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Fact Sheet

Uranium Hexafluoride (UF6)

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Introduction

Uranium hexafluoride (UF_6) is a chemical compound used in the 'front end' of the nuclear fuel cycle. The 'front end' consists of the following steps; mining and milling, refining, conversion, enrichment and fuel fabrication. UF_6 is used in the steps conversion, enrichment and fuel fabrication. UF_6 is converted from uranium ore concentrate (UOC) (see WNTI Fact sheet) in conversion plants and is used in uranium enrichment facilities to produce enriched UF_6. The enriched UF_6 is converted to uranium oxide in fuel fabrication plants to produce fuel for nuclear reactors for electricity generation.

02

Preparation

In a conversion plant the uranium ore concentrate (U_3O_8) is chemically converted to uranium tetrafluoride (UF_4). The UF_4 is then reacted with elemental fluorine (F_2) at elevated temperatures to create uranium hexafluoride (UF_6).

Because the commercial enrichment facilities use a physical process, the UF_6 does not undergo chemical changes during enrichment operations. The enriched UF_6 is chemically converted to uranium oxide (UO_2) in a fuel fabrication plant.

Image 1. - Natural Uranium Ore

Image 2. – Uranium Hexafluoride

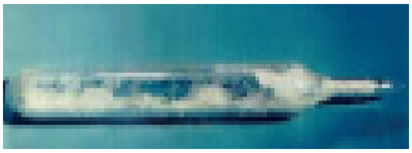


Image 3. - Uranium Hexafluoride

03

Properties

At 20°C, UF_6 is a solid, colourless, crystalline mass with a density of 5.06 g/cm^3. At a temperature of 56.5°C, the vapour pressure is atmospheric (1 bar or 100kPa). The triple point of UF_6 is at 64 °C and 1.5 bar. At and above the triple point, UF_6 exists in the solid, liquid and gaseous phases. Below its triple point, UF_6 can only be a solid or a gas. The different phases and phase changes are shown in the diagram below.

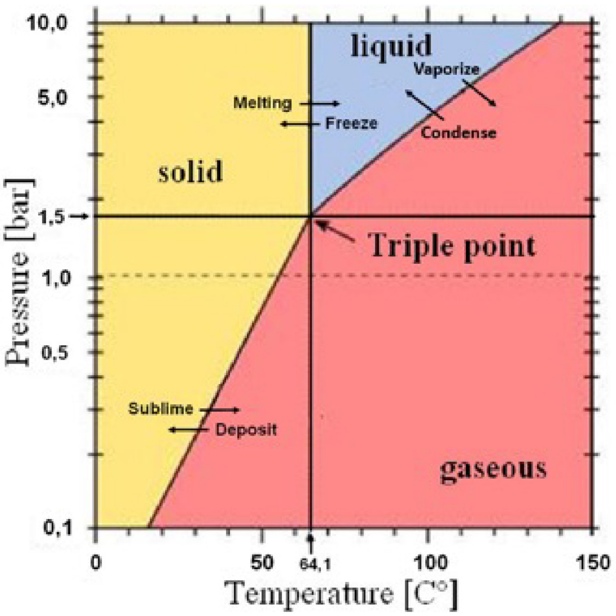


Image 4 - UF_6 Phase Diagram

UF_6 is a radioactive material. Its radioactivity derives from the uranium component. Uranium is mainly an alpha "α" and gamma "γ" emitter due to its characteristic decay products. There is a negligible beta "β" and neutron emission. A person standing for 2 hours next to a cylinder filled with natural UF6 would receive approximately a 7 microsievert (μSv) effective dose, which is comparable to one dental X-ray or a 2.5-hour commercial flight.

Although UF_6 is classified as a low specific activity material (LSA) for transportation, it bears a subsidiary hazard because it produces corrosive and chemotoxic by-products on contact with moist air if released to the atmosphere. The reaction of UF_6 with water results in soluble uranyl fluoride (UO_2F_2) and gaseous hydrogen fluoride (HF) according to the following equation.

$$UF_6 + 2\,H_2O \rightarrow UO_2F_2 + 4\,HF$$

The gaseous HF with water (body fluid) forms hydrofluoric acid, which is a strong corrosive. The reaction products of UF_6 also have significant toxic properties.

For larger quantities > 100 g per package:

The main hazard for solid UF6 in larger quantities, as determined by the transport regulations, is radioactivity followed by toxicity and corrosivity as subsidiary hazards. Since solid UF6 sublimes when exposed to ambient air, the real predominant hazard to be considered shall be that of its gaseous form considering the large quantities of UF6: corrosivity followed by toxicity and radioactivity.

For quantities < 100 g per package:

The main hazard for solid UF6 sample quantities, as determined by the transport regulations, is toxicity followed by corrosivity and radioactivity as subsidiary hazards. Since solid UF6 sublimes when exposed to ambient air, the real predominant hazard to be considered shall be that of its gaseous form considering the limited quantity of UF6: toxicity followed by corrosivity and radioactivity.

04

Application

Natural uranium consists mainly of two isotopes ^{238}U (99.3%) and ^{235}U (0.7%). The fuel required by most nuclear reactors needs a ^{235}U fissile isotope content of between 3.5 – 5%. This higher ^{235}U content is achieved through a process known as “enrichment” by e.g. gas centrifuges. In the past, the enrichment of UF_6 was also performed in diffusion plants. Due to extensively higher energy consumption, this technology is not cost effective and is not practised anymore.

UF_6 is the ideal chemical compound for the enrichment process because it exists in gaseous form at relatively low temperatures and pressures. In enrichment plants, centrifuges separate the fissile isotopes ^{235}U and ^{238}U in a physical process by using the slightly different masses of the isotopes. The result is a depleted UF_6 stream (^{235}U 0.2-0.3%) and an enriched UF_6 stream (^{235}U 3.5 – 5%).

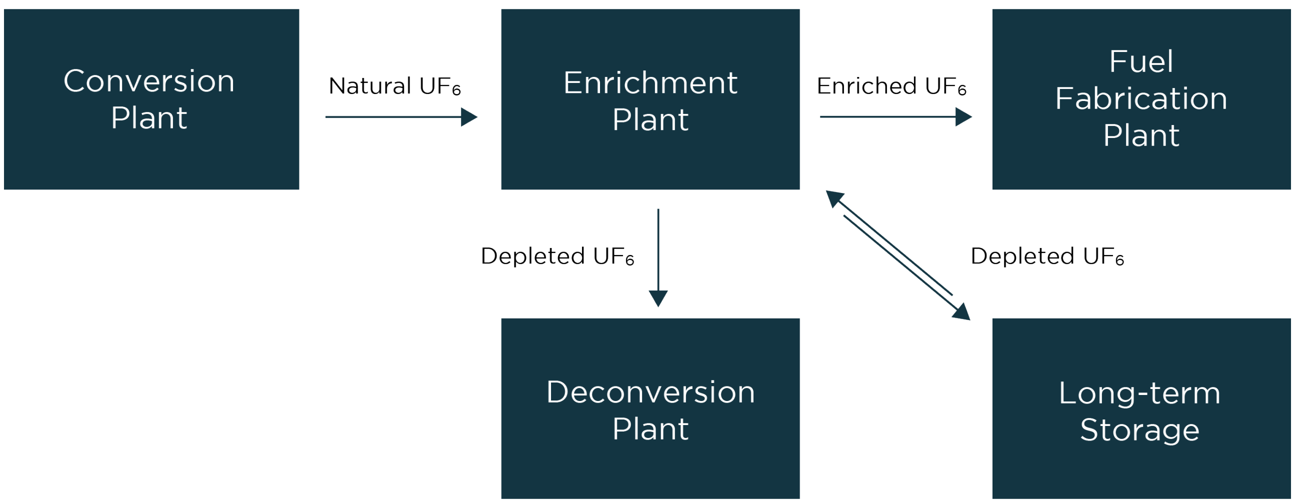


Image 5. - Transport of UF_6 between different industry branches

05

Transportation of UF6

UF_6 is transported via road, rail, sea and air. International and national dangerous goods regulations apply to the transport of UF_6. For quantities of UF_6 greater than 0.1 kg the primary hazard is from the radioactivity and therefore classified as Class 7, with Class 6.1 (toxic) and Class 8 (corrosive) as subsidiary risks. The cylinders need to withstand a fire test for 30 minutes under well-defined conditions and fulfil definite leakage rates and resist drop tests. These requirements are defined in the "IAEA Regulations for the Safe Transport of Radioactive Material" and in the "United Nations Recommendations for the Transport of Dangerous Goods" as well as in the derived dangerous goods transport regulations around the world.

Transport Cylinders

Natural and depleted UF_6 is transported in 48Y cylinders, whereas for enriched UF_6, smaller 30B cylinders are used. Outer protection such as thermal protection or protective shipping packages (PSP) may be required to comply with the regulatory transport requirements. For shipments of sample quantities of UF_6, other packages are used.

Image 6 - Type 30B Cylinder

30B Cylinder
Diameter: ~ 0,75m (30 inch)
Length: ~ 2m
Wall thickness: 12,7mm (1/2 inch)
Volume: ~ 750L
Tare weight: ~ 635kg
Max. fill: 2,277kg
Gross Weight: ~ 3,000kg
Proof pressure: 28 bar (5-year inspection)
Max. Operating temp: 121°C/250°F

Image 7 - Type 48Y Cylinder

48Y Cylinder
Diameter: ~ 1,25m (48 inch)
Length: ~ 4m
Wall thickness: 16mm (5/8 inch)
Volume: ~ 4.000L
Tare weight: ~ 2,500kg
Max. fill: 12,500kg
Gross Weight: ~ 15,000kg
Proof pressure: 28 bar (5-year inspection)
Max. Operating temp: 121°C/250°F

UF_6 is normally transported using standard multimodal container-based flatracks. These can be easily transferred between road, rail and maritime shipments. One flatrack can accommodate four 30B cylinders loaded in protective shipping packages or one 48Y cylinder. 48Y cylinders are also transported as single units on road trailers, railway wagons and in ship holds.

Image 8 - 30B Cylinder with PSP

Image 9 - 48Y Cylinder with outer protection

Labelling for Transport

There are two UN numbers available for the transport of UF_6 for quantities greater than 0.1 kg, UN2977 is used for “Radioactive Material, Uranium Hexafluoride, fissile” and UN2978 is used for “Radioactive Material, Uranium Hexafluoride, non fissile or fissile excepted”. The third UN number UN3507 “Uranium Hexafluoride, Radioactive Material, excepted package, less than 0.1 kg per package, non-fissile or fissile excepted” is only applicable to UF_6 quantities ≤ 0.1 kg.

Note - The transport regulations are cited according to international regulations and any national deviations are not considered in this Fact Sheet.

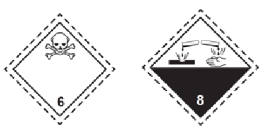
UN2977 RADIOACTIVE MATERIAL, URANIUM HEXAFLUORIDE, FISSILE

I-White or II-Yellow or III-Yellow and Toxic Corrosive Fissile

UN2978 RADIOACTIVE MATERIAL, URANIUM HEXAFLUORIDE, non fissile or fissile-excepted

I-White or II-Yellow or III-Yellow and Toxic Corrosive

UN3507 URANIUM HEXAFLUORIDE, RADIOACTIVE MATERIAL, EXCEPTED PACKAGE, less than 0.1 kg per package, non-fissile or fissile excepted



Toxic Corrosive

ASTM

ASTM International is an international standards organization that develops technical standards for a wide range of materials, products, systems, and services. There are two ASTM specifications defined for UF_6. For commercial natural UF_6 ASTM C787 defines impurity and uranium isotope limits and additional limits for reprocessed UF_6. ASTM C996 is the comparable standard for enriched UF_6 up to 5% ^{235}U.

Explanatory note:
Reprocessed uranium hexafluoride is not considered in this fact sheet.

References:
ASTM C787-15; ASTM C996-15; IAEA SSR-6; WNTI; world-nuclear.org; ead.anl.gov; rsc.org; nrc.gov

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