Transport of UF_6 in Compliance with TS-R-1

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1. Abstract

The IAEA Regulations TS-R-1 (ST-1, Revised) 1996 Edition include requirements for packages containing uranium hexafluoride (UF_6); these are the first and only substance specific requirements in the IAEA Regulations. These requirements already have particularly affected, and will further affect, the transport of non-fissile and fissile excepted UF_6 and the packages used for these transports.

Non-fissile and fissile excepted UF_6 (ASTM C 787) has been transported worldwide for decades in a safe and reliable manner, using internationally standardised packages.

Under the auspices of the World Nuclear Transport Institute (WNTI), an industry working group has been evaluating the existing packages against the requirements in TS-R-1. As new requirements came into effect, there were new challenges for the use of these standard packages, including the free drop test and the thermal requirements. In close cooperation with the WNTI HEXT Industry Working Group, a consortium of UF_6 producers/users has worked together on the design and development, testing and certification of technical solutions for modification and optimisation of the existing packages to comply with TS-R-1.

This paper reviews the existing standard packages against the requirements in TS-R-1. The paper further provides an update to describe the enhancements to the standard packages that have been designed and developed recently. The paper also describes how these solutions have been tested and certified, as well as the status of implementation. Finally, the paper reviews the options that are available internationally to transport UF_6 in compliance with TS-R-1.

2. Introduction

Since TS-R-1 [1] was published as ST-1 in 1996, the IAEA Regulations for the Safe Transport of Radioactive Material do include specific requirements for uranium hexafluoride (UF_6). These requirements for UF_6 are the first and only substance specific requirements in the IAEA regulations. The IAEA regulations were first published in 1961. IAEA publications previous to ST-1 addressed UF_6 only in the advisory material by reference to the UF_6 cylinder standards ANSI N14.1 and ISO 7195.

UF_6 is a chemical compound of uranium with fluorine used for the enrichment of uranium by diffusion or centrifuge technology. Routine handling and transport developed from the mid 40's in the previous century, following the development of nuclear energy as a source for generation of electricity. Since the radiological hazard of UF_6 is low, cylinders (30 inch) designed for other fluorine and chlorine compounds were initially used for packaging for storage and transport of UF_6. Based on this, the designs for the current 30 inch and large 48 in cylinders were developed.

The first document describing standardised cylinders for UF_6 was ORO-651, published in 1966 by USAEC (United States Atomic Energy Commission). That has since been revised several times and still exists today as USEC-651 [2]. The ANSI N14.1 standard was developed by the American National Standards Institute and it was first published in 1971. The latest issue of this standard is ANSI N14.1 – 2001 [3].

Both the ORO-651 document and the ANSI standard were used throughout the industry worldwide, creating the need for an international standard. For that reason ISO 7195 was developed and first published in 1993 [4]. ISO 7195 is basically the international equivalent of the ANSI 14.1 standard. A revised issue of ISO 7195 is due to be published by end 2004.

The standard 30 inch cylinder (Type 30B) is specifically used for enriched UF_6, which is a fissile material, above 1% U-235. For the transport of fissile UF_6 the 30 inch cylinder is transported in an overpack, together forming a Type A or a Type B package. The publication of the 1996 edition of TS-R-1 did not result in any significant changes in the packaging for transport of fissile UF_6 in comparison to previous issues of the regulations.

The standard 48 inch cylinder (Type 48Y and 48X) is used for non-fissile and fissile excepted UF_6, i.e. for feed material destined for enrichment and compliant with ASTM C 787 [5], as well as for depleted material. These 48 inch cylinders have an excellent safety record. Millions of tonnes of UF_6 have been transported throughout the world for decades, using these cylinders, with no significant transport incidents resulting in serious consequences from either the radiological or the chemical nature of UF_6.

Notwithstanding this excellent safety record and the use of internationally standardised packages, the IAEA felt it necessary to develop guidance material for the transport of UF_6. This was caused by two events; the Mont Louis transport accident that occurred near the coast of Belgium in 1984, and the Gore, Oklahoma plant accident in 1986. Both events attracted public and political attention, although the Mont Louis accident demonstrated the solidity of the cylinders and the Gore accident had nothing to do with transport.

The discussions in the IAEA committee meetings focused specifically on the thermal behaviour of the large UF_6 cylinders in a transport fire. Therefore a Co-ordinated Research Programme (CRP) was initiated. The CRP, however, ended non-conclusive. Nevertheless, the thermal requirement for UF_6 packages has been included in TS-R-1. More background information on these developments in the regulations is given in [6].

3. Evaluation of TS-R-1 by Industry

Industry has been evaluating the new IAEA regulations in a coordinated manner through the World Nuclear Transport Institute (WNTI). For that purpose WNTI-members formed two industry working groups, one for TS-R-1 in general and another to deal specifically with UF_6 issues. The WNTI HEXT Industry Working Group (HEXT=Uranium Hexafluoride Transport) focused on the impact of TS-R-1 on the transport of the large cylinders (48 inch) for UF_6 because there were no significant changes for the smaller cylinders (30 inch). This paper addresses 48 inch cylinders only.

The essential new requirements are contained in para 630 of TS-R-1.

Para 630(a) requires a structural test as specified in para 718, which is in fact the same as the hydraulic test from ANSI N14.1 and ISO 7195.

Para 630(b) requires a free drop test as specified in para 722, which is the standard drop test for testing packages to withstand normal conditions of transport. The free drop distance for a 48 inch cylinder with a maximum fill of UF_6 is 0.6 m, according to Table XIII of TS-R-1. The cylinder must be dropped in an orientation to suffer maximum damage. No loss or dispersal of UF_6 is allowed.

Para 630(c) requires a thermal test as specified in para 728. This is the standard thermal test in the regulations, but until TS-R-1 only required for Type B packages and for packages containing fissile material.

4. Evaluation of the Standard 48 Inch Cylinders

Structural test

48Y and 48X cylinders manufactured and tested to ANSI N14.1/ISO 7195 standard do comply with the requirement of Para 630(a). The compliance with the hydraulic test is documented in the affidavit of manufacture and the records of re-inspection and testing of cylinders. No additional evidence is required.

Free drop test

Large UF_6 cylinders underwent extensive drop testing in the 1960s and 1970s. Drop heights have been greater (up to 9 m) than the 0.6 m required by para 630(b), however the orientation was either horizontal or vertical. Hence, no evidence could be drawn from these tests about the results of a drop in the most damaging orientation.

Through computer modelling, initiated by an industry consortium, the most damaging orientation for a 48 inch cylinder appeared to be at an angle in the range of 20 to 25 degrees from the vertical with the valve facing downwards. Although a large UF_6 cylinder would never be in such an orientation during normal conditions in transport, the current text of TS-R-1 does not take this into consideration.
The computer modelling of the drop in this orientation, using finite element structural dynamic analyses, concluded that deformation of the cylinder skirt and contact with the cylinder valve would occur. In this case, the potential for leakage of the valve could not be eliminated.

Following the review of these results, the industry consortium developed a Valve Protector Assembly (VPA) that is bolted to the skirt and prevents the skirt from contacting the valve as a result of the drop. The successful compliance of the 48 inch cylinders with the VPA fitted to the cylinder skirt was demonstrated by actual drop testing and computer modelling. The actual drop test provided a very good confirmation of the results obtained through the modelling by computer. The VPA has been incorporated in the cylinder standards and is fully in use.

Additional computer analysis was carried out with regard to drops on the plug end of the large cylinders. The plugs have a hexagonal head and they are threaded into a coupling in the cylinder head. When installed, the hexagonal head of the cylinder plug protrudes above the cylinder surface. Depending on the cylinder skirt style (straight or tapered), the modelling predicted that over a range of drop angles the plug hex-head would be touched by the deforming cylinder skirt. This resulted in a prediction that lateral forces on the plug would be larger than the allowable shear forces. As mentioned before, during normal conditions in transport, UF_6 cylinders are only handled in a horizontal position and the orientations described do not occur. Nevertheless, the conditions of the drop test are required to be met under TS-R-1 and so the industry consortium developed an enhanced plug design, which resulted in an alternate plug with a recessed head. This so-called countersunk plug can be threaded flush into the cylinder plug coupling, so that the plug cannot be exposed to lateral forces. This alternate plug is currently being incorporated in the cylinder standards and, once that is completed, it will be phased in at the time of the cylinders' re-certification cycles.

Thermal test

Investigations into the thermal response of UF_6 cylinders date back to the 1960's. The IAEA CRP from 1993 to 1999 on the response of 48 inch cylinders exposed to IAEA thermal test conditions was contributed to by scientific investigators from Argentina, Germany, France, Japan, United Kingdom and the United States of America. The CRP concluded that survival times in the range of 25 to 35 minutes were to be expected for unprotected cylinders. However, no consensus could be reached on a methodology to extrapolate the scientific work to full scale behaviour. The CRP work [7] however is the most authoritative information available on the subject.

The CRP output of 30 minutes plus or minus 5 minutes for survival of the extreme conditions of the IAEA thermal test show that 48 inch cylinders filled with UF_6 have a large thermal mass to accumulate heat from a fire. Together with the low probability of transport accidents involving large fires, as reported in another paper at Patram 2004 [8], this could lead to the conclusion that large UF_6 cylinders meet the intent of the thermal test requirement and could be certified for shipment under TS-R-1, para 632(c).

The industry consortium faced the difficult task of providing a definitive prediction of the thermal behaviour of a full 48 inch cylinder using the available models, and so instead they turned their attention to developing an insulation system that would provide confidence in exceeding the 30 minute survival time criteria. The IAEA CRP was thereby taken as a starting point. At the outset, in order to exclude further discussion on the accuracy of modelling, cylinder orientation in fires, variation in cylinder physical properties, etc., a performance specification was adopted which is considerably more demanding than just a small adjustment of the thermal resistance of the bare cylinder (i.e. an extension of only five minutes of survival under the thermal test conditions). This specification for design of the thermal insulation system was established as follows:

"Under the standard IAEA thermal test conditions, with the insulation system fitted, the total heat transfer coefficient (averaged over the whole cylinder area) from the fire to the cylinder will be no more than about 50% of the total heat transfer coefficient without insulation".

On an overall dynamic similarity basis, this is expected by approximation, to roughly double the survival times from the CRP to a range of 50 to 70 minutes. This leads to the conclusion that the probability of the cumulative uncertainties resulting in a figure below 30 minutes, becomes vanishingly small.

A theoretical approach would be to perfectly insulate 50% of the effective cylinder surface area, leaving the rest fully exposed to the fire. Since every insulation system will have a residual heat transfer coefficient and to allow for smaller unprotected areas, the consortium chose to design an insulation system with "full" coverage. Two designs of thermal protection were developed on this basis, both in the form of a removable "cladding".

One design is called the Blanket Thermal Protector (BTP), which comprises 4 separate pieces of flexible blanket that wrap around both ends and middle sections in-between the skirts, leaving gaps for the support cradles. The BTP is composed of a sandwich of several layers of cover and insulating material.

The other design is called the Composite Thermal Protector (CTP), which comprises 8 rigid panels that clamp as a symmetrical top and bottom around both ends and the middle sections in between the stiffener rings. The CTP is composed of a rigid composite material formed from layers of silica cloth held together with resin.

These designs allow for the continued use of existing transport equipment, which differs from an earlier approach in Japan, where a completely new and very costly transport system was developed, the so-called Dedicated Transport Container (DTC).

To demonstrate compliance with the adopted performance specification mentioned above, the required maximum heat transfer coefficient of the BTP/CTP material was calculated based on the sum of the radiative and convective heat fluxes onto an unprotected cylinder. Representative samples of BTP and CTP material were tested to determine the actual heat transfer coefficients through the insulating layers.

The conclusion of compliance of the design of the thermal protectors with the thermal test requirements was drawn by comparing the actual with the required values, whereby the non-insulated areas such as the stiffener rings were accounted for. Demonstration of compliance was done in this way because full scale testing of a filled UF_6 cylinder is not a realistic option, since the filling could only be with UF_6 in order to give representative thermophysical behaviour. As a result of this work, 48 inch cylinders with a BTP or CTP were certified under GB/3570/H(U) and GB/3571/H(U) respectively.

5. The Options for Transport under TS-R-1

Unilateral approval is applicable for UF_6 packages that meet the requirements of para 629-631. In the absence of more decisive information on thermal behaviour of bare 48 inch cylinders being available at the time that it was necessary to address a means of achieving unilateral approval, the use of thermal protection of the bare cylinder during transport is implied.

Multilateral approval is applicable for UF_6 packages that meet the requirements of para 632. For 48 inch cylinders this implies that bare cylinders can be transported.

Special Arrangement may be approved for a transport, subject to the implementation of special provisions.

6. Status with Competent Authority Approvals

H(M) approval for the transport of full 48 inch cylinders was granted by US-DOT in 2001. This certificate received subsequent validations in other jurisdictions as listed in Table 1 below.

Table 1: H(M) approvals (August 2004)

Country	Certificate Number	Expiry Date	Remarks
USA	USA/0592/H(M)-96 (rev. 0)	1 September 2006	Original certificate
Canada	CDN/E201/-96 (rev. 0)	1 September 2006	-
Russia	RU/320/H(M)-96-T	1 September 2006	-
Belgium	B/74/H(M)-96 (rev. 1)	31 December 2004	-
France	F/736/H(M)-96(c)	31 December 2004	-
Germany	D/0101/H(M)-96 (rev. 3)	31 December 2004	-
Netherlands	NL/0195/H(M)-96 (rev. 0c)	31 December 2004	-
Spain	E/103/H(M)-96 (rev. 1)	31 December 2004	-
UK	USA/0592/H(M)-96(1) Issue 5	31 December 2004	-

H(U) approvals have been granted in Japan and by UK-DfT as listed below in Table 2.

Table 2: H(U) approvals (August 2004)

Country	Certificate Number	Expiry Date	Remarks
Japan	J/2002/H(U)-96	25 March 2005	DTC + 48Y
UK	GB/3570/H(U)-96	31 May 2007	48Y/X + BTP
UK	GB/3571/H(U)-96	31 May 2007	48Y/X + CTP

It can be concluded from the above tables that from 1 January 2005 onwards H(M) approval is available in the USA, Canada and Russia and is no longer available in the European countries listed.

7. Summary and Considerations

- UF_6 cylinders as standardised in ANSI N14.1/ISO 7195 have been developed to contain UF_6 as a chemical compound.
- UF_6 has been transported in 48 inch cylinders safely for decades.
- With TS-R-1 (ST-1), specific requirements for UF_6 have been introduced in the transport regulations.
- The thermal requirement for UF_6 packages aims to avoid chemical consequences of an accident involving a large fire.
- Industry has developed additional technical measures for use, where and when necessary.
- The use of thermal protection is costly and increases conventional safety related handling risks and the dose to transport workers.
- TS-R-1, through para 632(c), allows for taking credit of the thermal mass of large UF_6 cylinders as a risk-informed consideration.
- TS-R-1 recognises multilateral approvals-H(M) and unilateral approvals-H(U); both are currently available for use in the next years, although in different regions.
- Industry will continue to bring forward technical information and field experience when these become available; industry is committed to safe, efficient and reliable transport of UF_6.

References

[1] International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Materials, TS-R-1, 1996 Edition (as amended 2003), IAEA, Vienna (2004)

[2] USEC, "The UF_6 Manual, Good Handling Practices for Uranium Hexafluoride", Revision 8, USEC, USA (1999)

[3] American National Standards Institute, American National Standard for Nuclear Materials – Uranium Hexafluoride – Packaging for Transport, ANSI N14.1 – 2001, ANSI, USA (2001)

[4] International Organisation for Standardization, International Standard, Packaging of Uranium Hexafluoride (UF_6) for transport, ISO 7195, First Edition 1993-11-01, ISO, Switzerland (1993)

[5] American Society for Testing and Materials, Standard Specification for Uranium Hexafluoride for Enrichment, C 787-96, ASTM, USA (1996)

[6] B.G. Dekker, "IAEA Regulations TS-R-1 and Packages for UF_6". Proceedings of the 13th International Symposium on Packaging and Transportation of Radioactive Materials (PATRAM): Chicago, IL, USA (2001)

[7] International Atomic Energy Agency, Assessment of the Behaviour of Large Uranium Hexafluoride (UF_6) Transport Packages in Fires, IAEA-TECDOC-UF_6, Vienna (draft, April 1999).

[8] M.E. Darrough et al, "Analysis of Risk and Dose when using Thermal Protection on Non-Fissile and Fissile-Excepted UF_6 48-inch Cylinder Packages", Proceedings PATRAM 2004, Berlin.