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# SAFE TRANSPORT OF NUCLEAR FUEL MATERIALS IN JAPAN

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## ABSTRACT

In Japan, poor in energy resources, it is one of the major national energy policies to establish a nuclear fuel cycle. Under the circumstances, Nuclear Fuel Transport CO., Ltd.(NFT), as a sole domestic company specializing in transporting nuclear fuel materials in Japan, has engaged in the transport business over the past 30 years, since its establishment in 1973. At present in Japan, construction of nuclear fuel cycle facilities of Japan Nuclear Fuel Limited(JNFL) in Rokkasho-mura, Aomori Prefecture is underway. Some of them, a uranium enrichment plant, a low level radioactive waste(LLW) disposal center, a high level radioactive waste(HLW) storage center and a spent fuel(SF) storage facility, a part of spent fuel reprocessing plant, have already started operations. NFT is mainly responsible for transporting SF and LLW generated from the domestic nuclear power plant to the nuclear fuel cycle facilities. These transportations have been securely carried out following the rigorous national transport regulations, mainly based on the IAEA Safety Transport Regulations and set distinguished records. This paper outlines NFT's transport system of SF and LLW, the regulatory framework and the transport performance.

***Keywords:*** *Transport, Spent fuel, Low level radioactive waste*

## 1. Introduction

Japan is making a steady progress to establish the nuclear fuel cycle essential for the nation's long-term energy security. An essential component of this is a reprocessing of spent fuel(SF) which extracts the remaining uranium and plutonium for recycling. The Power Reactor and Nuclear Fuel Development Corporation (PNC, its current name is Japan Nuclear Cycle Development Institute(JNC)) has been operating a reprocessing plant in Tokai-mura, Ibaraki Prefecture since 1977. However, since the capacity of the plant is insufficient, electric power companies had consigned reprocessing operations to overseas companies. Shipments to the overseas reprocessing plants have completed in 1999 with the reprocessing contract terminated. After this, spent fuel generated from the nuclear power plant was to be sent to the reprocessing facility of JNFL, in Rokasho-mura, Aomori Prefecture. In December 1999, a spent fuel storage facility, a part of the reprocessing plant started operation. Other nuclear cycle facilities in Rokkasho, a uranium enrichment plant and a low level radioactive waste(LLW) disposal center already started operations in 1992, a high level radioactive waste(HLW) storage center in 1995. The reprocessing plant is still under construction toward starting a commercial operation (annual capacity 800 MTU of spent fuel) in 2006. Fig.1 shows the locations of nuclear power stations and nuclear fuel facilities in Japan.

Nuclear Fuel Transport CO., Ltd.(NFT), as a sole domestic company specializing in transporting nuclear fuel materials in Japan, has engaged in the transport business over the 30 years, since its establishment in 1973. NFT is mainly responsible for transporting by sea and land, SF from the domestic nuclear power plants to the Tokai Reprocessing Plant of JNC and the Rokkasho Reprocessing Plant of JNFL, and LLW generated from the domestic nuclear power plant to the LLW Disposal Center in Rokkasho. In addition, we also transport by land, a high-level radioactive vitrified residue and a natural uranium hexafluoride, transported from overseas to the Mutsu-Ogawara Port, nearby Rokkasho. These transportations have been surely carried out following the rigorous national transport regulations, mainly based on the IAEA Safety Transport Regulations and set distinguished records.

This paper outlines NFT's transport system of SF and LLW, the regulatory framework and the transport performance.

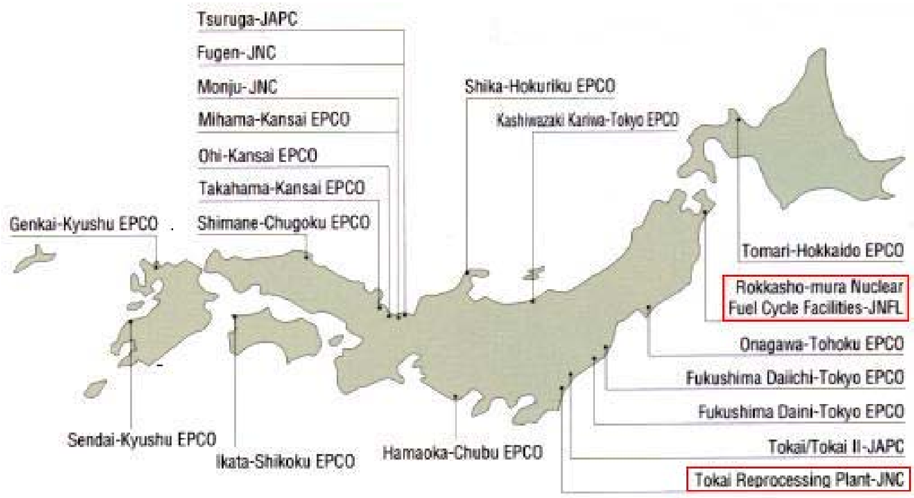



Fig.1 Locations of nuclear power stations and nuclear fuel facilities in Japan

2. Transported Materials

2.1 Spent fuel

1) Configuration of fresh fuel assemblies

There are two types of fuel assemblies for light water reactors, PWR and BWR.

(a) PWR fuel assembly (shown in Fig.2)

A PWR fuel assembly is an assembly loading fuel rods, containing $UO_2$ pellets of 3～4% uranium-235, into an array of 14×14, 15×15 and 17×17 square lattice. There are two kinds of assemblies: one is composed of fuel rods only, the other consists of fuel rods and control rod cluster. The weight of a single assembly is approximately 600 kg and the total length, approximately 4.2 meters.

(b) BWR fuel assembly (shown in Fig.3)

A BWR fuel assembly is an assembly loading fuel rods, containing $UO_2$ pellets of 2～3% uranium-235, into an array of 8×8 square lattice. The weight of a single assembly is approximately 200 kg and the total length, approximately 4.5 meters.

2) Characteristics of spent fuel

Nuclear fuel loaded into the light water reactor is taken out of its reactor core as "spent fuel" after a few years of irradiation in the reactor. Spent fuel contains residual uranium, plutonium and fission products. Fission products have a great amount of radioactivity and generate decay heat corresponding to the radioactivity.

Table 1 shows typical specification of spent fuel which was used as basic design for NFT type casks.

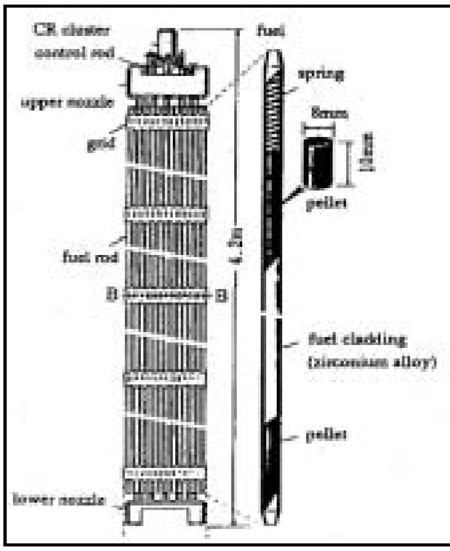



Fig.2 PWR fuel assembly

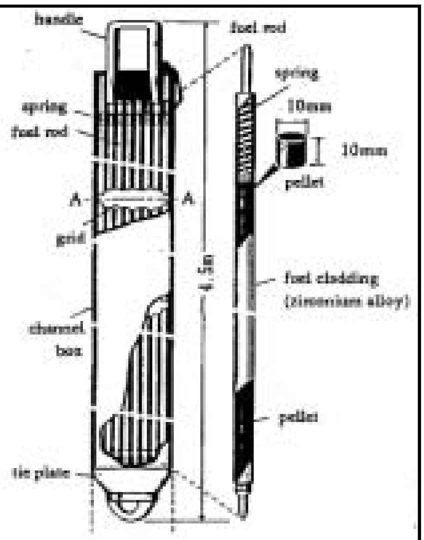



Fig.3 BWR fuel assembly

Table 1 Typical specifications of spent fuel

| Type of fuel | PWR Fuel | | BWR Fuel | |
|---|---|---|---|---|
| | conventional fuel | high burn-up fuel | conventional fuel | high burn-up fuel |
| Material: Fuel | $UO_2$ | $UO_2$ | $UO_2$ | $UO_2$ |
| Cladding | zircalloy | zircalloy | zircalloy | zircalloy |
| Initial enrichment (%) | 3.5 | 4.2 | 2.6 | 3.6 |
| Burn-up; average (MWD/T) | 35,000 | 44,000 | 27,500 | 40,000 |
| maximum (MWD/T) | | 48,000 | | 50,000 |
| Cooling period (days, min.) | 240 | 810 | 360 | 1,050 |
| Heat output (kW/assembly) | 4 | 2.5 | 1.5 | 0.7 |
| Major radionuclei | U-238, Pu-239, Sr-89, Sr-90, Ru-106, Cs-134, Cs-137, Ba-137 | | | |
| Radioactivity (TBq) | $3 \times 10^4$ | $2 \times 10^4$ | $1 \times 10^4$ | $6 \times 10^3$ |

2.2 Low level waste

LLW generated from the domestic nuclear power plants is packaged into 200-liter drums and temporarily stored on site. At the end of March 2003, LLW equivalent to about 420,000 drums are stored at nuclear power plants throughout Japan. LLW disposal center only accepts LLW in the form of cement asphalt or plastic homogenized solids within the regulatory specific radioactivity limits (e.g. Co-60 : $1.11\times 10^{13}$ Bq/ton, Ni-63 : $1.11\times 10^{13}$ Bq/ton).

3. Regulatory Framework

3.1 Regulations and competent authorities

Transport of nuclear fuel materials in Japan is governed and regulated by the competent authorities, mainly based on the two national law; Nuclear raw material, nuclear fuel and nuclear reactor control Law and Ship safety Law. The former is based on the Safety Transport Regulations of International Atomic Energy Agency (IAEA), the latter, SOLAS Convention of International Maritime Oraganization (IMO).

Ministry of Economy, Trade and Industry (METI), Ministry of Education, Culture, Sports, Science and Technology (MEXT), and Ministry of Land, Infrastructure and Transport (MLIT), Japan Coast Guard (JCG) and prefectural public safety commissions (PSC) are respectively responsible for regulating nuclear fuel materials transport outside/inside the nuclear power plants and fuel cycle facilities. The basic regulatory framework for nuclear fuel materials transport in Japan is shown in Fig.4.

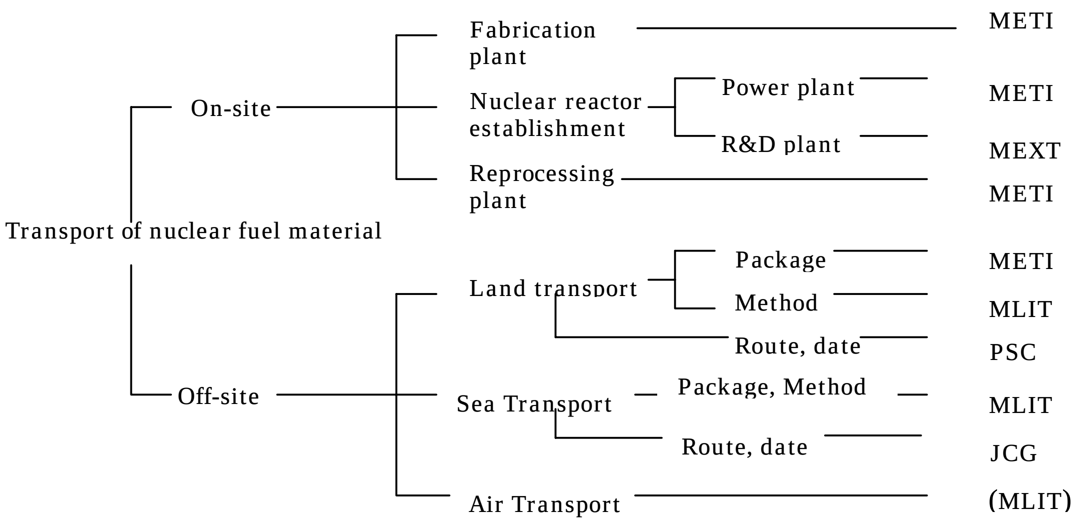



Fig.4 The basic regulatory framework for nuclear fuel material transport in Japan

3.2 Approval procedures

Confirmation of safety for the packages containing nuclear materials and the transport methods are implemented by the competent authorities following the three phases;

1) Approval of package design:
The competent authorities confirm whether a package design meets the technical requirements, by performing safety analysis in terms of package structure, heat, containment, shielding and criticality.
2) Approval of packaging:
The competent authorities confirm whether a transport packaging is manufactured in accordance with the approved package design.
3) Pre-shipment confirmation for package and method of transport:
Prior to shipment, a package is inspected for such items as surface dose rate, sealing performance, etc. Method of fastening the package to the conveyance, and method of radiation exposure control is also verified.

4. Transportation System

4.1 Transport process

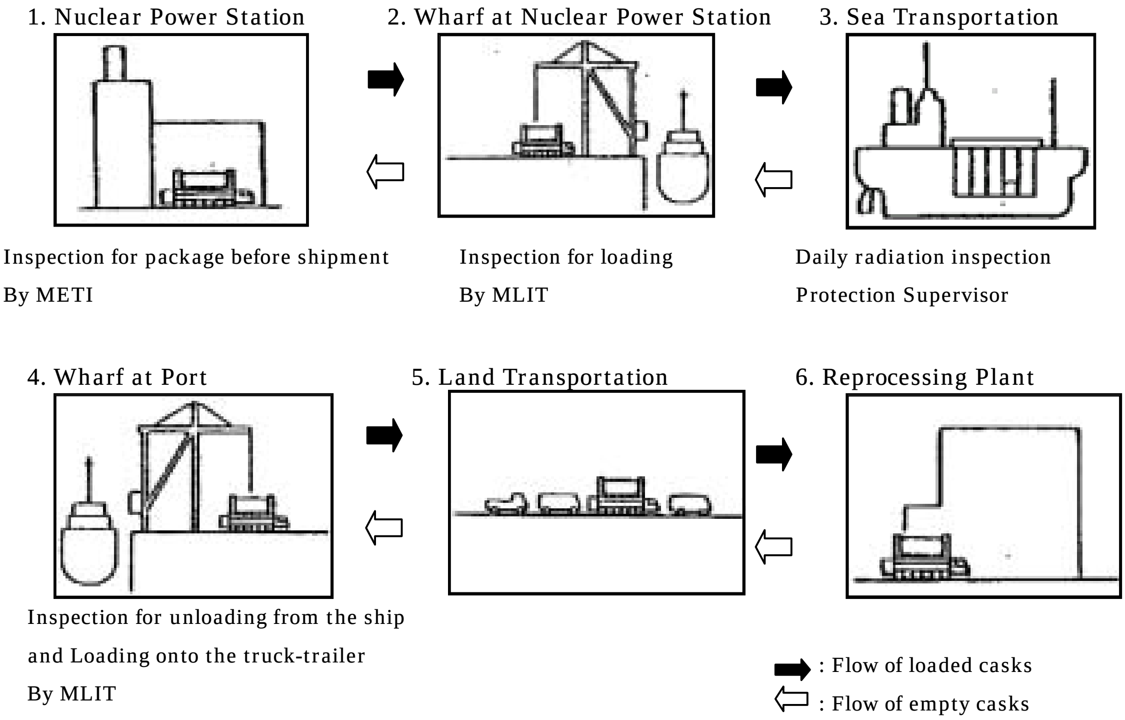
4.1.1 SF Transport process

NFT started in January 1978 to transport spent fuel (SF) from the domestic nuclear power plants to Tokai Reprocessing Plant of PNC. The SF transport operations are as follows;

- At a nuclear power plant, SF is loaded into the dedicated casks, that is, 7 PWR or 17 BWR fuel assemblies for each type of cask.
- After the casks were confirmed to comply with the regulatory requirements, they are transferred to the on-site private port or near-by public port.
- The SF casks are loaded into the dedicated SF transport ship by using a wharf crane.
- The ship carries the SF casks to the private port of Japan Atomic Power Company (JAPC) located in Tokai-mura.
- At the port, SF casks are unloaded from the ship by a wharf crane and loaded onto the dedicated SF transport truck-trailer. After safety inspection and radiation measurement of the casks, they are transported in a fleet to the Tokai Reprocessing Plant.

The SF transport operations are illustrated in Fig.5. Amount of SF transported from the nuclear power plants to the Tokai Reprocessing Plant was approximately 930 MTU, as of March 2003. NFT also started in September 1998 to transport SF to Rokkasho Reprocessing Facility of JNFL, basically in the same way.

Fig.5 SF transport operations



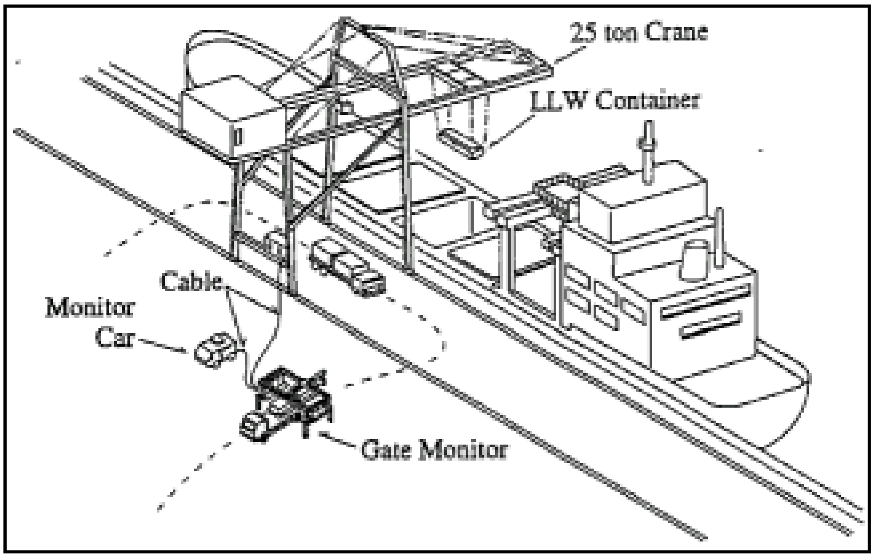
4.1.2 LLW transport process

NFT started to transport LLW in December 1992 from the nuclear power plants to the LLW Disposal Center of JNFL in Rokkasho. The LLW transport operations are as follows;

- At a nuclear power plant, LLW drums are confirmed to comply with the disposal requirements and packaged in the dedicated containers, eight for each, and then transported to the on-site private port or near-by public port.
- LLW containers are loaded into the dedicated LLW transport ship by using on-board crane.
- The ship carries the containers to Mutsu-Ogawara port (MO port).
- At the MO port, the containers are unloaded from the ship by a 25-ton wharf crane and loaded onto LLW transport trucks, two for each, and then radiation level around the vehicle is checked by automatic radiation measurement equipment.
- The containers are carried through the private road to the LLW Disposal Center, which is located approximately nine kilometers away from the wharf.
- The drums are unloaded from the containers, confirmed again to meet the disposal requirements and buried in a concrete pit.

The unloading operations of LLW containers are illustrated in Fig.6.

Fig.6 Unloading operation of LLW containers




4.2 Transport packages

4.2.1 SF transport package

So far, six types of NFT casks (two for PWR and four for BWR) were designed and manufactured, according to a cask handling capacity in the nuclear power plants (i.e. crane power to lift the casks, space to handle the casks, etc.). High burn-up fuel to be gradually loaded in the future was also considered in the design. The Dimensions and Weights of NFT-type Casks are shown in Table 2, Specifications of the high burn-up fuel in Table 3 and overview of a typical NFT-Type Cask in Fig.7.

Table.2 Dimensions and Weights of NFT-Type Casks

| Type of Cask | Dimension Limits | Weight Limits |
|---|---|---|
| NFT 10P | $2.6m^{D} \times 6.2m^{L}$ | 75 ton |
| NFT 14P | $2.6m^{D} \times 6.3m^{L}$ | 115 ton |
| NFT 12B | $2.3m^{D} \times 6.4m^{L}$ | 73 ton |
| NFT 22B | $2.6m^{D} \times 6.3m^{L}$ | 97 ton |
| NFT 32B | $2.4m^{D} \times 6.4m^{L}$ | 106 ton |
| NFT 38B | $2.6m^{D} \times 6.4m^{L}$ | 118 ton |

Table.3 High Burn-up Fuel Specifications

| Contents | Enrichment(w%) | Average burn-up (MWD/MT) | Cooling Time(month) |
|---|---|---|---|
| PWR fuel | 4.0～4.1 | 44,000 | 21(for large type)<br>15(for small type) |
| BWR fuel | 3.5～3.6 | 40,000 | 35(for large type)<br>19(for medium and small types) |

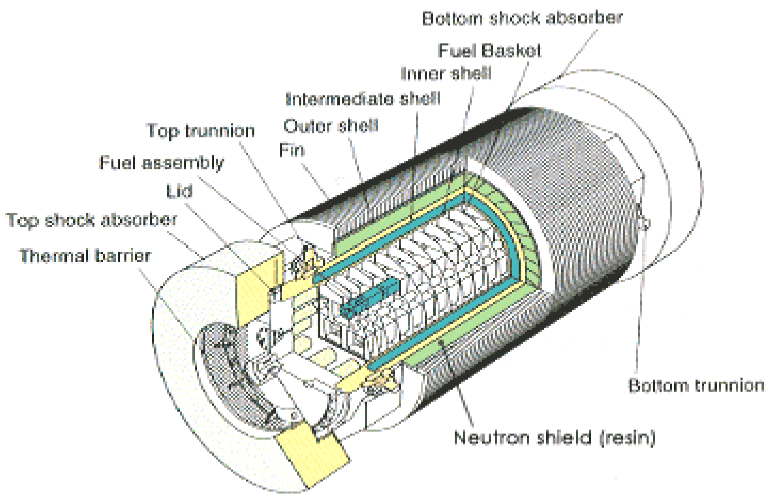



Fig.7 Overview of a typical NFT type Cask

4.2.2 LLW transport package

In developing the LLW transport packaging, NFT mainly considered for their safety and ease of handling. The packaging has the following special features compared to the ordinary freight containers.

1) Most containers used for the transport of ordinary cargo are either 6 or 12 meters in length, on one hand, the LLW transport container is much smaller as shown in Fig. 8. However, the same materials are used for their frames, steel plates and brackets, the structure results in very strong. Total weight of the LLW transport package is about 5 ton and about 1 ton for the container itself.
2) The packaging lid is securely fastened down with four bolts, not to be opened like an ordinary container.
3) To ensure that the drums do not move during transport, they are secured firmly by rubber packing on the lid and brackets on the floor.
4) The loading/unloading operation of the packages can be performed remotely by crane. Opening/closing operation of the lid is also carried out remotely.
5) Identification number of the packages can be automatically read by Data Carrier (DAC).

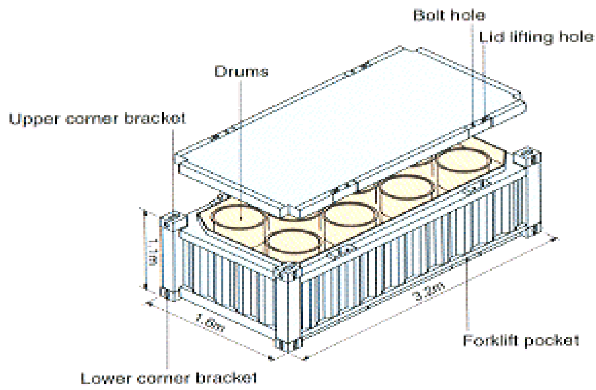



Fig.8 LLW package and drum

4.3 Transport Ship

The dedicated ships for each SF and LLW transport are designed and constructed with the following special features.

4.3.1 SF Transport Ship

NFT use the two dedicated ships for SF transport. One is Hinoura-maru(accommodating up to 4 SF casks) for Tokai Reprocessing Plant, the other is Rokuei-maru (accommodating up to 20 SF casks) for Rokkasho Reprocessing facility. Fig.9 shows the main system arrangements of Rokuei-maru.

1)Design requirements

The ship should be constructed to conform to the “Special Criteria for Irradiated Nuclear Transport Ships” which is based on the INF code of IMO.

2)Special features

The ship embodies the following features:

a) Double-hulled structure

The double-hulled structure ensures the safety of the cargo by preventing the seawater from entering into the hull and leading to sink in the event of a collision or stranding.

b) Refrigeration system and emergency flooding system

The refrigeration system keeps the ambient temperature around the casks at 38 degrees or less and the surface temperature of the casks at 85 degrees or less. In addition, an emergency system for flooding the holds with water can be operated from the bridge. These systems are redundant.

c) Tie-down device for securing casks

Tie-down device prevents the casks from moving and overturning in the hold. A fixed guide and rotating cleat system secure the casks. These can be remotely controlled.

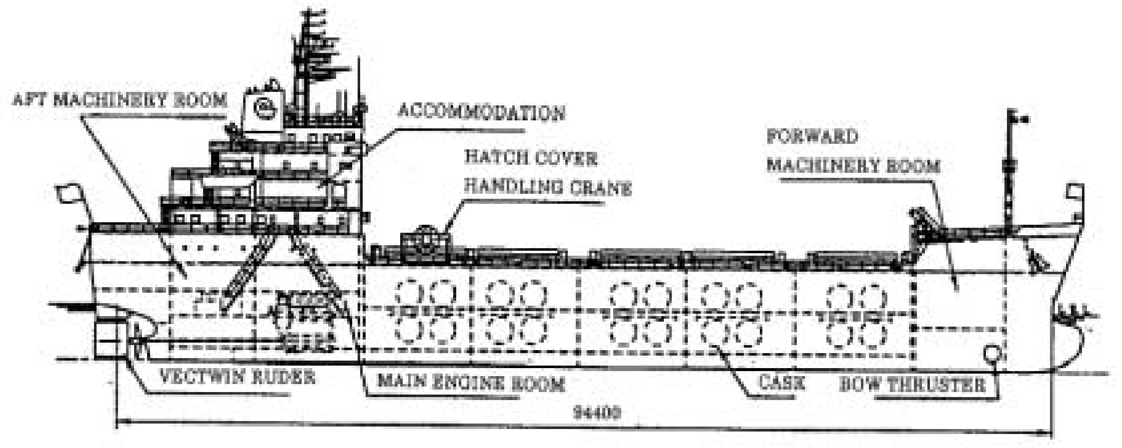
d) Radiation shielding

The ship holds are encased in thick steel plates and concrete to provide a full shielding against radiation.

3) Main specifications of Rokuei-maru

Length : approx. 100 m
Breadth : approx. 16.5 m
Draft : approx. 5.4 m
Dead weight : approx. 3,000 metric tons
Cargo loading capacity : 20 units of casks
Service speed : approx. 13 knots

Fig.9 Main system arrangements of a dedicated SF transport ship, Rokuei-maru




4.3.2 LLW Transport Ship

A dedicated ship, Seiei-maru is used to transport LLW from the nuclear power plants to Mutsu-Ogawara port nearby the LLW Disposal Center in Rokkasho. The ship is constructed to conform to the criteria for LLW transport ship, which is less restrictive than spent fuel transport ship, but requires double-hulled and double-bottom structure. Size of the ship, is as follows;

Length : approx. 100 m
Breadth : approx. 16 m
Draft : approx. 5 m
Cargo loading capacity : 3,000 LLW drums

4.4 Unloading operation

Unloading operations at Mutsu-Ogawara port are carried out by using the two size of crane, 150-ton for SF (shown in Fig.10) and 25-ton for LLW. They have the latest technology and system as follows;

1) Inverter Control System

The inverter-control system offers a wide range of speeds and provides smooth acceleration and deceleration, guaranteeing ease of operation.

2) Collision/Overload Prevention System
Each crane is equipped with sensors that prevent collisions by detecting the proximity of the other crane. The cranes are also fitted with devices that halt operations in the event that the load is too heavy.

3) Backup Motors/Power Supplies
In the unlikely event that the primary motor breaks down, the back-up motor can raise or lower the suspended cargo, or move it laterally. In addition, an emergency power supply can safely lower a suspended load in the event of a power failure.

4) Drop-Prevention System
If a load is left suspended by a power outage, double winding cables and a motor brake are activated to prevent it from dropping.

5) Curved Track System
In order to use the quay efficiently, when the cranes are not in use, they can be moved to the port apron along a curved track, rotating 90°in the process. Their ability to travel on a curve in this way makes them quite unique in the world.

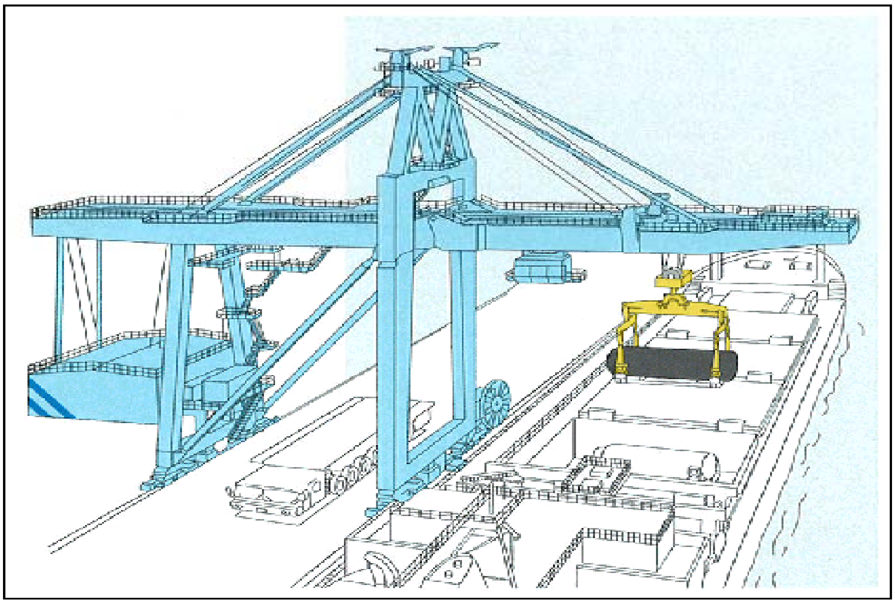


Fig.10 150-ton wharf crane installed at Mutsu-Ogawara Port

4.5 Overland Transport Carrier

4.5.1 Overland Transport Carrier for SF

Packages containing spent fuel, unloaded from the ship at the Mutsu-Ogawara port are placed onto specially designed overland transport carriers shown in Fig.11. Then, they are carried approximately 7 km through a private road to the Waste Storage Center. The carrier is self-powered with no inter-vehicle links. They have 48 wheels to minimize the danger of skidding during snowy winters. In addition to ordinary braking systems, they have safety brakes to stop the vehicle stably in emergencies. They also have rear obstruction detectors and rear-view TV cameras to allow the operator to check the vehicle's rear status when reversing. To enhance operational safety even further, the vehicles are designed to be able to handle ultra-heavy transport package over 100 tons.

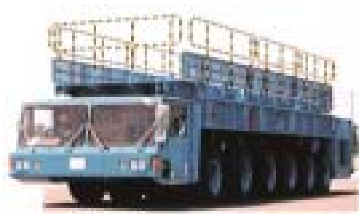


Fig.11 Overland Transport Carrier for SF

4.5.2 Overland Transport Carrier for LLW

After the LLW packages are unloaded at Mutsu-Ogawara port, they are placed onto specially designed 15-ton trucks two at a time and then carried through a private road to the LLW Disposal Center, some nine kilometers away. The trucks are equipped with an anti-lock braking system, anti-spin regulators and other safety equipment designed with winter travel in mind.

4.6 Radiation inspection

After the unloading operations, prior to the overland shipments to the nuclear cycle facilities in Rokkasho, the radiation levels at the surface of transport packages are inspected to confirm if the level meet the regulatory requirements. The inspections for the SF transport casks were implemented manually, on one hand, for the LLW transport containers, automatically by Gate monitor system shown in Fig.12, due to the high frequency of transport and large numbers of containers. The gate monitor plays a very important role in safety surveillance by measuring the radiation level around the LLW packages loaded onto trucks. The mobile system is operated remotely and atomically, and even extremely low levels of radiation can be detected quickly and accurately.

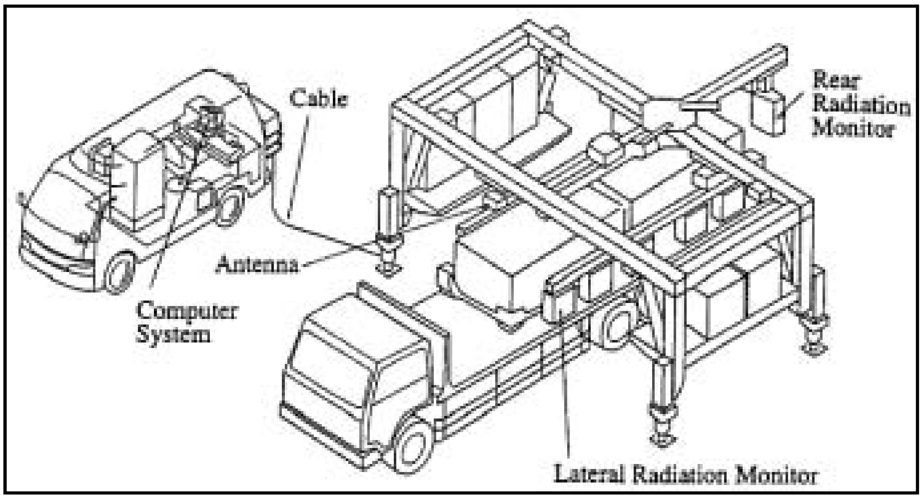



Fig.12 Gate monitor system

5. Transport performance

5.1 SF transport

By the end of march 2003, since the start of transportation in 1978 to Tokai Reprocessing Plant, approximately 930 MTU of spent fuel (about 410 casks) have been safely transported by Hinoura-maru, in about 180 voyages. Besides, since 1998 to Rokkasho Reprocessing Facility, approximately 780 MTU of spent fuel (total 140 casks) have been safely transported by Rokuei-maru, in about 25 voyages. Fig.13 shows the amount of spent fuel transported to the reprocessing facilities.

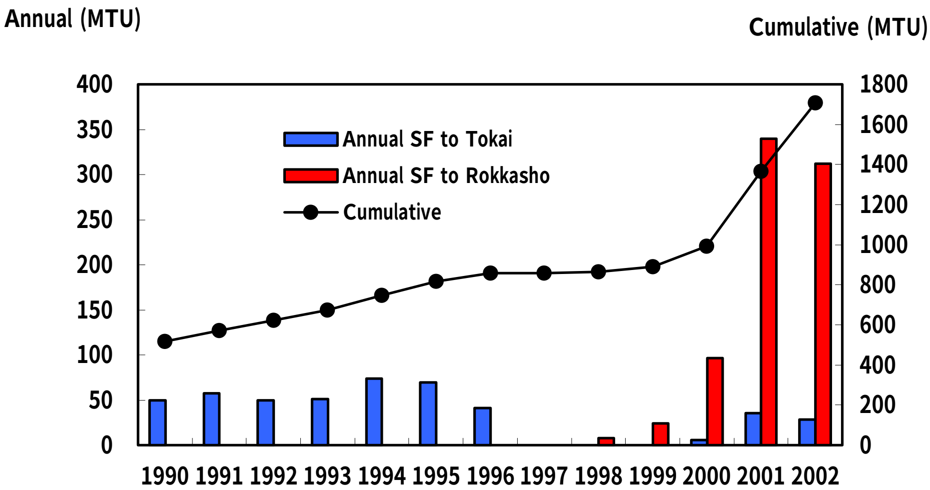



Fig.13 Amount of Spent Fuel Transported

5.2 LLW transport

LLW transport started in 1992 and about 150,000 drums have been safely transported by Seiei-maru, to the LLW Disposal Center in Rokkasho, by the end of March 2003.

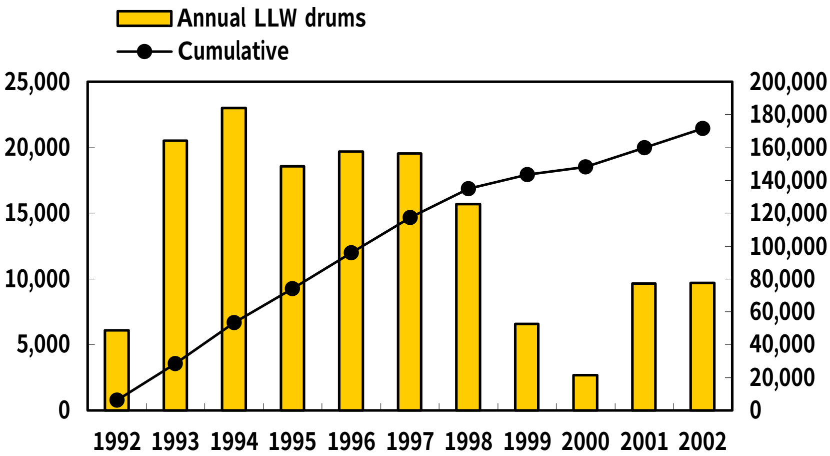



Fig.14 Amount of LLW Transported

6. Conclusion

Transport of nuclear fuel materials is one of the most important factors in nuclear fuel cycle. In Japan, since starting transport of spent fuel 25 years ago, none of the single accident has occurred during all the nuclear fuel materials transport, despite the large volumes and numbers of transport experiences. The distinguished transport performance demonstrates that NFT has executed its duties securely, as a sole domestic company specializing in transporting nuclear fuel materials, following the rigorous national transport regulations, mainly based on the IAEA Safety Transport Regulations. Under the recent adverse situation against nuclear energy in Japan, which was caused by several nuclear related scandals and accidents, like JCO accident, the safety performance has been undoubtedly contributing to the establishment of nuclear fuel cycle.