Transport Experience of New "TNF-XI" Powder Package

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1. Introduction

Since the Tokai criticality accident in 1999, there has been no specialized manufacturer conducting uranium re-conversion in Japan. For this reason, Nuclear Fuel Industries, Ltd. (NFI) imports from overseas almost all the uranium oxide powder used for manufacturing pellets for nuclear fuel assemblies.

To date, an NT-IX package has been used for transporting the uranium oxide powder. However, due to the adoption of IAEA TS-R-1 into Japanese domestic regulations, we have begun to use a new TNF-XI powder package because the NT-IX package can suffer major deformation under the drop test III condition.

The TNF-XI package was jointly developed by COGEMA LOGISTICS of France and NFI from 2000, and started to be used for actual transportation in 2003. This package has improved transport efficiency, handling operability and safety performance in comparison to its predecessor.

This paper describes the characteristics of the new TNF-XI package and its actual transportation records and performance.

2. NT-IX package

2.1 Outline of NT-IX package

The NT-IX package was conventionally used for transporting uranium oxide powder. As shown in Figure 1, the NT-IX package has a double structure consisting of a 200-liter steel open drum as an outer container and a 16-gallon drum as an inner container. The gap between the outer and inner containers is filled with pearlite alumina cement as a thermal insulating and shock absorbing material. The outer container is structured so that its lid is secured with a ring designed exclusively for a drum by tightening bolts. The inner container lid is sealed with 12 bolts. A plug made of pearlite alumina cement is installed between the outer and inner container lids.

As shown in Figure 1, one inner container holds 3 pails of uranium powder. Since a single pail can hold up to 25 kg of uranium powder, one package can hold up to 75 kg of uranium powder. However, the quantity of uranium oxide powder which can be transported by a package depends on the degree of uranium enrichment because of the constraint imposed by the criticality criterion.

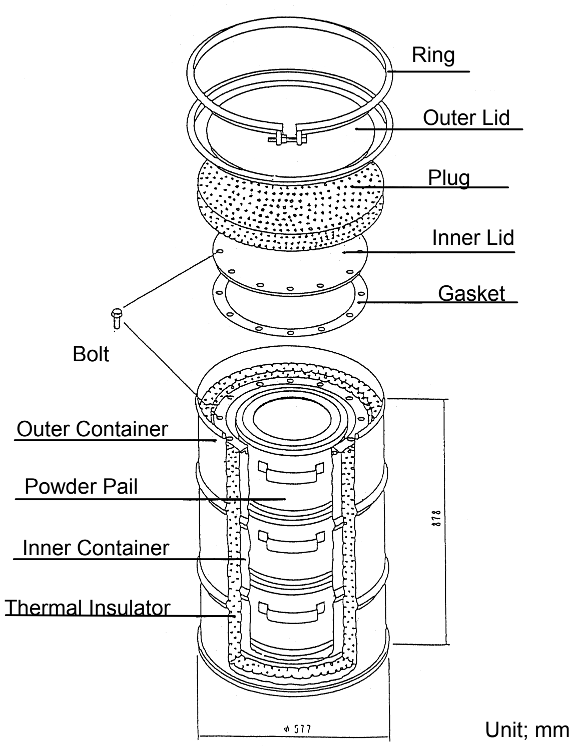

Figure 1 Outline of the NT-IX

Table 1 Maximum loading capacity per package

Uranium enrichment (%)	5.0	4.5	4.0	3.5	3.0
Maximum UO_2 (kg)	31.0	38.0	50.0	62.0	75.0

2.2 Shortcomings of the NT-IX package

As shown in Table 1, although NX-IX package had a maximum loading capacity of 75 kg of uranium oxide powder, it could hold only less than half of the maximum capacity in the case where uranium enrichment was 5%, thus reducing the transportation efficiency.

Since the inner and outer containers were made of iron and were coated on the surface, there were the risks of the coating peeling off from the surface or rust forming during transportation, so frequent maintenance was required in order to keep the integrity of the package.

Furthermore, as the inner container lid is secured with 12 bolts, each of which had to be loosened and then tightened every time powder pails were to be packed or unpacked, a considerable amount of time was required when handling several hundred packages.

Also, there was the risk of the NT-IX package losing its integrity if subjected to the drop test III.

2.3 Results of drop test III

IAEA's TS-R-1 requires an additional test condition for a fissile package, in addition to those required by the previous transportation rules, which states that the drop test III be applied to the package when it has a mass not greater than 500 kg and an overall density not greater than 1000 kg/m^3 based on the external dimensions.

Since the NT-IX package was subjected to the drop test I, in which it was dropped from the height of 9 m, according to the previous transportation rules to evaluate its safety, it was necessary to evaluate anew its safety against the drop test III. Since the NT-IX package weighed about 200 kg, it was speculated that the drop test III, in which a 500 kg iron plate was to be dropped from the height of 9 m onto the specimen, would present severer conditions than the drop test I.

The drop test III according to IAEA'S TS-R-1 was conducted on the NT-IX package. As a result, when the package was placed vertically, package integrity was maintained although the package suffered major deformation. When placed horizontally, the package suffered significant deformation, its inner lid was deformed, and the inner container lost its containment.

In view of these results of the drop test III, it was determined that the NT-IX package could not maintain criticality safety and so should not be used for transporting nuclear material in the future.

3. Design of TNF-XI package

3.1 Design conditions

In developing the new TNF-XI package to replace the NT-IX package, the following design specifications were defined in order to overcome the shortcomings of the NT-IX package and to obtain a new package with improved functionality:

(1) The new TNF-XI package must be able to accommodate powder pails for transportation, which are currently being used at NFI's fuel fabrication plant.
(Although NFI's powder pail is large with the outer diameter of 30 cm, which is disadvantageous for the criticality evaluation, the same powder pails used at the plant will be used for transportation as well in order to avoid decreasing work efficiency due to refilling work.)

(2) The TNF-XI package must be shaped such that it can be loaded in the ISO container in the proper manner, significantly improving the transportation efficiency.
(As the NT-IX package was drum shaped, the inner space of the ISO container could not be effectively used in loading the packages. For the TNF-XI package, the possibility of adopting a rectangular shape will be investigated. In addition, the quantity of uranium oxide powder to be contained in a package will be increased, thereby also improving the transportation efficiency of a single ISO container.)

(3) The TNF-XI package must be easily handled during normal operation.
(The package should be designed so that it can be easily handled by a conventional crane or forklift.

The number of bolts and nuts used in the package should be minimized.)

(4) The TNF-XI package must be structured to facilitate maintenance work.
(The number of replacement parts should be minimized, and must be easily replaced when necessary. Material which does not require painting should be selected. The package should be designed and finished such that its external surfaces are free from protruding features and can easily be decontaminated.)

(5) The TNF-XI package must be designed to comply with the transportation regulations and provide higher safety margins.
(The package must meet the laws in Japan, France and US as well as IAEA transportation rules. In addition, the package must be designed so that safety can be assured with sufficient margins under normal conditions of transport and accident conditions of transport.)

3.2 Outline of TNF-XI package

Figure 2 shows the outline of the TNF-XI package, which was designed based on the conditions mentioned above.

The package is cube-shaped with side length of about 1.1 m. The entire surface is covered with stainless steel. The gross weight of the package is 1050 kg or less.

The TNF-XI package consists of a main body including an outer container, 4 inner containers with neutron absorbers and heat resistant and shock absorbing material, and 4 each of outer and inner lids.

The inner container can accommodate 3 powder pails, the same as the NT-IX package. As the neutron absorber, there are resin containing boron surrounding the lateral sides and stainless steel with boron on the bottom of the inner container.

Each inner container has one outer lid and one inner lid. The outer lid contains heat-resistant and shock-absorbing material and stainless steel with boron.

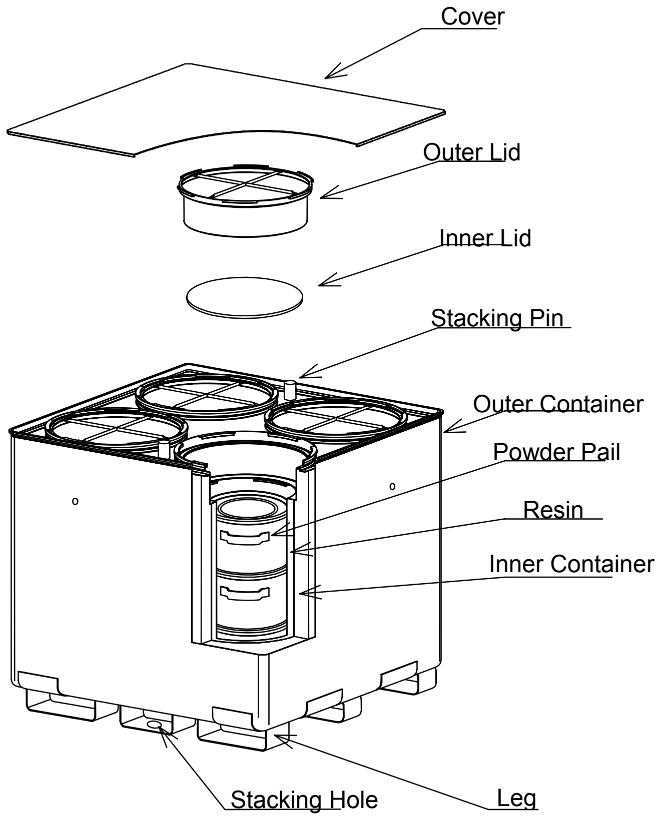

Figure 2 Outline of the TNF-XI

The outer lid is placed in a predetermined position by the bayonet system without bolts and nuts and then secured by rotating it with a handle on the upper surface. The inner lid similarly has the bayonet system and there is also an EPDM gasket on the lower surface so that the inner containers can be sealed.

As the heat-resistant and shock-absorbing material, phenolic foam, which has excellent heat resistance and shock-absorbing capacities, is used. The phenolic foam and resin containing boron are high-performance materials developed by COGEMA LOGISTICS specifically for transportation packages.

The TNF-XI package has been verified to meet the design conditions mentioned above. For example, the transport efficiency has been improved as follows. In the case of 4.1% enriched uranium oxide powder, which would be used in a standard PWR fuel assembly, if the quantities of uranium oxide powder which one 20-feet ISO container can accommodate are compared, the result will be as shown in Table 2, indicating that the TNF-XI package is two times more efficient in transportation than the NT-IX package.

Table 2 Comparison of accommodated amount per container

Package	Weight of content per package (kg)	Number of packages per container* (unit)	Weight of content per container* (kg)
NT-IX	45	60	2,700
TNF-XI	300	18	5,400

*20-feet ISO container

4. Safety analysis of TNF-XI

4.1 Structural analysis

Drop tests and fire tests were performed using five prototype TNF-XI packages to demonstrate that the package can maintain safety under normal conditions of transport and accident conditions of transport. The drop tests were conducted at the Laudun test facility owned by COGEMA LOGISTICS. Two prototypes were used in the preliminary test and three in the qualification test. 1.2 m free drop, 9 m drop and 1 m drop onto a puncture bar tests were performed with the same dropping attitude, and the cumulative effect on the amount of deformation was evaluated.

Figure 3 and Figure 4 shows before and after 9 m drop test.

The major results of the drop tests were as follows:

- Side drop tests showed that the amount of deformation in the package was 17 mm on average and 19 mm at maximum;
- Bottom drop tests showed that the legs were completely crushed and the amount of deformation in the package body was 11 mm on average;
- The deformation as a result of corner drop tests did not extend to the inner container, showing a volume reduction of about 3%;
- In one of the drop tests II, cracks with a maximum width of 12 mm formed in the outer container, resulting from the puncture drop test onto a bar 150 mm in diameter (according to the regulations);
- The inner containers neither deformed nor failed, and the seal of the powder pails was maintained.

Figure 3 Before 9 m drop test

Figure 4 After 9 m drop test

Fire tests were conducted by COGEMA LOGISTICS in a heat treatment furnace located in France. Of the packages which had been subjected to the drop tests, one was used in the preliminary test and two in the qualification test.

The heat treatment furnace was heated to 900°C and kept at that temperature, and then the furnace door was opened to place the test specimen in the furnace. The test specimen was removed from the furnace after being kept for 30 minutes at 800°C or higher.

The test results were as follows:

- Average surrounding temperature while the test specimen was placed in the furnace : 814°C;
- Maximum temperature of inner container gasket: 138°C;
- Maximum temperature of resin containing boron: 107°C;
- As a result of disassembling the test specimen after the fire tests, it was shown that the distance between the inner containers was slightly reduced by up to 4 mm due to side drop, and that the extent of carbonization of phenolic foam was 25 mm on average and 35 mm at maximum.

Thermal analysis and criticality analysis were performed based on these results.

Figure 5 After fire test

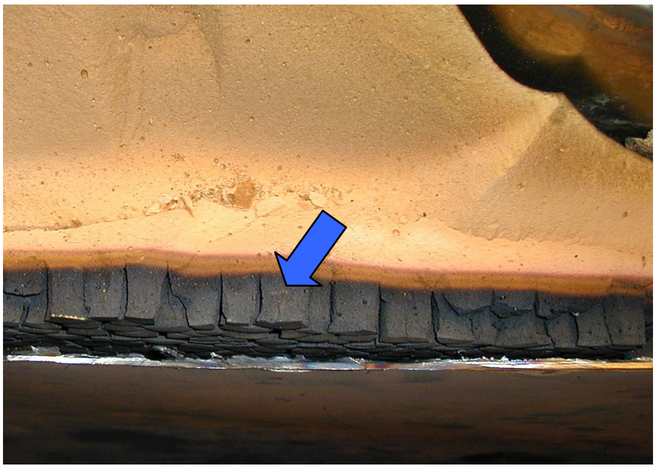

Figure 6 Carbonization of phenolic foam

4.2 Thermal analysis

Since, in conducting the fire tests, it would be impossible to consider temperature increases taking solar insolation into account, computer-code analyses were performed.

For the Japanese licensing application, the analysis was performed using the JTACO-3D code, which is based on the finite element method. A quarter of a package was three-dimensionally modeled. The analysis assumed that solar insolation, which is defined in the transportation regulations as that which evaluates the temperature of the package higher with the ambient temperature of 38°C, was continuously applied for 24 hours.

The analysis results showed that the temperature of the gasket, which was important in maintaining the containment of the inner container, was 52°C, and that of the resin containing boron, which plays an important role in the criticality assessment, was 50°C.

Considering the results of the analysis and fire tests, it was determined that the temperatures of the gasket and resin containing boron under accident conditions of transport would not exceed the criteria as shown in Table 3.

Table 3 Evaluation of temperatures under accident conditions of transport

Part	Acceptance criteria	Result of evaluation
Gasket	180°C	163°C
Resin with boron	150°C	130°C

Therefore, it was concluded that the air-tightness of the inner container would be maintained and there was no need to consider deterioration of resin containing boron in the criticality analysis.

The temperature of the gasket was conservatively used in the evaluation of the internal pressure of the inner container.

Figure 7 shows an example of the analysis results.

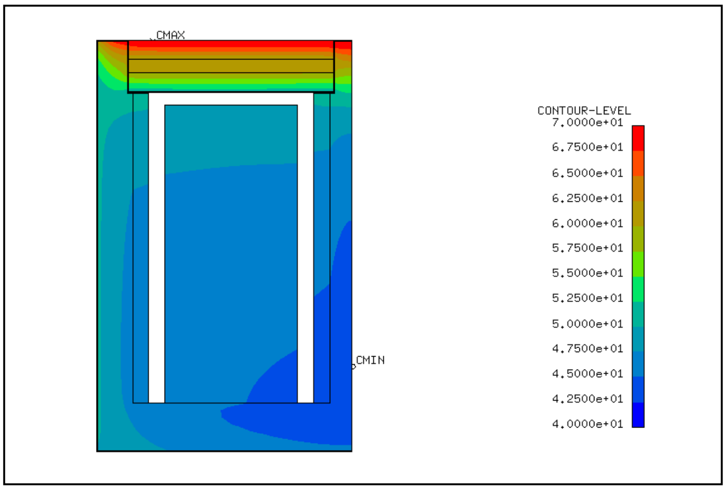

Figure 7 Example of the analysis results

4.3 Criticality analysis

In performing the criticality analysis, it was assumed that each inner container accommodates 75 kg of 5%-enriched uranium oxide powder, one package accommodates 300 kg of 5%-enriched uranium oxide powder, and the limit of the number of packages for transport was 100.

For the Japanese licensing application, the computer code KENO-V.a, which is based on the Monte Carlo method, was used for the analysis.

An analytical model was created as follows considering the results of the tests and analysis:

- 20 mm side deformation and 15 mm bottom deformation were assumed;
- A decrease in the distance between the inner containers was considered;
- 50 mm deep carbonization was assumed on the periphery of the surface of the phenolic foam;
- Powder pails were assumed to be lopsided toward the center of the main body.

In order to perform a survey under the severest conditions, the analysis considered parameters such as water density inside the inner container, water density inside the phenolic foam, fuel region height of the inner container, etc., to evaluate the case in which the effective multiplication factor became the largest.

The results showed that the effective multiplication factor under the severest condition was less than 0.95 even if 3 times the standard deviation derived from the Monte Carlo calculation was added. Therefore, it was concluded that there were no problems with criticality safety.

5. Experience in transportation

(1) Acquisition of permission for package transportation

Since the TNF-XI package is used for international transportation, the certificate of approval for package design has been obtained in Japan, France, U.S., U.K., Canada and Sweden. It is also planned to obtain the certificate in Belgium and Netherlands.

(2) Experience in transportation

The TNF-XI package was first used in early 2003. The NT-IX package was also used in 2003, but since the beginning of 2004, only the TNF-XI package has been used for transportation.

Table 4 shows the experience in transportation using the TNF-XI package.

For each year, the upper row shows the total quantity transported and the lower row shows the quantity of reprocessed uranium transported by a type IP package and the number of times of transportation.

Table 4 Experience in transportation using TNF-XI package

Item	Weight of uranium oxide (kg)	Number of packages	Remarks
2003	92,451	416	Total quantity (12 transport campaigns)
	(11,717)	(45)	Transported as type IP package (One transport campaign for reprocessed uranium)
2004 (Jan – July)	221,257	955	Total quantity (23 transport campaigns)
	(12,072)	(46)	Transported as type IP package (One transport campaign for reprocessed uranium)