Chapter 50

Radioactive Uranium Hexafluoride (UF6)

50.1 Production, Processing and Use of UF6

The raw material to make fuel for nuclear power stations is uranium ore, the main sources of which are South Africa, North America, Australia and the former Soviet Bloc countries of Eastern Europe. The ore is first ground and purified at the mining site using chemical and physical processes to produce a dry powder of natural uranium oxide, known as uranium ore concentrate (UOC).

This material contains 0.72% of the uranium 235 isotope (U235), which is fissionable. The rest consists of non-fissionable uranium 238 and small traces of other naturally occurring isotopes such as thorium.
To be manufactured into nuclear fuel for pressurised water or light water reactors, the fuel needs to contain 4 to 5% U235. This is achieved by ‘enriching’ the proportion of U235 in a gaseous diffusion plant or, increasingly, in a gas centrifuge plant. The feedstock needed for this process is in the form of natural uranium hexafluoride (UF6). Uranium ore concentrate is transported worldwide to conversion plants in Europe and North America, where it is converted into uranium hexafluoride by reacting it with anhydrous hydrogen fluoride and fluorine gas. Commercial enrichment plants are in operation in North America and Western and Eastern Europe, which gives rise to the international transport of UF6 between conversion plants and enrichment plants. Following enrichment, UF6 is transported worldwide to nuclear fuel manufacturing plants, where it is processed back into the form of uranium dioxide powder. The powder is processed into nuclear fuel pellets by pressing and sintering. Depleted UF6, the residual product from the enrichment process, has the same physical and chemical properties as natural UF6 and is transported in the same way. For transport, following the conversion process, large cylindrical steel cylinders 48 inches in diameter each holding up to 12.5 t are filled with natural UF6. The UF6 solidifies inside the cylinder on cooling to room temperature. On reaching the enrichment plant, the cylinders are warmed by electrical trace heating,
which turns the solid into the gaseous form needed for the enrichment process. After enrichment, the enriched UF6 is transported in 30 inch steel cylinders inside an overpack to prevent a criticality excursion (an unwanted nuclear chain reaction).

**50.2 The Hazards of UF6**

UF6 presents both radioactive and chemical hazards but, for the purposes of transport regulation under the IMDG Code (Reference 19), the radioactive nature of the material takes precedence and it is therefore categorised as radioactive Class 7.

**Radioactive effects**

UF6 poses potential health risks due to the radioactive nature of the uranium and the other radioactive elements it decays into. For natural UF6, the radiological hazard is low and the main hazard is due to the chemical effects of a release. Enriched UF6 poses a hazard with respect to the possibility of a criticality excursion, which would result in very large pulses of gamma radiation within tens of metres of the packages.

**Chemical effects**

If UF6 is released to the atmosphere, the uranium compounds that are formed by reaction with moisture in the air are chemically hazardous. Uranium is a heavy metal that, in addition to being radioactive, can have chemical effects, principally on the kidneys, if it enters the bloodstream by ingestion or inhalation. When UF6 comes into contact with water vapour in the air, it reacts to form hydrogen fluoride and uranyl fluoride, which are intensely corrosive to the skin and toxic if inhaled.

Figure 50.2: UF6 cylinder being loaded onto a flat-rack container.
50.3 IAEA/IMDG Code Regulations for the Transport of UF6

UF6 transport is subject to comprehensive and strict regulation. The International Atomic Energy Agency (IAEA) has developed and continuously revises these regulations, which are used as the basis for relevant sections of the IMDG Code (Reference 19). The IAEA approach is that the safety of radioactive material transport is defined by the design, construction and operation of the packages used and that the level of package safety is proportional to the hazard of the material it contains. UF6 packages have to be able to withstand normal and accident conditions during transport. They are designed in accordance with ISO Standard 7195 (Reference 80), which is specific to UF6 packages. They are tested to withstand hydraulic tests to 2.76 MPa, a drop test onto the most vulnerable part of the package and a thermal test consisting of immersion in a fire at 800°C for 30 minutes.

In addition, cylinders designed to carry enriched UF6 must be able to withstand a drop test from a height of 9 m without rupture or degradation of criticality safety. The packages must be approved by the Competent Authority, and this includes quality assurance during construction and operation and periodic testing during use.

50.4 Current and Future Levels of UF6 Transport

There are no official figures, but the current annual level of uranium ore transport worldwide is believed to be about 30,000 to 40,000 t from the source to the plants that convert it to UF6. As these conversion plants are in Europe and North America, this means that most of this material is transported by sea. When converted to UF6, about 10,000 to 15,000 t are believed to be transported by sea to enrichment plants. This represents up
to 2,000 packages. After enrichment, about 3,000 t of enriched UF6 are transported from enrichment plants to the fuel fabricators, many of which are located overseas. Cylinders returning from these transports often contain residues of UF6, known as ‘heels’, and some cylinders are returned slightly contaminated after washing. In future years, it is known that some conversion facilities will close and it is anticipated that this will result in a 10% increase in sea transport of UF6 between Europe and the USA. In addition, it is impossible to anticipate variations in monetary exchange rates and, because uranium enrichment costs are largely based on the cost of electricity, this may also cause a significant variation in transport levels.

50.5 Accidents Involving UF6

Two significant accidents have occurred during sea transport of UF6.

On 25th August 1987, a French cargo ship, the ‘Mont Louis’, sank in the English Channel after a collision with a car ferry. The ‘Mont Louis’ was carrying 30 cylinders of UF6 containing 12 t of material each. Although there was damage to some of the cylinders, no significant release of UF6 occurred. The recovery campaign was complex and lengthy because of the sea conditions and the need to carry out extensive checks to the cylinders before their onward transport. In addition, there was a very large programme of environmental testing carried out by the French and UK Authorities.

On 23rd May 1989, a container vessel carrying nine cylinders of UF6 residues was involved in an incident while on passage from Rotterdam to Montreal. During a mid-Atlantic storm, three cylinders, which were inadequately secured inside a closed 40 ft freight container, broke loose, damaging the freight container and two adjacent containers. The valves of two of the cylinders were broken off and UF6 residue escaped, contaminating the deck of the ship, other
equipment and cargo in the adjacent containers. A section of the dock area was also contaminated when the freight containers were unloaded in Montreal.

The accident was caused by improper stowage of the UF6 cylinders inside the freight containers. Each of the cylinders had been tied to straps on the wall of the freight container using half inch thick polypropylene rope, which snapped during the storm. Although there was no significant radiological risk to the crew, workers or the public, there was a very large insurance claim for the subsequent monitoring and clean-up operation.

### 50.6 Club Cover and the ‘Excepted Matter’ Regulations

UF6 transport presents particular difficulties in assessing whether it is ‘excepted matter’ under the Nuclear Installations (Excepted Matter) Regulations 1978. If it is ‘excepted matter’, it is covered by the Club, but if it is not then the consignor, or in some cases the consignee, is required to arrange nuclear liability insurance in place of Club cover and provide the carrier with a certificate of financial security to demonstrate this. This certificate must be countersigned by the government of the country concerned.

UF6 is transported in a variety of quantities, enrichments and activities and, unlike chemical products, which have a single UN number for each material, UF6 may be UN 2978, 2977, 2919, 3331, 2910 or 2908. Natural UF6, i.e. non-enriched, is transported as UN 2978 and, although this should always be ‘excepted matter’, it is necessary to check since it is not unusual to find consignments that are misdeclared.

Enriched UF6 is transported in full, partially full, empty or contaminated cylinders. It is, therefore, always necessary to check the total quantity of U235 in a consignment to determine whether it is more or less than the limit of 600 gms and so whether it is covered for ‘excepted matter’ by the Club. This is achieved by converting the net quantity of UF6 to the weight of uranium and then, knowing the % enrichment, calculating the weight of U235.

Members should contact the Club for advice if there is any doubt as to whether or not the cargo is ‘excepted matter’.