**The Safe and Secure Transport of Radioactive Materials**

**Trevor Dixon, Specialist Advisor**

World Nuclear Transport Institute, 7 Old Park Lane, London, W1K 1QR, U.K.

Tel: +44 (0)20 7408 1944
Fax: +44 (0)20 7495 1964
Email: trevord@wnti.co.uk

## 1 Introduction

The safe and efficient transport of radioactive materials is vital to many aspects of modern life, from the generation of electricity, to medicine and health, scientific research, and agriculture. All these industries are becoming increasingly global in terms both of products and services. Maintaining safe and secure national and international transport by all modes is essential to support them.

The international transport of all radioactive materials, including nuclear fuel cycle materials, is governed by a stringent regulatory regime which includes standards, codes and regulations that have been continuously revised and updated over the past four decades. The safety and security record of these shipments is impressive; in over 45 years there has never been an incident which has given rise to significant radiological damage to man or the environment.

Yet despite this excellent safety and security record a worrisome trend for global supply is that some shipping companies, air carriers and ports have instituted policies of not accepting radioactive (or Class 7) materials.

This paper describes the major radioactive materials and the means by which they are packaged and transported. The reasons for increasing delays and denials of shipments also are briefly discussed together with the various initiatives to address the problem including industry efforts through the World Nuclear Transport Institute (WNTI).

## 2 International regulatory regime

Radioactive material is only one of a total of nine classes of dangerous goods that are routinely transported worldwide. The use of dangerous goods is commonplace in modern society and as world trade in chemicals and other goods continues to expand so too, in parallel, does the international movement of such goods. The United Nations (UN) Recommendations for the Transport of Dangerous Goods provide the guiding principles for land, air and sea transports of dangerous goods throughout most of the world. These Recommendations fully incorporate the International Atomic Energy Agency's (IAEA's) recommended regulatory standards for international radioactive materials transport activities. In addition, the UN Recommendations form the basis for the International Maritime Dangerous Goods Code, a mandatory instrument, regulating the transport of dangerous goods by sea.

The Technical Instruments regulating the transport of dangerous goods by air, developed by the International Civil Aviation Organization, also use the UN Recommendations as a foundation.

## 3 Transport packagings

The IAEA Regulations for the Safe Transport of Radioactive Material set the basis for the safe transport of all radioactive materials. The basic concept is that safety is vested principally in the package which has to provide shielding to protect workers, the public and the environment against the effects of radiation, to prevent criticality excursions i.e. an unwanted fission reaction, and also to provide protection against dispersion of the contents. All this has to be achieved under both normal and accident conditions of transport. In addition, it is important to reduce radiation doses to workers and the public as far as reasonably achievable by adopting best practice at the operating level.

The Regulations provide for five different primary packages, i.e. Excepted, Industrial, Type A, Type B and Type C and set the criteria for design based on the nature of the radioactive materials they are to contain. The Regulations also prescribe the appropriate test procedures. This graded approach to packaging whereby the package integrity is related to the potential hazard, i.e. the more hazardous the material the tougher the package, is important for efficient commercial transport operations.

Road, rail and sea transport are all commonly used for nuclear fuel cycle materials. Air transport has been used to a limited extent.

## 4 The nuclear fuel cycle

Radioactive materials fuel the nuclear power industry; an industry generating electricity in 31 countries, supplying over 16% of the world's demand for electricity making clean, affordable energy available to people the world over. To sustain this important source of energy, it is essential that nuclear fuel cycle materials continue to be transported safely and efficiently.

The nuclear fuel cycle consists initially of the processes for the preparation of the new fuel for loading into the reactor starting from mined uranium ore, the so-called front end processes. The back end of the fuel cycle covers all the operations for spent fuel that leaves the reactors. When the spent fuel is discharged from the reactor there are two back end options. The spent fuel can either be reprocessed to recover the unused uranium and plutonium generated in the reactor, both of which can be recycled, or it can be stored for eventual direct disposal. The various fuel cycle materials and the methods by which they are packaged and transported are briefly described below.

## 5 Front end materials

### 5.1 Uranium ore concentrate

Uranium ore is widely distributed. The main sources are in North America, Australia, South Africa and Eastern Europe. After mining the processes used are similar to those for upgrading other metals, typically chemical leaching and concentration, followed by precipitation to yield a dry powder of natural uranium oxide known as uranium ore concentrate (UOC).

UOC is a low specific activity material. It is normally transported in sealed 200 litre drums (an Industrial package) in standard containers. These can be transported by road, rail or sea. Loading is by crane or fork-lift truck with limited access by workers. The total world annual requirements for UOC amount to about 70,000 tonnes, all of which has to be transported from the mining areas to conversion plants mainly for manufacture into uranium hexafluoride (Hex).

### 5.2 Uranium hexafluoride

Hex produced from the conversion of UOC is a very important intermediate in the manufacture of new reactor fuel. In the production process, large cylindrical steel transport cylinders some 1.25m (48") in diameter, each holding up to 12.5 tonnes of material are filled directly with Hex which can be liquid or gaseous depending on the manufacturing process. The Hex then solidifies inside the cylinder on cooling to room temperature. In storage and during transport the Hex material inside the cylinders is in a solid form. Hex is also stored in these cylinders prior to being transported to an enrichment plant. Hex is routinely transported by road, rail or sea, or more commonly, by a combination of modes. Hex cylinders are transported using trailers, rail wagons or standard ISO flat rack containers.

### 5.3 Enriched uranium hexafluoride

Only 0.7% of natural uranium is 'fissile', or capable of undergoing fission, the process by which energy is produced in a nuclear reactor. This is enriched to the level required for most common types of nuclear reactors. Commercial enrichment plants are in operation in the USA, Western Europe and Russia and this gives rise to extensive international transport operations involving Hex between conversion and enrichment plants.

Smaller universal cylinders are used to transport enriched Hex. These cylinders are some 76 cm (30") in diameter and are loaded in overpacks to guard against a criticality excursion i.e. an unwanted fission reaction. The loaded overpacks are generally transported using ISO flat rack containers for transport to fuel fabrication plants.

### 5.4 Fabricated uranium fuel

Reactor fuel is generally in the form of ceramic pellets. The pellets are encased in metal tubes to form rods which are then arranged into a fuel assembly ready for introduction into a reactor. The fuel assemblies are transported in specially designed packages and the configuration of packages during transport guarantees that criticality excursions could not occur.

## 6 Back end materials

### 6.1 Spent fuel, MOX fuel, and vitrified high-level waste

Fuel is discharged periodically from nuclear reactors, typically after about three to five years as it becomes less efficient. This highly radioactive 'spent' fuel can either be sent to a reprocessing plant or stored pending final disposal.

Reprocessing separates out the usable uranium (96%) and plutonium (1%) from the 3% waste in the spent fuel. The uranium can then be recycled in enrichment plants and the plutonium converted into new mixed uranium/plutonium oxide (MOX) fuel. The high-level wastes are transformed into a solid glass form by a vitrification process. Recycling spent fuel into MOX reduces the volumes of nuclear waste, compared with the direct disposal option. Following commercial reprocessing, all the products have to be returned to the country of origin.

The solid nature of the products – spent fuel, MOX fuel, and vitrified high-level waste – is one of the most important safety factors. The materials are characterised by long-term stability and low solubility in water and will stay contained in a solid form after accident. Spent fuel and MOX fuel are very similar in that they are both made of hard ceramic pellets that are contained in zirconium alloy metal tubes (fuel rods).

In the case of vitrified high-level waste, the vitrification process allows the fission products to be incorporated into a molten glass which is then poured into a stainless steel canister, where it solidifies. As a result, the fission products are immobilised and the vitrified product is protected by the stainless steel canister.

In accordance with the IAEA Regulations, spent fuel, MOX fuel, and vitrified high-level waste are transported in specially designed, robust transport packagings known as flasks or casks (termed as Type B packages in the Regulations). Type B packages range in size from small drums to massive heavily shielded containers.

Spent fuel is transported extensively across Western Europe, and from the Far East to reprocessing plants in France and the UK. Vitrified high-level waste is transported internationally by rail, road and sea.

Plutonium derived from the commercial reprocessing of spent fuel is normally returned to the country of origin in the form of MOX fuel elements. MOX fuel is transported under special conditions by road or rail and in dedicated vessels for sea transport. Extensive experience in MOX transport has been built up in Western Europe over many years and recently also by sea from Europe to the Far East.

Sea transport of these back end materials is by specialist ships designed and operated in accordance with the Irradiated Nuclear Fuel (INF) Code of the International Maritime Organization (IMO).

## 6.2 Environmental studies

The transport systems for spent fuel, vitrified high-level waste and MOX fuel involves a series of independent barriers – solid cargoes, casks, ships - between the materials and environment ensuring a high level of safety.

Several well-supported studies have concluded that even in the highly improbable event of a cask being damaged in a maritime accident, the level of effect to people or the environment would be insignificant compared to natural background radiation.

# 7 Non-fuel cycle radioactive materials

Radioactive materials are also widely used in gamma processing which provides 40% of the world's sterile medical disposables and devices (from swabs and syringes to hip joints and heart valves) as well as sterile ingredients for pharmaceuticals. Large sources are also used for sterilisation purposes in the food industry and in many industrial applications, for example in the radiography of high-duty metal fabrications. These gamma sources are manufactured in very few countries and sea transport is therefore vital to distribute them from the manufacturers to several hundred users worldwide. Radioactive materials are also used in medicine for diagnostic purposes and therapy, and in the manufacture of radio-pharmaceuticals.

All these industries are becoming increasingly global in terms both of products and services. Safe and secure national and international transport by all modes is essential to support them.

Non-fuel cycle material comes in a variety of chemical and physical forms and the potential hazards they present differ widely. Packages used for these materials range from capsules of radio-pharmaceuticals in cardboard boxes, millions of which are transported each year, to gamma sources in massive, shielded containers weighing several tonnes.

# 8 Security

Security in transport involves the various measures to guard against the consequences of intentional malicious acts and this is mainly the responsibility of individual States, which have to set up the necessary regulatory framework. The main concern in the past has been theft and diversion of radioactive material but the tragic events of 11 September 2001 in the USA have heightened sensitivities to security against potential terrorist action. The IAEA has initiated work on the need for enhanced measures for security in the transport of radioactive materials, including nuclear fuel cycle materials to complement the security requirements in the UN "Model Regulations". The Model Regulations contain a basic security level for the transport of all dangerous goods as well as additional requirements for an enhanced security level for goods defined as 'high consequence dangerous goods', which have the potential to give rise to serious consequences in the event of a terrorist incident.

The Model Regulations feed into the Modal Regulations for air, sea and land transports. These Regulations become mandatory through the International Maritime Dangerous Goods (IMDG) Code and the International Civil Aviation Organisation's

Technical Instruments for sea and air transports. Security requirements may include close monitoring of the transport operations, a necessary degree of confidentiality, a strict international regulatory regime and appropriate protection measures.

## 9 Delays and denials of shipments

Denials and delays of shipments of radioactive materials can have potentially a serious impact on those industries reliant upon such materials. Over recent years the transport industry has, in certain instances, faced a reduced availability of routes and carriers as a result of decisions by commercial carriers, ports and handling facilities not to accept radioactive cargoes.

Impediments to the timely transport of radioactive materials is not only time-consuming, costly and inconvenient, it can in certain circumstances adversely impact safety. There is growing recognition internationally of the problems created by shipment delays and denials and they now are being addressed in a more concerted way by such organisations as the International Atomic Energy Agency (IAEA). The World Nuclear Transport Institute (WNTI) is committed to do all it can to support the international efforts to address this important subject and has created an industry task force on sustaining shipping options to look at the problems of denial and delay from a solutions-oriented perspective.

## 10 Industry Experience

The IAEA Regulations for the Safe Transport of Radioactive Material have provided a sound basis for the design of equipment and procedures for the safe and efficient transport of radioactive materials. No sector of the transport industry is more highly regulated and incidentally, no sector of the transport industry has a better safety record. In over 45 years there has never been a single incident which has resulted in significant radiological damage to man or the environment. This is due in part to the strict regulatory regime; but credit is due also to the professionalism of those entities performing packaging and transport activities.