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TESTING OF SPENT FUEL STORAGE/TRANSPORT PACKAGES IN JAPAN

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ABSTRACT

The present paper introduces current status of spent fuel transport / storage in Japan. It systematically introduces major testings using full-scale casks for spent fuel storage/transport. Some of them have been reported in the past and present PATRAM symposiums. Among them, this paper introduces essence of “Momentary leak from metal cask without impact limiters”, “Heat removal tests” and “Canister drop tests” of concrete cask storage. Finally, it introduces on-going research and testings on spent fuel storage technology for the future.

INTRODUCTION

Nuclear policy of Japan is to reprocess spent fuel and recycle the nuclear materials. The spent fuel storage and transport become important in the nuclear fuel cycle and the amount is increasing in Japan. The safety of spent fuel storage/transport is of particular interest under the circumstances. In addition to regulatory tests, various tests using full-scale packages have been performed.

CURRENT STATUS OF TRANSPORT AND STORAGE OF SPENT NUCLEAR FUEL IN JAPAN

Transport of Spent Fuel

Figure 1 shows annual and accumulated amount of spent fuel transport in Japan [1]. The transport of spent fuel will increase up to approximately 800 tU/year in 2008 when operation of the reprocessing plant in Rokkasho will start.

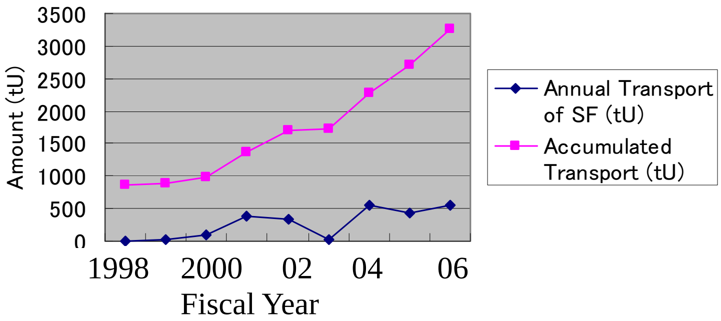


Figure 1. Spent Fuel transport in Japan

Storage of Spent Fuel

Figure 2 shows the amount of spent fuel storage in the existing 17 nuclear power stations with their storage capacity as of March 31, 2006 [2]. The total amount of spent fuel generation in Japan is increasing and will be approximately 1,400 tU in 2010 which exceeds the annual amount of spent fuel reprocessing at Rokkasho (800tU/year). Therefore, interim storage will be required in the near future. Currently, no spent fuel is stored away from reactor sites. Under these circumstances, a new company, Recyclable Fuel Storage Company, was founded in order to store spent fuel away from reactor sites. They submitted a license application for the storage activity in Japan on March 2007, aiming start of operation of the first storage facility in 2010.

MAJOR TESTINGS OF FULL-SCALE CASKS FOR SPENT FUEL STORAGE/TRANSPORT IN JAPAN

Based on the strong need of spent fuel storage, lots of testings of spent fuel storage/transport packages have been performed. Table 1 summarizes major testings of full-scale casks, etc, for spent fuel storage/transport in Japan

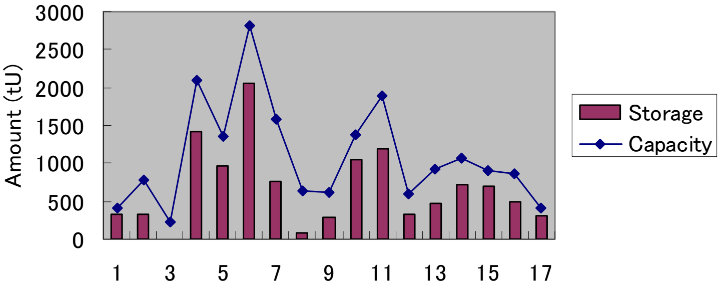


Figure 2. Spent Fuel Storage and Capacity

Table 1. Major testings of full-scale casks, etc. for spent fuel storage/transport in Japan

Name of testing	Purpose	Ref.
1. Metal Cask		
a. Non-regulatory drop tests of metal casks without impact limiters	To demonstrate integrity of metal casks without impact limiters under accidental drop in storage facility.	[3]
b. Momentary leak from metal cask without impact limiters	To demonstrate the momentary but negligible leak from metal gasket of dual purpose metal cask under accidental drop in storage facility.	[4]
c. Regulatory drop test of metal cask with aged metal gaskets	To demonstrate the transport integrity of dual purpose metal cask after long term storage	[5]
d. Drop tests of ductile cast iron	To demonstrate fracture toughness of ductile cast iron cask under -40 degree in Celsius.	[6]
e. Dynamic crash tests of metal cask without impact limiters	To demonstrate integrity of dual purpose metal cask under hypothetical crash of a storage building	[3]
f. Metal cask toppling tests by earthquake (1/3 scale)	To demonstrate stability of standing metal cask without tie-down to floor.	[7]
g. Long-term containment test of metal cask	To demonstrate long-term containment of metal cask with metal gasket	[8]
2. Concrete Cask		
a. Heat removal tests	To demonstrate heat removal performance of concrete cask under normal and accident conditions	[9][10]
b. Canister drop tests	To demonstrate containment of metal canister under accidental drop during transfer from metal cask to concrete cask	[11]
c. Toppling test by earthquake	To demonstrate stability of standing concrete cask without tie-down to floor.	[12]

Some of these tests have been reported in the past and present PATRAM symposiums, etc. Essence of the underlined tests in Table 1 is introduced in this paper.

Momentary Leak from Metal Cask without Impact Limiters

Conventionally, leakage tests are performed before and after drop tests of the package. On the other hand, it has been known that packages may leak momentarily at the moment of the mechanical impact [13]. The momentary leak from a full-scale metal cask without impact limiters was quantitatively measured. In the full scale drop tests, leak rate, amount of leakage, lid displacement, acceleration, pressure in the space between the primary lid and the secondary lid were measured.

Specimen cask and test conditions

Drop tests of the full scale metal cask (2524 mm in diameter, 5433.5 mm in length and 120 t of gross weight) without impact limiters were carried out by simulating drop accidents during handling in a storage facility. Details of lids and gaskets are shown in Table 2. The target was designed to simulate a floor of a reinforced concrete in the facility (Figure3). The first test was a horizontal drop from a height of 1 m (Figure4). The second test was to simulate a rotational impact around an axis of a lower trunnion of the cask from the horizontal status at a height of 1 m.

Table 2 Design of Lids and Gaskets

	Primary Lid	Secondary Lid
Diameter of Lid	1946mm	2236mm
Thickness of Lid	198mm	235.5mm
Diameter of Gasket	1738mm	2032mm
Diameter of Gasket Coil	5.6mm	10mm
Meterial of Outer of Gasket	Aluminum	Aluminum
Bolt Number	40	48
Stress per one bolt	58MPa	105MPa
Gap between Lid and shell	1.11mm	0.65mm

The lid structure of this cask and the position of leak rate measurement are shown in Fig.5. The double type metal gasket was installed on the bottom of each of the primary lid and the secondary lid, and the containment was kept by the metal gaskets.

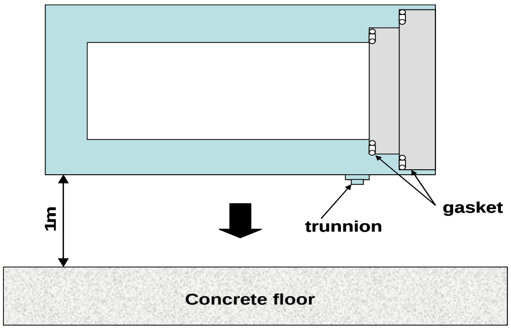


Figure 3. Horizontal drop test condition

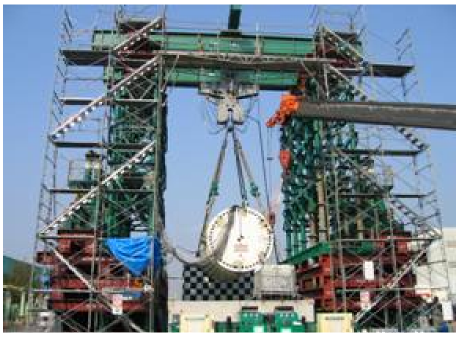


Figure 4. Overall view of the horizontal drop test

Momentary leak rates were quantitatively measured at both the primary and secondary lids by the helium leak detectors. In this test, 4 atm (gauge pressure) of helium was filled in the space between the lids. In addition, eddy current displacement sensors (accuracy of ±0.01mm) were used for displacement measurement of the lids.

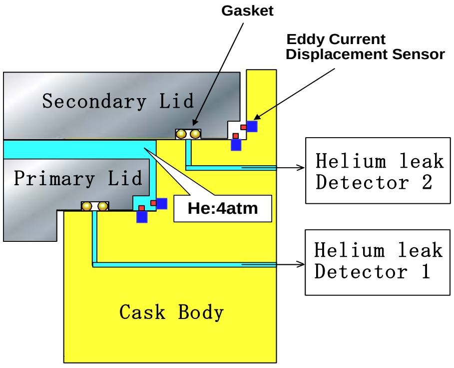


Figure 5. Leak rate measurement positions

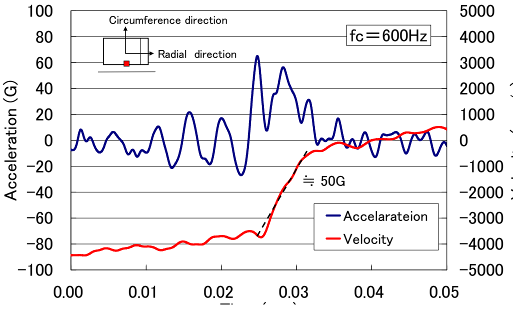


Figure 6. Time histories of acceleration and velocity (horizontal drop test)

Results of Horizontal drop test

In this test, the front trunnion attacked the concrete floor, directly. Figure 6 shows the time histories of acceleration and velocity of the cask body. The data measurement started after the cask body collided with the concrete floor. Until about 0.02 sec after the impact, the trunnion penetrated into the concrete floor gradually, but the cask body part behind the trunnion continued to fall. The large positive acceleration was generated in the center of the main cask body at about 0.02 seconds after the impact, when the cask bottom collided with the concrete floor. The average acceleration near the point became about 50 G by calculating from the speed inclination. Figures 7 and 8 show the time histories of the leak rate from the primary lid and the secondary lid, respectively. The maximum sliding displacements were about 0.4 mm at the primary lid and about 0.3 mm at the secondary lid, respectively. These were observed at the direction of the drop. On the other hand, no significant opening displacements were observed at either the primary lid or the secondary lid. Moreover, no decrease of the pressure between lids was observed immediately after the drop impact. The leak rate from the primary lid increased one order of magnitude immediately after the impact. 10 minutes later, it restored to the background level. However, it increased again by one order of magnitude after about 25 minutes and restored to the background level, again. After that, such phenomenon was not observed within 6 hours. Therefore, the leak rate seemed to have restored to the background level completely. On the other hand, the leak rate from the secondary lid increased by two orders of magnitude after the impact immediately. The high leak rate was kept for about 1 hour. After that, the leak rate seemed to have restored to the background level completely.

The amount of helium gas leakage was calculated by integrating the leak rate with time. The total amount of helium gas leakage from the primary and secondary lids was 2.0×10^{-6}Pa・m^3. This value is 9.6×10^{-9}% of the initially installed helium gas. The amount of leakage was insignificant.

Table 3 shows the summarized results of this test. The amount of penetration to the concrete floor of the trunnion was about 100 mm. No significant opening displacements were observed at both of the primary lid and the secondary lid. The momentary measurements of leak rate and amount of leakage data were obtained.

Similar results were obtained for the rotational impact test from the height of 1m. The total amount of leakage from the primary and secondary lids was $1.7x^{-5}$Pa・m^3. This is 8.5×10^{-8}% of the initially installed helium gas. A little decrease in pressure between lids was observed. The leak seems to be from the helium filling port, not from the lid gaskets.

Table 3 Results of the horizontal drop test

Acceleration	Main body	50G
	Lid	16G
Primary lid	Sliding	0.4mm
	Lid opening	No significant change
Secondary lid	Sliding	0.3mm
	Lid opening	No significant change
	Axial stress of bolt	No significant change
Maximum leak rate	Primary lid	2.38×10^{-10}Pa・m^3/s
	Secondary lid	2.85×10^{-9} Pa・m^3/s
Leak rate after 6 hours	Primary lid	1.52×10^{-11}Pa・m^3/s
	Secondary lid	7.90×10^{-12}Pa・m^3/s
Pressure between lids		No significant change

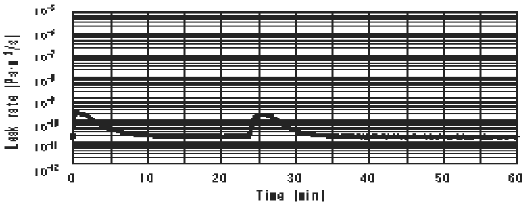


Figure 7. Time histories of leak rate from the primary lid (horizontal drop test)

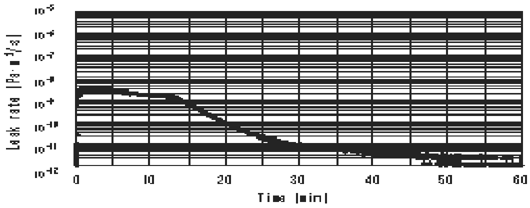


Figure 8. Time histories of leak rate from the secondary lid (horizontal drop test)

Discussion and Summary

At both the horizontal and the rotational drop tests, momentary leakage of helium gas was measured, but was insignificant. In addition to the results, a relationship between the maximum sliding displacements of the lids and the leak rates has been obtained from the scale models. Here, the result of the scale models was adjusted to the full scale metal cask. It was found that the relationship between the maximum sliding displacement of the lid and the leak rate of the full scale metal cask can be evaluated by the results of the scale model.

Heat removal test of concrete casks

Recently, concrete cask is noted with interest from the economical point of view. However, quantitative data for its safety analysis have not been sufficient. Objective of this study is to obtain quantitative data needed for the safety analysis on concrete cask especially in a field of thermal evaluation. Concrete cask is different from metal cask. In case of concrete cask, cooling air goes into concrete body and cools the canister surface. Heat transfer of natural convection by air is very important. Thermal hydraulic analysis by numerical code can be applied to the concrete cask. It is necessary to confirm the calculation results compared with the test results.

Tsuji et al (2003)[14] and Sakai et al (2002) [15] performed heat removal tests using a full-scale concrete cask and made numerical calculations. Detail temperature distribution in the concrete cask both under normal and abnormal conditions has not been reported. Furthermore, for the concrete cask, there is an accident condition which must be taken into account unlike the metal cask. That is blockage of air inlet as off-normal or accident conditions. For blockage of air inlets, it is very difficult to simulate by numerical calculation because drift flow occurs. Especially for blockage of all inlets, flow pattern of the outlets can not be predicted without test results. In this paper, test results both under normal and accident conditions are described.

Test apparatus

Table 4 shows the preliminary design parameter, with which the concrete casks were designed. Two types of concrete casks shown in Figure 9 were used for verification tests. One is a reinforced concrete cask (RC cask) and the other is a concrete filled steel cask (CFS cask). Figure 10 shows a bird's eye view of the test facility.

Table 4. Basic design parameter for cask

Design storage period	40~60 years
Fuel type	17x17 array for PWR
Enrichment (wt % U235)	4.90%
Burn-up (Max)	55 MWd/kgHM
Cooling time	10 years
Environmental temperature	33°C
No.of fuel assenbly per cask	21
Total heat load (max)	22.6 kW

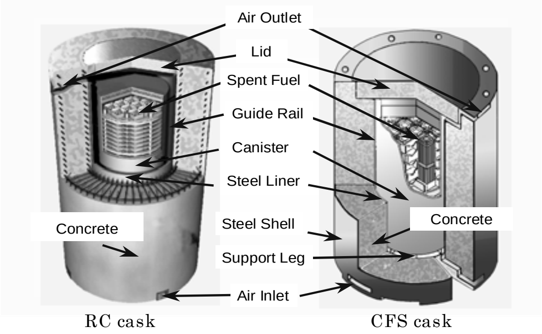


Figure 9. Outline of two types of casks

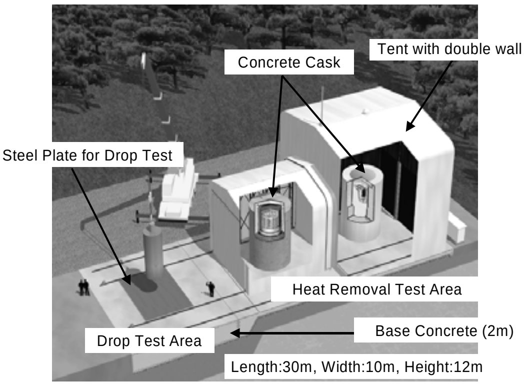


Figure 10. Test facility

Test results

Heat balance

Heat discharged from the cask to the environment is distributed by heat convection of the cooling air (Q1), hest transfer from the side of the concrete container (Q2), heat transfer from the top of the concrete container (Q3), and heat transfer from the bottom of the concrete container to the floor surface (Q4). Figure 11 shows the ratio of the heat transfer. It was found that 80 % of the total heat is removed by the cooling air in the case of RC cask.

Concrete temperature

Figure 12 shows the temperature distributions inside the concrete container, provided that the inlet air temperature is 33 °C. In the case of 22.6kW, the concrete temperature around the outlet is very high. Maximum concrete temperature is 91 °C. This value exceeds the temperature limit of the concrete (90°C). So it is necessary to modify the cask design. On the other hand, maximum concrete temperature in the case of 10kW is under 65°C. Figure13 shows the temperature distribution of the cask components in the cases of 22.6 kW and 10 kW. Although the heater temperature as well as the canister surface temperature varies largely between the cases, the difference is few in concrete surface temperature. For 50% blockage of air inlet, temperature increase in the concrete cask is small. When two air inlets among four are closed, decreased rates of air flow are about 5% for the RC cask and 22% for the CFS cask.

For 100% blockage of air inlet, different types of flow pattern were observed according to the shape of the air outlet. In case of the air outlet with “down-step” shape, air does not go out from the air outlet. On the other hand, in case of the air outlet with “up-step” shape, air goes out and in from different air outlets. In the former case, temperature increase is larger than that in the latter case.

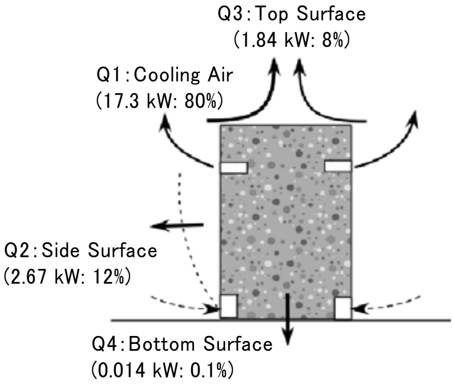


Figure 11. Heat balance

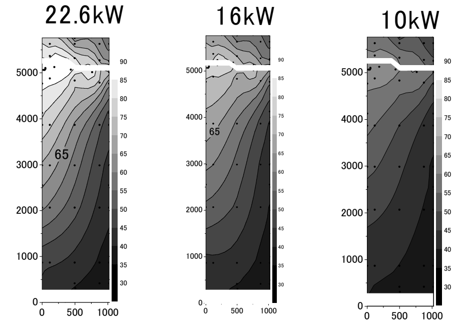


Figure 12. Concrete temperature (RC cask) with various decay heat of spent fuel

If air does not go out from the air outlet, heat energy accumulates inside and temperature continues to increase. For the both cases of 50% and 100 % blockage, increase in the concrete temperature was within the design temperature limit.

Discussion and Summary

Design modification may be necessary for RC cask, because an area exceeding the temperature limit of the concrete (90°C) were observed inside of the outlet at the condition of initial storage period. The concrete cask has a characteristic cooling system that the air goes through the annulus gap between the concrete container liner and the canister. From a view point of the heat removal, design of the flow channel is important for the concrete cask. Finally, it was shown that the aluminum alloy is thermally effective material for the basket of the canister.

<u>Canister drop test</u>

Due to the lack of the experimental studies related to tipping-over or drop event scenarios, in this research program, the demonstration drop test program using double-lid welded multi-purpose canister (MPCs) was executed, with the aim of obtaining basic data for regulating safety. This paper introduces the summary of the drop test program.

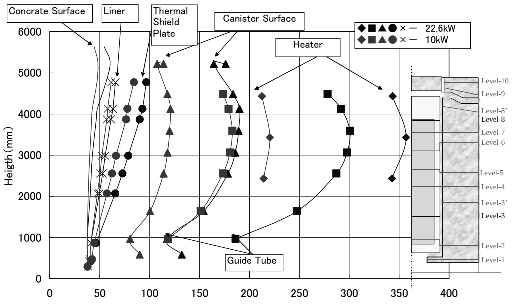
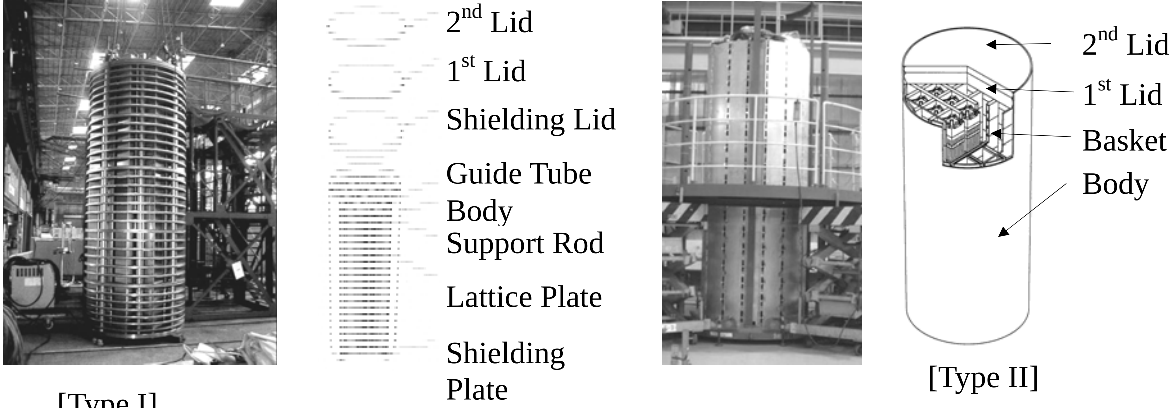


Figure 13. Temperature distribution (RC cask)



[Type I]

[Type II]

Figure 14. Outline of the two type of the test MPC

Test Specimens and Conditions

Two types of full-scale MPC were designed and fabricated to apply to the drop tests as shown in Figure 14. Each canister can store 21 PWR spent fuels, and for each canister body, high corrosion-resistant material is used. The basket of type I consists of guide tubes and stainless steel plates. The stainless steel plate fixed at constant intervals of distance by steel rod has 21 square holes for the guide tube. The guide tubes are placed in the hole and fixed to the plate. To increase thermal conduction, aluminum plate is fixed to the stainless steel plate. The basket of type II is the assembly of rectangular hollow block made of aluminum alloy.

Two drop tests in horizontal and vertical orientations were conducted considering non-mechanistic drop or impact events during handling, and each drop heights were 1m and 6m, respectively.

Horizontal Drop Test Results

Figure 15 shows photographs of the test canister before and after the drop test. The test canister was slightly deformed near the impacted area. He leak tests were performed before and after the drop tests to confirm the integrity of leak-tightness of the test MPCs (especially welded lids) against impact loads. Measured leakage rates shows the integrity of sealability at lids and canister shell, as all values are under 1.0×10^{-9} Pa*m^3/s. In Figure 19, photographs of the cut section of the directly impacted welded part during horizontal drop test through microscope with magnified by 5.7 times are shown. Crack initiation could be found in this figure due to the impulsive moment around the top corner of the test canister. However, the initiated crack was arrested in the first welded layer.

Figure 15. Overall view of the horizontal drop test

Vertical Drop Test Results

Figure 18 shows photographs of the test canister in the drop test. The bottom plate of the test canister was deformed by the force of inertia of the contents as shown in Figure 18. However, the basket was slightly deformed near the impacted area. The average deceleration value was about 1153G at the center of the shell. He leak tests were performed before and after the drop tests to confirm the integrity of leak-tightness of the test MPCs (especially welded lids) against impact loads. Measured leakage rates shows the integrity of sealability at lids and canister shell, as all values are under 1.0×10^{-9} Pa*m^3/s. Indicative echoes were detected during UT inspections before drop test. Although a small air blow hole was observed, no crack initiation could be found in the canister. From these results, it seems that the crack initiation may be avoided in the drop events with the vertical orientation even if the impact load over 1000G was applied.

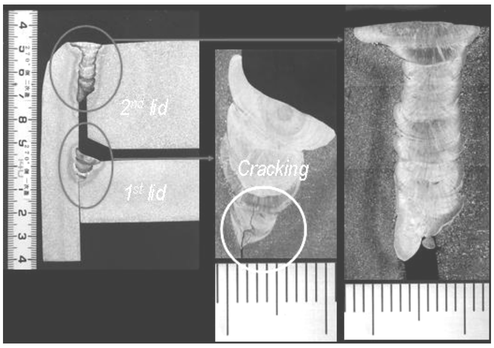
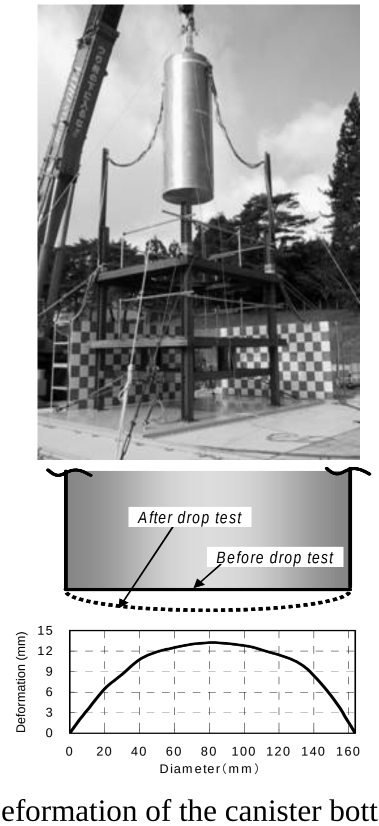


Figure 16. Magnified view of the cross section of the welded lid impacted in the horizontal drop test



(Deformation of the canister bottom)

Figure 17. Vertical drop test of canister

Discussion and Summary

Two drop tests in horizontal and vertical orientations with the full-scale MPCs made of high-corrosion-resistance materials were conducted onto the hard target, and each drop heights were 1m and 6m, respectively. During drop tests, the accelerations and strains were measured in each part of components, and the leak-tightness tests were executed before and after drop tests. After drop tests, the welded parts were cut to the pieces to evaluate the occurrence of the crack initiation. According to these investigations, the structural and sealability integrities of the MPC were verified, even if subjected to extreme loads related to the non-mechanical drop or impact events.

CONCLUSION

Testings of full-scale casks for spent fuel /transport have been almost completed to demonstrate safety of dual purpose metal cask and concrete cask storage technologies.

Currently, stress corrosion cracking (SCC) of canisters for concrete cask storage is being tested and evaluated. Optional counter measures to overcome SCC are also investigated. As to security of metal cask storage method, airplane crash test is being conducted. Vault storage of spent fuel is also studied for the next generation method of spent fuel storage. Those results will be reported in the next opportunity.

ACKNOWLEDGMENTS

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