# TRANSPORT OF UF6 AND THE FUTURE OF THERMAL COMPLIANCE

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## ABSTRACT

The International Atomic Energy Agency (IAEA) Transport Safety Regulations (TS-R-1) require, amongst other, compliance with the standard thermal test for packages designed to contain 0.1 kg or more of uranium hexafluoride (UF6). This compliance with TS-R-1 requires H(M) or H(U) approvals for packages involved. The H(U) approvals are currently based on the use of thermal protectors on large UF6 cylinders (mainly 48Y).

The thermal protectors most in use are the so-called Blanket Thermal Protector (BTP) and the Composite Thermal Protector (CTP). The use of BTPs and CTPs started in early 2005 and more than 4 years of experience is available now. The paper will review this experience.

Following the development and approval of the BTP/CTP, further work on the computer modelling and analysis used in the approval process has been started, in order to improve the precision of the thermal case. With more refinement in the calculations and additional support of physical testing a demonstration for thermal compliance without additional thermal protectors on standard UF6 cylinders shall be considered. The paper will report on the status of this work.

## INTRODUCTION

Uranium hexafluoride (UF6) is a chemical compound of uranium and fluorine which is used for the enrichment of uranium. For this purpose it has to be shipped from conversion facilities to enrichment plants. Millions of tonnes of UF6 have been transported throughout the world for many decades with no significant incidents that resulted in serious consequences from either the radiological or the chemical nature of UF6. This excellent safety record is amongst others attributed to the robustness of the UF6 packagings.

The hazardous properties of UF6 have to be evaluated and judged appropriately to guarantee safe transport of the chemical. Because of the limited radiological risk, non-fissile and fissile excepted UF6 are classified as Low Specific Material materials: (LSA-1) for unirradiated uranium and LSA-2 for reprocessed uranium. The subsidiary risk “corrosive” has to be considered for transport as well. The hazards of UF6 are adequately taken into consideration by its classification into Class 7 (Radioactive Material) of the United Nations model regulations and by the assignment to the subsidiary risk class 8 (“Corrosive”).

The basis for the worldwide transport regulations of Class 7 material are the Regulations for the Safe Transport of Radioactive Material, TS-R-1 of the International Atomic Energy Agency (IAEA) /1/. In these regulations, UF6 is the only material regulated as a specific substance.

Since January 2005, thermal protectors are used on 48-inch cylinders containing non-fissile and fissile excepted UF6 for domestic transport within each country in Europe and for most international transports.

This paper reviews the regulatory transport situation regarding requirements for UF6 packages, the current transport package approval situation and the potential future thereof. Furthermore, it reports on the experience with the thermal protectors currently used.

Packages for fissile UF6 are not discussed in this paper.

For the history of regulatory developments, reference is made to an earlier WNTI paper on UF6 transport and TS-R-1 presented at PATRAM 2007 /2/.

## UF6 CYLINDER STANDARDS AND REGULATORY REQUIREMENTS

The standard UF6 transport cylinders are designed as pressure vessels and are also used as process cylinders in the conversion and enrichment facilities. There are two important UF6 cylinder standards which are the US National Standard ANSI N14.1 /3/ and the International Standard ISO 7195 /4/.

Before ISO 7195 was first published in 1993, ANSI N14.1 was the UF6 cylinder standard used throughout the industry worldwide and was at the time referenced in IAEA Safety Series documents. (See Safety Series No. 6, the predecessor of ST-1 resp. TS-R-1)

ISO 7195 has been issued as an international alternative of ANSI N14.1 with no intent to develop or introduce new or additional provisions. Cylinders manufactured, tested and maintained to ANSI N14.1 can be considered to be in accordance with ISO 7195 for the purpose of compliance with TS-R-1.

Each package designed to contain 0.1 kg or more of UF6 requires an approval by the relevant competent authority. One fundamental condition to obtain approval is the demonstration of compliance with the test requirements defined in TS-R-1.

Since the 1996 Edition of the TS-R-1 (named ST-1 then), three tests have been relevant with regard to packages for non fissile or fissile excepted UF6.

These packages need to withstand:

- a structural test without leakage;
- a free drop test without loss or dispersal of UF6; and
- a thermal test without rupture of the containment system.

The structural test required in TS-R-1 is the hydrostatic pressure test as specified in the cylinder standards ISO 7195/ANSI N14.1. The compliance with this test is confirmed in the documentation of manufacture or records of re-inspection.

The free drop test is a requirement first introduced in the 1996 Edition of TS-R-1 and although drop testing had been done before, the cylinder orientation condition was new. New drop testing had to be carried out and a project has been initiated by an industry consortium. The work, which included computer simulations, resulted in the development of a new valve protector assembly and a new plug design in order to demonstrate compliance with the new requirement.

The thermal test was also newly introduced in 1996 and demonstration of a bare 48 inch cylinder to withstand the standard IAEA fire test conditions without rupture was not available. A Coordinated Research Programme (CRP) /5/ in 1992-1998 under the auspices of the IAEA had resulted in no consensus on that question. The survival time calculated ranged from about 25 to 35 minutes, whereas 30 minutes is required. Full compliance with the thermal test conditions have been demonstrated, yet for the 48 inch cylinders with thermal protectors only.

## DEVELOPMENT OF THERMAL PROTECTORS BY INDUSTRY

TS-R-1 allows in § 632(c) for the transport of cylinders without demonstration of compliance with the thermal test if they contain more than 9,000 kg of UF6, but this is subject to the multilateral approval of the competent authorities. Not all competent authorities are willing to approve transport under this option in TS-R-1.

The industry consortium which worked on the free drop test continued their cooperation and started another project developping a protection system that would provide confidence to competent authorities in surviving the thermal test requirement and would result in a unilateral approval.

An essential condition for a system to be developed was that the infrastructure which exists in most facilities for handling and transport of UF6 cylinders should remain usable.

The combination of thermal protection and the transport system that had been previously developed in Japan - the so-called Dedicated Transport Container (DTC) /6/ - did not fulfil the handling condition.

The new project followed a parallel track and resulted in two protector systems:

- The Blanket Thermal Protector (BTP); and
- The Composite Thermal Protector (CTP).

The protection effect of both systems is an insulation system that halves the heat input and, with that, doubles the survival times established in the IAEA CRP (see above) to a range from 50 to 70 minutes. These survival times hold enough safety margin for inaccuracies in the modelling and calculations.

European unilateral approvals were issued for 48-inch cylinders with these thermal protectors for the first time in 2004, and have been renewed since then when necessary.

## REGULATORY OPTIONS FOR TRANSPORT

The options in TS-R-1 for the transport of UF6 in 48-inch cylinders are:

- under unilateral approval (H(U)); currently only possible using thermal protectors, and

- under multilateral approval (H(M)); in bare cylinders without thermal protectors.

Competent authorities in Europe require a unilateral approval for transport since 2004.

In the USA, Canada and Russia, transports take place under multilateral approvals. In practice, that means that national transports of UF6 cylinders on the territory of these countries can be carried out without thermal protectors as long as the transport is limited to the national territory. Transport between USA and Canada is also being carried out under multilateral approval.

Table 1 shows the currently approvals available for bare cylinders and cylinders fitted with BTPs or CTPs. Also, the approval for the Japanese transport system is shown.

| PACKAGE | COUNTRY | APPROVAL |
|---|---|---|
| bare 48Y | USA | USA/0592/H(M)-96 R1 |
| | Canada | CDN/E201/-96 R1 |
| | Russia | RUS/320/H(M)-96T R5 |
| 48X/Y + BTP | UK (Europe) | GB/3570/H(U)-96 I3 |
| | USA | USA/0679/H(U)-96 R4 |
| | Russia | RUS/320/H(M)-96T R5 |
| 48X/Y + CTP | UK (Europe) | GB/3571/H(U)-96 I4 |
| | USA | USA/680/H(U)-96 R5 |
| | Russia | RUS/320/H(M)-96T R5 |
| 48Y + DTC | Japan | J/2002/H(U)-96 |

*Table 1: Current Transport Approvals for filled UF6 48 inch cylinders*

Since UF6 is transported worldwide, the difference in approach by competent authorities has created challenges for industry. Sometimes, bare cylinders can be transported and sometimes, thermal protectors are needed, depending on geography.

## EXPERIENCE WITH BTPS AND CTPS

Thermal Protectors for 48-inch cylinders currently in use are:

- the Blanket Thermal Protector (BTP) (see figure 1);
- The Composite Thermal Protector (CTP) (see figure 2).

Figure 1: BTP

Figure 2: CTP

The BTP comprises four separate pieces of insulating blanket which wrap both ends of a cylinder and the two middle sections in-between the skirts, leaving gaps for the support cradle. The pieces are held in place by fire proof straps and buckles. The weight of each piece is approximately 25 kg for the ends and approximately 18 kg for the middle sections.

The BTP is composed of a sandwich of several layers: an inner 11 mm insulator composed of refractory fibres cloth, and an outer surrounding shell made of 1 mm reinforced fire resistant textile with silicon coating.

The CTP comprises eight separate rigid panels which fit around both ends and the two middle sections. The corresponding top and bottom pieces are held together with toggle catches. Each end is also secured by removable fasteners hooked over the stiffening rings. The weight of each piece is approximately 32 kg for the ends and 28 kg for the middle sections.

The CTP is made of composite material formed from layers of silica cloth held together with resin. There is also a steel mesh running through the entire structure to give additional strength to fittings under fire conditions. The thin outer layer is composed of gel-coat, which gives a cosmetic smooth surface finish but does not play a role in the structural or thermal properties. The top pieces have non-slip surfaces to allow for safe walking when necessary.

The UF6 industry has successfully implemented the use of these thermal protectors into the routine transport operations. Close cooperation within the industry by establishing user groups to share experience and develop logistical concepts supported the implementation. Thousands of shipments have been made since the introduction.

In spite of this success, the use of thermal protectors has created a big burden to industry. Not only the development but the production of the thermal protectors also required large investments. In addition, the cost of the transport operations has risen considerably, due to extra handling, additional on and off-site logistics, storage, maintenance and repair.

## HANDLING OF BTPS AND CTPS

Standard procedures have been developed to enable a safe and efficient assembly and disassembly of the BTPs and CTPs on 48Y cylinders.

BTPs are manually handled normally by a team of two workers because of the lower weight, but also because of their flexible nature.

CTPs can also be handled manually, but because of their rigid nature, CTP segments may also be handled using mechanical means. A combination of a special cylinder saddle in combination with a manipulator system has been developed to ease the assembly and reduce manual handling time. The manipulator, a so-called flexheffer, is shown in figure 3. The manipulator can lift pieces by vacuum grippers and turn them in the right position.

## ON-SITE AND OFF-SITE LOGISTICS

The large number of BTP and CTP sets required a sound logistic system to manage numbering of sets and segments as well as their registration and tracking.

BTPs have a unique number and each segment is sub-numbered. The segments of the BTPs do not have to stay together; they can be used in any combination.

CTPs also have unique numbers which are present on each individual CTP segment as a bar code label. By using a barcode reader the individual numbers can be transferred to the computer system for further processing. The individual segments can be used in any combination, as well.

A storage (on or off-site) and transport concept was also required for BTPs and CTPs when not in use on cylinders. This concept was developed to provide for easy handling and protection against damages.

For BTPs, standard foldable crates proved to be a viable solution for folded BTP segments (see figure 4).

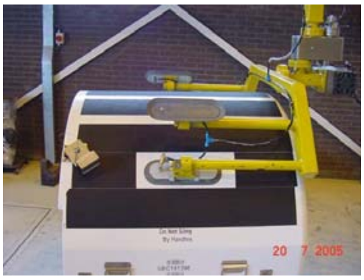

Figure 3: Flexheffer

Figure 4: Foldable BTP crates in ISO boxes

Unfortunately no adequate concept for CTPs was available on the free market. Thus, cages to contain CTP sets had to be designed. Figure 5 shows a storage and transport cage in an ISO box. For manual loading and unloading, the upper part of the cage can be separated from the lower one and placed aside. For the purpose of off-site transport of BTPs in crates and CTPs in cages, conventional 20-foot ISO boxes are used, but other means of transport are also possible. The crates designed for the CTPs have special provisions for quick and secure fixing inside an ISO box. ISO boxes are also used for storage purposes on or off-site.

Figure 5: CTP cages secured in ISO box

## MARKING AND LABELLING

The marking and labelling of packages is required by the transport regulations.

Marking that does not vary such as Approval Number, Permissible Gross Mass, UN number, Proper Shipping Name and Package Type can be affixed permanently.

On CTPs these permanent markings are affixed on the surface as shown in figure 6. Other markings and labels which vary according to the individual mass and activity, or regarding the consignor and consignee, can be attached to a dedicated metal plate that allows for easy removing of labels after the shipment is terminated.

On BTPs, all kinds of markings and labels can be inserted into transparent pouches resp. glued on smooth plastic surfaces permanently affixed on the BTP skin. (see figure 7).

Figure 6: Marking / labelling on CTPs

Figure 7: marking / labelling on BTPs

## REPAIR AND MAINTENANCE

The repair and maintenance of BTP or CTP segments are normally carried out at conversion or enrichment sites where the protectors are assembled and disassembled. The activities are limited to minor repairs or replacement by spare parts.
Based on an acceptance catalogue, decisions are made if repair or replacement is needed.

In the case of BTPs, repair and maintenance focuses on:

- patching of tears or holes to inner or outer skin by silicone adhesive;
- repair or replacement of straps and buckles.

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For CTPs, the repair and maintenance focuses on:

- replacement of catches, plates and handles;
- re-bonding or replacement of pultrusion bars (reinforcing bars supporting the shape of the segments);
- repair of gel coat.

## BTP VS. CTP COMPARISON

The development of the BTP and the CTP took place in parallel and both turned out to be a usable solution. Although each serves the same purpose, there are typical differences.

BTPs weigh less and can be folded to reduce their volume. They are however susceptible to damage. The latter is of concern in loading operations when changing transport modes.

Tears or holes on the outer surface of the BTP can lead to water absorption into the insulation. This increases the weight, making handling more difficult in cold areas where the absorbed water may freeze making the segments rigid and inflexible.

CTPs can easily withstand external forces and double stacking of cylinders fitted with CTPs is not a concern. CTPs weigh more than BTPs and handling of segments needs mechanical support.

## RISK CONSIDERATIONS

The CTPs and BTPs reduce the statistical risk of a thermal incident during transport. But the use of thermal protectors has increased radiation exposure to workers and the conventional risk from handling the thermal protector segments has increased as well.

The paper “Analysis of Risk and Dose when Using Thermal Protection on Non-Fissile and Fissile-Excepted UF6 48 inch Cylinder Packages” /7/ presented at PATRAM 2004 reports on a conservative estimate of occurrence of a severe fire environment during transport of UF6 cylinders and the subsequent rupture of cylinders.

The study showed that cylinders would be unlikely to encounter the hypothetical thermal accident during hundreds of thousands of years of operations, whereas the dose of the typical workers who assemble and disassemble the thermal protectors is expected to increase on a day to day basis because the resident time near cylinders is longer. Furthermore the risk for conventional accidents by thermal protector handling has increased.

The study concluded that the use of thermal protectors is unwarranted and overall counterproductive.

## FUTURE OF THERMAL COMPLIANCE FOR 48-INCH CYLINDERS

From 1992 to 1996, the CRP under the auspices of the IAEA undertook to assist the decision for inclusion of the thermal test in the regulations for cylinders used for non-fissile and fissile excepted UF6. Amongst the Chief Scientific Investigators (CSIs) from six countries, no consensus was reached as to whether a 48Y cylinder would rupture in the fire test. The calculated survival time ranged from about 25 to 35 minutes.

An IAEA Consultant Services Meeting (CSM) /8/ held in 1995 advised not to include the thermal requirements at that stage, but to continue the CRP to reach a consensus. The CSM considered 48-inch cylinders to be able to survive the thermal test conditions because of the large thermal mass.

The thermal test was introduced in the 1996 Edition of TS-R-1 requiring a unilateral approval (H(U)). The large thermal mass of 48-inch cylinders was addressed in § 632 (c) with the option for transport under multilateral approval (H(M)).

Due to the fact that the transport under H(M) approval is not accepted worldwide, international~~,~~ transports of natural and depleted UF6 are currently carried out under H(U) approval and with thermal protectors.

While it is expected, it still need to be formally confirmed that the bare 48-inch cylinder complies with the TS-R-1 thermal test. The CRP work has not been continued and there is only a draft report available. Three of the six CSIs in the CRP concluded then the opposite, although only a few minutes fail. Some individual CSIs have been updating their work demonstrating survival /9/ but that has not been accepted by all regulators.

There is a need for further study in this area. The earlier work is more then 15 years old and new capabilities have come available in the field of computer modelling.

Industry recently started an initiative to resume the investigation of the thermal behaviour of 48-inch cylinders under IAEA thermal test conditions. A new study based on the available data from previous studies and using improved possibilities with regard to computer modelling as well as new physical testing is expected to deliver new information on the behaviour of bare UF6 cylinders under the fire conditions. The successful work of the industry consortium so far, will be continued for this purpose.

Industry is planning to invest a substantial amount of money to clear up the uncertainties which currently exist.

The new consortium intends to commission Sandia Laboratories that has demonstrated expertise in the area of thermal computer modelling with UF6 to undertake a new thermal study in different phases.

The main goal of this study is to obtain more precise information on the thermal behaviour of UF6 cylinders of 48Y type. Enhanced computer modelling capabilities in combination with physical testing will be used for the study. TS-G-1.1 /11/ addresses in § 630.5 the possibility for the use of scale models and surrogate material combined with reference to previous satisfactory demonstrations such as laboratory tests, calculations and reasoned arguments. The study may make use of these possibilities.

A frequent communication between the consortium and the regulators is foreseen in order to achieve a common understanding of the conditions for the study. This will allow for optimisation of the project outcome and contribute to the understanding and acceptance by a broad community of experts.

Further technical details on the study are given in the PATRAM 2010 paper of Carlos Lopez from Sandia Laboratories on the project /12/.

The project will be run following three priority levels:

**Firstly**, the bare standard cylinder will be investigated. Standard cylinder means a cylinder to ISO/ANSI standards.
In the case of a successful demonstration, the entire fleet of existing 48Y cylinders can be used for national and international transport without thermal protection.

**Secondly**, if such a demonstration cannot be delivered, an enhancement of the standard cylinder will be considered. Enhanced standard cylinder means a cylinder to ISO/ANSI standards, but with increased quality through parameters such as:

- reduced corrosion allowance;
- high end of wall thickness tolerances; and
- 100% of weld verification.

These enhancements will contribute to a longer survival time in the fire.

In the case of successful demonstration against the enhanced criteria, cylinders can be transported without additional protection. Cylinders which do not meet the enhanced criteria would require the use of thermal protectors.

**Thirdly**, if the enhanced quality parameters do not deliver the expected positive effect, the possibility for a reduction of the number of segments of the CTP and BTP will be investigated. The objective is to find out if only the middle sections are sufficient to demonstrate survival.

All three options are expected to reduce the risks and the operational costs, securing safe, efficient and reliable transport of UF6 in 48Y cylinders, but under realistic and warranted conditions.

## CONCLUSIONS

Thermal Protectors of type BTP and CTP are predominantly used for the worldwide shipment of UF6. This became necessary in Europe in early 2005 since the option for H(M) approval without thermal protectors was not available from European competent authorities any more.

The development and the introduction of BTPs and CTPs was necessary at that time to ensure continued transport of UF6 as needed for the production of fuel for electricity production. The CRP work had stalled and additional work of some individual CSIs was not honoured.

An industry consortium is planning to revise the scientific work done more than 15 years ago and apply most recent knowledge in computer modelling supported by physical testing. The goal of the study is to reach a broadly accepted understanding on how a 48Y cylinder behaves under the extreme fire conditions of the IAEA thermal test.

The project is anticipated to clear up the uncertainties that currently exist.

A frequent communication with regulators will be established to optimise the understanding and acceptance of the project outcome.

The project is expected to deliver a realistic and warranted solution for the future of safe, efficient and reliable transport of UF6.

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