Demonstrative Drop Tests of Transport and Storage Full-Scale Canisters with High Corrosion-resistant material

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INTRODUCTION

The concrete modular dry storage technologies are becoming widely-used, aiming at better economic performances. In 1997, we commenced a research program of the demonstration test for interim storage of spent fuel, mainly involving concrete cask storage technologies, particularly aiming at the realization of dry storage away from reactor in 2010. Key issues of this research include safety standards in operation and maintenance during storage and unloading/loading for transportation, long-term integrity of metal canister and concrete materials, and so on. To propose safety standards for concrete cask structures, systems, components, the demonstration program† for qualification of concrete cask performance under the normal, ab-normal and accidental events was successfully terminated[1],[2]. Especially, 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 CRIEPI's drop test program.

DEMONSTRATION PROGRAM FOR QUALIFICATION OF CONCRETE CASK PERFORMANCE

A schedule of the overall demonstration program is shown in Fig.1. To perform the heat removal tests and drop tests with full-scale test bodies efficiently, the demonstration test facility as shown in Fig.2 was constructed in the Akagi Test Center of CRIEPI, located in the north of about 130 km from the center of Tokyo. In this facility, there are heat removal test area and drop test area. In the drop test area, a steel plate is fixed on the base concrete. Size of the steel plate is 7.5m length, 4.5m width and 50mm thickness. Thickness and weight of the base concrete is 2m and 550tons, respectively.

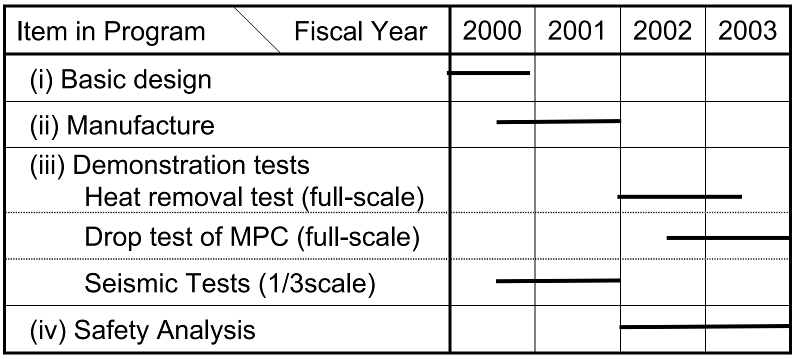


Fig.1 Schedule of demonstration program for concrete cask

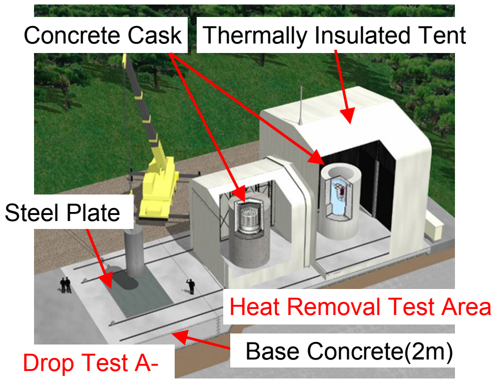


Fig.2 Demonstration test facility

Basic design of Japanese type concrete cask

Strength and safety must be maintained to the load when considering the conditions under which casks are used (size of the site, installation on the shoreline, seismic factors) which is peculiar to our country about the structure and the use material of the cask and to be assumed during the design storage period. Preliminary design parameters are shown in Table I. The concrete cask was assumed to be for indoor use.

Two types of concrete cask, a reinforced-concrete cask (RC cask) and concrete-filled-steel cask (CFS cask) to store the high burn-up spent fuel, were designed. Preliminary designs for two types of cask, RC cask and CFS cask were employed as the basic structure as shown in Fig.3 and Table2.

† This work has been being executed under contract with Ministry of Economy and Trade Industry.

The RC cask is made from reinforced concrete storage container and the reinforced concrete becomes a structure strength part to the assumed load. On the other hand, at the CFS cask, concrete storage container consists of concrete covered with a steel sheet, creating a steel structure; concrete is not a structure strength part and is a radiation shielding material.

Fabrication of full-scale test MPC

Two types of full-scale MPC were designed and fabricated to apply to the drop tests as shown in Fig.4. 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.

Fig.5 shows the welding procedure for the lids for preparation of drop tests. During welding procedures, Helium leak test, penetration tests and ultrasonic tests were executed to assure the welding quality.

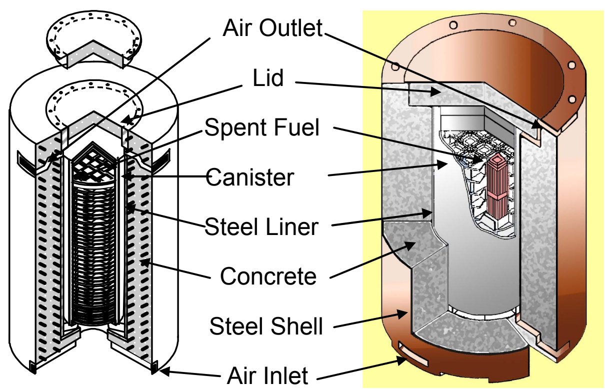


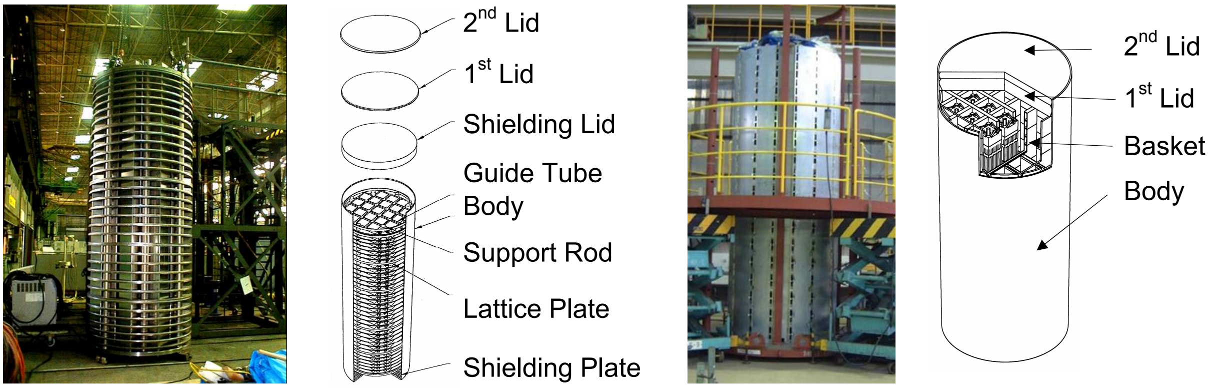
Fig.3 Outline of the two type of Cask

Table I Preliminary design parameter

Design storage period	40~60 years
Fuel type	17x17 array for PWR
Enrichment (wt % U^{235})	4.9%
Burn-up (Max)	55 MWd/kgHM
Cooling time	10 years
Environmental temperature	33°C
Storage cell	21
Total heat load (max)	22.6 kW

Table2 Specifications of the concrete cask

Cask type	RC	CFS
Height	5787 mm	6120 mm
Outside diameter	3940 mm	3800 mm
Inside diameter	1850 mm	1838 mm
Total Weight	185 t	184 t
Canister type	Type I	Type II
Height	4630 mm	4470 mm
Outside diameter	1676 mm	1640 mm
Weight (with spent fuels)	35 t	30 t
Body	Super stainless steel	Austenitic-ferritic stainless steel
Basket	Stainless steel	Aluminum alloy



[Type I] [Type II]

Fig.4 Outline of the two type of the test MPC

Fig.5 Welding procedure for the lids

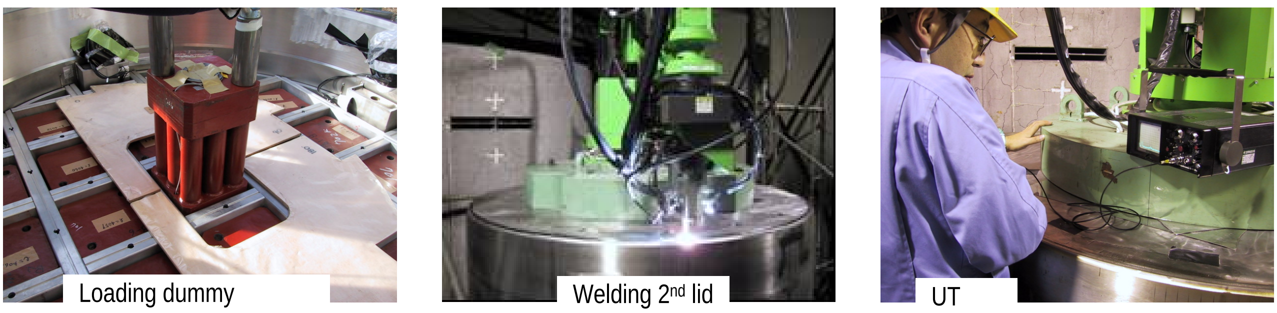
Preparation for measurements
#1 Preparing sensors
Machining
#2 Fabrication of 1st lids
#3 Groove Inspection
#4 Loading basket & dummy weights

→

Welding 1st lid
#5 Setting 1st lids & Welding machine
#6 Welding 1st lid
#71 Inspection
> Progress PT, UT, He-leak test
#8 Welding Port-Cover
> PT

→

Welding 2nd lid
#9 Machining 2nd lid
#10 Setting 2nd lid & Welding Machine
#11 Welding 2nd lid
#12 Inspection
> Progress PT, UT

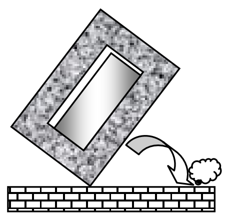
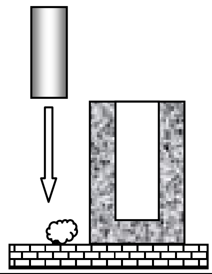


DROP TEST

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

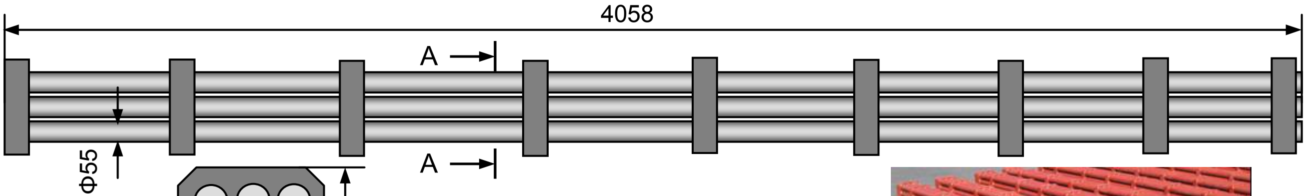
As for the object target, the hard target, namely, the 5cm thickness steel plate attached to the concrete block (Widh13m, Thickness2m, Length10m, total weight about 550ton) was applied. Moreover, to monitor the impact response of the target block during the tests, the accelerometers were set inside the concrete block.

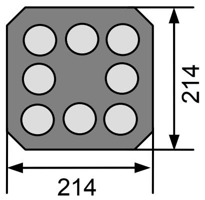
Regarding contents of MPC, dummy steel structures equal to the total weights of the spent fuels (14.7ton) were used as shown in Fig.7.

Canister	Type I	Type II
Non-mechanical drop or impact events during handling	Tipping-over 	Drop 
Orientation	Horizontal	Vertical
Height	1m*	6m**

* Equivalent drop height for rotational velocity caused by tipping-over from height of GC
** Drop height from cask height

Fig.6 Drop test condition





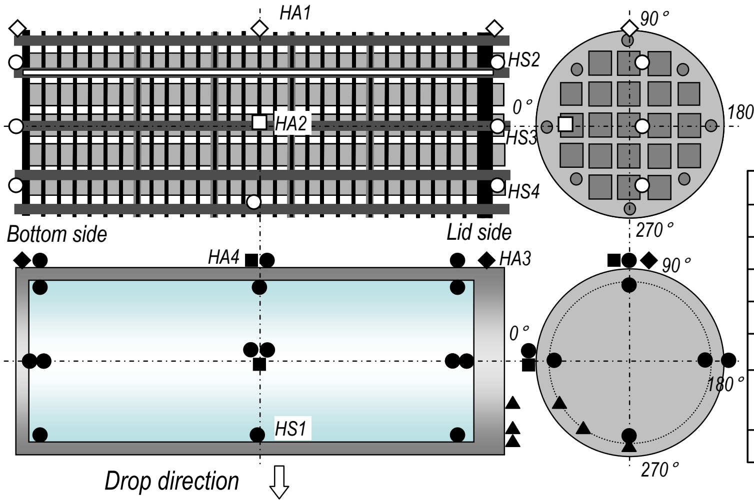
Section A-A

Mas	701k
Manufacture num-	2

Fig.7 Specifications of dummy

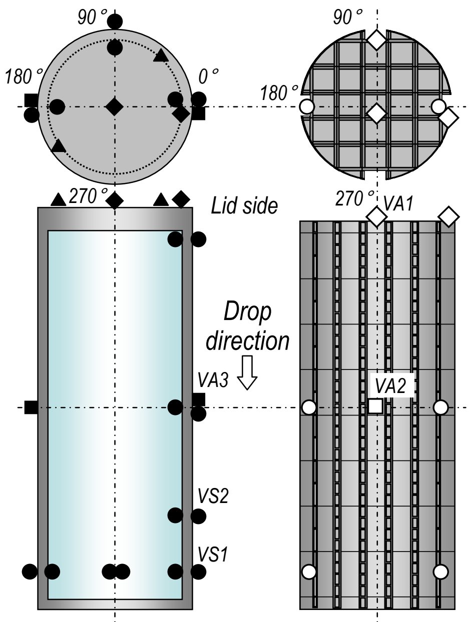
Measurements

To estimate the impact forces and plastic deformations on the MPCs, acceleration and strain were measured at various points in the test MPCs during drop tests. Fig.8 and Fig.9 shows the measuring points of acceleration and strain for each drop tests. Considering the impulsive vibrations due to the impact of the test MPC on to the steel plate, specified gauge-type accelerometer with large capacity (max 10,000G) was applied. Measuring sampling rate was set to 1μsec and all of data were measured simultaneously without delays. The high frequency components were removed from these mesured time histories by a low-pass filter (1kHz) as shown in Fig.10.



Mark	Point	Type
○	Basket plate	Strain gauge
◇	Basket	Acc. 10000G
□	Dummy Weight	Acc. 5000G
●	Shell body	Strain gauge
▲	Welded line	Strain gauge
◆	Bottom (90°) Top (90°)	Acc. 10000G
■	Center (0°, 90°)	Acc. 5000G

Fig.8 Measuring points at horizontal drop tests



Mark	Point	Type
○	Basket block	Strain gauge
◇	Basket	Acc. 10000G
□	Dummy Weight	Acc. 10000G
●	Shell body	Strain gauge
▲	Welded line	Strain gauge
◆	Top (Center, 0°)	Acc. 10000G
■	Center (0°, 180°)	Acc. 10000G

Fig.9 Measuring points at vertical drop tests

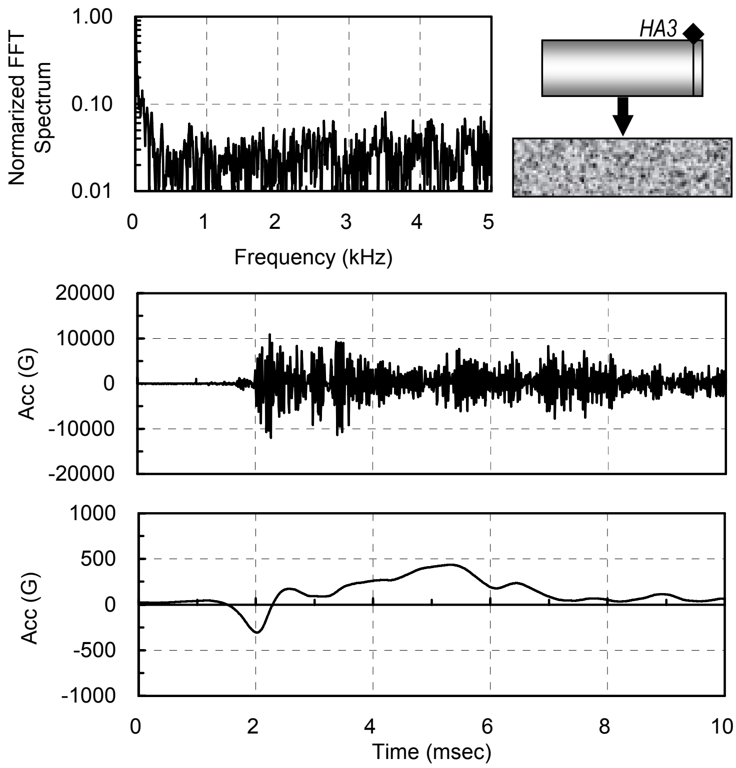


Fig.10 Example of filtered acceleration time history

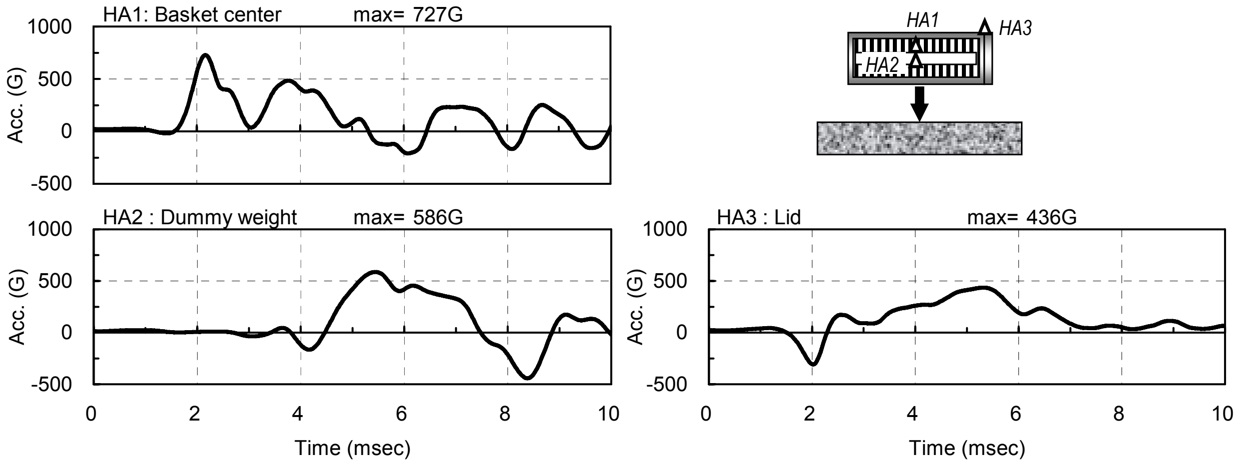
Horizontal Drop Test Results

Fig.11 shows photographs of the test canister before and after the drop test. The test canister was slightly deformed near the impacted area. Fig.12 shows time histories of accelerometers and strain gauges at various points in the test canister, measured in the drop test. The average deceleration value was about 436G at the top of the lids.

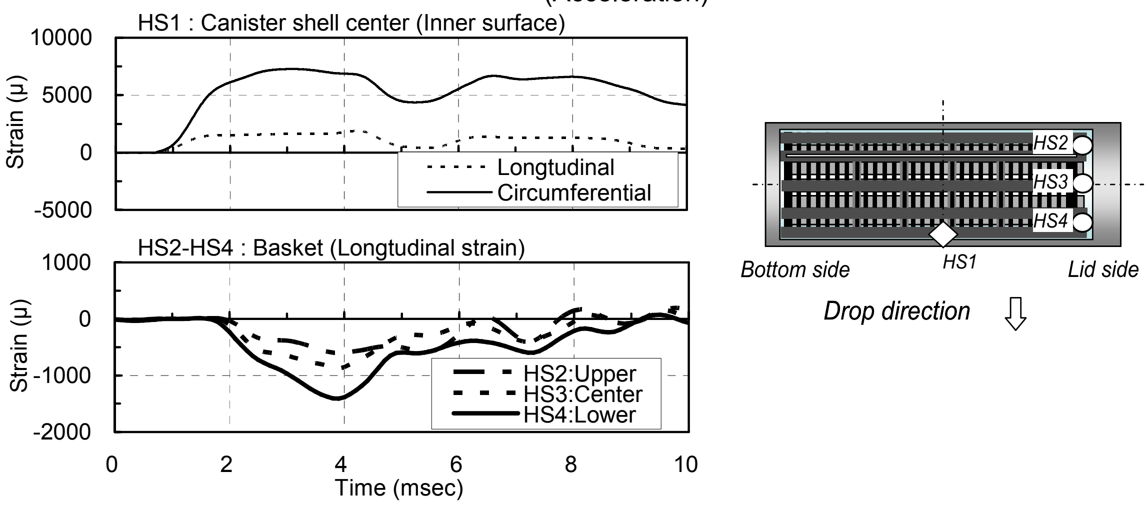
Fig.13 shows the schematic view of He leak test for 2nd lid. He leak tests were performed before and after the drop tests to confirm the integrity of leak-tightness of the test MPCs (especially welded lids) against impact loads. Measured leakage rates shows the integrity of sealability at lids and canister shell, as all values are under 1.0×10^{-9} Pa*m^3/s.

In Fig.14, 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.

Fig.11 Overall view of the horizontal



(Acceleration)



(Strain)

Fig.12 Measured time histories during horizontal drop test

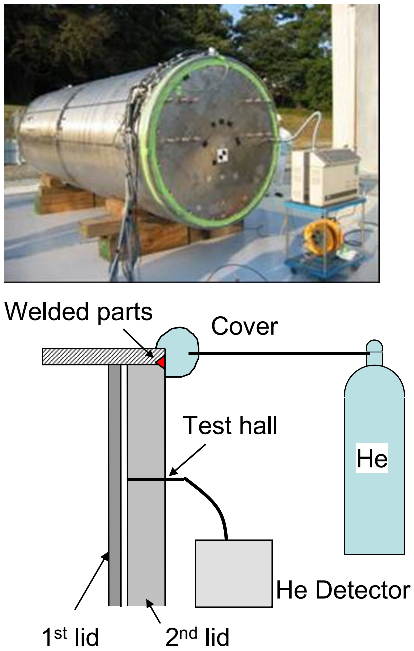


Fig.13 He leak test for 2nd

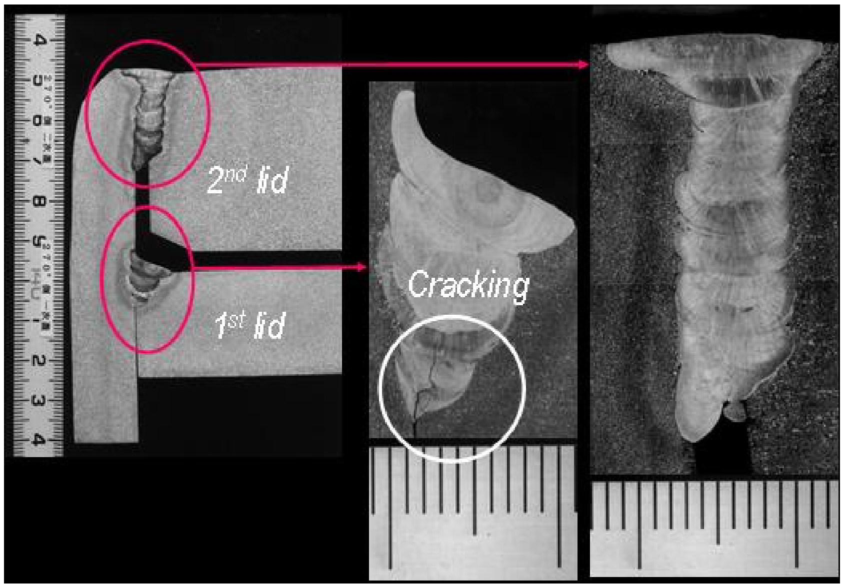


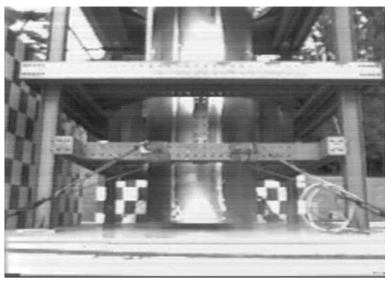
Fig.14 Magnified view of the cut section of the directly impacted welded part during horizontal drop test

Vertical Drop Test Results

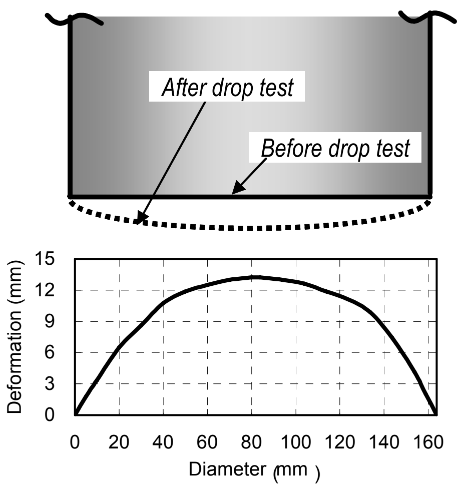
Fig.15 shows photographs of the test canister before and after the drop test. The bottom plate of the test canister was deformed by the force of inertia of the contents as shown in Fig.15. However, the basket was slightly deformed near the impacted area. Fig.16 shows time histories of accelerometers and strain gauges at various points in the test canister, measured in the drop test. 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.


(Before drop


(At the moment of impact)


(Deformation of the bas-



(Deformation of the bottom plate of the test canister)

Fig.15 Overall view of the vertical drop test

In Fig.17, photographs of the cut section of the welded part through microscope, in which the indicative echoes were detected during UT inspections before drop test, are shown. Although a small air blow hole was observed, no crack initiation could be found in this figure. From these results, it seems that the occurrence of the crack initiation, may be avoidable for the drop events in the vertical orientation even if the impact load over 1000G was applied.

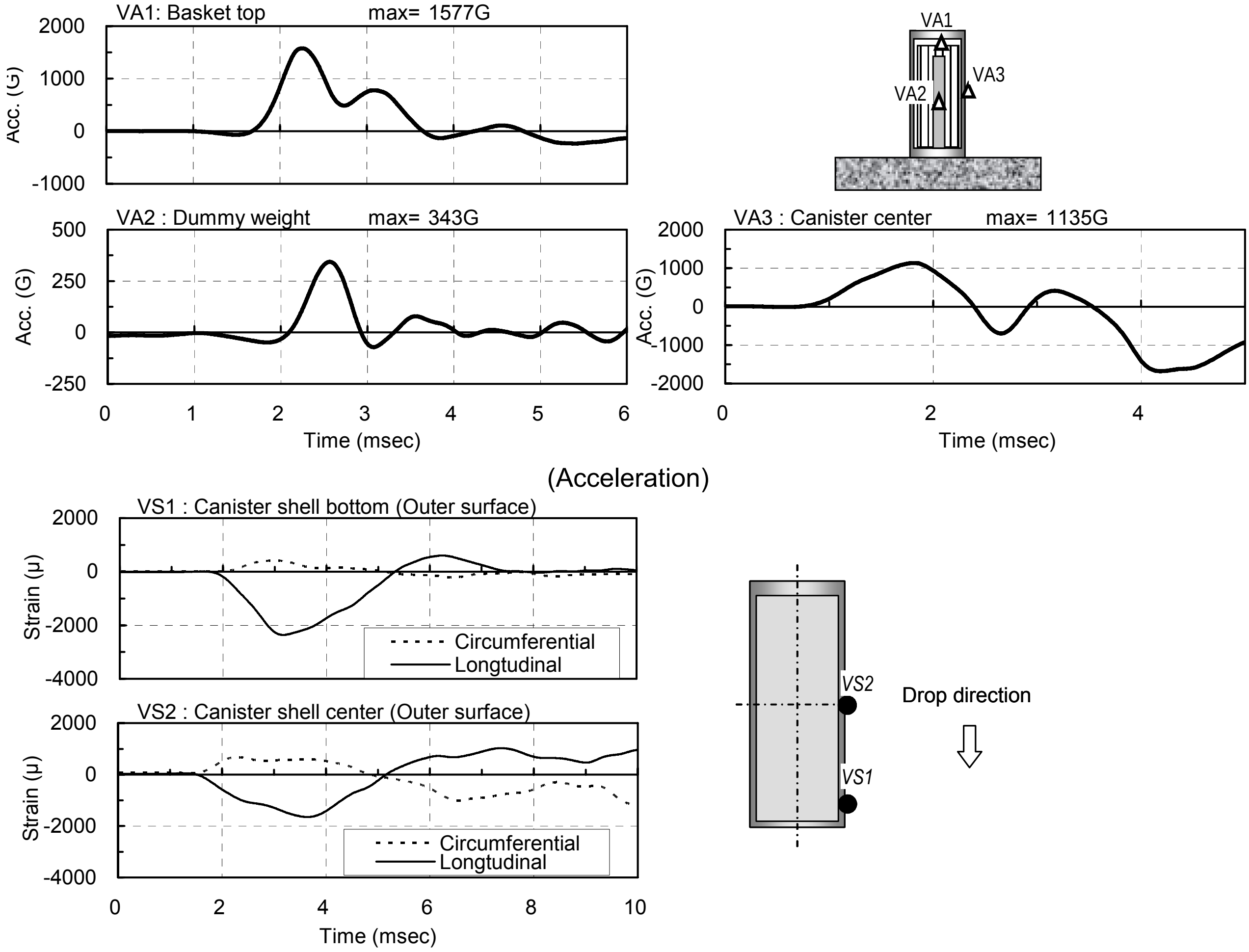


Fig.16 Measured time histories during the vertical drop test

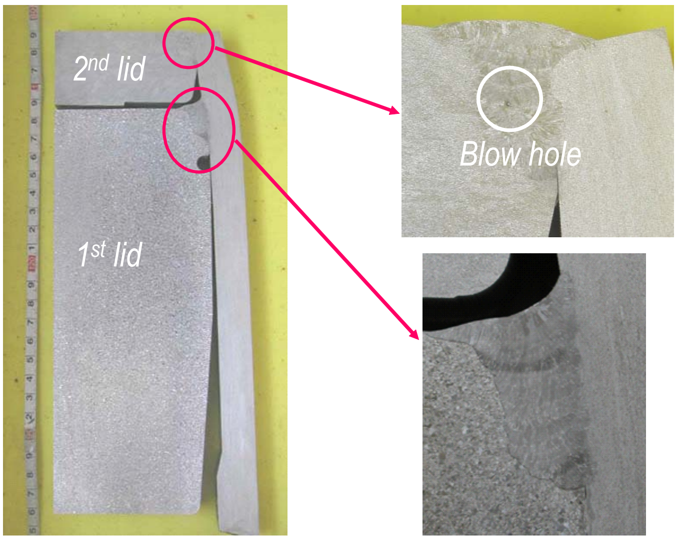


Fig.17 Magnified view of the cut section of the directly impacted welded part during vertical drop test

DROP TEST ANALYSIS

To investigate the impact loads and strain distributions occurred in the MPC's bodies and inner structures during drop tests, impact analyses were executed using LSDYNA code. Fig.18 shows the finite element model. One-half symmetric and one-quarter double symmetric models were taken for the horizontal and vertical drop test analyses, respectively. To simulate the welded joints, the lid nodes and shell body nodes were tied. For initial conditions, the free-fall velocity from the drop height was applied to each node of finite element models. Table3 shows the material properties of the canister used in the analyses. These properties were obtained from static tensile tests of specimen machined from the base material. The stress-strain relation of these materials were expressed by bilinear approximation and based on the isotropic hardening rule. For failure criterion, the Von-Mises yield criterion was applied, but the strain rate effect was not considered. In Fig.19, the test results and the analytical results were compared as to the acceleration time history for each drop test. In the analysis, the maximum acceleration is in good agreement with the test results in each drop orientation. Table4 shows the summary of the drop analysis. An important plastic strain occurred in the vicinity of the welded joints, however the corresponding strains were considerably less than the ultimate strain of the material in each drop orientation.

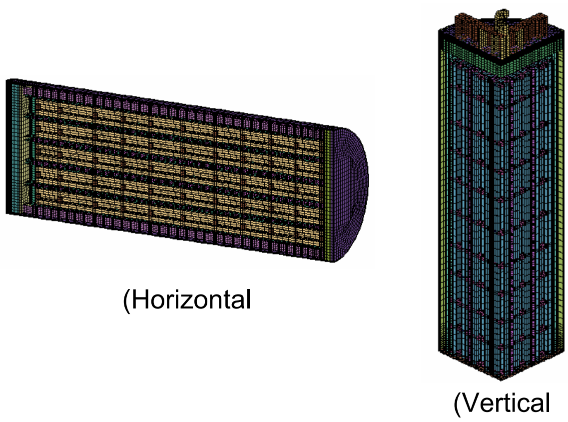


Fig.18 Finite element

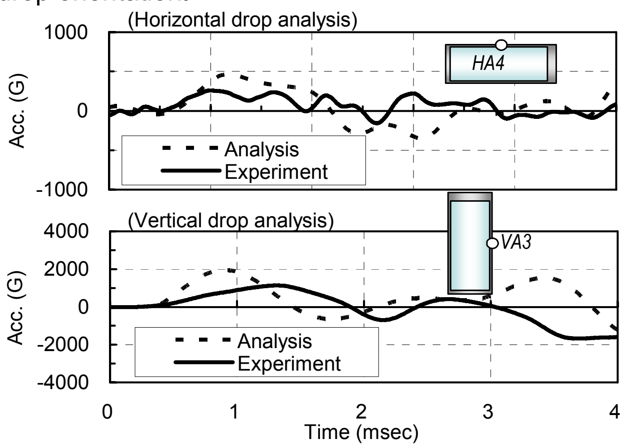


Fig.19 Comparison time history of acceleration

Table3 Material properties of the canister

Material	Super stainless	Austenitic-ferritic stainles
Density	8.0 g/cm^3	8.0 g/cm^3
Elastic modulus	192GPa	213GPa
Hardening modulus	1012MPa	786MPa
Yield stress	407MPa	664MPa
Poisson ratio	0.31	0.27

Table4 Summary of drop analysis

Part	Plastic strain	
	Horizontal	Vertical
Shell Body	8.4%	5.0%
1st Lid	5.3%	2.6%
2nd Lid	5.4%	7.0%

CONCLUSION

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 initiaton. Moreover, to investigate the impact loads and strain distributions occurred in the MPC's bodies and inner structures during drop tests, impact analyses were executed using LS-DYNA3D code. 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.

REFERENCES

[1] WATARU, M., et al., Demonstration tests on the full-scale concrete casks, International Seminar on Interim Storage of Spent Fuel, Tokyo, Japan, May, 2003.
[2] SHIRAI, K. et al., Current Status of R&D Program of Spent Fuel Storage Technology, Storage of Spent Fuel from Power Reactors, 2003 Conference, IAEA-CSP-20, IAEA, Vienna, June, 2003.