Enclosure 4 to E-60283

MX-6 Safety Analysis Report
(Public Version)

PUBLIC VERSION

MX-6 Safety Analysis Report

(English translation)

CERTIFICATE FOR APPROVAL OF PACKAGE DESIGN FOR THE TRANSPORT OF RADIOACTIVE MATERIALS is issued by NUCLEAR REGULATION AUTHORITY

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Chapter I　Description of Nuclear Fuel Package

Chapter I Description of Nuclear Fuel Package

I-A Purpose and conditions

1.	Intended use of package	To be used to transport fresh fuel assemblies stored in a spent fuel pool of a light water reactor power plant to a fuel fabrication facility.
2.	Model of packaging	MX-6
3.	Type of package	Type A package containing fissile material
4.	Restriction number of packages	No restriction
5.	Transport index	0.1 or less
6.	Criticality safety index	0
7.	Gross weight of package	Not more than 19.5 ton (transport frame not included)
8.	Outside dimensions of packaging	External diameter: approx. 2.1 m, Length: approx. 6.0 m (Top and rear shock absorbing covers included)
9.	Material of packaging	
	Body:	Stainless steel, Copper, Alloy steel, Resin
	Lid parts:	Titanium alloy, Alloy steel, Resin
	Basket:	Aluminum alloy, Borated stainless steel
	Shock absorbing cover:	Wood, Stainless steel, Alloy steel
10.	Nuclear material contained in packaging	The nuclear material specifications are shown in Table I-A.1.
11.	Transport mode	Land transportation by vehicle and marine transportation by ship

Table I-A.1: Specifications of nuclear material contained in packaging

Items \ Type of fuel assembly				9 × 9 fuel	
Description				Fresh fuel assembly for BWR [1]	
Physical state				Solid (UO_2 Pellet or Gadolinia - UO_2 Pellet)	
Per packaging	Number of assemblies			10 or less	
	Weight of content (kg)			or less	
	Activity	Total activity (GBq)		or less (Total Major Nuclides: or less)	
		Major nuclides [2] (GBq)		^{232}U	
				^{234}U	
				^{235}U	
				^{236}U	
				^{238}U	
				^{99}Tc	
	Heat generation rate			N/A (Fresh fuel assembly)	
Enrichment (wt%)				5.0 or less	
Per fuel assembly	Weight	Fuel assembly (kg) (Including channel box)		or less	
		Uranium oxide (kg)		or less	
		Uranium (kg)		or less	
	Burn up rate			N/A (Fresh fuel assembly)	
	Cooling time			N/A (Fresh fuel assembly)	
Impurity specification of enriched uranium				^{232}U	≤ μg/gU
				^{234}U	≤ μg/g^{235}U
				^{236}U	≤ μg/gU
				^{99}Tc	≤ μg/gU
				In case of ^{236}U < μg/gU, ^{232}U and ^{99}Tc are not applicable.	

Note 1) Fresh fuel assembly stored in a spent fuel pool

Note 2) For enrichment of 5.0 wt%

I-B Type of package

Type A package containing fissile material

A supplementary description about the type of package is included in Appendix-1, Chapter I.

I-C Packaging

C.1 Design summary

As shown in Figure I-C.1, this cylindrical packaging is housed in a maritime container and horizontally installed on a transport frame that also serves as a tie down device during transport.

A general view of the packaging is shown in Figure I-C.2 and a longitudinal cross section of the packaging in Figure I- C.3.

The following gives a summary of the packaging:

- The packaging is handled with trunnions or handling belts mounted onto the body.
- The packaging has a shock absorbing cover on the top and another on the rear to alleviate any impact caused by a drop or other incident.
- The packaging is designed to ensure leaktightness. As shown in Figure I-C.4, the inner surface of the shell part, the inner surface of the bottom, the inner surface of the lid, the lid gasket, the inner surface of the quick connection cover and the quick connection cover gasket constitute a containment boundary.
- The major shielding materials include stainless steel, titanium alloy, aluminum alloy and resin that make up the packaging.
- The basket used to hold fuel assemblies in the packaging uses borated stainless steel as neutron poison.
- The exterior of the packaging has been finished to be a smooth surface so that any contaminants can easily be removed if contaminated with radioactive material.

(Unit: mm)

Figure I-C.1: Example of packing style of package

Figure I-C.2: General view of packaging

(Unit: mm)

Figure I-C.3: Longitudinal cross section of packaging

Figure I-C.4: Containment boundaries of packaging

C.2 Structure

The packaging mainly consists of four parts: body, lid parts, basket, and top and rear shock absorbing covers.

(1) Body

The body consists of a shell part and bottom parts. Figure I-C.5 to Figure I-C.9 show the longitudinal cross section, the end surface geometry, the lateral cross section, the trunnion structure and the handling belt structure respectively.

The shell part consists of a cylindrical inner shell of a thickness of [redacted] mm, [redacted] stiffeners of a thickness of [redacted] mm radially installed around the perimeter of the inner shell, [redacted] external plates of a thickness of [redacted] mm installed so as to sandwich the stiffeners, a top flange which has surfaces to assemble lid and top shock absorbing cover and trunnion bases, and a bottom of a thickness of [redacted] mm which has surface to assemble rear shock absorbing cover and trunnion bases. These components are made of stainless steel.

The inner shell is [redacted] The inner shell, the top flange and the bottom are [redacted]

The stiffeners and the inner shell are [redacted] The stiffeners and the external plates are [redacted] The external plates are [redacted] each other. The external plates and the top flange and the bottom are [redacted]

The area enclosed by the inner shell, the stiffeners and the external plates is filled with shell part resin. In this area, [redacted]

On the top end of the external plates, a thermal protection consisting of stainless steel plates filled with [redacted] wood is installed in the gap between the top shock absorbing cover and the external plates to prevent the ingress of heat into the top flange in case of a fire accident.

The external plates are mounted with a pressure regulating valve to control the pressure in the area between the inner shell and the external plates and with a fusible plug to release the pressure in case of an accident. Furthermore, on the outer surface of the external plates, positioning pins are provided to specify the installation position of the handling belts.

The bottom parts consist of a bottom, bottom resin of a thickness of [redacted] mm and a stainless steel bottom resin cover.

All the trunnions are made of stainless steel. There are four trunnions on the top flange and two on the bottom. All these trunnions are installed with [redacted] trunnion fixing bolts and used for tilting up (tilting down) or vertical (horizontal) lifting.

The handling belt is ring shape and its cross section is [redacted] of outside dimensions of [redacted] These belts are installed onto the top and rear sides of the shell part with lining laid under them each and used for horizontal lifting of the packaging with the shock absorbing covers installed.

(Unit: mm)

Figure I-C.5: Longitudinal cross section of body

* See Figure I-C.6

(Unit: mm)

Figure I-C.6: Body end geometry

* See Figure I-C.5

Figure I-C.7: Lateral cross section of body

* See Fig I-C.5

(Unit: mm)

Figure I-C.8: Trunnion structure

(Unit: mm)

Figure I-C.9: Handling belt structure

(2) Lid parts

The lid parts consist of a lid, lid resin and a lid resin cover. The structure of the lid parts are shown in Figure I-C.10.

The lid is made of titanium alloy and has a disk shape with its central part of a thickness of [redacted] mm and its circumferential flange section of a thickness of [redacted] mm. The lid is mounted onto the top flange with [redacted] lid tightening bolts. [1] The contact surface of the lid against the top flange has a double gasket groove into which EPDM gaskets (lid gaskets) are installed to ensure leaktightness of the contact surface.

A quick connection is installed on the lid at an [redacted] position for sampling of the internal gas in the packaging. This quick connection is protected with a stainless steel quick connection cover. The quick connection cover is installed onto the lid with [redacted] bolts. The contact surface of the quick connection cover against the lid has a double gasket groove into which EPDM gaskets (quick connection cover gaskets) are installed to ensure leaktightness of the contact surface.

In order to allow leaktightness tests on the lid and quick connection cover gaskets, a test hole to the area between the double gaskets is provided in the lid and the quick connection cover each. The connection for testing tools has a test plug.

[redacted] is to be installed with [redacted]

Note 1) The body, as stated in the previous section, mounted with the lid parts is called a "packaging body", which may be used as appropriate in Chapter II and the following as an assembly name for analysis or other purpose.

(Unit: mm)

Figure I-C.10: Lid parts structure

(3) Basket

The basket mainly consists of aluminum alloy disks of a thickness of [redacted] mm ([redacted]) and lodgment made of borated stainless steel containing fuels. The structure of the basket is shown in Figure I-C.11.

Each lodgment is a [redacted] assembly of [redacted] mm thick plates and is of pipe type having a square cross section of inner width of [redacted] mm x [redacted] mm.

The [redacted] have 10 holes through which the lodgments penetrate. [redacted] are [redacted] spaced along the axial direction. The [redacted] are axially fastened together with each other using [redacted] of a diameter of [redacted] mm. The lodgment is [redacted] in the cross-section direction with [redacted]

For the purpose of adjusting the longitudinal position of the basket, a basket support consisting of an aluminum alloy disc, [redacted] and [redacted] is provided in the bottom part.

On the aluminum spacers installed on the perimeter of the aluminum plates, aluminum alloy additional shielding of thickness [redacted] mm are secured with [redacted] to supplement the shielding performance.

[redacted] The whole basket is tied to [redacted]

(unit :mm)

Figure I-C.11: Basket structure

(4) Shock absorbing covers

The shock absorbing cover is [redacted] of stainless steel outer plates and [redacted] of thickness of [redacted] mm, [redacted] The inner space of the structure is filled with [redacted] wood as a shock absorber. The structure of the top shock absorbing cover and the rear shock absorbing cover are shown in Figure I-C.12 and Figure I-C.13 respectively. The top and rear covers have almost the same size and are installed to the top flange and to the bottom respectively with [redacted] tightening bolts each. [redacted]

Since the shock absorbing covers are installed so as to cover the trunnions, the inner surface of the covers has dents in the positions corresponding to the trunnions.

[redacted]

Around the perimeter of the top and rear shock absorbing covers, lifting lugs and feet to be used for temporary placement alone are provided.

(Unit: mm)

Figure I-C.12: Top shock absorbing cover structure

(Unit: mm)

Figure I-C.13: Rear shock absorbing cover structure

C.3 Material

The packaging uses materials shown in Table I-C.1.

The resin used in the packaging (shell part resin, bottom resin and lid resin) is a mixture of [redacted], as the principal material, and other materials in the specified proportion listed in Table I-C.2.

Table I-C.1: Packaging components and their major materials (1/2)

Component	Material	Standard [1]
1. Body		
Inner shell	Stainless steel	[redacted]
Stiffener	Stainless steel	
External plate	Stainless steel	
[redacted] plate	[redacted]	
Shell part resin	[redacted] resin	———
Thermal protection	Stainless steel	[redacted]
	[redacted] wood	———
Top flange	Stainless steel	[redacted]
Trunnion	Stainless steel	
Trunnion fixing bolt	Alloy steel	
Handling belt (upper/lower belt)	Stainless steel	
Lifting handle	Stainless steel	
Lifting handle pin	Stainless steel	
Connecting bolt	Alloy steel	
Bottom	Stainless steel	
Bottom resin	[redacted] resin	———
Bottom resin cover	Stainless steel	[redacted]
2. Lid parts		
Lid	Titanium alloy	[redacted]
Lid tightening bolt	Alloy steel	
Lid resin	[redacted] resin	———
Lid resin cover	Stainless steel	[redacted]
Quick connection cover	Stainless steel	
Gasket	EPDM	———

Note1) Materials meeting the requirements of the standards or their equivalent materials are used.

Table I-C.1: Packaging components and their major materials (2/2)

Component	Material	Standard [1)]
3. <u>Basket</u>		
Lodgment	Borated stainless steel	[redacted]
[redacted]	Aluminium alloy	
[redacted]	Aluminium alloy	
[redacted]	Aluminium alloy	
Aluminum spacer	Aluminium alloy	
Additional shielding	Aluminium alloy	
[redacted]	Aluminium alloy	
Basket support	Aluminium alloy	
	[redacted]	—
[redacted]	Aluminium alloy	[redacted]
4. <u>Top and rear shock absorbing covers</u>		
Shock absorber	[redacted] wood	—
Outer plate, [redacted]	Stainless steel	[redacted]
[redacted]	Stainless steel	
Tightening bolt	Alloy steel	
[redacted]	Stainless steel	
	[redacted] wood	—
Lifting lug, foot	Stainless steel	[redacted]

Note 1) Materials meeting the requirements of the standards or their equivalent materials should be used.

Table I-C.2: Resin ingredients and their proportion

Material	Weight ratio (%)
[redacted]	[redacted]

C.4 Dimensions

The packaging has the dimensions shown in Table I-C.3.

Table I-C.3: Dimensions of packaging (1/2)

(Unit: mm)

Component			Dimension	See
1. Body				
Overall length			5,189	Fig I-C.5
Inner shell	Internal cavity diameter		1,072	
	Thickness		[redacted]	Fig I-C.7
Stiffener	Thickness			
External plate	Thickness			
[redacted]late	Thickness			
Shell part resin	Thickness			Fig I-C.5
Bottom	Thickness			
	External diameter			
Bottom resin	Thickness			
Trunnion	External diameter	(top)		Fig I-C.8
		(rear)		
	Height	(top)		
		(rear)		
Handling belt	Internal diameter (belt [1])			Fig I-C.9
	Cross section profile			
Lifting handle	Distance			

Note 1) Liner thickness not included

Table I-C.3: Dimensions of packaging (2/2)

(Unit: mm)

Component		Dimension	See
2. <u>Lid parts</u>			
Lid	External diameter		Fig I-C.10
	Thickness		
Lid tightening bolt	Size		
Lid resin	Thickness		
3. <u>Basket</u>			
External diameter			Fig I-C.11
Overall length			
Lodgment	Inner width		
	Thickness		
	Thickness		
Additional shielding	Thickness		
4. <u>Top shock absorbing cover</u>			
	External diameter	2,125	Fig I-C.12
	Thickness	826	
5. <u>Rear shock absorbing cover</u>			
	External diameter	2,125	Fig I-C.13
	Thickness	736	

C.5 Weight

This package has a gross weight of not more than 19.5 ton. The weight of the components is shown in Table I-C.4.

Table I-C.4 : Package weight

(Unit: ton)

Component or content	Weight
Body	
Lid parts	
Top shock absorbing cover	
Rear shock absorbing cover	
Basket	
Contents 1)	
Package gross weight (max.)	19.5

Note 1) The contents include 10 fuel assemblies as well as packing materials to be contained in the package.

I-D Contents of packaging

(1) Fuel assemblies

The contents of this packaging is fresh BWR fuel assemblies and example of the specifications is shown in Table I-D.1. General drawing and section drawings of the BWR fuel assembly contained in the packaging are shown in Figure I-D.1 to Figure I-D.3 respectively.

The fuel assembly consists of fuel rods having square array and the both ends are supported by tie plates. And fuel rods between both tie plates are supported by the spacers.

The fuel is uranium oxide pellet which enrichment is not more than 5wt%. The pellets are inserted into cladding made of zircalloy which is sealed by welded plugs at both ends. The fuel may contain the burnable poison Gd_2O_3.

A fuel assembly is housed in the package alone or with a channel box mounted. An example of the specifications of the channel box to be installed onto the fuel assembly is shown in Table I-D.2.

Only fresh fuel assemblies are housed. Among the content specification items, combustion conditions (burnup and cooling time) and decay heat generation are not applicable.

The fuel assembly is housed in a lodgment along with packing materials such as card boards, cotton bags as necessary.

(2) Stools

A stainless steel stool is installed in the bottom of the compartment so that the fuel assembly can settle in the compartment stably. An example of the stool structure is shown in Figure I-D.3.

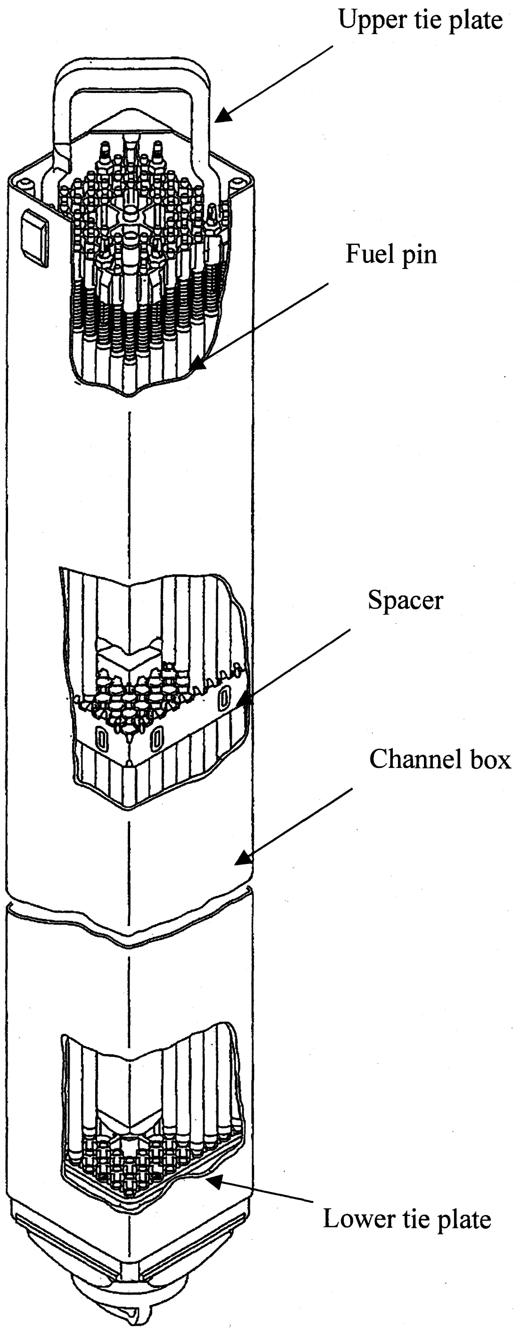


Figure I-D.1: General view of BWR fuel assembly

Figure I-D.2: Cross section of BWR fuel assembly

Table I-D.1: Example of fuel assembly type and specifications

Major items \ Type of fuel assembly	9 x 9 fuel
Material	
Fuel	Uranium dioxide
Cladding	Zircaloy-2 (Zirconium lining)
Channel box	Zircaloy-4
Pellet density (theoretical density, %)	Approx.
Enrichment (wt%)	5.0 or less
Dimensions	
Length of assembly (mm)	Approx.
Active length of fuel (mm)	Approx.
Fuel rod diameter (mm)	
Fuel rod pitch (mm)	
Assembly width (mm)	
Number of fuel rods	
Weight	
Fuel assembly weight (kg) (including channel box)	or less
Uranium dioxide weight (kg)	or less
Uranium weight (kg)	or less

Table I-D.2: Example of channel box specifications

Items	Specifications
Dimensions	
Overall length (mm)	
Channel width (mm)	
Total width (mm)	
Channel thickness (mm)	
Weight	
Total weight (kg)	
Material	
Channel material	Zircaloy-4

Figure I-D.3: Example of stool structure

(3) Fuel composition specifications

The fuel composition specifications of the content are shown in Table I-D.3.

Table I-D.3: Contents (fuel) composition specifications

		Fuel composition
^{235}U		≤ 5.0 wt%
^{238}U		Rest
Impurities contained in enriched uranium [1)]	^{232}U	≤□μg/gU
	^{234}U	≤□μg/g^{235}U
	^{236}U	≤□μg/gU
	^{99}Tc	≤□μg/gU

Note 1) If ^{236}U contains impurities of less than□μg/gU, ^{232}U and ^{99}Tc are not applicable.

(4) Quantity of radioactive material of major nuclides

The major nuclides of the contents have specific activity used to calculate the radioactivity and the calculated radioactivity shown in Table I-D.4 and Table I-D.5 respectively.

Table I-D.4: Specific activity used to calculate radioactivity

Major nuclides	Specific activity (Bq/g)	
	Progeny nuclides not included [1)]	Progeny nuclides included [2)]
^{232}U	7.923×10^{11}	5.757×10^{12}
^{234}U	2.313×10^{8}	2.313×10^{8}
^{235}U	8.001×10^{4}	1.601×10^{5}
^{236}U	2.395×10^{6}	2.395×10^{6}
^{238}U	1.244×10^{4}	3.735×10^{4}
^{99}Tc	6.275×10^{8}	6.275×10^{8}

Note 1) Specific activity with progeny nuclides excluded (Source: Origen2 database)

Note 2) Specific activity with progeny nuclides included after a decay period of 10 years (Result of calculation by Origen2)

Table I-D.5: Activity of major nuclides

Major nuclides	Activity 1) (GBq / package)	
	Progeny nuclides not included	Progeny nuclides included
^{232}U		
^{234}U		
^{235}U		
^{236}U		
^{238}U		
^{99}Tc		
Total		

Note 1) For an enrichment of 5.0 wt%

Chapter I Appendix – 1 Supplementary description about the type of packages

The contents of this package are "fresh BWR fuel assemblies" that contain "unirradiated uranium of an enrichment of less than 5%".

The uranium falls under the "U (unirradiated uranium of an enrichment of not more than 20%)" listed in Schedule 1 of the "Notification to specify particulars related to technical standards on the transport of nuclear material off-site" (hereinafter referred to as the "Notification"). The "quantity (A_2 value) of nuclear material if the materials is any other type than the special form nuclear material" of the uranium is "unlimited".

On the other hand, the related fuel assemblies are those stored in a spent fuel pool of a light water reactor nuclear power plant. Although these fuel assemblies are washed for cleaning of the surface of the assemblies after being taken out of the pool, part of the radioactive material may remain on the assembly surface.

As a virtual, conservative assumption, a 1 mm film of pool water containing radioactive material is assumed to remain on the surface of each of the fuel assemblies, and the quantity of contamination would be [redacted] [^{60}Co TBq/packaging] (See Chapter (II), D.2 (2) Surface contamination by pool water).

The A_2 value for ^{60}Co described in Schedule 1 of the Notification is 0.4 [TBq]. Therefore, the radioactivity of ^{60}Co deposited on the fuel assembly is sufficiently smaller than the A_2 value and is classified into Type A package.

This package may contain up to [redacted] kgU uranium of an enrichment of 5% or less, which means that each packaging may contain up to [redacted] kg^{235}U of fissile nuclides. Thus the package falls under the package containing fissile material.

Therefore, this package is classified into Type A package containing fissile material.

Chapter II　Safety Analysis of Nuclear Fuel Package

Chapter II Safety Analysis of Nuclear Fuel Package

A safety analysis of this package is conducted to indicate that the package conforms to the technical standards for the Type A package containing fissile material according to the "Regulation related to the transport of nuclear materials off-site (1978 Ordinance of Prime Minister's Office No. 57) (hereinafter referred to as "Regulation") and the "1990 Japan Science and Technology Agency Notification No.5 (Notification to specify particulars related to technical standards on the transport of nuclear material off-site")" (hereinafter referred to as "Notification").

The following gives a summary of the analysis:

1. Structural analysis

A structural analysis has verified that no crack or damage occurs in the package under routine conditions of transport and that the containment system maintains integrity under normal conditions of transport.

In order to obtain evaluation conditions for thermal and shielding analyses, the package state and integrity under normal and accident conditions of transport was evaluated.

Furthermore, since this package is a Type A package containing fissile material, the package state and integrity under normal and accident conditions of transport for packages containing fissile material have been evaluated to evaluate subcriticality.

2. Thermal analysis

With considerations given to the result of the structural analysis stated above, a thermal analysis was conducted to evaluate the temperature and pressure in various parts of the package under normal and accident conditions of transport, rendering evaluation conditions for structure, shielding and criticality analyses.

3. Containment analysis

A containment analysis has verified that the containment system maintains its integrity under normal conditions of transport, proving that the package conforms to the technical standards for Type A packages.

4. Shielding analysis

With consideration given to the evaluation conditions obtained through the structural and thermal analyses, a shielding analysis has evaluated the equivalent dose rate on the package surface or in a position 1 m away from the surface under routine conditions of transport and normal conditions of transport, proving that the criteria are satisfied.

5. Criticality analysis

With considerations given to the results of the structural and thermal analyses stated above, a criticality analysis has verified subcriticality in any case of a package under routine conditions of transport, an isolated package, or an isolated package or an package in an array of packages under normal and accident conditions of transport for packages containing fissile material.

In terms of deformation of the contents, the analysis model under the normal and accident conditions of transport assumes sufficiently conservative conditions to provide conservative evaluation.

6. Evaluation of conformity to Regulation and Notifications

These results and the description of nuclear fuel package in Chapter I can be put together to indicate that the design of this package conforms to the technical standards set forth in the Regulation and Notification.

The following Sections A to F, Chapter II, describe the details of the analyses and evaluations.

Chapter II-A Structural Analysis

II-A Structural analysis

A.1 Structural design

A.1.1 Summary

The basic structure and configuration necessary for safe handling of the package are as follows:

As shown in Figure I-C.2, this packaging consists of a body consisting of a shell part (including an inner shell, external plates, stiffeners and a top flange) and a bottom, a lid secured to the top flange with lid tightening bolts, a basket to contain 10 BWR fuel assemblies, and top and rear shock absorving covers to mitigate mechanical impacts caused by, for example, a drop.

The packaging constitutes a containment vessel. The joint between the body and the lid ensures leaktightness with double gaskets.

Other containment boundaries include the penetration in the lid with a quick connection. As shown in Figure I-C.10, the penetration is designed to ensure leaktightness with quick connection cover gaskets.

Note that the lid tightening bolts used in the joint between the body and the lid as well as the quick connection cover tightening bolts are covered with the top shock absorving cover during transport and cannot be accidentally opened, as shown in Figure I-C.3.

As shown in Figures I-C.5 and I-C.6, the lid and bottom sides of the packaging have two sets and one set of trunnions respectively so that the packaging can be lifted, tilted up or tilted down in an easy, safe manner.

The shell part has a handling belt on its top and bottom sides each so that the packaging can be horizontally lifted in an easy, safe manner.

The basket to be installed inside the packaging has 10 lodgments to support the fuel assemblies as shown in Figure I-C.11 in order to prevent the fuel assemblies from making contact with each other to be damaged or from coming together to reach criticality.

This analysis is intended to evaluate the behavior of the packaging under the test conditions set forth in the applicable laws and regulations and to demonstrate that the packaging conforms to the design criteria described in the following section.

A.1.2 Design criteria

According to the requirements of the Notification, criteria applicable to each analysis item have been established with considerations given to the material, form and load conditions of the components:

(1) Criteria

The following shows the criteria established for the relevant test conditions and analysis items:

a. Routine conditions of transport (lifting and tie down devices)

[1] The stress intensity (the absolute value for the difference in principal stress) shall be not higher than the yield stress.

[2] All lifting devices shall be subjected to fatigue evaluation and the calculated allowable number of cycles shall be not lower than the assumed number of times.

b. Normal conditions of transport

(a) Thermal evaluation

[1] The lid tightening bolts shall be applied with the following criteria for stress evaluation:

$$\sigma m \leq \frac{2}{3}\ Sy$$

$$\sigma m + \sigma b \leq Sy$$

where, σm: Average tensile stress, σb: Bending stress, Sy: Design yield stress

Fatigue evaluation shall also be conducted. The calculated allowable number of cycles shall be not lower than the assumed number of cycles.

[2] For all components except the lid tightening bolts, relevant stresses shall be classified. Each stress intensity shall be applied with the following criteria:

$$Pm \leq Min.\ \{\frac{1}{3}\ Su,\ \frac{2}{3}\ Sy\}$$

$$PL,\ PL + Pb \leq 1.5 \times Min.\ \{\frac{1}{3}\ Su,\ \frac{2}{3}\ Sy\}$$

$$PL + Pb + Q \leq 3 \times Min.\ \{\frac{1}{3}\ Su,\ \frac{2}{3}\ Sy\}$$

where, Pm: General primary membrane stress intensity,

PL: Local primary membrane stress intensity

Pb: Primary bending stress, Q: Secondary stress intensity

Su: Design tensile stress

[3] For components used in the containment seal part, the stress intensity shall not exceed the yield stress.

[4] The basket shall have no thermal stress due to constraints.

(b) Water spray

[1] To resist water spray.

(c) Free drop

[1] The lid tightening bolts shall be applied with the following stress criteria:

$\sigma m \leq Sy$

$\sigma m + \sigma b \leq Sy$

[2] All components except the lid tightening bolts shall have no deformation that would have to be considered in other analysis.

[3] The fuel cladding shall not rupture.

(d) Stacking test

[1] The shell part of the body shall not have a stress intensity exceeding the yield stress.

(e) Penetration

[1] The external plates shall have no penetration.

c. Normal conditions of transport for packages containing fissile material

(a) Water spray

[1] To resist water spray.

(b) Free drop

[1] In the packaging body and basket, any deformation that would have to be considered in the criticality analysis shall be identified.

[2] The lid tightening bolts shall not rupture.

[3] The fuel cladding shall not rupture.

(c) Stacking test

[1] In the shell part of the body, any deformation that would have to be considered in the criticality analysis shall be identified.

(d) Penetration

[1] Any deformation that would have to be considered in the criticality analysis shall be identified.

d. Accident conditions of transport for packages containing fissile material

(a) Mechanical test Drop I (9 m drop)

[1] In the packaging body and basket, any deformation that would have to be considered in the criticality analysis shall be identified.

[2] The lid tightening bolts shall not rupture.

[3] The fuel cladding shall not rupture.

(b) Mechanical test Drop II (1 m drop)

[1] In the packaging body and basket, any deformation that would have to be considered in the criticality analysis shall be identified.

[2] The fuel cladding shall not rupture.

(c) Thermal test

[1] In the packaging body and basket, any deformation that would have to be considered in the criticality analysis shall be identified.

[2] The lid tightening bolt shall not rupture.

[3] The fuel cladding shall not rupture.

(d) Immersion (0.9 m)

[1] For criticality evaluation, ingress of water is assumed in advance.

The evaluation criteria for the various test conditions and analysis items are summarized in Table II-A.1.

(2) Combinations of load conditions

Combinations of load conditions for various analysis items according to design conditions are summarized in Table II-A.2.

(3) Safety margin

Among the analysis results, those with established quantitative design criteria shall be evaluated for the following margin of safety (MS):

$$\text{Safety margin (MS)} = \frac{\text{Design criteria}}{\text{Analysis result}} - 1$$

For those to which no safety margin can be applied, the relative criteria value etc. shall be put in the relevant position.

According to the aforementioned design criteria, the structural analysis conditions, analysis items and analysis methods are summarized in Table II-A.3 (1/7) to Table II-A.3 (7/7).

Table II-A.1: Criteria for structural analysis (1/2)

<table>
<tr><th rowspan="2">Condition</th><th rowspan="2">Analysis item</th><th rowspan="2">Component to be evaluated</th><th colspan="3">Criteria</th></tr>
<tr><th>Primary stress intensity</th><th>Primary + secondary stress intensity</th><th>Primary + secondary + peak stress intensity</th></tr>
<tr><td rowspan="6">Routine condition of transport</td><td rowspan="2">Lifting device</td><td>Trunnion</td><td>≤ Sy</td><td>-</td><td>Number of operating cycles ≤ Na</td></tr>
<tr><td>Handling belt</td><td>≤ Sy</td><td>-</td><td>Number of operating cycles ≤ Na</td></tr>
<tr><td>Tie down device</td><td>Shell part</td><td>≤ Sy</td><td>-</td><td>-</td></tr>
<tr><td>Pressure</td><td>Package</td><td colspan="3">To resist outside pressure variations.</td></tr>
<tr><td>Vibration</td><td>Package</td><td colspan="3">To resist vibration during transport.</td></tr>
<tr style="display:none"></tr>
<tr><td rowspan="10">Normal conditions of transport</td><td rowspan="4">Thermal test</td><td>Body, lid</td><td colspan="2">$Pm \leq Min. \{\frac{1}{3} Su, \frac{2}{3} Sy\}$
PL, PL + Pb
$\leq 1.5 \times Min. \{\frac{1}{3} Su, \frac{2}{3} Sy\}$
PL + Pb + Q
$\leq 3 \times Min. \{\frac{1}{3} Su, \frac{2}{3} Sy\}$</td><td>-</td></tr>
<tr><td>Containment seal part</td><td colspan="2">≤ Sy</td><td>-</td></tr>
<tr><td>Lid tightening bolt</td><td colspan="2">$\sigma m \leq \frac{2}{3} Sy$
$\sigma m + \sigma b \leq Sy$</td><td>Number of operating cycles ≤ Na</td></tr>
<tr><td>Basket</td><td colspan="3">No thermal stress shall be caused by constraints.</td></tr>
<tr><td>Water spray</td><td>Package</td><td colspan="3">To resist water spray.</td></tr>
<tr><td rowspan="3">Free drop</td><td>Body, lid basket</td><td colspan="3">No deformation that would have to be considered in other analysis shall occur.</td></tr>
<tr><td>Lid tightening bolt</td><td>$\sigma m \leq Sy$
$\sigma m + \sigma b \leq Sy$</td><td>-</td><td>-</td></tr>
<tr><td>Fuel cladding</td><td colspan="3">No rupture.</td></tr>
<tr><td>Stacking test</td><td>Body</td><td>≤ Sy</td><td>-</td><td>-</td></tr>
<tr><td>Penetration</td><td>External plate</td><td colspan="3">Anti-puncture strength</td></tr>
</table>

Pm: General primary membrane stress, PL: Local primary membrane stress, Pb: Primary bending stress, Q: Secondary stress, Na: Allowable number of cycles, σm: Average tensile stress, σb: Bending stress

Table II-A.1: Criteria for structural analysis (2/2)

Condition	Analysis item	Component to be evaluated	Criteria
Normal conditions of transport for packages containing fissile material	Water spray	Package	To resist water spray.
	Free drop	Body, lid basket	Identify any deformation that would have to be considered in criticality analysis.
		Lid tightening bolt	No rupture
		Fuel cladding	No rupture
	Stacking test	Body	Identify any deformation that would have to be considered in criticality analysis.
	Penetration	External plate	Identify any deformation that would have to be considered in criticality analysis.
Accident conditions of transport for packages containing fissile material	Drop test I (9 m drop)	Body, lid basket	Identify any deformation that would have to be considered in criticality analysis.
		Lid tightening bolt	No rupture
		Fuel cladding	No rupture
	Drop test II (1 m drop)	Body, lid basket	Identify any deformation that would have to be considered in criticality analysis.
		Fuel cladding	No rupture
	Thermal test	Body, lid basket	Identify any deformation that would have to be considered in criticality analysis.
		Lid tightening bolt	No rupture
		Fuel cladding	No rupture

Table II-A.2: Combinations of load conditions (1/2)

Condition	Analysis item	Component to be evaluated	Load conditions			
			Weight	Pressure	Thermal expansion	Miscella-neous
Routine condition of transport	Lifting device	Trunnion	○	-	-	○ (Initial tightening force)
		Handling belt	○	-	-	○ (Initial tightening force)
	Tie down device	Shell part	○	○	-	-
	Pressure	Package	-	△	-	-
	Vibration	Package	-	-	-	△
Normal conditions of transport	Thermal test	Body, lid,	-	○	○	-
		Lid tightening bolt	-	○	○	○ (Initial tightening force)
		Basket	-	-	△	-
	Water spray	Package	-	-	-	△
	Free drop	Body, lid, basket	△	-	-	-
		Lid tightening bolt	○	-	-	○ (Initial tightening force)
		Fuel cladding	○	○	-	-
	Stacking test	Body	△	-	-	-
	Penetration	External plate	-	-	-	△

○: Evaluate according to combinations of load conditions; △: Evaluate according to single load

Table II-A.2: Combinations of load conditions (2/2)

Condition	Analysis item	Component to be evaluated	Load conditions			
			Weight	Pressure	Thermal expansion	Miscella-neous
Normal conditions of transport for packages containing fissile material	Water spray	Package	-	-	-	△
	Free drop	Body, lid, basket	△	-	-	-
		Lid tightening bolt	○	-	-	○ (Initial tightening force)
		Fuel cladding	○	○	-	-
	Stacking test	Body	△	-	-	-
	Penetration	External plate	-	-	-	△
Accident conditions of transport for packages containing fissile material	Drop test I (9 m drop)	Body, lid, basket	△	-	-	-
		Lid tightening bolt	○	-	-	○ (Initial tightening force)
		Fuel cladding	○	○	-	-
	Drop test II (1 m drop)	Body, lid, basket	△	-	-	-
	Thermal test	Body, lid	-	○	○	-
		Lid tightening bolt	-	○	○	○ (Initial tightening force)
		Basket	-	-	△	-
		Fuel cladding	-	△	-	-

○: Evaluate according to combinations of load conditions; △: Evaluate according to single load

Table II-A.3: Analysis conditions and methods for structural analysis (1/7)

Condition	Item	Analysis condition						Analysis method		Remarks
		See	Material	Temperature (°C)	Load		Index	Applicable formula or elements	Criteria	
					Type	Loading factor				
Routine condition of transport	[Chemical and galvanic reactions]	-	-	-	Corrosion	-	Activated potential difference	-	No chemical or galvanic reaction should occur.	A.4.1
	[Low temperature strength]	-	Stainless steel, etc.	-40	Low temperature	-	Material deterioration	-	Strength shall be maintained.	A.4.2
	[Containment system]									A.4.3
	1. Lid	Figure I-C.10	Titanium alloy	-	Opening by misoperation	-	Mis-operation OK/NG	Whether misoperation with the top shock absorbing cover installed is OK or NG.	Shall not be opened by mis-operation.	
	2. Quick connection cover	Figure I-C.10	Stainless steel	-		-				
	[Lifting devices]									A.4.4
	1. Trunnion 1) Trunnion cylinder	Figure II-A.2	Stainless steel		Package weight	3	Stress intensity	$S=\sqrt{\sigma^2+4\tau^2}$	Sy	
	2) Trunnion fixing bolt	-	Alloy steel		Package weight Initial tightening force	3	Tensile stress Fatigue evaluation	$\sigma_1=\frac{M}{Z}$ $\sigma_2=T\cdot k$ $\sigma_T=\sigma_1+\sigma_2$ Allowable number of cycles	Sy Assumed number of cycles or more	
	2. Handling belt 1) Top and rear belts	Figure II-A.3 - Figure II-A.8	Stainless steel		Package weight	3	Stress intensity	Membrane stress, Membrane stress + Bending stress	Sy	
	2) Lifting handle	Figure II-A.9 - Figure II-A.14	Stainless steel		Package weight	3	Stress intensity	Membrane stress, Membrane stress + Bending stress	Sy	
	3) Lifting handle pin	-	Stainless steel		Package weight	3	Stress intensity	$\tau=\frac{F}{2\cdot\pi d^2/4}$ $S=2\tau$	Sy	
	4) Connecting bolt	-	Alloy steel		Package weight Initial tightening force	3	Tensile stress Fatigue evaluation	$\sigma_1=\frac{F}{\pi d^2/4}$ $\sigma_2=T\cdot k$ $\sigma_T=\sigma_1+\sigma_2$ Allowable number of cycles	Sy Assumed number of cycles or more	
	[Tie down device] Shell part of body Longitudinal direction 2 G Lateral direction 2 G Vertical direction 2 G (up) 3 G (down) (including dead load)	Figure II-A.15 - Figure II-A.19	Stainless steel		Package weight Internal-external pressure difference	1	Stress intensity	Membrane stress, Membrane stress + Bending stress	Sy	A.4.5

Table II-A.3: Analysis conditions and methods for structural analysis (2/7)

Condition	Item	Analysis condition						Analysis method		Remarks
		See	Material	Tempera-ture (°C)	Load		Index	Applicable formula or elements	Criteria	
					Type	Loading factor				
	[Pressure]	-	-	-	Internal-external pressure difference	-	Stress	-	No damage shall occur.	A.4.6
	[Vibration]	Figure II-A.20 - Figure II-A.23	Stainless steel		Vibration during transport	-	Frequency	Natural frequency	No vibration resonance shall occur.	A.4.7
Normal conditions of transport	[Thermal test]									A.5.1
	1. Body, lid	Figure II-A.24 - Figure II-A.28	Stainless steel Titanium alloy		Internal pressure, temperature distribution and initial tightening force	1	Stress intensity	Pm PL, PL + Pb PL + Pb + Q	Min. $\{\frac{1}{3}$ Su, $\frac{2}{3}$ Sy$\}$ 1.5×Min. $\{\frac{1}{3}$ Su, $\frac{2}{3}$ Sy$\}$ 3×Min. $\{\frac{1}{3}$ Su, $\frac{2}{3}$ Sy$\}$	Sy for containment seal part
	2. Lid tightening bolt	Figure II-A.24 - Figure II-A.28	Alloy steel		Ditto	1	Tensile stress Combined stress Fatigue evaluation	σm σm + σb Allowable number of cycles	$\frac{2}{3}$ Sy Sy Assumed number of cycles or more	
	3. Basket 1) Thermal expansion of basket and body	-	Stainless steel Aluminum alloy		Thermal expansion	1	Expansion difference	$\triangle L=(L_1-L_2)+(\triangle L_1-\triangle L_2)$ $\triangle D=(D_1-D_2)+(\triangle D_1-\triangle D_2)$	Axial/radial clearance: 0 mm or more	
	[Water spray]	-	Stainless steel Paint	-	Water spray	-	Deterioration or water pool by water absorption	Water absorptivity Smoothness for water	None Good	A.5.2

Table II-A.3: Analysis conditions and methods for structural analysis (3/7)

Condition	Item	Analysis condition						Analysis method		Remarks
		See	Material	Temperature (°C)	Loading		Index	Applicable formula or elements	Criteria	
					Type	Loading factor				
Normal conditions of transport	[Free drop] 1. Deformation of shock absorbing covers 1) Vertical drop 2) Horizontal drop 3) Corner drop	Figure II-A.29 - Figure II-A.32	Stainless steel wood		Impact velocity	1	Deformation	Maximum displacement in drop direction	-	A.5.3
	2. Body and lid 1) Vertical drop 2) Horizontal drop 3) Corner drop	Figure II-A.29 - Figure II-A.31, Figure II-A.33	Stainless steel Titanium alloy		Impact velocity, initial tightening force	1	Plastic strain	Maximum plastic strain, strain distribution	Leaktightness shall be maintained and there shall be no deformation that would have to be considered in other analysis.	
	3. Lid tightening bolt 1) Top vertical drop 2) Horizontal drop 3) Top corner drop	Figure II-A.29 - Figure II-A.31	Alloy steel		Ditto	1	Tensile stress Combined stress	σm $\sigma m + \sigma b$	Sy Sy	
	4. Basket 1) Horizontal drop	Figure II-A.34 - Figure II-A.37	Borated stainless steel Aluminum alloy		Impact velocity, body velocity history	1	Plastic strain	Maximum plastic strain, strain distribution	There shall be no deformation that would have to be considered in other analysis.	
	5. Fuel cladding	Figure II-A.38 - Figure II-A.41	Zircaloy-2		Impact velocity, body/basket velocity history, internal pressure	1	Plastic strain	Maximum plastic strain	No rupture	
	[Stacking test] 1. Vertical position	Figure II-A.42 - Figure II-A.44	Stainless steel		5 times the package weight	1	Stress intensity	Membrane stress, Membrane stress + Bending stress	Sy	A.5.4
	2. Horizontal position	Figure II-A.45 - Figure II-A.47	Stainless steel		Inertia force 6 times the dead load to be loaded	1	Stress intensity	Membrane stress, Membrane stress + Bending stress	Sy	
	[Penetration]	Figure II-A.48	Stainless steel		Drop energy	-	Necessary energy for penetration	$W_P = m g h$ $W = \int_0^t \tau_{cr} \pi d (t - y) dy$	$Wp < W$	A.5.5

Table II-A.3: Analysis conditions and methods for structural analysis (4/7)

Condition	Item	Analysis condition						Analysis method		Remarks
		See	Material	Temperature (°C)	Load		Index	Applicable formula or elements	Criteria	
					Type	Loading factor				
Radioactive contents	[Fuel cladding strength]							(Evaluate by citing Chapter I and Section A.9)		A.8
Normal conditions of transport for packages containing fissile material	[Water spray]	-	Stainless steel Paint	-	Water spray	-	Deterioration or water pool by water absorption	Water absorptivity Smoothness for water	None Good	A.9.1
	[Free drop] 1. Deformation of shock absorbing covers 1) Vertical drop 2) Horizontal drop 3) Corner drop	Figure II-A.29 - Figure II-A.32	Stainless steel wood		Impact velocity	1	Deformation	Maximum displacement in drop direction	Identify any deformation that would have to be considered in criticality analysis.	A.9.1
	2. Body and lid 1) Vertical drop 2) Horizontal drop 3) Corner drop	Figure II-A.29 - Figure II-A.31, Figure II-A.33	Stainless steel Titanium alloy		Impact velocity, initial tightening force	1	Plastic strain	Maximum plastic strain, strain distribution	Identify any deformation that would have to be considered in criticality analysis.	A.9.1
	3. Lid tightening bolt 1) Top vertical drop 2) Horizontal drop 3) Top corner drop	Figure II-A.29 - Figure II-A.31	Alloy steel		Ditto	1	Tensile stress Combined stress	σm σm + σb	No rupture No rupture	A.9.1
	4. Basket 1) Horizontal drop	Figure II-A.34 - Figure II-A.37	Boron stainless steel Aluminum alloy		Impact velocity, body velocity history	1	Plastic strain	Maximum plastic strain, strain distribution	Identify any deformation that would have to be considered in criticality analysis.	A.9.1
	5. Fuel cladding	Figure II-A.38 - Figure II-A.41	Zircaloy-2		Impact velocity, body/basket velocity history, internal pressure	1	Plastic strain	Maximum plastic strain	No rupture	A.9.1

Table II-A.3: Analysis conditions and methods for structural analysis (5/7)

Condition	Item	Analysis condition						Analysis method		Remarks
		See	Material	Tempera-ture (°C)	Loading		Index	Applicable formula or elements	Criteria	
					Type	Loading factor				
Normal conditions of transport for packages containing fissile material	[Stacking test] 1. Vertical position	Figure II-A.42 - Figure II-A.44	Stainless steel		5 times the package weight	1	Stress intensity	Membrane stress, Membrane stress + Bending stress	Sy	A.9.1
	2. Horizontal position	Figure II-A.45 - Figure II-A.47	Stainless steel		Inertia force 6 times the dead load to be loaded	1	Stress intensity	Membrane stress, Membrane stress + Bending stress	Sy	
	[Penetration]	Figure II-A.48	Stainless steel		Drop energy	-	Necessary energy for penetration	$W_P = m\,g\,h$ $W = \int_0^t \tau_{cr} \pi\, d\, (t - y) dy$	$W_p < W$	A.9.1

Table II-A.3: Analysis conditions and methods for structural analysis (6/7)

Condition	Item	Analysis condition						Analysis method		Remarks
		See	Material	Temperature (°C)	Loading		Index	Applicable formula or elements	Criteria	
					Type	Loading factor				
Accident conditions of transport for packages containing fissile material	[Drop test I] 1. Deformation of shock absorbing covers 1) Vertical drop 2) Horizontal drop 3) Corner drop 4) Slap down drop	Figure II-A.49 - Figure II-A.54	Stainless steel wood	-	Impact velocity	1	Deformation	Maximum displacement in drop direction	Identify any deformation that would have to be considered in criticality analysis.	A.9.2
	2. Body and lid 1) Vertical drop 2) Horizontal drop 3) Corner drop 4) Slap down drop	Figure II-A.55 - Figure II-A.59	Stainless steel Titanium alloy		Impact velocity, initial tightening force	1	Plastic strain	Maximum plastic strain, strain distribution	Identify any deformation that would have to be considered in criticality analysis.	
	3. Lid tightening bolt 1) Top vertical drop 2) Top corner drop 3) Slap down drop	-	Alloy steel		Ditto.,	1	Tensile stress Combined stress	σm σm + σb	No rupture	
	4. Basket 1) Horizontal drop	Figure II-A.60 - Figure II-A.62	Borated stainless steel Aluminum alloy		Impact velocity, body velocity history	1	Plastic strain	Maximum plastic strain, strain distribution	Identify any deformation that would have to be considered in criticality analysis.	
	5. Fuel cladding	Figure II-A.63 - Figure II-A.66	Zircaloy-2		Impact velocity, body/basket velocity history, internal pressure	1	Plastic strain	Maximum plastic strain	No rupture	
	[Drop test II] 1. Top vertical drop 1) Direct hit with lid	-	Stainless steel wood, resin	-	Drop on to mild steel bar	1	Damaged condition	model test	Identify any deformation that would have to be considered in criticality analysis.	A.9.2
	2. Bottom vertical drop 1) Direct hit with bottom	-	Stainless steel wood, resin	-	Drop on to mild steel bar	1	Damaged condition	model test	Identify any deformation that would have to be considered in criticality analysis.	
	3. Horizontal drop 1) Direct hit with shell part	Figure II-A.67 - Figure II-A.74	Stainless steel Resin	-	Drop on to mild steel bar	1	Damaged condition Deformation condition	model test Maximum deformation of basket	Identify any deformation that would have to be considered in criticality analysis.	

Table II-A.3: Analysis conditions and methods for structural analysis (7/7)

Condition	Item	Analysis condition						Analysis method		Remarks
		See	Material	Temperature (°C)	Load		Index	Applicable formula or elements	Criteria	
					Type	Loading factor				
Accident conditions of transport for packages containing fissile material	[Thermal test]									A.9.2
	1. Body, lid	Figure II-A.75 - Figure II-A.76	Stainless steel Titanium alloy		Internal pressure, temperature distribution and initial tightening force	1	Plastic strain	Maximum plastic strain	Identify any deformation that would have to be considered in criticality analysis.	
	2. Lid tightening bolt	-	Alloy steel		Ditto	1	Tensile stress Tension + Bending	σm $\sigma m + \sigma b$	No rupture	
	3. Basket 1) Thermal expansion difference between basket and body	-	Stainless steel Aluminum alloy		Thermal expansion	1	Expansion difference	$\Delta L=(L_1-L_2)+(\Delta L_1-\Delta L_2)$ $\Delta D=(D_1-D_2)+(\Delta D_1-\Delta D_2)$	Identify any deformation that would have to be considered in criticality analysis.	
	4. Fuel cladding	-	Zircaloy-2		Internal pressure	1	Stress intensity	$S=Max\{\lvert\sigma_\theta-\sigma_Z\rvert, \lvert\sigma_Z-\sigma_r\rvert, \lvert\sigma_\theta-\sigma_r\rvert\}$	No rupture	
	[Immersion (0.9 m)]	-	-	-	-	-	-	-	- (Ingress of water is considered in criticality analysis).	A.9.2

A.2 Weight and center of gravity

The gross weight of the packaging and its contents and the weight of individual components are shown in Table I-C.4. The center of gravity of the package is shown in Figure II-A.1.

Figure II-A.1: Center of gravity

A.3 Mechanical properties of materials

The mechanical properties of materials used for analyses are shown in Table II-A.4.

Table II-A.4: Mechanical properties of materials (1/3)

Material	Component	Design yield stress (Temperature) [MPa](˚C) 1)	Design tensile stress (Temperature) [MPa](˚C) 1)	Elongation (Temperature) [%](˚C) 1)	Poisson's ratio 2)	Density [10^3 kg/m^3]	Young's modulus (Temperature) [10^5 MPa](˚C)	Coefficient of linear thermal expansion (Temperature) [1/˚C x 10^6](˚C)
stainless steel	Inner shell Stiffener External plate				0.3	[5] 7.8	[1]	[1]
	Top flange Bottom							
	Handling belt - Upper/lower belt - Lifting handle - Lifting handle pin			-				
	Trunnion			-	-	-		
Titanium alloy	Lid				0.3	[2] 4.42		
stainless steel	Shock absorbing cover 3) outer shell,	-	-	-	0.3	[5] 7.9	-	-

Note 1) Design requirement specification value

Note 2) Representative value

Note 3) The stress-strain relationship used for drop analysis is shown in A.10.2, Appendix-2.

Table II-A.4: Mechanical properties of materials (2/3)

Material	Component	Design yield stress (Temperature) [MPa](°C) 1)	Design tensile stress (Temperature) [MPa](°C) 1)	Elongation (Temperature) [%](°C) 1)	Poisson's ratio 2)	Density [10^3 kg/m^3]	Young's modulus (Temperature) [10^5 MPa](°C)	Coefficient of linear thermal expansion (Temperature) [1/°C x 10^6](°C)
Alloy steel	Lid tightening bolt	[redacted]	-	-	0.3	[1] 7.75	[1] [redacted]	[1] [redacted]
	Trunnion fixing bolt		-	-	-	-		
	Handling belt connecting bolt		-	-	0.3	-		
[redacted] wood	Shock absorber 3)	-	-	-	-	[redacted] 1)	-	-

Note 1) Design requirement specification value

Note 2) Representative value

Note 3) The stress-strain relationship used for drop analysis is shown in A.10.2, Appendix-2.

Table II-A.4: Mechanical properties of materials (3/3)

Material	Component	Design yield stress (Temperature) [MPa](°C) 1)	Design tensile stress (Temperature) [MPa](°C) 1)	Elongation (Temperature) [%](°C) 1)	Poisson's ratio 2)	Density [10^3 kg/m^3]	Young's modulus (Temperature) [10^5 MPa](°C)	Coefficient of linear thermal expansion (Temperature) [1/°C x 10^{-6}](°C)
Boron stainless steel	Lodgment (Basket)				0.3	[4] 7.8	[4]	-
Aluminum alloy	(Basket)		-		0.3	[1] 2.78		[1]
	(Basket)		-		0.3	[1] 2.78		
	(Basket)		-		0.3	[1] 2.70		

Note 1) Design requirement specification value

Note 2) Representative value

A.4 Requirements for package

A.4.1 Chemical and galvanic reactions

Table II-A.5 lists dissimilar materials that may come into contact with each other within the packaging or between the packaging and the contents. No chemical or galvanic reactions will occur between dissimilar materials when they come into contact with each other since the package is transported in dry condition.

Table II-A.5: List of dissimilar materials that may come into contact with each other

Dissimilar materials that may come into contact with each other	Components that may come into contact with each other
Stainless steel - Titanium alloy	Top flange - lid
Stainless steel - [redacted]	Inner shell, stiffener, external plate - [redacted] plate
Stainless steel - [redacted] resin	Inner shell, stiffener, external plate - Shell part resin Lid resin cover - Lid resin, Bottom resin cover - Bottom resin Bottom - Bottom resin
Titanium alloy - Alloy steel	Lid - Tightening bolt
Stainless steel - Alloy steel	Shock absorbing cover, top flange, quick connection cover - Tightening bolt Trunnion - Fixing bolt
Stainless steel - [redacted] wood	Shock absorbing cover outer shell, [redacted] - Shock absorber Thermal protection - Shock absorber
Stainless steel - EPDM	Top flange, quick connection cover - Gasket
Stainless steel - Elastomer	External plate, upper belt, lower belt - Liner
Titanium alloy - EPDM	Lid - Gasket
Stainless steel - Aluminum alloy	Inner shell - Basket Lodgment - [redacted]
[redacted] - [redacted] resin	[redacted] plate - Shell part resin
Stainless steel - Zirconium alloy	Lodgment - Fuel assembly (or channel box)

A.4.2 Low temperature strength

(1) Low temperature characteristics of components

The materials used in the packaging listed in Table I-C.1 will not have a brittle fracture or crack at −40°C. Therefore, they cannot have a crack or breakage within the temperature range from −40°C to 70°C specified in the Regulation.

(2) Strength at low temperature

The [redacted] stainless steel used in the inner shell, stiffeners and external plates that constitute the shell part of the body as well as the borated stainless steel used in the basket are both thin plates and will not have strength degradation at low temperature due to a brittle fracture. (The less the plate thickness is, the more unlikely to have a brittle fracture these plates are. Therefore, the fracture toughness test is not applicable to thin plates of a thickness of less than 16 mm [6]).

The titanium alloy used in the lid will not show low-temperature brittleness even at an ultra-low temperature. [7]

The aluminium alloy of the basket and the [redacted] stainless steel of the shock absorbing covers will not show low-temperature brittleness.

The forged [redacted] stainless steel used in the top flange and bottom of the body and the alloy steel used in the lid tightening bolts show low-temperature brittleness. These materials are subjected to an impact test at −40°C to ensure that materials with the required toughness are used.

EPDM used in the lid gasket can be used at −40°C. [8]

The [redacted] wood used in the shock absorbers will not have any strength degradation even at a low temperature and can be used at −40°C. [9]

In conclusion, the strength and other mechanical performance of this packaging will not have degradation or damage of mechanical strength even at low temperatures under normal or accident conditions of transport.

A.4.3 Containment system

The lid and lid tightening bolts of the packaging are covered with the top shock absorbing cover under routine conditions of transport as shown in Figure I-C.3. The quick connection cover protecting the quick connection of the lid is also covered with the top shock absorbing cover. This means that the lid and quick connection cover, which can both serve as an opening to the inside of the packaging, cannot be accidentally opened by misoperation.

[redacted]

A.4.4 Lifting devices

The package has four (two pairs of) trunnions on the top side and two (one pair of) trunnions on the rear side as shown in Figure I-C.5 and can be lifted using these trunnions.

The package can be lifted horizontally with one pair of top trunnions and one pair of rear trunnions or vertically with one pair of top trunnions.

The analysis here focuses on the top trunnions that have a smaller diameter than that of the rear trunnions to evaluate vertical lifting during which the top trunnions are applied with a maximum load. [1)]

The package also has a handling belt installed onto the top and rear sides of the shell part each as shown in Figure I-C.3. These handling belts are used to carry out horizontal lifting.

(1) Stress evaluation

a. Trunnions

(a) Maximum load

The maximum load applied to the trunnions can be calculated using the equation below. Note that the maximum load F applied to the trunnions should be calculated using the total mass of the package although the shock absorbing covers have been removed from the package before lifting with the trunnions:

$$F = m \times g \times \frac{G}{N}$$

where, m : Package mass [19,500 kg]

g : Gravity acceleration [9.81 m/s^2]

G: Loading factor [3]

N: Number of trunnions [2]

Therefore,

$$F = 2.87 \times 10^5 \text{ N}$$

(b) Stress calculation

The dimensions and loading points of various parts of the trunnions are shown in Figure II-A.2.

i. Cylinder section of trunnions

The maximum bending stress and the shearing stress that occur in the cylinder section of the trunnions can be expressed using the beam theory as follows:

Note 1) Evaluation for rear trunnions under horizontal lifting operation shows a result that top trunnions under vertical lifting operation is more severe. (See Apendix-5)

(Unit: mm)

Figure II-A.2: Top trunnion dimensions and loading points

(i) Maximum bending stress (σ)

$$\sigma = \frac{M}{Z}$$

$$M = F \times L$$

where, M: Bending moment (N·mm)

F : Maximum load applied to a single trunnion [2.87×10^5 N]

L : Distance between the F loading point and the cross section to be evaluated [Section A-A:□mm, Section B-B:□mm]

Z : Section modulus (mm^3)

$Z = \frac{\pi}{32} D^3$ (D : Trunnion cylinder diameter [Section A-A:□mm, Section B-B:□mm])

(ii) Shearing stress (τ)

$$\tau = \frac{F}{A}$$

where, F : Maximum load applied to a single trunnion [2.87×10^5 N]

A : Sectional area (mm^2)

$$A = \frac{\pi}{4} D^2$$

(iii) Stress intensity (S)

$$S = \sqrt{\sigma^2 + 4\tau^2}$$

An evaluation of the section A-A and the section B-B in Figure II-A.2 has revealed that the stress intensity is □MPa for the section A-A and □MPa for the section B-B. The criteria (Sy) for this item is □MPa (□°C [1]).

The safety margin MS in this case is:

$$MS = \frac{\square}{\square} - 1 = \square$$

Therefore, the cylinder section of the trunnion has a sufficient strength against the load during handling.

Note 1) Package temperature under normal conditions of transport for thermal analysis in II-B (The same applies to the following).

ii. Trunnion fixing bolts

The package is designed so that the shearing load applied to the trunnion is borne by its cylinder section to be engaged with the flange. Therefore, the trunnion fixing bolts are applied with a tensile load due to the moment during lifting as well as the axial force by the initial tightening torque.

(i) Tensile stress due to moment

The maximum tensile stress σ_1 due to the moment at the support of Point O shown in Figure II-A.2 occurs in the bolts □ and □ and can be determined by the equation:

$$\sigma_1 = M \times \frac{\square}{I} \quad (\square \text{ Distance between Point O and the bolt } \square \text{ or } \square \ [\square \text{ mm}])$$

$$M = F \times L$$

$$I = \frac{\pi}{64} \times dr^4 \times \square + \sum_{i=1}^{\square} \left(\frac{\pi\, dr^2}{4} \times Di^2 \right) \times 2$$

where, F : Maximum load applied to a single trunnion [2.87×10^5 N]

M : Moment (N·mm)

I : Moment of inertia of the section (mm^4)

L : Moment arm [□ mm]

Di : Distance between Point O and the bolt (mm)

dr : Minimum diameter of bolt (□ [□ mm]

Therefore,

σ_1 = □ MPa

(ii) Tensile stress due to initial tightening torque

The tensile stress due to the initial tightening torque σ_2 can be determined by the equation:

$$\sigma_2 = T \times \frac{1}{0.2d} \times \frac{1}{(\pi dr^2/4)}$$

where, T : Initial tightening torque [□ N·mm]

d : Nominal diameter of bolt [□ mm]

Therefore,

σ_2 = □ MPa

Then, the tensile stress σ that occurs in the trunnion fixing bolts during lifting is:

$\sigma = \sigma_1 + \sigma_2$ = □ MPa

The criteria (Sy) for this is □ MPa (□ °C).

Then, the safety margin MS in this case is:

MS = [redacted] / [redacted] − 1 = [redacted]

Therefore, the trunnion fixing bolts have a sufficient strength against the tensile stress during handling.

b. Handling belts

The package is horizontally lifted using two handling belts installed in the positions shown in Figure I-C.3. So, this section evaluates the strength of the handling belts when they are applied with an acceleration during lifting.

(a) Upper and lower belts

The upper and lower sections of a handling belt are [redacted] as shown in Figure I-C-9. So, the analysis code ABAQUS is used to determine the stress that occurs in the various portions of the upper and lower sections of the handling belts.

i. Analysis model

A plane symmetry 3-dimensional model is used for analysis of the upper and lower sections of the handling belt. [redacted] constituting the upper/lower section of the handling belt has been modeled [redacted].

The upper and lower sections are [redacted].

Furthermore, the shell part of the packaging on which the handling belts are installed has been modeled to determine the mass borne by the handling belts.

The general view, dimensional drawing and mesh model are shown in Figures II-A.3 to Figures II-A.5.

ii. Load and boundary conditions

(i) Load condition

[redacted], the mass m' of the shell part of the packaging is set to:

$$m' = m \times \frac{1}{4}$$

where, m: Package mass [19,500 kg]

Therefore,

$$m' = 4{,}875 \text{ kg}$$

Figure II-A.3: General view of analysis model (lifting devices: upper and lower belts)

(Unit: mm)

Figure II-A.4: Dimensional drawing of analysis model (lifting devices: upper and lower belts)

Figure II-A.5: Mesh model (lifting devices: upper and lower belts)

During lifting operation, the lower belts of the handling belts are applied with the dead load of the package multiplied by the loading factor of operation.

Therefore, the entire analysis model is applied with an acceleration three times the gravity acceleration (9.81 m/s^2).

(ii) Boundary condition

The handling belts are

iii. Analysis results

The deformation is shown in Figure II-A.6 and the stress contour in Figure II-A.7. According to the target positions shown in Figure II-A.8, the results of stress evaluation for the relevant components are shown in Table II-A.6. As shown in the table, the stress that occurs in the upper/lower belts of the handling belts is within the criteria. In conclusion, the upper and lower belts of the handling belts have an enough strength against the load during lifting operation.

Figure II-A.6: Lifting device analysis results (upper and lower belts) (Deformation diagram)

Figure II-A.7: Lifting device analysis results (upper and lower belts)
(Stress contour diagram <Tresca stress intensity>)

Figure II-A-8: Stress evaluation positions of lifting devices (upper and lower belts of handling belt)

Table II-A.6: Evaluation of stress in lifting devices during lifting operation (upper and lower belts of handling belt)

Evaluation position	Type of stress	Stress intensity (MPa)	Criteria[1] (MPa)	Safety margin (MS)
	Membrane stress			
	Membrane stress+ Bending stress			
	Membrane stress+ Bending stress			
	Membrane stress+ Bending stress			
	Membrane stress+ Bending stress			
	Membrane stress			
	Membrane stress+ Bending stress			
	Membrane stress+ Bending stress			
	Membrane stress+ Bending stress			
	Membrane stress			
	Membrane stress			
	Membrane stress			
	Membrane stress+ Bending stress			

Note 1) The criteria specifies Sy for the membrane stress or the membrane stress + bending stress.

(b) Lifting handles

The lifting handles of the handling belts have a complex shape as shown in Figure I-C.9. The analysis code ABAQUS is used to determine the stress that occurs in their various parts:

i. Analysis model

A 3D model for a single lifting handle modeled with solid elements is use for analysis. The dimensional drawing is shown in Figure II-A.9 and the mesh model in Figure II-A.10.

ii. Load and boundary conditions

(i) Load condition

[redacted] the maximum load F_H on each lifting handle can be determined using the equation:

$$F_H = \frac{\alpha}{N} \times g \times m$$

where, α : Loading factor [3]

N : Number of lifting handles [4]

G : Gravity acceleration [9.81 m/s^2]

M : Package mass [19,500 kg]

Therefore,

$$F_H = 1.44 \times 10^5 \text{ N}$$

This load is applied to [redacted]

(ii) Boundary condition

[redacted] These load and boundary conditions are shown in Figure II-A.11.

iii. Analysis results

The deformation is shown in Figure II-A.12 and the stress contour in Figure II-A.13.

(Unit: mm)

Figure II-A.9: Dimensional drawing of analysis model (lifting device: lifting handle of handling belt)

Figure II-A.10:Mesh model (lifting device: lifting handle of handling belt)

Figure II-A-11: Load and boundary conditions for analysis of lifting device (lifting handle of handling belt)

Figure II-A.12: Results of analysis of lifting device (lifting handle of handling belt) (Deformation diagram)

Figure II-A.13: Analysis results of lifting device (lifting handle of handling belt) (Stress contour diagram <Tresca stress intensity>)

The results of stress evaluation for the target positions shown in Figure II-A.14 are shown in Table II-A.7. As shown in the table, the stress that occurs in the lifting handle is within the criteria. In conclusion, the lifting handles of the handling belts have an enough strength against the load during lifting operation.

Figure II-A.14: Stress evaluation positions of lifting device (lifting handle of handling belt)

Table II-A.7: Evaluation of stress in lifting devices during lifting (lifting handle of handling belt)

Evaluation position	Type of stress	Stress intensity (MPa)	Criteria[1)] (MPa)	Safety margin (MS)
①	Membrane stress+ Bending stress			
②	Membrane stress+ Bending stress			
③	Membrane stress			
④	Membrane stress+ Bending stress			

Note 1) The criteria specifies Sy for the membrane stress or the membrane stress + bending stress.

(c) Lifting handle pins and connecting bolts

i. Maximum load

The maximum load F_B applied to the lifting handle pins and connecting bolts of the handling belts can be calculated using the equation below. It should be taken into account that the top and bottom handling belts, [ ]

[ ]

and that a pair of (two) lifting handle pins and a pair of (two) connecting bolts are installed in a single handling belt.

$$F_B = \frac{\alpha}{N \times n} \times g \times m$$

where, α : Loading factor [3]

N : Number of handling belts [2]

n : Number of lifting handle pins and connecting bolts [2]

G : Gravity acceleration [9.81 m/s^2]

m : Package mass [19,500 kg]

Therefore,

$F_B = 1.44 \times 10^5$ N

ii. Calculating stress in lifting handle pins

A load associated with lifting of the package is applied to the lifting handle pins as a shearing stress. The shearing stress τ caused by the shearing load can be expressed in the equation:

$$\tau = \frac{F_B}{2 \times A_1}$$

where, A_1: Sectional area of lifting handle pin

$A_1 = \pi d_1^2 / 4$

where, d_1 : Diameter of lifting handle pin [[ ] mm]

Therefore,

τ = [ ] MPa

Then, the stress intensity S is:

S = 2τ = [ ] MPa

The criteria (Sy) for this is [ ] MPa ([ ] °C).

Then, the safety margin MS in this case is:

$$MS = \frac{[\ ]}{[\ ]} - 1 = [\ ]$$

Therefore, the lifting handle pins have a sufficient strength against the shearing stress during lifting operation.

iii. Stress calculation for connecting bolts

The connecting bolts are applied with a longitudinal load associated with lifting of the package as well as the axial force by the initial tightening torque.

(i) Tensile stress due to longitudinal load

The tensile stress σ_1 due to the longitudinal load can be expressed in the equation:

$$\sigma_1 = \frac{F_B}{A_2}$$

where, A_2 : Minimum sectional area of connecting bolt (mm^2)

$A_2 = \pi d_2^2 / 4$

where, d_2 : Minimum diameter of connecting bolt (□ [□ mm]

Therefore,

σ_1 = □ MPa

(ii) Tensile stress due to initial tightening torque

The tensile stress σ_2 due to the initial tightening torque can be expressed in the equation:

$$\sigma_2 = T \times \frac{1}{0.2 d_3} \times \frac{1}{(\pi d_2^2 / 4)}$$

where, T : Initial tightening torque [□ N·mm]

d_3 : Nominal diameter of bolt [□ mm]

Therefore,

σ_2 = □ MPa

Then, the tensile stress σ that occurs in the connecting bolts during lifting by the handling belts is:

$\sigma = \sigma_1 + \sigma_2$ = □ MPa

The criteria (Sy) for this is □ MPa (□ °C).

Then, the safety margin MS in this case is:

$$MS = \frac{□}{□} - 1 = □$$

Therefore, the connecting bolts of the handling belts have a sufficient strength against the tensile stress during lifting operation.

(2) Fatigue evaluation

Fatigue evaluation is based on the actual load and uses the impact factor (the maximum value to be conservatively taken) specified by the Crane Structure Standards [10] as a loading factor. Therefore, the stress intensity to be used to calculate the cyclic peak stress intensity is corrected as follows according to the ratio of the loading factor for stress evaluation to the loading factor for fatigue evaluation.

The corrected stress intensity is shown in Table II-A.8.

$S_F = S \times (A / B)$

where, S_F : Stress intensity of parts used for fatigue evaluation(MPa)

S : Stress intensity of parts for stress evaluation (MPa)

A : Loading factor for fatigue evaluation [1.6]

B : Loading factor for stress evaluation [3]

Table II-A.8: Stress intensity for fatigue evaluation

Component	Part	Stress intensity (MPa)	
		Stress evaluation	Fatigue evaluation
Trunnion	Trunnion cylinder		
	Trunnion fixing bolt		
Handling belt	Upper and lower belts		
	Lifting handle		
	Lifting handle pin		
	Connecting bolt		

a. Trunnions

The stress that occurs in the trunnions is evaluated by comparing the allowable number of cycles with the assumed number of times for the cyclic stress intensity with the stress concentration taken into account.

(a) Trunnion cylinder

i. Cyclic peak stress intensity

$Sa = S \times Kt \times (1.95 \times 10^5 / Et) / 2$

where, Sa : Cyclic peak stress intensity (MPa)

S : Stress intensity of trunnion cylinder section [☐ MPa]

Kt : Stress concentration factor

[5 (Maximum value for structural discontinuity] [6]

Et : Young's modulus of material at service temperature [☐ MPa (☐ °C)]

Therefore,

Sa = ☐ MPa

ii. Allowable number of cycles

According to the design fatigue strength curves for ☐ stainless steels shown in Figure II-A. Appendix 1.1 in A.10.1 Appendix-1, the allowable number of cycles Na for Sa (☐ MPa) is:

Na = ☐ times

Assuming that the number of times of lifting during transport is 20, the allowable number of cycles is sufficiently higher than the assumed number of times. In conclusion, the trunnions have a sufficient fatigue strength.

(b) Trunnion fixing bolts

i. Cyclic peak stress intensity

$Sa = S \times Kt \times (2.07 \times 10^5 / Et) / 2$

where, Sa : Cyclic peak stress intensity (MPa)

S : Stress intensity of trunnion fixing bolt (stress range) [☐ MPa]

Kt : Stress concentration factor

[4 (Maximum value for the threaded part of bolts)] [6]

Et : Young's modulus of material at service temperature [☐ MPa (☐ °C)]

Therefore,

Sa = ☐ MPa

ii. Allowable number of cycles

According to the design fatigue curves for high strength steel bolting shown in Figure II-A. Appendix 1.2 in A.10.1 Appendix-1, the allowable number of cycles Na for Sa (☐ MPa) is:

Na = ☐ times or more

Assuming that the number of times of lifting during transport is 20, the allowable

number of cycles is sufficiently higher than the assumed number of times. In conclusion, the trunnion fixing bolts have a sufficient fatigue strength.

b. Handling belts

The stress that occurs in the handling belts is evaluated by comparing the allowable number of cycles with the assumed number of times for the cyclic stress intensity with the stress concentration taken into account.

(a) Upper and lower belts

i. Cyclic peak stress intensity

$$Sa = S \times Kt \times (1.95 \times 10^5 / Et) / 2$$

where, Sa : Cyclic peak stress intensity (MPa)

S : Maximum stress intensity shown in Table II-A.8 [[redacted] MPa]

Kt : Stress concentration factor

[5 (Maximum value for structural discontinuity)]

Et : Young's modulus of material at service temperature [[redacted] MPa ([redacted] °C)]

Therefore,

Sa = [redacted] MPa

ii. Allowable number of cycles

According to the design fatigue strength curves for [redacted] stainless steels shown in Figure II-A. Appendix 1.1 in A.10.1 Appendix-1, the allowable number of cycles Na for Sa ([redacted] MPa) is:

Na = [redacted] times

Assuming that the number of times of lifting with the handling belts during transport is 10, the allowable number of cycles is higher than the assumed number of times. In conclusion, the upper and lower sections of handling belts have a sufficient fatigue strength.

(b) Lifting handles

i. Cyclic peak stress intensity

$$Sa = S \times Kt \times (1.95 \times 10^5 / Et) / 2$$

where, Sa : Cyclic peak stress intensity (MPa)

S : Maximum stress intensity shown in Table II-A.8 [[redacted] MPa]

Kt : Stress concentration factor

[5 (Maximum value for structural discontinuity)]

Et : Young's modulus of material at service temperature [[redacted] MPa ([redacted] °C)]

Therefore,

Sa = [redacted] MPa

ii. Allowable number of times

According to the design fatigue strength curves for [redacted] stainless steels shown in Figure II-A. Appendix 1.1 in A.10.1 Appendix-1, the allowable number of cycles Na

for Sa ([ ]MPa) is:

Na = [ ] times

Assuming that the number of times of lifting with the handling belts during transport is 10, the allowable number of cycles is higher than the assumed number of times. In conclusion, the lifting handles of the handling belts have a sufficient fatigue strength.

(c) Lifting handle pins

i. Cyclic peak stress intensity

$Sa = S \times (1.95 \times 10^5 / Et) / 2$

where, Sa : Cyclic peak stress intensity (MPa)

S : Stress intensity of lifting handle pin [[ ]MPa]

Et : Young's modulus of material at service temperature [[ ]MPa ([ ]°C)]

Therefore,

Sa = [ ]MPa

ii. Allowable number of cycles

According to the design fatigue strength curves for [ ] stainless steels shown in Figure II-A. Appendix 1.1 in A.10.1 Appendix-1, the allowable number of cycles Na for Sa ([ ]MPa) is:

Na = [ ] times or more

Assuming that the number of times of lifting with the handling belts during transport is 10, the allowable number of cycles is sufficiently higher than the assumed number of times. In conclusion, the lifting handle pins of the handling belts have a sufficient fatigue strength.

(d) Connecting bolt

i. Cyclic peak stress intensity

$Sa = S \times Kt \times (2.07 \times 10^5 / Et) / 2$

where, Sa : Cyclic peak stress intensity (MPa)

S : Stress intensity of connecting bolt (stress range) [[ ]MPa]

Kt : Stress concentration factor

[4 (Maximum value for the threaded part of bolts)]

Et : Young's modulus of material at service temperature [[ ]MPa ([ ]°C)]

Therefore,

Sa = [ ]MPa

ii. Allowable number of cycles

According to the design fatigue curves for high strength steel bolting shown in Figure II-A. Appendix 1.2 in A.10.1 Appendix-1, the allowable number of cycles Na for Sa ([ ]MPa) is:

Na = [ ] times

Assuming that the number of times of lifting with the handling belts during transport is 10, the allowable number of cycles is sufficiently higher than the assumed number of times. In conclusion, the connecting bolts of the handling belts have a sufficient fatigue strength.

A.4.5 Tie down devices

This packaging has no tie down device. As shown in Figure I-C-1, the packaging is mounted on the transport frame with its shell part secured to the frame. Therefore, with a focus placed on the zones of the shell part installed with the transport frame, the strength of the zones when applied with an acceleration during transport is evaluated.

The acceleration during transport is assumed to be:

- 2 G in the longitudinal direction
- 2 G in the lateral direction
- 2 G in the vertical direction (upward) or 3 G in the vertical direction (downward)

The stress that occurs in the zones of the shell part installed with the transport frame is determined by using an analysis model in which the transport frame mounting position is set to a support condition and the analysis code ABAQUS.

(1) Analysis model

The analysis model consists of the body and the lid parts. A mass equivalent to the mass of the shock absorbing cover is applied to the top and bottom end surfaces each. The resin density is adjusted so that individual components have their mass equivalent to actual.

Considering symmetry of analysis model, 3-dimensional plane symmetry model is used.

The dimensional drawing is shown in Figure II-A.15 and the mesh model in Figure II-A.16.

(2) Load and boundary conditions

a. Load condition

A load due to an acceleration and another load due to an internal pressure are applied during transport.

(a) Load due to acceleration

For axial acceleration, the acceleration value in the longitudinal direction during transport is applied. For radial acceleration, the vector sum of the acceleration value in the lateral direction and that in the vertical direction is applied. In addition, as the load by the basket and its contents is applied to the shell part, its equivalent density is given to [redacted] of the inner shell.

(Unit: mm)

Figure II-A.15: Dimensional drawing of analysis model (tie down devices)

Figure II-A.16: Mesh model (tie down devices)

(b) Load due to an internal pressure

According to the thermal analysis in II-B, the maximum pressure of the package under normal conditions of transport is [redacted] MPa absolute. Even if the external pressure drops to 0.060 MPa due to fluctuations of the outside air pressure, the maximum difference between the internal and external pressures is [redacted] MPa. In this evaluation, the difference between the internal and external pressures is conservatively assumed to be [redacted] MPa.

b. Boundary condition

The transport frame is installed onto the shell part in such a manner that secures the shell part for the entire perimeter. In terms of the radial direction, the shell part is supported along a half of the perimeter regardless of the direction of acceleration. In terms of the axial direction in turn, the shell part is secured with the transport frame by means of friction between the shell and the frame. Therefore, the zones installed with the transport frame are restrained by displacement constraints in the radial and longitudinal directions as a boundary condition.

These load and boundary conditions are shown in Figure II-A.17.

(3) Analysis results

The deformation is shown in Figure II-A.18 and the stress contour in Figure II-A.19.

The results of stress evaluation for the components of the shell part (the inner shell, stiffeners and external plates) in the vicinity of the zones installed with the transport frame are shown in Table II-A.9. As shown in the table, the stress is below the criteria for all the components. In conclusion, the shell part has a sufficient strength for the acceleration during transport.

Figure II-A.17: Load and boundary conditions of shell part against acceleration during transport (Unit: mm)

Figure II-A.18: Results of analysis of shell part against acceleration during transport (Deformation diagram)

Figure II-A.19: Results of analysis of shell part against acceleration during transport

(Stress contour diagram <Tresca stress intensity>)

Table II-A.9: Results of stress evaluation of the shell part against the acceleration during transport

Evaluation position		Type of stress	Stress intensity (MPa)	Criteria[1] (MPa)	Safety margin (MS)
Inner shell	Lid side	Membrane stress			
		Membrane stress+ Bending stress			
	Bottom side	Membrane stress			
		Membrane stress+ Bending stress			
Stiffener	Lid side	Membrane stress			
		Membrane stress+ Bending stress			
	Bottom side	Membrane stress			
		Membrane stress+ Bending stress			
External plate	Lid side	Membrane stress			
		Membrane stress+ Bending stress			
	Bottom side	Membrane stress			
		Membrane stress+ Bending stress			

Note 1) The criteria specifies Sy for the membrane stress or the membrane stress + bending stress.

A.4.6 Pressure

The maximum internal pressure under normal conditions of transport is [redacted] MPa absolute. In A.5.1 Thermal test, the strength of the body and lid parts was evaluated under the internal-external pressures difference of [redacted] MPa, verifying the integrity. When the external pressure drops to 60 kPa (0.060 MPa) due to fluctuations of the atmospheric pressure, the maximum internal-external pressure difference is [redacted] MPa. This means that integrity of the packaging is not impaired.

A.4.7 Vibration

As shown in Figure I-C.1, the package is transported with the shell part secured to the transport frame. This section determines the natural frequency of the package secured to the transport frame and then compares it with the vibration frequency during transport to assess the possibility of vibration resonance.

The natural frequency of the package is determined by using an analysis model in which the transport frame installation area is set to a support condition and the analysis code ABAQUS.

(1) Analysis model

The analysis model consists of the body and the lid parts. A mass equivalent to the shock absorbing cover is applied to the top and bottom end surfaces each. The resin density is adjusted so that individual components have their mass equivalent to actual.

A 360° 3-dimensional model is used for analysis.

As the mass of the basket and contents is applied to the shell part, its equivalent density is given to [redacted] of the inner shell.

The dimensional drawing and mesh model of the analysis model are shown in Figure II-A.20 and Figure II-A.21 respectively.

(2) Boundary condition

The transport frame is installed onto the shell part in such a manner that secures the shell for the entire perimeter, the external plates, which correspond to the area in which the transport frame is to be installed, are restrained by displacement constraints. The boundary condition is shown in Figure II-A.22.

(3) Analysis results

Among the vibration phase diagrams, the two cases with the smallest natural frequency are shown in Figure II-A.23. According to the figure, the natural frequency of the package is:

Analysis result	Natural frequency of package
	[redacted] Hz or higher

Therefore, the package will have no vibration resonance due to the vibration during transport (mainly 20 Hz or less).

Furthermore, the lid tightening bolts and other tightening bolts are securely tightened and will not easily be loosened due to the vibration during transport.

Therefore, the package will not be affected by the vibration during transport.

(Unit: mm)

Figure II-A.20: Dimensional drawing of analysis model (vibration)

Figure II-A.21: Mesh model (vibration)

(Unit: mm)

Figure II-A.22: Boundary condition for vibration analysis

Figure II-A.23: Vibration analysis results (Vibration phase diagrams)

A.5 Normal conditions of transport

A.5.1 Thermal test

The evaluation of the package temperatures under normal conditions of transport (II-B Thermal Analysis, B.4 Normal conditions of transport) conservatively takes into account the solar insolation.

A.5.1.1 Summary of temperatures and pressures

The temperature of the package under normal conditions of transport is described in II-B.4. Based on the temperature, the object temperature criteria for the test is set to [redacted]°C for all components.

The internal pressure of the package under normal conditions of transport is [redacted]MPa absolute. Even if the external pressure drops to 0.060 MPa due to fluctuations of the outside air pressure, the maximum difference between the internal and external pressures is [redacted] MPa. Therefore, this test conservatively uses an internal-external pressure difference of [redacted] MPa for evaluation.

A.5.1.2 Thermal expansion

The packaging will have a thermal stress in its components due to thermal expansion under normal conditions of transport.

The thermal stress in the packaging body is described in A.5.1.3 where combinations of loads due to the internal pressure and the initial tightening force of bolts are taken into account.

For basket, the decrease of clearance between the basket and the packaging body due to a difference in thermal expansion is calculated to assess whether any thermal stress is caused by constraints.

(1) Longitudinal direction

The longitudinal clearance between the basket and the shell part of the packaging body will be smaller due to a difference in thermal expansion between the basket and the shell part.

The longitudinal clearance between the basket and the inner surface of the packaging body ΔL can be determined by the equation:

$$\Delta L = (L_1 - L_2) - \{L_2 \times (T_2 - 20) \times \alpha_2 - L_1 \times (T_1 - 20) \times \alpha_1\}$$

where, L_1 : Length of cavity of packaging body [[redacted]mm]

L_2 : Overall length of cavity [[redacted]mm]

T_1 : Temperature of shell part [[redacted]°C]

T_2 : Temperature of basket [[redacted]°C]

α_1 : Coefficient of linear thermal expansion of shell part [[redacted]/°C ([redacted]°C)]

α_2 : Coefficient of linear thermal expansion of basket [[redacted]/°C ([redacted]°C)]

Therefore, ΔL=[redacted]mm > 0mm

This means that there is a longitudinal clearance between the basket and the inner surface of the packaging body. No thermal stress will occur due to constraints.

(2) Radial direction

The radial clearance between the basket and the shell part of the packaging body will be smaller due to a difference in thermal expansion between the basket and the shell part.

The packaging body has inner and outer diameters as follows:

- Inner diameter of packaging body: mm
- Outer diameter of basket: mm

Therefore, the minimum inner diameter of packaging body D_1 and the maximum outer diameter of basket D_2 are:

- D_1 = mm
- D_2 = mm

The clearance between the inner surface of the packaging body and the outer surface of the basket ΔD can be calculated using the equation:

$$\Delta D = (D_1 - D_2) + \{D_1 \times (T_1 - 20) \times \alpha_1 - D_2 \times (T_2 - 20) \times \alpha_2\}$$

where, T_1 : Temperature of shell part [°C]

T_2 : Temperature of basket [°C]

α_1 : Coefficient of linear thermal expansion of shell part [/°C (°C)]

α_2 : Coefficient of linear thermal expansion of basket [/°C (°C)]

Therefore, ΔD = mm > 0mm

This means that there is a radial clearance between the inner surface of the packaging body and the outer surface of the basket. No thermal stress will occur due to constraints.

A.5.1.3 Stress calculation

This section calculates the stress that occurs in the components of the packaging body during a thermal test under normal conditions of transport.

The heat generation from the contents is negligible, but the package will have a higher temperature with heat supply from solar insolation. Increasing of temperature will give differences of thermal expansion between the components of the packaging body, which will generate thermal stresses.

By using the analysis code ABAQUS, this section determines the primary stress due to the internal pressure and the initial tightening force of bolts and the (primary + secondary) stress with the difference in thermal expansion among the components taken into account.

(1) Analysis model

A 3-dimensional model of the packaging body is used for analysis

This model consists of the body (top flange, inner shell, stiffeners, external plates and bottom) and the lid parts (lid and lid tightening bolts). The lid is connected to the top flange with the lid tightening bolts. The contact between the lid and the top flange is taken into account.

The dimensional drawing and mesh model of the analysis model are shown in Figure II-A.24 and Figure II-A.25 respectively.

(2) Load and boundary conditions

a. Load condition

For calculation of the primary stress, the inner surface of the packaging body is applied with ☐ MPa and the lid tightening bolts are applied with an axial force by the initial tightening.

The axial force F due to the initial tightening torque is given by the equation:

$$F = T \times \frac{1}{0.2\ d}$$

where, T : Initial tightening torque [☐ N·mm]

d : Nominal diameter of bolt [☐ mm]

Therefore, $F = 2.36 \times 10^5$ N

Then, to calculate the (primary + secondary) stress, the entire analysis model is subjected to the temperature (☐°C) of normal conditions of transport.

b. Boundary condition

The center of bottom is restrained by displacement constraints in axial direction. The central axis is restrained by displacement constraints in radial direction. The symmetrical surfaces are restrained by displacement constraints in circumference direction.

(3) Analysis results

The deformation and stress contour diagrams according to the calculation of the (primary + secondary) stress are shown in Figure II-A.26 and Figure II-A.27 respectively.

For the target positions shown in Figure II-A.28, the primary stress evaluation is shown in Table II-A.10 and the (primary + secondary) stress evaluation is shown in Table II-A.11. As shown in these tables, the stresses that occur in the packaging body are below the criteria. Therefore, the package will not be affected by the thermal test under normal conditions of transport.

(Unit: mm)

Figure II-A.24: Dimensional drawing of analysis model (thermal test under normal conditions of transport)

Figure II-A.25: Mesh model (thermal test under normal conditions of transport)

Figure II-A.26: Results of analysis of thermal test under normal conditions of transport
(Deformation diagram)

Figure II-A.27: Results of analysis of thermal test under normal conditions of transport
(Stress contour diagram <Tresca stress intensity>) (1/2)

Figure II-A.27: Results of analysis of thermal test under normal conditions of transport
(Stress contour diagram <Tresca stress intensity>) (2/2)

Figure II-A.28: Stress evaluation positions for thermal test under normal conditions of transport

Table II-A.10: Results of stress evaluation for primary stress in packaging body components during a thermal test under normal conditions of transport

Evaluation position		Stress classification [1)]	Stress intensity (MPa)	Criteria[2)] (MPa)	Safety margin (MS)
Lid	①	Pm			
		PL+Pb			
	②	PL			
External plate	③	PL			
	④	Pm			
	⑤	PL			
Inner shell	⑥	PL			
	⑦	Pm			
	⑧	PL			
Stiffener	⑨	PL			
	⑩	PL			
	⑪	PL			
Bottom	⑫	PL			
	⑬	Pm			
		PL+Pb			

Note 1) Pm: General primary membrane stress intensity, PL: Local primary membrane stress intensity, Pb: Primary bending stress intensity

Note 2) The criteria is Min. $\{\frac{1}{3}$ Su, $\frac{2}{3}$ Sy$\}$ for Pm, 1.5 x Min. $\{\frac{1}{3}$ Su, $\frac{2}{3}$ Sy$\}$ for PL or PL + Pb, and Sy for the containment seal part.

Table II-A.11: Results of stress evaluation for (primary + secondary) stress in packaging body components during a thermal test under normal conditions of transport

Evaluation position		Stress intensity (MPa)	Criteria[1)] (MPa)	Safety margin (MS)
Lid	①			
	②			
External plate	③			
	④			
	⑤			
Inner shell	⑥			
	⑦			
	⑧			
Stiffener	⑨			
	⑩			
	⑪			
Bottom	⑫			
	⑬			
Lid tightening bolt	σm			
	$\sigma m + \sigma b$			

Note 1) $3 \times$ Min. $\{\frac{1}{3}$ Su, $\frac{2}{3}$ Sy$\}$ for (primary + secondary) stress, Sy for the containment seal part, $\frac{2}{3}$ Sy for σm of the lid tightening bolts, and Sy for $\sigma m + \sigma b$

(4) Fatigue evaluation

The stress that occurs in the lid tightening bolts is evaluated by comparing the allowable number of cycles with the assumed number of times for the cyclic stress intensity with the stress concentration taken into account.

a. Cyclic peak stress intensity

$$Sa = S \times Kt \times (2.07 \times 10^5 / Et) / 2$$

where,
- Sa : Cyclic peak stress intensity (MPa)
- S : Stress intensity of lid tightening bolt (stress fluctuating range) [☐ MPa]
- Kt : Stress concentration factor [4 (Maximum value for the threaded part of bolts)] [6]
- Et : Young's modulus of material at service temperature [☐ MPa (☐ °C)]

Therefore,

Sa = ☐ MPa

b. Allowable number of times

According to the design fatigue curves for high strength steel bolting shown in Figure II-A. Appendix 1.2 in A.10.1 Appendix-1, the allowable number of cycles Na for Sa (☐ MPa) is:

Na = ☐ times

Thus, the allowable number of cycles is sufficiently higher than the assumed number of times. In conclusion, the lid tightening bolts have a sufficient fatigue strength.

A.5.1.4 Comparison with allowable stress

As shown in Tables II-A.10 and II-A.11, any safety margin of the criteria for the stress that occurs in the packaging has a positive value. Therefore, the integrity of the package during a thermal test under normal conditions of transport will be maintained.

A.5.2 Water spray

The packaging has stainless steel or painted stainless steel external surfaces. These external surfaces will not deteriorate due to water absorption during water spray or will not be corroded by water pool.

Therefore, water spray will not impair the leaktightness or lead to increse of equivalent dose rate.

A.5.3 Free drop

Since the maximum weight of the package is 19.5 ton, the height of a free drop for the drop test is 0.3 m according to the Notification.

To determine the behavior of the packaging during a drop, a model of a [redacted] of the actual packaging was subjected to the drop test and the deformation, impact acceleration and leaktightness were measured in various drop directions and conditions. The test revealed that the packaging body has no deformation or damage in the leaktightness after a drop from the height of 9 m. Therefore, in this test where the packaging is dropped from a height of 0.3 m, the required structural integrity of the packaging should be able to be maintained. Still, this section uses an analysis approach to quantitatively determine the behavior of the packaging during the free drop and assess the possible effect of this test on the packaging.

(1) Packaging body

The packaging body and shock absorbing covers are modeled according to the actual profile. The dynamic analysis code LS-DYNA is used to analyze the event in which the package is dropped from a height of 0.3 m, to determine the stress and strain that occur in the components of the packaging body, and to demonstrate that no deformation that would affect other analysis occurs.

Since the impact load applied to the packaging body depends on the shock absorbing characteristics of the shock absorbing covers, adequacy of the characteristics of the shock absorbing covers given to the analysis model has been determined through verification analyses focusing on typical cases of mock-up tests. (See Appendix-2)

a. Analysis model

A plane symmetry 3-dimensional model is used for analysis so as to be commonly applied to the different drop directions (vertical, horizontal and corner). This model includes shock absorbing covers based on the analysis conditions verified with the drop test verification analysis of the drop test using the [redacted] model and consists of the lid parts integrated with the lid tightening bolts, the shell part and the bottom. Resin is added to the model as a density-adjusted area so that the entire analysis model has a mass equal to the design mass. To reflect the load applied by the contents, an area of an equivalent density is provided with the basket shape taken into account.

The dimensional drawing and mesh model of the analysis model are shown in Figure II-A.29 and Figure II-A.30 respectively.

For conservative calculation of the plastic strain that occurs in the structural strength members, the stress-strain relationship based on the nominal stress and elongation (see Figure II-A.31) has been used as material characteristics.

Figure II-A.29: Dimensional drawing of analysis model (free drop/packaging body)

Figure II-A.30: Mesh model (free drop/packaging body)

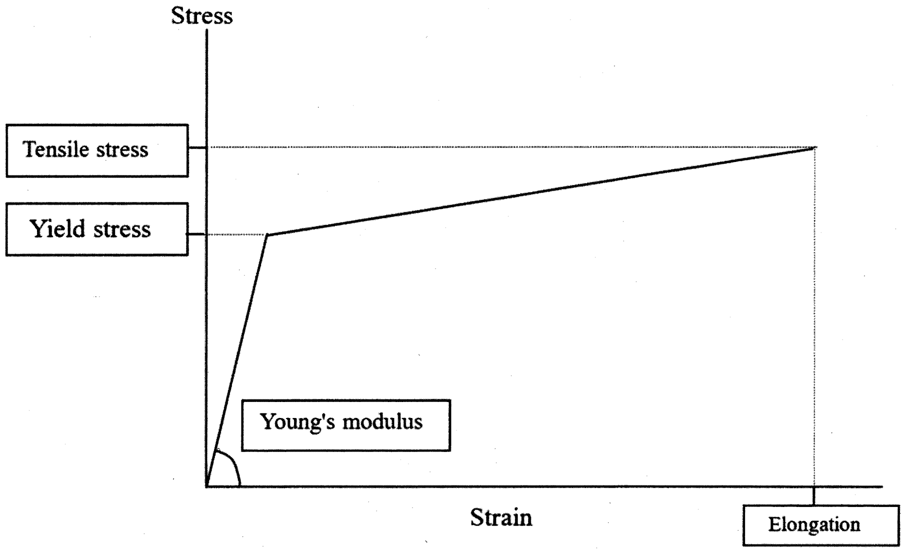


Figure II-A.31: Stress-strain relationship given to evaluation target components

b. Load and boundary conditions

The analysis model is made into contact with a rigid surface at an angle corresponding to the relevant drop direction. First, the lid tightening bolts are applied with a tensile stress ([redacted] MPa) due to the initial tightening torque. Next, an impact velocity (2.43 m/sec) of the free drop is given.

Analysis is made for the following drop directions:

[1] Vertical drop (top and bottom)

[2] Horizontal drop

[3] Corner drop (top and bottom)

c. Analysis results

The analysis was continued until the time at which the maximum deformation was identified. As a result, the analysis derived the maximum deformation, the plastic strain occurring in the structural strength members after a drop and the stress in the lid tightening bolts for evaluation of the leaktightness. The deformation diagrams of the shock absorbing covers for the different drop directions are shown in <u>Figure II-A.32</u>.

The following describes the results of the analysis of the damaged condition for the different drop directions:

(a) Top vertical drop

The components of the packaging body have no plastic strain or no deformation that would have to be considered in other analysis. The stress in the lid tightening bolts is below the criteria (Sy), so the leaktightness will be maintained.

(b) Bottom vertical drop

The components of the packaging body have no plastic strain or no deformation that would have to be considered in other analysis.

(c) Horizontal drop

Among the components of the packaging body, [redacted] have a plastic strain of not greater than [redacted] % (see <u>Figure II-A.33</u>). However, [redacted]. This means that the form is adequately maintained.

Therefore, any deformation that would have to be considered in other analysis will not occur in the packaging body after a horizontal drop. Furthermore, the stress in the lid tightening bolts is below the criteria (Sy), so the leaktightness will be maintained.

(d) Top corner drop

The components of the packaging body have no plastic strain or no deformation that would have to be considered in other analysis. The stress in the lid tightening bolts is below the criteria (Sy), so the leaktightness will be maintained.

Figure II-A.32: Free drop / packaging body analysis results (Deformation diagram)

Figure II-A.33: Results of analysis of 0.3 m horizontal drop / packaging body
(Plastic strain contour diagram)

(e) Bottom corner drop

The components of the packaging body have no plastic strain or no deformation that would have to be considered in other analysis.

These analysis results are summarized in Table II-A.12.

As shown in the table, the leaktightness will be maintained for all the drop directions and a deformation that would have to be considered in other analysis will not occur. The structural integrity will be maintained against the free drop test.

Table II-A.12: Summary of results of analysis of packaging body subjected to free drop test (1/2)

Drop direction	Shock absorbing cover maximum deformation (mm)	Component	Plastic strain (%)	Evaluation
Top vertical		Lid		
		Top flange		
		Inner shell		
		Stiffener		
		External plate		
Bottom vertical		Inner shell		
		Stiffener		
		External plate		
		Bottom		
Horizontal		Top flange		
		Inner shell		
		Stiffener		
		External plate		
Top corner		Lid		
		Top flange		
		Inner shell		
		Stiffener		
		External plate		
Bottom corner		Inner shell		
		Stiffener		
		External plate		
		Bottom		

Table II-A.12: Summary of results of analysis of packaging body subjected to free drop test (2/2)

Target component	Drop direction	Type of stress	Analysis results (MPa)	Criteria[1)] (MPa)	Safety margin (MS)
Lid tightening bolt	Top vertical	σm			
		$\sigma m + \sigma b$			
	Horizontal	σm			
		$\sigma m + \sigma b$			
	Top corner	σm			
		$\sigma m + \sigma b$			

Note 1) The criteria specifies Sy for σm or $\sigma m + \sigma b$.

(2) Basket

The basket is applied with an inertia force due to its dead load and an inertia force by the contents at a drop test. Among the drop directions, the horizontal drop is the severest condition for the basket because it has to bear the total load of the contents. This section determines the strain occurring in the basket when it is applied with an impact of the horizontal drop by using the dynamic analysis code LS-DYNA in order to demonstrate that the structural integrity necessary for the basket will be maintained.

a. Analysis model

The basket [redacted]

The packaging body is modeled as an annular ring consisting of an inner shell, stiffeners, external plates and shell part resin to simulate the condition in which the basket is supported by the shell part of the packaging body at horizontal drop.

The contents are modeled as a rectangular solid of the density calculated from the volume of a prism having a total length equal to the active length of fuel and a cross sectional area equal to that of the channel box.

The physical properties given to the basket, [redacted], which are one of the major structural components, are considered as elastic-perfectly plastic solid and the other components are applied with the stress-strain relationship based on the nominal stress and elongation as shown in Figure II-A.31, in order to conservatively calculate the strain.

The dimensional drawing and mesh model of the analysis model are shown in Figure II-A.34 and Figure II-A.35 respectively.

b. Load and boundary conditions

The basket is given the impact velocity of the free drop (2.43 m/sec). The lateral section of the shell part of the packaging body supporting the basket is given the velocity history of the center of the shell part (shown in Figure II-A.36) that has been derived from the analysis of the packaging body subjected to a horizontal drop.

The both sliced end surfaces of the basket are assumed to be symmetrical.

[redacted], the test is conducted for [redacted] drop directions [redacted] as shown in Figure II-A.37.

c. Analysis results

The analysis derived the plastic strain that occurred in the basket components. Table II-A.13 summarizes the results of analysis for the different drop directions. As shown in the table, no deformation that would have to be considered in other analysis did not occur in any of the drop directions. In conclusion, the structural integrity of the basket will be maintained after the free drop test.

(Unit: mm)

Figure II-A.34: Dimensional drawing of analysis model (free drop/basket)

Figure II-A.35: Mesh model (free drop/basket)

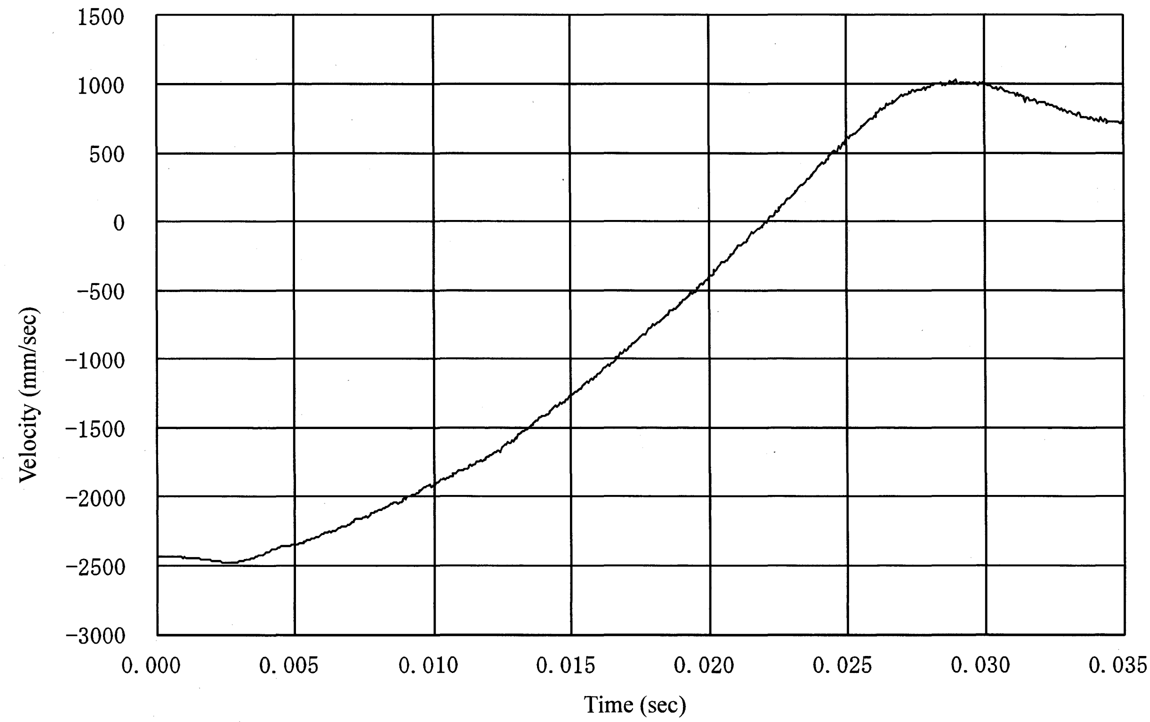


Figure II-A.36: Packaging body velocity history

Figure II-A.37: Basket drop directions

Table II-A.13: Summary of results of analysis of basket subjected to free drop test

Drop direction	Component	Plastic strain (%)	Evaluation
	Lodgment		
	Aluminum spacer		
	Lodgment		
	Aluminum spacer		
	Lodgment		
	Aluminum spacer		

(3) Fuel cladding

The BWR fuel assemblies contained in the packaging is applied with an impact load by the packaging at a drop test.

Assuming that the impact load is directly applied to the fuel cladding containing fuel pellets, this section determines the maximum plastic strain that occurs in the fuel cladding by using the dynamic analysis code LS-DYNA in order to demonstrate that the fuel cladding has no rapture.

Among the various drop directions, vertical and horizontal drops are selected because the fuel cladding bears the maximum compression load for the former drop and the maximum bending load for the latter drop.

The fuel assembly specifications and the fuel cladding physical properties used for the analysis are shown in Table II-A.14 and Table II-A.15 respectively.

Table II-A.14: Fuel assembly specifications

Item	Value used for evaluation
Fuel assembly weight (including channel boxes)	[redacted]kg
Number of fuel rods	[redacted]
Fuel pellet weight (per assembly)	[redacted]kg
Active length	[redacted]mm
Fuel cladding external diameter	[redacted]mm
Fuel cladding internal diameter	[redacted]mm
Spacer span	[redacted]mm
Internal gas pressure (20°C)	[redacted]MPa absolute

Table II-A-15: Physical properties of fuel cladding [11]

Item	Value used for evaluation
Density (10^3 kg/m^3)	6.55
Young's modulus (10^5 MPa)	[redacted]([redacted]°C)
Yield stress (MPa)	[redacted]([redacted]°C)
Tensile strength (MPa)	[redacted]([redacted]°C)
Poisson's ratio	[redacted]([redacted]°C)
Elongation (%)	[redacted]([redacted]°C)

a. Analysis model

The fuel rods are supported by almost equally spaced spacers. So, a length of fuel cladding equivalent to a spacer span is modeled.

In terms of the physical properties given to the analysis model, the stress-strain relationship based on the nominal stress and elongation (see Figure II-A.31) is applied in order to conservatively calculate the strain.

The mesh model of the analysis model is shown in Figure II-A.38.

b. Load and boundary conditions

(a) Vertical drop

For a vertical drop, it is assumed that the fuel cladding will directly collide with the inner surface of the packaging.

The surface to be collided by the fuel cladding is defined as a rigid body on the assumption that the absorption of the drop energy of the fuel rod by the surface in the form of deformation is ignored.

The analysis model is given the impact velocity (2.43 m/sec) of the free drop and the collided surface is given the velocity history shown in Figure II-A.39. The velocity history has been extracted from the bottom subjected to a bottom vertical drop test, which involves a higher impact than that of a top vertical drop.

Since the inertia force of the pellets is taken by the pellets themselves during a vertical drop, it is assumed that the mass of the fuel assemblies (including channel boxes) deducted by the mass of the pellets is applied. This resultant mass is then divided by the number of fuel rods, which is applied to the top end of the analysis model.

The inner surface of the fuel cladding bears the internal gas filling pressure. Since the internal gas filling pressure is □ MPa absolute at 20°C, the internal-external pressure difference P at □°C can be calculated as follows:

$$P = \square \times \frac{273 + \square}{273 + 20} - 0.101 = \square \text{ MPa}$$

Therefore, a pressure of □ MPa is applied to the inner surface of the analysis model.

As a boundary condition, symmetrical condition is given to the both ends of the analysis model.

(b) Horizontal drop

For a horizontal drop, it is assumed that the spacer positions of the fuel assemblies are retained in the inner surfaces of the lodgments and the fuel cladding is subject to bending deformation with the spacers as the support points.

In order to simulate the condition in which the fuel cladding is supported by the spacers, the fuel cladding is so modeled that it's both ends are held by a rigid surface each.

The analysis model is given the impact velocity (2.43 m/sec) of the free drop and the rigid surface on the both ends is given the velocity history shown in Figure II-A.40. The velocity history has been extracted from the basket subjected to a horizontal drop.

Figure II-A.38: Fuel cladding analysis model for drop test

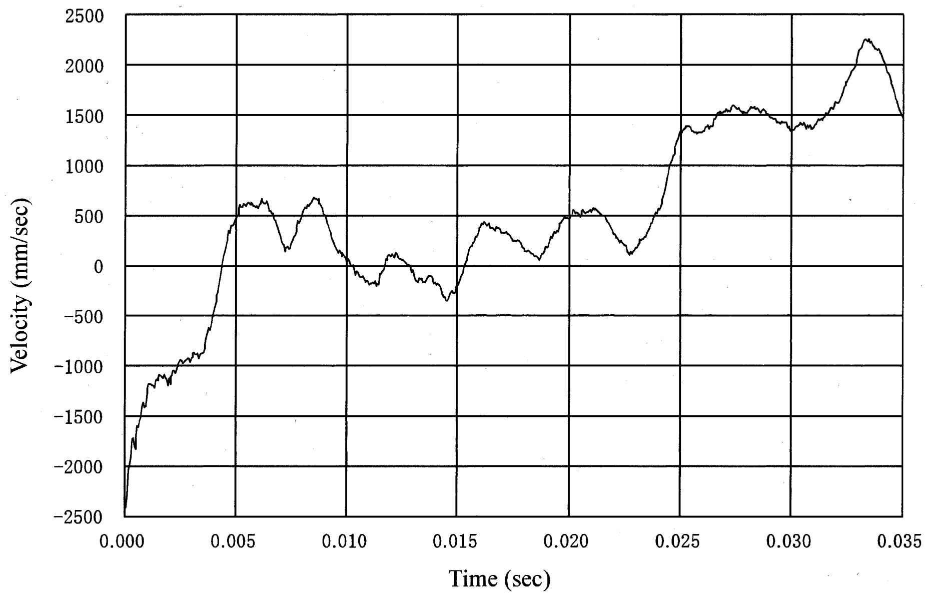


Figure II-A.39: Packaging body velocity history (bottom vertical drop)

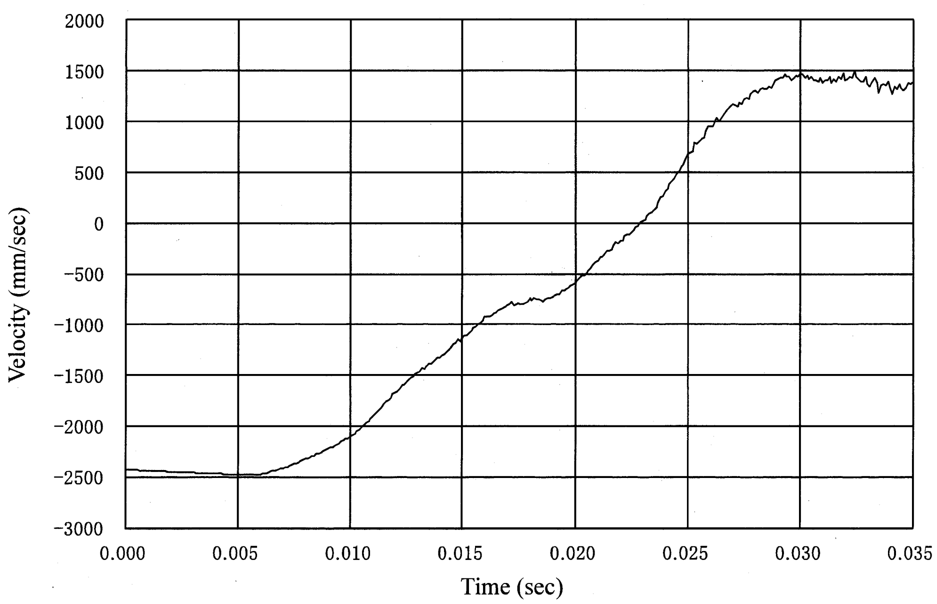


Figure II-A.40: Basket velocity history (horizontal drop)

Since the inertia force of the pellets is all taken by the fuel cladding, the pellet mass is uniformly applied to the inner surface.

In addition, pressure of MPa is applied to the inner surface of the analysis model.

As a boundary condition, symmetrical condition is given to the both ends of the analysis model.

c. Analysis results

The results of analysis for vertical and horizontal drops are shown in Table II-A.16.

For a vertical drop, a plastic strain of up to % occurs around the lowermost part of the fuel cladding as shown in Figure II-A.41. However, this strain is sufficiently smaller than the elongation of the fuel cladding. On the other hand, no plastic strain occurs at horizontal drop.

Therefore, the fuel cladding will not rupture at free drop.

Table II-A-16: Summary of results of analysis of fuel cladding subjected to free drop

Conditions	Maximum plastic strain (%)	Elongation (%)
0.3 m vertical drop		
0.3 m horizontal drop		

Figure II-A.41: Results of analysis of 0.3 m vertical drop/fuel cladding
(Plastic strain contour diagram)

A.5.4 Stacking test

In this test, a load equivalent to five times the gross weight of the package or the projected area of the packaging multiplied by 13 kPa, whichever is higher, should be applied. For this packaging, a load equivalent to five times the package weight (19.5 ton) is applied to evaluate the strength of the packaging body.

(1) Vertical position

The stress that occurs in the shell part when a load equivalent to five times the gross weight of the package is applied to the top end of the packaging body is determined using the analysis code ABAQUS.

a. Analysis model

In order to determine the stress in the components of the shell part, a [redacted] 3-dimensional model of the packaging, which was used in the thermal test in A.5.1, is used for analysis.

The dimensional drawing and mesh model of the analysis model are shown in Figure II-A-24 and Figure II-A-25 respectively.

b. Load and boundary conditions

A load equivalent to six times the package weight is applied to the end surface of the top flange as a distributed load and the surrounding part of the bottom surface of the bottom is fixed. The applied load F is:

$$F = m \times g \times 6 \times \frac{[redacted]}{360°}$$

where, m : Package mass [19,500 kg]

g : Gravity acceleration [9.81 m/s^2]

Therefore,

F = [redacted] N

In addition, the central axis is restrained by displacement constraints in radial direction. The symmetrical surfaces are restrained by displacement constraints in circumference direction. The load and boundary conditions given to the analysis model is shown in Figure II-A.42.

c. Analysis results

The deformation and stress contour diagrams are shown in Figure II-A.43 and Figure II-A.44 respectively.

Evaluation of the stress in the components of the shell part is shown in Table II-A.17.

For all the components, the stress is below the criteria. In conclusion, the structural integrity of the shell part will not be affected by a stacking test in vertical position.

Figure II-A.42: Load and boundary conditions for stacking test (vertical position)

Figure II-A.43: Results of analysis of stacking test/vertical position (Deformation diagram)

Figure II-A.44: Results of analysis of stacking test/vertical position
(Stress contour diagram <Tresca stress intensity>)

Table II-A.17: Shell part stress evaluation after stacking test (vertical position)

Target position	Type of stress	Stress intensity (MPa)	Criteria[1] (MPa)	Safety margin (MS)
Inner shell	Membrane stress			
	Membrane stress+ Bending stress			
External plate	Membrane stress			
	Membrane stress+ Bending stress			
Stiffener	Membrane stress			
	Membrane stress+ Bending stress			

Note 1) The criteria specifies Sy for the membrane stress or the membrane stress + bending stress.

(2) Horizontal position

In actual operation, packagings will never be stacked. An acceleration six times the gravity acceleration is applied to simulate the condition in which a load equivalent to five times the package weight (19.5 ton) is applied. Then, the stress that occurs around the area in which the transport frame is to be installed is determined using the analysis code ABAQUS.

a. Analysis model

A plane symmetry 3-dimensional model of the packaging body, which was used for A.4.5 Tie down devices is used.

The dimensional drawing and mesh model of the analysis model are shown in Figure II-A.15 and Figure II-A.16 respectively.

b. Load and boundary conditions

A vertical acceleration of 6 G is applied. The of the inner shell is given a density equivalent to the total mass including the mass of basket and contents so that the load of the basket and contents is applied to the shell part.

The transport frame is installed onto the shell part in such a manner that secures the shell for the entire perimeter, the lower half of the shell part is restrained by displacement constraints in radial direction.

The load and boundary conditions given to the analysis model are shown in Figure II-A.45.

c. Analysis results

The deformation and stress contour diagrams are shown in Figure II-A.46 and Figure II-A.47 respectively.

(Unit: mm)

Figure II-A.45: Load and boundary conditions for stacking test (horizontal position)

Figure II-A-46: Results of analysis of stacking test/horizontal position
(Deformation diagram)

Figure II-A-47: Results of analysis of stacking test/horizontal position
(Stress contour diagram <Tresca stress intensity>)

Evaluation of the stress in the components of the shell part is shown in Table II-A.18.

For all the components, the stress is below the criteria. In conclusion, the structural integrity of the shell part will not be affected by a stacking test in horizontal position.

Table II-A.18: Shell part stress evaluation after stacking test (horizontal position)

Target position		Type of stress	Stress intensity (MPa)	Criteria[1)] (MPa)	Safety margin (MS)
Inner shell	Lid side	Membrane stress			
		Membrane stress+ Bending stress			
	Center	Membrane stress			
		Membrane stress+ Bending stress			
	Bottom side	Membrane stress			
		Membrane stress+ Bending stress			
Stiffener	Lid side	Membrane stress			
		Membrane stress+ Bending stress			
	Center	Membrane stress			
		Membrane stress+ Bending stress			
	Bottom side	Membrane stress			
		Membrane stress+ Bending stress			
External plate	Lid side	Membrane stress			
		Membrane stress+ Bending stress			
	Center	Membrane stress			
		Membrane stress+ Bending stress			
	Bottom side	Membrane stress			
		Membrane stress+ Bending stress			

Note 1) The criteria specifies Sy for the membrane stress or the membrane stress + bending stress.

A.5.5 Penetration

A mild steel bar of a mass of 6 kg and a diameter of 3.2 cm is dropped from a height of 1 m on to the outer surface of the package. Whether the bar penetrates the package is examined.

This test is intended to evaluate the effect of such a drop impact of the mild steel bar on the leaktightness of the packaging and focuses on components constituting a containment boundary. Among the outer surfaces of the packaging body except the shock absorbing covers whose damage has no impact to leaktightness, the external plates, which have the lowest thickness (□mm), are selected to demonstrate that they cannot be penetrated by the bar.

The potential energy (Wp) of the bar before a drop is expressed in the equation:

$$W_P = m\ g\ h$$

where, m: Bar mass [6 kg]

g : Gravity acceleration [9.81 m/s^2]

h : Drop height [1,000 mm]

Therefore,

$$W_P = 6 \times 9.81 \times 1000 = 5.89 \times 10^4\ N \cdot mm$$

The necessary energy for the bar to penetrate the external plate of a thickness of □mm (W) can be determined using the equation: (See Figure II-A.47).

$$W = \int_0^t \tau_{cr} \pi d (t-y) dy = \tau_{cr} \pi d \times \frac{1}{2} \times t^2$$

where, τ_{cr}: Shearing strength of external plate

[0.6 Su = □MPa (□°C)]

d : Bar diameter [32 mm]

t : External plate thickness [□mm]

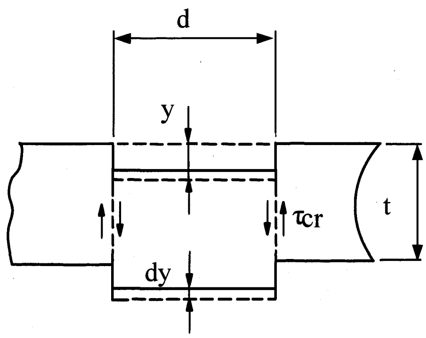


Figure II-A.47: Shearing model

The integral is evaluated and relevant values are substituted:

$$W = \tau_{cr}\ \pi d \times \frac{1}{2} \times t^2$$

$$= \square \times \pi \times 32 \times \frac{1}{2} \times \square^2 = \square\ N \cdot mm$$

The potential energy of the bar is compared with the necessary energy for the bar to penetrate the external plate of a thickness of □mm:

$$W_P\ (5.89 \times 10^4\ N \cdot mm) < W\ (\square\ N \cdot mm)$$

This means that the external plates will not be penetrated by the dropped bar.

In conclusion, the containment system will not be affected by the dropped bar and integrity of the package will not be affected.

A.5.6 Corner or edge drop

This package is a steel cylinder weighing 19.5 ton and does not fall under the target of corner or edge drop.

A.5.7 Summary of results and evaluation

This section summarizes the status after various tests under normal conditions of transport:

(1) Thermal test

The stress in the body, lid or lid tightening bolts is below the criteria. Clearance between basket and inner surface of the packaging body is maintained, and no thermal stress due to constraints will occur.

Therefore, the structural integrity and containment performance of the packaging is maintained during the thermal test.

(2) Water spray

The water spray does not deteriorate or corrode any component of the packaging. Therefore, containment performance and shielding performance will not be affected.

(3) Free drop

The packaging body had a minute plastic strain of not greater than [redacted]% in [redacted] after a horizontal drop, but had no plastic strain after a vertical or corner drop. The stress in the lid tightening bolts or containment seal surface after the drop test in any drop position is below the design yield stress of the criteria.

The basket has no plastic strain in its components after a horizontal drop, which is the severest drop position.

Therefore, the packaging maintains its structural integrity and containment performance during the free drop test.

Concerning the fuel assemblies which is the contents, analysis focused to the fuel cladding shows a plastic strain of [redacted]% at a vertical drop, but this is sufficiently smaller than the elongation. No plastic strain occurred at a horizontal drop.

Therefore, the fuel cladding will have no crack or rupture at the free drop.

(4) Stacking test

The stress in the shell part when it is applied with a load equivalent to five times the weight of package is below the criteria.

Therefore, the shell part maintains its structural integrity against the stacking test.

5) Penetration

When a bar of 6 kg is dropped from a height of 1 m on to the external plates, the bar will not penetrate and containment performance will not be affected.

A.6 Accident conditions of transport

This package is classified into Type A package and does not fall under this test conditions.

A.7 Enhanced water immersion test

This package has a maximum radioactivity of not higher than the A_2 value and does not fall under the test conditions in this section.

A.8 Radioactive contents

The radioactive contents of this package are fresh BWR fuel assemblies.

The specifications and structure diagram of the BWR fuel assemblies are shown in Table I-D.1 and Figure I-D.2 respectively.

The strength of the fuel assemblies is evaluated in section A.9 Packages containing fissile material. The fuel cladding had a plastic strain after a free drop under normal conditions of transport and after a 9 m drop under accident conditions of transport for packages containing fissile material, but these strains are sufficiently smaller than the elongation. Therefore, the fuel cladding will not rupture to release the fuel in the cladding to the space inside the packaging.

A.9 Packages containing fissile material

This package falls under the packages containing fissile material.

Therefore, the damaged condition of packages assumed in the criticality analysis in II-E is evaluated to the following test conditions:

A.9.1 Normal conditions of transport for packages containing fissile material

For normal conditions of transport for packages containing fissile material, the effect of superposition of water spray, free drop, stacking and penetration tests is considered.

By taking into account the evaluation method described in the criticality analysis in II-E, the damaged condition affecting package is evaluated as follows according to the analysis results in section A.5:

(1) Water spray

Same as A.5.2, the package has no damage.

(2) Free drop

Same as A.5.3, the shock absorbers have deformation, but the packaging body constituting the criticality configuration has no damage.

As described in A.5.3, the fuel cladding has some plastic strain after a free drop, but the strain is sufficiently smaller than the elongation, so it will not rupture.

(3) Stacking test

Same as A.5.4, the packaging body constituting the criticality configuration has no damage.

(4) Penetration

Same as A.5.5, the packaging body constituting the criticality configuration has no damage.

From these results, the damaged condition of the package under normal conditions of transport for packages containing fissile material can be summarized in Table II-A.19. This package meets the requirements for normal conditions of transport for packages containing fissile material specified in the Regulation and Notification as shown in Table II-A.20.

Table II-A.19: Damaged condition of package under normal condition of transport for packages containing fissile material

Test condition	Damaged condition of package	Remarks
Water spray	No damage	-
Free drop	Deformed shock absorbing cover	Shock absorbing covers are ignored in the criticality analysis
	Deformed fuel cladding	Deformation of fuel cladding is considered in the criticality analysis
Stacking	No damage	-
Penetration	No damage	-

Table II-A-20: Compliance evaluation under normal condition of transport for packages containing fissile material

Requirements for packages containing fissile material	Evaluation
The structure shall have no dent that can embrace a cube measuring 10 cm per side.	The shock absorbing covers are deformed, but have no dent that can embrace a cube measuring 10 cm per side.
All sides of any rectangular solid circumscribing the package shall have a length of 10 cm or longer.	All sides of any rectangular solid circumscribing the package have a length of 10 cm or longer.

A.9.2 Accident conditions of transport for packages containing fissile material

Under accident conditions of transport for packages containing fissile material, the packaging is exposed to either of the following test process, whichever is severer to the package:

(a) Damaged condition after subjected to normal conditions of transport + 9 m drop test + 1 m drop test + Thermal (fire resistance) test + 0.9 m water immersion test

(b) Damaged condition after subjected to normal conditions of transport + 15 m water immersion test

This packaging has a sufficient structural strength against an external pressure equivalent to a water depth of 15 m. Any component of the packaging body will not be damaged. (See Appendix-4)
Therefore, of the test conditions (a) and (b) above, the condition (a) in which the package would be damaged is used to consider the effect of superposition.
For normal conditions of transport to be here, a free drop causing damage as shown in Table II-A.19 is considered.
The damaged condition of the package under accident conditions of transport for packages containing fissile material is evaluated as follows.

(1) 9 m drop test

The shock absorbing covers have maximum deformation and the package is applied with a maximum impact when the free drop of A.9.1 and the 9 m drop share the same drop position. Therefore, 0.3 m is added to 9 m to obtain a total drop height of 9.3 m. This section discusses the damaged condition for a drop test from a height of 9.3 m.
As described in A.5.3, a model of the actual packaging was subjected to a mock-up test to determine the behavior of the package during a drop. For various drop directions and conditions, the deformation, impact acceleration and the state of containment function were measured. The test revealed that the packaging body was not deformed and the containment function was not affected by the 9 m drop test.
The following quantitatively determines the behavior of the packaging body, basket and contents during a drop by using analysis approaches.

a. Packaging body

The packaging body and shock absorbing covers are modeled according to their actual form. The dynamic analysis code LS-DYNA is used to simulate events during a 9 m drop (from a height of 9.3 m). Then the stress and strain that occur in the components of the packaging body are determined. Any deformation that would affect the criticality analysis is evaluated. Since the impact load applied to the packaging body depends on the shock absorbing characteristics of the shock absorbing covers, adequacy of the characteristics of the shock absorbing covers given to the analysis model has been determined through a verification analysis focusing on typical cases of mock-up test. (See Appendix-2)

(a) Analysis model

The same analysis model as the one used for the free drop evaluation in A.5.3 is applied.

(b) Load and boundary conditions

The analysis model is made into contact with a rigid surface at an angle corresponding to the relevant drop direction. First, the lid tightening bolts are applied with a tensile stress ([redacted]MPa) due to the initial tightening torque. Next, an impact velocity (13.6 m/sec. for the drop height of 9.3 m) of the 9 m drop is given.

Analysis is made for the following drop directions:

[1] Vertical drop (top and bottom)

[2] Horizontal drop

[3] Corner drop (top and bottom)

[4] Slap down drop (secondary impact: lid side, inclination: 30°)

(c) Analysis results

The analysis was continued until the time at which the maximum deformation was identified, and the maximum deformation, the strain in the structural parts and the stress in the lid tightening bolts were picked out as results of the analysis. The deformation diagrams of the shock absorbing covers for the different drop directions are shown in Figure II-A.49 to Figure II-A.54.

The results on the damaged condition for the different drop directions are as follows.

i. Top vertical drop

Among the components of the packaging body, [redacted] have a plastic strain of not greater than [redacted]%, but they will not rupture [redacted]. The other components have no plastic strain.

Therefore, the packaging body will not have any deformation that would have to be considered in the criticality analysis during a top vertical drop test.

ii. Bottom vertical drop

Among the components of the packaging body, [redacted] have a plastic strain of maximum [redacted]%、[redacted]%、[redacted]% and [redacted]% respectively (see Figure II-A.55). However, [redacted], therefore, the form is adequately maintained..

Therefore, the packaging body will not have any deformation that would have to be considered in the criticality analysis during a bottom vertical drop test.

Figure II-A.49: Results of analysis of packaging body / 9 m top vertical drop
(Deformation diagram)

Figure II-A.50: Results of analysis of packaging body / 9 m bottom vertical drop
(Deformation diagram)

Figure II-A.51: Results of analysis of packaging body / 9 m horizontal drop
(Deformation diagram)

Figure II-A.52: Results of analysis of packaging body / 9 m top corner drop
(Deformation diagram)

Figure II-A.53: Results of analysis of packaging body / 9 m bottom corner drop
(Deformation diagram)

Figure II-A.54: Results of analysis of packaging body / 9 m slap down drop
(Deformation diagram)

Figure II-A.55: Results of analysis of packaging body / 9 m bottom vertical drop
(Plastic strain contour diagram) (1/2)

Figure II-A.55: Results of analysis of packaging body / 9 m bottom vertical drop
(Plastic strain contour diagram) (2/2)

iii. Horizontal drop

Among the components of the packaging body, [redacted] has a plastic strain of not greater than [redacted] % and [redacted] have a plastic strain of maximum [redacted] %, [redacted] %, [redacted] % and [redacted] % respectively (see Figure II-A.56). However, [redacted], therefore, the form is adequately maintained. The lid tightening bolts only have a stress that is below the yield stress and have no plastic strain, therefore, they will not rupture.

Therefore, the packaging body will not have any deformation that would have to be considered in the criticality analysis during a horizontal drop.

iv. Top corner drop

Among the components of the packaging body, [redacted] have a plastic strain of maximum [redacted] %, [redacted] % and [redacted] % respectively (see Figure II-A.57). However, [redacted] therefore, the form is adequately maintained. The lid tightening bolts only have a stress that is below the yield stress and have no plastic strain, therefore, they will not rupture.

Therefore, the packaging body will not have any deformation that would have to be considered in the criticality analysis during a top corner drop.

v. Bottom corner drop

Among the components of the packaging body, [redacted] has a plastic strain of not greater than [redacted] % and [redacted] have a plastic strain of maximum [redacted] %, [redacted] % and [redacted] % respectively (see Figure II-A.58). However, [redacted], therefore, the form is adequately maintained.

Therefore, the packaging body will not have any deformation that would have to be considered in the criticality analysis during a bottom corner drop.

vi. Slap down drop

Among the components of the packaging body, [redacted] has a plastic strain of maximum [redacted] % and [redacted] have a plastic strain of not greater than [redacted] % (see Figure II-A.59). However, [redacted], therefore, the form is adequately maintained. The lid tightening bolts only have a stress that is below the yield stress and have no plastic strain, therefore, they will not rupture.

Therefore, the packaging body will not have any deformation that would have to be considered in the criticality analysis during a slap down drop.

These results of analysis of the packaging body are summarized in Table II-A.21.

Figure II-A.56: Results of analysis of packaging body / 9 m horizontal drop
(Plastic strain contour diagram) (1/2)

Figure II-A.56: Results of analysis of packaging body / 9 m horizontal drop
(Plastic strain contour diagram) (2/2)

Figure II-A.57: Results of analysis of packaging body / 9 m top corner drop
(Plastic strain contour diagram)

Figure II-A.58: Results of analysis of packaging body / 9 m bottom corner drop
(Plastic strain contour diagram) (1/2)

Figure II-A.58: Results of analysis of packaging body / 9 m Bottom corner drop
(Plastic strain contour diagram) (2/2)

Figure II-A.59: Results of analysis of packaging body / 9 m slap down drop
(Plastic strain contour diagram)

Table II-A.21: Summary of analyses of packaging body subjected to 9 m drop test (1/2)

Drop direction	Shock absorbing cover maximum deformation [1] (mm)	Component	Maximum plastic strain (%)	Elongation (%)	Evaluation
Top vertical		Lid			
		Top flange			
		Inner shell			
		Stiffener			
		External plate			
Bottom vertical		Inner shell			
		Stiffener			
		External plate			
		Bottom			
Horizontal		Lid			
		Top flange			
		Inner shell			
		Stiffener			
		External plate			
		Bottom			
Top Corner		Lid			
		Top flange			
		Inner shell			
		Stiffener			
		External plate			
Bottom Corner		Inner shell			
		Stiffener			
		External plate			
		Bottom			
Slap down (30°)		Inner shell			
		Stiffener			
		External plate			
		Bottom			

Note 1) The deformation of the shock absorbing covers is taken into account in the analysis model for the thermal analysis under accident conditions of transport.

Table II-A.21: Summary of analyses of packaging body subjected to 9 m drop test (2/2)

Component	Drop direction	Type of stress	Analysis results (MPa)	Evaluation
Lid tightening bolt	Top vertical	σm		
		σm + σb		
	Horizontal	σm		
		σm + σb		
	Top Corner	σm		
		σm + σb		
	Slap down (30°)	σm		
		σm + σb		

Note 1) Sy (yield stress) in the lid tightening bolts is MPa (°C).

b. Basket

Using the dynamic analysis code LS-DYNA, this section determines the strain in the basket components during a horizontal drop in which all the load of the contents is imposed in order to demonstrate that the basket maintains its required structural integrity.

(a) Analysis model

- The same analysis model as the one used for free drop evaluation in A.5.3 is applied.

(b) Load and boundary conditions

An impact velocity (13.6 m/sec. for the drop height of 9.3 m) of the 9 m drop is given to the basket. The lateral section of the shell part of the packaging body supporting the basket is given the velocity history of the center of the shell part (shown in Figure II-A.60) that has been derived from the analysis of the packaging body subjected to a horizontal drop. The both end surfaces of the basket are assumed to be symmetrical as shown in A.5.3.

[redacted] the test is conducted for [redacted] drop directions [redacted] as shown in Figure II-A.37.

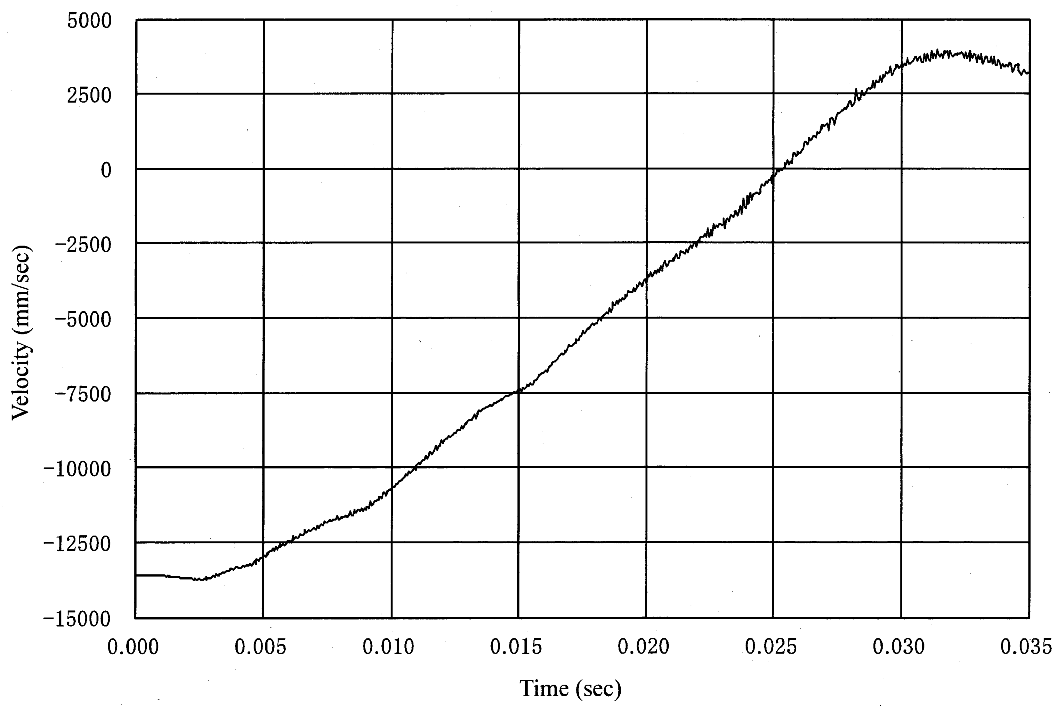


Figure II-A.60: Velocity history of packaging body (horizontal drop)

(c) Analysis results

The basket is damaged as follows after being subjected to a horizontal drop:

- [redacted] that support the contents and maintain their arrangement have no plastic strain. [redacted] have a plastic strain of maximum [redacted] %, but [redacted] No deformation that would have to be considered in the criticality analysis occurs.
- In the aluminum spacers around the basket, [redacted] have a plastic strain of maximum [redacted] % due to compression. However, [redacted] and no deformation that would have to be considered in the criticality analysis occurs.

Figures II-A.61 and II-A.62 show the plastic strain contour of the basket components for the drop direction in which the maximum plastic strain occurred.

The analysis results of the basket are summarized in Table II-A.22.

Figure II-A.61: Results of analysis of basket / 9 m horizontal drop (Plastic strain contour diagram) (Lodgment/[redacted] drop)

Figure II-A.62: Results of analysis of basket / 9 m horizontal drop (Plastic strain contour diagram)
(Aluminum spacer / drop)

Table II-A.22: Summary of analyses of basket subjected to 9 m drop test

Drop direction	Component	Maximum plastic strain (%)	Elongation (%)	Evaluation
	Lodgment			
	Aluminum spacer			
	Lodgment			
	Aluminum spacer			
	Lodgment			
	Aluminum spacer			

c. Fuel cladding

This section determines the maximum plastic strain in the fuel cladding in the same manner as for the evaluation method used in A.5.3 to demonstrate that the fuel cladding will not rupture.

In terms of drop direction, the analysis focuses on vertical and horizontal drops in which the fuel cladding bears maximum compressive load and maximum bending load.

The specifications of the fuel assemblies and the physical properties of the fuel cladding shown in Tables II-A-14 and II-A.15 are used for analysis.

(a) Analysis model

The same analysis model as the one used for the free drop evaluation in A.5.3 is applied.

(b) Load and boundary conditions

i. Vertical drop

An impact velocity (13.6 m/sec.) for a 9 m drop (from a height of 9.3 m) is given to the analysis model. The velocity history shown in Figure II-A.63 is given to the impact surface. The velocity history has been extracted from the bottom subjected to a bottom vertical drop test, which involves a higher impact than that for a top vertical drop.

The load and boundary conditions except the drop velocity and velocity history are shown in A.5.3.

ii. Horizontal drop

An impact velocity (13.6 m/sec.) for a 9 m drop (from a height of 9.3 m) is given to the analysis model. The velocity history shown in Figure II-A.64 is given to the impact surface. The velocity history has been extracted from the basket subjected to a horizontal drop.

The load and boundary conditions except the drop velocity and velocity history are shown in A.5.3.

(c) Analysis results

The analysis results of vertical and horizontal drop tests are shown in Table II-A.23.

For a vertical drop, maximum [redacted]% plastic strain occurs around the lowest part as shown in Figure II-A.65. For a horizontal drop, maximum [redacted]% plastic strain occurs in the both ends as shown in Figure II-A.66. These strains are quite smaller than the elongation of the fuel cladding. Therefore, the fuel cladding will not rupture at a 9 m drop.

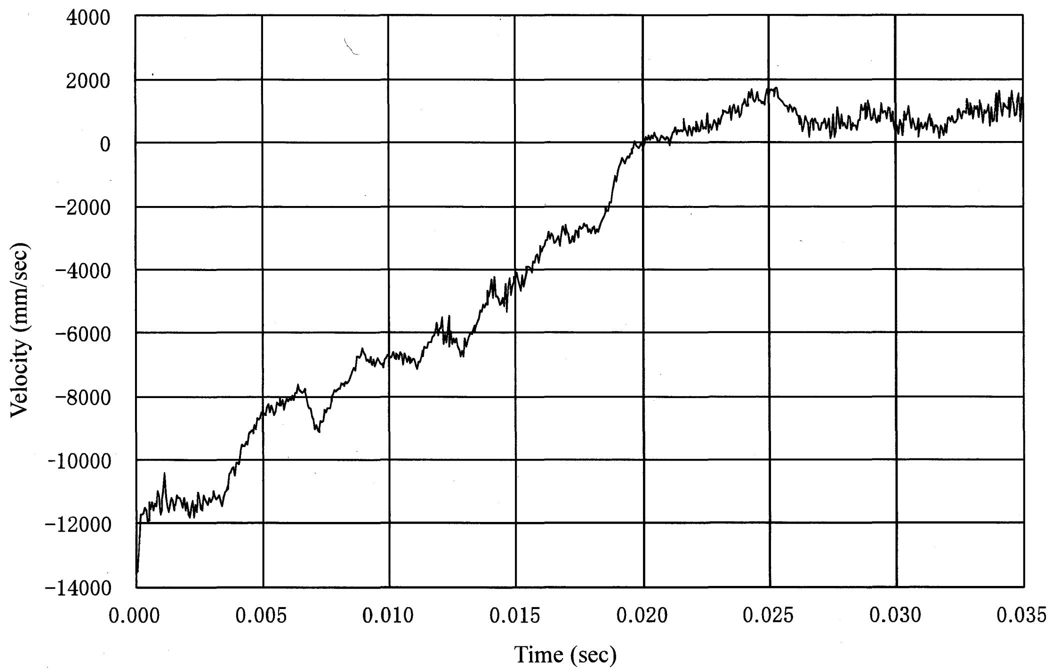


Figure II-A.63: Velocity history of packaging body (bottom vertical drop)

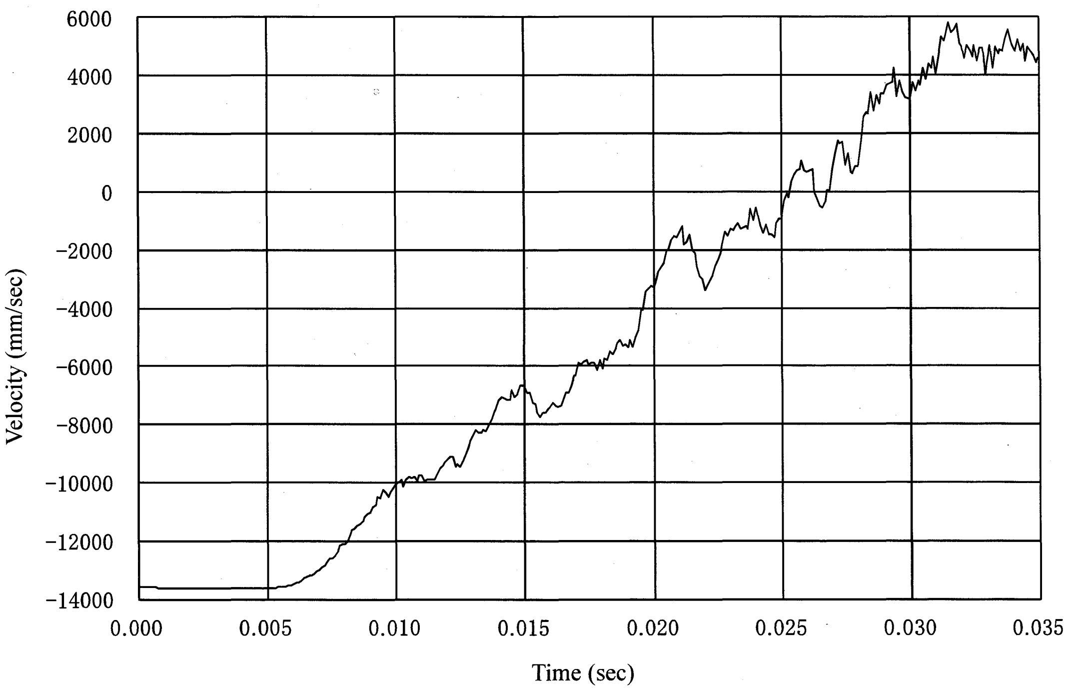


Figure II-A.64: Velocity history of basket (horizontal drop)

Table II-A.23: Summary of analyses of fuel cladding subjected to 9 m drop

Condition	Maximum plastic strain (%)	Elongation (%)
9 m vertical drop		
9 m horizontal drop		

Figure II-A.65: Results of analysis of fuel cladding / 9 m vertical drop (Plastic strain contour diagram)

Figure II-A.66: Results of analysis of fuel cladding / 9m horizontal drop (Plastic strain contour diagram)

(2) 1 m drop test

In this test, the packaging is dropped from a height of 1 m on to a mild steel bar of a diameter of 15 cm so that the package suffers maximum damage.

As mentioned above, a [redacted] model was subjected to a mock-up test to determine the behavior of the packaging during a drop. 1 m drop tests on to a mild steel bar were also conducted along with 9 m drop. In the mock-up test, a vertical drop making a direct hit with the lid parts, another vertical drop making a direct hit with the bottom, and a horizontal drop making a direct hit with the shell part were carried out. Any changes in the damaged condition of the directly hit parts and containment performance were measured. In all the cases, any damage that would affect the criticality analysis did not occur.

The following describes the evaluations based on the mock-up tests and analysis in the different drop directions:

a. Vertical drop making a direct hit with the lid parts

The test condition is shown in Photo II-A.1 and the state of the part directly hit after the drop is shown in Photo II-A.2.

The following was observed in the test:

- The lid cover is penetrated.
- The lid resin has a dent of up to [redacted] mm. The lid resin cover has semi-circular cracks.
- The lid is found to have no damage.
- The packaging body leakage rate measured after the following 9 m top vertical drop (helium leakage test) is below the level of leaktight (10^{-8} $Pa{\cdot}m^3{\cdot}s^{-1}$), proving that the containment performance is maintained.

These results imply the possible effect of the damage caused by the direct hit with the lid parts during the 1 m drop on the criticality analysis as follows:

- The top shock absorbing cover may be penetrated and the lid resin cover may have a dent of up to about [redacted] mm [redacted]. However, these are just local and do not have a significant effect on the thermal analysis under accident conditions of transport.
- The top shock absorbing cover and the lid resin are ignored in the criticality analysis assuming that the package has an infinite length in the longitudinal direction, therefore, the damage of lid part will not affect.

b. Vertical drop making a direct hit with the bottom

The test condition is shown in Photo II-A.3 and the state of the part directly hit after the drop is shown in Photo II-A.4.

The following was observed in the test:

- The rear shock absorbing cover is penetrated.
- The bottom resin has a dent of up to [redacted] mm. The bottom resin cover has no crack.

- The packaging body leakage rate measured after the drop (helium leakage test) is below the level of leaktight (10^{-8} Pa·m^3·s^{-1}), proving that the containment performance is maintained.

These results imply the possible effect of the damage caused by the direct hit with the bottom during the 1 m drop on the criticality analysis as follows:

- The rear shock absorbing cover may be penetrated and the bottom resin cover may have a dent of up to about [redacted] mm [redacted] However, these are just local and do not have a significant effect on the thermal analysis under accident conditions of transport.
- The rear shock absorbing cover and the bottom resin are ignored in the criticality analysis assuming that the package has an infinite length in the longitudinal direction, therefore, the damage of bottom part will not affect.

c. Horizontal drop making a direct hit with the shell part

For this direct hit with the shell part, a drop direction at an angle of [redacted] from the horizontal is used so that the external plates and stiffeners suffer maximum damage.

The test condition is shown in Photo II-A.5, and the state of the part directly hit after the drop is shown in Photo II-A.6.

The following was observed in the test:

- The external plates and stiffeners ruptured, and the shell part had a dent of a depth of up to [redacted] mm. This dent caused part of the inner shell to swell toward the inside.
- The packaging body leakage rate measured after the drop (helium leakage test) is below the specified leaktightness level (10^{-8} Pa·m^3·s^{-1}), proving that the containment is maintained.

These results imply the possible effect of the damage caused by the direct hit with the shell part during the 1 m drop on the criticality analysis as follows:

- Damage in the stiffeners, which serve as a thermal conductor, is limited to the part directly hit by the drop. Although the shell part resin may be exposed through the cracks in the external plates, it is self-extinguishable. Therefore, the possible damage in the shell part does not have a significant effect on the thermal analysis under accident conditions of transport.
- The shell part resin and stiffeners are ignored in the criticality analysis, therefore, the damage in these components of the shell part will not affect. The deformation of the inner shell is only limited and will not affect the analysis conditions of the criticality analysis.

Photo II-A.1: Vertical drop making a direct hit with lid parts (before test)

Photo II-A.2: Vertical drop making a direct hit with lid parts (after test)

Photo II-A.3: Vertical drop making a direct hit with bottom (before test)

Photo II-A.4: Vertical drop making a direct hit with bottom (after test)

Photo II-A.5: Horizontal drop making a direct hit with shell part (before test)

Photo II-A.6: Horizontal drop making a direct hit with shell part (after test)

As described above, the shell part has a dent in the part directly hit by the drop and the deformation may even affect the inner shell. The deformed inner shell may further deform part of the basket. Then, the deformation of the basket during the 1 m drop test involving a direct hit with the shell part is evaluated using an analysis approach as follows.

(a) Analysis model

The part of the inner shell that was deformed by the ruptured external plates and stiffeners due to the direct hit by the mild steel bar is modeled on a full-scale basis by applying the analysis model verified with the simulated drop test using the [redacted] model. (See Appendix-3)

The part that is not directly hit by the mild steel bar consists of a shell part made up by an inner shell, stiffeners, external plates and shell part resin, and lid parts and bottom part with a simple geometry. Each of these regions is given an equivalent density so that the model mass is equal to the design weight.

In terms of the basket, the analysis model that was used for the basket drop test analysis is applied to the region that includes [redacted] with its central one being the one expected to be deformed by the direct hit by the mild steel bar. The both end sections longitudinally outside this target region are represented by a simple cylinder each with a equivalent density.

The mesh model of the analysis model is shown in Figure II-A.67.

(b) Load and boundary conditions

The whole model is given an impact velocity for the 1 m drop (4.43 m/sec). The mild steel bar modeled as a rigid body is restrained by displacement constraints in all directions.

(c) Analysis results

Among the drop directions for the basket, the [redacted] shown in Figure II-A.68 [redacted] were analyzed. As a result, the following observation was obtained. The maximum deformation in each case is shown in Figure II-A.69.

The damaged condition of the basket in these cases is as follows.

i. [redacted]

- [redacted] has a plastic strain of maximum [redacted]% locally [redacted]. However, the plastic strain [redacted] is lower than [redacted]%, therefore, the deformation of [redacted] is only limited to the vicinity of the directly hit part (see Figure II-A.70).
- [redacted] have a local plastic strain of maximum [redacted]%, which is [redacted]. Therefore, [redacted] will not rupture (see Figure II-A.71).

Figure II-A.67: Mesh model (1 m drop of actual packaging model)

Figure II-A.68: Drop directions of basket

Figure II-A.69: Deformation of basket (maximum deformation)

Figure II-A-70: Plastic strain in (direction)

Figure II-A.71: Plastic strain in lodgments (direction)

- There is a clearance between the lodgments and the contents. Therefore, the fuel assemblies will not be damaged by any deformed [redacted]

ii. [redacted]

- [redacted] has a plastic strain of maximum [redacted] % locally in [redacted] the plastic strain [redacted] is maximum [redacted] %, therefore, the deformation of [redacted] is only limited to the vicinity of the directly hit part (see Figure II-A.72).
- [redacted] have a local plastic strain of maximum [redacted] %, which is [redacted]. Therefore, [redacted] will not rupture (see Figure II-A.73).
- There is a clearance between the lodgments and the contents. Therefore, the fuel assemblies will not be damaged by any deformed [redacted].

iii. [redacted]

- [redacted] has a plastic strain of maximum [redacted] % locally [redacted]. The plastic strain [redacted] maximum [redacted] % and [redacted] as well [redacted] (see Figure II-A-74).
- The lodgments have no plastic strain. Therefore, the fuel assemblies will not be damaged.

Figure II-A-72: Plastic strain in (direction)

Figure II-A-73: Plastic strain in lodgments (direction)

Figure II-A.74: Plastic strain in [redacted] ([redacted] direction)

Thus, the basket is deformed in the vicinity of the directly hit part during the 1 m drop test involving a direct hit with the shell part, but the deformation will not damage the fuel assemblies, therefore, the analysis conditions of the criticality analysis will not be affected..

(3) Thermal evaluation (thermal test)

a. Packaging body

Damaged conditions that would affect the analysis conditions of the criticality analysis for the packaging body subjected to a thermal test are evaluated as follows:

The maximum temperature of the components 30 minutes after the occurrence of a fire accident is shown in Table II-A.24.

The maximum internal pressure of the package under accident conditions of transport is MPa absolute. Therefore, the internal-external pressure difference is assumed to be MPa for the test evaluation.

Table II-A.24: Maximum temperature of components 30 minutes after fire accident

(Unit: °C)

Packaging body component	Thermal analysis results
External plate	
Stiffener	
Inner shell	
Top flange	
Bottom	
Lid	
Lid tightening bolt	

The thermal test created a big difference in temperature between the outer and inner surfaces of the shell part as shown in Table II-A.24. The thermal expansion of the external plates and stiffeners on the outer surface may lead to deformation of the inner shell which is the inner surface of the shell part.

The form of the inner shell is one of the analysis conditions of the criticality analysis. To conservatively evaluate the inner shell deformation, the external plates and stiffeners are assumed to be an elastic solid while the inner shell, top flange, bottom and lid are assumed to be elastic-perfectly plastic solid. Then, the deformation behavior of the inner shell is evaluated by the elastic-plastic analysis using the ABAQUS analysis code.

(a) Analysis model

In the same manner as for A.5.1, a 3-dimensional model of the packaging is used for analysis.

This model consists of the body (top flange, inner shell, stiffeners, external plates and bottom) and the lid parts (lid and lid tightening bolts). The lid is connected to the top flange with lid tightening bolts. Contact between the lid and the top flange is taken into account.

(b) Load and boundary conditions

i. Load condition

The inner surface of the packaging is applied with an internal-external pressure difference ([redacted]MPa). The lid tightening bolts are applied with an axial force due to the initial tightening torque. Furthermore, they are given the temperature distribution 30 minutes after the fire accident in which the packaging body has a maximum temperature difference.

ii. Boundary condition

The center of the bottom is restrained by displacement constraints in axial direction. The central axis is restrained by displacement constraints in radial direction. The symmetrical surfaces are restrained by displacement constraints in circumferential direction.

(c) Analysis results

The deformation diagram is shown in Figure II-A.75, and the plastic strain contour of the inner shell is shown in Figure II-A.76.

The maximum plastic strain in [redacted] is not greater than [redacted]%, which is [redacted]. Therefore, [redacted] will not rupture.

On the other hand, due to difference of thermal expansion between the external plates and stiffeners and the inner shell, the central part of the inner shell swells to have a larger internal radius by maximum [redacted]mm as shown in Figure II-A.75.

The results of evaluation of the components except the external plates and stiffeners that were assumed to be an elastic solid are summarized in Table II-A.25.

Figure II-A.75: Results of analysis of thermal test under accident conditions of transport
(Deformation diagram)

Figure II-A.76: Results of analysis of thermal test under accident conditions of transport
(Plastic strain contour of inner shell)

Table II-A.25: Summary of results of analyses of packaging body subjected to thermal test under accident conditions of transport (1/2)

Packaging body component	Maximum plastic strain (%)	Elongation (%)	Evaluation
Inner shell			
Top flange			
Lid			
Bottom			

Table II-A.25: Summary of results of analyses of packaging body subjected to thermal test under accident conditions of transport (2/2)

Component	Type of stress	Stress (MPa)	Evaluation
Lid tightening bolt	σm		The stress is below Sy[1)] and will not cause rupture.
	$\sigma m + \sigma b$		

Note 1) The lid tightening bolts have Sy (yield stress) of ☐ MPa (☐°C).

b. Basket

As described in II-B.5, the maximum temperature of the basket subjected to a thermal test is not higher than [redacted] °C, which does not exceed the upper limit of the material service temperature range [1)]. The temperature difference within the basket is small and no significant thermal stress will occur.

This section evaluates the possible effect of the thermal expansion difference between the basket and the packaging body on the basket.

(a) Axial direction

The axial clearance is reduced by any thermal expansion difference between the basket and the shell part of the packaging body.

From the results of thermal analysis with a slice model, the temperatures are identified at the time when the temperature difference between the basket and the shell part is maximum. Then, the axial clearance between the basket and the inner surface of the packaging body ΔL can be determined using the following equation. Note that the maximum temperature of [redacted] is used as the basket temperature and the minimum temperature of the external plates is used as the shell part temperature.

According to the results of thermal analysis, the temperature difference between the maximum temperature of [redacted] and the minimum temperature of the external plates becomes maximum 12 hours after the fire accident. The temperatures are [redacted] °C and [redacted] °C respectively.

$$\Delta L = (L_1 - L_2) + \{ L_1 \times (T_1 - 20) \times \alpha_1 - L_2 \times (T_2 - 20) \times \alpha_2 \}$$

where、 L_1 : Cavity length of packaging body [[redacted] mm]

L_2 : Overall length of basket [[redacted] mm]

T_1 : Temperature of shell part [[redacted] °C]

T_2 : Temperature of basket [[redacted] °C]

α_1 : Coefficient of linear thermal expansion of shell part [[redacted] /°C ([redacted] °C)]

α_2 : Coefficient of linear thermal expansion of basket [[redacted] /°C ([redacted] °C)]

Therefore, ΔL = [redacted] mm

This means that there is a clearance between the basket and the inner surface of the packaging body and that no thermal stress will occur due to constraints.

(b) Radial direction

The radial clearance is reduced by any thermal expansion difference between the basket and the shell part of the packaging body.

Like the evaluation for the axial direction, the radial clearance between the basket and the inner surface of the packaging body ΔD can be determined using the equation below:

$$\Delta D = (D_1 - D_2) + \{ D_1 \times (T_1 - 20) \times \alpha_1 - D_2 \times (T_2 - 20) \times \alpha_2 \}$$

Note 1) ASME Sec. II, Part D [1] provides the physical properties of aluminum alloy, which is used in [redacted], for temperatures of up to 200 °C. The relevant temperature is within the service temperature range.

where, D_1 : Minimum value for inner diameter of packaging body [[redacted] mm]
(Minimum value with tolerance taken into account)

D_2 : Maximum value for external diameter of basket [[redacted] mm]
(Maximum value with tolerance taken into account)

T_1 : Temperature of shell part [[redacted] °C]

T_2 : Temperature of basket [[redacted] °C]

α_1 : Coefficient of linear thermal expansion of shell part
[[redacted] /°C ([redacted] °C)]

α_2 : Coefficient of linear thermal expansion of basket
[[redacted] /°C ([redacted] °C)]

Therefore, ΔD = [redacted] mm

This means that expansion of the basket in radial direction may cause the outer surface of the basket to temporarily come into contact with the inner surface of the shell part. In this case, the aluminum spacers located on the perimeter of the basket may be applied with a compression force by the shell part. This compression by the shell part can be absorbed by the aluminum spacers having a hollow structure with a sufficient deformation allowance. Therefore, [redacted], which are one of the structural parts of the basket, will not be deformed

In conclusion, the deformation of the basket subjected to the thermal test to accident conditions of transport is negligible and will not affect the analysis conditions of the criticality analysis.

c. Fuel cladding

This section evaluates the effect of the internal pressure change due to a temperature increase during thermal test on the fuel cladding.

As described in II-B.5, the maximum temperature of the basket subjected to a thermal test is not higher than [redacted] °C. Then, the temperature of the fuel cladding is conservatively assumed to be [redacted] °C.

The internal pressure (gauge pressure) of the fuel cladding Pi during the thermal test is as follows:

$$Pi = Po \times \frac{T}{To} - 0.101$$

where, Po : Filling pressure of internal gas (20 °C) [[redacted] MPa absolute]

To : Initial temperature of internal gas [293 K (20 °C + 273 °C)]

T : Maximum temperature of fuel cladding [[redacted] K ([redacted] °C + 273 °C)]

Therefore,

$$Pi = \text{[redacted]} \times \frac{\text{[redacted]}}{293} - 0.101 = \text{[redacted]} \text{ MPa}$$

The stress in the fuel cladding caused by the internal pressure Pi can be determined using the equation for cylinders under an internal pressure:

(Circumferential stress) $\sigma_\theta = Pi \times \frac{b^2 + a^2}{b^2 - a^2}$

(Longitudinal stress) $\sigma_Z = Pi \times \frac{a^2}{b^2 - a^2}$

(Radial stress) $\sigma_r = - Pi$

where, b : External radius of fuel cladding (mm)

a : Internal radius of fuel cladding (mm)

From the external diameter (□mm) and internal diameter (□mm) of the fuel cladding shown in Table II-A-14,

b =□mm

a =□mm

The maximum stress intensity S of the fuel cladding can be determined as follows:

$S = Max \{ |\sigma_\theta - \sigma_Z| , |\sigma_Z - \sigma_r| , |\sigma_\theta - \sigma_r| \}$

Namely, S =□MPa

This is sufficiently smaller than the tensile strength (□MPa) of the fuel cladding at □°C. In conclusion, the fuel cladding will not rupture with any internal pressure change due to a temperature increase during a thermal test.

(4) 0.9 m water immersion test

This test, which is intended to evaluate the possibility of the ingress of water into the package, is excluded because ingress of water immersion into the package is considered by the criticality analysis.

From these results, the damaged condition of the package under accident conditions of transport can be summarized in Table II-A.26.

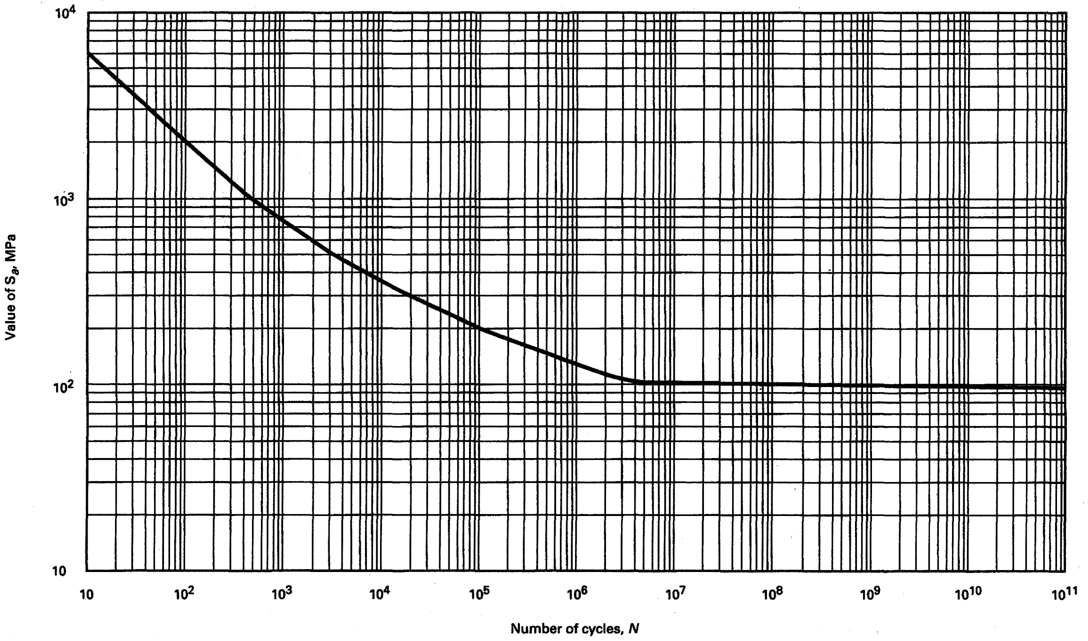
Table II-A.26: Damaged condition of package under accident conditions of transport for packages containing fissile material

Condition	Damaged condition of package	Remarks
9 m drop	- The shock absorbing covers are deformed. - The packaging body and basket have a plastic strain but no deformation that would have to be considered in the criticality analysis occurs. - The fuel cladding is deformed but will not rupture.	- The shock absorbing covers are ignored in the criticality analysis. - Deformation of the fuel cladding is considered in the criticality analysis.
1 m drop	- The shock absorbing covers, lid parts, bottom parts and shell part are damaged in their directly hit parts. - For a horizontal drop involving a direct hit with the shell part, [redacted] is damaged [redacted] have a plastic strain but will not rupture.	- The shock absorbing covers, lid parts and bottom parts are ignored in the criticality analysis. - The external plates, shell part resin and stiffeners are ignored in the criticality analysis, therefore, the damage of these shell part components will not affect. - Deformation of the inner shell and basket is just local and does not have a significant effect on the analysis conditions of the criticality analysis.
Thermal test	- The packaging body has a plastic strain and the inner shell has a larger internal radius by maximum [redacted] mm, and they will not rupture.	- Deformation of the inner shell is considered in the criticality analysis.
0.9 m water immersion	-	- Water immersion is assumed in the criticality analysis.

A.10 Appendix

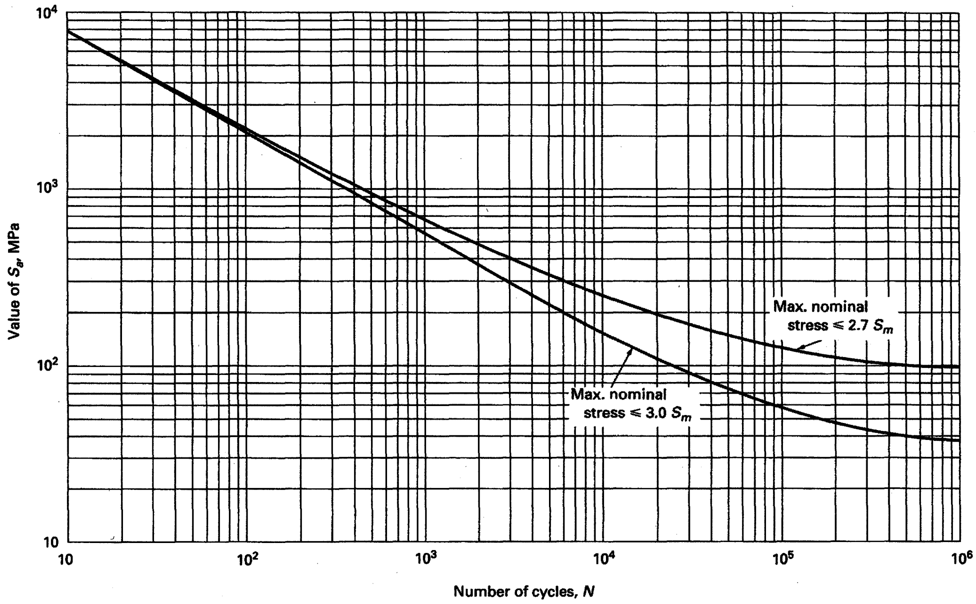
A.10.1 Appendix-1 Design fatigue strength curves

Figure I-9.2M
Design Fatigue Curves for Austenitic Steels, Nickel–Chromium–Iron Alloy, Nickel–Iron–Chromium Alloy, and Nickel–Copper Alloy for Temperatures Not Exceeding 425°C



GENERAL NOTES:
(a) $E = 195 \times 10^3$ MPa
(b) Table I-9.2 contains tabulated values and an equation for an accurate interpolation of this curve.

Figure I-9.4M
Design Fatigue Curves for High Strength Steel Bolting for Temperatures Not Exceeding 370°C



GENERAL NOTES:
(a) E = 207 × 10^3 MPa
(b) Table I-9.0M contains tabulated values and an equation for an accurate interpolation of these curves.

Figure II-A Appendix 1.2: Design fatigue curve (high tension bolts)[12]

A.10.2 Appendix-2 [redacted] model drop test verification analysis

(1) Summary

An analysis is conducted according to the same conditions as those for the drop test using the [redacted] model, in order to verify that the behavior observed in the drop tests can be simulated by analyses.

The acceleration and deformation measurements obtained in the drop tests are compared with the analysis results using an analysis model (drop test verification model) based on the [redacted] model in order to evaluate the adequacy of the analysis with the relevant analysis model.

(2) Summary of drop tests

a. [redacted] model

The appearance of the [redacted] model (specimen) is shown in Photo II-A. Appendix 2.1.

The [redacted] model was fabricated into a [redacted] of the actual packaging. However, the design at that time when the tests were conducted is different from the current design in thickness of the shell part resin and the external diameter of the body is slightly smaller.

The shock absorbing covers that would be deformed when they are dropped on to the ground have a geometry/construction faithfully [redacted] of the actual packaging.

[redacted].

Tests were conducted at room temperature. The components of the body and lid parts used materials of a strength equivalent to that of the materials used in the actual packaging at the temperature during transport. On the other hand, the shock absorbing covers used the same stainless steel and the shock absorbers used the same material as those used in the actual packaging. Since the actual packaging finally used another resin material, a [redacted] model of the shell part was then used to carry out a drop test to verify the applicability of the 1m drop test to the shell part that is always affected by the resin characteristics (Appendix-3).

Although a basket designed to be delivered to Europe was installed, the basket configuration is basically same as that of this packaging (i.e., a combination of [redacted] and lodgments).

A comparison of specifications between the actual packaging and the [redacted] model is shown in Table II-A. Appendix 2.1.

Photo II-A Appendix 2.1: Appearance of model

Table II-A Appendix 2.1: Comparison of specifications between actual packaging and [redacted] model (1/3)

Component	Mass (kg)	
	Actual packaging	[redacted] model
Whole package	19500 (Max.)	[redacted]

Table II-A Appendix 2.1: Comparison of specifications between actual packaging and [redacted] model (2/3)

Component	Major materials	
	Actual packaging	[redacted] model
Body		
Inner shell, stiffener, external plate, top flange, bottom	[redacted]	Carbon steel [1)]
Resin	[redacted] resin	[redacted] resin [2)]
Lid parts		
Lid	[redacted]	[redacted]
Gasket	EPDM	EPDM
Shock absorbing cover		
Shock absorber	[redacted] wood	[redacted] wood
Shock absorbing cover outer plate, [redacted]	[redacted]	[redacted]

Note 1) Material of a strength equivalent to a projected lower strength due to a higher temperature was selected.

2) The actual packaging finally used another resin material.

Table II-A Appendix 2.1: Comparison of specifications between actual packaging and model (3/3)

Component	Major dimensions (mm)	
	Actual packaging	model
Body		
Overall length	5,189	
Cavity length		
Inner shell, inner diameter	1,072	
Inner shell, thickness		
Stiffener, thickness		
External plate, thickness		
Shell part resin, thickness		
Bottom, thickness		
Bottom, external diameter		
Bottom resin, thickness		
Bottom resin cover, thickness		
Lid parts		
Lid, external diameter		
Lid, thickness		
Lid resin, thickness		
Lid resin cover, thickness		
Top shock absorbing cover		
External diameter	2,125	
Inner diameter (outside)		
Inner diameter (inside)		
Thickness	826	
Shock absorber, thickness (outside)		
Shock absorber, thickness (inside)		
Outer plate/, thickness		
Rear shock absorbing cover		
External diameter	2,125	
Inner diameter (outside)		
Inner diameter (inside)		
Thickness	736	
Shock absorber, thickness (outside)		
Shock absorber, thickness (inside)		
Outer plate/, thickness		

b. Test results

Nine cases of drop tests were conducted including 0.3 m, 9 m and 1 m drops. Table II-A. Appendix 2.2 shows the maximum acceleration measurements and the deformation of the shock absorbing covers for the drop cases.

Among these cases, the following four cases were subjected to verification analysis:

- 0.32 m horizontal drop
- 9.51 m top vertical drop
- 9.51 m top corner drop
- 9.51 m slap down drop (25°)

For these four target cases, deformation of the shock absorbing covers is shown in Photo II-A. Appendix 2.2 to Photo II-A. Appendix 2.5.

Table II-A Appendix 2.2: Summary of drop test results

Case	Drop direction	Drop height (m)	Maximum acceleration 1) (G)	Shock absorbing cover Maximum deformation (mm)
[1]	Horizontal	0.32		
[2]	Slap down	9.51		
[3]	Top vertical (Drop on to a bar)	1.17		
[4]	Top vertical	9.51		
[5]	Top corner	9.51		
[6]	Bottom corner (Drop on to a bar)	1.27		
[7]	Bottom corner	9.51		
[8]	Horizontal (Drop on to a bar)	1.06		
[9]	Bottom vertical (Drop on to a bar)	1.11		

Note 1) The filter has a cut-off frequency of Hz.

2) The higher acceleration occurs due to the effect of the orifice and its protection cover installed in the bottom. (These components are designed to be delivered to Europe and are not included in this packaging).

Photo II-A. Appendix 2.2: Deformation after 0.32 m horizontal drop

Photo II-A. Appendix 2.3: Deformation after 9.51 m top vertical drop

Photo II-A. Appendix 2.4: Deformation after 9.51 m top corner drop

Photo II-A. Appendix 2.5: Deformation after 9.51 m slap down drop

(3) Drop test verification analysis

a. Configuration of drop test verification model

The drop test verification model consists of the shock absorbing covers, packaging body and basket.

Since the impact after a drop of this packaging is taken by the shock absorbing covers, all the components except the shock absorbing covers that show a deformation behavior do not require advanced modeling. Therefore, the body and lid parts are geometrically simplified while their outside dimensions are maintained and assuming that the lid is integrated in the body by ignoring the lid tightening bolts. The basket is also geometrically simplified and given an equivalent density to allow consideration of the mass.

b. Analysis procedure

The analysis uses the dynamic analysis code LS-DYNA.

From the results of an analysis according to drop test conditions (drop direction and height), the deformation and acceleration of the shock absorbing covers are determined and compared with measurement data obtained in the drop tests for evaluation.

c. Analysis conditions

(a) Dimensions of analysis model

The dimensions of the analysis model are shown in Figure II-A. Appendix 2.1.

(b) Analysis model diagram

The mesh model of the analysis model is shown in Figure II-A. Appendix 2.2.

(c) Material properties of shock absorbing covers

The physical properties to be given to the stainless steel and shock absorbers that consist of the shock absorbing covers were established by referring to the constitutive equation proposed in JAERI-M88-191.

The stress-strain relationship given to the stainless steel used as material of the outer plate of shock absorbing covers and [redacted] is shown in Figure II-A. Appendix 2.3. The stress-strain relationship given to the [redacted] wood used as shock absorbers is shown in Figure II-A. Appendix 2.4.

(Unit: mm)

Figure II-A Appendix 2.1: Dimensional drawing of drop test verification model

Figure II-A Appendix 2.2: Mesh model

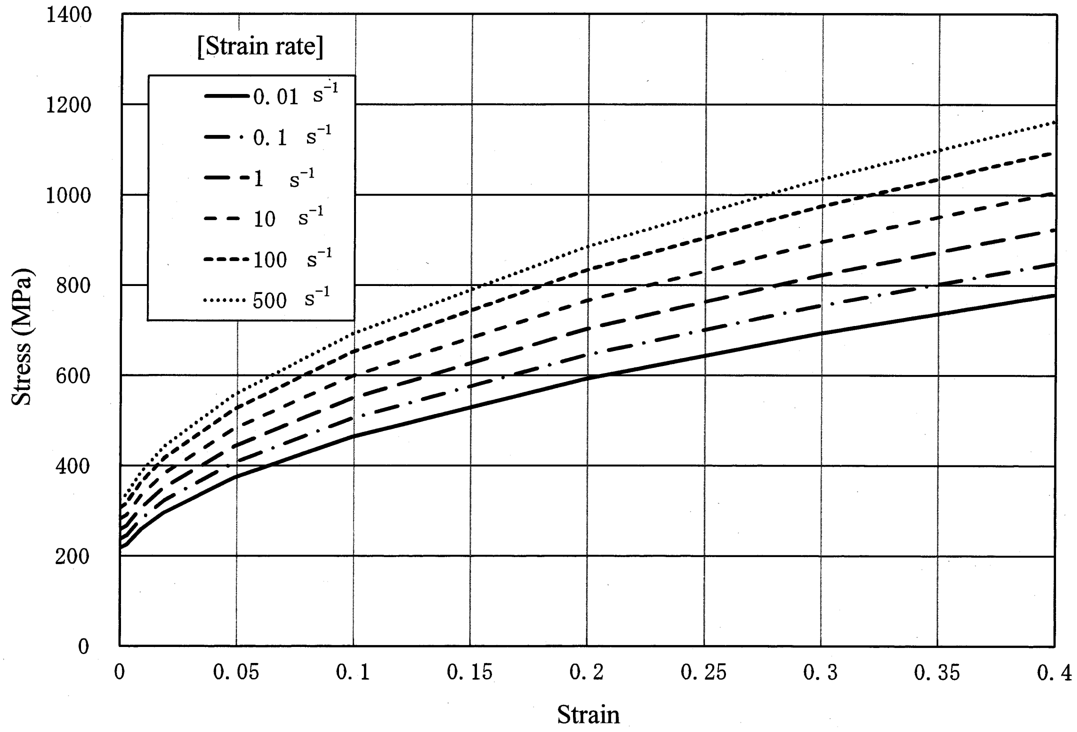


Figure II-A Appendix 2.3: Stress-strain relationship given to physical properties of stainless steel

Figure II-A Appendix 2.4: Stress-strain relationship given to physical properties of wood

d. Analysis results

(a) Comparison of deformation

A comparison of deformation of the shock absorbing covers between the [redacted] model and the drop test verification model is shown in Table II-A. Appendix 2.3.

For all the drop directions, the deformation of the shock absorbing covers for the drop test verification model is in good agreement with the test results.

(b) Comparison of acceleration

For each drop direction, the acceleration measured with the [redacted] model is compared with the acceleration obtained with the drop test verification model. The comparison is shown in Figure II-A. Appendix 2.5.

The acceleration data obtained with the drop test verification model has been determined by applying the same processing as the Butterworth (8th) filtering used for the drop test measurement to the acceleration data at the nodal points close to the measuring points for the [redacted] model.

The 0.32 m horizontal drop diagram indicates good similarity of the waveform and amplitude. In the other drop diagrams, the waveform and the impact occurrence time show a similar trend although the amplitude is somewhat different from each other.

(4) Validation of drop test verification model

According to the comparison between the [redacted] model and the drop test verification model stated in the previous section, these two models generally show quite similar deformation and acceleration. It can be concluded that the analysis using the drop test verification model is appropriate.

Table II-A Appendix 2.3: Comparison of deformation (1/4)

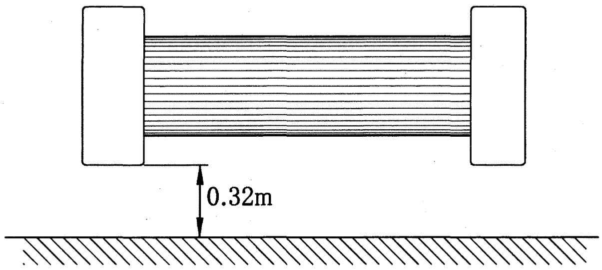
	0.32 m Horizontal drop
Drop direction	
Drop test	
Analysis results	

Table II-A Appendix 2.3: Comparison of deformation (2/4)

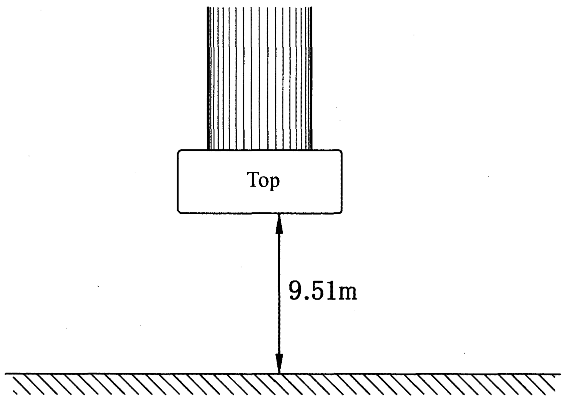
	9.51 m Top vertical drop
Drop direction	
Drop test	
Analysis results	

Table II-A Appendix 2.3: Comparison of deformation (3/4)

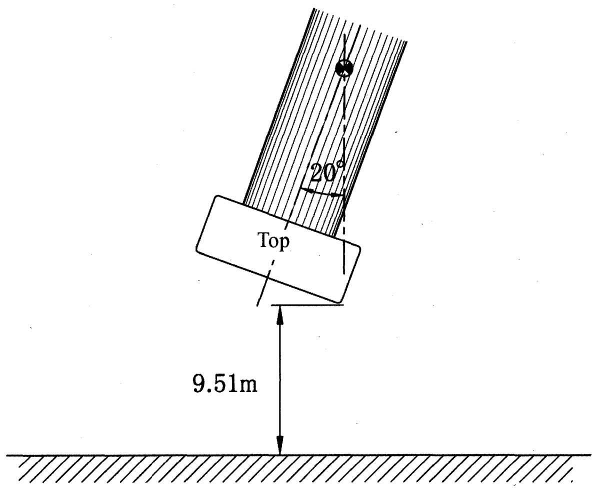
	9.51 m Top corner drop
Drop direction	
Drop test	
Analysis results	

Table II-A Appendix 2.3: Comparison of deformation (4/4)

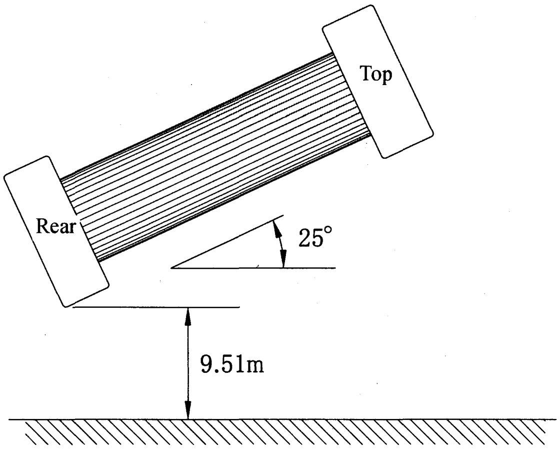
	9.51 m Slap down drop
Drop direction	
Drop test	
Analysis results	

Figure II-A Appendix 2.5: Comparison of acceleration (1/2)

Figure II-A Appendix 2.5: Comparison of acceleration (2/2)

A.10.3 Appendix-3 [redacted] model drop test verification analysis

(1) Summary

As mentioned above, the [redacted] model for the drop tests used [redacted] resin as material of the shell part resin, but it was changed to newly-developed [redacted] resin during the design phase of this packaging.

Among the 1 m drop tests, the one making a direct hit with the shell part causes the external plates and stiffeners to rupture and the inner shell to swell toward inside when the packaging is dropped in a position for maximum damage. The damaged condition of the shell part is affected by the resin characteristics. Therefore, in order to evaluate the damaged condition of the shell part using the aforementioned [redacted] resin and verify that the material change will not affect the safety performance of the packaging, a [redacted] model was subjected to drop tests.

Deformation of the inner shell may deform the basket, affecting the form of the lodgments that contain the fuel.

Then, in order to verify the analysis model applied to the deformed part of the inner shell for the 1 m drop test analysis of the actual packaging, an analysis simulating a drop test using the [redacted] model is conducted. The deformation is compared between the analysis results and the test results to evaluate the adequacy of the analysis model.

(2) Summary of drop tests

a. [redacted] model

The appearance of the [redacted] model as a specimen is shown in Photo II-A. Appendix 3.1. The [redacted] model is a specimen cut from the shell part into a piece of an arc of [redacted] and a length of [redacted] mm. It is fabricated using the same material in the same manufacturing method as that of the actual packaging, but to dimensions [redacted] of the actual.

Table II-A. Appendix 3.1 shows the specifications of the actual packaging and [redacted] model.

b. Test method

In the drop tests, the [redacted] model is inclined at [redacted] and fixed to a test jig. A carbon steel round bar of a diameter of [redacted] mm installed with a weight equivalent to [redacted] of the package mass of the actual packaging is dropped from a height of 1 m.

[redacted].

The resin has a lower strength at an increased temperature. The [redacted] model must simulate the temperature condition during transport. Then, the model was heated and maintained at temperature around [redacted] °C prior to a drop test. (This temperature level is conservative against the temperature of normal conditions of transport of [redacted] °C). Photo II-A. Appendix 3.2 shows how the drop test was conducted.

[redacted]

Photo II-A. Appendix 3.1: Appearance of [redacted] model

Table II-A Appendix 3.1: Specifications of actual packaging and [redacted] model

Component	Major dimensions (mm)	
	Actual packaging	[redacted] model
Inner shell, thickness	[redacted]	[redacted]
Stiffener, thickness		
External plate, thickness		
Inner shell, inner diameter	φ1,072	

Photo II-A. Appendix 3.2: Drop test

c. Test results

As with the 1 m drop test of the [redacted] model, the external plates and stiffeners ruptured and the inner shell was deformed to swell toward inside. This deformed inner shell was subjected to a liquid penetrant examination. It was confirmed in the examination that the inner shell had no crack or damage that would affect the leaktightness.

The damaged condition of the [redacted] model is shown in Photo II-A. Appendix 3.3.

Photo II-A. Appendix 3.3: Test results (damaged condition)

(3) Verification analysis

a. Configuration of analysis model

The analysis model consists of a [redacted] model and a mild steel bar.

The [redacted] model consists of a stainless steel plate and resin. The external plates, stiffeners and resin that will rupture when they are directly hit by the mild steel bar are given a condition with which they should rupture.

The mild steel bar is given a mass equivalent to the total mass of the weight and round bar that were used in the test.

b. Analysis procedure

The dynamic analysis code LS-DYNA is used for analysis.

An analysis model simulating the [redacted] model is given the analysis conditions including the rupture observed in the test. Then, the deformation of the inner shell is compared with the test results for evaluation.

c. Analysis conditions

(a) Dimensions of analysis model

The dimensions of the analysis model are shown in Figure II-A. Appendix 3.1.

(b) Analysis model diagram

The mesh model of the analysis model is shown in Figure II-A. Appendix 3.2.

d. Analysis results

(a) Comparison of deformation

Table II-A. Appendix 3.2 compares the deformation of the outer and inner surfaces of the [redacted] model with that of the drop test results and also compares the deformation dimensions of the inner shell.

As shown in the comparison table, the deformation of the model is in good agreement with the test results and the deformation dimensions of the inner shell are also very similar.

(4) Validation of analysis model

As stated in the previous section, the deformation of the inner shell of the analysis model successfully simulates the test results. Thus it has been verified that the analysis model for deformation of the inner shell is appropriate to be used for the 1 m drop test involving a direct hit with the shell part of the actual packaging.

Figure II-A Appendix 3.1: Dimensional drawing of model for drop test analysis

Figure II-A Appendix 3.2: Mesh model

Table II-A Appendix 3.2: Comparison of deformation (1/3)

	Deformation of outer surface of model
Drop test	
Analysis model	

Table II-A Appendix 3.2: Comparison of deformation (2/3)

	Deformation of inner surface of [ ] model
Drop test	
Analysis model	

Table II-A Appendix 3.2: Comparison of deformation (3/3)

	Deformation dimensions of inner shell
Drop test	
Analysis model	

A.10.4 Appendix-4 Strength of packaging body subjected to 15 m water immersion test

This section determines the stress of the packaging components when they are applied with an external pressure equivalent to a water depth of 15 m and then evaluates deformation that would affect the criticality analysis.

The stresses in the components of the packaging body due to the external pressure is determined using the analysis code ABAQUS.

(1) Analysis model

As with A.5.1, a □ 3 dimensional model of the packaging body is used. This model consists of the body (top flange, inner shell, stiffeners, external plates and bottom) and the lid parts (lid and lid tightening bolts). The lid is connected to the top flange with lid tightening bolts. Contact between the lid and the top flange is taken into account.

(2) Load and boundary conditions

For the load condition, a pressure (0.15 MPa) equivalent to a water depth of 15 m is applied to the outer surface of the packaging and an axial force due to the initial tightening torque is applied to the lid tightening bolts.

For the boundary condition, the center of the bottom is bound to prevent axial displacement, the central axis is bound to prevent radial displacement, and the symmetrical surfaces are bound to prevent circumferential displacement.

(3) Analysis results

The deformation diagram is shown in Figure II-A. Appendix 4.1 and the distributed stress diagram shown in Figure II-A. Appendix 4.2.

Table II-A. Appendix 4.1 shows the results of evaluation of the stresses in the major evaluation target positions shown in Figure II-A. Appendix 4.3. As shown in the table, all the stresses in the components of the packaging body are below the yield stress, which means that no significant deformation will occur.

Figure II-A Appendix 4.1: Analysis results of 15 m water immersion test
(Deformation diagram)

Figure II-A Appendix 4.2: Analysis results of 15 m water immersion test
(Stress contour diagram <Tresca stress intensity>) (1/2)

Figure II-A Appendix 4.2: Analysis results of 15 m water immersion test
(Stress contour diagram < Tresca stress intensity>) (2/2)

Figure II-A Appendix 4.3: Target positions of stress evaluation for 15 m water immersion test

Table II-A Appendix 4.1: Stresses in packaging body components during 15 m immersion test

Target position		Stress classification [1]	Stress intensity (MPa)	Yield stress (MPa)
Lid	①	Pm		
		PL + Pb		
	②	PL		
External plate	③	PL		
	④	Pm		
	⑤	PL		
Inner shell	⑥	PL		
	⑦	Pm		
	⑧	PL		
Stiffener	⑨	PL		
	⑩	PL		
	⑪	PL		
Bottom	⑫	PL		
	⑬	Pm		
		PL + Pb		
Lid tightening bolt		σm		
		σm + σb		

Note 1) Pm: General primary membrane stress intensity

PL: Local primary membrane stress intensity Pb: Primary bending stress

σm: Average tensile stress σb: Bending stress

A.10.5 Appendix-5 Strength of rear trunnions under horizontal lifting operation

In this section, the stress generated in the rear trunnions under horizontal lifting operation is evaluated by the same method of A.4.4.

(1) Maximum load

The maximum load applied to the rear trunnions under horizontal lifting operation can be calculated using the equation below. Note that the maximum load F applied to the trunnions should be calculated using the total mass of the package although the shock absorbing covers have been removed from the package before lifting with the trunnions:

$$F = m \times g \times \frac{G}{N}$$

where, m : Package mass [19,500 kg]

g : Gravity acceleration [9.81 m/s^2]

G : Loading factor [3]

N : Number of trunnions [4]

Therefore,

$$F = 1.44 \times 10^5 \text{ N}$$

(2) Stress calculation

The dimensions and loading points of various parts of the rear trunnions are shown in Figure II-A. Appendix 5.1

Figure II-A Appendix 5.1: Rear trunnion dimensions and loading points

a. Cylinder section of trunnions

The maximum bending stress and the shearing stress that occur in the cylinder section of the trunnions can be expressed using the beam theory as follows:

(a) Maximum bending stress (σ)

$$\Sigma = \frac{M}{Z}$$

$$M = F \times L$$

where, M : Bending moment (N·mm)

F : Maximum load applied to a single trunnion [1.44×10^5 N]

L : Distance between the F loading point and the cross section to be evaluated

[Section A-A:□mm, Section B-B:□mm]

Z : Section modulus (mm^3)

$$Z = \frac{\pi}{32} D^3$$ (D: Trunnion cylinder diameter

[Section A-A:□mm, Section B-B:□mm])

(b) Shearing stress (τ)

$$\tau = \frac{F}{A}$$

where, F : Maximum load applied to a single trunnion [1.44×10^5 N]

A : Sectional area (mm^2)

$$A = \frac{\pi}{4} D^2$$

(c) Stress intensity (S)

$$S = \sqrt{\sigma^2 + 4\tau^2}$$

An evaluation of the section A-A and the section B-B in Figure II-A. Appendix 5.1 has revealed that the stress intensity is □MPa for the section A-A and □MPa for the section B-B. The criteria (Sy) for this item is□MPa (□°C).

The safety margin MS in this case is:

$$MS = \frac{\square}{\square} - 1 = \square$$

b. Trunnion fixing bolts

The package is designed so that the shearing load applied to the trunnion is borne by its cylinder section to be engaged with the flange. Therefore, the trunnion fixing bolts are applied with a tensile load due to the moment during lifting as well as the axial force by the initial tightening torque.

(a) Tensile stress due to moment

The maximum tensile stress σ_1 due to the moment at the support of Point O shown in Figure II-A. Appendix 5.1 occurs in the bolts □ and can be determined by the equation:

$$\sigma_1 = M \times \frac{\square}{I} \quad (\square\text{: Distance between Point O and the bolt } \square \text{ [} \square \text{ mm])}$$

$$M = F \times L$$

$$I = \frac{\pi}{64} \times d_r^4 \times \square + \sum_{i=1}^{\square} \left(\frac{\pi\, d_r^2}{4} \times D_i^2 \right)$$

where, F : Maximum load applied to a single trunnion [1.44×10^5 N]

M : Moment (N·mm)

I : Moment of inertia of the section (mm^4)

L : Moment arm [□ mm]

Di : Distance between Point O and the bolt (mm)

dr : Minimum diameter of bolt (□) [□ mm]

Therefore,

$\sigma_1 =$ □ MPa

(b) Tensile stress due to initial tightening torque

The tensile stress due to the initial tightening torque σ_2 can be determined by the equation:

$$\sigma_2 = T \times \frac{1}{0.2d} \times \frac{1}{(\pi\, d_r^2 / 4)}$$

where, T : Initial tightening torque [□ N·mm]

d : Nominal diameter of bolt [□ mm]

Therefore,

$\sigma_2 =$ □ MPa

Then, the tensile stress σ that occurs in the trunnion fixing bolts during lifting is:

$\sigma = \sigma_1 + \sigma_2 =$ □ MPa

The criteria (Sy) for this is □ MPa (□ °C).

Then, the safety margin MS in this case is:

$$MS = \frac{\square}{\square} - 1 = \square$$

(3) Comparison of evaluation results between top trunnions and rear trunnions

Comparison with the evaluation results obtained in A.4.4 is shown in Table II-A Appendix 5.1. As shown in this table, the results of top trunnions are more severe.

Table II-A Appendix 5.1: Comparison of evaluation results between top trunnions and rear trunnions

Parts	Positions	Stress intensity (MPa)	Safety margin (MS)
Top trunnions (Under vertical lifting)	Cylinder section of trunnions		
	Trunnion fixing bolts		
Rear trunnions (Under horizontal lifting)	Cylinder section of trunnions		
	Trunnion fixing bolts		

A.10.6 Appendix-6 References

[1] ASME Boiler and Pressure Vessel Code, Sec.II, Part D (2015)

[2] "Heat Transfer Engineering Materials, 5th ed.", The Japan Society of Mechanical Engineers (2009)

[3] Titanium Metals Corporation, TIMETAL 6-4 Technical Data (1998)

[4] Industeel (ArcelorMittal group), NUCL 18-10 B4 Technical Data (2011)

[5] NF EN 10088-1 Stainless steel - Part 1: 2014-12

[6] ASME Boiler and Pressure Vessel Code, Sec.III, Div.1 NB (2015)

[7] "Deformation and Fracture Characteristics of Titanium Alloys at Low Temperatures", The Iron and Steel, Vol.75 (1989) No.5

[8] "Comprehensive Composite Material Engineering", Industrial Technology Research Institute (1976)

[9] "Wood Industry Handbook, Rev.3", Editor: Experimental Forestry Station (1982)

[10] Crane Structure Standards (2003 Notification of the Ministry of Health, Labor and Welfare No.399) (2003)

[11] "Data Collection of Zircaloy Cladding", Kobe Steel Engineering Reports, Vol.20, No.2, April, 1970

[12] ASME Boiler and Pressure Vessel Code, Sec III, Div.1 Appendices (2015)

Chapter II-B Thermal Analysis

II-B Thermal analysis

B.1 Summary

This package has the following thermal design features:

(a) The contents refer to fresh fuel assemblies whose decay heat is negligible.

(b) The heat supply to the package includes the heat from solar insolation to the outer surface of the package and the heat of a fire accident, if occurs, under accident conditions of transport for packages containing fissile material.

(c) The heat of the outer surface of the package is transferred to the inner surface of the packaging body by heat conduction.

(d) The heat of the inner surface of the packaging body is transferred to the basket and to the inner surfaces of the basket lodgments by heat conduction and radiation.

(e) The heat of the inner surface of the basket lodgments is transferred to the fuel assemblies which is the contents by heat conduction and radiation. Since the thermal power of the fuel assemblies is negligible, the temperature of the fuel assemblies will never reach or exceed the maximum temperature of the basket. Therefore, the maximum temperature of the fuel assemblies can be represented by the maximum temperature of the basket.

(f) Fusible plugs are installed onto the external plates and onto the outer shell of the shock absorbing covers to prevent an increase in internal pressure due to a gas generated with the heat during a fire accident.

(g) This package is transported in a horizontal position.

To provide conservative evaluation of the package, this analysis determines the temperature of the components of the package under normal conditions of transport on the assumption that the heat supply from the solar insolation occurs.

The analysis also determines the temperature of the components of the package under accident conditions of transport to evaluate the effect of the temperature on the components, presenting a precondition of the criticality analysis.

The analysis conditions and methods for each analysis item are shown in Table II-B.1.

Table II-B.1: Analysis conditions and methods

	Analysis condition				Analysis method	
	Thermal power of contents	Ambient temperature	Solar insolation	Ambient emissivity	Analysis code	Calculation model
1. Package temperatures						
(1) Normal conditions of transport	0 kW	38°C	Yes	1.0	Simple solution	-
(2) Accident conditions of transport for packages containing fissile material					ABAQUS code	- Slice model - Axisymmetric model
a. Before fire accident	0 kW	38°C	Yes	1.0		
b. During fire accident	0 kW	800°C (30 min.)	Yes	0.9		
c. After fire accident	0 kW	38°C	Yes	1.0		
2. Maximum internal pressures						
(1) Normal conditions of transport	Internal gas temperature under normal conditions of transport				See II-B.4.4	-
(2) Accident conditions of transport for package containing fissile material	Internal gas temperature under accident conditions of transport				See II-B.5.4	-
3. Maximum thermal stresses						
(1) Normal conditions of transport	Maximum temperature under normal conditions of transport				See II-A.5.1	
(2) Accident conditions of transport for packages containing fissile material	Temperature distribution under accident conditions of transport				See II-A.9.2	

B.2 Thermal properties of materials

Among the materials used in the packaging, those subjected to thermal analysis have the thermal properties shown in Table II-B.2.

B.3 Technical specifications of components

For some of the materials used in the major components, their performance may be affected by the available temperature condition. The following shows the specifications and service temperature range of the materials:

(1) [redacted] resin

- Service temperature range [1] : [redacted]

(2) Gasket (EPDM)

- Service temperature range [2] : −40°C to 150°C

Table II-B.2: Physical properties of materials (1/4)

Material	Component	Thermal conductivity (temperature) (W/m·K)(˚C)	Specific heat (temperature) (J/kg·K)(˚C)	Density (10^3 kg/m^3)	Emissivity 1)	Solar absorption 1)
Stainless steel [3] [4]	Inner shell Stiffener External plate Top flange Bottom			7.8		
Stainless steel [3] [4]	Shock absorbing cover Outer shell, Lid resin cover Thermal protection cover Bottom resin cover			7.9		

Note 1) 0.8 for the outer shell (outer surface) of the shock absorbing covers only during a fire accident

Table II-B.2: Physical properties of materials (2/4)

Material	Component	Thermal conductivity (temperature) (W/m·K)(°C)	Specific heat (temperature) (J/kg·K)(°C)	Density (10^3 kg/m^3)	Emissivity	Solar absorption
Titanium alloy [5] [6]	Lid	[redacted]		4.42	[redacted]	-
[redacted] [5]	[redacted] plate			[redacted]	-	-
[redacted] resin [1]	Shell part resin Lid resin Bottom resin				-	-
[redacted] wood [7]	Shock absorber				-	-
Painting [4]	Outer surface of external plate	-	-	-	[redacted] [Before fire] 0.8 [During fire] [redacted] [After fire]	[redacted] [Before fire] 0.8 [During fire] [redacted] [After fire]

Table II-B.2: Physical properties of materials (3/4)

Material	Component	Thermal conductivity (temperature) (W/m・K)(˚C)	Specific heat (temperature) (J/kg・K)(˚C)	Density (10^3 kg/m^3)	Emissivity	Solar absorption
Borated stainless steel [4] [8]	Lodgment (Basket)			7.8		-
Aluminium alloy [3] [4]	(Basket)			2.78		-
Aluminium alloy [3]	Aluminum spacer (Basket)			2.70		-
Aluminium alloy [4] [9]	Additional shielding (Basket)			2.84		-

Table II-B.2: Physical properties of materials (4/4)

Material	Temperature (˚C)	Density (kg/m^3)	Thermal conductivity (W/m·K)	Specific heat (KJ/kg·K)	Kinematic viscosity (mm^2/s)	Prandtle number (-)
Air [10]	27	1.1763	0.02614	1.007	15.83	0.717
	127	0.8818	0.03305	1.015	26.39	0.715
	227	0.7053	0.03951	1.031	38.58	0.710
	327	0.5878	0.0456	1.052	52.36	0.710
	427	0.5038	0.0513	1.076	67.7	0.715
	527	0.4408	0.0569	1.099	84.5	0.719
	627	0.3918	0.0625	1.122	102.7	0.722
	727	0.3527	0.0672	1.142	122.1	0.732
	827	0.3206	0.0717	1.160	143.0	0.742

B.4 Normal conditions of transport

The temperature of the package under normal conditions of transport is conservatively evaluated according to the following condition:

The package is assumed to be under the solar insolation condition (i.e., normal condition of transport for Type B(M) packages containing fissile material) described in Annex 4 of the "Notification to specify particulars related to technical standards on the transport of nuclear materials outside any plant or office" (hereinafter referred to as the "Notification").

B.4.1 Thermal analysis model

Since the contents of this package have very small decay heat, the thermal heat of the contents is ignored in the analysis.

Therefore, the temperature increase of the package under normal conditions of transport is caused by the heat supply from solar insolation at an ambient temperature of 38°C.

This analysis assumes that the heat supply to the package is attributable to the solar insolation and that the heat radiation from the package is attributable to natural convection and radiation to the environment. This section determines through a simplified calculation the surface temperature of the package in steady state where an equilibrium between the heat supply and the heat dissipation is established.

B.4.1.1 Analysis model

(1) Geometric model

Since the side face of the body, which is also the surface of the package, is cylindrical, a cylinder that is horizontally placed is used as a geometric model.

(2) Thermal condition

The thermal conditions under normal conditions of transport used for the analysis is shown in Table II-B.3.

B.4.1.2 Test model

No test model is used.

Table II-B.3: Thermal condition under normal conditions of transport

Item		Condition	
		Maximum temperature condition	Minimum temperature condition
Decay heat (W)		0	0
Environmental condition	Ambient temperature (°C)	Still air 38	Still air −40
	Solar insolation (W/m^2)	400 1)	0
	Ambient emissivity	1.0	1.0
Package surface	Emissivity 2)		
	Solar absorption 2)		

Note 1) Radiation heat for "other surfaces" described in Annex 4 of the Notification.

Note 2) The value for the outer shell of the shock absorbing covers (stainless steel) with a higher heat supply than for the external plates (painted surface) is used.

B.4.2 Maximum temperatures

By calculating the heat balance in the outer surface of the package in steady state, this section determines the maximum temperature of the package under normal conditions of transport.

Since the heat from solar insolation is the only heat input, the surface temperature of the package represents the maximum temperature. In steady state, the package has a uniform surface temperature.

The heat output is the sum of the heat release due to radiation Q_1 and the heat release due to natural convection Q_2. Then, the package surface temperature T (°C) at which the heat input $Q_{in} = Q_1 + Q_2$ is determined.

(1) Solar insolation Q_{in}

$$Q_{in} = 400\ (W/m^2) \times a \times A$$

a : Solar absorption of package surface [ ]

A : Package surface area (m^2)

(2) Heat release due to radiation Q_1

$$Q_1 = A \times \varepsilon \times \sigma \times \{(T + 273)^4 - (To + 273)^4\}$$

ε : Package surface emissivity [ ]

σ : Stefan-Boltzmann constant ($W/m^2 \cdot K^4$)

To: Ambient temperature [38 °C]

(3) Heat release due to natural convection Q_2

The coefficient of heat transfer due to natural convection of the horizontal cylinder surface can be expressed in the equation below according to the Schutz's rule [11]:

$$Nu = 0.10\,(Gr \cdot Pr)^{1/3} \quad (5 \times 10^8 < Gr \cdot Pr < 10^{10})$$

$$= h \cdot d/\lambda \qquad \text{: Nusselt number}$$

$$Gr = g \cdot \beta \cdot d^3 \cdot \Delta T / \nu^2 \qquad \text{: Grashof number}$$

$$Pr = \nu/a \qquad \text{: Prandtl number}$$

where,

- h : Heat transfer rate of horizontal cylinder surface ($W/m^2 \cdot K$)
- d : Characteristic length (cylinder diameter) [☐ m]
- λ : Thermal conductivity of air ($W/m \cdot K$)
- g : Gravity acceleration [9.8 m/s^2]
- β : Coefficient of cubical expansion of air $1 / (T_o + 273)$ (1 / K)
- ΔT: Temperature difference ($T - T_0$) (°C)
- ν : Kinematic viscosity of air (m^2/s)
- a : Thermal diffusivity of air (m^2/s)

For the physical properties of air listed above (λ, ν, a), the value at a mean temperature of T_0 and T is used.

The heat output due to natural convection Q_2 can be expressed in the equation below using the heat transfer rate h:

$$Q_2 = h \cdot A \cdot \Delta T$$

(4) Calculating the package surface temperature T

The package surface temperature T is determined by convergent calculation so that the equation $Q_{in} = Q_1 + Q_2$ holds.

The result of the calculation is : T = ☐ °C.

Therefore, the maximum temperature of this package is assumed to be ☐ °C.

B.4.3 Minimum temperatures

The temperature of the packaging components in still air at −40°C with no heat from solar insolation is uniformly −40°C since the decay heat of the package is negligible.

This temperature is within the service temperature range of the gasket (EPDM) used in the package. The major materials including stainless steel, titanium alloy, resin and aluminium alloy will not embrittle at −40°C.

This package is of dry type that uses no coolant. The package will not be broken due to freezing. Therefore, the integrity of this packaging will be maintained.

B.4.4 Maximum internal pressures

This package contains fresh fuel assemblies that were stored in a spent fuel pool. These fuel assemblies are supposed to be processed to get rid of any adhesion water before being put in the packaging. This section determines the maximum internal pressure by conservatively taking into account the pressure increase due to the saturated water vapor.

The maximum internal pressure under normal conditions of transport (P) is:

$$P = P_O \times \frac{T}{T_O} + P_V$$

where, Po : Initial pressure during transport [□ MPa absolute [1)]]

To : Initial temperature of internal gas [293K]

T : Temperature of internal gas under normal conditions of transport (K)

Pv : Saturated vapor pressure at internal gas temperature under normal conditions of transport (MPa)

The temperature of internal gas under normal conditions of transport is □ °C (□ K) as shown in the results in B.4.2.

Therefore,

P = □ × □/293 + □ (saturated water vapor pressure at □ °C [5]) = □ MPa absolute

B.4.5 Maximum thermal stresses

The thermal stress under normal conditions of transport is below the criteria and will not affect the structural strength as described in A.5.1 of II-A Structural Analysis.

Note 1) This value has been conservatively set with fluctuations of the atmospheric pressure taken into account.

B.4.6 Summary of results and evaluation

(1) Maximum temperatures

The maximum temperature of the package under normal conditions of transport is □°C. This temperature is within the service temperature range of the packaging components. Therefore, the integrity of the packaging will not be lost.

(2) Minimum temperatures

The minimum temperature of the package is −40°C. This temperature is within the service temperature range of the packaging components. Therefore, the integrity of the packaging will not be lost.

(3) Maximum internal pressures

The maximum internal pressures is □ MPa absolute. However, the internal-external pressure difference to □ MPa is conservatively assumed in the evaluations of the structural analysis. As shown in A.5.1 of II-A Structural Analysis, the stress is below the criteria and the structural integrity of the packaging will not be lost.

(4) Maximum thermal stresses

The thermal stress under normal conditions of transport is below the criteria as described in A.5.1 of II-A Structural Analysis. Therefore, the structural integrity of the packaging will not be lost.

B.5 Accident conditions of transport

B.5.1 Thermal analysis model

This package is a Type A package containing fissile material. This section evaluates the package under accident conditions of transport for packages containing fissile material.

The temperature of the package under accident conditions of transport is calculated by transient heat transfer analysis using the analysis code ABAQUS.

B.5.1.1 Analysis model

(1) Geometric model

The following two models of the package are used for the analysis:

- A model reflecting a lateral cross section (slice model)
- A model reflecting a longitudinal cross section (axisymmetric model)

For these analysis models, the contents are not modeled to ensure conservative conditions for the packaging temperature by ignoring the thermal capacity of the contents.

a. Slice model

For the model reflecting a lateral cross section, the shell part has an axially uniform geometry except the end surfaces while [redacted] Then, a sliced geometry (3-dimensional) [redacted] is developed. The analysis model thus consists of the components ranging from the external plate as the packaging exterior to the basket lodgment.

The dimensional drawing and mesh model of the slice model are shown in Figure II-B.1 and Figure II-B.2 respectively.

As shown in A.9 of II-A Structural Analysis, the packaging did not show any deformation that would affect the heat transfer in the 9 m drop test, and it was partly broken in the 1 m drop test, however, the partial breakage only occurred in the part directly hit by the mild steel bar and would not have a significant effect on the heat transfer of the whole package. Therefore, there is no deformation that should be reflected in the slice model.

b. Axisymmetric model

For the model reflecting a longitudinal cross section, an axisymmetric model (2-dimensional) is used. Since [redacted] are not circumferentially uniform, [redacted].

[redacted]

(Unit: mm)

Figure II-B.1: Dimensional drawing of analysis model (slice model)

Figure II-B.2: Mesh model (slice model)

[redacted].

The basket is represented by a single cylinder having the same opening area and the same plate sectional area with 10 lodgments. In the cylinder, [redacted], additional shielding and aluminum spacer are arranged on concentric circle. The lid resin and bottom resin are assumed as insulation area.

The dimensional drawing and mesh model of the axisymmetric model are shown in Figure II-B.3 and Figure II-B.4 respectively. This axisymmetric model reflects the deformation of the shock absorbing covers with considerations given to the results of the 9 m drop test in which the shock absorbing covers were deformed and had a shorter distance of heat transfer.

(2) Thermal condition

The thermal condition under accident conditions of transport used for the analysis is shown in Table II-B.4.

As the boundary condition applied to the analysis under accident conditions of transport, the heat transfer between components and between package and ambient are shown in Figure II-B.5 and Figure II-B.6 respectively.

For the coefficient of convectional heat transfer of natural convection between the outer surface of the packaging and the surrounding, a value according to the empirical formulas below related to a horizontal cylinder for the shell's outer surface or the cylinder surface of the shock absorbing covers, or related to a vertical flat plate for the end surface of the shock absorbing covers is used:

- Horizontal cylinder : (Schutz's rule)[11] $Nu = 0.10 (Gr \cdot Pr)^{1/3}$ $(5 \times 10^8 < Gr \cdot Pr < 10^{10})$
- Vertical flat plane : (Jakob's rule) [11] $Nu = 0.129 (Gr \cdot Pr)^{1/3}$ $(10^8 < Gr \cdot Pr < 10^{12})$

where, Nu: Nusselt number, Gr: Grashof number, Pr: Prandtl number

The initial temperature of the package is uniformly set to [redacted]°C, which is the maximum temperature for normal conditions of transport.

B.5.1.2 Test model

No test model is used.

(Unit: mm)

Figure II-B.3: Dimensional drawing of analysis model (axisymmetric model)

Figure II-B.4: Mesh model (axisymmetric model)

Table II-B.4: Thermal condition under accident conditions of transport

Item			Conditions	
			Fire accident for 30 min.	After fire accident
Decay heat (W)			0	0
Environmental condition		Ambient temperature (°C)	800	Still air 38
		Solar insolation (W/m²)	Cylinder surface: 400 [1)] Vertical surface: 200 [2)]	Cylinder surface: 400 [1)] Vertical surface: 200 [2)]
		Ambient emissivity	0.9	1.0
Package surface	Painted surface	Emissivity	0.8	
		Solar absorption	0.8	
	Stainless steel	Emissivity	0.8	
		Solar absorption	0.8	

Note 1) Radiation heat for "other surfaces" described in Annex 4 of the Notification.
Note 2) Radiation heat for "vertically transported surfaces" described in Annex 4 of the Notification.

Figure II-B.5: Boundary condition (slice model)

Figure II-B.6: Boundary condition (axisymmetric model)

B.5.2 Package conditions

(1) Damage condition of package during strength test

a. For 9 m drop under accident conditions of transport for packages containing fissile material

This section indicates the maximum deformation of the shock absorbing covers with considerations given to the deformation of the shock absorbing covers due to a free drop under normal conditions of transport for packages containing fissile material as well as an accumulation of deformation caused by this test.

For the thermal model (axisymmetric model) under accident conditions of transport, a deformation of [redacted] mm in the horizontal direction, [redacted] mm in the top corner direction and [redacted] mm in the bottom corner direction was considered so as to envelope these deformations.

The package except the shock absorbing covers has no deformation that would affect the heat transfer performance.

- Top vertical drop : [redacted] mm
- Bottom vertical drop : [redacted] mm
- Horizontal drop : [redacted] mm (top), [redacted] mm (bottom)
- Top corner drop : [redacted] mm
- Bottom corner drop : [redacted] mm
- Slap down drop : [redacted] mm ([redacted])

b. For 1 m drop under accident conditions of transport for packages containing fissile material

- For a top vertical drop, the lid shock absorbing cover is penetrated and the lid resin cover has a dent of up to about [redacted] mm. But these damages are only locally found.
- For a bottom vertical drop, the bottom shock absorbing cover is penetrated and the bottom resin cover has a dent of up to about [redacted] mm. But these damages are only locally found.
- For a horizontal drop involving a direct hit with the center of the shell part (slap down drop), the external plates and stiffeners rupture and have a dent of a depth of up to about [redacted] mm. But these damages are only locally found.

(2) Impact on thermal performance

For a 9 m drop, the maximum deformation of the shock absorbing covers has been taken into account in the analysis model.

For a 1 m drop, deformation is limited to the part directly hit by the mild steel bar. For a top or bottom vertical drop, the shock absorbing covers are only locally penetrated and have no significant change in their insulation effectiveness. For a horizontal drop involving a direct hit with the shell part, the part of the external plates directly hit by the mild steel bar ruptures, which may partially expose the resin to the outside. However, this will not affect the heat transfer of the whole package [redacted].

B.5.3 Temperatures of package

The maximum temperature of the package components under accident conditions of transport along with the elapsed time since the occurrence of a fire accident is shown in Table II-B.5.

The temperature distribution of the packaging 30 minutes after the occurrence of a fire accident when the temperature of the outer surface of the package is highest is shown in Figure II-B.7 and Figure II-B.8. The temperature history of the packaging components is shown in Figure II-B.9 and Figure II-B.10.

The maximum temperature of the lid including the lid gasket is °C, which is below 150°C that is the service temperature of the gasket (EPDM).

Table II-B.5: Maximum temperature of each part of package

Parts of package	Temperature 1) (°C)
Outer surface of shell part	
Inner surface of shell part	
Lid	
Top flange	
Bottom	
Outer surface of basket	
Lodgment	

Note 1) Within the parentheses indicates the elapsed time since the occurrence of a fire accident.

Figure II-B.7: Temperature contour diagram of slice model (30 min. after fire accident) (1/2)

Figure II-B.7: Temperature contour of slice model (30 min. after fire accident) (2/2)

Figure II-B.8: Temperature contour diagram of axisymmetric model (30 min. after fire accident)

Figure II-B.9: Temperature history of packaging components (slice model)

Figure II-B.10: Temperature history of packaging components (axisymmetric model)

B.5.4 Maximum internal pressures

This package contains fresh fuel assemblies that were stored in a spent fuel pool. These fuel assemblies are supposed to be processed to get rid of any adhesion water before being put in the packaging. This section determines the maximum internal pressure by conservatively taking into account the pressure increase due to saturated water vapor.

The maximum internal pressure under accident conditions of transport (P) is:

$$P = P_O \times \frac{T}{T_O} + P_V$$

where, Po : Initial pressure during transport [□ MPa absolute [1)]]

To : Initial temperature of internal gas [293K]

T : Temperature of internal gas under accident conditions of transport (K)

Pv : Saturated vapor pressure at internal gas temperature under accident conditions of transport (MPa)

Since the temperature of internal gas under accident conditions of transport never exceeds the maximum temperature of the basket, it is set to □°C (□K) based on the maximum temperature of the basket components shown in Table II-B.5.

Therefore,

$$P = \square \times \frac{\square}{293} + \square \text{ (saturated water vapor pressure at } \square{}^{\circ}\text{C [5]) } = \square \text{ MPa absolute}$$

Note 1) This value has been conservatively set with the general weather condition taken into account.

B.5.5 Maximum thermal stress

Under accident conditions of transport, the packaging body and basket have thermal strain due to the temperature distribution and a variation of the coefficient of linear thermal expansion. As described in A.9 of II-A Structural Analysis, the thermal strain that occurred in the inner shell 30 minutes after the occurrence of a fire accident at which the thermal gradient was largest is sufficiently smaller than the elongation, and the inner shell will not rupture. A deformation would be possible due to this thermal stress. However, the possible effect of the deformation is considered in the criticality analysis.

B.5.6 Summary of results and evaluation

(1) Maximum temperatures

The temperature and temperature changes of the package under accident conditions of transport are shown in Table II-B.5 and Figures II-B.9 and II-B.10 respectively.

Since the maximum temperature of the gasket is below the service temperature, the leaktightness will never be lost. The [redacted] resin will never be burned down although part of its surface may be carbonized when it is made into contact with the external plate. Note that the resin is ignored in the criticality analysis under accident conditions of transport as well as the wood. The other components will not reach a temperature at which they are damaged.

Therefore, the packaging performance cannot be lost by the temperature of the package under accident conditions of transport.

(2) Maximum internal pressures

The maximum internal pressure is [redacted] MPa absolute. For the structural analysis, the difference between the internal and external pressures is set to [redacted] MPa for evaluation.

(3) Maximum thermal stresses

Due to the temperature distribution and a variation of the coefficient of linear thermal expansion, the packaging body may have thermal strain to deform the inner shell. However, the possible effect of the deformation is considered in the criticality analysis.

Therefore, the temperature and pressure under accident conditions of transport will not affect the critical safety of the package.

B.6 Appendix

B.6.1 Appendix-1: References

[1] COGEMA LOGISTICS, "Development of a new neutron shielding material, TN resin Vyal for transport/storage casks for radioactive materials", PATRAM 2004.

[2] "Comprehensive Composite Material Engineering", Industrial Technology Research Institute (1976)

[3] ASME Boiler and Pressure Vessel Code, Sec. II, Part D (2015)

[4] R. Siegel and J. R. Howell, "Thermal Radiation Heat Transfer", Fourth Edition (2002)

[5] "Heat Transfer Engineering Materials, 5th ed.", The Japan Society of Mechanical Engineers (2009)

[6] Titanium Metals Corporation, TIMETAL 6-4 Technical Data (1998)

[7] F. Kollmann and W. A. Côté, "Principles of Wood Science and Technology", Springer-Verlag (1968)

[8] Industeel (ArcelorMittal group) NUCL 18-10 B4 Technical Data (2011)

[9] Japan Aluminium Association, "Aluminium Material Properties Database", (2007)

[10] "Heat Transfer Engineering Materials, 4th ed.", Japan Society of Mechanical Engineers (1986)

[11] The standard by Atomic Energy Society of Japan, "Safety design and inspection standards of packages for spent fuel, fresh mixed-oxide fuel or high-level radioactive waste: 2013", AESJ-SC-F006:2013, November 2014

Chapter II-C Containment Analysis

II-C Containment analysis

C.1 Summary

This packaging is constructed to have leaktightness as described in I-C.

As described in II-A Structural Analysis and II-B Thermal Analysis, the containment system will maintain its leaktightness without being damaged under normal conditions of transport.

C.2 Containment system

C.2.1 Containment system

The containment system of this packaging consists of the following components. (See Figure I-C.4)

- Body and lid
- Lid gasket
- Quick connection cover gasket

As described in II-A Structural Analysis and II-B Thermal Analysis, this packaging is designed to be able to sufficiently resist the temperature, pressure and impact of the packaging under normal conditions of transport. Furthermore, as described in A.4.1 of II-A Structural Analysis, the packaging components will not chemically or galvanicaly react with each other or with the package. Under normal conditions of transport, the lid gasket and quick connection cover gasket have temperatures within the service temperature range. (See II-B Thermal Analysis)

Therefore, the containment system is designed to ensure the leaktightness under normal conditions of transport.

C.2.2 Penetrations of containment system

The penetrations of this packaging include quick connection fixing parts provided in the lid. The structure of the quick connection fixing parts is shown in Figure I-C.10. The containment boundary is shown in Figure I-C.4.

C.2.3 Gaskets and welds of containment system

C.2.3.1 Gasket

The containment system of this packaging has the following gasket:

- Lid gasket
- Quick connection cover gasket

These gaskets are made of EPDM and will maintain their performance under normal conditions of transport since their temperature is within the service temperature range as described in II-B Thermal Analysis.

Each gasket should be checked for damage or other fault every transport.

C.2.3.2 Welding area

The leaktightness of the package may be affected by the following welding areas:

- [redacted]
- [redacted]

All these welding areas are [redacted] A working method verification test should be conducted to demonstrate that these welding areas have a structural strength equivalent to that of the base material. In addition, a non-destructive examination ([redacted]) is carried out to demonstrate that the welding areas have no crack, incomplete fusion or other defect. A leak test is also conducted to verify that they have no leakage (i.e., they are leak tight). Verification with these tests will ensure that the welding areas maintain their integiry at the maximum and minimum temperatures as well as the maximum internal pressure under normal conditions of transport shown in B.4 of II-B Thermal Analysis and will maintain the leaktightness like the base material.

C.2.4 Lid

The lid parts have containment boundaries including the contact surface between the lid and the top flange as well as the contact surface between the quick connection cover and the lid. These contact surfaces are provided with an EPDM gasket seal each. (See Figure I-C.10)

The lid is installed to the top flange with [redacted] bolts. As described in II-A Structural Analysis, the lid has an enough strength to sufficiently resist the temperature, pressure and impact under normal conditions of transport.

C.3 Normal conditions of transport

As described in II-C.2, the II-A Structural Analysis and II-B Thermal Analysis have revealed that the leaktightness of the containment system cannot be lost under normal conditions of transport.

C.3.1 Leakage of radioactive material

As mentioned above, it has been revealed that the containment system of the packaging will maintain its integrity under normal conditions of transport.

Therefore, no radioactive material will leak from the package under normal conditions of transport.

C.3.2 Pressurization of containment system

The package may be internally pressurized mainly with thermal expansion of the internal gas. The maximum internal pressure conservatively determined based on the temperature of normal conditions of transport is [redacted] MPa (absolute). The package will not be pressurized to such an extent that can impede the leaktightness.

C.3.3 Contamination of coolant

This packaging is of the dry type that uses no coolant and does not involve coolant contamination.

C.3.4 Loss of coolant

This packaging is of the dry type that uses no coolant and does not involve loss of coolant.

C.4 Accident conditions of transport

This package is a Type A package and is not required to maintain its leaktightness under accident conditions of transport. Therefore, the requirement of this section is not applicable.

C.5 Summary of results and evaluation

The results of the containment analysis evaluation are shown in C.2 and C.3. The leaktightness of the package meets the technical standards for Type A packages specified in the Regulation.

Chapter II-D　Shielding Analysis

II-D Shielding analysis

D.1 Summary

This packaging contains fresh BWR fuel assemblies stored in a spent fuel pool.

The fuel assemblies are cleaned to fully get rid of pool water before being put in the packaging. Therefore, they may suffer very little surface contamination by the radioactive material contained in the pool water. Still, this section conservatively assumes that part of the radioactive material originating in the pool water remains on the surface of the fuel assemblies for evaluation purpose.

The major shielding components of this packaging include the inner shell, external plates (stainless steel) and resin as well as the lid (titanium alloy) and resin in the top side and the bottom (stainless steel) and resin in the bottom side.

Under normal conditions of transport, the top and rear shock absorbing covers may be slightly deformed by a free drop as described in II-A Structural Analysis. In the Shielding Analysis, these shock absorbing covers are conservatively replaced with air. Therefore, the shielding analysis model for routine conditions of transport is used.

The 2-dimensional transport calculation code DORT [1] are used for the gamma rays shielding calculation for routine and normal conditions of transport.

D.2 Source specifications

This packaging contains up to 10 BWR fuel assemblies. Each fuel assembly contains maximum ☐kg of uranium dioxide pellets of an enrichment of not more than 5.0 wt%.

Sources to be taken into account include those related to the fuel composition and the fuel assembly surface contamination with the radioactive material contained in the pool water.

(1) Sources related to fuel composition

The fuel composition to be considered as a possible radioactive source and the source analysis specifications are shown in Table II-D.1:

Table II-D.1: Fuel composition and source analysis specifications

(Per fuel assembly)

		Fuel composition	Source analysis specification
Weight of U		-	☐kg
Enrichment of ^{235}U		≤5.0 wt%	5.0 wt%
Weight of ^{235}U		-	☐g
Weight of ^{238}U		-	☐g
Impurities	^{232}U	≤☐ μg/gU	☐g
	^{234}U	≤☐ μg/g^{235}U	☐g
	^{236}U	≤☐ μg/gU	☐g
	^{99}Tc	≤☐ μg/gU	☐g
Decay period		-	10 years

(2) Surface contamination with pool water

Part of the radioactive materials contained in the pool water is assumed to remain on the surface of the fuel assemblies, which is considered as radioactive source. For further information, see D.2.1 (2).

D.2.1 Gamma sources

(1) Radioactive sources related to fuel composition

For radioactive sources related to the fuel composition, the gamma source intensity is determined using the burn-up calculation code ORIGEN2[2]. The calculated gamma source intensity is shown in Table II-D.2:

Table II-D.2: Gamma source intensity related to fuel composition

(Per package)

Group	Mean energy (MeV)	Gamma source intensity (photons / sec)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
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20		
21		
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23		
24		
25		
26		
27		
28		
29		
30		
31		
32		
33		
34		
35		
36		
37		
38		
39		
40		
41		
42		
43		
44		
45		
46		
47		

(2) Surface contamination with pool water

For the source intensity of the surface contamination with the radioactive material contained in the pool water, the gamma source intensity is calculated from the conservative radioactive concentration of the pool water and the [redacted]. The radioactive source of surface contamination with the pool water is shown in Table II-D.3. ^{60}Co has been selected as the representative source of the surface contamination.

Table II-D.3: Source of surface contamination with pool water

Item	Specifications	Remarks
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	Not to be considered as shielding
Pool water contamination concentration (^{60}Co Bq / m^3)	4×10^8	3.7×10^8 Bq / m^3 [3] to be rounded up
Number of contents (assemblies)	10	
Source intensity (^{60}Co Bq / package)	[redacted]	

D.2.2 Neutron sources

Neutron sources include those released by the spontaneous fission of uranium or by the (α, n) reaction of oxygen. The rate of these reactions is negligible.

D.3 Model specifications

D.3.1 Analysis model

(1) Routine conditions of transport

The shielding analysis model for routine conditions of transport is shown in <u>Figure II-D.1</u> and <u>Figure II-D.2</u>. The following describes the modeling concept:

- [redacted] are conservatively ignored.
- The most peripheral layer of the lodgments equivalent to the minimum thickness is placed on the inner surface of aluminum spacer. The remaining part of the lodgment is homogenized in the fuel region (grid, upper plenum, active length and lower tie plate).
- In terms of the basket, the peripheral aluminum spacers and basket support are modeled according to the actual geometry. [redacted] at bottom is conservatively replaced by air.
- In terms of the packaging body, the inner shell, shell part resin, external plates, bottom, bottom resin, lid, lid resin and lid resin cover are basically modeled according to the actual geometry.
- With considerations given to possible longitudinal movement of the fuel assemblies, the assemblies are assumed to be brought into contact with the bottom surface of the lid on their top end and with the basket support on their bottom end. In other words, the length of the packaging and basket is reduced by the difference between the cavity and the length of the fuel assemblies.
- The shock absorbing covers are conservatively replaced by air and only the distance is considered.

The parts in which streaming should be considered include the quick connections of the lid parts. However, [redacted] and shock absorbing covers [redacted] the quick connections are not taken into account in the model. Therefore, this conservative model includes the effect of streaming.

(2) Normal conditions of transport

The analysis model for normal conditions of transport is shown in <u>Figure II-D.3</u> and <u>Figure II-D.4</u>. As described in D.1, the shielding analysis model for normal conditions of transport is the same as that for routine conditions of transport.

However, the top and rear shock absorbing covers may be deformed by a free drop. Therefore, this deformation should be considered in determining the evaluation points for shielding analysis to normal conditions of transport.

(Unit: mm)

Figure II-D.1: Shielding analysis model for routine conditions of transport (Lid side)

(Unit: mm)

Figure II-D.2: Shielding analysis model for routine conditions of transport (bottom side)

(Unit: mm)

Figure II-D.3: Shielding analysis model for normal conditions of transport (Lid side)

(Unit: mm)

Figure II-D.4: Shielding analysis model for normal conditions of transport (bottom side)

D.3.2 Atomic number density in each region of analysis model

The atomic number density of various materials in each region used for the shielding analysis is shown in Table II-D.4.

The values for dimensions and atomic number density used for the analysis are those at room temperature.

Table II-D.4: Atomic number density of materials used for shielding analysis (1/4)

Region		Density (g/cm^3)	Volume ratio (%)	Nuclide	Atomic number density (atoms / barn·cm)
1.1 Handle (Outside the basket)	Fuel structural components (Stainless steel)	7.9		Cr	
				Fe	
				Ni	
1.2.1 Grid (Outside the basket)	Cladding (Zircaloy)	6.55		Ti	
				Cr	
	Fuel structural components (Stainless steel)	7.9		Fe	
				Ni	
	Fuel structural components (Inconel)	8.25		Zr	
				Sn	
1.2.2 Grid (Basket area)	Cladding (Zircaloy)	6.55		^{10}B	
	Fuel structural components (Stainless steel)	7.9		Ti	
				Cr	
	Fuel structural components (Inconel)	8.25		Fe	
				Ni	
	Basket (Borated Stainless steel)	7.8		Zr	
				Sn	
1.3 Upper plenum	Cladding (Zircaloy)	6.55		^{10}B	
	Fuel structural components (Stainless steel)	7.9		Cr	
				Fe	
	Basket (Borated Stainless steel)	7.8		Ni	
				Zr	
				Sn	

Table II-D.4: Atomic number density of materials used for shielding analysis (2/4)

Region		Density (g/cm^3)	Volume ratio (%)	Nuclide	Atomic number density (atoms / barn·cm)
1.4 Active length	Pellet	10.63		O	
				^{10}B	
	Cladding (Zircaloy)	6.55		Ti	
				Cr	
				Fe	
	Fuel structural components (Inconel)	8.25		Ni	
				Zr	
	Basket (Borated stainless steel)	7.8		Sn	
				^{235}U	
				^{238}U	
1.5 Lower tie plate	Cladding (Zircaloy)	6.55		^{10}B	
				Ti	
	Fuel structural components (Stainless steel)	7.9		Cr	
				Fe	
	Fuel structural components (Inconel)	8.25		Ni	
	Basket (Borated stainless steel)	7.8		Zr	
				Sn	

Table II-D.4: Atomic number density of materials used for shielding analysis (3/4)

Region		Density (g/cm^3)	Volume ratio (%)	Nuclide	Atomic number density (atoms/barn・cm)
2. Inner shell, external plate, bottom ([redacted] stainless steel)		7.8	[redacted]	Cr	[redacted]
			[redacted]	Fe	[redacted]
			[redacted]	Ni	[redacted]
			[redacted]	Cu	[redacted]
			[redacted]	Mo	[redacted]
3. Resin cover (Stainless steel)		7.9	[redacted]	Cr	[redacted]
			[redacted]	Fe	[redacted]
			[redacted]	Ni	[redacted]
4. Lid (Titanium alloy)		4.42	[redacted]	Al	[redacted]
			[redacted]	Ti	[redacted]
5. Shell part resin	Resin	—[1]	[redacted]	[redacted]	[redacted]
			[redacted]	[redacted]	[redacted]
			[redacted]	[redacted]	[redacted]
			[redacted]	[redacted]	[redacted]
	[redacted] stainless steel	7.8	[redacted]	[redacted]	[redacted]
			[redacted]	[redacted]	[redacted]
			[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
			[redacted]	[redacted]	[redacted]
			[redacted]	[redacted]	[redacted]

Note 1) The resin is specified by the atomic number density in the specifications.

Table II-D.4: Atomic number density of materials used for shielding analysis (4/4)

Region	Density (g/cm^3)	Volume ratio (%)	Nuclide	Atomic number density (atoms/barn·cm)
6. Lid and bottom resin (Resin)	—1)		H	
			^{10}B	
			C	
			O	
			Al	
7. Lodgment (Borated stainless steel)	7.8		^{10}B	
			Cr	
			Fe	
			Ni	
8. Basket support (Aluminium alloy)	2.78		Mg	
			Al	
			Cu	
9. Additional shielding (Aluminium alloy)	2.84		Al	
			Cu	
10. Aluminum spacer (Aluminium alloy)	2.70		Mg	
			Al	
11. Air	1.205×10^{-3}		N	
			O	

Note 1) The resin is specified by the atomic number density in the specifications.

D.4 Shielding evaluation

The following describes the evaluation method used to determine the equivalent dose rate of the package under routine / normal conditions of transport and the results of calculation.

(1) Shielding evaluation method

The equivalent dose rate of gamma rays is calculated using the DORT code.

The cross section is determined using the SCALE library.

This library was created by U.S. Oak Ridge National Laboratory from ENDF/B-VII nuclear data files.

This data library has 47 energy groups of gamma rays. The conversion coefficient from the flux to the equivalent dose rate for the energy group is based on the ICRP Publication 74 [4].

(2) Calculation results

The results of calculation of the maximum equivalent dose rate of lid, side and bottom directions of the package under routine / normal conditions of transport are shown in Table II-D.5.

As shown in the table, the equivalent dose rate of the package surface and the position 1 m from the surface is below the criteria specified in the Regulation and Notification.

For the package under normal conditions of transport, only the shock absorbing covers will be deformed and the packaging body will not be deformed. Therefore, the position and value for the maximum equivalent dose rate are the same as those for routine conditions of transport.

In conclusion, the maximum equivalent dose rate of the surface of the package under normal conditions of transport will not substantially increase.

Table II-D.5: Maximum equivalent dose rate of package components [1)]

(Unit: μSv/h)

		Package surface			1 m from surface		
		Lid	Side	Bottom	Lid	Side	Bottom
Routine conditions of transport	Gamma rays due to fuel composition						
	Gamma rays due to pool water contamination						
	Total						
Normal conditions of transport	Gamma rays due to fuel composition						
	Gamma rays due to pool water contamination						
	Total						
Criteria	Routine conditions of transport	2,000			100		
	Normal conditions of transport	2,000			—		

Note 1) The maximum equivalent dose rate is indicated by an integer obtained by rounding up the first decimal place.

D.5 Summary of results and evaluation

<u>Table II-D.6</u> summarizes the results of analysis of the package under routine conditions of transport and normal conditions of transport.

The calculated maximum equivalent dose rate is shown in Table II-D.6 and is below the criteria specified by the Regulation and Notification. There will be no substantial increase in the maximum equivalent dose rate under normal conditions of transport.

Table II-D.6: Summary of analysis results

(Unit: μSv/h)

	Package surface		1 m from surface	
	Maximum equivalent dose rate	Criteria	Maximum equivalent dose rate	Criteria
Routine conditions of transport		2,000		100
Normal conditions of transport		2,000		

D.6 Appendix

D.6.1 Appendix-1 References

[1] RSIC Code Package CCC-484, "DORT two dimensional discrete ordinates transport code system", Oak Ridge National Laboratory, Nov. 1989.

[2] A.G. Croff, "ORIGEN2 - A Revised and Updated of the Oak Ridge Isotope Generation and Depletion Code", ORNL-5621, July 1980.

[3] The standard by Atomic Energy Society of Japan,"Safety design and inspection standards of packages for spent fuel, fresh mixed-oxide fuel or high-level radioactive waste: 2013", AESJ-SC-F006:2013, November 2014

[4] ICRP 74, "Conversion Coefficient for use in Radiological Protection against External Radiation", Ann. ICRP 26 (3-4), 1996.

Chapter II-E Criticality Analysis

II-E Criticality analysis

E.1 Summary

This analysis demonstrates that the package will maintain its subcritical state under the conditions specified by the Regulation.

The important characteristics for critical safety of this package are shown in II-A Structural analysis as follows:

- The basket will not have deformation that would impair the criticality performance under normal and accident conditions of transport for packages containing fissile material.
- The packaging will have deformation of the shock absorbing covers under normal conditions of transport for packages containing fissile material.
- The packaging will have deformation of the inner shell, external plates, stiffeners, shell part resin and shock absorbing covers under accident conditions of transport. In addition, the resin will be partially carbonized.
- The fuel cladding will have deformation under normal and accident conditions of transport for packages containing fissile material but will not rupture.

With these characteristics taken into account, a conservative model in which the longitudinal length is assumed to be infinite and the external plates, stiffeners, shell part resin, lid, bottom and shock absorbing covers are ignored has been established for criticality analysis model of this package. The same model is used for routine conditions of transport and normal / accident conditions of transport for packages containing fissile material.

The test conditions specified in the Regulation and their own analysis conditions are shown in Table II-E.1. With all these conditions taken into account, the criticality analysis was conducted using the water density and boundary condition as parameters.

The criticality calculation uses the SCALE system [1] developed by U.S. Oak Ridge National Laboratory. The calculation of effective multiplication factor (keff) uses the multigroup Monte Carlo calculation code KENO-VI.

The analysis has revealed that the severest analysis condition for either individual packages or package arrays is a case in which an infinite number of packages exist in a given arrangement and leakage of water into package and that such packages are sufficiently subcritical even if the effective multiplication factor (keff) is added by 3σ.

Therefore, this package is subcritical under any of the conditions specified in the Regulation.

Table II-E.1: Conditions specified in Regulation and analysis conditions

Conditions specified in Regulation				Analysis condition		
Condition	Number of packages	Leakage of water into package	Close reflection of water	Package arrangement	Leakage of water into package	Boundary condition around package
1. Routine conditions of transport	No requirements	No	No	Assuming that an infinite number of packages exist in a given arrangement	Yes 3)	Total reflection
2. An individual package in isolation	1	Yes	Yes			
3. Normal conditions of transport	1 (Individual package)	Yes	Yes			
4. Accident conditions of transport	1 (Individual package)	Yes	Yes			
5. Normal conditions of transport	5N 1) (Package arrays)	No requirements	Yes			
6. Accident conditions of transport	2N 1) (Package arrays)	Yes 2)	Yes			

Note 1) "N" indicates the allowable number of packages.

Note 2) As described in A.9.2 of II-A Structural Analysis, leakage of water is already assumed in the 0.9 m water immersion test under accident conditions of transport for packages containing fissile material.

Note 3) In case of this package, it is not necessary to consider leakage of water into the package for routine condition of transport and package arrays under normal condition of transport. However, leakage of water is considered as an analysis condition conservatively based on the evaluation results of the Appendix-1.

E.2 Analysis items

E.2.1 Contents

This packaging contains up to 10 BWR fuel assemblies.

The model and specifications of fuel assemblies contained in this packaging are shown in Table II-A.1. The major specifications of the fuel assemblies subjected to criticality analysis are shown in Table II-E.2.

The fuel assembly may include fuel rods containing gadolinium. However, such fuel rods are conservatively ignored and the enrichment of pellet is conservatively considered to be 5.0 wt% for all cases as shown in Table II-E.2.

With considerations given to the deformation of the fuel assemblies under accident conditions of transport for packages containing fissile material, the fuel assemblies to be contained in the packaging are assumed to have their rod pitch variations for all spans. Specifically, the channel boxes are conservatively ignored and the fuel rods are assumed to be evenly distributed in the lodgment as the rod pitch variations.

E.2.2 Packaging

This packaging will have the following deformation under normal and accident conditions of transport for packages containing fissile material:

- The shock absorbing covers are deformed by a drop test under normal conditions of transport for packages containing fissile material.
- The inner shell, external plates, stiffeners, shell part resin and shock absorbing covers are deformed by a drop test under accident conditions of transport for packages containing fissile material.
- The inner shell is deformed to have a larger radius by a thermal test under accident conditions of transport for packages containing fissile material. (The effect of this deformation on the effective multiplication factor is negligible and does not need to be considered as shown in Appendix-2). In addition, part of the resin is carbonized.

With these characteristics taken into account, a conservative model in which the longitudinal length is assumed to be infinite and the external plates, stiffeners, shell part resin, lid, bottom and shock absorbing covers are ignored has been established for criticality analysis model of this package.

This packaging uses a basket made of aluminium alloy and borated stainless steel to retain the fuel assemblies in their position. The basket will not have deformation that would impair the criticality performance under normal and accident conditions of transport for packages containing fissile material.

E.2.3 Neutron poison

This packaging uses borated stainless steel in the basket as a neutron poison. The boron content of the stainless steel is not less than ☐ wt%.

Since the neutron flux in this packaging is low, the neutron poison will not be substantially consumed by capturing the flux even after a long period of time.

Table II-E.2: Major specifications of fuel assembly subjected to criticality analysis

Item	Values used in criticality analysis
Fuel material	Uranium dioxide
Fuel cladding material	Zircaloy
Fuel rod diameter (mm)	☐
Fuel pellet diameter (mm)	☐
Fuel cladding thickness (mm)	☐
Active length of fuel (mm)	☐
Fuel rod array	9 × 9
Number of fuel rods per assembly	☐
Fuel rod pitch (mm)	☐
^{235}U enrichment (wt%)	5.0

E.3 Model specifications

E.3.1 Analysis model

The effective multiplication factor for the package is calculated using the analysis model shown in Figure II-E.1 to Figure II-E.3. The analysis model consists of:

1. Fuel
2. Fuel cladding (zircaloy)
3. Lodgment (borated stainless steel)
4. [redacted]
5. [redacted]
6. [redacted]
7. Additional shielding (aluminum alloy)
8. Aluminum spacer (aluminum alloy)
9. Inner shell (stainless steel)
10. Water
11. Space (void)

The following conditions are taken into account in the analysis model to ensure conservative evaluation:

- The longitudinal length is infinite and the external plates, stiffeners, shell part resin, lid, bottom and shock absorbing covers are ignored.
- The water density in the packaging is set to [redacted] g/cm^3 to maximize the effective multiplication factor.
- The package is surrounded by void and has a total reflection boundary to maximize the effective multiplication factor.
- The water rods and channel boxes are conservatively ignored.
- With considerations given to the deformation of the fuel assemblies, all the fuel assemblies are arranged in the lodgments with their largest fuel rod pitch for all spans.

Figure II-E.1: Criticality analysis model (longitudinal section)

Figure II-E.2: Criticality analysis model (lateral section)

Figure II-E.3: Criticality analysis model (lateral section)

E.3.2 Atomic number density in each region of analysis model

The atomic number density of elements constituting each region used for the criticality analysis is shown in Table II-E.3.

Note that the values for atomic number density listed in the table are those at room temperature.

Table II-E.3: Atomic number density by region used for criticality analysis (1/2)

Region	Material	Density (g/cm^3)	Volume ratio (%)	Nuclide	Atomic number density (atoms/barn·cm)
1. Fuel	Uranium dioxide	10.63	100	O	
				^{235}U	
				^{238}U	
2. Fuel cladding	Zircaloy	6.55	100	Zr	
				Sn	
3. Lodgment	Borated stainless steel	7.80	100	^{10}B	
				^{11}B	
				Cr	
				Fe	
				Ni	
4. 5.	Aluminum alloy	2.78	100	Mg	
				Al	
				Cu	
6.	Aluminum alloy	2.80	100	Mg	
				Al	
				Cu	
				Zn	
7. Additional shielding	Aluminum alloy	2.84	100	Al	
				Cu	
8. Aluminum spacer	Aluminum alloy	2.70	100	Mg	
				Al	

Table II-E-3: Atomic number density by region used for criticality analysis (2/2)

Region	Material	Density (g/cm^3)	Volume ratio (%)	Nuclide	Atomic number density (atoms/barn·cm)
9. Inner shell	stainless steel	7.80	100	Cr	
				Fe	
				Ni	
				Cu	
				Mo	
10. Water	Water	1.00	100	H	
				O	

E.4 Subcriticality evaluation

E.4.1 Calculation conditions

This section discusses the adequacy of the modeling of the contents, packaging and neutron poison.

(1) Contents

This analysis assumes cases in which the package contains the maximum number of fuel assemblies, i.e., 10 assemblies. For the fuel shown in Table II-E.2, the fuel rods are uniformly distributed in the lodgments for all spans with considerations conservatively given to the deformation of the fuel assemblies under normal and accident conditions of transport for packages containing fissile material (see Appendix-3).

(2) Packaging

For criticality analysis, the longitudinal length is assumed to be infinite and the external plates, stiffeners, shell part resin, lid, bottom and shock absorbing covers are ignored for the purpose of conservative assumption.

(3) Neutron poison

The boron content in the borated stainless steel used as a neutron poison is set to ☐ wt%, which is the minimum guaranteed value, to provide a sufficiently conservative analysis model. Since the neutron flux in this packaging is low, the neutron poison will not be substantially consumed by capturing the flux even after a long period of time.

E.4.2 Leakage of water into package

To maximize the effective multiplication factor for evaluation purpose, it is assumed that water enters the package. (See Appendix-1).

It is also assumed that the package is surrounded by void and has a total reflection boundary to maximize the effective multiplication factor. (As described in Appendix-1, the effect of the presence of water in the void arround the packaging on the effective multiplication factor is negligible and does not need to be considered).

E.4.3 Calculation method

The criticality calculation uses the SCALE system [1] developed by U.S. Oak Ridge National Laboratory. The calculation of effective multiplication factor (keff) uses the multigroup Monte Carlo calculation code KENO-VI.

Calculation of the group constant for all the regions except the fuel region uses the resonance calculation code CENTRN/PMC/WORKER. Calcuation of the group constant for the fuel region uses the resonance calculation codes BONAMI, CENTRN/PMC/WORKER and one- dimensional transport calculation code XSDRNPM. The nuclear data library uses the ENDF/B-VII 238 group library data, which is one of the internal library data sets of the SCALE system.

E.4.4 Calculation results

The results of criticality calculation are shown in Table II-E.4.

This calculation was made on package arrays under accident conditions of transport for packages containing fissile material, which is the severest condition of those listed in Table II-E.1. The calculation results have revealed that the packages are sufficiently subcritical.

Table II-E.4: Results of criticality analysis

keff	σ	keff+3σ

E.5 Bench mark test

The SCALE code system is an analysis code developed by U.S. Oak Ridge National Laboratory for evaluation of nuclear related approvals and has been fully verified by different bench mark analyses.

A bench mark analysis has been carried out here on a critical experiment conducted in U.S. Pacific Northwest Laboratories (PNL) [2].

(1) Bench mark test

The PNL-3602 critical experiment subjected to a bench mark analysis used a basic test system in which three clusters (low enriched uranium fuel rods arranged in square lattice) have in-between neutron poisons. The experiment was conducted using several different test systems with varying factors considered to be important for criticality analysis of the package, for example, type and thickness of the neutron poison, water gap width and uranium enrichment of the fuel. The overview of the experiment system is shown in Figure II-E.4.

(2) Bench mark analysis condition

From the evaluation reports of the International Criticality Safety Benchmark Evaluation Project (ICSBEP), the bench mark tests with low enriched uranium dioxide fuel [3] - [6] were selected. This bench mark analysis uses the ENDF/B-VII library and KENO-VI calculation code as in the criticality analysis of this package.

(3) Results of bench mark analysis

The results of bench mark analysis are shown in Table II-E.5. These results are in good agreement with the results of the criticality analysis. The analysis code and nuclear data used have been proven to provide adequate results.

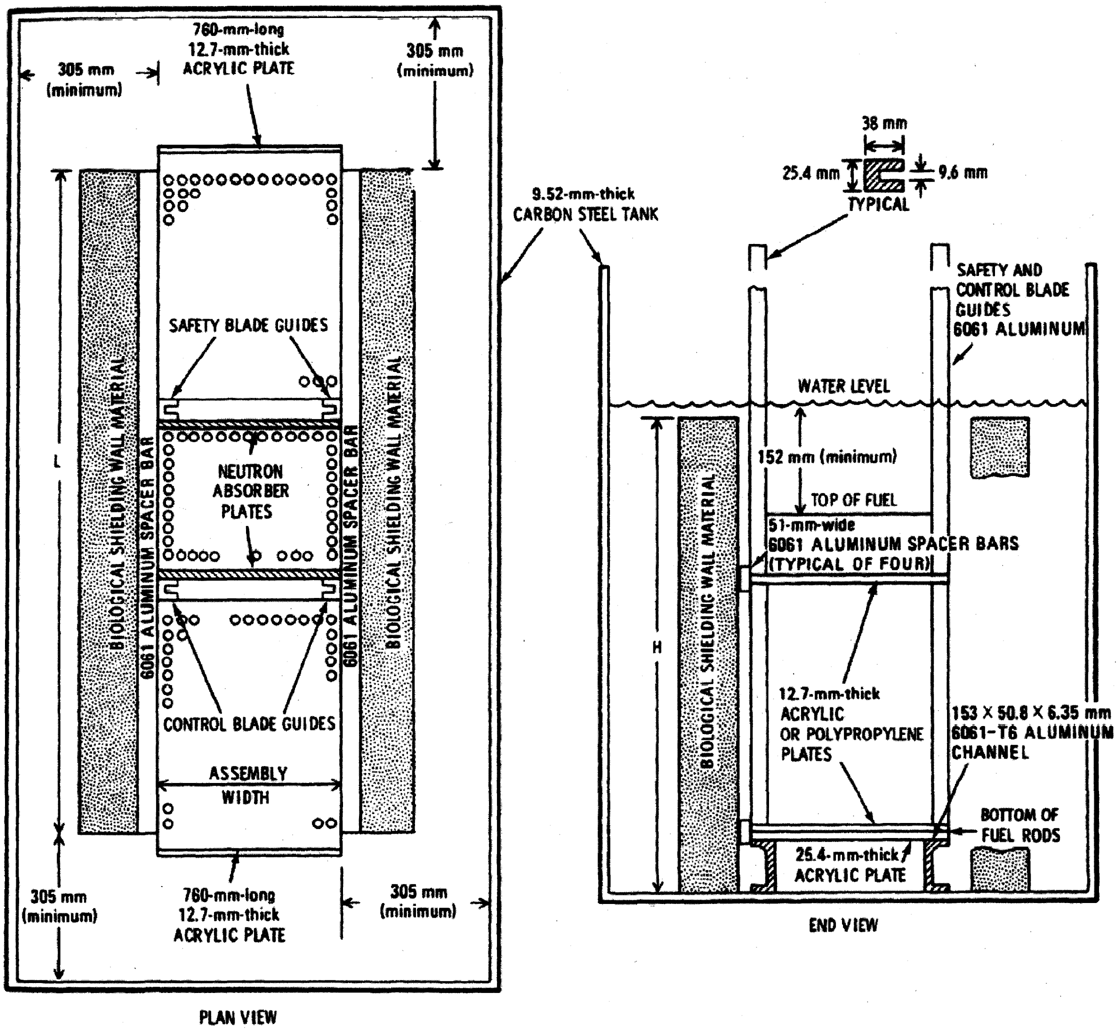


Figure II-E.4: PNL-3602 criticality experiment system

Table II-E.5: Bench mark analysis results

Test No.	^{235}U enrichment (wt%)	Neutron poison	keff	σ
LEU-COMP-THERM-017-CASE17	2.35	-	0.99845	0.00024
LEU-COMP-THERM-042-CASE1	2.35	SUS304L	0.99679	0.00025
LEU-COMP-THERM-042-CASE2	2.35	SUS304L-1.1wt%B	0.99694	0.00026
LEU-COMP-THERM-042-CASE3	2.35	BORAL B	0.99795	0.00026
LEU-COMP-THERM-042-CASE4	2.35	BORAFLEX	0.99783	0.00028
LEU-COMP-THERM-042-CASE5	2.35	Cadmium	0.99772	0.00028
LEU-COMP-THERM-042-CASE6	2.35	Copper	0.99876	0.00026
LEU-COMP-THERM-042-CASE7	2.35	Copper-Cadmium	0.99670	0.00027
LEU-COMP-THERM-010-CASE17	4.31	-	1.00144	0.00028
LEU-COMP-THERM-013-CASE1	4.31	SUS304L	1.00051	0.00029
LEU-COMP-THERM-013-CASE2	4.31	SUS304L-1.1wt%B	1.00078	0.00029
LEU-COMP-THERM-013-CASE3	4.31	BORAL B	1.00007	0.00029
LEU-COMP-THERM-013-CASE4	4.31	BORAFLEX	1.00076	0.00029
LEU-COMP-THERM-013-CASE5	4.31	Cadmium	0.99968	0.00028
LEU-COMP-THERM-013-CASE6	4.31	Copper	0.99997	0.00028
LEU-COMP-THERM-013-CASE7	4.31	Copper-Cadmium	0.99966	0.00029
		Average	0.99900	
		Standard deviation	0.00156	
		Minimum	0.99670	
		Maximum	1.00144	

E.6 Summary of results and evaluation

This packaging uses a basket for fuel assemblies to ensure that the assemblies cannot be spread out or put together during transport. The lodgments to contain fuel assemblies use a neutron poison of borated stainless steel.

The criticality analysis of this packaging was conducted under the severest condition No.6 among the following conditions:

1. Routine conditions of transport
2. Individual package in isolation
3. Individual package in isolation under normal conditions of transport
4. Individual package in isolation under accident conditions of transport
5. Package arrays under normal conditions of transport
6. Package arrays under accident conditions of transport

And the result shows subcriticality with sufficient margin.

Therefore, the packaging will maintain its subcriticality under any of the conditions No.1 to 6 above.

E.7 Appendix

E.7.1 Appendix-1 Evaluation of effect of water density in space inside/outside packaging

As shown in E.3.1, the density of water in the packaging is assumed to be [redacted] g/cm^3. The space among packages is assumed to be void as shown in E.4.2. This section surveys the effect of the density of water in the space inside/outside the packaging on the effective multiplication factor of the package to verify that these assumptions are conservative.

(1) Evaluation of the effect of water density in the space inside the packaging

The same analysis conditions as those shown in E.3 Model Specifications are used. The density of water in the space inside the packaging is varied from 0.0 g/cm^3 to 1.0 g/cm^3 to survey the effect on the effective multiplication factor of the package.

The survey has revealed that the effective multiplication factor of the package is highest when the density of water in the space inside the packaging is [redacted] g/cm^3 as shown in Table II-E Appendix 1.1 and Figure II-E Appendix 1.1.

(2) Evaluation of the effect of water density in the space outside the packaging

The same analysis conditions as those shown in E.3 Model Specifications are used. Assuming that water exists in the space outside the packaging, the density of water is varied from 0.0 g/cm^3 to 1.0 g/cm^3 to survey the effect on the effective multiplication factor of the package.

The survey has revealed that the effect of the existence of water in the space outside the packaging on the effective multiplication factor of the package is negligible as shown in Table II-E Appendix 1.2 and Figure II-E Appendix 1.2.

Table II-E Appendix 1.1: Evaluation of effect of water density in space inside packaging

Water density g/cm^3	keff	σ	keff+3σ
0.0			
0.05			
0.1			
0.2			
0.3			
0.4			
0.6			
0.8			
1.0			

Figure II-E Appendix 1.1: Evaluation of effect of water density in space inside packaging

Table II-E Appendix 1.2: Evaluation of effect of water density in space outside packaging

Water density g/cm³	keff	σ	keff+3σ
0.0			
0.1			
0.2			
0.3			
0.4			
0.6			
0.8			
1.0			

Figure II-E Appendix 1.2: Evaluation of effect of water density in space outside packaging

E.7.2 Appendix-2 Effective multiplication factor with inner shell expansion taken into account

As described in A.9.2 of II-A Structural Analysis, the inner shell is deformed to have a larger radius by about □ mm during a thermal test under accident conditions of transport for packages containing fissile material. To determine the effect, calculation using an analysis model with the expansion of the inner shell taken into account was conducted.

The analysis model is shown in Figure II-E. Appendix 2.1 and Figure II-E. Appendix 2.2. The only difference from the analysis model shown in E.3.1 is the radius of the inner shell. The other analysis conditions are the same as those shown in E.3 Model Specifications.

As shown in Table II-E. Appendix 2.1, it has been verified that the effect of the inner shell expansion on the effective multiplication factor is negligible.

Figure II-E Appendix 2.1: Criticality analysis model for evaluation of effect of inner shell expansion (lateral section)

Figure II-E Appendix 2.2: Criticality analysis model for evaluation of effect of inner shell expansion (lateral section)

Table II-E Appendix 2.1: Comparison of effective multiplication factor between with and without inner shell expansion

Inner shell	keff	σ	keff+3σ
Without expansion			
With expansion			

E.7.3 Appendix-3 Evaluation of effect of fuel rod pitch

As shown in E.2.1, with considerations given to the deformation of the fuel assemblies under accident conditions of transport for packages containing fissile material, the fuel assemblies are assumed to have their fuel rod pitch variations for all spans. Specifically, a case in which the fuel rods are uniformly distributed in the lodgment is considered.

This section surveys the effect of the fuel rod pitch on the effective multiplication factor of the package to verify that the assumption is conservative. Assuming that the fuel rods are arranged in square lattice, the survey was conducted for various fuel rod pitches including from a case in which the adjacent fuel rods are made into contact with each other to a case in which they are spread apart from each other by a maximum distance in each lodgment. The same analysis model as the one described in E.3 Model Specifications was used except the fuel rod pitch.

The effect of the fuel rod pitch on the effective multiplication factor of the package is shown in Table II-E Appendix 3.1 and Figure II-E Appendix 3.1. The survey has revealed that the package has the highest effective multiplication factor for the largest fuel rod pitch.

Table II-E Appendix 3.1: Effect of fuel rod pitch on effective multiplication factor of package

Pitch cm	keff	σ	Keff + 3σ

Figure II-E Appendix 3.1: Effect of fuel rod pitch on effective multiplication factor of package

E.7.4 Appendix-4 References

[1] Scale: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design, ORNL/TM-2005/39, Version 6.1, June 2011, Oak Ridge National Laboratory

[2] S. R. Bierman and E. D. Clayton, "Criticality Experiments with Subcritical Clusters of 2.35 Wt% and 4.31 Wt% 235U Enriched UO2 Rods in Water with Steel Reflecting Walls", NUREG/CR-1784 (PNL-3602), U.S. Nuclear Regulatory Commission, 1981

[3] LEU-COMP-THERM-017, "Water-Moderated U(2.35)O2 Fuel Rods Reflected by Two Lead, Uranium, or Steel Walls", (1998).

[4] LEU-COMP-THERM-042, "Water-Moderated Rectangular Clusters of U(2.35)O2 Fuel Rods (1.684-cm Pitch) Separated by Steel, Boral, Boroflex, Cadmium, or Copper Plates, with Steel Reflecting Walls", (2003).

[5] LEU-COMP-THERM-010, "Water-Moderated U(4.31)O2 Fuel Rods Reflected by Two Lead, Uranium, or Steel Walls", (1996).

[6] LEU-COMP-THERM-013, "Water-Moderated Rectangular Clusters of U(4.31)O2 Fuel Rods (1.892-cm Pitch) Separated by Steel, Boral, Boroflex, Cadmium, or Copper Plates, with Steel Reflecting Walls", (2003).

Chapter II-F Evaluation of Compliance to the Regulation and the Notification

II - F Evaluation of compliance to the Regulation and the Notification

This package is type A package containing fissile material. The evaluation of the compliance to the Regulation and the Notification for this package is shown in Table II -F.1.

Table II -F.1 Evaluation of compliance with the technical criteria of the Regulation and the Notification (1/7)

<table>
<tr><th>Items in the Regulation</th><th>Items in the Notification</th><th>Criteria</th><th>Explanation</th><th>Corresponding items described in the application document</th><th>Remarks</th></tr>
<tr><td>Article 3
Item 1
No.2</td><td>Article 4 and Schedule 1</td><td><table><tr><th>Category</th><th>Category of nuclear fuel material , etc.</th><th>Quantity of radioactivity</th></tr><tr><td rowspan="2">Type A</td><td>Special foam nuclear fuel material , etc.</td><td>Not greater than A_1 value</td></tr><tr><td>Others than Special foam nuclear fuel material , etc.</td><td>Not greater than A_2 value</td></tr></table></td><td>The nuclear fuel material contained in this packaging falls under the category called “Others than special foam nuclear fuel materials etc.” It is un-irradiated uranium with maximum enrichment of 5% and maximum radioactive quantity of[ ]GBq. Thus the uranium falls under the “U (un-irradiated uranium of an enrichment of not more than 20%)” in Schedule 1 of the Notification and A_2 value “unlimited”.
On the other hand, the radioactive quantity adhered on the contents is sufficiently smaller than A_2 value even if the influence of storage in a spent fuel pool is considered.
Thus the radioactivity contained in this packaging does not exceed the A_2 value, and this packaging is categorized as the type A package.</td><td>I-B
I-D
Chapter-I
Appendix-1</td><td></td></tr>
<tr><td>Article 5
No.1</td><td></td><td>It must be capable of being handled easily and safely.</td><td>This package is designed so that handling operation is capable easily by using trunnions or handling belts on body and a dedicated lifting device with crane.</td><td>I-C
II-A.4.4</td><td>Article 4 No.1 of the Regulation applies mutatis mutandis</td></tr>
</table>

Table II -F.1 Evaluation of compliance with the technical criteria of the Regulation and the Notification (2/7)

Items in the Regulation	Items in the Notification	Criteria	Explanation	Corresponding items described in the application document	Remarks
Article 5 No.1		There must be no possibility of cracks, breakage, etc. due to changes of temperature and pressure and vibrations, etc. expected to occur during transportation.	As shown in the followings, this packaging is designed so that there is no possibility of cracks, breakage, etc. due to changes of temperature and pressure and vibration, etc. expected to occur during transportation as shown below. 1. There is no possibility of cracks, breakage, etc. due to temperature and pressure under normal condition of transport, which are more severe than temperature and pressure expected during transportation. 2. As there is difference between the natural frequency of the package and the vibration frequency expected during transportation, there is no resonance and no possibility of cracks, breakage, etc. 3. The package is transported with fixing the packaging body to the transport frame. The packaging body fixed to the transport frame has a sufficient strength against the acceleration of 2G in the longitudinal direction, 3G in the vertical direction and 2G in the lateral direction.	II-A.5.1 II-A.4.7 II-A.4.5	Article 4 No.2 of the Regulation applies mutatis mutandis
		It must not have unnecessary protrusions on the surface and any contamination of the surface must be easily removed.	The surface of this package is finished smoothly and removing contaminations can be performed easily when it is contaminated with radioactive material.	I-C	Article 4 No.3 of the Regulation applies mutatis mutandis

Table II -F.1 Evaluation of compliance with the technical criteria of the Regulation and the Notification (3/7)

<table>
<tr><th>Items in the Regulation</th><th>Items in the Notification</th><th>Criteria</th><th>Explanation</th><th>Corresponding items described in the application document</th><th>Remarks</th></tr>
<tr><td>Article 5 No.1</td><td></td><td>There must be no possibility of hazardous physical action or chemical reaction to occur between any combinations of the materials or between materials and nuclear fuel material, etc. loaded in the package.</td><td>As this package is transported with dry condition, no hazardous physical or chemical reaction could occur between any combinations of the materials constituting the packaging or between the materials constituting the packaging and the radioactive materials etc.</td><td>I-C
II-A.4.1</td><td>Article 4 No.4 of the Regulation applies mutatis mutandis</td></tr>
<tr><td></td><td></td><td>Measures must be taken to preclude any incorrect operation of the valves.</td><td>The removal parts, which open into the inside of package, are only lid and quick connection cover installed on the lid. [redacted] during transportation, it is not possible to be accidentally operated by incorrect operation.</td><td>II-A.4.3</td><td>Article 4 No.5 of the Regulation applies mutatis mutandis</td></tr>
<tr><td></td><td>Article 9</td><td>Contamination on the surface must not exceed the contamination defined by the Nuclear Regulatory Authority (hereinafter referred to as "External contamination limit").
<table><tr><th>Classification of radioactive material</th><th>Contamination</th></tr><tr><td>Radioactive material of alpha emitters</td><td>0.4 Bq/cm^2</td></tr><tr><td>Radioactive material except alpha emitters</td><td>4 Bq/cm^2</td></tr></table></td><td>Contamination on the surface of this package is checked to confirm that it does not exceed the criteria at the inspection before shipment.</td><td>IV-A.2</td><td>Article 4 No.8 of the Regulation applies mutatis mutandis</td></tr>
<tr><td></td><td></td><td>Anything other than document and something necessary for use, etc. of nuclear fuel material etc. (limited to what will not impair the safety of the nuclear fuel package) is not allowed to be loaded in it.</td><td>As the contents inspection is carried out as an inspection before shipment when fuels are loaded to confirm that there is nothing to be loaded other than specified things, it is not possible that something, which could impair the safety of this package, are loaded.</td><td>IV-A.2</td><td>Article 4 No.10 of the Regulation applies mutatis mutandis</td></tr>
</table>

Table II -F.1 Evaluation of compliance with the technical criteria of the Regulation and the Notification (4/7)

Items in the Regulation	Items in the Notification	Criteria	Explanation	Corresponding items described in the application document	Remarks
Article 5 No.2		Each side of the circumscribed rectangular solid shall be more than 10 cm	This package is cylindrical container with outside dimensions having external diameter of approx. 2.1m and total length of approx. 6.0m.	I-A	
Article 5 No.3		Such measures shall be taken as a seal, which is resistant to tear, is installed in order to prevent undue opening and to indicate clearly that it has been opened if that is the case.	Removal parts to open this package are only lid and quick connection cover installed on the lid. [redacted] during transportation, no undue operation is possible and [redacted].	I-C II-A.4.3	
Article 5 No.4		The components parts shall have no possibility of having any crack, breakage, etc. in the temperature range from –40°C to 70 °C. However , if the temperature during its transport are identifiable, this shall not apply as a limit.	The components of this packaging have no crack or breakage in the change of ambient temperature from –40°C to 70°C. And, as this package is dry type without coolant, there is no possibility of breakage of package due to freezing.	I-C II-A.4.2 II-B.4.3 II-B.4.6	
Article 5 No.5		No leakage of radioactive material is allowed when the ambient pressure is assumed to be 60Pa.	As the containment system of this packaging has no defect when the outside pressure is 60kPa absolute, no leakage of radioactive material is possible.	II-A.4.6	
Article 5 No.7 & No.8	Article 8	The maximum equivalent dose rate on the surface shall not exceed 2mSv/h. The maximum equivalent dose rate at 1m away from the surface shall not exceed 100μSv/h.	The maximum equivalent dose rate on the surface of the package is not more than [redacted] μSv/h and not more than [redacted] μSv/h at 1m away from the surface, and they never exceed the limit of equivalent dose rate.	II-D.4	
Article 5 No.9	Article 13 & Annex 3	The package shall conform to the following criteria when it is to be placed under normal conditions of transport for the type A package defined by the Nuclear Regulatory Authority.	(The following)		

Table II -F.1 Evaluation of compliance with the technical criteria of the Regulation and the Notification (5/7)

Items in the Regulation	Items in the Notification	Criteria	Explanation	Corresponding items described in the application document	Remarks
Article 5 No.9A		No leakage of radioactive material is allowed	The containment performance is maintained without degradation under normal conditions of transport, and no leakage of radioactive materials is possible.	II-C.3.1	
Article 5 No.9B		The maximum equivalent dose rate on the surface shall not substantially increase and shall not exceed 2mSv/h.	The defect of the package under normal condition of transport is slight deformation of shock absorbing covers, and there is no substantial increase of maximum equivalent dose rate on the surface of the package. And, the maximum equivalent dose rate on the surface of the package under this conditions is not more than □μSv/h and it never exceed the criterion.	II-D.4	
Article 11		A nuclear material package shall be the package which never reach criticality, and also shall conform to the following each technical criteria of each article.	It is confirmed that the package never reach criticality under the envelope condition of during transportation, and also the package conform to the each article as follows.	II-E.6	
Article 11 No.1	Article 24 & Annex 11	The package shall conform to the following criteria when it is to be placed under normal conditions of transport for packages containing fissile material defined by the Nuclear Regulatory Authority.	(The following)		
Article 11 No.1A		Any dent that can embrace a cube measuring 10 cm per side must not be formed in the structural parts of packaging.	The components of this package have no dent that can embrace a cube measuring 10 cm per side when this package is placed under these conditions.	II-A.9.1	

Table II -F.1 Evaluation of compliance with the technical criteria of the Regulation and the Notification (6/7)

Items in the Regulation	Items in the Notification	Criteria	Explanation	Corresponding items described in the application document	Remarks
Article 11 No.1B		Each side of the circumscribed rectangular solid must not be less than 10 cm.	Each side of the circumscribed rectangular solid is not less than 10 cm when this package is placed under these conditions.	II-A.9.1	
Article 11 No.2		The package never reach criticality in any case shown in the followings.	(The following)		
Article 11 No.2 A	Article 25	In case that the package is placed under the condition of individual package in isolation defined by the Nuclear Regulatory Authority.	As the effective multiplication factor is when a package same as this package is placed under envelop conditions, which cover all of conditions specified by notification, it is not possible to reach criticality.	II-E.4 II-E.6	
Article 11 No.2 B	Article 24 & Annex 11 and Article 25	In case that the package, which was placed under normal conditions of transport for the packages containing fissile material defined by the Nuclear Regulatory Authority, is placed under the condition of individual package in isolation defined by the Nuclear Regulatory Authority.	(Ditto)	II-E.4 II-E.6	
Article 11 No.2 C	Article 25 and Article 26 & Annex 12	In case that the package, which was placed under accident conditions of transport for the packages containing fissile material defined by the Nuclear Regulatory Authority, is placed under the condition of individual package in isolation defined by the Nuclear Regulatory Authority.	(Ditto)	II-E.4 II-E.6	

Table II -F.1 Evaluation of compliance with the technical criteria of the Regulation and the Notification (7/7)

Items in the Regulation	Items in the Notification	Criteria	Explanation	Corresponding items described in the application document	Remarks
Article 11 No.2 D	Article 24, Annex 11 and Article 27	In case that a package same as this package containing fissile materials, which was placed under normal conditions of transport for packages containing fissile material defined by the Nuclear Regulatory Authority, is placed under the conditions of package arrays, which are 5 times of allowable number of package with a conditions of maximum neutron multiplication between packages containing fissile material.	(Ditto)	II-E.4 II-E.6	
Article 11 No.2 E	Article 26, Annex 12 and Article 27	In case that a package same as this package containing fissile material, which was placed under accident conditions of transport for packages containing fissile material defined by the Nuclear Regulatory Authority, is placed under the conditions of package arrays, which are 2 times of allowable number of package with a conditions of maximum neutron multiplication between packages containing fissile material.	(Ditto)	II-E.4 II-E.6	
Article 11 No.3		The components shall have no possibility of having any crack, breakage, etc. in the ambient temperature within the range from –40℃ to 38 ℃. However, if the lowest temperature during its transport are identifiable, this shall not apply as a limit.	The components of this packaging will have no crack or breakage due to changes in temperature within the range from -40˚C to 70˚C. As this package is dry type without coolant, there is no possibility of breakage of package due to freezing.	I-C II-A.4.2 II-B.4.3 II-B.4.6	

Chapter III　Fundamental Policy of Quality Management

Chapter III Fundamental Policy of Quality Management

III- A Quality management system

Mitsubishi Nuclear Fuel Company, LTD (hereinafter referred to as “MNF”) shall establish and maintain the quality management system based on ISO9001:2015 to ensure the conformity with the customer’s requirements and regulatory technical standards.

A.1 Quality manual

(1) Quality manual

A quality manual is a first-tier document which provides requirements of ISO9001:2015, and defines practice standards of quality assurance activities required at each stage of procurement, design, fabrication, use (including handling), maintenance, etc. as well as quality policy and quality objectives.

The Safety and Quality Assurance Department shall prepare, revise and issue a quality manual under the quality policy decided by the president.

(2) Quality assurance program

The Safety and Quality Assurance Department and the related departments shall establish and document quality assurance programs concerning design, fabrication, procurement, use (including handling), maintenance, etc. of the packaging considering the following items properly based on the quality manual. In addition, it shall ensure that the packaging conforms to the customer’s requirements, regulatory technical standards, design specification in the application for the design approval, fabrication methods in the application for the packaging approval, etc. Procedures and other documents issued by the Safety and Quality Assurance Department, the Manufacturing Department, the Procurement Department, the General Affairs Department, the Fuel and Core Engineering Department and the Transportation and Service Department shall constitute the quality assurance programs.

(a) Each related department shall clarify respective responsibility for management of design, fabrication, procurement, use, maintenance, etc. of the packaging. The Transportation and Service Department and the Fuel and Core Engineering Department shall reasonably carry out part of work of design, fabrication, use, maintenance, etc. of the packaging by receiving supplies of services from professional companies with appropriate quality management systems as needed.

(b) The Transportation and Service Department and the Fuel and Core Engineering Department shall pre-establish and implement inspection procedures concerning manufacturing and performance retention of the packaging to verify manufacturing and maintenance of the packaging at appropriate stages of the work. In addition, the Transportation and Service Department and the Fuel and Core Engineering Department shall provide the requirements from MNF for the inspection to the packaging manufacturer, etc. if the inspection is conducted based on the inspection procedures

prepared by the packaging manufacturer, etc., and review that the requirements from MNF are reflected appropriately in the inspection procedures prepared by the packaging manufacturer, etc., and approve the procedures. The departments shall verify that the manufacturer has conducted inspections according to the procedures.

(c) The Transportation and Service Department and the Fuel and Core Engineering Department shall describe acceptance/ rejection criteria in the inspection procedures established in the above (b).

(d) Each department shall prepare effective procedures (procedures, manuals, and instructions) according to the quality assurance programs and perform quality assurance activities according to the procedures. The extent provided in the procedures, etc. and the level of their details shall be determined depending on operation complexity, operation methods, and skill and extent of training of a worker who carries out the operation.

(e) The Safety and Quality Assurance Department shall clarify quality records affecting quality concerning design, fabrication, procurement, use, maintenance, etc. of the packaging and define procedures for documentation and storage of the quality records.

(3) Quality policy and quality objectives

(a) Quality policy

The president shall establish the following as product quality policy:

Quality policy for products On the basis of corporate philosophy, management policies and the employees' code of conduct, all employees of MNF, group companies and subcontracting companies make sure to perform operations according to the following policies to improve product quality, to fulfill corporate responsibility, and to contribute to society. (1) We foster a culture which prioritizes nuclear safety by working on thorough quality control for realizing high quality, the active prevention of non-conformance and the tradition of technology based on correct understanding of the effect of our products on nuclear safety. (2) To ensure the world's highest level of quality, we continuously improve our quality management system and respond to the society's changes in a prompt and flexible manner. In addition, to achieve sustainable growth, we create new processes with innovative ideas. (3) We aim to be an organization that creates new values by supplying highly safe and reliable products and services, through accurate understanding of the social trends and customer's intention, and our advantages of being involved in all phases of business, including development, design, procurement, manufacturing, marketing, transportation and services.

The president is responsible for assigning a director as a management representative,

distributing required resources and developing the quality management system, to ensure achievement of the above quality policy.

(b) Quality objectives

Each involved department manager shall set quality objectives with an evaluable attainment level, evaluate the status of the achievement and be approved by a management representative as a process for continuous improvement of the quality management system for quality objectives in order to achieve the quality policy.

(4) Management review

The president shall hold regular meetings for review of product quality management to confirm that the quality management system meets the quality policy and quality objectives and is operated effectively, and to review the quality management system.

The management review shall be conducted for the following items.

1. Results of internal audit and external audit
2. Customer feedback
3. Process performance, product conformity and quality trend
4. Status of preventive and corrective actions
5. Implementation status of activities to foster safety culture
6. Follow-up actions from previous management reviews
7. Changes that could affect the quality management system
8. Others

A.2 Document control

(1) Scope of documents and data control

The scope of control shall be applied to documents and data concerning packaging quality.

The documents to be controlled are contract specifications, drawings, order specifications, quality assurance programs, operation procedures, inspection procedures including quality manuals. They also include external documents of official standards such as JIS.

(2) Approval and publication of documents and data

1. Appropriateness of documents and data shall be discussed and approved by the authorized representatives of each department who are entrusted with the discussion and the approval by each department head prior to their publication.

   When the packaging structure is changed and the change has some influence on the use or the operation, the order specifications, etc. shall be reviewed by the related departments.
2. The current version of each document shall be controlled by a register ensuring the following:

(a) Use of appropriate documents/versions

(b) Disposal of invalid and/or obsolete documents

(c) Appropriate identification of obsolete document to be retained

(3) Changes of documents and data

1. Identification of extent affected by changes
   - (a) Systematization of documents concerning manufacturing specification of the packaging
   - (b) When there are changes in a higher document, the presence or absence of the influence shall be confirmed sequentially on the basis of the above systematization of documents to ensure that the changes are reflected in a lower document. In case there is some influence on the manufacturing specification of the packaging as a result of confirmation, a notification of changes shall be submitted to the packaging owner or the packaging manufacturer to instruct them to confirm the presence or absence of the influence.
2. Implementation of changes
   - (a) When a document has an influence of changes, the document shall be listed and follow-up shall be conducted to issue the revised version.
   - (b) Any changes of documents and data shall be implemented in accordance with the same procedure as when the documents and data are issued.
   - (c) Each involved department shall provide supporting evidences to checkers and approvers to change the documents and data. In addition, the details of the changes shall be identified in the document or its attachment.
   - (d) The revised version of the documents which require changes shall be issued as soon as possible so that the lower documents can be revised and issued sequentially as necessary. In addition, when there is some influence on a manufacturing specification of the packaging, the packaging owner or the packaging manufacturer shall be instructed to revise the corresponding documents and submit the revised version.

A.3 Control of quality records

(1) Types of quality records

Each department shall identify the scope of records to be controlled by reference to the following representative documents.

- Records of management review
- Quality documents (quality assurance programs, standards, procedures, etc.)
- Review records of contract
- Order specifications, drawings, etc.
- Inspection records (manufacturing inspections, periodical voluntary inspections, inspections before shipment)
- Audit records (for internal and the suppliers)
- Nonconformance reports and corrective action reports
- Education and training records

(2) Storage of quality records

1. Quality records shall be legible, and stored in an environment suitable to prevention of their deterioration, damage and loss.

2. Quality records shall be retained in an easily-retrievable condition.
3. The storage period of quality records shall be identified.

(3) Disposal of quality records

Each department in charge shall dispose of quality records after storage periods. Quality records shall be incinerated or shredded.

III- B Responsibility of applicants

Figure III.1 shows a diagram of a quality assurance system concerning design, fabrication, procurement, maintenance, etc. of the packaging. MNF submits an order for manufacture of the packaging through the packaging owner or directly to the packaging manufacturer evaluated as having sufficient supplying capacity, under MNF's responsibility. Services for a part of maintenance and maintenance control of the packaging are outsourced to maintenance companies that have sufficient supplying capacity, as needed.

MNF's quality assurance organization is shown in Figure III.2. Work and responsibility of each department in MNF is described below. The final responsible person for the activities in each department shall be the corresponding department manager.

(a) President

The president shall have responsibility and authority for the following items.

1. Establishment of organization with clear responsibility and authority of each position involved in quality assurance, and proper assignment of management resources such as budget, personnel, equipment, etc. to ensure quality meeting requirements of the customer.
2. Setting and documentation of quality policy.
3. Appointment of a management representative and assignment of his/her responsibility and authority for quality assurance activities.

(b) Management representative (director)

A management representative shall be a director appointed by the president and have responsibility and authority for the following items regardless of other responsibility.

1. Establishment and promotion of quality assurance programs.
2. Overall responsibility for quality including the following five items and assessment for validity and effectiveness of the quality assurance programs. Appropriate actions taken when any improvement is required.
   (i) Implementation of actions to prevent nonconformance regarding products, processes and quality management systems.
   (ii) Clarification and records of the problems related to products, processes and quality management systems.
   (iii) Search, recommendation and offer of a solution in a specified manner.
   (iv) Verification of implementation of the solution.
   (v) Suspension of delivery of nonconformance products to the next process until the nonconformance is corrected.
3. Reports to the president on the implementation for the above items in 1 and 2 and need for their improvement.
4. Promoting to each organization to enhance its recognition of importance of meeting requirements of the customer.

(c) Safety and Quality Assurance Department

The Safety and Quality Assurance Department shall be independent of other departments in the organization and have responsibility and authority for the following items.

1. Planning and implementation of quality management systems.
2. Implementation of internal quality audits and instructions of corrective actions.
3. Coordination of evaluation and certification of the packaging suppliers.
4. Implementation of quality audits and instructions of corrective actions to the packaging suppliers.
5. Approval of nonconformance reports and approval of operation stop instructions, corrective and preventive actions when needed.
6. Implementation of education and training.
7. Approval of reports and corrective actions on nonconformance of a packaging observed in the process of product packing, on-site inspections, UF_6 cylinder cleaning, retests, evaporation and storage (hereinafter referred to as “usage step”).

(d) Transportation and Service Department

The Transportation and Service Department shall have responsibility and authority for the following items.

1. Application services for a license related to the packaging.
2. Inspection prior to shipment of the package and application for confirmation on transportation.
3. Receiving of the packaging and check of its expiration date.
4. Preparation of attachments for a license application related to the packaging (except for documents prepared by the Fuel and Core Engineering Department).
5. Maintenance control of the packaging.
6. Preparation of nonconformance reports and consideration of corrective and preventive actions.
7. Implementation of education and training.
8. Preparation of order specifications related to the packaging components and implementation of inspections.
9. Packaging control at a usage step (except for control by the Manufacturing Department)

(e) Fuel and Core Engineering Department

The Fuel and Core Engineering Department shall have responsibility and authority for the following items.

1. Preparation of order specifications related to the packaging design.
2. Examination and approval of design documents such as drawings and analysis documents related to the packaging design.

3. Preparation of design and quality requirements and order specifications related to fabrication of the packaging.
4. Approval of application documents for the fabrication (drawings for fabrication, inspection procedures, etc.).
5. Inspections related to fabrication of the packaging.
6. Preparation of attachments for a license application related to the packaging (on the technology of design and fabrication).
7. Confirmation of contract details related to the design.
8. Evaluation of the packaging suppliers' technical capacity.

(f) Manufacturing Department

The Manufacturing Department shall have responsibility and authority for the following items.

1. Cleaning of uranium hexafluoride cylinders
2. 5-year periodic inspection (hereinafter referred to as "retest") for uranium hexafluoride cylinders.
3. Uranium hexafluoride cylinder control at a usage step (material storage and evaporation process)
4. Packaging control at a usage step (product packing)

(g) General Affairs Department

The General Affairs Department shall have responsibility and authority for the following items.

1. Management of education/training programs.
2. Management of personnel.

(h) Procurement Department

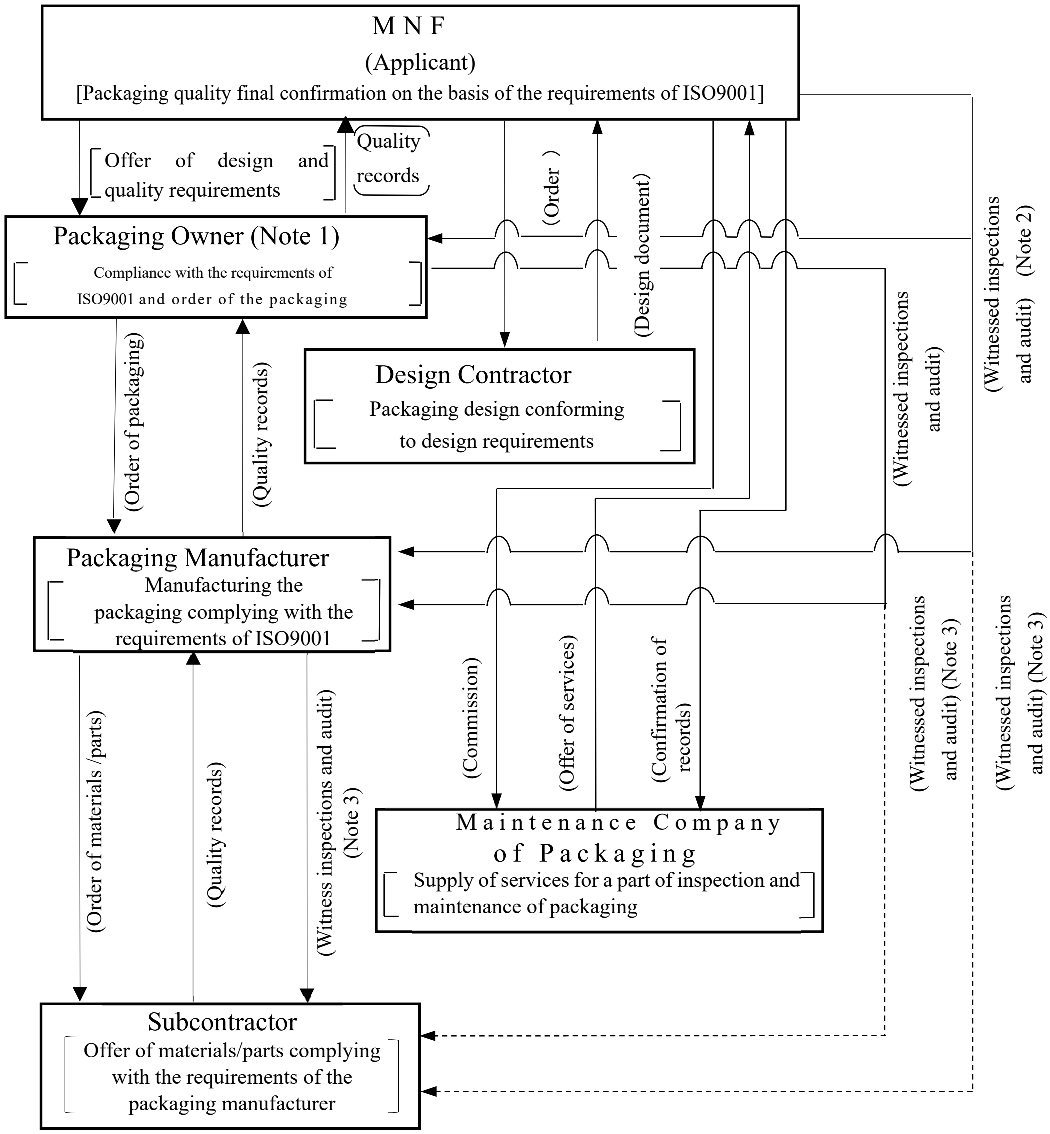
The Procurement Department shall have responsibility and authority for the following items.

1. Signing contracts.
2. Order concerning design, fabrication and procurement of the packaging and its components.
3. Order concerning usage and maintenance of the packaging.

(i) Marketing and Sales Department

The Marketing and Sales Department shall have responsibility and authority for the following items.

1. Confirmation of customer requirements for the packaging.



(Note 1) Omit the box of "Packaging Owner" when MNF orders the packaging directly.

(Note 2) Only when new packaging is fabricated.

(Note 3) To be implemented as needed.

Figure III.1: Quality system of design, fabrication, procurement, maintenance of the packaging

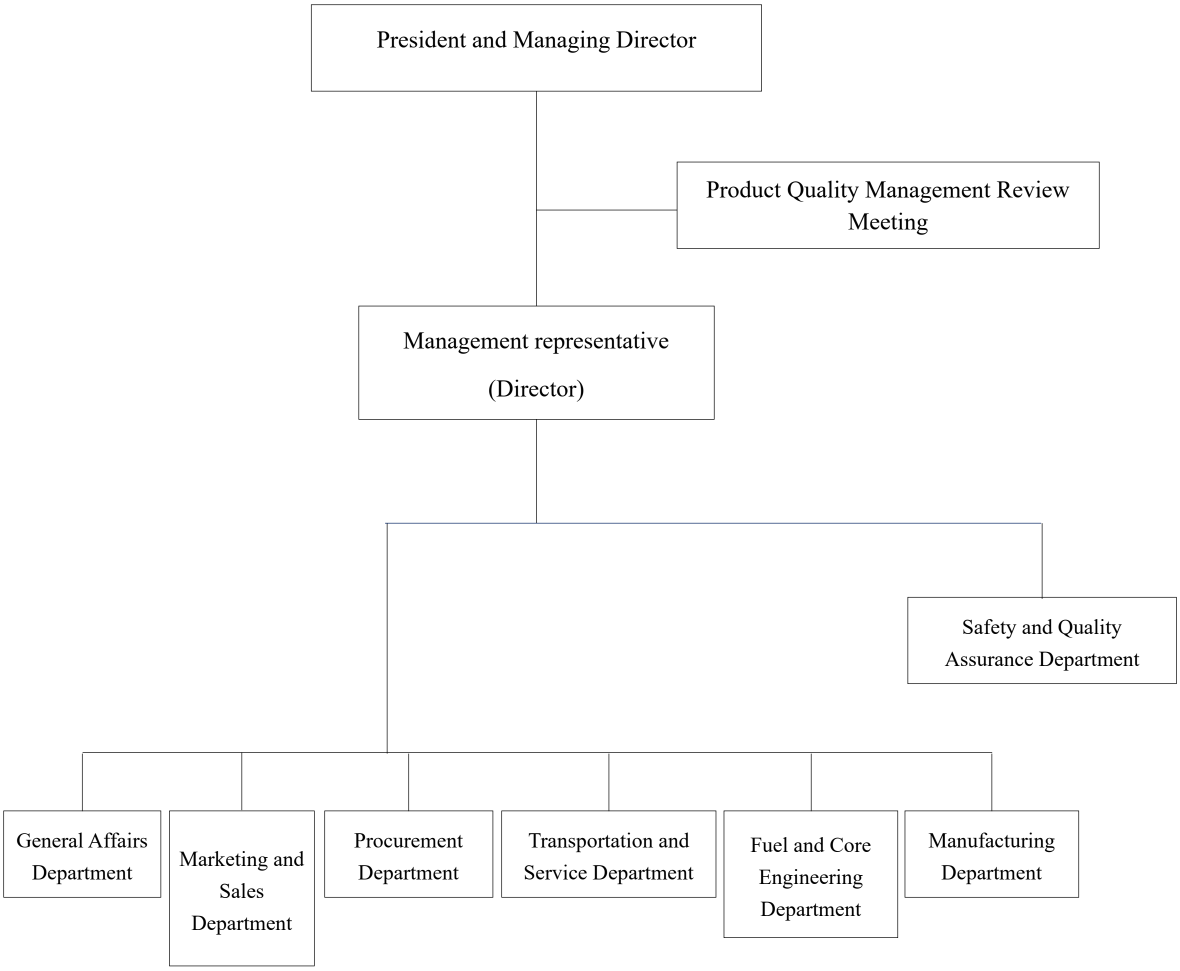


Figure III.2: Organization of MNF packaging quality

III-C Education and training

Necessary education and training programs shall be planned and implemented for personnel involved in services affecting quality concerning the packaging to their needs. Similarly, it shall be confirmed that such education and training programs are implemented for the packaging manufacturer, etc.

(1) Implementation outline

The followings shall be implemented for personnel involved in services affecting the packaging quality.

(a) Planning of education and training.

(b) Implementation of education and training programs and storage of their records.

(c) Requirement of implementation to the packaging manufacturer according to the quality assurance program.

III- D Design control

The following items shall be conducted to ensure that the packaging design conforms to the design requirements.

D.1 Design control for commission to outside the company

(1) Design control

(a) When the Fuel and Core Engineering Department concludes a contract with a packaging design contractor (hereinafter referred to as “designer”), the order specification shall include design specifications based on the customer’s requirements, regulatory technical standards, performance and functional requirements, etc. and be provided to the designer.

(b) When employing new design and technology or special materials, the Fuel and Core Engineering Department shall promote exchange of information between the designer and material suppliers on relations between safety and the specification and reasons behind the decision of the specification as needed to have the designer fully understand the design requirements.

(c) The Fuel and Core Engineering Department shall examine whether the design requirements are reflected appropriately in design documents (drawings, calculation sheets, analysis documents, etc.) prepared by the designer.

(2) Design verification

The Fuel and Core Engineering Department shall examine that the designer has conducted design verification with verification tests and/or alternative calculations, etc. as needed when employing new design and technology or special materials based on the above design results.

(3) Design change

The Fuel and Core Engineering Department shall provide the designer with written details of changes in the design specification. When the department asks the designer to change or the designer himself changes the design due to the changes in the design specification, it shall examine whether the design requirements are reflected appropriately in design documents (drawings, calculation sheets, analysis documents, etc.) prepared by the designer for approval. In addition, the Department shall inform the involved organizations with the written details of the design changes.

D.2 Design control for in-house design

(1) Design plan

The packaging shall be designed by summarizing the design requirements for the packaging based on the long-term transportation plan of packages.

(2) Input into design

Details of the requirements for the packaging shall be confirmed. To design the packaging, the Fuel and Core Engineering Department shall document design input information including written design preconditions, applicable laws/rules and other requirements and confirm that the requirements are appropriate based on the confirmation results of the requirements for the packaging. The design shall be reviewed and input based on the information obtained from a previous similar design, if applicable. The input information shall be recorded.

(3) Output from the designer

Output of packaging design (specifications, drawings, test/inspection procedures, etc.) shall satisfy the requirements for safety required for the packaging, interface between the packaging and its transportation methods, applicable laws/rules and safety analysis documents, which shall be approved by the Fuel and Core Engineering Department. Further, design requirements, acceptance/rejection criteria and characteristics of fabrication, handling and inspections shall be incorporated in output information.

(4) Design review

Output of the packaging design shall satisfy the requirements. Problems detected as a result of the review shall be identified to take appropriate actions. A person in charge of other work shall be assigned for review in addition to the involved person in charge (the designer) as required.

(5) Design verification

The Fuel and Core Engineering Department shall verify that the output from the packaging designer satisfies the requirements provided by input to the packaging design. The verification results shall be recorded.

(6) Design validation

The Fuel and Core Engineering Department shall conduct the design validation to ensure that the requirements according to the specified application or the intended application are achieved. The validation results shall be recorded.

(7) Management of design changes

(a) Management of design changes

The Fuel and Core Engineering Department shall identify and document design changes to review their details.

When the details of the design changes can affect the supplier, the Fuel and Core Engineering Department shall notify the written details of the design changes to those involved.

(b) Management of changes in specification

The Fuel and Core Engineering Department shall identify the changes in the specification at the stage of packaging fabrication, and review, verify and validate the plan documents considering any effects on other specifications. The changes in the specification shall be recorded.

III- E Production order of packaging

The following items shall be conducted to ensure that the packaging conforms to the customer's requirements, regulatory technical standards, design specification in the application for the design approval, its fabrication methods in an application for the packaging approval, etc.

1. Evaluation of the packaging manufacturer

The manufacturing capacity of the packaging shall be evaluated considering the following items on the responsibility of the Safety and Quality Assurance Department.

(a) Technology, personnel and manufacturing facility related to manufacturing of the packaging

(b) Quality policy, quality assurance programs and their implementation of the packaging owner and the packaging manufacturer

(c) Supply history of the packaging or similar products

(d) Usage history of the packaging or similar products and their quality records

(e) Evaluation of prototypes, samples, etc. (in case of no similar products)

2. Requirements for quality management systems toward the packaging manufacturer

When placing a manufacturing order to the packaging owner or the packaging manufacturer, the Fuel and Core Engineering Department shall clearly instruct in specifications and make them fulfill the following requirements on the responsibility of the Fuel and Core Engineering Department.

(a) Scope of service for the packaging owner or the packaging manufacturer

(b) Technical requirements for design, fabrication, inspections, applicable laws, etc.

(c) Requirements for submission of quality assurance programs

(d) Requirements for access to sites of the packaging manufacturer for quality audits and inspections

(e) Requirements for submission and storage of documents and records

(f) The packaging manufacturer shall establish and implement quality control programs specifying organization and procedures for quality control of the products ordered by MNF. The quality control programs shall conform to "III. Quality management details conducted by packaging manufacturers", "Quality management guideline of packaging fabrication method" in the annex of the Nuclear Regulation Authority's application guide on February 26^{th}, 2020. When the packaging manufacturer places an order for part of the packaging structure with its subcontractors, the quality management system requirements toward the subcontractors shall be included in the quality control programs of the packaging manufacturer.

(g) MNF and regulatory authority staff shall conduct inspections during manufacturing and quality control checks of the packaging at the sites of the packaging owner, the packaging manufacturer and their subcontractors.

(h) MNF shall examine and approve criteria for selection of the packaging manufacturer by the packaging owner.

Or, MNF shall examine and approve criteria for selection of the packaging manufacturer and its subcontractors and also check the selection criteria.

(i) The responsibility among service providers involved in manufacturing of the packaging shall be identified by written agreements.

(j) Adequate understanding for values of safety important material specification provided by MNF and their meanings shall be given to the packaging owner, the packaging manufacturer and their subcontractors.

(k) Exchange of information and technical study for execution, analyses, inspection methods of manufacturing among service providers involved in manufacturing of the packaging shall be promoted when employing special materials with more safety importance.

(l) Arrangements of operation instructions and delivery shall be identified to establish a close connection in the process where several providers are involved in manufacturing of the packaging.

(m) When the packaging with nonconformance is used after repairing, written notification shall be given to MNF to receive handling instructions.

In addition, procedures for corrective and preventive actions shall be established and retained to prevent its recurrence.

(n) Conditions of special processes for the packaging manufacturer shall be established in procedures. An important change in the manufacturing process and any supplier change of the packaging manufacturer and its subcontractors shall be reported to MNF immediately for approval.

(o) The packaging owner and the packaging manufacturer shall conduct the following items toward their subcontractors.

(i) Evaluate their subcontractors' ability.

(ii) Instruct the subcontractors to comply with the requirements that MNF asked the packaging owner and the packaging manufacturer to meet.

(iii) Verify that the MNF requirements are satisfied by conducting quality audits and inspections on the packaging manufacturer and its subcontractors by the packaging owner and on its subcontractors by the packaging manufacturer.

However, the following cases are not applied to the above requirements.

(i) Contract work that is approved to be unrelated to inspection items of the packaging license.

(ii) Work under direct control with witnessed inspections by the packaging manufacturer.

(iii) Permissible manufacturing according to official standards like JIS and official qualification systems.

(iv) Allowable work only with inspections at the time of acceptance because of simple and general checking items.

When procuring the packaging already fabricated as a whole or in part, the Safety and Quality Assurance Department shall confirm based on records, etc. that the packaging manufacturer conforms to "III. Quality management details conducted by packaging manufacturers", "Quality management guideline of packaging fabrication method" in the annex of the Nuclear Regulation Authority's application guide on February 26th, 2020, or has the quality management system (ISO9001, etc.) equivalent to it.

3. Verification by inspection and quality audit related to packaging fabrication

The following items shall be conducted to verify that the packaging conforms to procurement requirements.

(1) The Safety and Quality Assurance Department shall conduct quality audits as follows to confirm the implementation of the system provided in the quality assurance programs.

- Timing of implementation: At the time when completion inspection for the first manufacturing lot becomes ready to be conducted and at the time when manufacturing is conducted after three years or more passed from the previous audit
- Audit details: Process control, identification control, control items concerning inspections and tests, control of subcontractors, control of nonconforming products, corrective and preventive actions and items directly related to manufacturing such as statistical method
- Implementation outline: To prepare an audit notification and send it to an audited organization. To conduct an audit using a check sheet in which necessary items are listed.

The Safety and Quality Assurance Department shall establish audit procedures and audit programs and conduct quality audits according to them.

The department also shall identify quality audits on the subcontractors by the packaging manufacturer and take responsibility for conducting quality audits directly on the subcontractors when the need arises.

(2) The Fuel and Core Engineering Department shall prepare inspection procedures, etc. considering safety importance, official standards, official qualification systems, special process conditions, quality control of the packaging owner, manufacturer and their subcontractors for witnessed inspections and record check.

When procuring the packaging already fabricated as a whole or in part, the Safety and Quality Assurance Department and the Fuel and Core Engineering Department shall conduct additional

inspections or re-inspections on the packaging as needed as well as the confirmation of records, etc. on the status of quality activities at the time of fabrication and inspection results to verify that the packaging was fabricated appropriately.

III- F Handling and maintenance

F.1 Maintenance control

(1) The Transportation and Service Department shall prepare procedures that clarify requirements including ones described in the safety analyses report (SAR) and perform periodical inspections and maintenance in accordance with the procedures. As to some of periodical inspections and maintenance services concerning maintenance control of the packaging, the Transportation and Service Department outsources them to maintenance companies with sufficient supplying capacity, if needed.

(2) Results of periodical voluntary inspections and maintenance shall be retained during a specified period.

(3) If part of periodical inspection and maintenance service of the packaging is outsourced, the Transportation and Service Department shall check the records of periodical inspections and maintenance of the packaging submitted by outsourcing companies to verify their implementation status.

(4) When nonconformance products are detected by periodical voluntary inspections and maintenance of the packaging, necessary actions shall be taken according to control, corrective and preventive actions for nonconformance products.

(5) The Safety and Quality Assurance Department shall confirm the implementation status of the maintenance control of the packaging by conducting periodical internal audit for the Transportation and Service Department.

F.2 Inspection prior to shipment

(1) Before transportation, the Transportation and Service Department shall conduct inspections prior to shipment of packages in accordance with the procedures that clarify the requirements. When a witness check or safety check is conducted by the authorities at departure, the Transportation and Service Department shall be subjected to the check.

(2) Before transportation, the Transportation and Service Department shall apply for verification of package transport. In the application, it shall confirm that the packaging to be used has been approved and passed the specified periodical voluntary inspections. However, in the case of transportation which does not use the packaging approved beforehand, it shall confirm that the packaging conforms to the details written in the application for verification of package transport.

(3) Inspection results prior to shipment shall be retained during a specified period.

(4) When nonconformance products are detected by inspections prior to shipment, necessary actions shall be taken according to control, corrective and preventive actions for nonconformance products.

III- G Measurement, Analysis and Improvement

G.1 Internal Quality Audits

Internal quality audits shall be conducted to verify the status and appropriateness of quality assurance activities with respect to MNF activities that affect the packaging quality.

Internal quality audits are conducted as follows.

(1) The Safety and Quality Assurance Department shall plan internal quality audits based on the status and importance of quality assurance activities. Auditors shall be appointed by those who have been certified in accordance with auditing guidelines.

(2) In principle, internal quality audits shall be conducted once a year for departments engaged in quality activities.

G.2 Control of nonconforming products

(1) Procedures for dealing with nonconforming products

When nonconforming products are found at the stage of packaging fabrication, the following procedures shall be implemented to prevent misuse of nonconforming products.

(a) The Fuel and Core Engineering Department shall have suppliers report details of the nonconforming products.

(b) The Fuel and Core Engineering Department shall communicate with a person who makes the reports and confirm the occurrence.

(c) The Fuel and Core Engineering Department, together with the Safety and Quality Assurance Department and related departments, shall review and evaluate the reports from suppliers, decide on actions and give written instructions to suppliers.

(d) The Fuel and Core Engineering Department shall conduct an on-site inspection or record confirmation as necessary in the event of repair or alteration of the packaging.

(2) Holding of nonconforming products

Nonconforming products shall be attached an identification label or physically isolated.

(3) Implementation of actions and Release of Holding

Nonconforming products shall be re-inspected before removing the identification label on the nonconforming products after implementation of actions.

(4) Action reports

The Fuel and Core Engineering Department instructs suppliers to report the following actions.

(a) Confirmation of actions and reporting to relevant internal departments (including departments in charge of quality assurance)

(b) Submission of action reports on nonconforming products to MNF

Action reports of nonconforming products submitted by suppliers shall be submitted to the Safety and Quality Assurance Department via the Fuel and Core Engineering Department.

G.3 Corrective and preventive actions

(1) Corrective actions

Corrective actions shall be implemented in accordance with the following procedures.

(a) Investigations of the cause of nonconformity by suppliers, planning recurrence prevention actions by suppliers, reporting to MNF and validation by MNF

(i) MNF shall review and check the report from the supplier and instruct to consider the cause investigations and the recurrence prevention actions.

(ii) MNF shall review and evaluate the reports on recurrence prevention actions from suppliers and shall instruct implementation of specific recurrence prevention actions as necessary.

(b) Implementation of recurrence prevention actions by suppliers, reporting to MNF and validation by MNF

(2) Preventive actions

The Safety and Quality Assurance Department shall detect potential causes of nonconformities from the results of on-site inspections, external quality audits, internal quality audits and nonconformance reports and shall instruct suppliers to implement preventive actions through the Transportation and Service Department or The Fuel and Core Engineering Department. In the case of internal departments, the Safety and Quality Assurance Department instructs the department to implement preventive actions.

Chapter IV Maintenance of Packaging and Handling Procedure of Nuclear Fuel Package

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IV-A Handling procedure of package

A.1 Loading method

The following describes how to load the contents (fuel assemblies) into the packaging as well as the inspections and special preparation:

(1) Preliminary work and preparation

(a) Prior to packaging work, remove any pool water deposited on the fuel assemblies, check the identification number of the fuel assemblies and carry out a visual inspection (contents inspection).

(b) Check in advance the cranes, lifting attachments and other jigs used for handling the packaging or contents to verify their integrity.

(c) Move the packaging and remove the shock absorbing covers. Move the packaging to the fuel loading work position and install the packaging there in vertical position.

(d) Install the safety frame to protect the packaging against overturning.

(2) Fuel loading operation

(a) Remove the lid tightening bolts and attach the eye bolts. Remove the lid.

(b) Inspect visual appearance of the basket inside the packaging visually (subcriticality inspection).

(c) Package the fuel assemblies along with packaging material (as necessary) and load them into the lodgments in the packaging.

(d) Check that the contents are housed in their corresponding lodgments according to the loading plan.

(e) Inspect the sealing surfaces of the lid gasket and top flange visually to check that they have no harmful deformation, flaw or crack.

(f) Install a new gasket onto the lid and then install the lid onto the packaging body. Tighten the lid tightening bolts with the specified torque.

(g) Remove the quick connection cover and inspect visually the sealing surface of gasket to check that it has no harmful deformation, flaw or crack.

(h) Install new gaskets onto the quick connection cover and then assemble the quick connection cover. Tighten the fixing bolts with the specified torque.

(i) During the steps above, ensure that nothing but those necessary for packaging of the contents is included in the package.

(j) Filling of shielding water, coolant or any other liquid is not applicable since this packaging is of the dry type. The procedure above does not involve putting of water into the packaging and does not require internal drying or remaining water content control of the packaging.

(3) Installation of shock absorbing covers

(a) After moving the packaging, install the top and rear shock absorbing covers to the packaging and tighten the tightening bolts with the specified torque.

(b)

A.2 Inspection before shipment

Carry out the inspection before shipment shown in Table IV-A-1 to verify the package integrity.

A.3 Unloading method

The following describes how to unload the contents from the packaging and necessary safety measures.

(1) Preparation

(a) Check in advance the cranes, lifting attachments and other jigs used for handling the packaging or contents to verify their integrity.

(b) Move the packaging and remove the shock absorbing covers. Move the packaging to the fuel unloading work position and install the packaging there in vertical or horizontal position. Note that the vertical or horizontal position installation will be conducted according to the procedure of the facility where the contents are unloaded.

(2) Fuel unloading

(a) Using the lid handling jig, remove the lid tightening bolts and remove the lid.

(b) Unload the fuel assemblies from the lodgments of the packaging.

(c) Inspect visual appearance of the basket inside the packaging visually to check that it has no abnormal deformation or damage.

(d) Carry out a visual inspection of the lid gasket to check that it has no harmful flaw.

(e) Using the lid handling jig, install the lid onto the packaging body and tighten the lid tightening bolts with the specified torque.

A.4 Preparation of empty packaging

In the empty packaging preparation phase, carry out a visual inspection of the packaging to check that shapes of the packaging body, lid and shock absorbing covers, and the paint have no abnormal flaw or crack. If any abnormality that needs to be repaired is found, carry out re-inspection of the relevant part after repair to verify that the repair has been properly done.

The replacement of the quick connection cover gasket and the sealing surface check described in section A.1 Loading method (A.1(2) (g) and (h)) may be conducted before the preparation of the empty packaging, if so required.

Table IV-A-1: Inspection before shipment procedure

Inspection item	Inspection method	Acceptance criteria
1. Visual inspection	Visual appearance of the package shall be inspected visually.	Shapes and paint of the package shall have no abnormal flaw or crack.
2. Dose rate inspection	Dose rate shall be inspected on the surface and 1m from the surface of the package by using survey meters.	The gamma dose rate shall not exceed the followings: Surface : 2 mSv/h 1m from surface : 100 μSv/h
3. Subcriticality inspection	Visual appearance of the basket inside the packaging shall be inspected visually.	The basket shall have no abnormal deformation or damage.
4. Lifting inspection	Visual appearance of the trunnions and the handling belts shall be inspected visually after lifting operations.	The trunnions and handling belts shall have no abnormal deformation or damage.
5. Weight inspection	The total weight of the packaging and contents shall be determined by calculation and inspected that the result is not higher than the criteria.	The weight of package shall be not more than 19.5 ton. (including channel boxes)
6. Contents inspection	1) The specifications of the fuel to be loaded shall be inspected. 2) The contents shall be inspected visually that the contents have no deformation or damage. 3) Any materials loaded in the packaging shell be checked visually.	1) The package specifications shall be in accordance with the conditions described or to be described in the application for confirmation of the transport by vehicle. 2) The contents shall have no abnormal deformation or damage. 3) Nothing but the fuel assemblies (including channel boxes), the stools, the packaging material and other packaging components shall be loaded.
7. Surface contamination inspection	The surface contamination density of the package shall be measured by smear method, etc.	The radioactive material of alpha emitters shall not exceed 0.4 Bq/cm^2. The radioactive material except alpha emitters shall not exceed 4 Bq/cm^2.

IV-B Maintenance conditions

As a general rule, the periodical inspection will be conducted not less than once every year (or not less than once every 10 uses of the packaging whose usage exceeds 10 times per year) according to the method shown in Table IV-B-1.

If the packaging has been stored without use for long period after the last periodical inspection, another periodical inspection will be conducted according to the method shown in Table IV -B.2 focusing on the packaging exterior only. Before use of the relative packaging, the periodical inspection of the packaging including its internal will be conducted according to the method shown in Table IV -B.1.

If it is determined through the periodical inspection that the packaging needs to be repaired, the repair must be done before the packaging is used for next transport. After repair, the relative part will be re-inspected to ensure that the repair has been properly done.

Table IV-B-1: Periodical inspection procedure

Inspection item	Inspection method	Acceptance criteria
1. Visual inspection	Visual appearance of the body, the lid parts and the shock absorbing covers of the packaging, and the basket inside the packaging shall be inspected visually.	They shall have no harmful deformation, flaw or crack.
2. Subcriticality inspection	Visual appearance of the basket inside the packaging shall be inspected visually.	Visual appearance and shape of the basket shall have no abnormality.

Table IV-B-2: Periodical inspection procedure for long period storage

Inspection item	Inspection method	Acceptance criteria
1. Visual inspection	Visual appearance of the body and the shock absorbing covers of the packaging shall be inspected visually.	They shall have no harmful deformation, flaw or crack.

B.1 Visual inspection

At the periodical inspection, the body and lid parts of the packaging and the shock absorbing covers, and the basket inside the packaging are inspected visually to check that they have no harmful deformation, flaw or crack.

B.2 Pressurized inspection

During the manufacturing process, a specified pressure is applied inside of the packaging and it is inspected that any parts of the packaging body has no permanent deformation.

While the packaging is in service, the body and lid parts are inspected to check that they have no deformation, damage or crack affecting its pressure resistance at the visual inspection of the periodical inspection.

B.3 Leak tightness inspection

During the manufacturing process, the leak rates of the lid gasket and quick connection cover gasket are measured on their double O-ring by pressure rise test method etc.

While the packaging is in service, the gaskets are replaced with new ones and inspected visually that the lid gasket and its sealing surface as well as the quick connection cover gasket and its sealing surface have no harmful deformation, flaw or crack affecting its containment performance.

B.4 Shielding inspection

The dose rates of each part of the package loading the fuel assemblies are measured and it is checked that the shielding performance has not been deteriorated.

This inspection should be carried out as the dose rate inspection during the inspection before shipment.

B.5 Subcriticality inspection

At the periodical inspection, visual appearance and shape of the basket inside the packaging are inspected visually to check that they have no abnormality.

B.6 Thermal test

This inspection is not applicable since the thermal power of the contents is negligible.

B.7 Lifting inspection

After the lifting operation of the packaging, visual appearance and shape of the trunnions and handling belts are inspected visually to check that they have no abnormal deformation.

This inspection should be carried out during the inspection before shipment.

B.8 Workability inspection

This inspection is not applicable since this packaging does not use the auxiliary cooling system, neutron shielding tank or other subsystem.

B.9 Maintenance of subsystem

This is not applicable since this packaging is not provided with any subsystem.

B.10 Maintenance of valves and gaskets of containment system

This packaging is not provided with valves.

The lid gasket and the quick connection cover gasket composing the containment boundary are replaced with new ones every time the contents are loaded.

B.11 Storage of packaging

The packaging will be stored indoor or stored outdoor covered with a waterproof sheet to prevent rainwater poured.

B.12 Storage of records

While the packaging is in service, the manufacturing inspection records and the periodical inspection records will be stored.

B.13 Miscellaneous

Not applicable