Transport of Nuclear Fuel Cycle Materials and Products

Trevor Dixon
Specialist Advisor, WNTI

IUMI 2004, Singapore, 12-15 September 2004

1. Introduction

Each day thousands of shipments of radioactive materials of all kinds are transported on national and international routes. These consignments, which are carried by road, rail, sea and inland waterway, can range from smoke detectors and cobalt sources for medical uses, to nuclear fuel cycle materials for electricity production.

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 record of these shipments is impressive; in over 40 years there has never been an incident which has given rise to significant radiological damage to man or the environment.

This paper describes the major nuclear fuel cycle materials and the means by which they are packaged and transported.

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 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. Radioactive materials in context

The US Agency for Toxic Substances and Disease Registration (ATSDR) and the US Environmental Protection Agency (EPA), are required by US law to maintain a "Priority List of Hazardous Substances" for transport. The most hazardous radioactive material in the priority list is Uranium ranked at position 92. Among those materials ranked higher than Uranium are, for example, Arsenic (1), Lead (2), Vinyl Chloride (4), Cyanide (26), Cobalt (49), Methane (65), Chlorine (84), and Asbestos (90). Cobalt 60 and Plutonium 239 are ranked 126th, 130th respectively.

4. The nuclear fuel cycle

Nuclear power is important if the world is to satisfy its growing demand for electricity and at the same time meet its environmental obligations, particularly the need to curb carbon dioxide emissions.

Nuclear power currently supplies some 16% of the world's demand for electricity from over 400 reactors in 32 countries. The majority of these reactors are either pressurised water reactors or boiling water reactors and in both cases the primary fuel is enriched uranium oxide. The fuel core for these light water reactors contains typically many fuel assemblies consisting of sealed fuel rods each filled with sintered uranium dioxide (UO2) pellets with a concentration of the fissile component of uranium, U-235, of 3-5%.

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. 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 the plutonium generated in the reactor, both of which can be recycled, or it can be stored for eventual direct disposal, which is the once-through concept. The various operations are briefly described below.

4.1 Mining and milling of uranium

Uranium ore is widely distributed. The main sources are North America, Australia, South Africa and Eastern Europe. After mining, the processes used are similar to those for the upgrading of 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).

4.2 Conversion of uranium ore concentrate to uranium hexafluoride

UOC is transported worldwide from the mining areas to conversion plants. It is first chemically purified and then converted by a series of chemical processes into natural uranium hexafluoride (Hex), which is the form required for the following enrichment stage.

4.3 Enrichment of uranium hexafluoride

The valuable isotope of uranium that splits (fissions) in a nuclear reactor is U-235, but only around 0.7% of naturally occurring uranium is U-235. This is increased to the level required, about 3-5% for light water reactors, either by gaseous diffusion process or in gas centrifuges. 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.

4.4 Fuel fabrication

The enriched uranium hexafluoride is first converted into uranium dioxide powder which is then processed into pellets by pressing and sintering. The pellets are stacked into zirconium alloy tubes which are then made up into fuel assemblies for transport from the fabrication plant to the reactor site.

4.5 Spent fuel storage

Fuel is discharged periodically from nuclear reactors, typically after about 3-5 years, and this highly radioactive spent fuel is first stored, usually under water to provide both cooling and shielding, at the reactor site. After a period of temporary storage, the spent fuel can either be sent to a reprocessing plant or stored pending final disposal.

4.6 Spent fuel reprocessing

Spent fuel consists typically of 96% of the original uranium, 1% of plutonium formed in the reactor and 3% of highly radioactive fission products. These can be separated in a reprocessing plant by a series of chemical processes. The uranium can then be recycled in enrichment plants and the plutonium converted into new mixed uranium/plutonium oxide (MOX) fuel. The fission product wastes are transformed into a solid glass form by a vitrification process. Following commercial reprocessing, all the products have to be returned to the country of origin.

5. The safe transport of nuclear fuel cycle materials

The IAEA Regulations for the Safe Transport of Radioactive Material set the basis for nuclear fuel cycle materials transport. 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 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.

5.1 Uranium ore concentrate

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 to conversion plants mainly for manufacture into Hex.

5.2 Uranium hexafluoride

The natural Hex produced from the conversion of UOC is a very important intermediate in the manufacture of new reactor fuel. There is large commercial trading in it which involves extensive international transport. 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. Natural 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.

Although Hex is a low specific activity material there would be a chemical hazard in the unlikely event of a release because it produces toxic by-products on reaction with moist air.

5.3 Enriched uranium hexafluoride

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 Depleted uranium hexafluoride

Depleted Hex, the residual product from the enrichment process, has the same physical and chemical properties as natural Hex and is transported using the same type of cylinder.

5.5 Uranium dioxide powder and fabricated fuel

Uranium dioxide powder derived from Hex of less than 5% enrichment is also classified as low specific activity material. The fuel assemblies manufactured from it are some 4m long. They are transported in specially designed packages and the configuration of packages during transport guarantees that criticality excursions could not occur.

5.6 Spent fuel

Spent nuclear fuel is intensely radioactive. It is transferred first from the reactor to the on-site storage ponds for shielding and to allow radioactivity to decay. For subsequent transport off the reactor site, either to off-site storage or to reprocessing facilities at home or abroad, it is transported in high integrity Type B flasks. These flasks are massively constructed from steel weighing typically around 100 tonnes. The large steel thickness is needed to attenuate the very high levels of gamma radiation and additional shielding is also needed to reduce the neutron flux. The flasks may incorporate cooling fins to allow the residual heat to be dissipated and keep surface temperatures to acceptable levels. They may also provide protection against impact.

Spent fuel is transported extensively by rail across Western Europe and also by sea in Sweden, and from the Far East to reprocessing plants in France and the UK. Sea transport is by specialist ships designed and operated according to the Irradiated Nuclear Fuel (INF) Code of the International Maritime Organization (IMO).

5.7 Vitrified high-level waste

Vitrified high-level waste from the reprocessing of spent fuel is stored temporarily at the reprocessing plant to allow fission product heating to decay before it is returned to the country of origin. The transport flasks are similar in design and construction to those for spent fuel and the transport operations whether by rail or sea also are similar. Several sea and rail shipments of vitrified waste have been successfully carried out.

5.8 Mixed oxide fuel (MOX)

The plutonium derived from the commercial reprocessing of spent fuel is normally returned to the country of origin in the form of MOX fuel elements in which the enriched uranium isotope is replaced by plutonium. They are 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.

6. Experience in nuclear materials transport

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 nuclear fuel materials. On this foundation the nuclear transport industry, both those organisations solely dedicated to nuclear transport, as well as the many transport companies for which nuclear transport is only a part of their business, have operated safely and successfully for over 40 years. No incident has occurred which has resulted in significant radiological damage to man or the environment.

For further information contact:

WNTI
7 Old Park Lane
London W1K 1QR
United Kingdom
Tel: +44 (0)20 7408 1944
Fax: +44 (0)20 7495 1964
Website: www.wnti.co.uk
e-mail: wnti@wnti.co.uk