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ANALYSIS OF THE BEHAVIORS OF THE TS-69B CASK FOR TRANSPORT AND STORAGE OF SPENT NUCLEAR FUEL IN DROP TESTS

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ABSTRACT

In Japan, spent nuclear fuel is stored on an interim basis until it is being reprocessed. Thus, it is mandatory that metal casks maintain safety functions as they are placed in the interim storage as well as in a process of transport. At Toshiba Energy Systems & Solutions Corp., design of the TS-69B, a dry metal cask for dual purposes of transport and storage, is in progress in recent years. As part of the design efforts, Toshiba verified the integrity of the cask under the specific conditions for the 9-meter drop tests, which are required by the government regulations for transport casks. During the evaluation of the 9-meter drop tests, cask behaviors for each section were analyzed with the use of non-linear analysis in "LS-DYNA®".

In the event of a vertical drop on the cask's lid-side, the impact load may become larger due to the delayed impact resulting from the gap (i.e. space) between the primary lid and the contents. This study focused on the delayed impact load and the cask contents in the event of a vertical drop on the lid-side for further evaluations of seal integrity of the TS-69B. During the study, data for content movement were obtained as the gap between the primary lid and the contents, and the various fuel assembly models were used as parameters.

As a result, accelerations become the largest when the largest value is assumed for the gap between the primary lid and the cask contents. Impact behaviors on cask contents and other sections vary depending on the parameters for fuel assembly models. Accordingly, acceleration values obtained from this study also verified the seal integrity of TS-69B.

INTRODUCTION

Required by the Japanese regulations, the structural integrity of metal casks for dual purposes of transport and storage are to be evaluated under the 9-meter drop test conditions.

Under lid side vertical drop test, the gap between the top of the cask contents and the lid may cause delayed impact. While drop tests and analysis are performed by using the equivalent weight of fuel assembly in rectangular shape, behaviors of fuel assembly may be different for actual phenomenon.

In this study, examining the impact by different gaps and the behaviors of fuel assembly during the drop tests, dynamic analysis was performed for the evaluation of the structural integrity of TS-69B, a dual purposes cask for transport and storage, developed by Toshiba. And furthermore dynamic analysis under the slap down drop test conditions was performed for the evaluation of the integrity of TS-69B, because it is concerned that higher impact acceleration may occur on the side of the second collision in the event of the slap down drop compared with the horizontal drop case.

(1) Impact Evaluation Caused by the Gap in the Vertical Drop Down Event

Methodology

Using “LS-DYNA®”, a dynamic analysis code, for the lid side vertical drop tests, the time history of acceleration, lid opening and sliding displacement during the collisions were analyzed. LS-DYNA is a trademark or registered trademark of Livermore Software Technology Corporation in the United States and/or other countries.

Models

The TS-69B cask is a dual purpose metal cask, being capable of storing sixty-nine (69) BWR spent nuclear fuel. Figure 1 shows the analysis model used for this study, in which the vessel, primary, secondary and the tertiary lids, bolts for the three lids, bolts for shielding covers, upper ring, outer cover, fins, and the top and bottom shock absorber were modeled.

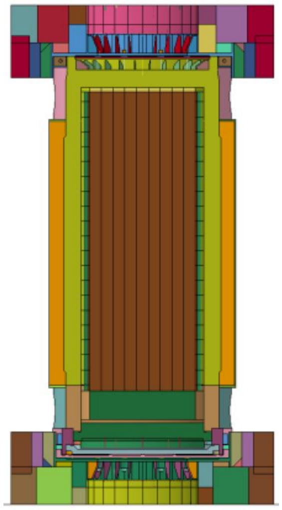


Figure 1. Analysis model of TS-69B cask (in lid side vertical drop down event)

Conditions

With regard to a gap, the following three cases were examined in this study:

Case A — The contents touch the bottom plate and the gap between the top of the contents and inside the lid is the largest among the three (3) cases.

Case B — The size of the gap is smaller than that of Case A because the contents are lifted up during the 9.3-meter drop tests.

Case C — The contents touch inside the primary lid and no gap exists between them.

Results

Figure 2 shows the time history of acceleration, sliding displacement and lid opening in each position. Table 1 indicate the relationships between the gaps and the highest acceleration recorded in each position.

Case A has the highest acceleration, followed by Case B, and Case C has the lowest, in each position. Due to the smaller size of the gaps, Cases B and C were less impacted. For all three (3) cases, the sliding displacement for the primary lid were very low and short. The lid opening for the primary lid was observed, however duration of time for opening was short, the primary lid returned to the original states eventually. It is assumed TS-69B maintains the leaktight criteria of transport after vertical drop test in comparison with Reference1.

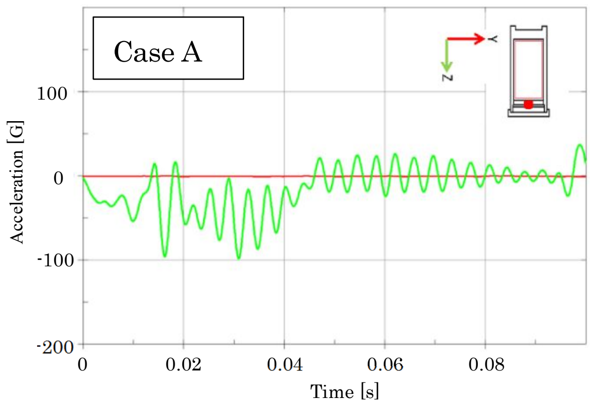
The acceleration waveforms recorded outside middle body at 0, 90 and 180 degrees were almost the same. For all three cases, the highest acceleration values were almost the same.

In the cask contents, acceleration occurs in the initial stage for Case C; the accelerations for Cases A and B are approximately zero (0) G for 0.01 second regardless of the differences in gap size. This time lag is assumed to be the duration of time that it took for the contents to collide with the primary lid. While it took approximately 0.07 second for Case C to reach maximum acceleration, it took only 0.015 second for Cases A and B to reach that level. With regard to the acceleration to the Z direction, Case C reached the highest level at the second collision; however, both Cases A and B reached their highest levels at the first collision.

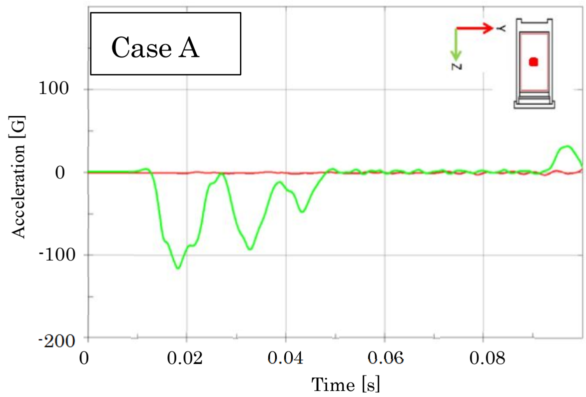
Reference 2 describes that in the case of a vertical drop, the allowable acceleration for a BWR spent fuel cladding made of zircaloy 2 is approximately 360 G. Most of acceleration values obtained from the analysis are less than 360 G; therefore, the spent fuel cladding maintains the structural integrity for vertical drop test of TS-69 cask even though the difference in size of gap is taken into account.

Table 1. Maximum Acceleration for lid side vertical drop test analysis

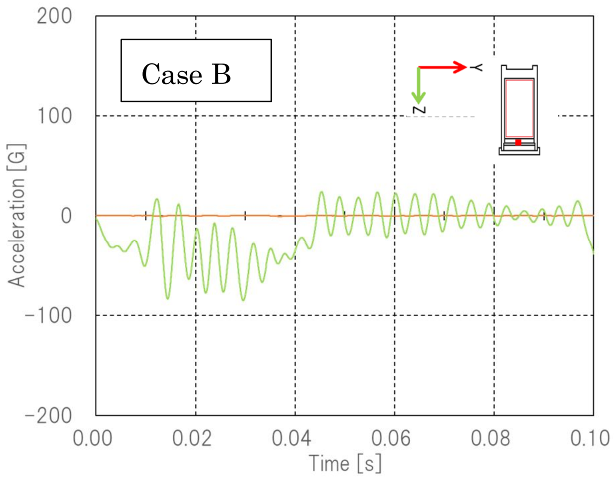
Position \ Gap	Case A	Case B	Case C
Primary lid	98 [G]	85 [G]	58 [G]
Body (middle, 0°)	59 [G]	60 [G]	51 [G]
Body (middle, 90°)	59 [G]	61 [G]	51 [G]
Body (middle, 180°)	59 [G]	60 [G]	51 [G]
Content	116 [G]	105 [G]	55 [G]



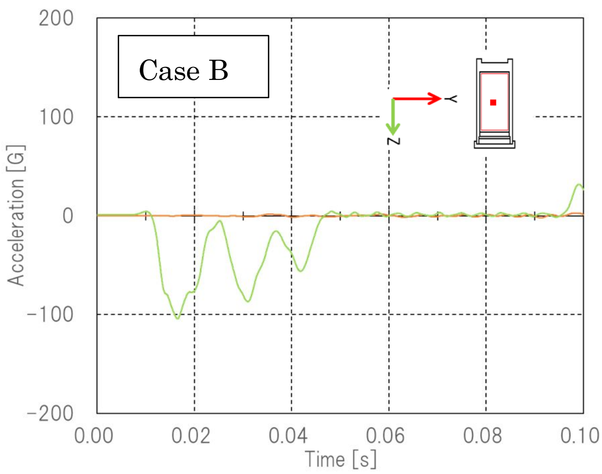
(a) Acceleration of the primary lid



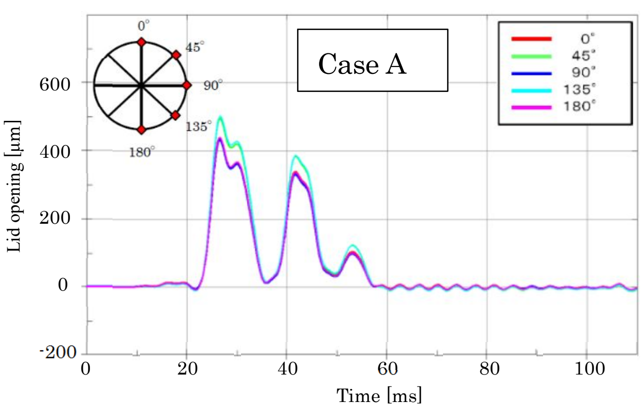
(b) Acceleration of the cask contents



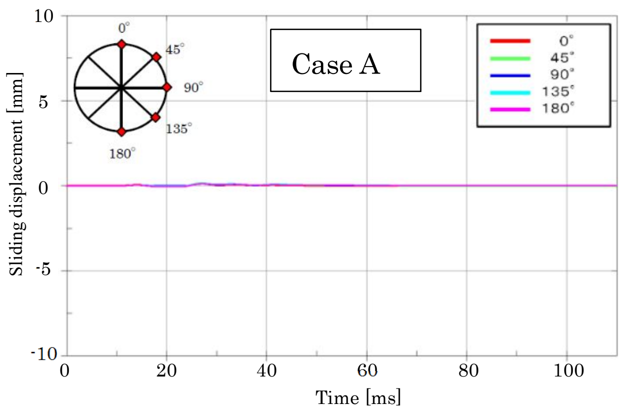
(c) Acceleration of the primary lid



(d) Acceleration of the cask contents



(e) Lid opening in the primary lid



(f) Sliding displacement in the primary lid

Figure 2. Time history for lid side vertical drop test analysis (1)

(2) Evaluation of Behaviors of Fuel Assembly in the Vertical Drop Down Event

Methodology

It is difficult to insert an actual fuel assembly model into the drop test analysis due to the complexity of the shape and the displacement. Thus, the reaction forces were obtained when a single fuel assembly model was collided with the rigid wall on the handle at 9.3-meter high with 13.5 m/s. Then, the forces were loaded as a pressure load onto inside the primary lid of the cask model as it is dropped vertically on the lid; and the delayed impacts for the cask and contents were examined.

Models

The analysis model for fuel assembly is 9×9 BWR fuel. Figure 3 shows the overview of the fuel assembly model; Figure 4 indicates the time history of the reaction forces. Fuel is divided in the basket; in the event of a vertical drop on the lid, a fuel load does not interfere with other fuel in square lattice. The cask models, physical properties, analysis software and other conditions used for the analysis are the same as described in (1).

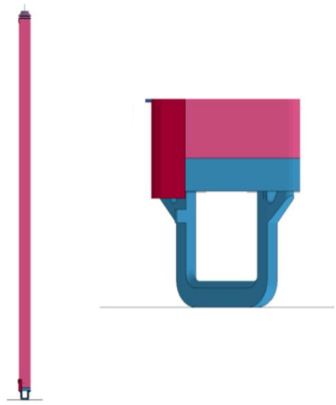


Figure 3. Collision with the rigid wall on the handle of fuel assembly model

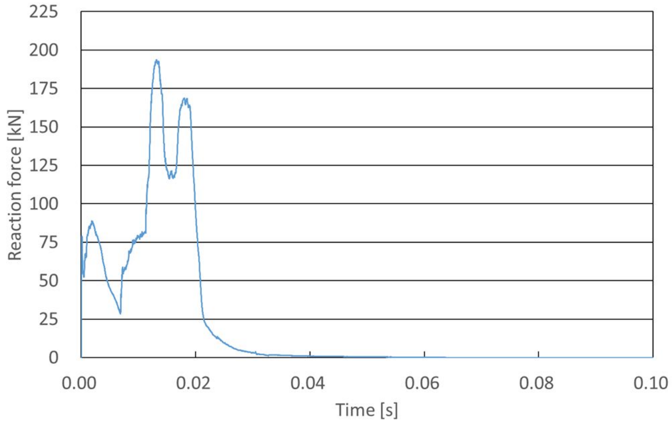
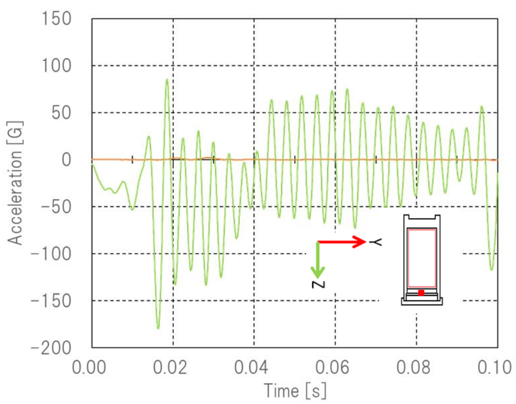


Figure 4. Time history of reaction forces

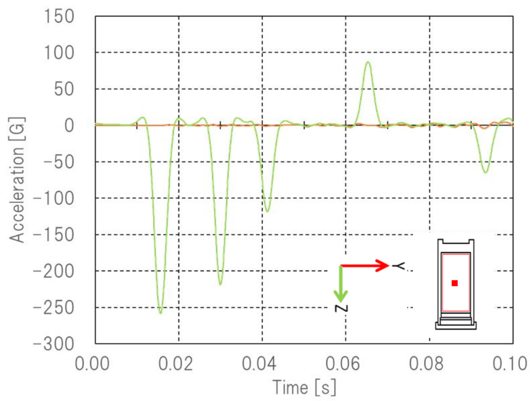
Results

Figure 5 indicates the time history of acceleration, lid opening and sliding displacement in each position considered the reaction forces by collision of fuel assembly. The waveforms showed almost the same patterns as the results obtained from (1). On the other hand, the acceleration became the highest when the reaction force was considered. In the cask contents, it is assumed that the peak of approximately 0.015s was caused by the first collision, and the peak of 0.07s occurred due to the vibrations caused by the cask contents. It is almost certain that TS-69B maintains the leaktight criteria of transport after vertical drop test considered the reaction forces.

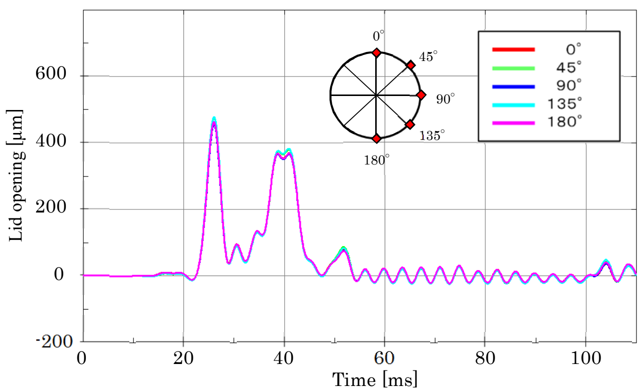
In the positions outside the cask (at 0, 90 and 180 degrees), the acceleration waveforms and the maximum acceleration levels showed almost the same patterns as the results obtained from Case B.



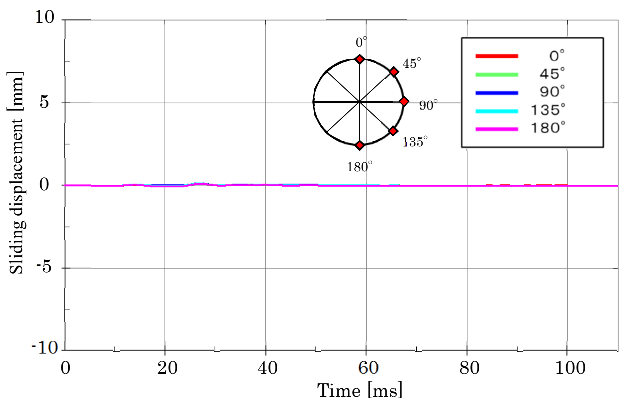
(a) Acceleration of the primary lid



(b) Acceleration of the cask contents



(c) Lid opening in the primary lid



(d) Sliding displacement in the primary lid

Figure 5. Time history for lid side vertical drop test analysis (2)

(3) Evaluation on Behaviors of the TS-69B Cask in a Slap Down Event

Methodology

The slap down drop tests were performed under the condition that the cask hits the ground on the bottom first and then on the lid. The test results were analyzed using "LS-DYNA®", evaluating the time history of impact acceleration and the extent of lid opening and sliding displacement. The results obtained from the analysis were compared with those from the horizontal drop tests for further examination.

Models

TS-69B cask models, physical properties, software and other conditions used for the analysis are the same as described in (1).

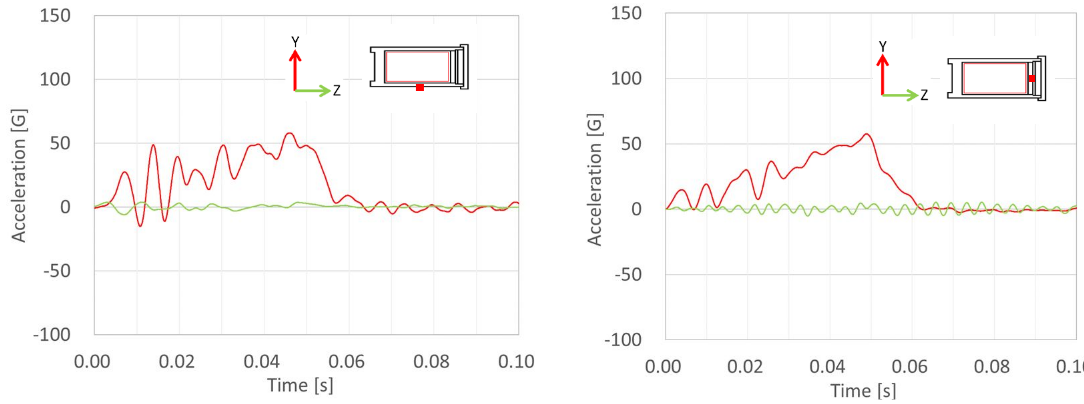
Conditions

Under the conditions of 9.3 meters slap down drop tests, the TS-69B cask behaviors were examined when it was dropped at an angles of 5 and 20 degrees with respect to the ground.

Results

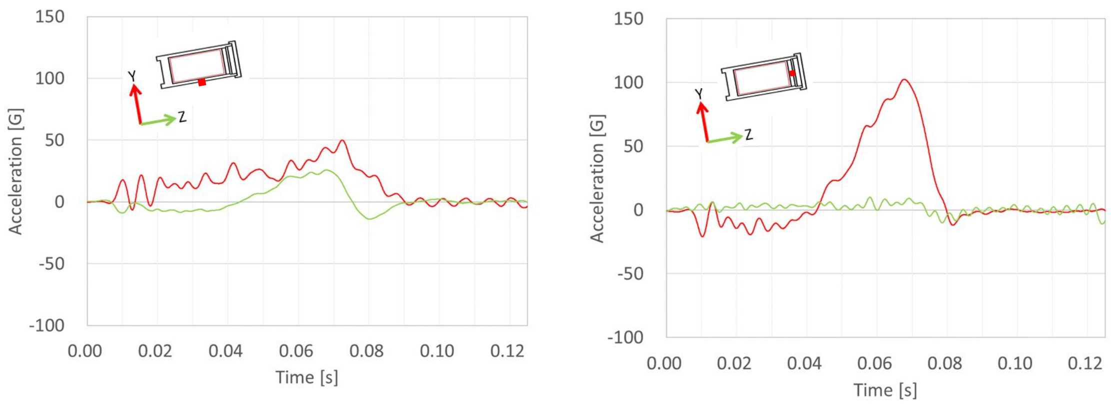
It was found that acceleration occurred in the body and primary lid during the slap down drop was faster at 5-degree than 20-degree. Accordingly, the followings present discussions focusing on the results obtained from the slap down at 5-degree and horizontal drop test conditions. Figure 6 shows the time history of accelerations occurred in the body and the primary lid positions. When compared with acceleration occurred under the horizontal drop tests conditions, acceleration occurred in the body was lower under the slap down drop test conditions. In comparison, acceleration occurred in the primary lid during the slap down drop was twice as much as that obtained from the horizontal drop tests.

Figure 7 shows the lid opening and sliding displacement in the primary lid in slap down at 5-degree. While the sliding displacement was observed for the primary lid, the value was within the allowable range specified for the metal gasket. With regard to lid opening, duration of time for being open for the primary lid was shorter compared with that of the horizontal drop tests; primary lid returned to the original states eventually.



Body Primary lid

(a) Horizontal Drop Test Condition



Body Primary lid

(b) Slap Down Test condition (at an angle of 5°)

Figure 6. Time history of acceleration in slap down drop analysis

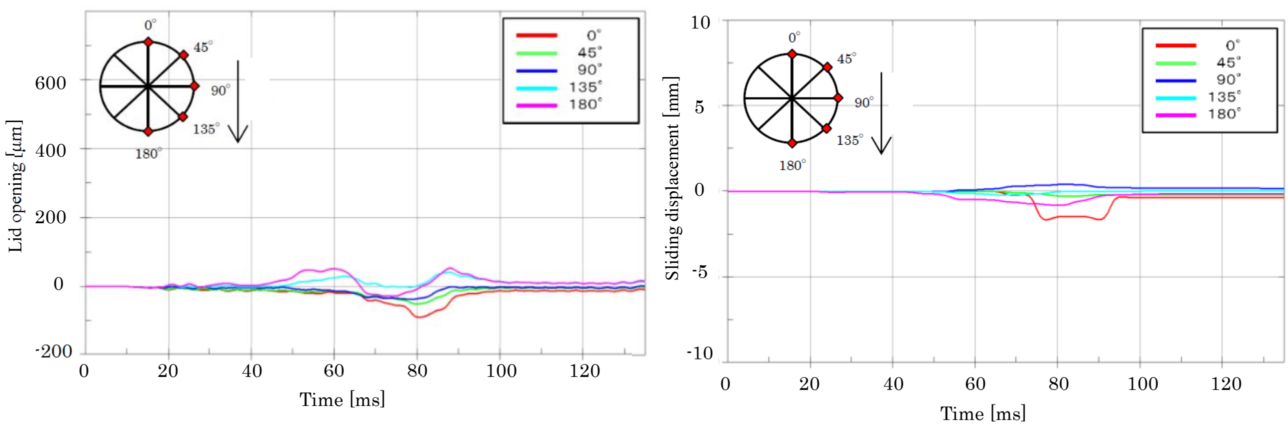


Figure 7. Lid opening and sliding displacement in the primary lid in slap down at 5-degree

CONCLUSIONS

(1) While the cask content behaviors differ depending on the size of a gap, acceleration is higher at the first collision than the second. The accelerations were the highest in many positions when the gap is the largest.

(2) When fuel assembly behavior during a lid side vertical drop test was considered to drop test analysis, it was found that acceleration was relatively large at the first collision and also that the acceleration levels were impacted by the vibrations of the cask contents. It is recommended that the conditions, such as fuel assembly handle and fuel bundle, should be included for drop test analysis and test.

(3) Acceleration in the primary lid position during the slap down drop tests was greater than that of the horizontal drop tests; the sealing performance of the TS-69B cask was ensured under the slap down drop test conditions.

REFERENCES

1) Japan Nuclear Energy Safety Organization, "Test Report for Metal Storage Cask Technology", (2004). (in Japanese)

2) Atomic Energy Society of Japan, "Standard for Safety Design and Inspection of Metal Casks for Spent Fuel Interim Storage Facilities", (2010). (in Japanese)