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Design of a New MOX Powder Transport Packaging to Support FBR Cycle Development Mission

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INTRODUCTION

The Japan Nuclear Cycle Development Institute (JNC), which plays a leading role in research and development for the Fast Breeder Reactor (FBR) cycle in Japan, has a plan to procure Mixed Oxide (MOX) powder from the Rokkasho Reprocessing Plant (RRP), which the Japan Nuclear Fuel Limited (JNFL) is constructing at Rokkasho-mura, Kamikita-gun of Aomori prefecture for completion in July 2006. The MOX will be for fuel fabrication for the experimental "JOYO" and the prototype "MONJU" FBRs. The mixed oxide storage canister used in RRP is larger than that being used in the Tokai Reprocessing Plant and the Plutonium Fuel Production Facility (PFPF) in Tokai Works of JNC, and it contains approx. 36 kg of MOX powder. Because the existing packagings can not accommodate the RRP type of canister, the design of a new type packaging that can accommodate this canister was implemented. The structure of the packaging was arranged and the safety analysis of the package was carried out.

SCHEDULE OF PACKAGING DEVELOPMENT

Fabrication of fresh MOX fuel assemblies for "MONJU" is interrupted currently. When the fabrication will be resumed for the preparation of the restart of "MONJU", together with continuous fabrication of fresh MOX fuel assemblies for "JOYO", the JNC will need more plutonium. Therefore, the design work for the packaging started in 2002 for the first transport of MOX powder in 2009.
The schedule of packaging development is shown in **Fig. 1**.

Item	Fiscal Year							
	2002	2003	2004	2005	2006	2007	2008	2009
Conceptual Design	▬							
Detailed Design		▬						
Modification Design			▬					
Fabrication of Model Packaging				▬				
Demonstration Tests					▬			
Licensing (Design Approval)						▬		
Fabrication of Packagings							▬	▬
Transport (tentative)								▪▪▪

Fig. 1 Schedule of Packaging Development

OUTLINE OF REQUIREMENTS FOR DESIGN

The outline of the requirements for the design of the packaging is shown below.

(1) To be able to accommodate the storage canister used in RRP.
(2) To meet the requirements specified for a Type B(U)F package in the related laws for transport in Japan and the IAEA regulation for the Safe Transport of Radioactive Material (TS-R-1), 1996 Edition.
(3) To be able to accommodate the packages in an ISO 20ft container.

(4) To meet the restrictions of the related facilities and the carrier with regard to the size and weight of the package.
(5) To consider the structure and the loading method of the storage canister used in RRP with regard to the housing part of the packaging.

CONTENT OF PACKAGING

The content of the packaging is a storage canister that contains MOX powder in three powder cans.
The specifications of the MOX powder, which determines the design of the package, are shown in **Table 1**.

Table 1 Specifications of MOX powder

Item	Specifications per unit
Weight	
Plutonium dioxide + Uranium dioxide	46 kg or less
Plutonium + Uranium	40 kg or less
Plutonium	20 kg or less
Uranium	20 kg or less
Fissile Plutonium	16.6 kg or less
Enrichment	
Plutonium enrichment (fissile Pu /Pu)	83 % or less
U235 enrichment	1.6 % or less
Radioactivity	9.94 PBq or less
Heat generation	700 W or less

OUTLINE OF PACKAGING

This packaging is a dry type, consisting of the body, lid, upper shock absorber, and bottom shock absorber. The external view of the packaging is shown in **Fig. 2**.

(1) Specifications of packaging

(a) Outer diameter	: Approx.	1,440mm
(b) Height	: Approx.	2,210mm
(c) Maximum package weight	: Approx.	4,100kg

(2) Packaging components

(a) Body

The body consists of inner shell, bottom plate of inner shell, upper flange, outer shell, bottom plate of outer shell, attaching lugs for upper and bottom shock absorbers (the above components are made of stainless steel), neutron absorber (stainless steel with 1% boron [95% enrichment ^{10}B]), neutron shielding (resin), side shock absorber, and fin (copper).

The neutron absorber is installed inside of the inner shell, bottom plate of the inner shell, the upper flange body, and the lid.

(b) Lid

The lid is fixed onto the upper flange of the body by securing bolts. Double O-rings on the lid maintain the containment around the joint part of the lid and body.

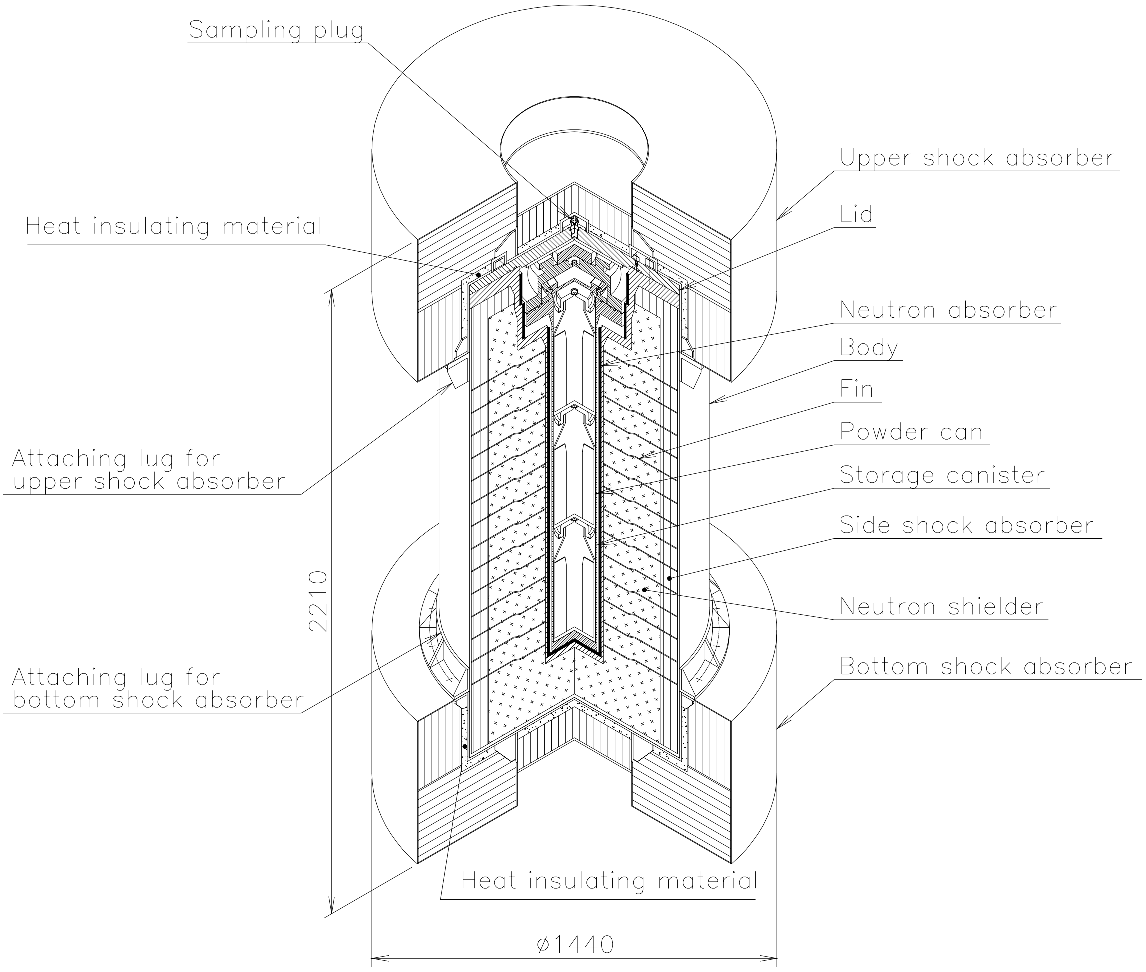
A sampling plug on the lid permits replacing the atmosphere in the packaging by helium gas after loading the MOX storage canister into the packaging. It also is used for checking radioactive contamination by sampling helium gas from the packaging after transport.

To confirm the containment performance, a leak-tightness test hole is provided between the double O-rings on the lid and on the sampling plug respectively.

(c) Shock absorber

There are upper and lower shock absorbers. These shock absorbers are fixed to the top and bottom of the packaging by securing bolts.

The shock absorber consists of a surface enclosure of stainless steel, a shock absorbing layer of balsa-wood (processed to be difficult to burn) and fir-plywood, and a heat insulation layer of alumina cement.



[Unit : mm]

Fig. 2 External view of packaging

OUTLINE OF SAFETY ANALYSIS

(1) Structural analysis

The structural analysis shows that the package meets all the standards as shown below. Code LS-DYNA was used for the evaluation of the drop, and code ANSYS was used for the evaluation of the pressure.

(a) Requirements for “routine conditions of transport”

Chemical and electrical reactions, low temperature strength, possible opening of the containment system by operational mistake, lifting device, tie-down device, pressure, and vibration.

(b) Requirements for “normal conditions of transport”

Thermal test, water spray test, free drop test, stacking test, and penetration test

(c) Requirements for “accident conditions of transport”

Drop Test-I , Drop Test-II , thermal test, and water immersion test

As an example, the maximum deceleration and deformation in Drop Test-I are shown in **Table 2**. The status diagram for the upper corner drop is shown in **Fig. 3**. Deformations of the shock absorber do not exceed the allowable thickness and the stresses occurring on the various locations of the package do not exceed the criteria values.

(d) Requirements for the fissile package under normal conditions of transport and accident conditions of transport.

Table 2 Maximum deceleration and deformation in Drop Test-I

Item		Maximum deceleration (G)	Deformation (mm)	Allowable thickness (mm)
Vertical drop	Upper	300	47	170
	Bottom	289	47	170
Horizontal drop		205	69	138
Corner drop	upper	148	137	296

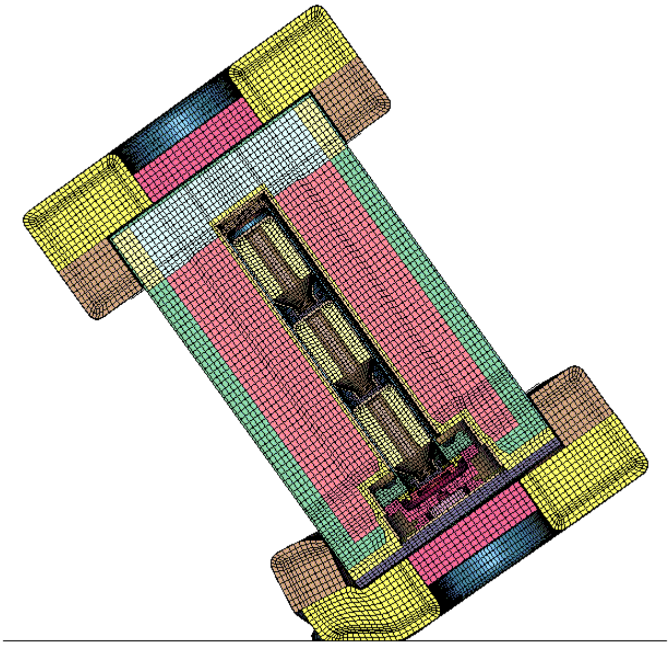


Fig. 3 Status diagram of upper corner drop

(2) Thermal analysis

(a) Normal conditions of transport

Code TRUMP calculated the steady-state temperature distribution.

The result shows that package meets the criteria values of all items as shown in **Table 3**. The integrity of all structural materials of the package can be maintained, even when the package is exposed to temperatures as low as -40℃.

(b) Accident conditions of transport

Code TRUMP also calculated the transient temperature distribution during an accident. The result shows that package meets all the criteria values of all items as shown in **Table 3**.

Table 3 Result of thermal analysis

Location	Normal conditions of transport (℃)	Accident conditions of transport (℃)	Criteria value (℃)
O-ring of the storage canister flange	104 *2	150	200
O-ring of the lid	79 *2	185	300
Sampling plug	82 *2	178	300
Outer shell	62 *1	-	85
Maximum pressure	40 (kPa)	80 (kPa)	700 (kPa)

*1：Solar heat load: none *2：Solar heat load: existing

(3) Containment analysis

Experiments have established the quantity of plutonium dioxide powder that accompanies helium gas that leaks out through a small orifice. The maximum density of plutonium dioxide powder that accompanies the helium gas is reported to be $5\times10^{-3}\mu$ g/cm^{3}.[1] Therefore, MOX powder density which leaks out from the packaging is assumed to be $5\times10^{-3}\mu$ g/cm^{3}. The leak-tightness test before transport must pass the criteria of the being not more than 1.0×10^{-3}Pa·m^{3}/s.

In the containment analysis, assuming that MOX powder leaks into the sealing boundary of the packaging with the density of $5\times10^{-3}\mu$ g/cm^{3}, the leakage rate equivalent to the criteria value under each of the conditions specified in the regulations of transport was compared with the leakage rate at the leak-tightness test. The leakage rate at the leak-tightness test was calculated by using the expression in ISO 12807.

The result shows that the packaging meets the criteria value (1 or less) as follows.

(a) Normal conditions of transport

Margin of pass criteria of the leak-tightness test before transport: 1.77×10^{-1}

(b) Accident conditions of transport

Margin of pass criteria of the leak-tightness test before transport: 3.89×10^{-5}

(4) Shield analysis

Radiation source intensity was calculated by using code ORIGEN2 as follows.

(a) Gamma source intensity: 2.119×10^{14} photons/sec

(b) Neutron source intensity with consideration of effective multiplication factor of the neutron source in the sub-critical system: 5×10^{7} neutrons/sec

[Primary neutron source intensity (α -n reaction, spontaneous fission): 3.040×10^{7} neutrons/sec]

The dose equivalent rates of the gamma source and neutron source were calculated by using DLC23/E library and code DOT3.5 in the case of routine conditions of transport, normal conditions of transport, and accident conditions of transport. The conditions of the shield analysis are shown in **Table 4**. Examples of the shield analysis model are shown in **Fig. 4**. The result shows that the packaging meets the criteria values of all items as shown in **Table 5**.

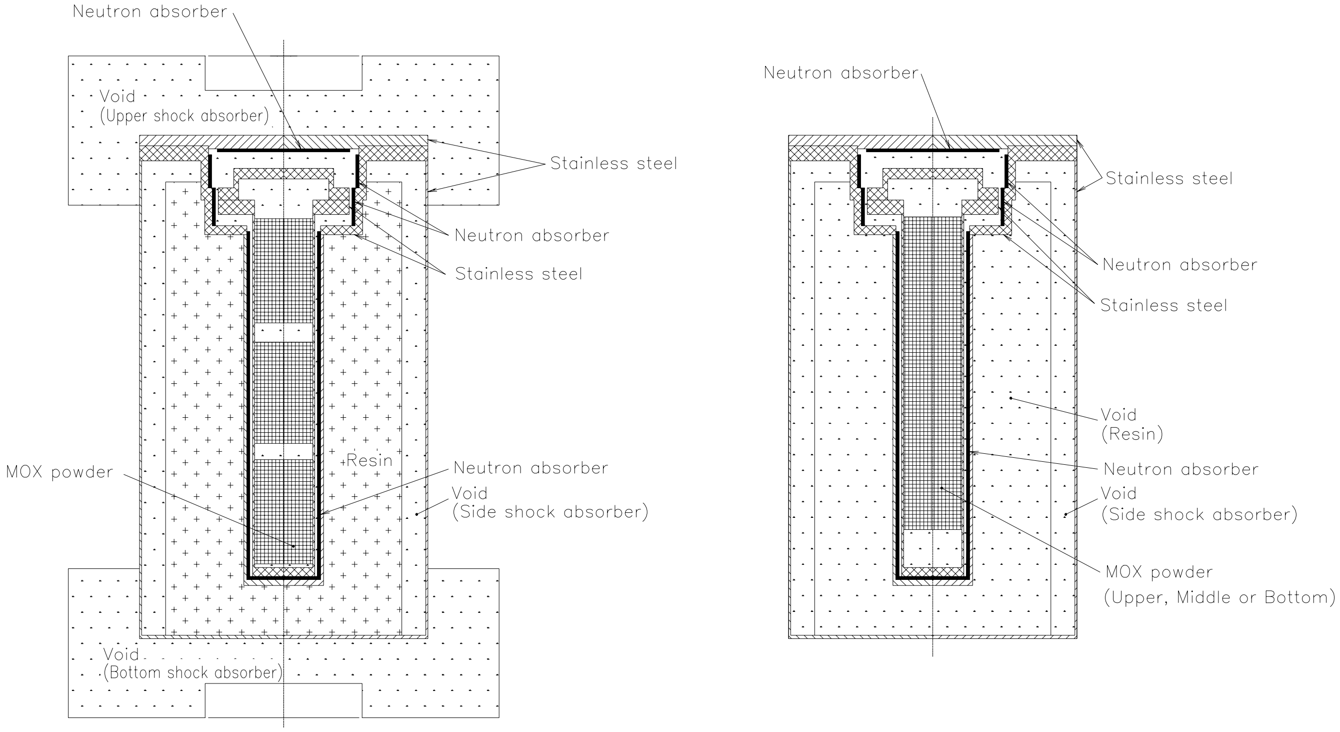
Table 4 Conditions of shield analysis

		Routine conditions of transport	Normal conditions of transport	Accident conditions of transport
MOX powder	Density (g/cm^{3})	1.5		
	Water content (%)	0		
	Position	Powder can: 3 cans		Concentrate at upper, middle or bottom
Upper and bottom shock absorber		· Consideration of only the effect of distance (Void)	· Consideration of only the effect of distance (Void) · Consideration of the deformation at drop	None
Powder can		None		None
Side shock absorber		Void		Void
Neutron shield		Existing		Void

Table 5 Result of shield analysis (unit:μ Sv/h)

Item \ Position	Package surface			At 1m from the surface		
	Upper	Side	Bottom	Upper	Side	Bottom
Routine conditions of transport	660	115	57	60	23	7
Criteria value	2000 or less			100 or less		

Normal conditions of transport	660	115	57	-		
Criteria value	2000 or less					
Accident conditions of transport	-			199	332	143
Criteria value				10000 or less		



Routine conditions of transport Accident conditions of transport

Fig. 4 Shield analysis model

(5) Criticality analysis

The effective multiplication factor (Keff) was calculated by using code system SCALE by "238 group" of the ENDF/B-V library and code KENO-Va.

The conditions of the criticality analysis are shown in **Table 6**. The criticality analysis model is shown in **Fig. 5**. These are the severest conditions in the criticality analysis and were obtained by parametric survey calculations assuming hypothetical entry of water into the packaging. The result shows that the package is sub-critical as shown in **Table 7**.

Table 6 Conditions of criticality analysis

Analysis conditions	Allowable number of packages	No limit	Hypothesizing an infinite number of packages Boundary condition of the analysis model with complete reflection
	Aligned allowable number of the packages		
	Contents	MOX powder (Severest condition of the contents in criticality analysis: density 4.0g/cm^3, all MOX powder gathered into upper end)	
	Damage condition	Regarding upper, bottom, and side shock absorbers (fir-plywood) and neutron shield (resin) as void	
	Water reflection	Assuming outside boundary interface of the packages with complete reflection condition, and that an infinite number of packages exist	
	Water density	Considering that water penetrates the inside sealing device and enters the inside storage canister	

	Concentration of the contents	MOX powder equivalent to 3 cans of powder can concentrates in 1 place

Table 7 Result of criticality analysis

Condition	Keff	σ	Keff +3σ
Damaged isolated-system	0.9367	0.0014	0.9409

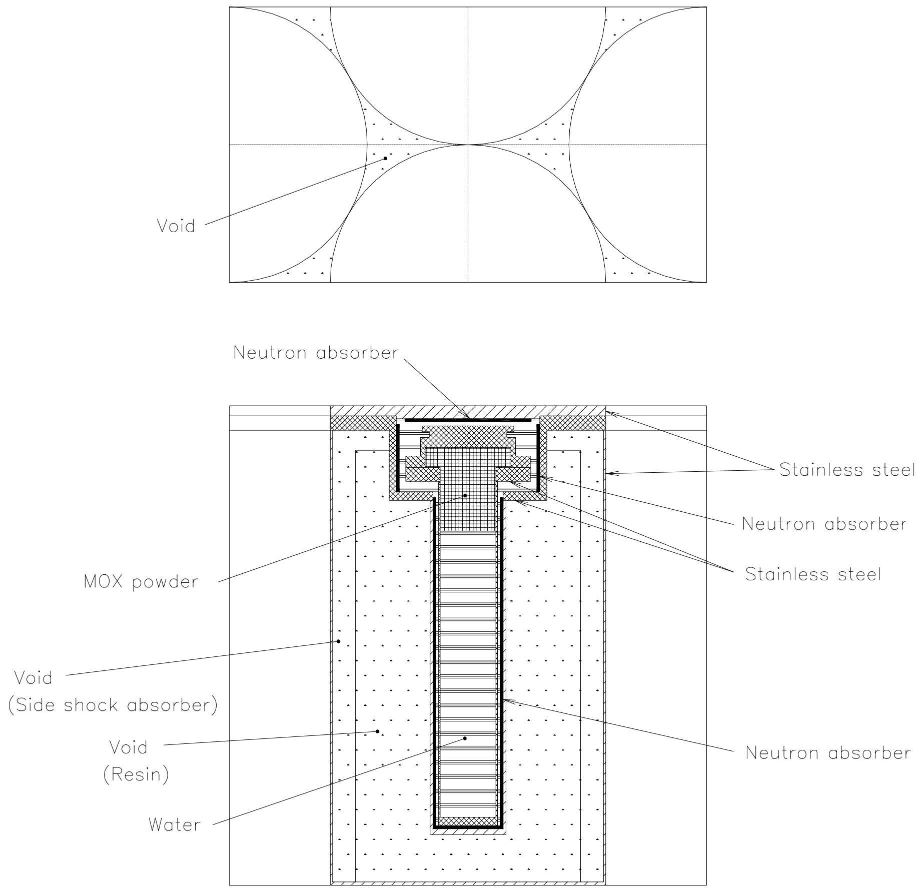


Fig. 5 Criticality analysis model

FURTHER WORK

In the current design result, the dose equivalent rates of the upper part of packaging meet design criteria, but they are larger than in other parts of the package. Therefore, modification of the packaging structure will continue in order to reduce possible exposure of operators to be low as practicable. The safety analysis will be carried out once again.

We are scheduling the safety demonstration test, which is shown in **Fig. 6**, after manufacturing the full scale model of the packaging (prototype packaging).

By comparing the analysis values with the values obtained in the tests on deceleration, strain, deformation and temperature, we plan to confirm the validity of the evaluation method that is used in safety analysis. And we also plan to confirm the integrity of the sealing performance of the prototype packaging by the leak-tightness test.

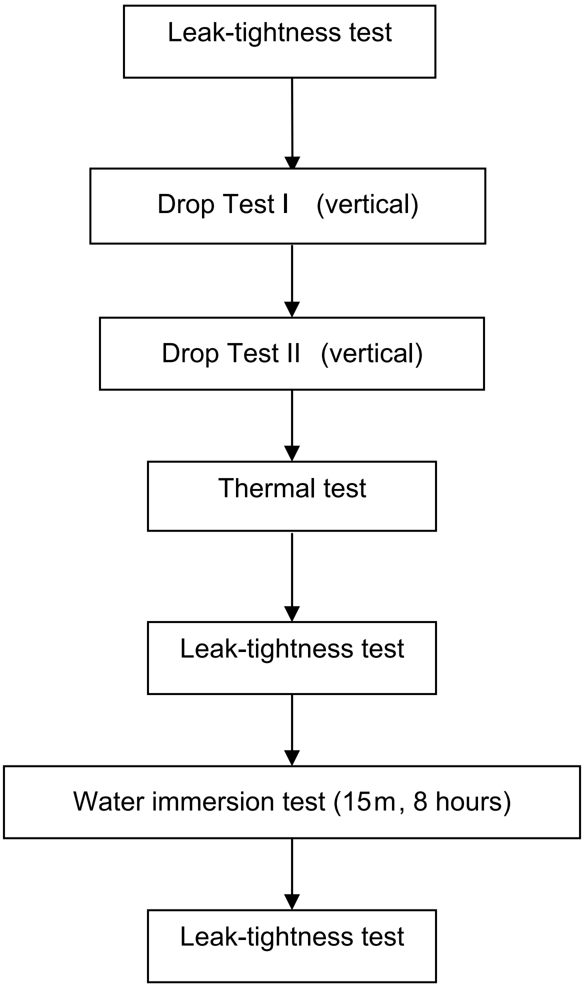


Fig. 6 Items of safety demonstration test (tentative)

CONCLUSION

The detailed design of the packaging for transporting MOX powder from RRP to PFPF has been implemented.

The design is based on the requirements specified for Type B(U)F packages in the IAEA regulation for the Safe Transport of Radioactive Material (TS-R-1), 1996 Edition. In addition, due to the amount of plutonium, the design process has emphasized performance in terms of sub-criticality and an efficient heat release. Packaging is as compact as possible in pursuit of handling and transport efficiency. The weight of a package is limited to 5 tons.

The basic packaging structure is the result of optimization of the configuration and choice of appropriate materials based on a wide variety of analyses and assessments. This ensures sub-criticality with a margin. Moreover, the inside heat release fins have improved the heat transfer. The results of detailed analysis indicate that the package meets all the requirements of Type B(U)F packaging. In the near future, we plan further modification of the packaging structure and a repeat of the safety analysis. The 9 m drop test, a thermal test, etc. will confirm the validity of design of the packaging.

REFERENCE

[1] NUREG/CR-1302 “Study of Plutonium Oxide Powder Emissions from Simulated Shipping Container Leaks”, 1980