Safety Requirements for the Pu Carrier

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INTRODUCTION

Nowadays, the Japanese electric power companies are assigning BNFL in United Kingdom and COGEMA in France for the reprocessing of most of the spent fuel produced by their nuclear power stations. And from this autumn on, a large quantity of plutonium (Pu) recovered in reprocessing will be carried back to Japan.
While we have little experience in the carriage of Pu by sea, safety is an important issue, since an accident, if occurred, would bring about immeasurable influence on society. So, with this in mind, Ministry of Transport (MOT) has considered safety requirements for the structure and equipment of the specially designed ship carrying Pu.

First of all, we investigated the transport system of Pu and then the present situation of countermeasures for safety in the light of its characteristics compared with other chemicals and nuclear fuel. The followings are the outcome of investigation:

(1) Total quantity of Pu to be returned from U.K. and France will be about 30 tons and the first lot being about one ton. It will be packed in casks in the form of plutonium dioxide powder (PuO_2) and then carried by the specially designed ship.

(2) Pu has a long half-life and a high radiotoxicity, since it is alpha emitter having a high-level specific activity. As regards radiotoxicity, in general, physical protection measures are taken such as restriction of leaked quantity specified in respect of each carriage by means of A_2 value as described in the IAEA Regulations.

(3) Pu is thought to have strong chemical toxicity affecting human body. However, it will not be a serious problem as long as sufficient physical protection measures have been taken against radiotoxicity.

(4) Minimum critical quantity of Pu is smaller than that of uranium. But in general, design, manufacturing and handling are controlled in accordance with the IAEA Regulations so as to prevent critical condition even when plural damaged packages are stowed together.

(5) Compared with uranium, Pu can easily be converted to atomic weapons since it can be the material without enrichment. Therefore, high grade physical protection measures to safeguard is required. So, special treatment is provided, as to safe transport of Pu by sea, in the Agreement for Cooperation between the Governments of Japan and the United States of America Concerning Peaceful Uses of Nuclear Energy.

Based on the above investigation, sufficient safety measures are being taken for an individual package. As regards transport method, it will not be necessary to adopt a particular method for Pu, except for safeguarding as mentioned in para. (5) above. However, in view of the large quantity to be carried at one time, we have hereby formulated our fundamental ideas for the structure and equipment of the specially designed ship as follows from the viewpoint of minimizing risks:

1 Safety of the ship should be considered in the light of the potential risk apprehended in the respective parts of the ship.
2 Degree of the risk as mentioned above can be denoted by the total radioactivity, $10^6 A_2$ for instance, of cargo to be carried by one shipment, which is obtained by a multiple of A_2 value.

Requirements for the structure and equipment of the Pu carrier have been considered on the basis of the above. As regards requirements for the structure and equipment of the nuclear fuel carrier, international consideration for the spent-fuel carrier is in progress in IMO. On the other hand, MOT has so far required the special structure and equipment for the ship carrying large quantities of radioactive materials in accordance with the respective level of potential risks, formulating the requirements for the spent-fuel carrier in 1974 and for the low level radioactive waste carrier in 1988 (refer to Table 1 attached).

As a result of comparing potential risk level of the Pu carrier with the above two types of carriers, the Pu carrier was appraised to be almost the same as the spent-fuel carrier. Structure and equipment of the Pu carrier, therefore, were required to be the same as the spent-fuel carrier which had good achievements for safety.

The following requirements have been laid down for the Pu carrier, taking into account the abovementioned fundamental principle and also the recent SOLAS Convention as well as the fact that strict treatment is required for safeguarding of nuclear materials, while Pu has lower calorific value compared with spent fuel.

1. STRUCTURE

1.1 Damage Stability

As regards damage stability, structural requirements for the spent-fuel carrier are fully applied to the Pu carrier. These requirements have been laid down making reference to the damage stability of the type-1 chemical tanker specified by IMO. And in the case of the Pu carrier, damage stability should be better than that of the type-1 chemical tanker in that sufficient stability must be maintained for simultaneous flooding into the holds or other spaces which are located at a distance exceeding B/5 from the shell plating.

Under the assumed damage described in the following paragraphs (i) or (ii), the Pu carrier should satisfy the survival capability requirements (iii).
The permeability of spaces assumed to be damaged should be taken as 85% for machinery space and other spaces at such value as may be determined in accordance with the loading condition of cargo, fuel oil, water ballast, etc. (The beforementioned permeability means a percentage of the volume being able to occupy by water against the entire capacity of the space.)

(i) Side damage

a. Longitudinal extent:	$1/3L^{2/3}$ or 14.5m, whichever is the less (the length of damaged portion on inboard plating of double hull is applied 1/2 length of the above value.) where: L = the ship's length (m)
b. Transverse extent: (measured inboard from the ship's side at right angles to the centerline at the level of the summer load line)	B/5 or 11.5m, whichever is the less (in this case, simultaneous flooding into the spaces located at a distance exceeding B/5 from the shipside should be considered.) where: B = the ship's breadth (m)
c. Vertical extent: from the moulded line of the bottom shell plating at centerline	upwards without limit

(ii) Bottom damage

	for 0.3L from the forward perpendicular of the ship	any other part of the ship
a. Longitudinal extent:	L/10	L/10 or 5m, whichever is the less
b. Transverse extent:	B/6 or 10m, whichever is the less	5m
c. Vertical extent:	B/15 or 6m, whichever is the less	B/15 or 6m, whichever is the less

(iii) Survival capability

a. Stability at final equilibrium after flooding
Residual stability on the righting lever curve ... 20° or more
Maximum residual righting lever .... at least 0.1m

b. Maximum angle of heel at final equilibrium after flooding
not exceeding 15° (or 17° if no deck immersion occurs)
In ships below 150m, the angle of heel should not exceed 25°.
Cross-flooding arrangements may be provided for the purpose of reducing large angles of heel due to unsymmetrical flooding.

1.2 Structure of Cargo Hold
Requirement for cargo hold is basically the same as that of the spent-fuel carrier but, in the light of the recent SOLAS convention, it has been laid down that all parts of the cargo hold must be located more than 760mm apart from the shipside or bottom. This requirement is almost equal to that of IMO type-1 chemical tanker, but requirement for a position of the foremost hold bulkhead is added.

(i) Longitudinal bulkheads should be fitted at both sides of cargo hold. This bulkhead should be located at a distance from the shipside of not less than B/5, which is measured inboard at right angle to the centerline at the level of the summer load line.

(ii) A double bottom should be fitted in the cargo hold and its height should be exceeded the following value:
$468 + 4.1L$mm or $b/8$mm, whichever is the greater
where: b = the breadth of cargo hold (mm)

(iii) Every boundary of the cargo hold should be located at a distance from the shell plating or bottom plating of not less than 760mm.

(iv) A foremost hold bulkhead should be provided at a distance 0.15L abaft the forward perpendicular. This bulkhead should not be used as a collision bulkhead.

1.3 Anti-collision Structure
Requirement for the spent-fuel carrier is applied unchanged to the Pu carrier. Minorsky method adopted for the reactor section of nuclear power ships, "SAVANNA" and "MUTSU", has been modified to make this requirement. The collision energy from a colliding ship is absorbed by the shipside structure with 1/5 of the ship's breadth.

2. EQUIPMENT

2.1 Cask Cooling System
In the case of the spent-fuel carrier, cask cooling system is required in view of the fact that spent fuel has a high calorific value and, depending upon the environmental temperature, designed surface temperature limit specified by the IAEA Regulations might be exceeded.

On the other hand, plutonium calorific value is low and its surface temperature limit is not considered to be exceeded. However, taking into consideration that it may be carried in tropical zone, it is required that a suitable ventilating system etc. should be installed when the surface temperature of the cask is considered to exceed 85℃.

2.2 Tie-down System
As in the case of the spent-fuel carrier, a tie-down system should be installed so as to withstand additional acceleration of one gravity (1 G) in all directions or acceleration for 45° rolling and 10° pitching. This requirement is the same as that adopted for installation of the safety system of the reactor of "MUTSU".

2.3 Radiation Measuring Equipment, etc.
As in the case of the spent-fuel carrier, safety equipments to measure radiation dose equivalent, surface contamination by radioactive materials, etc. and protective equipments against radiation exposure should be provided.

2.4 Bilge Pumping System
As in the case of the spent-fuel carrier, a bilge pumping system, including a tank to store contaminated bilge, should be installed and this system should not be used for other purposes.

2.5 Emergency Flooding System
As in the case of the spent-fuel carrier, a flooding system to protect cargo in the hold in case of fire or other emergency must be equipped. This system should be controlled in the bridge or other safe area and flooding should not endanger the safety of the ship.

2.6 Emergency Source of Electrical Power System
Instead of 18 hours electric supply to the ordinary ocean-going ship, 36 hours supply is required for the Pu carrier as in the case of the passenger ship engaged in international voyage. And the objects to be supplied with electricity are emergency flooding system and nuclear material safeguarding system, which are peculiar to the Pu carrier, in addition to fire alarming, navigational radar, fire extinguisher and other systems as in the case of the ordinary ocean-going ship.

2.7 Navigational Equipment
In addition to ordinary navigational systems, extra radar, collision preventing system and positioning system should be equipped to promote the safe maneuvering.

3. STRUCTURE and EQUIPMENT for PHYSICAL PROTECTION

In view of the physical protection for safeguarding, Pu is classified as Category I when it reaches two kilograms (2 kgs) and high grade physical protection measures should be taken compared with spent fuel.
Accordingly, the following structure and equipment are required making reference to the Annex 5-B of Agreement between Japan and the U.S.A. Concerning Peaceful Uses of Nuclear Energy and other provisions.

1 Monitoring system for the packages
2 Warning system to keep off the area where packages are stowed
3 Extra communication system in addition to the ordinary one
4 Structure and equipment to prevent removing packages easily
5 Structure and equipment enabling the ship to make voyage without calling.

Table 1 Specification of Specially Designed Ship

Type of Ship / Item	Spent-Fuel Carrier (PNTL Ship)	Low Level Waste Carrier	Plutonium Carrier
【CONSIGNMENT】 Type of package	Type B	Type IP (~ 3,000 drums)	Type B
Contents	Spent fuel (Nuclear fuel)	Radioactive waste (mixed with cement, etc.)	Plutonium oxide (Nuclear fuel)
Radionuclide	^{238}U, ^{239}Pu, ^{89}Sr, ^{90}Sr, ^{106}Ru, ^{134}Cs, ^{137}Cs, ^{137}Ba, etc.	^{54}Mn, ^{60}Co, ^{134}Cs, ^{137}Cs, etc.	^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, etc.
Radioactivity (per ship, unit-TBq)	$\sim 10^7$ TBq	$\sim 10^2$ TBq	$\sim 4\times 10^5$ TBq
Radioactivity (per ship, unit-A_2)	$\sim 10^8$ A_2	$\sim 10^2$ A_2	$\sim 10^8$ A_2
【VESSEL】 Deadweight	about 3,000 tons	about 3,000 tons	about 3,000 tons [1]
Radiation Shielding	Packaging and ship's shielding installation	ship's shielding installation	Packaging [and ship's shielding installation] [2]
【Criticality safety】	need	no need	need
【Safety requirements】	Division notice 610 in 1974	Division notice 450 in 1988	Division notice 604 in 1991
【Service area】	Route from Japan to U.K. and France	Area surrounding Japanese islands	Route from U.K. and France to Japan (non-stop)

[1]: Deadweight is estimated about 3,000 tons including the cargo and safety margin on the basis of 700-ton fuel oil and 200-ton freshwater which should be stored to ensure the voyage without calling between Europe and Japan.

[2]: Shield installation is blocked in square bracket since there is no need to equip owing to the packaging specification.