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Chapter 49 – Radioactive Cargoes

If a radioactive cargo is not 'excepted matter', the consignment is not covered by P&I Club Rules and the consignor must arrange nuclear liability insurance and produce a certificate of financial security.

Transport of radioactive materials is a well-regulated international activity and it may be surprising to many people to know that approximately 15,000,000 radioactive packages are transported around the world each year, with up to 1,500,000 of these by sea. Records show that the transport of radioactive material is a highly safe activity in terms of people and the environment because of the regulatory standards to which the carriage is subject internationally, and the careful application of them by industry and transporters. As with the transport of all hazardous materials, the carrier places great reliance on the consignor to declare the materials correctly. In the case of liability insurance, there is an additional question of whether or not the consignment is 'excepted matter'. If it is not 'excepted matter', the consignment is not covered by P&I Club Rules and the consignor must arrange nuclear liability insurance and produce a certificate of financial security from their government before the consignment can be moved.

The following case involving an international shipment highlights the fact that, while Members may think they know that a certain shipment is probably 'excepted matter', they should always consult the Club for their nuclear consultant's confirmation.

Two consignments of uranium – one of uranium trioxide and one of uranium metal ingots – were shown on the dangerous goods note as being *Radioactive Material, Low Specific Activity (LSA-II),* and as being *'fissile excepted'.* However, the dangerous goods note also showed that, from the weights of uranium and of the U_{235} fissile isotope, the uranium trioxide was 5.55% fissile and the uranium ingots were 1.23% fissile. In each case, the limit for the quantity involved to be fissile excepted was 1.0%. When the Member refused these consignments, the consignor reverted with revised weights for the U_{235} fissile isotope that brought both consignments within the 1.0% limit. The Club's nuclear consultant was able to confirm that the revised figures were correct by obtaining the relevant data independently from the consignee, asking them what they were expecting to receive.

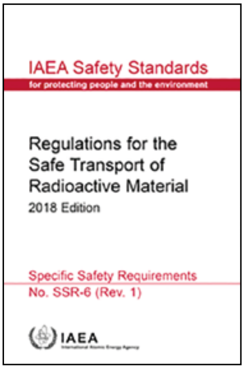
In this case, the outcome was satisfactory, but if the U_{235} fissile isotope weights in the first dangerous goods note had been correct and the packages had been stowed on a vessel in the proximity of other fissile material, there would have been a real risk of a 'criticality excursion' (chain reaction).

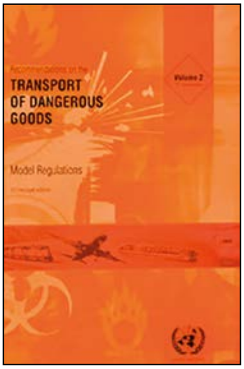
The Association's Rule 5, Exclusion of Nuclear Risks, applies.

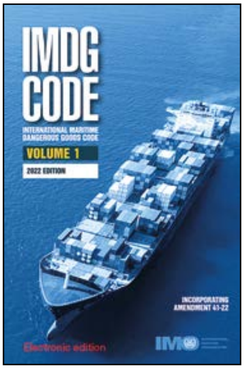
49.1 The Regulatory Framework (IAEA – UN Model Regulations – IMDG Code)

Transport of radioactive materials 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. UF_6 packages, as an example, must be able to withstand normal and/or accident conditions during transport. They are designed in accordance with ISO Standard 7195 (Reference 80), which is specific to UF_6 packages.

The packages must be approved by the Competent Authority, and this includes quality assurance during construction and operation, and periodic testing during use.







49.2 UOC and UF_6 – Production, Processing and Use

The raw material to make fuel for nuclear power stations is uranium ore. 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 (U_{235}), which is fissionable. The rest consists of non-fissionable uranium 238 and small traces of other naturally occurring isotopes such as thorium.

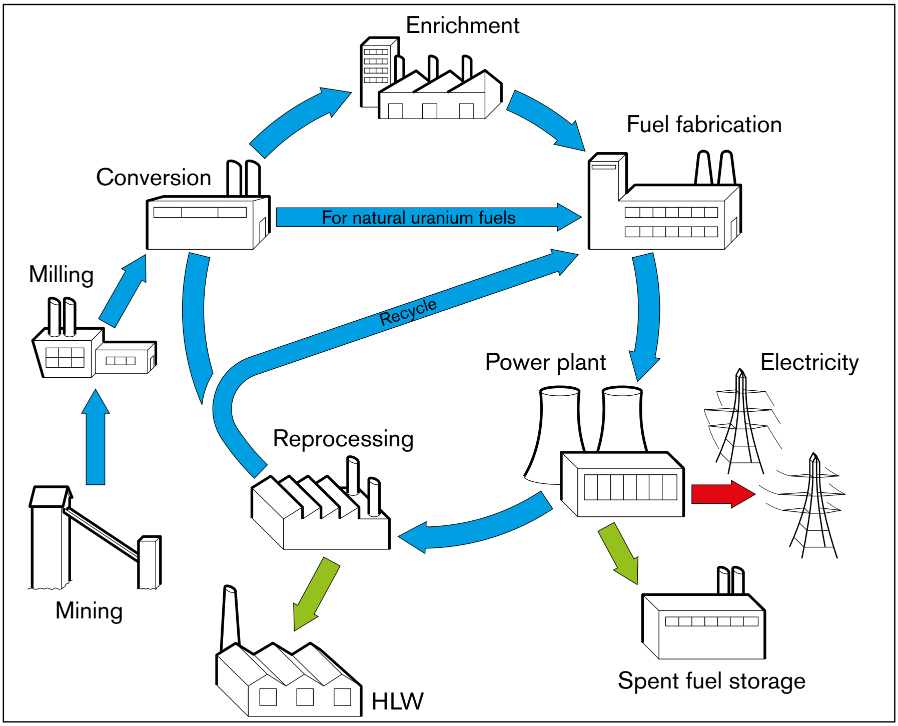


Figure 49.1: Nuclear fuel production processes.

To be manufactured into nuclear fuel for pressurised water or light water reactors, the fuel needs to contain 1 to 5% U_{235}. This is achieved by 'enriching' the proportion of U_{235} in a centrifuge enrichment plant. The feedstock needed for this process is in the form of natural uranium hexafluoride (UF_6).

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 fluorine gas. Commercial enrichment plants are in operation in North America and Western and Eastern Europe, which gives rise to the international transport of UF_6 between conversion plants and enrichment plants.

Following enrichment, UF_6 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 UF_6, the residual product from the enrichment process, has the same physical and chemical properties as natural UF_6 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 UF_6. The UF_6 solidifies inside the cylinder on cooling to room temperature. On reaching the enrichment plant, the cylinders are heated, which turns the solid into the gaseous form needed for the enrichment process. After enrichment, the enriched UF_6 is transported in 30 inch steel cylinders inside a protective structural package to provide protection against transport accidents. Enriched UF_6 packages are designed in accordance with ISO Standard 7195 (Reference 80), which is specific to UF_6 packages. They are required to withstand hydraulic tests to 2.76 MPa, including a drop test from 9 m onto the most vulnerable part of the package and a thermal test consisting of immersion in a fire at 800°C for 30 minutes.

49.3 The Hazards of UF_6

UF_6 presents a radioactive, toxic and chemical hazard 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
UF_6 poses potential health risks due to the radioactive nature of the uranium and the other radioactive elements it decays into. For natural UF_6, the radiological hazard is low and the main hazard is due to the chemical effects of a release. Enriched UF_6 poses an increased but still low radiological hazard and a low risk of a criticality excursion.

Chemical effects
If UF_6 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 UF_6 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 49.2: UF_6 cylinder being loaded onto a flat-rack container.

Figure 49.3: 48 inch cylinder for natural UF_6.

49.4 Current Levels of Uranium Ore and UF_6 Transport

There are no official figures, but the current annual level of uranium ore transport worldwide is believed to be about 40,000 to 50,000 T from the source to the plants that convert it to UF_6. As these conversion plants are in Europe and North America, this means that most of this material is transported by sea. When converted to UF_6, about 8,000 to 13,000 T are believed to be transported by sea to enrichment plants. This represents up to 2,000 packages annually. After enrichment, about 3,000 T of enriched UF_6 are transported from enrichment plants to the fuel fabricators, located everywhere in the world. Cylinders returning from these transports often contain residues of UF_6, known as 'heels', and some cylinders are classified under the IMDG Code as UN 2908 empty packages after washing. Uranium enrichment costs are largely based on the cost of electricity which is influenced, among other things, by variations in monetary exchange rates that are difficult to predict. Fluctuations in these costs can cause significant variation in transport levels.

49.5 Accidents Involving UF_6

Two significant accidents have occurred during sea transport of UF_6.

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 UF_6 containing 12 T of material each. Although there was damage to some of the cylinders, no significant release of UF_6 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.

Figure 49.4: Nuclear fuel assembly being loaded into nuclear power plant.

On 23rd May 1989, a container vessel carrying nine cylinders of UF_6 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 UF_6 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 UF_6 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.

49.6 Club Cover and the 'Excepted Matter' Regulations

UF_6 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. The certificate must be countersigned by the government of the country concerned.

UF_6 is transported in a variety of quantities, enrichments and activities and, unlike chemical products, which have a single UN number for each material, UF_6 may be categorised as UN 2978, 2977, 2919, 3331, 2910 or 2908. Natural, non-fissile UF_6, in quantities greater than 0.1 kg, is transported as UN 2978 and, although this should always be, 'excepted matter', it is necessary to check that consignments are not misdeclared.

Enriched UF_6 is transported in full, partially full, or emptied cylinders. It is, therefore, always necessary to check the total quantity of U_{235} in a consignment to determine whether it is more or less than the limit of 600 g, and therefore whether it is covered for 'excepted matter' by the Club. This is achieved by converting the net quantity of UF_6 to the weight of uranium and then, knowing the % enrichment, calculating the weight of U_{235}, eg 5 kg of UF_6 enriched to 4% contains 5 × 0.6761 = 3.3805 kg of uranium. The quantity of U_{235} is 3.3805 kg × 0.04 = 0.13522 kg or 135.22 g of U_{235}.

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

49.6.1 Other Radioactive Cargo

Plutonium, fission products, uranium and other transuranic elements combine to form used nuclear fuel. To decrease heat and radiation levels, used fuel is stored on site for up to five months. It can then be transported by land or sea to a reprocessing plant. Sea transportation requires purpose built ships containing Type B casks, composed of either steel or steel and lead. Approximately 300 used fuel transportations have been made by sea to date.

Over one-third of the energy produced in nuclear power plants come from plutonium, which has two different isotopic categories:

- 'Reactor-grade' plutonium, a by product of used fuel from nuclear reactors after it has been irradiated for around 3 years
- 'weapons-grade' plutonium, which is recovered from uranium that has been irradiated for a short period (2–3 months) and is made for military purposes.

Once irradiated (burned), reactor plutonium is transported as an oxide powder, ie in its most stable form. Cargo packages must be of a specific design and weight to be transported by sea. A typical container holds several packages, in weights ranging from 80 to 200 kg of plutonium oxide.

49.6.2 Naturally Occurring Radioactive Material (NORM)

Although NORM potentially includes all radioactive elements found in the environment, it usually refers to all naturally occurring radioactive materials where human activities have increased the potential for exposure. Therefore, NORM can be detected in industry, such as the production of oil and gas, mining and mineral sands extraction. NORM includes long-lived radioactive elements, primarily uranium, potassium and thorium, and their decay products such as radon and radium. Exposure to these naturally occurring elements contributes to a person's annual radiation dose, on average making up the majority of that dose.

Hydraulic fracturing (fracking) for gas production increases the release of NORM in water and drill cuttings. NORM causes operational safety issues for oil and gas industry workers during maintenance, decommissioning and waste transport. This is particularly problematic when pipe internals are exposed to Pb-210 deposits. However, external exposure tends to be low enough to keep workers below annual limits and prevent serious health risks.

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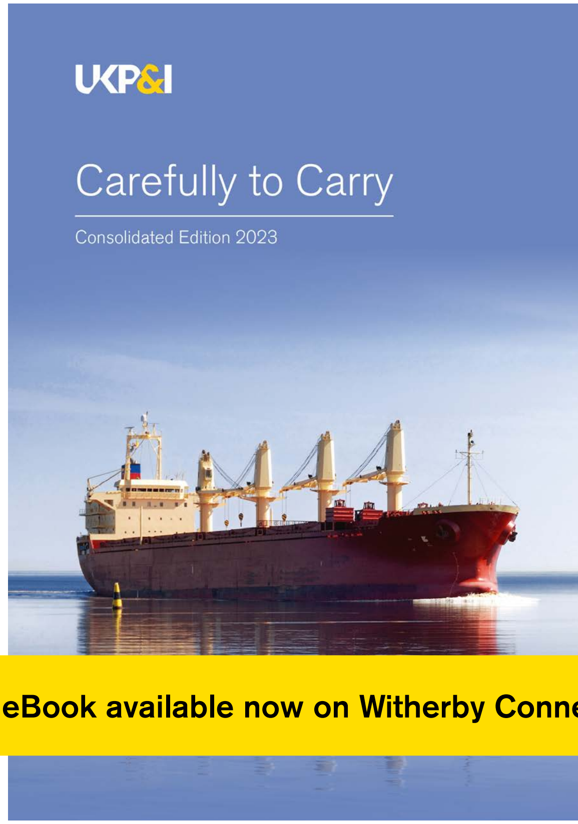

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