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Why is Uranium Hexafluoride not regulated in a similar manner as radioactive material with subsidiary hazards?

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The IAEA Regulations for the Safe Transport of Radioactive Material (SSR-6 (Rev. 1), 2018 Edition) regulates radioactive material by package type, whose definitions are based on the activity on the contents, except for uranium hexafluoride (UF_6) which contains substance specific requirements. This is a departure from the requirements of paras 110 and 507, which indicate that the radioactive properties of the material are covered by the IAEA Regulations, and the subsidiary hazard must be in compliance with the relevant transport regulations for those dangerous goods.

As a result, the corrosiveness and toxic properties of UF_6 are being regulated more stringently by the IAEA than materials with similar properties covered by other regulations. For example, Anhydrous Hydrogen Fluoride (AHF), which has identical corrosive and toxic properties, is safely regulated and transported according to the requirements of the UN Model Regulations (Recommendations on the Transport of Dangerous Goods) and by the Modal Regulations This difference in regulatory requirements could be considered unwarranted, representing an undue burden on the nuclear industry.

This paper discusses the matter by comparing the requirements for packages containing UF_6 and AHF, focussing on their chemical and toxic properties. The paper generates a provocative conclusion that there is a need to either harmonise the packaging requirements for UF_6 with the UN Model Regulations or to discontinue the constant re-examination of conformity with the IAEA Regulations and not impose further requirements for UF_6 packages.

Introduction

The IAEA safety standards establish the fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

More specifically, the IAEA Specific Safety Requirements No. SSR-6 (Rev.1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition, establish **standards of safety which provide an acceptable level of control of the radiation, criticality and thermal hazards to people, property and the environment that are associated with the transport of radioactive material**. This is further expanded in paragraph 104 of the IAEA transport regulations SSR-6 which state the following:

> 104. The objective of these Regulations is to establish requirements that must be satisfied to ensure safety and to protect people, property, and the environment from harmful effects of ionizing radiation during the transport of radioactive material. This protection is achieved by requiring:
>
> (a) Containment of the radioactive contents;
> (b) Control of external dose rate;
> (c) Prevention of criticality;
> (d) Prevention of damage caused by heat.

The IAEA safety standards and the transport regulations do not propose to regulate dangerous good properties other than the radioactive properties of radioactive material.

This is in fact the purview of the UN Model Regulations which regulate the transport of dangerous goods in order to prevent, as far as possible, accidents to persons or property and damage to the environment, the means of transport employed or to other goods. At the same time, regulations should be framed so as not to impede the movement of such goods.

This is further supported by paragraph 507 of the IAEA Regulations which reads as follows:

> OTHER DANGEROUS PROPERTIES OF CONTENTS
>
> 507. In addition to the radioactive and fissile properties, any other dangerous properties of the contents of the package, such as explosiveness, flammability, pyrophoricity, chemical toxicity and corrosiveness, shall be taken into account in the packing, labelling, marking, placarding, storage and transport in order **to be in compliance with the relevant transport regulations for dangerous goods of each of the countries** through or into which the materials will be transported, and, where applicable, with the regulations of the cognizant transport organizations, as well as these Regulations.

Hence, for most radioactive material which have other dangerous properties, the UN Model Regulations would apply in regards to the packaging, labelling, marking, placarding, storage and transport of the other dangerous goods properties. However, in the case of UF_6 the IAEA Regulations imposes the packaging requirements for the other dangerous properties as well. This is not only a deviation from the philosophy of the regulations, it also causes undue burden to the industry by imposing stricter requirements than those imposed for the transport of Anhydrous Hydrogen Fluoride as set out in the UN recommendations.

This situation, with substance specific requirements for UF_6 only, is in existence since the publication of the 1996 Edition of the IAEA Regulations. Before that time, the current paragraph 507, relating to other dangerous properties, did apply also to UF_6. For a description and discussion of the important events and occurrences, connected with the introduction of the UF_6 specific requirements in the IAEA Regulations, reference is made to the WNTI paper “Industry Experience with Thermal Protectors on 48-inch UF_6 Cylinders” at PATRAM 2007 in Miami, USA.

Classification and package identification for UF_6 and AHF

Uranium hexafluoride reacts with water to produce uranyl fluoride (UO_2F_2) and hydrogen fluoride (HF).

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

The IAEA Regulations classifies the material uranium, found in natural UF_6, as low specific activity material LSA-I and therefore this material can be transported in a Type IP-1 package. Similarly, enriched UF_6 can also be transported in a Type IP-2 package for fissile material.

With respect to the other dangerous properties of UF_6, the HF gas (produced from the reaction of UF_6 with water), comprises corrosive and toxic hazards and is therefore classified as a Class 8 material with a subsidiary Class 6.1. Class 8/6.1 material can be transported in a package which meets the packing group I requirements of the UN regulations.

UF_6 is transported in standardized steel cylinders, such as the Model 30B and 48Y. The 30B cylinders have a nominal gross mass of about 2.9 tons and a capacity of 2.3 tons of UF_6, whereas 48Y cylinders have a nominal gross mass of about 14.8 tons and a capacity of 12.5 tons of UF_6.

Figure 1 - 48Y Cylinder

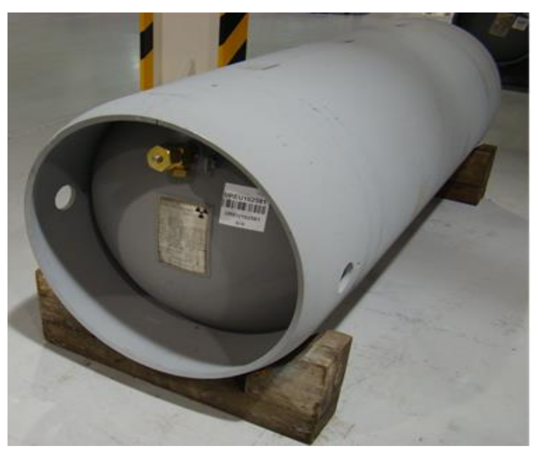

Figure 2 – 30B Cylinder

On the other hand, Anhydrous Hydrogen Fluoride (which is liquefied HF gas) is transported in 34 metric ton portable tanks with a capacity of 22,400 liters to 23,500 liters of Anhydrous Hydrogen Fluoride.

Figure 3 – Portable Tank 22,400 L

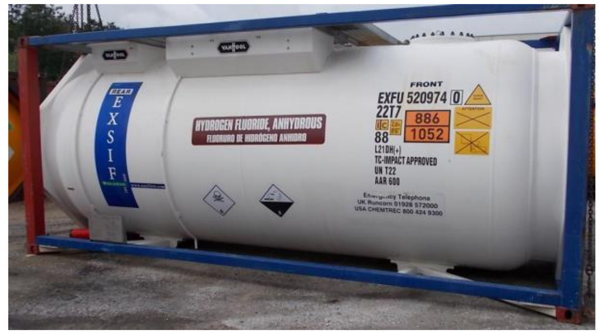

Figure 4 – Portable Tank 23,500 L

Packaging requirements for UF_6 cylinders

UF_6 is transported in solid form under vacuum in cylinders. UF_6 has the UN number 2977 and 2978 for fissile and natural/depleted material respectively. The minimum shell thickness for a cylinder is 7.94 mm (5/16”) for 30B cylinders and 12.7 mm (1/2”) for 48Y cylinders. UF_6 cylinders have a maximum fill limit.

The minimum test pressure is 27.6 bars for 30B and 48Y cylinders and also shells shall be designed and constructed to withstand a hydraulic test pressure not less than 2.0 times the design pressure. UF_6 cylinders are not equipped with a pressure relief device and have no bottom openings. The diameter for a cylinder is 30 inches (762 mm) for a 30B cylinder and 48 inches (1220 mm) for a 48Y cylinder.

Competent authority, or its authorized body, approval is required for the design of a 30B or 48Y cylinder.

The cylinders shall be designed and constructed in accordance with the requirements of a pressure vessel code recognized by the competent authority. The shells, heads and skirts of cylinders have to be manufactured from steel conforming to ASTM A516/A516M:2005 grade 55, 60, 65 or 70 or from steel conforming to EN 10028-3:2003, grade P275NL1 or P355NL1.

Cylinders shall be suitable for the external environment in which they may be transported.

Cylinders are manufactured and tested in accordance with ISO 7195 and ANSI N14.1. In addition cylinders must also comply with the IAEA Regulations, which includes the general requirements for all packaging and packages. This includes requirements for handling, securing to the conveyance during transport and lifting (with appropriate safety factors to cover snatch), and it requires the design to be easily decontaminated, to prevent the collection of water, and to withstand the effects of acceleration, vibration or vibration resonance. In addition, materials used have to be chemically compatible to themselves and the radioactive contents, valves have to be protected from being opened, and the cylinder have to withstand the effect of temperature and pressure during transport and have sufficient shielding. As well, SSR-6 para. 618 indicates that for radioactive material having other dangerous properties, the package design shall take into account those properties.

Service equipment (valves and plugs) shall be protected, in order to prevent loss or dispersal of UF_6 following the regulatory drop tests (0.6 meter for 48Y cylinders and 9 m for 30B cylinders, onto an unyielding target).

48Y cylinders undergo a 0.6 meter drop test onto an unyielding target. 30B cylinders, which are designed to contain fissile material, must withstand the accident conditions of transport and undergo a 9-meter drop test onto an unyielding target.

All cylinders carrying more than 0.1 kg of UF_6 must further withstand the IAEA thermal test (30 minutes, 800°C fully engulfing hydrocarbon fire) without rupture of the containment system.

Cylinders must undergo in-service inspections and testing. All cylinders shall be routinely examined prior to filling, emptying or shipping operations. In addition, at 5-year intervals, cylinders undergo an external and internal inspection, a hydrostatic pressure test, a leak test, measurement of wall thickness if necessary and have the tare weight re-established.

Cylinders shall be fitted with a corrosion resistant metal plate permanently attached with the following information:

- Owner information
- Manufacturing information
- Approval information
- Pressures
- Temperatures
- Materials
- Capacity
- Periodic inspections and tests

Packaging Requirements for Anhydrous Hydrogen Fluoride (AHF)

AHF is transported in liquid form in portable tanks. AHF has the UN number 1052 and is assigned the portable tank instruction T10 in column 10 of the Dangerous Goods List in Chapter 3.2 of the UN Model Regulations. The minimum shell thickness is 6 mm (less than ¼ inch).

Section 4.2.5.2.5 of the UN Model Regulations also allow additional portable tanks which possess higher test pressures, greater shell thicknesses, more stringent bottom opening and pressure-relief device arrangement to be used. Hence, for a portable instruction specified as T10, portable tank instruction also permitted are T14, T19, T20 and T22. As such, AHF can also be transported under T22 portable tank instruction, in which case the shell thickness is 10 mm (13/32 inch or a little more than 3/8 inch). AHF portable tanks have a maximum fill limit of about 84%.

The minimum test pressure is 4 bars for T10 portable tank and 10 bars for a T22 portable tank. AHF portable tanks are equipped with a pressure relief device and no bottom openings. The diameter of portable tank can be more than 1.8 meters (70 inches). A typical AHF portable tank has a diameter of 2.32 meters.

Competent authority or its authorized body approval is required for the design of an AHF portable tank.

The shells of the portable tanks shall be designed and constructed in accordance with the requirements of a pressure vessel code recognized by the competent authority. Shells shall be designed and constructed to withstand a hydraulic test pressure not less than 1.5 times the design pressure. The UN recommendations allow for the selection of different materials for the shell. Nonetheless, the shells shall be made of metallic materials suitable for forming and welding and in conformance with national or international material standards. The material typically used for AHF portable tanks is EN 10028-3 P355NL1.

Portable tank materials shall be suitable for the external environment in which they may be transported, and resilient to attack by the substance intended to be transported. Contact between dissimilar metals which could result in damage by galvanic action shall be avoided.

Portable tanks shall be designed to withstand, without loss of contents, at least the internal pressure due to the contents, and the static, dynamic and thermal loads during normal conditions of handling and transport. The design shall demonstrate that the effects of fatigue, caused by repeated application of these loads through the expected life of the portable` tank, have been taken into account.

Service equipment (valves) shall be so arranged as to be protected against the risk of being wrenched off or damaged during handling and transport.

AHF portable tanks do not undergo a fire test.

Portable tanks are designed and constructed with a frame which provides protection during transport. The frame is also used for lifting and tie-down. The frame of the AHF portable tanks are subject to testing as per ISO 1496-3:1995. The portable tanks and its framework are subject to a Dynamic Longitudinal Impact Test of 3 g and 5 g. Portable tanks are designed and constructed with a support structure to provide a secure base during transport. The portable tank and its fastening shall be capable of absorbing the following separately applied static forces, with a safety factor of 1.5 in relation to the yield point.

- Direction of travel: 2g times the maximum permissible gross mass.
- Right angles to the direction of travel: 1g or 2g when direction of travel is not well defined times the maximum permissible gross mass.
- Vertically upwards: 1g times the maximum permissible gross mass.
- Vertically downwards: 2g times the maximum permissible gross mass.

Inspection and testing – AHF portable tanks are required to be initially inspected and then undergo a 5-year periodic inspection and test with an intermediate test and inspection (2.5 years).

The intermediate 2.5-year periodic inspection and test shall at least include an internal and external examination of the portable tank and its fittings, a leak proof test and a test of the satisfactory operation of all service equipment. However, for portable tanks dedicated to the transport of a single substance, the 2.5-year internal examination may be waived or substituted by other test methods or inspection procedures specified by the competent authority or its authorized body.

Portable tanks shall be fitted with a corrosion resistant metal plate permanently attached to the portable tank with the following information:

- Owner information

- Manufacturing information
- Approval information
- Pressures
- Temperatures
- Materials
- Capacity
- Periodic inspections and tests

Summary comparing IAEA regulations to UN recommendations

The table below provides a comparison of the various requirements for the transport of Anhydrous Hydrogen Fluoride versus the transport of Uranium Hexafluoride. It is noted that there are additional requirements for packages containing fissile UF_6, however this is not pivotal for the comparison of the requirements.

Requirement	**Portable Tank for AHF**	**30B Cylinder**	**48Y Cylinder**
Form of material in normal transport	Liquid	Solid	Solid
Classification of the material	Class 8, subsidiary 6.1	Class 7, subsidiary 6.1 and 8. (Fissile)	Class 7, subsidiary 8 and 6.1.
Standards applicable	ISO 1496-3:1995	ISO 7195:2005	ISO 7195:2005
Competent Authority Approval	Yes	Yes	Yes
Designed to the pressure vessel code	Yes	Yes	Yes
Capacity	19.3 metric ton	2.3 metric ton	12.5 metric ton
Diameter	2.32 meters	30 inches (0.762 m)	48 inches (1.22 m)
Minimum Shell thickness	6 mm to 10 mm (¼ to 13/32 inch)	7.94 mm (5/16”)	12.7 mm (1/2”)
Valves	– One pressure relief valve – Two liquid phase valves – One or two gas phase valves	– No pressure relief valve – One empty and filling valve – Requirement to minimize the number of penetrations.	– No pressure relief valve – One empty and filling valve – Requirement to minimize the number of penetrations.
Other openings	One bolted manhole	One plug to clean the cylinder	One plug to clean the cylinder
Shell material	Steel: EN 10028-3 P355NL1.	Steel: ASTM A516/A516M:2005 grade 55, 60, 65 or 70 or EN 10028-3:2003, grade P275NL1 or P355NL1.	Steel: ASTM A516/A516M:2005 grade 55, 60, 65 or 70 or EN 10028-3:2003, grade P275NL1 or P355NL1.
Minimum Test Pressure	4 bars to 10 bars	27.6 bars	27.6 bars

Hydraulic test pressure	1.5 times the design pressure	2.0 times the design pressure	2.0 times the design pressure
Impact Testing	Dynamic Longitudinal Impact Test of the transport fame with tank. 3 to 5 g impact.	9-meter drop test, 1-meter penetration test, 1-meter puncture test and 15-meter water immersion test	0.6-meter drop test
Thermal test	None	800°C fully engulfing fire for 30 minutes.	800°C fully engulfing fire for 30 minutes.
Handling and securing	Tank is within transport frame which is tested for handling, lifting and securing.	– No lifting attachments. – Cylinders are transported in protective shipping packagings.	– Lifting lugs are designed and tested for lifting and securing. – Cylinder transported on cradles.
Inspection	Every 5 years with intermediate periodic inspection (every 2.5 years)	Recertification every 5 years with routine inspection prior to shipping, filling etc.	Recertification every 5 years with routine inspection prior to shipping, filling etc.
Nameplate Required	Yes	Yes	Yes

UF_6 is transported in solid form under vacuum. In the potential accident scenario, the UF_6 has to react with humidity to form HF (the other dangerous good) and UO_2F_2. Since the rate constant of the reaction is high, the reaction rate is dependent on the availability of water.

The minimum amount of water necessary to hydrolyze 1000 kg of UF_6 is 100 kg. Hence, at 25°C and 50% humidity this amount of water represents approximately 6000 m^3 of air.

It can therefore be concluded that the hydrolysis of UF_6 will take a considerable amount of time, particularly if the leak is through the valve only. Whereas, anhydrous hydrogen fluoride is in liquid form with vapors already present.

The paper would not be complete without a discussion of a potential accident involving a fire.

For the transport of Anhydrous Hydrogen Fluoride in portable tanks, the potential increase in pressure in the tank is addressed through the pressure relief valve. The pressure relief valve is set to release at a pressure less than the minimum test pressure for the portable tank. This allows for a controlled release of AHF and prevents a complete rupture of the portable tank. On the other hand, UF_6 cylinders are not equipped with pressure relief devices, according to the IAEA Regulations.

However, this is not aligned with the graded approach used in the IAEA Regulations, which allows the release of material from Type IP-1 or IP-2 packages during an accident. Therefore, it can be surmised that there is little apprehension over the radiological hazard involved with the uranium, hence the concern must be about the corrosive and toxic HF gas produced when UF_6 reacts with humidity or water. However, the same substance is allowed to be released through a pressure relief valve during an accident involving AHF. This discrepancy on how these risks are managed is not justifiable.

The table above illustrates that Anhydrous Hydrogen Fluoride is safely transported as a liquid in larger quantities in portable tanks that do not meet the same rigor as UF_6 cylinders with UF_6 in solid form and in smaller quantities.

It is unclear why the UF_6 cylinders are required to meet more stringent regulatory requirements such as higher shell thickness at lower volumes, higher test pressure, higher hydraulic tests pressure, no allowance for pressure relief valves as well as higher impact test requirements and a thermal test for fissile-excepted UF_6.

These exceed the requirements for AHF portable tanks which are used to transport material with the same dangerous hazard, but in an even more readily dispersible form.

This discrepancy continues to pose undue burden to the front end fuel cycle industry with increased cost and no apparent safety justification.

Conclusion

The IAEA Regulations allow the transport of uranium in industrial packages. However, due to the corrosive and toxic properties of UF_6, cylinders are required to withstand additional testing and requirements, even in addition to those in the cylinder standards. However, when compared to the transport of anhydrous hydrogen fluoride, the reaction product from hydrolysis of UF_6, these tests and requirements exceed those of portable tanks in the UN regulations.

The cylinders used for UF_6 are robust and already exceed the requirements for the transport of anhydrous hydrogen fluoride, representative for the other dangerous hazard of UF_6. As the toxic and corrosive risk are well addressed with the UN Model Regulations, there is an opportunity to consider better harmonising the UF6 corrosive and toxic packaging requirements within the IAEA Regulations for the Safe Transport of Radioactive Material with the UN Model Regulations. Furthermore, there is no need to constantly re-examine regulatory conformity with a view to enhance the regulatory requirements relating to the chemical properties of UF_6 within the IAEA Regulations.

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