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# The Packaging and Transport of Nuclear Fuel Cycle Materials

conference paper

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**Dedicated to the  
safe, efficient  
and reliable  
transport of radioactive  
materials**

## Abstract

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. In order to sustain nuclear power, it is essential that nuclear fuel cycle materials continue to be transported internationally both safely and efficiently. This paper describes the major nuclear fuel cycle materials and the means by which they are packaged and transported. These transport operations have been carried out safely for over 40 years and during the whole of this period there has never been an incident which has given rise to significant radiological damage to man or the environment.

## 1. The nuclear fuel cycle

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 ( $UO_2$ ) 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.

### 1.1 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 beneficiation 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, or UOC.

### 1.2 Conversion of uranium ore concentrate (UOC) to uranium hexafluoride (Hex)

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 Hex, which is the form required for the following enrichment stage.

### 1.3 Enrichment of uranium hexafluoride (Hex)

The concentration of the fissile isotope in Hex is 0.71%. This is increased to the level required, about 3-5% for light water reactors, either by a 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.

### 1.4 Fuel fabrication

The enriched Hex 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.

### 1.5 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 prepared for long-term storage prior to permanent disposal.

### 1.6 Spent fuel reprocessing

Spent fuel consists typically of 96% unused uranium, 1% of plutonium formed in the reactor and 3% of highly radioactive fission product waste. 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 processed into stable forms for disposal, the highly active stream being converted into glass by a vitrification process. Following commercial reprocessing, all the products have to be returned to the country of origin.

### 1.7 Waste disposal

The radioactive wastes from reactor and fuel processing operations have to be disposed of safely by isolating them from the biosphere. Current plans are to achieve this by geological disposal. When spent fuel is reprocessed, the wastes arising are immobilised for disposal. In the once-through cycle the spent fuel has to be disposed of directly as a waste.

## 2. The safe transport of nuclear fuel cycle materials

Nuclear power is expected to continue to play an important role in meeting the world's increasing demand for affordable and sustainable electricity, and to sustain the nuclear power industry fuel cycle materials have to be transported safely and efficiently. The nature of the industry is such that most countries with important nuclear power industries cannot provide all the necessary fuel cycle services themselves and consequently nuclear fuel cycle transport activities are international.

The International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Materials set the basis for nuclear fuel cycle materials transport. The basic concept is that safety is vested 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; that is, 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. The graded approach to packaging whereby the package integrity is related to the potential hazard; that is, the more hazardous the material the tougher the package, is important for efficient commercial transport operations. This is the case with nuclear fuel cycle materials.

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

## 2.1 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 to conversion plants mainly for manufacture into Hex.

## 2.2 Uranium hexafluoride (Hex)

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, Hex is condensed as a solid directly into universal 48Y cylinders, which are large cylindrical steel transport cylinders some 1.25m (48 inches) in diameter, each holding about 12.5 tonnes of Hex. It can be stored in these cylinders prior to being transported, normally bolted down in standard containers, to an enrichment plant by either road, rail or sea, or more likely, by a combination of modes of transport. Although Hex is a low specific activity material there are significant hazards due to its chemical nature. It produces toxic by-products on reaction with water or water vapour and there also is a danger that cylinders could rupture if subjected to high temperatures. For these reasons, Hex packages are subjected to appropriate extra requirements, beyond those required because of the radioactive inventory, and have to be approved.

For enriched Hex for water reactors the concentration of the fissile isotope,  $U_{235}$ , is increased to about 3-5% and at this enrichment it is necessary to transport it in smaller universal 30B cylinders. These cylinders are some 30 inches in diameter and are transported in overpacks in order to guard against criticality excursions. The cylinders in overpacks can be bolted into containers for transport to fuel fabrication plants.

## 2.3 Uranium dioxide powder ( $UO_2$ ) and fabricated fuel

$UO_2$  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 normally designed to Type A standards (but with the additional requirements for packages containing fissile materials). The configuration of packages during transport guarantees that criticality excursions could not occur.

## 2.4 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 dedicated ships designed and operated according to the Irradiated Nuclear Fuel (INF) Code of the International Maritime Organization (IMO).

## 2.5 High-level wastes

High-level vitrified 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.

## 2.6 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.

## 3. 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. It is important that all those involved in nuclear fuel cycle transport, that is the industry, the IAEA, the modal organisations and the regulators, should continue to co-operate closely to ensure that these high standards are maintained. Industry worldwide, through the World Nuclear Transport Institute (WNTI), is co-operating to ensure that it fully meets the requirements of the international transport safety regulatory regime.

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