Disposal Container Safety Assessment – The Comprehensive Performance Evaluation of a 'Yoyushindo Disposal' Waste Container by Drop Test - 10087

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ABSTRACT

To be prepared for decommissioning nuclear power plants, the Federation of Electric Power Companies of Japan has undertaken studies into "*yoyushindo* disposal," whose concept is similar to "intermediate disposal" called by international organizations, of higher-activity low-level radioactive waste. One of the studies is the development of a disposal container to store radioactive waste. To assess drop events of a waste package in the safety assessment of power plants and disposal facility, the drop resistance performance of the disposal container was evaluated by conducting a drop test using the three disposal containers in the actual dimensions, drop analysis under conservative conditions, and fracture mechanics assessment.

The lids of the full-scale specimens for drop test were welded by automated remote control using a welding machine without pre- and post-weld heat treatment, simulating the situation of manufacturing an actual waste package. Results of the drop test showed that the disposal container underwent no penetration crack and splash of its content, under such conditions as the maximum weight and height expected in the handling. Drop analysis and the fracture mechanics assessment indicate that the strain of the disposal container caused by the drop impact does not exceed the fracture strain and unstable fracture does not occur. These tests and evaluation show that the disposal container is sufficiently drop-resistant under expected handling conditions.

INTRODUCTION

To be prepared for decommissioning nuclear power plants, the Federation of Electric Power Companies of Japan has undertaken studies into "*yoyushindo* disposal," whose concept is similar to "intermediate disposal" called by international organizations, of higher-activity low-level radioactive waste.

The object wastes of *yoyushindo* disposal are mainly structures of the reactors, specifically channel boxes and control rods in boiling-water reactors and burnable poisons and control rods in pressurized-water reactors. The wastes are almost activation materials and their Co-60 radioactive concentration is estimated to be up to about 10^{14} Bq/t.

For the disposal of these radioactive wastes, the development of the disposal container is promoted systematically. The three drop tests by using three specimens in the actual dimensions were conducted under conservative conditions to assess drop events of a waste package in the safety assessment of power plants and disposal facility. The drop analysis and the fracture mechanics assessment were performed after the drop test.

There are two methods for closing the lid of the container, namely welding and bolting. However, the study as for the disposal container welding the lid is described in this paper.

DISPOSAL CONTAINER FOR "*YOYUSHIDO* DISPOSAL"

Structure

The container consists of the body (four side walls and bottom), lid, and lifting grippers. The lid is welded to the body after wastes are put into the container. It is called this container with wastes as a waste package. The additional shielding plates inside of the disposal container are placed to reduce the dose rate at the surface of the container depending on the radiation strength.

Shape/dimensions

The container is cubic, so that it can meet the capacity of existing cranes used in power plants and other facilities and provide higher efficiencies for storing wastes and being placed in disposal sites. Its dimensions are 1.6 m in length, width, and height (or 1.2 m in height in some cases). Thickness of member is basically 50 mm, determined according to the expected strength necessary for piling up in power plants and disposal site. The four corners of the container are rounded vertically, so that the container's load-bearing strength would increase and the containers could be stored in a transport cask efficiently.

Material

The carbon steel (JIS G 3106, which is equivalent to SM490A) is used as a material of the container, because it provides better productivity and workability. This material is reasonable price in the market and widely available in significant quantities.

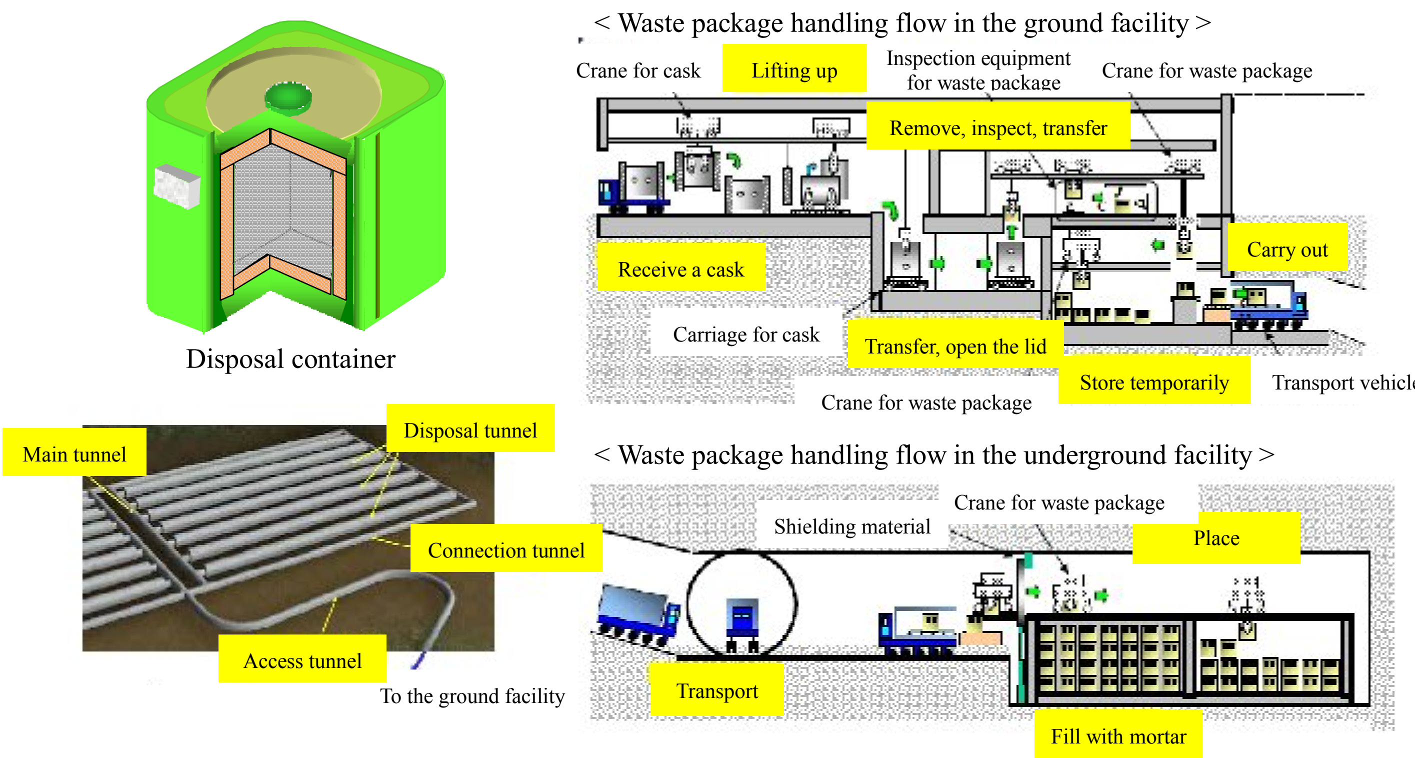
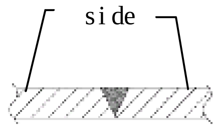
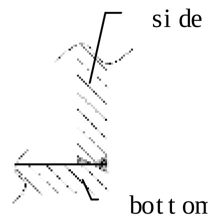
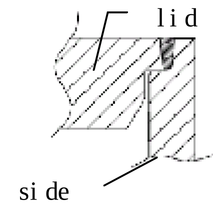


Fig. 1. Conceptual diagram of "yoyushindo disposal"

MANUFACTURE OF DORP TEST SPESIMENS

Three specimens in the actual dimensions were manufactured for the drop test. As described in detail below, steel dummy weights were placed in each specimen to simulate the weight of the waste package, and the gap between the specimen and the dummy weights was filled with mortar. Welding of lid to containers would be operated by remote control due to a high-dose environment at power plants. So simulating this condition, welding robot be used to weld the lid to the specimen body. And it may be difficult to perform pre- and post-weld heat treatment at power plants. Therefore, the both heat treatments were not performed. Table I shows specifications and conditions for manufacturing the specimens, including welding conditions.

Table I. Manufacture specifications of specimens

External dimensions	body	W1600mm×L1600mm×H1600mm thickness 50mm		
	lid	W1540mm×L1540mm×H100mm thickness 50mm (minimum part)		
Material		SM490A (JIS G 3106)		
Welding parts		side-side	side-bottom	side-lid
Welding condition	groove			
	Welding method	MAG	MAG	MAG
		semi-auto	semi-auto	auto
	Welding material	YGW11 (φ1.6)	YGW11 (φ1.6)	YGW11 (φ1.6)
	Sheild gas	CO_2	CO_2	$Ar+CO_2$
	Preheat	yes	yes	non
	Postheat	yes	yes	non

DROP TEST

The drop test was conducted three times using the three specimens at the drop test facility of the Federal Institute for Materials Research and Testing in Horstwalde, Germany. The test conditions were chosen from the handling conditions, so that they could be severer to the waste package than other conditions. The weight of each specimen was 28.2 t or 20.6 t, determined from the maximum weight of the waste package expected when the dose rate at the surface of the waste package was limited to 10 mSv/h or 500 mSv/h. The drop height was 8 m, according to the maximum handling height expected at disposal facility. As for the drop orientation and target, we referred to results of a drop analysis[1] of the container. As a result, each specimen was dropped onto a concrete slab, so that the lid corner of the specimen met the specimen's center of gravity on the vertical line (hereinafter, this drop orientation is referred to as "corner drop"). The concrete slab used as the drop target was manufactured on the basis of specifications of concrete floors for the disposal facility. Measured compressive strengths of the concrete previously manufactured on the basis of the same specifications were 80 - 95 MPa at one year after its casting, while its design compressive strength in the specifications was 60 MPa. To make the test conditions conservative, the slabs were manufactured so that it could provide compressive strength of 100 MPa or greater at the day of the drop test. Main reinforcing bars, with a diameter of 32 mm, were arranged at intervals of 150 mm in a reticular pattern. Shear reinforcement bars, with a diameter of 22 mm, were placed at crossing positions of the main reinforcing bars at intervals of 150 mm lengthwise and of 300 mm widthwise. The outline dimensions of the concrete slab were 3,200 mm in width, 1,600 mm in length, and 800 mm in height. As for test temperature of specimens, temperature of the lid weld should be 0 degrees Celsius or less, because the lowest temperature in the handling environment of the waste package in power plants and disposal facility is more than 0 degrees Celsius. Table II shows conditions of the drop test. In the drop test the leak tests were conducted, in other words to confirm the presence of penetration cracks on the container. When any penetration crack was present, the amount of particles leaking from the inside of the container was measured. The deformation of the container, temperature of the lid weld, strain, deceleration, and destroyed depth of the concrete slab by the drop impact were also measured.

Table II. Conditions of the drop test

Test No.	1	2	3
Specimen Weight	28.2t	20.6t	28.2t
Drop Height	≧8m		
Drop Orientation	Corner drop		
Test Temperature[*1]	≦0 degrees Celsius		
Drop Target	Concrete slab（compressive strength：≧100MPa）		

*Temperature of the lid weld

The drop test was conducted three times under the planned conditions of drop height, drop orientation, and temperature of the specimens. Observation of the specimens immediately after falling showed that all of them did not undergo significant deformation or cracks, except local plastic deformation found in the drop corner of each specimen. Figure 2 shows appearance views of the specimen after the first drop test.

The leak test, in conformity with DIN EN 1593, was conducted after drop at a pressure of 0.1 MPaG applied for 30 minutes. As a result, no bubbles from the perimeter of the lid weld and the portion with plastic deformation were found, suggesting that the content of the containers did not leak. These results suggest that the container prevents a splash of its content under conservative conditions for drop event. Table III shows major results of the drop test.

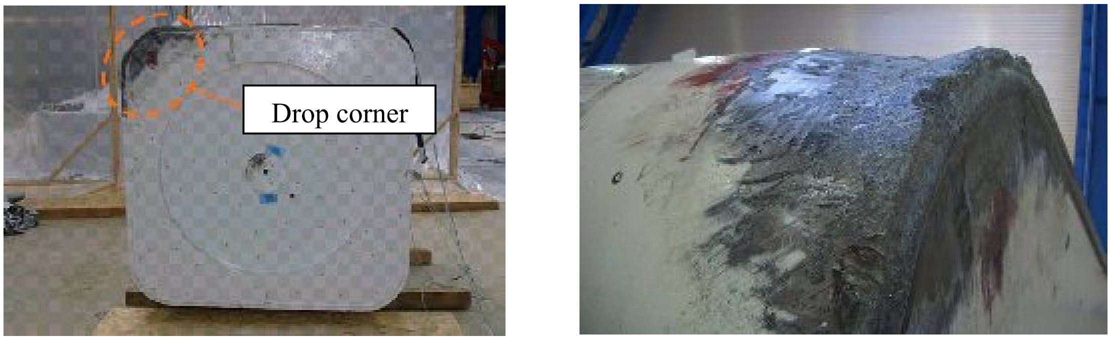


Fig.2. Appearance of the first drop specimen after drop

Table III. Results of the drop test

Test No.	Conditons					Results			
	Specimens Weight	Drop Height	Drop Orientation	Tem. of spesimens	Comressive Strengh of concrete slab	Through Crack	Deformation	Destroed depth of concrete slab	deceleration upper :lid lower :body
	t	m		celsius degrees	MPa		mm	mm	
1	28.2	8	corner drop	-4.1	147.9 MPa	**non**	16mm	205mm	not mesured
2	20.6		corner drop	-2.7	142.9 MPa	**non**	19mm	178mm	1560m/s^2 1110m/s^2
3	28.2		corner drop	0.0	139.7 MPa	**non**	20mm	230mm	1470m/s^2 1226m/s^2

DROP ANALYSIS

The drop analysis was carried out, using the LS-DYNA code for simulation of the drop test conditions. Using the symmetry of the shape of the container, 1/2 model was used, while modeling the container, dummy weight, and mortar using solid elements. Solid elements and beam elements were used for modeling of the concrete and the reinforcing bars of the concrete slab, respectively. Figure 3 illustrates the analysis model. As for physical property values of materials, data obtained by a tensile test were used for SM490A, the weld metal and reinforcing bars. For other materials, standard values were used. Data of strain and deceleration obtained by the drop test, together with adjustment of the contact conditions and physical property values of the concrete, made it possible for the analysis to reproduce the results of the drop test. Table IV shows the analysis conditions.

Equivalent plastic strains of the container due to drop impact are illustrated in Figure 4. Equivalent plastic strain in around the drop corner edge was comparatively large, but it did not exceed fracture strain, which was converted to true strain, in all portions of the main unit, lid, and weld metal. Values of the fracture strain, which was converted to true strain, obtained by the tensile test were approximately 140% in material SM490A and 120% in the weld metal.

Table IV. Conditions of the drop analysis

Model	3-D model（half）
Specimen Weight（t）	28.2
Drop Height(m)	8
Drop Orientation	Corner Drop

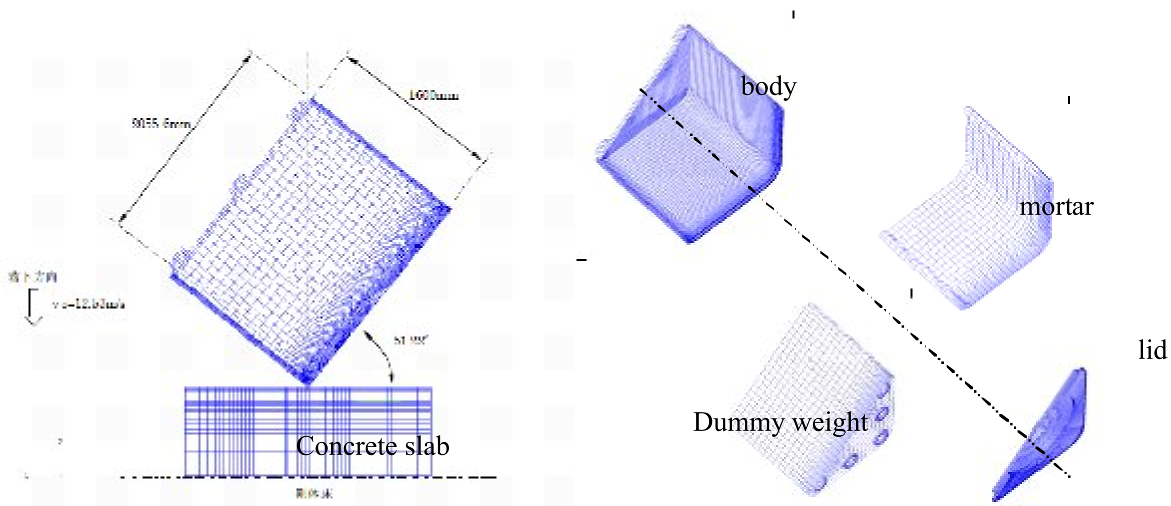


Fig.3 Model of the drop analysis

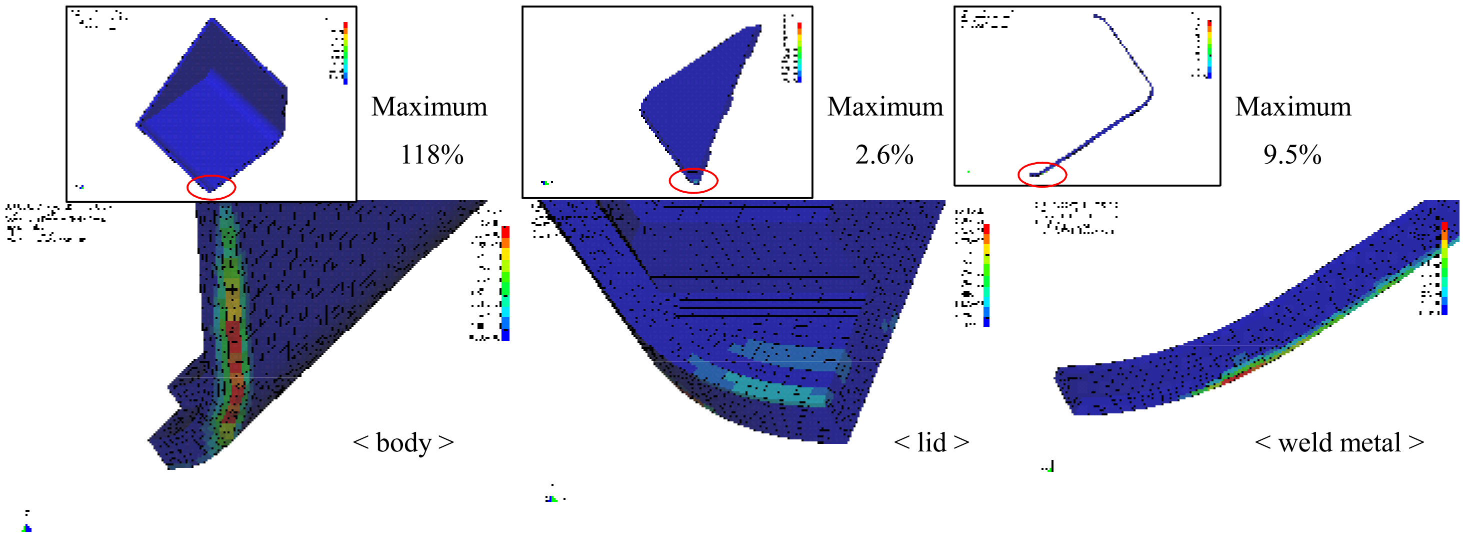


Fig.4. Equivalent plastic strain distribution for each part of the disposal container

FRACTURE MECHANICS ASSESSMENT

The fracture mechanics assessment of the lid weld was performed using the 2-parameter method[2]. Evaluation of the unstable fracture using the 2-parameter method requires values of the stress intensity factor, dynamic fracture toughness, load, and plastic collapse load. The stress intensity factor per unit operating stress was calculated using ABAQUS code, and the stress intensity factor was determined using the stress obtained from the drop analysis. The stress in drop analysis was used the largest one which acts in the direction that the lid opens. The stress intensity factor was analyzed under the plane strain condition, as illustrated in Figure 6. Operating stress were resolved unit bending stress and unit membrane stress. As physical property values of the base material and weld metals, same Young's modulus of which value was 205.6 MPa was used. This analysis provided the stress intensity factor in the opening mode (Mode I) and the shear mode (Mode II). Therefore, the tangential stress intensity factor $K_{\theta,max}$[3] was applied to evaluate a mix of the Mode I and II. Table V shows calculation result of the stress intensity factor when the specimen of 28.2 t drops form 8 m. stress intensity factor analyses under conditions that the specimen had a 2-mm or 4-mm crack vertically and upward from the root edge were also performed. The value of dynamic fracture toughness was determined from a fracture toughness test of the weld metal and bond. To obtain a value that is equivalent to the rate of K (in the order of 10^5 - 10^6) in the case of 8-m drop, the dynamic fracture toughness test by applying weight drop method was performed, which was to drop weights on to the welded test bar which was supported at two side points. K_d(J) values at the weld metal and bond were never below 135 MPa√m. Therefore, this value was used as the dynamic fracture toughness of the container. The load and plastic collapse load were calculated using stresses obtained by the drop analysis.

As a result of the fracture mechanics assessment in the case of 8-m drop, unstable fracture did not occur even if there is a 4-mm crack with the route edge, as shown in Figure 5.

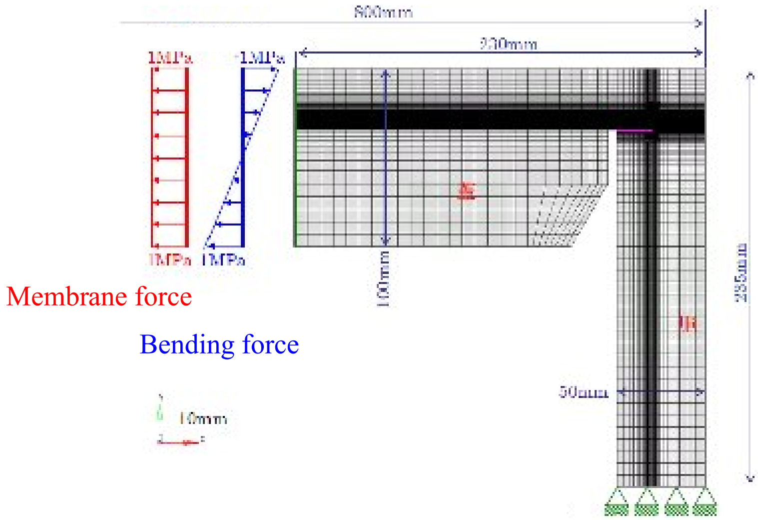
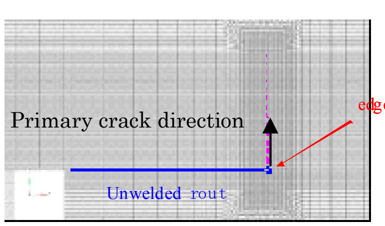
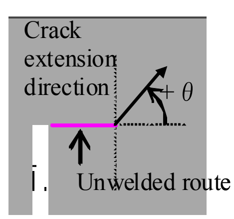


Fig. 5. Model of stress intensity factor analysis

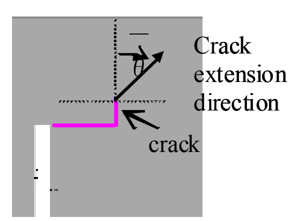
Table V. Results of stress intensity factor analysis in 28t, 8m drop

model	crack lengh (mm)	membrane stress σ_m bending stress σ_b	stress intensity factor ($\sigma_m+\sigma_b$)			
			K_I (MPa√m)	K_{II} (MPa√m)	$K_{\theta,max}$ (MPa√m)	crack extension direction : θ (degree)
plane starin	0	σ_m=6MPa σ_b=42MPa	61.92	-13.72	66.1	23.0
	2	σ_m=6MPa σ_b=42MPa	55.57	21.43	65.8	-34.6
	4	σ_m=6MPa σ_b=42MPa	64.66	19.45	72.4	-29.2





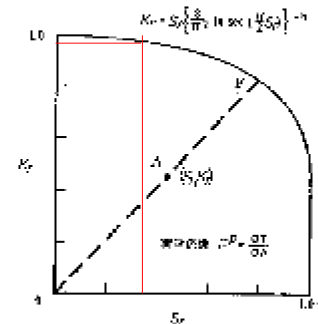
Non-crack case



Crack case

Table VI. Results of the fracture mechanics assessment in 28t, 8m drop

Crack length in unwelded route (m)	0	2	4
Tangential stress intensity factor $K_{\theta,max}$	66.1	65.8	72.4
Dynamic fracture toughness $K_d(J)$	135		
$K_{\theta,max}/K_d(J)$ =Kr	0.49	0.49	0.54
Load/plastic collapse load (=Sr)	0.35		
Unstable fracture condition	0.98		
Unstable fracture condition > Kr	Yes	Yes	Yes



Unstable fracture condition on the 2-parameter method

CONCLUSION

Simulating the situation of manufacturing waste packages at power plants, three specimens were manufactured, to which lids were welded by automated remote control using a welding robot without pre- and post-weld heat treatment. The drop test was performed using these specimens. As a result, no penetration crack and splashes of the disposal content were observed even under conservative conditions of weight, height, and drop orientation. Drop analysis and the fracture mechanics assessment showed that strain of the container caused by the drop impact did not exceed fracture strain, and that unstable fracture did not occur. These results show that the disposal container has a sufficient drop resistance under expected handling conditions at facilities.

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