Transport of Used Nuclear Fuel – A Summary of Canadian and International Experience

NWMO TR-2009-14 **April 2009**

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ABSTRACT

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Report No.: **NWMO TR-2009-14**
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Company: Nuclear Waste Management Organization
Date: April 2009

Abstract

Each day, thousands of radioactive material shipments are made by road, rail, water and air around the world. Of particular interest is the transport of used nuclear fuel, a by-product of electricity production at nuclear generating stations. Used nuclear fuel is classified as both radioactive material and hazardous waste.

This report provides a brief summary of Canadian and international experiences in the transportation of used nuclear fuel. Also discussed is Canada's governing regulatory framework for transportation of dangerous goods and hazardous waste.

In particular, this report provides a summary of:

1. Canadian and international experience in the transport of used nuclear fuel;
2. the current regulatory framework which governs the transport of hazardous waste, and in particular, used nuclear fuel within Canada;
3. waste volumes transported annually;
4. the types of packages used to transport used nuclear fuel; and
5. the regulatory tests that transportation packages must meet.

The transportation of used nuclear fuel has been and continues to be conducted safely in Canada and internationally. In over 45 years of used nuclear fuel transport, not a single incident or accident has resulted in significant radiological damage to people or the environment. In all, over 80,000 tonnes of used nuclear fuel have been transported around the world to date. The industry's excellent safety record is a direct result of robust international standards which have been adopted and implemented by national regulatory programs.

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1. INTRODUCTION

Each day around the world, thousands of radioactive material shipments are made by road, rail, water and air. These shipments range from smoke detectors and isotopes used in medicine to used nuclear fuel. The transportation of radioactive material has become essential to our way of life.

Adaptive Phased Management (APM), Canada's approach for the long-term management of its used nuclear fuel includes transportation of used nuclear fuel from the interim storage sites to a centralized facility.

1.1 Purpose

This report provides information on the Canadian and international experience associated with used nuclear fuel transport, and serves as a source of information of the current state of used nuclear fuel transport around the world. It also provides an overview of the regulatory framework governing waste transport in Canada with a focus on used nuclear fuel transportation.

1.2 Background

Radioactive materials transport has a history spanning five decades and it encompasses everything from the shipment of radioisotopes for medical purposes in small cardboard boxes (Figure 1) to the shipment of radioactive used nuclear fuel in massive steel containers (Figure 2). It has been estimated that, throughout the world, approximately 20 million packages of radioactive material are shipped each year (WNA, 2009c).

Over this period a stringent regulatory regime has been developed at both international and national levels. The strength of this regime is demonstrated by an impressive transportation safety record: in over 45 years, no transport incident involving radioactive materials has caused radiological damage to people or the environment.

1.2.1 What is Used Nuclear Fuel?

Used nuclear fuel (also known as spent fuel) is a by-product of electricity production at nuclear generating stations or from the operation of other nuclear reactors such as research reactors. Nuclear fuel becomes "used" once it can no longer give off sufficient heat energy for the efficient production of electricity.

Nuclear fuel is most commonly in the form of solid, cylindrical ceramic pellets encased in metal tubes. For CANDU nuclear fuel, these tubes are assembled into cylindrical fuel bundle assemblies roughly 10 cm in diameter by 50 cm long, each weighing approximately 24 kg. The fuel bundles are specifically designed and manufactured to contain the fuel pellets during reactor operations and long-term storage. Due to their radioactive nature, used nuclear fuel bundle assemblies are regarded as hazardous waste.

Figure 1: Medical Isotopes and Packaging (Source: UK Health Protection Agency)

Figure 2: Pegase IU-04 Cask shipment to Whiteshell (Source: OPG)

2. DANGEROUS GOODS AND HAZARDOUS WASTE

This section briefly examines the relationship between dangerous goods and hazardous waste. Used nuclear fuel falls into both of these categories.

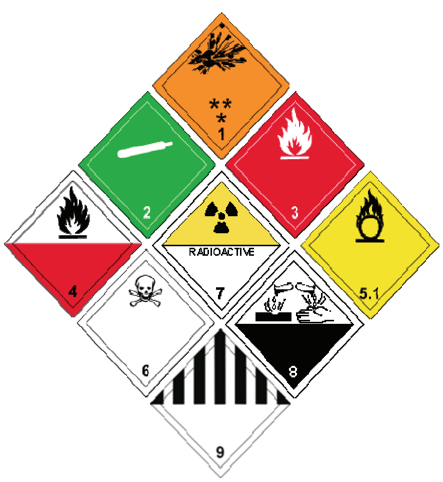
2.1 Dangerous Goods

Dangerous goods are any solids, liquids or gases that may be harmful to people or the environment. Dangerous goods are found in virtually every residential, commercial and industrial setting and include everything from the gasoline and household cleaners to acids, oils, and chemicals.

The classification system in the international *Transportation of Dangerous Goods* (TDG) *Regulations* provides the basis for national regulations throughout the world. According to this classification system, there are nine classes of dangerous goods which include flammable, explosive, toxic, corrosive, biohazardous, and radioactive materials.

Safety marks identifying the type of dangerous goods being transported must be posted on all vehicles or conveyances used during transport. The radioactive materials, including used nuclear fuel, fall under Class 7 (see Figure 3).

All shipments of dangerous goods (including radioactive materials) within Canada must comply with the Canadian TDG regulations (Transport Canada, 2008). Under certain conditions, the transport of limited quantities of some dangerous goods may be exempt. For example, the shipment of propane in a tanker truck is subject to the TDG regulations, however transporting a filled bar-b-cue propane tank in personal vehicles is not. There are no exemptions for to Class 7, radioactive materials.



- Class 1, Explosives
- Class 2, Gases
- Class 3, Flammable Liquids
- Class 4, Flammable Solids
- Class 5, Oxidizing Substances and Organic Peroxides
- Class 6, Toxic and Infectious Substances
- **Class 7, Radioactive Materials**
- Class 8, Corrosives
- Class 9, Miscellaneous Products, Substances or Organisms

Figure 3: Dangerous Goods Safety Marks

2.2 Hazardous Waste

Hazardous waste is any waste that may be harmful to people or the environment because if its reactive or toxic nature. Hazardous waste is produced by consumers and industry on a regular basis. For example, batteries and discarded electronic equipment including televisions and computers are hazardous waste. Industrial hazardous waste includes: materials left over from manufacturing processes such as acids used to clean components; biomedical wastes from hospitals; photo-finishing chemicals; waste pesticides; PCBs and used motor oil, just to name a few. Radioactive waste, including used nuclear fuel, is a small subset of this waste stream.

In Canada, all hazardous waste must be disposed of properly at specialized treatment facilities or specially designed landfills. The responsibility for hazardous waste management is shared between the federal and provincial and territorial governments.

International movements of hazardous waste are federally regulated, whereas the provincial and territorial governments regulate and monitor generators, waste management facilities and transportation within their jurisdictions.

2.3 Shipments and Volumes

Transport Canada estimates that approximately 930 million tonnes (Provencher, 2004) of goods are transported each year in Canada. Of these, dangerous goods account for roughly 30 million shipments moving 200 million tonnes. Approximately 800,000 to 1 million Class 7 radioactive shipments are made each year (Canada Gazette, 2000).

On the waste side, approximately 27 million tonnes (Statistics Canada, 2006) of waste is transported within Canada each year, 6 million tonnes (Environment Canada, 2003) of which is hazardous waste.

3. CANADIAN TRANSPORT EXPERIENCE

3.1 Used Nuclear Fuel Shipments

Canada's 18 operating nuclear reactors provide over 12,600 MWe of power, or about 16% of the country's electricity consumption.

The transport of used nuclear fuel in Canada dates back to the 1970's. Shipments within Canada have mainly been limited to small quantities of used nuclear fuel shipped to support research and nuclear reactor quality control programs. For example, three used nuclear fuel shipments were made in 1976 in which used CANDU fuel bundles were transported from the Douglas Point Generating Station near Port Elgin, Ontario to Atomic Energy of Canada Limited's Whiteshell Laboratories in Pinawa, Manitoba. In total, 360 fuel bundles were shipped to the Whiteshell Laboratories (see Figure 2 and Appendix A.2).

To date, more than 500 shipments of used nuclear fuel have been made in Canada (CEAA, 1997). Approximately 5 to 10 used nuclear fuel shipments are made annually. The majority of these shipments are made between the operating nuclear reactors in Ontario, Québec and New Brunswick and the Atomic Energy of Canada Limited (AECL) research facilities in Chalk River, Ontario. All shipments are made in a safe and secure manner, following Canada's existing standards and regulations. Road transport has been the preferred mode because of the relatively small numbers of shipments and limited quantities of used nuclear fuel transported. Details of several packages certified to transport used nuclear fuel in Canada are provided in Appendix A.

3.2 Other Nuclear Fuel Shipments

While the bulk of the used fuel shipments have been associated with used CANDU fuel, there have been small quantities of other used fuels from small research reactors, and also shipments of special nuclear fuel materials.

There are numerous small nuclear research reactors within Canada. The majority of these reactors are powered by fuel owned by the United States. Once the research reactor fuel has reached its end-of life, the used nuclear fuel is returned to the waste owner in the United States as part of the US Department of Energy (DOE) program to return US-origin fuels from foreign research reactors. Several of these shipments have taken place over the past decade. In one example, the fuel assemblies and reactor core of the University of Toronto research reactor were returned to the US DOE Savannah River Site in June 2000 (US DOE, 2006) as part of the university's reactor decommissioning process.

To investigate the possibility of using mixed oxide (MOX) fuel to power the Canadian CANDU reactors, two shipments of MOX test fuel were made in 2000. The first MOX fuel shipment was transported to Canada by road from the United States and then flown to AECL's Chalk River Laboratories by helicopter. Later that year, test samples of Russian MOX fuel were flown into Canada and subsequently transported to Chalk River via helicopter. These test samples of unirradiated (fresh) fuel contained plutonium.

3.3 Radioactive Materials Shipments

Each year between 800,000 and 1 million radioactive materials shipments are made in Canada (Canada Gazette, 2000). The high quantity of shipments is largely due to Canada's world leadership in the production of radiopharmaceuticals and radioactive isotopes for the medical industry. Unlike used nuclear fuel transportation packages which require very robust package designs, radioactive medical isotope packages can be very small and may consist of cardboard and polystyrene packaging, as illustrated in Figure 1, to meet transportation requirements.

The Canadian Nuclear Safety Commission (CNSC) regulations require that certain incidents related to the transport of radioactive materials be reported. Reportable incidents include transportation accidents, packages that show evidence of damage or tampering, radiological release, contamination, and lost or stolen packages. On average, less than 20 transportation incidents are reported to the CNSC annually (CNSC, 2007). The most common incidents involved the incorrect labelling, documentation, marking or preparation of packages.

Over the years where data are available, none of these incidents resulted in the exposure of workers or the public to radiation exceeding regulatory limits, nor were there any releases to the environment in excess of regulatory limits.

4. INTERNATIONAL USED NUCLEAR FUEL TRANSPORT EXPERIENCE

While the transport of used nuclear fuel in Canada has been limited to relatively few and infrequent shipments, other countries around the globe have amassed extensive transport experience with an impressive safety record. Since the onset of used nuclear fuel transport, more than 80,000 tonnes of used nuclear fuel has been transported requiring approximately 20,000 shipments and covering a total distance of over 30 million kilometres (WNA, 2009c).

This section provides a brief summary of used nuclear fuel transportation in several countries that have well established transportation programs.

To date, all used nuclear fuel shipments have been successfully completed without a significant incident. There has never been an accident in which a cask carrying high level radioactive material has been breached, or has leaked. This impressive safety record is rooted in the very robust regulations published by the International Atomic Energy Agency (IAEA). These regulations, discussed in Section 5, have been adopted by many countries around the world.

4.1 United States

With over 100 commercially operating nuclear power reactors, the United States of America is the largest producer of nuclear power in the world. Over the past 40 years, more than 3,000 used nuclear fuel shipments have been made covering a total distance of over 2.5 million kilometres (Sproat, 2008). The majority of the shipments have been used nuclear fuel movements between nuclear generating sites. Like in Canada, shipments have also been made for research purposes. There are approximately 100 million shipments of dangerous goods in the USA each year (ANS, 2008); the shipment of radioactive materials account for only approximately 2 to 5 million of these.

Within the United States, used nuclear fuel shipments are made by road or rail. However, under a US Department of Energy (DOE) program to return US-origin uranium based fuels from foreign research reactors, used nuclear fuel is also shipped to the United States by sea. These research reactor fuels mainly consist of highly enriched uranium fuels and are transported to the DOE Savannah River Site in Georgia. DOE used nuclear fuel shipments are tracked and escorted 24 hours a day.

Radioactive waste from military origin in the USA is transported (see Figure 4) to the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. WIPP is the world's first licensed deep geological repository. It has been in operation since 1999 and has received over 7,200 shipments of waste (US DOE, 2009).

In over 40 years of used nuclear fuel transport, only 9 transportation accidents have been reported to the US Atomic Energy Commission and the DOE (NEI, 2007). Four of these involved empty casks (Holt, 1997). In the most severe accident, a tractor-trailer carrying a 25 ton used nuclear fuel cask swerved to avoid a head-on collision and overturned. The cask separated from the trailer and came to rest in a ditch. The cask was slightly damaged, however did not release any radioactive materials. No accident has resulted in a release of radioactive material causing damage to the environment, workers or the public.

Much like Canada's regulatory framework discussed in Section 5, the transport of radioactive materials is jointly regulated by the Nuclear Regulatory Commission (NRC) and the US Department of Transportation.

Figure 4: RH 72B Cask on Tractor Trailer (Source: US DOE)

4.2 United Kingdom

The United Kingdom has 19 nuclear reactors which generate one fifth of the electricity consumed. In the United Kingdom, used nuclear fuel has been transported regularly since the mid 1960's. About 7,000 shipments of the annual volume of approximately 500,000 radioactive materials shipments (Smith, 2008) are related to the nuclear power industry and roughly 300 of those are used nuclear fuel shipments.

Most of the used nuclear fuel shipments in the United Kingdom are by rail. These trains (see Figure 5) can frequently be observed en-route from the nuclear generating stations to the spent fuel reprocessing facility at Sellafield in northwest England. Direct Rail Services (DRS) was established in 1995 by the UK Nuclear Decommissioning Authority to provide the nuclear industry with a strategic rail transport service.

Several of the regularly scheduled transport routes travel through heavily populated urban areas near London. A special unit of the London Fire Brigade (as well as other emergency staff throughout the UK) has been trained to respond in the event of an accident involving these trains. The used nuclear fuel shipments cover a total distance of over 500,000 km each year.

Figure 5: Trains carrying used nuclear fuel en-route to Sellafield (Source: Direct Rail Services)

4.3 France

France has 59 commercial nuclear reactors which provide approximately 63,000 MWe of electricity or 78% of all electricity consumed. Of the 1,200 tonnes of used nuclear fuel produced each year, 850 tonnes are transported to the French reprocessing plant in La Hague on the Normandy coast (WNA, 2009a). As in the United Kingdom, high level radioactive wastes in France are predominantly shipped by rail.

Approximately 300,000 radioactive material shipments are made annually in France. As in Canada, most shipments in France consist of radioisotopes for medical, pharmaceutical or industrial use. Only a small portion of shipments deal with the transport related to fuel cycle materials (uranium, fuel assemblies, etc.) and waste from research centres, reprocessing plants and power plants. About 300 fresh fuel, 250 used nuclear fuel, 30 MOX fuel and 60 plutonium oxide powder shipments are made annually in France (ASN, 2007).

4.4 Germany

Germany's 17 nuclear reactors provide one quarter of the country's electricity needs. In Germany, the transport of used nuclear fuel and high level radioactive waste has mostly been associated with reprocessing activities (Figure 6). A number of shipments in the 1990's led to a temporary moratorium on further shipments of wastes or spent fuel to the long-term facility in Gorleben, Germany.

Transport of used nuclear fuel to the French and British reprocessing plants and the return of the vitrified waste produced by reprocessing initially resumed in March 2001. Over the next four years a total of 267 casks were transported to the reprocessing plants and 72 casks of vitrified waste were returned (BfS, 2008). Germany stopped the reprocessing of its used nuclear fuel in 2005, significantly reducing the transport of used nuclear fuel within the country.

Figure 6: A typical train carrying used nuclear fuel in CASTOR casks between France and Germany (Source: de.indymedia.org)

4.5 Sweden

Sweden has 10 nuclear power reactors that provide half of the electricity consumed. Sweden has been transporting used nuclear fuel from its nuclear generating stations to the interim central fuel storage facility (CLAB) since 1985. Since Swedish reactors are all located in coastal communities, used nuclear fuel transport is currently done by sea in a purpose-built ship, the m/s Sigyn (Figure 7).

m/s Sigyn makes approximately 30 to 40 trips per year between the nuclear power plants and CLAB (Large, 2007). The ship may also be chartered out for other heavy (not necessarily radioactive) special shipments. Since transport operations began, more than 1,250 cask shipments (3,710 tonnes of uranium or 19,200 fuel assemblies) (Dybeck, 2003) have been made in Sweden.

The annual transport schedule is prepared one year in advance of the shipments.

m/s Sigyn
Constructed: 1982
Deadweight tonnage: 2,044 tonnes
Overall Length: 90.33 metres
Width: 18.04 metres
Draught fully loaded: 4 metres
Gross tonnage: 4,166 tonnes
Payload with filled shielding tanks: 1,400 tonnes
Engine power: 2 x 1,170 kW
Cruising speed: 12 knots

Figure 7: Swedish Ship m/s Sigyn (Source: SKB)

The fuel is shipped in standard TN17/2 used nuclear fuel casks which weigh approximately 60 tonnes each. Special transporters are used at the terminal points for cask loading and unloading operations as shown in Figure 8.

Figure 8: Loading/unloading of radioactive waste onto SKB's m/s Sigyn in Sweden
(Source: SKB; Photographer: Bengt O Nordin)

4.6 Japan

Nuclear power generation in Japan is supplied by 53 commercial nuclear reactors that produce approximately 30% of Japan's electricity requirements (WNA, 2009b).

None of the nuclear generating stations in Japan have railroad access. Almost all are situated on the coast and have a private wharf. Consequently, Japan's used nuclear fuel is transported by ship to the spent fuel storage facility located in Rokkasho-mura. Since the start of transport in 1978, approximately 200 shipments (870 tonnes) of used nuclear fuel has been transported (Mori, 2003).

Like the United Kingdom and France, Japan reprocesses some of its used nuclear fuel. Japan's reprocessing facility at Rokkasho-mura is in the final stages of commissioning. Until the time when the facility is fully operational, Japan's used nuclear fuel is being transported by sea to the British and French reprocessing facilities at Sellafield and La Hague, respectively. These shipments arrive by sea aboard purpose-built ships operated by Pacific Nuclear Transport Limited (PNTL). Since operations began in 1975, PNTL has safely and successfully made over 170 shipments involving over 2,000 flasks and covering a total distance of over 8 million kilometres (Brown, 2005).

The PNTL ships (see Figure 9) were specially designed to meet or exceed all applicable regulatory and safety requirements. Cargo compartments are protected by a double hull. All essential systems are separated and duplicated providing a fully operational emergency back-up. The ships are designed to allow each of the cargo holds to be filled with seawater to enhance fire or radiation shielding protection, if required. The ship will remain afloat and capable of safe navigation even with each hold flooded. The special 100-tonne casks containing the nuclear material are bolted to the ship's structure. Some of the PNTL ships are fitted with features such as fixed naval guns to provide additional security for MOX fuel and plutonium dioxide transport (www.pntl.co.uk).

Figure 9: PNTL Ship Pacific Heron (Source: PNTL)

5. REGULATORY FRAMEWORK

The regulation of all transport within Canada is jointly shared by separate governmental levels and ministries. The transportation mode, (i.e. by road, rail, water or air) plays a role in establishing responsibility. The governmental responsibility by transportation mode is presented in Table 1.

Table 1: Governmental Responsibility for Transportation

Mode	Municipal	Provincial, Territorial	Federal
Road	✓	✓	✓
Rail		✓	✓
Marine			✓
Air			✓

The various governmental organizations responsible for regulating transportation have developed administrative agreements or memorandums of understanding to avoid duplication and overlap. For example, administrative agreements between each province and territory and the Federal government address the overlap for the transport of dangerous goods. Likewise, a Memorandum of Understanding (MOU), first signed in 1981 and renewed in December 2007, between Transport Canada and the Canadian Nuclear Safety Commission (CNSC) delineates responsibilities regulating the transport of nuclear substances. The MOU clarifies responsibilities for the transport of radioactive materials in Canada and promotes enhanced collaboration and communication between the two parties.

5.1 Canadian Regulations

Regulation of packaging and transport of nuclear substances is jointly shared between Transport Canada and the CNSC. The two organizations cooperate with each other; each in their specific area of expertise. Only one organization has the lead while the other provides support.

For shipment of radioactive materials, Transport Canada is primarily responsible for:

- establishing and enforcing transportation requirements for the consignors and carriers;
- establishing requirements and undertaking compliance inspections for aspects such as training and documentation;
- setting and enforcing requirements for Emergency Response Assistance Plans.

The CNSC is primarily responsible for:

- setting transportation package performance requirements;
- certification of transportation package designs;
- establishing and enforcing the radiation protection program for the carriers;
- investigating in the event of a dangerous occurrence;
- all aspects of physical security measures.

The Canadian regulations governing radioactive materials transport under the *Transportation of Dangerous Goods Act* and the *Nuclear Safety and Control Act* are:

- Transport Canada, Transportation of Dangerous Goods Regulations;
- CNSC, General Nuclear Safety and Control Regulations;
- CNSC, Packaging and Transport of Nuclear Substances Regulations; and
- CNSC, Nuclear Security Regulations.

The CNSC regulations are primarily concerned with the protection of health, safety, security and the environment with regards to nuclear substances. These regulations are complemented by those issued by Transport Canada which have general application to the transport of all classes of dangerous goods. Figure 10 illustrates the Canadian regulatory framework for the transport of radioactive materials.

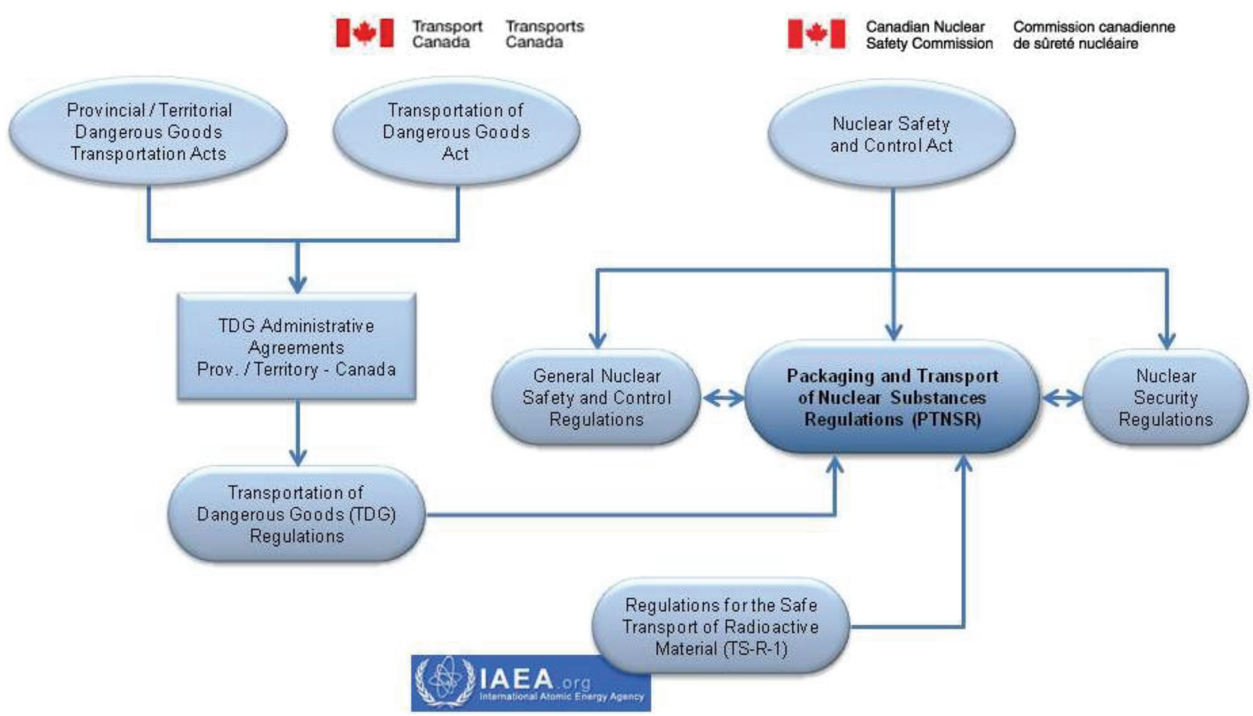


Figure 10: Regulatory Framework for the Transport of Radioactive Materials

The packaging requirements in the CNSC's *Packaging and Transport of Nuclear Substances Regulations* (PTNSR) (CNSC, 2003) are largely based on the international regulations published by the International Atomic Energy Agency (IAEA) (IAEA, 2000). The certifications and licences required to package and transport radioactive materials are stipulated in the PTNSR. To transport used nuclear fuel within Canada, a *Certificate for Transport Package Design* must be obtained from the CNSC for every package design used. Additionally, a CNSC *Licence to Transport Category I, II or III Material* is required to transport material such as used nuclear fuel, plutonium, low-enriched fuel, and MOX fuel. Detailed security and emergency response assessments must be provided in the application to obtain such a licence.

5.2 International Regulations

The IAEA *Regulations for the Safe Transport of Radioactive Material* (IAEA, 2000) have been adopted by industrialized nations, including Canada. The regulations were developed to standards of safety which provide an acceptable level of control of the radiation, criticality and thermal hazards to persons, property and the environment, and to facilitate the harmonized and safe transport of radioactive materials, worldwide. They are periodically updated and revised to ensure that they remain relevant, useful and suitable for worldwide use. Representatives from Transport Canada, the CNSC and experts from the nuclear industry routinely participate in the IAEA technical meetings as a part of the review and revision process. This participation ensures that Canadian viewpoints are taken into consideration in the development of the international regulatory consensus standard.

The IAEA transport requirements are incorporated into the United Nations (UN) *Recommendations for Transport of Dangerous Goods – Model Regulations* which form the basis of many other national and international regulations including those of the International Civil Aviation Organization (ICAO) in their *Technical Instructions for the Safe Transport of Dangerous Goods by Air* and the International Maritime Organization (IMO) in their *International Maritime Dangerous Goods Code*. Canada's *Transport of Dangerous Goods Regulations* (TDG) reference both modal requirements for air and sea transport.

In the context of the regulations, transport encompasses all aspects of, and associated with the movement of radioactive material from package design, through manufacture, quality assurance, maintenance and repair and transport operations which include preparation, consigning, loading, shipment, receipt and unloading of the material.

6. RADIOACTIVE MATERIALS PACKAGING

6.1 Package Types

Regulations governing radioactive materials packaging have been established to define safety standards that provide an acceptable level of control of radiological hazards. Since not all radiological hazards are the same (radiopharmaceuticals used in medicine do not present the same hazard as a used nuclear fuel shipment), the regulations apply a graded approach to the packaging requirements. For example, a cardboard and polystyrene package as shown in Figure 1 can be designed meet the regulatory requirements to transport radiopharmaceuticals; whereas a typical package required to transport used nuclear fuel as shown in Figure 2 must be able to withstand tests simulating severe accident conditions. A pictorial overview of the graded approach is presented in Figure 11 (IAEA, 2006).

Radioactive materials packaging is dependant the classification of the material to be transported. The five package categories include: Excepted, Industrial (Type IP), Type A, Type B and Type C.

Excepted packages are for materials presenting insignificant radiological hazards such as radiopharmaceutical shipments. Industrial packages (Type IP-1, Type IP-2 and Type IP-3) are designed to contain materials which have low levels of radioactivity or materials where the associated radioactivity is not easily spread. The regulatory requirements for the three categories of Industrial packages range from meeting the general requirements for all packages (Type IP-1), to being able to withstand conditions that might be expected during normal transport (Type IP-3), such as a fall from a vehicle to being struck by a sharp object. Ores containing naturally occurring radioactivity, low and intermediate level radioactive wastes and unirradiated nuclear fuel are typically transported in industrial packages.

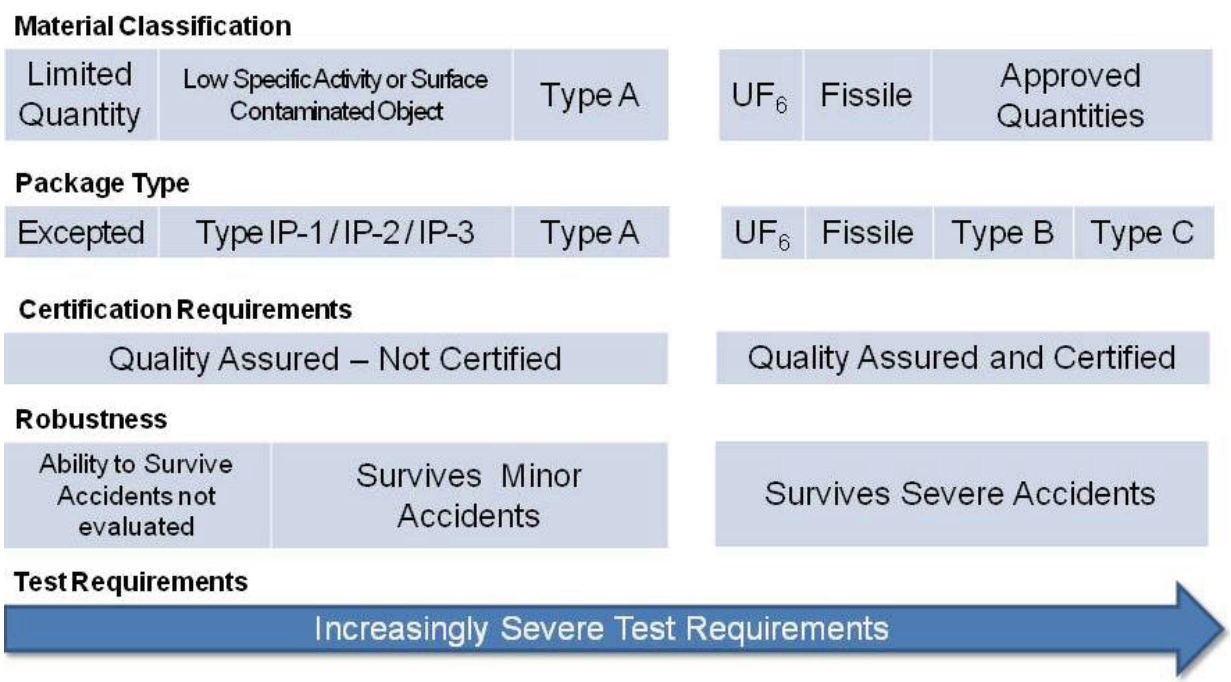


Figure 11: Graded Approach to Packaging Requirements

Small, but significant quantities of radioactive materials are commonly transported in Type A packages. However, the amount of radionuclides they may contain is limited by the regulations. Type A packages are subject to various tests simulating normal transport conditions. Packages containing liquid contents have additional requirements to minimise potential dispersal in the event of an accident. Typical examples of materials transported in Type A packages are radioisotopes used in medical diagnoses and some low and intermediate level radioactive wastes.

The transport of highly radioactive material such as radioactive sources used in medical imaging equipment, components removed from the core of nuclear reactors and used nuclear fuel require Type B packaging (Figure 12). Type B packaging must be able to survive severe accident conditions without leaking or spilling. Type B package designs must be certified by the competent authorities or regulators of all the countries in with the packages are used.

Type C packages were introduced in the 1996 edition of the IAEA regulations (IAEA, 2000). They are intended for the transport of highly radioactive materials by air. To date, no package of this type has been developed.

In any of the radioactive materials package categories, the package design can vary substantially. For example: Type B packages designed for used nuclear fuel tend to be very large and heavy, whereas Type B packages designed to contain radioactive sources used in various industrial devices could be small enough to fit in the trunk of a car.

With the exception of Type C packages, packaging requirements are essentially independent of transport mode, be it by road, rail, water or air.

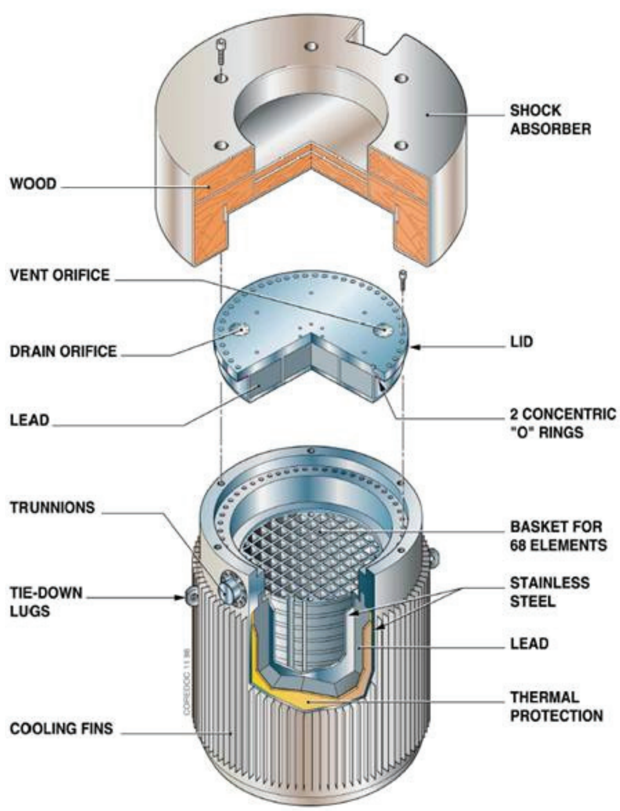


Figure 12: A typical Type B used nuclear fuel transportation cask (TN-TMR) (Source: Transnucleaire)

6.2 Regulatory Tests

The regulatory requirements are presented in the form of performance standards rather than prescriptive specifications (IAEA, 2000). The use of performance standards or tests ensures that safety issues are addressed without placing prescriptive limitations on package design. The tests specified for the various packaging types are presented in Table 2.

Used nuclear fuel is transported in packages referred to as Type B packages. In addition to meeting the general requirements for all packages, Type B packages must also be able to withstand hypothetical accident conditions without a breach of containment or a significant change in radiation level. Each Type B package design must be demonstrated to withstand the following tests in sequence:

- A 9 metre drop test from onto an unyielding surface;
- A puncture test (1 metre drop onto a 15 cm diameter steel bar);
- A thermal test (a fully engulfing fire of 800°C intensity for 30 minutes);
- A water immersion test (15 metres for 8 hours); and
- For packages carrying a large amount of radioactive material, an enhanced immersion test (200 metres for 1 hour) is also required.

Table 2: Regulatory Tests by Package Type

Test	Drop 0.3 m – 1.2 m	Stacking	Water Spray	Penetration 1 m	Penetration 1.7 m	Drop / Crush 9 m	Pin Drop 1 m	Thermal	Water Immersion 15 m	Water Immersion 200 m	Puncture / Tearing	Enhanced Thermal	Impact
Excepted													
Type IP-1													
Type IP-2	✓	✓											
Type IP-3	✓	✓	✓	✓									
Type A	✓	✓	✓	✓	liq.	liq.							
Type B	✓	✓	✓	✓		✓	✓	✓	✓	LQ			
Type C	✓	✓	✓	✓		✓				✓	✓	✓	✓

Notes:
- a set of general performance requirements apply to all package types in addition to specified tests.
- Type C packages are required for large quantities of radioactive materials transported by air.
- liq. – additional requirements for packages containing liquids
- LQ – additional requirement for packages containing a large quantity (high activity) of radioactive material

6.3 Validation of Regulatory Requirements

Prescribing a series of tests to simulate every possible real-life accident scenario would be very difficult, if not impossible. Therefore, validation is required in order to ensure that the prescribed regulatory package certification tests are adequate to bound real-life accidents.

Tests beyond the scope of existing regulations have been conducted in the United States, the United Kingdom and Germany to simulate real-life accident conditions; to validate the regulatory performance requirements; and to benchmark computer analyses techniques. Drop, impact, explosion and fire tests have all been conducted on used nuclear fuel transportation packages. A few examples are presented as follows:

In the 1970s and 1980s, numerous tests were performed in the United States at Sandia National Laboratories in New Mexico. These tests included:

- A flatbed tractor trailer loaded with a full-scale cask driven into a 700-ton concrete wall at 135 km/h (84 mph);
- A rail car loaded with a full-scale cask driven into a 700-ton concrete wall at 130 km/h (80 mph);
- A full-scale cask broad-sided by a 120-ton locomotive traveling 130 km/h (80 mph) (see Figure 13); and
- A transportation cask dropped 610 m (2,000 feet) onto soil as hard as concrete traveling 380 km/h (235 mph) at impact.

Figure 13: A Type B transportation cask being broadsided by a Locomotive in tests in USA (Source: DOE)

In each case, the impact forces were not sufficient to cause significant damage to the casks or to cause a breach of containment.

An independent test in 1984 by the Central Electricity Generating Board in the United Kingdom rammed an unmanned locomotive travelling at 160 km/h (100 mph) into a used nuclear fuel cask. The cask, designed to meet IAEA requirements, survived with only superficial damage.

In November 1997, a rail car carrying petrol exploded near a train station in Elsterwerda, Germany. This accident raised concerns about the integrity of a used nuclear fuel cask, had one been near the exploding tank car. A test was conducted by the German Federal Institute for Materials Research and Testing (BAM) in 1999 (Droste, 2007) to investigate this accident scenario. A propane filled rail tank car in close proximity to a used nuclear fuel cask was exposed to a fire. Within 17 minutes, the propane car exploded directly hitting the cask. The cask overturned and embedded itself into the ground about 10 m away (see Figure 14).

As in the British and American tests, the cask survived intact and prevented release of its contents.

Conducting these extreme real-life tests demonstrates the robustness of the regulatory package performance requirements and the inherent safety of packages designed to meet these requirements.

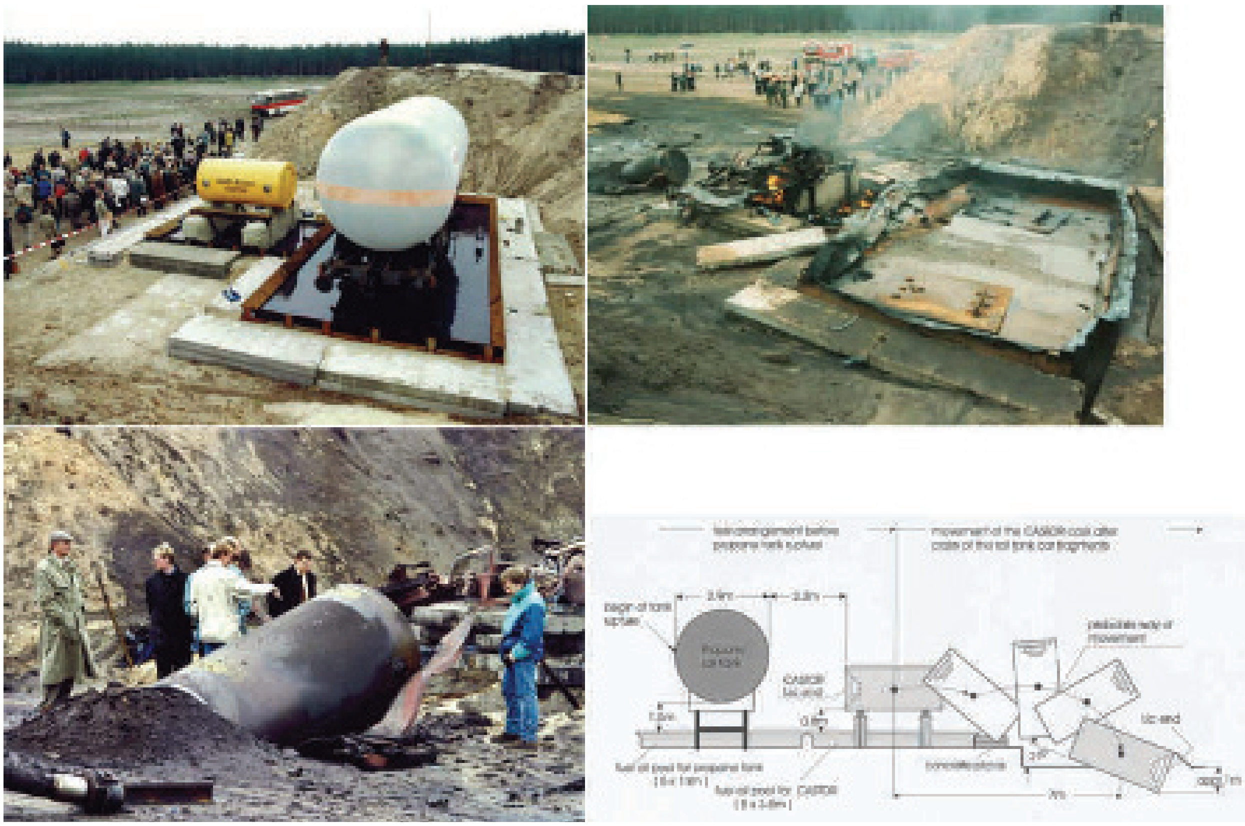


Figure 14: A Type B transportation cask struck by an exploding propane tank in a test in Germany (Source: BAM)

7. CONCLUSIONS

Approximately 800,000 to 1 million radioactive materials shipments are made annually within Canada. About 20 million shipments are made annually worldwide. The transport of materials related to electricity production, however, represent only a small fraction of the total radioactive material shipments made worldwide.

The transportation of used nuclear fuel in Canada and other countries has been conducted safely. In over 45 years of used nuclear fuel transport, not a single incident or accident has resulted in a significant radiological impact on people or the environment. Over 80,000 tonnes of used nuclear fuel have been transported around the world to date.

The industry's excellent safety record is a direct result of robust international transportation standards which have been adopted and implemented by national regulatory programs. The development and implementation of the Canadian regulations is jointly shared by Transport Canada and the Canadian Nuclear Safety Commission. The regulations specify performance requirements packages containing radioactive materials must meet which are commensurate with the hazard of the materials they are designed to contain.

Extra-regulatory testing of radioactive materials transportation packages and investigation of severe actual accidents not involving radioactive materials has demonstrated that the existing regulatory framework is strong and that the transport of radioactive materials, including used nuclear fuel, is safe.

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APPENDIX A: USED NUCLEAR FUEL TRANSPORTATION CASKS IN CANADA

Numerous casks used to transport used nuclear fuel have been certified for use in Canada by the Canadian Nuclear Safety Commission (CNSC) and its predecessor the Atomic Energy Control Board (AECB). Some of these cask designs are briefly described in this appendix.

A.1 NOD-F1

The NOD-F1 cask was developed and certified for use in Canada. The cask was capable of transporting up to 2 bundles of CANDU fuel. The cask was used primarily to transport fuel from the nuclear generating stations to research facilities for post irradiation examination (PIE). As can be seen in Figure A1, the NOD-F1 was a rectangular steel container approximately 0.94 m (37") square by 1.90 m (74½") long, with a horizontal cavity containing a drawer to hold the fuel bundles. The typical wall cross section consisted of several layers of 51mm (2") thick mild steel plates welded together to form a thick walled box.

The package had four lifting lugs on the top surface and flanges along the base for bolting to transport vehicles. Trunnions mounted on the sides of the package accommodated vertical lifts. The 13.6 tonne package was usually loaded at the nuclear stations in the wet fuel bays and dry unloaded at the Atomic Energy of Canada Limited (AECL) research facility in Chalk River, Ontario.

The nature of the laminated design meant that many of the structural welds were inaccessible for regular inspections. The NOD-F1 was taken out of service in the early 2000's.

Figure A1: NOD-F1 being examined in a laboratory (Source: OPG)

A.2 Pegase IU-04 Transport Cask

The Pegase IU-04 is a cylindrical cask which consists of two concentric steel walls with a lead filled inter-space. It was developed in France, and licensed for use in Canada in the 1970's. The cask body is mounted on a base plate and closed at the top with a lead shielded lid and impact limiter. An isometric sketch of the Pagase is shown in Figure A2. Radiological containment is provided by the inner steel shell. The outer steel shell incorporates cooling fins.

The Pegase supports an inner cavity that can accommodate a variety of fuel baskets allowing the cask to transport various types of used nuclear fuel. In 1976, the Pegase cask was used to transport 360 CANDU fuel bundles from the Douglas Point reactor in Tiverton, Ontario to Whiteshell Laboratories in Pinawa, Manitoba.

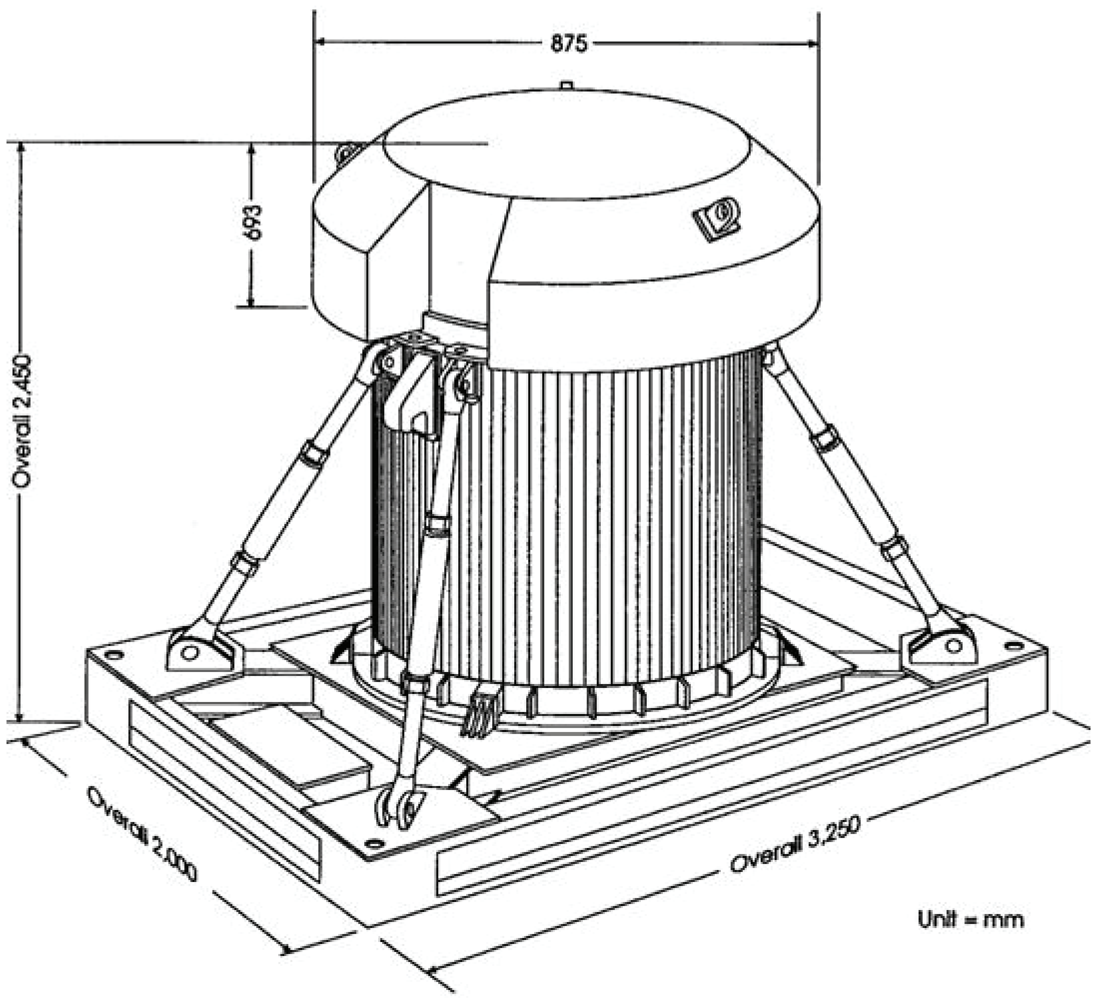

Figure A2: Isometric sketch of Pegase Cask (Source: US DOE)

A.3 NAC/NLI 6502

NAC/NLI 6502 cask shown in Figure A3 was originally designed to ship Light Water Reactor (LWR) fuel. The cask was modified to permit shipments of irradiated core components, research reactor fuel and other high activity wastes.

The NAC Cask consisted of a cylindrical steel shell nominally 0.83 m (32½”) in diameter and 3.96 m (156”) in length. The cask wall was of steel-lead-steel construction with a 13mm (½”) thick outer shell and a 25 mm (1”) thick inner shell. The two shells were separated by 76 mm (3”) of lead. The internal cavity was centered in the inner shell and has depleted uranium shielding at the corners. The remaining region is filled with lead. Each end of the cylindrical body was closed off with a 0.62 m (24½”) diameter by 127 mm (5”) thick carbon steel lid. The package had a gross weight of 20,600 kg (45,300 lbs.).

The cask was normally dry loaded and unloaded at the nuclear stations. However, shipments to Chalk River Laboratory were unloaded in the wet fuel pool. The cask was retired in 1997.

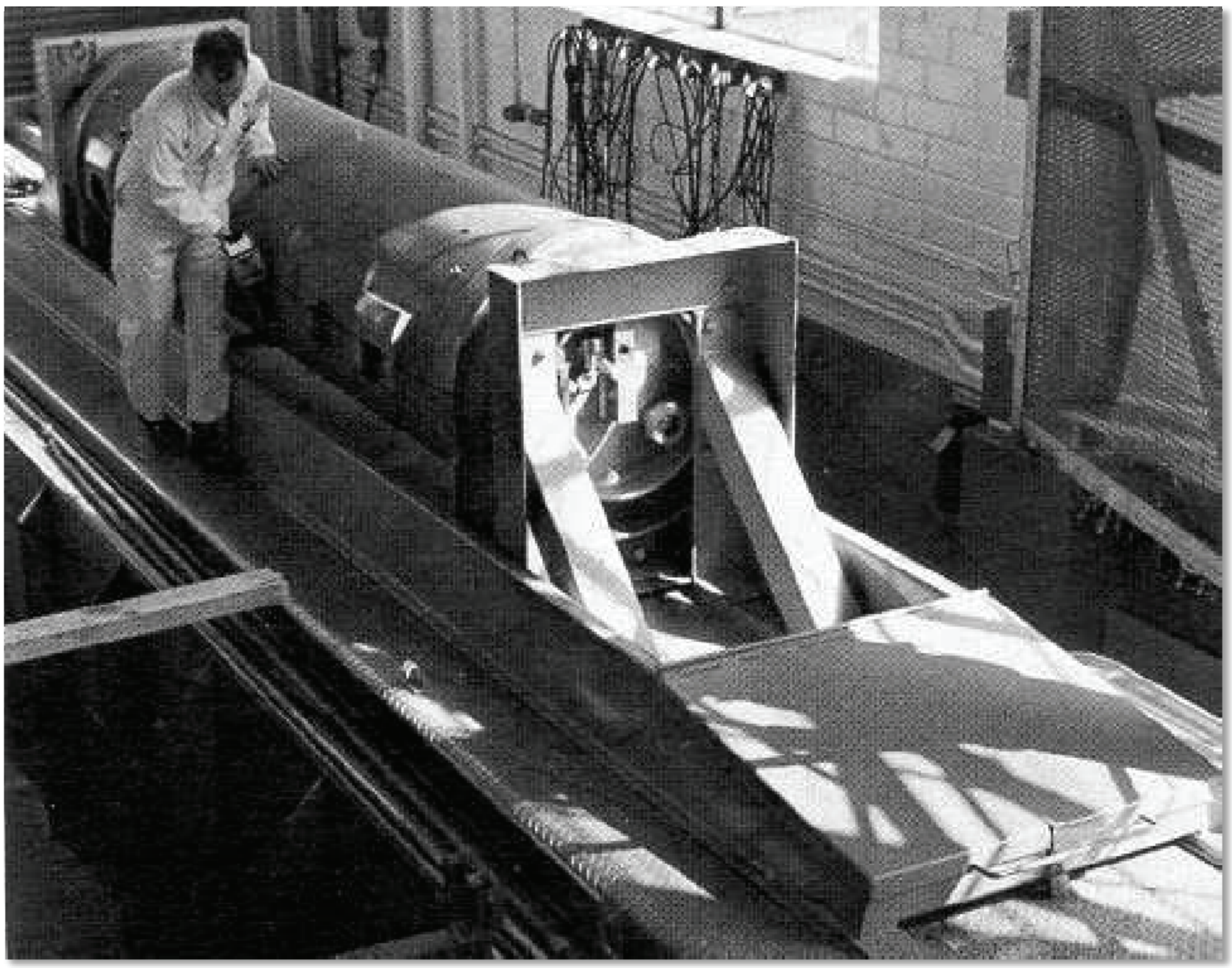

Figure A3: NAC/NLI 6502 Cask (Source: OPG)

A.4 Irradiated Material Transportation Package (IMT)

The Irradiated Material Transportation Package, as shown being handled at Atomic Energy of Canada Limited's (AECL) Chalk River Laboratories in Figure A4, is designed to transport a single bundle (45 kg) of CANDU fuel. The cask body consists of a single monolithic stainless steel forging. Lids at each end of the package are secured with eight 25 mm diameter cap screws. During transport, the lids are protected by impact limiters secured to each end. One impact limiter can be seen beside the package on the right. With the impact limiters installed, the cylindrical package is 1,220 mm in diameter and 1,930 mm long.

The package is transported in the horizontal position. It can be rotated to the vertical position via trunnions on each side of the package to facilitate loading and unloading. The total package mass is approximately 5,550 kg. The cask is in active service.

Figure A4: IMT Cask being handled at AECL Chalk River (Source: OPG)

A.5 Irradiated Fuel Transportation Cask (IFC)

The IFC is one of the two package designs certified in Canada to transport large quantities of CANDU fuel. The other package design, the Dry Storage Container Transportation Package (DSCTP) is described in Appendix A.6.

The IFC is capable of transporting two fuel modules stacked on top of one another containing a total of 192 fuel bundles. See Figures A5 and A6. The body is machined from a single forged block of stainless steel. The rectangular base of the IFC measures 1,566 mm x 1,881 mm with a height and wall thickness of 1697 mm and 267 mm, respectively. The container weighs approximately 28 tonnes empty and 33 tonnes fully loaded. A lid containing a Viton O-ring seal is bolted to the top of the container to form a sealed enclosure. During transport, an impact limiter, constructed of redwood blocks encased in a steel sheath is bolted to the container lid. Trunnions on opposing sides of the cask enable handling and securing to the conveyance.

One IFC has been built. However, since used nuclear fuel is currently stored at the generation stations, it has never been used.

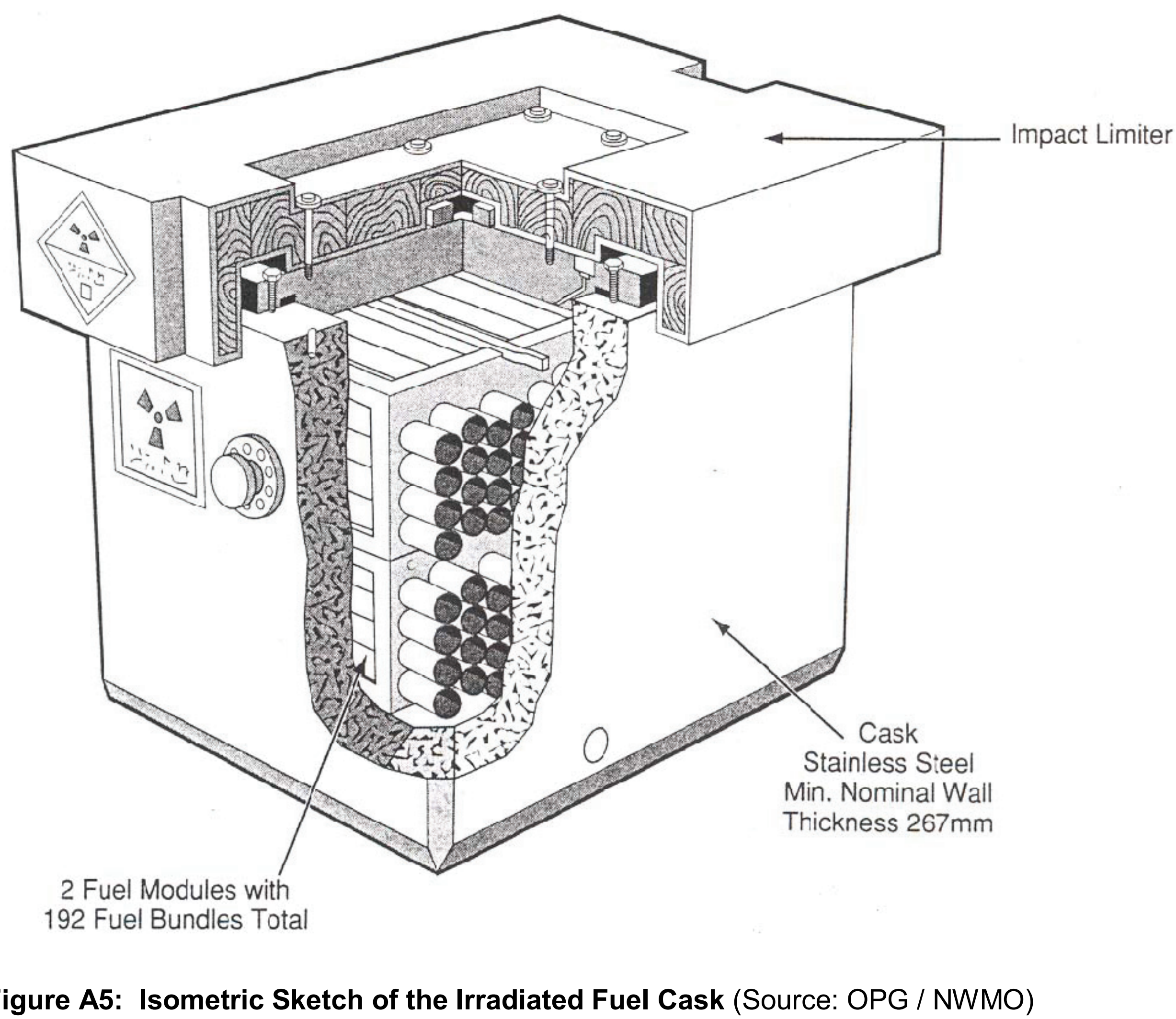

Figure A5: Isometric Sketch of the Irradiated Fuel Cask (Source: OPG / NWMO)

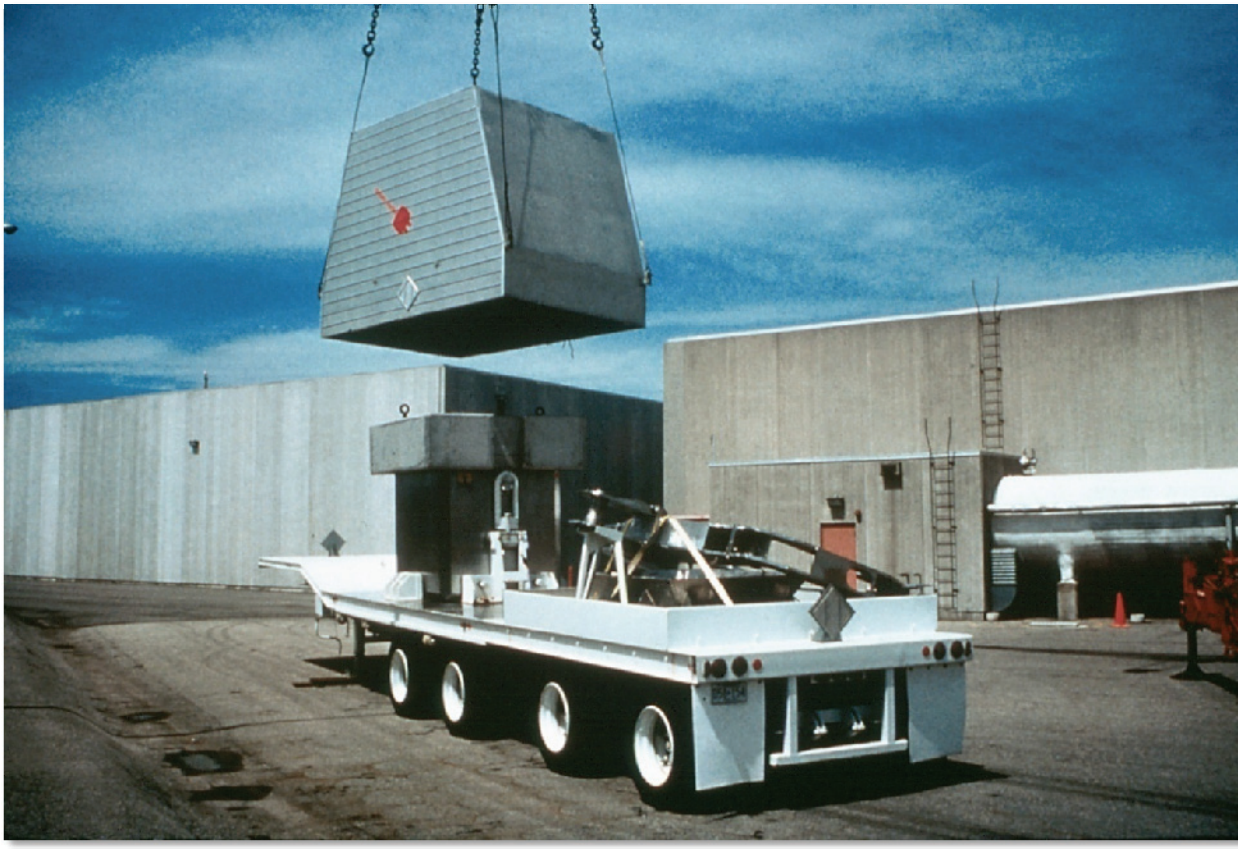

Figure A6: Photo of Ontario Power Generation's Irradiated Fuel Cask on trailer (Source: OPG / NWMO)

A.6 Dry Storage Container Transportation Package (DSCTP)

The intent of the DSCTP is to facilitate transport of a dry storage container (DSC) containing used nuclear fuel. A DSC is a massive steel encased concrete container that contains 4 fuel modules each containing 96 used CANDU fuel bundles for a total of 384 fuel bundles. The DSC in rectangular in shape with approximate dimensions of 2,419 mm in width, 2,120 mm in breadth and 3,550 mm high. Each fully loaded DSC weighs approximately 70 tonnes. As of 2009, over 1,000 DSCs are in storage at three dry storage facilities in Ontario.

The DSCTP consists of a DSC fitted with impact limiters on each end. A sketch of the package is provided in Figure A7. Shielding, heat dissipation and structural strength of the package are provided by the DSC. Impact protection is provided by the impact limiters. The impact limiters are comprised of a steel shell filled with polyurethane foam. Armoured plating positioned between the impact limiters provides impact protection of the DSC in areas not covered by the impact limiters.

The fully assembled package is rotated onto its side for transport. The package is certified by the CNSC for transport by rail and sea. Due to its size and weight, any movement of the 100 tonne package by road would require special permits. Although many DSCs have been fabricated, the impact limiters required to complete the DSCTP have not, because used nuclear fuel is stored at the reactor sites and there is no current requirement for off-site transport.

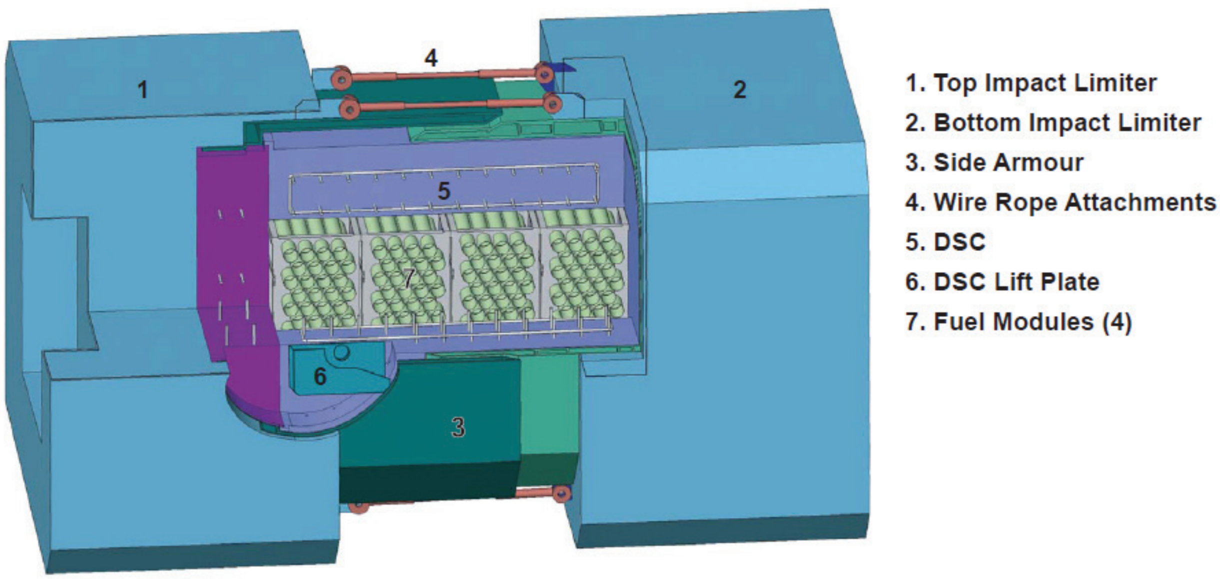

Figure A7: Cut-away Sketch of the Dry Storage Container Transportation Package
(Source: OPG / NWMO)

DSCs are loaded with used nuclear fuel at the generating stations. The loaded DSCs are then transferred to a dry storage facility using a specially designed vehicle or “transporter” (see Figure A8). Each generating station has its own transporters and dry storage facility located within the site boundary. Since the these transfers occur within the site boundary, they are subject to the CNSC regulations applicable to nuclear facilities rather than the CNSC Packaging and Transport of Nuclear Substances Regulations. On-site transfers of the DSCs take place without impact the limiters required for off-site transport installed. However, the low speed transfers only take place in good weather under controlled conditions.

Figure A8: On-site movement of a Dry Storage Container (Source: OPG)