impact load of the scale cask. The peak value of the total reaction forces measured with six load cells was 485kN and the impact duration was 10msec. Although the outer shell of the metal cask, which enclosed the neutron absorber (resin), was ruptured in the vicinity of the impacted area, there was no significant damage to the cask body and lid structure based on a post-impact test visual inspection.

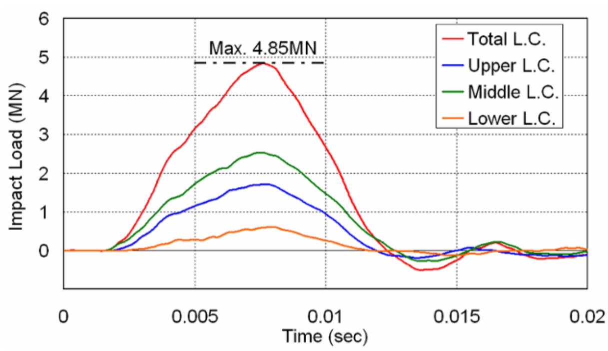

Fig. 7. Time Histories of Reaction Forces Measured with Load Cells

Fig. 8 shows the time histories of the sliding and opening displacements of the lid. The sliding displacement at the lid peaked at about 0.6 mm, and it was considered that in the 315˚ direction (at the impact point) the lid touched the shell of the cask body, and because of the oval deformation, the lid moved toward the shell in directions of 45˚ and 225˚. Lid opening displacement of about 0.08 mm was observed at the 315˚ point. Fig. 9 shows the time histories of the stresses of the tightening lid bolts. No significant loss of axial tightening stress (yielding stress: 890MPa) was observed at the lid during impact load. Fig. 10 shows the leak rate from the lid measured on impact test. Although this value increased by 5 orders of magnitude (from 10^{-11} to 10^{-6} $Pa{\cdot}m^3/s$) immediately on impact, the leak rate shows the integrity of the leak-tightness at the lid, as the value is under 1.0×10^{-5} $Pa{\cdot}m^3/s$. Based on this test result, it seems that the release of radioactive substances in the cask would be avoided in the event of impact with a horizontal orientation, even if the metal cask were exposed to a severe impact due to an aircraft engine crash. Moreover, according to the similarity law, the scale ratio of the leak rate is set to 4/25. If this were applied to the measured leak rate, the estimated leak rate value would be expected to be under 1.0×10^{-6} $Pa{\cdot}m^3/s$. This value appears to correlate well with the corrected relationship between the maximum sliding displacement and leak rate as shown in Fig. 2 and the applicability of the similarity law was confirmed through this test [8].

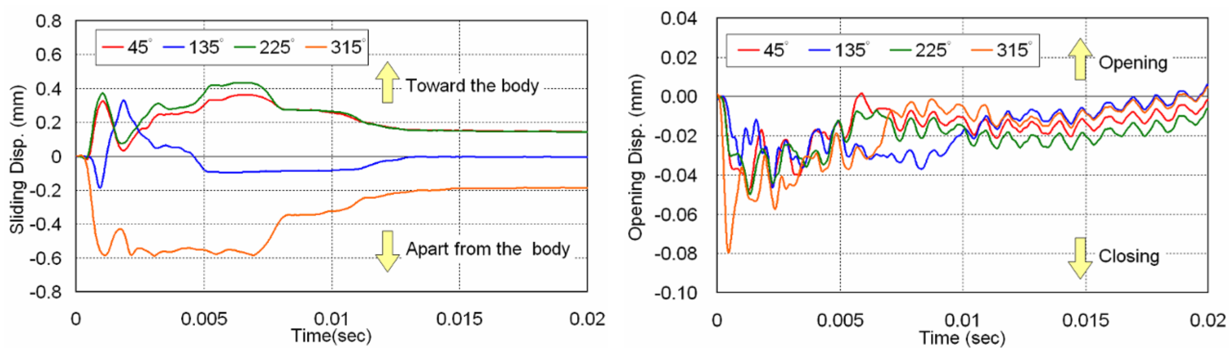

Fig. 8. Time Histories of the Sliding and Opening Displacements of the Lid

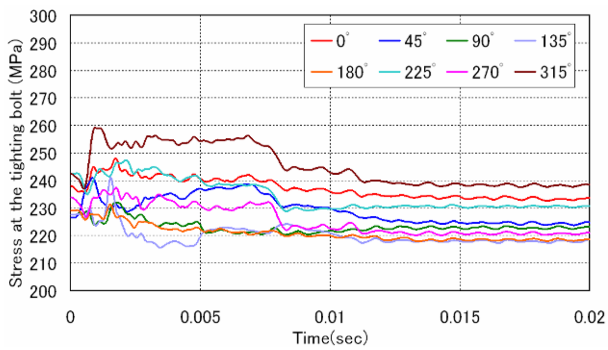

Fig. 9. Time Histories of the Stresses of the Tightening Lid Bolts

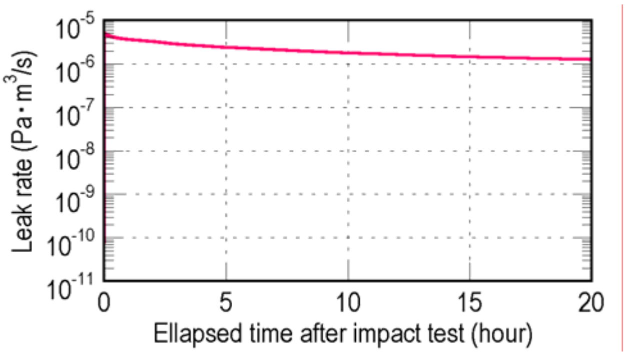

Fig. 10. Time History of the Leak Rate from the Lid

VERTICAL IMPACT TEST

Test description

The full-scale lid model cask as shown in Fig. 11 was mounted on a supporting frame structure as shown in Fig. 1 and the reaction forces were measured by load cells installed between the model cask and the supporting frame. Before the test, load cells were pre-stressed up to 0.45MN to

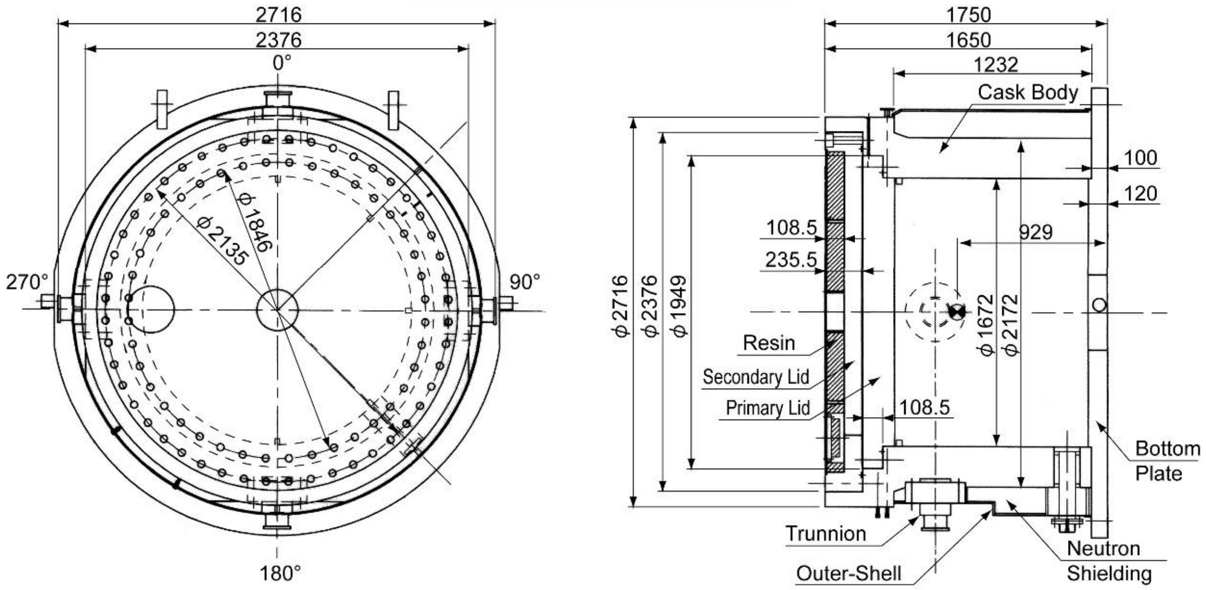

Fig. 11. Overview of the Full-Scale Lid Structure

measure the negative reaction force generated at the time of impact. As the missile, a simplified deformable missile (weight 303kg, diameter 500mm) was used and accelerated to the specified impact velocity (66m/sec) by the driving force caused by the explosion of gunpowder inserted in its tail, hitting the full-scale lid structure with the primary and secondary lids. Subsequently, the leak rate, inner pressure between the lids and displacement of the lids were measured as shown in Fig. 12.

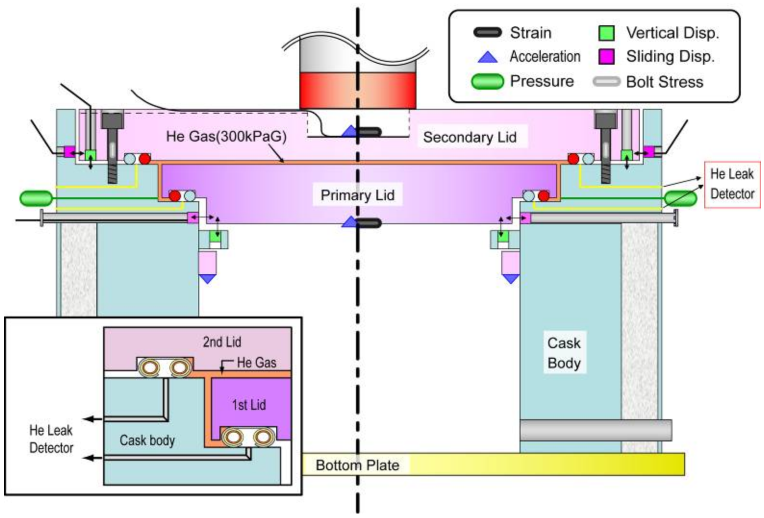

Fig. 12. Measuring Positions for the Vertical Impact Test

<u>Test results</u>

Figs. 13 and 14 show the test view for the vertical impact and time histories of the measurement. At the time of impact during the test, the leak rate, inner pressure between the lids and displacement of the lids were all measured. While the leakage rate from the primary lid might be considerably low (less than 1.0×10^{-7} Pa·m^3/s), that of the secondary lid exceeded 1.0×10^{-3} Pa·m^3/sec. Therefore, a small loss (10kPa decrease from the initial value 305kPa) of inner pressure between the lids was recorded due to the instantaneous opening deformation of the secondary lid. However, as no residual lid opening displacement occurred after loading, the leak rate recovered to less than 1.0×10^{-6} Pa·m^3/sec 3 hours after the impact test. Moreover, there was no plastic deformation in the lid system, nor any considerable loss of torque of the lid bolts. Consequently, it could be concluded that the loss of inner pressure in the cask could be avoided during the extreme impact loading due to the aircraft engine crash.

Fig. 13. Aircraft Engine Crash Test: Vertical Impact

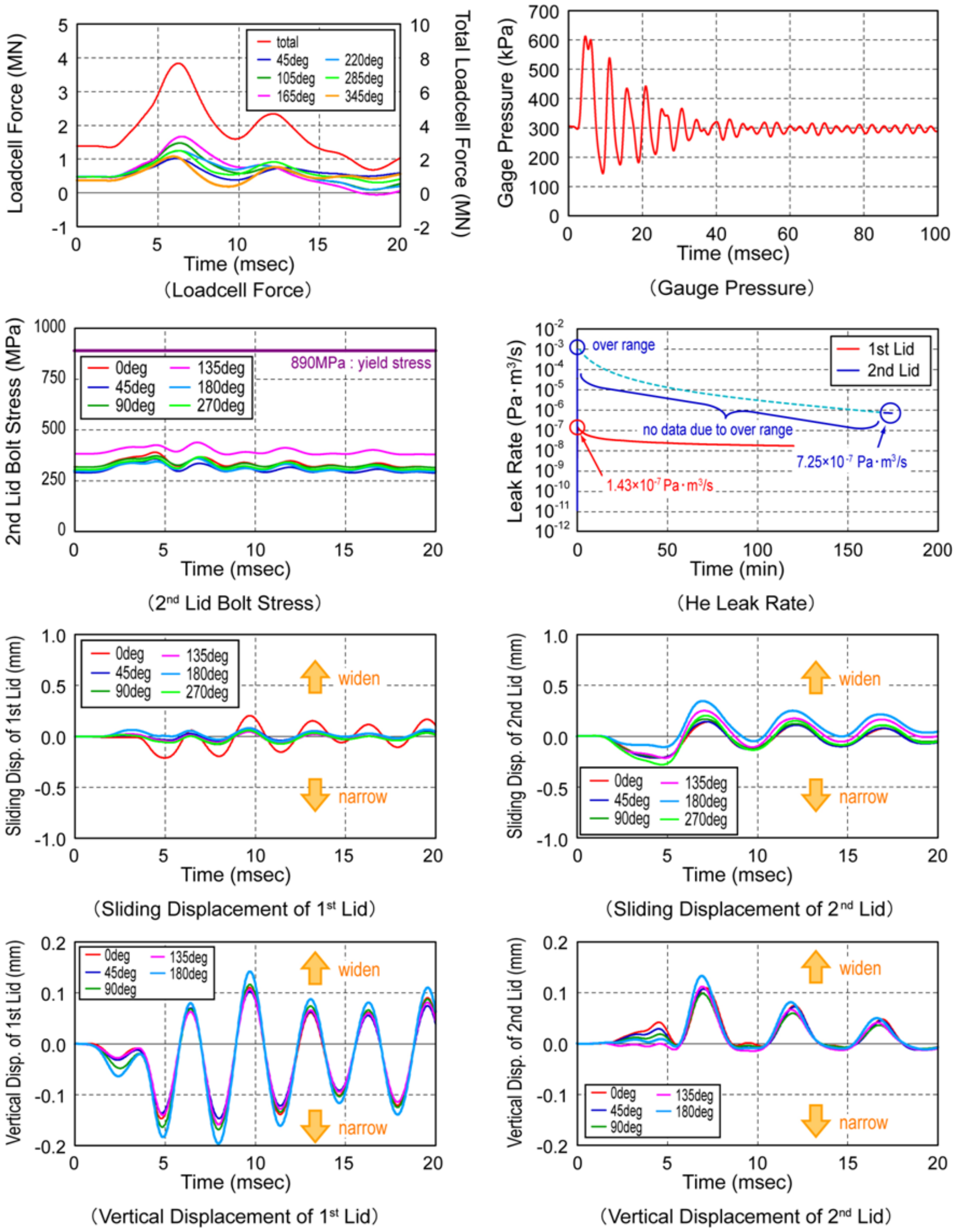

Fig. 14 Time Histories of the Measurement: Vertical Impact Test

CONCLUSIONS

To investigate the integrity of the lid structure of the metal cask during extreme impact loads due to an aircraft engine crash, two impact tests involving aircraft engine missiles striking the metal cask without impact limiters were carried out considering both a vertical impact onto the lid structure and a horizontal impact hitting the cask. During the tests, simplified deformable missiles were used considering the rigidity of an actual aircraft engine and accelerated to about 60m/s.

In the horizontal test, a scale model with a single lid was used. The leak rate from the lid was measured on the impact test. Although this increased by 5 orders of magnitude immediately on impact, it also showed the effective leak-tightness of the lid, as it remained under $1.0\text{x}10^{-5}$ $Pa \cdot m^3/s$.

During the vertical test, a full-scale lid structure with primary and secondary lids was used. At the point of impact in the test, the leak rate, inner pressure between the lids and displacement of the lids were all measured. The leak rate of the secondary lid exceeded 1.0×10^{-3} $Pa \cdot m^3/sec$ at the time of impact. However, as no residual lid opening displacement occurred after loading, the leak rate recovered to less than 1.0×10^{-6} $Pa \cdot m^3/sec$ 3 hours after the impact test.

Based on these experimental results, it seems that the loss of inner pressure of the cask cavity might be avoided in an impact event with horizontal and vertical orientation, even if the metal cask were exposed to a severe impact load due to the aircraft engine crash.

ACKNOWLEDGMENTS

These works were carried out under contract from NISA/METI of the Japanese government.

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