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TRANSPORTING LABORATORY QUANTITIES OF UF₆ IN EXISTING PACKAGES

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ABSTRACT

Outer protective packaging is commonly available for large ANSI N14.1 specification UF₆ cylinder types such as the 30B and 48Y. However, standard overpacks do not exist for small 1S and 2S cylinders containing UF₆ enriched to greater than 1.0 wt.% ²³⁵U. The U.S. Department of Transportation (USDOT) regulation 10 CFR 173.417 allows transport in Type A packaging of fissile material limited to quantities specified by 10 CFR part 71, subpart C general license. Therefore, Type A packaging approved for fissile material can be adapted for transport of small UF₆ cylinders containing quantities of UF₆ allowed by the NRC general license. The use of a package approved for fissile material can be shown to satisfy the thermal protection design requirement for uranium hexafluoride packaging, and the Type A design requirements include the free drop test design requirement for UF₆ packaging. This paper describes the process and limitations of shipping under the general license.

INTRODUCTION

Daher-TLI received a request to determine if there was a way to make domestic shipments of small quantities of both natural and enriched UF₆ in 2S cylinders. The quantities exceeded the fissile and nonfissile exemption limits for uranium hexafluoride, so packaging was required that would carry the 2S cylinder, and would satisfy the requirements for shipping uranium hexafluoride and fissile material.

Packaging for UF₆ enriched to greater than 1.0 wt.% ²³⁵U consists of an inner UF₆ cylinder and outer protective packaging. ANSI N14.1 [1] specifies the standard cylinders that meet all the acceptance criteria for UF₆ handling. The most commonly used UF₆ cylinder types are 48Y for natural and depleted uranium, 30B for low enriched (LEU), and 5A cylinders for high enriched (HEU). Thermal protective covers are used for 48Y cylinder transport outside the United States, and protective overpacks are used for 30B and 5A cylinders. However, no overpack exists for the small 1S and 2S cylinders containing enriched UF₆.¹

Because the transports were to be domestic shipments of less than Type A quantities of fissile and non-fissile UF₆, the project team began with a careful analysis of the USDOT regulations [2]

to determine what was permissible and then progressed to identifying a packaging solution that was available, and then concluded by providing technical analyses to demonstrate that that selected packaging satisfied the requirements.

REGULATORY ANALYSIS

The starting point was an analysis of the sections in the USDOT regulations (49 CFR Part 173) that pertained to this particular type of transport, which are §173.415, *Authorized Type A packages*, §173.417, *Authorized fissile materials packages*, and §173.420, *Uranium hexafluoride (fissile, fissile excepted and non-fissile)*.

USDOT Authorized Type A Packages

49CFR section 173.415 describes four types of authorized Type A packagings that may be used. They are (1) a USDOT specification 7A package; (2) any Type A packaging that meets the applicable requirements for fissile materials in 10 CFR Part 71 and is used in accordance with §173.471; (c) any Type B(U) or Type B(M) packaging that meets §173.416 requirements, or (4) any foreign-made packaging that meets the standards in IAEA TS-R-1 and bears the marking “Type A.”

Considering the four options, Daher-TLI determined that option (4) was viable. The regulation allows the domestic transport of any foreign made packaging that satisfies TS-R-1 Type A requirements and bears the marking “Type A.” Option (1) was not applicable because there are no USDOT Specification 7A packagings available for this transport. Option (2) was not an option because there is no NRC approved Type AF packaging licensed for this type of transport. And option (3) was not applicable because there are no Type B packagings approved for transport of 2S cylinders.

Hence it was determined that it was permissible to use a foreign made package that satisfied the TS-R-1 Type A requirements.

USDOT Authorized Fissile Materials Packages

Concerning the transport of fissile material in the United States, 49CFR173.417 is the governing regulation. It describes four types of packages that are authorized to carry not more than an A2 quantity of fissile material.

The four types are: (1) any packaging listed in §173.415 and is limited to the Class 7 materials specified in 10CFR71, subpart C, *General Licenses*; (2) any Type AF, Type B(U)F, or Type B(M)F packaging that meets the applicable standards for fissile material packages in 10CFR71; or (3) Any Type AF, Type B(U)F, or Type B(M)F packaging that meets the applicable requirements for fissile material packages in TS-R-1, and for which the foreign Competent Authority certificate has been revalidated by the U.S. Competent Authority; and (4) transporting “heel” quantities of enriched solid uranium hexafluoride is permissible without a protective overpack in any metal cylinder that meets the applicable requirements of §173.415, §178.350, and §173.420.

An analysis of the four options presented in §173.417 gave the conclusion that only option (1) was viable. It authorizes any Type A packaging per §173.415 so long as it satisfies one of the General License conditions in 10CFR71, subpart C. Option (2) was not applicable because there are no Type AF or B(U)F packagings licensed to carry UF₆ in 2S cylinders. Option (3) was not applicable because it applies to import/export only. Finally, option (4) was found to be possible but it was not preferred for reasons explained below.

The 2S cylinder does not have an authorized heel quantity. And while it was possible to transfer the material into a 30B cylinder and transport the 30B as a heel, this option was eliminated because there was no practical way to remove the material from the cylinder at the receiving site.

Therefore, it was determined that in order to satisfy the fissile materials requirements of the regulations, the packaging must satisfy the provisions of 10CFR71, subpart C, *General Licenses*.

NRC Requirements for Fissile Material

The next step was to determine what was permissible in accordance with the NRC regulations. Per 10CFR71, the packaging had to satisfy one of the following requirements. The packaging (1) had to be an NRC-licensed package (i.e., Certificate of Compliance issued), (2) could be a foreign approved package that has been endorsed by the USDOT if were used for import or export, or (3) had to satisfy the conditions of §71.22, *General License: Fissile material*.

Of the requirements given under subpart C, only §71.22, *General License: Fissile Material*, was applicable. Option (1) did not apply because there are no packages certified by the NRC to transport the 2S cylinder. Option (2) did not apply because it pertains only to import or export. Hence, any packaging that was used had to satisfy the conditions of §71.22.

In order to transport fissile material in accordance with section §71.22, the package had to meet four conditions. They are (1) the material must be contained in a Type A package but did not have to meet the fissile package requirements of 10CFR71; (2) the licensee must have a quality assurance program that is approved by the NRC, (3) the package must not contain more than a Type A quantity of radioactive material, and (4) the package must have a criticality safety index (CSI) that, when calculated using the formula given in the section, was not greater than 10.

At this point, Daher-TLI determined that it would be permissible to transport the fissile material in a Type A package if the CSI, calculated per the formula, was less than 10. The CSI formulation severely limited the amount of fissile material that could be transported in a package but the small quantities that were involved caused Daher-TLI to believe that this was a viable path.

The final step was to determine what the requirements were for shipping uranium hexafluoride.

USDOT Requirements for Uranium Hexafluoride

Section §173.420 contains the requirements for transport of quantities of greater than 0.1 kg of fissile or non-fissile uranium hexafluoride. It gives specific requirements for the packaging, the contents, and the package (packaging plus the contents).

The packaging must comply with the version of ANSI N14.1 that was in effect at the time the packaging was manufactured in its design, fabrication, initial testing, cleaning and inspection prior to first use, periodic inspections and recertification, and repair. The 2S cylinder satisfies these requirements.

The contents must be in solid form, and the volume of the material must not exceed 61% of the certified volumetric capacity of the packaging at 20 °C.

Finally, the package had to satisfy three conditions. It must (1) withstand a hydraulic test at an internal pressure of at least 1.4 MPa (200 psi) without leakage, (2) survive the Type A 1.2-m free drop test described in §173.465 without loss or dispersal of the uranium hexafluoride, and (3) pass the Hypothetical Accident Condition (HAC) thermal test described in 10CFR71.73 without rupture of the containment system.

Daher-TLI recognized there was one more section in the USDOT regulations that addressed the transport of uranium hexafluoride. Section §173.477 was not directly referenced in any other sections that governed uranium hexafluoride transport, but it does describe USDOT requirements for packagings containing greater than 0.1-kg of non-fissile or fissile-excepted UF₆. Because the package was intended for both the fissile and non-fissile transports, the packaging had to meet this requirement.

Section §173.477 requires that the offeror of the package maintain a complete safety analysis on file for at least one year after the latest shipment. The safety file must include documentation of any tests demonstrating that the package meets the requirements of §173.420, and must be provided to the USDOT upon request. It further requires that the offeror obtain a U.S. Competent Authority Certificate for the packaging design prior to the first export shipment of a package.

Regulatory Analysis Conclusion

The analysis of the USDOT and USNRC regulations gave the conclusion that it would be acceptable to transport the small quantities of fissile and non-fissile UF₆ in an ANSI N14.1 compliant cylinder in a foreign made packaging that satisfied the TS-R-1 Type A requirements, met the fissile requirements of 10CFR71.22, and withstood a hydraulic test and the Hypothetical Accident Condition (HAC) thermal test without rupture of the containment system. During the course of the regulatory analysis, Daher-TLI communicated with both the USDOT and USNRC and received concurrence that the interpretation of the regulations was correct and the proposed course of action was consistent with the regulations. Table 1 shows the progression of the analysis.

Table 1: Regulatory Analysis

Authorized Type A 49CFR173.415	Authorized Fissile 49CFR173.417	10CFR71 Subpart C General License	Authorized for UF ₆ 49CFR173.420	Additional for UF ₆ 49CFR173.477
(1) USDOT 7A package				
(2) Type A packaging that meets fissile requirements in 10CFR71				
(3) Type B(U) or Type B(M) packaging				
(4) Foreign-made packaging that satisfies TS-R-1 and bears the marking "Type A."	(1) Any packaging listed in §173.415 and is limited to the Class 7 materials specified in 10CFR71, subpart C, <i>General Licenses</i>	(1) NRC-licensed package under 10CFR71.17 or 10CFR71.19		
		(2) Foreign approved package under 10CFR71.21 that has been endorsed by the USDOT if were used for import or export,		
		(3) Satisfy General License conditions of 10CFR71.22 Type A package but did not have to meet the fissile requirements of 10CFR71 Licensee must have a NRC approved QA program Package must not contain more than a Type A quantity of radioactive material Package must have a calculated CSI ≤ 10	<p>Packaging - ANSI N14.1</p> <p>Contents - solid form, and the volume < 61%</p> <p>Package - must satisfy</p> <p>(1) Hydraulic test, (2) Type A 1.2-m free drop test, (3) HAC thermal test</p>	Offeror must maintain a complete safety analysis on file for at least one year after the latest shipment.
		(2) Type AF, Type B(U)F, or Type B(M)F packaging that meets 10CFR71		
		(3) Type AF, Type B(U)F, or Type B(M)F packaging that meets TS-R-1, and is validated by USDOT		
		(4) Approved cylinder for "heel" transport		

PACKAGING OPTIONS AND SOLUTION

Type A Packaging

Daher-TLI determined that the packaging requirements for shipping UF₆ under these conditions could be met with the foreign made Model BU-D package design, with a foam insert designed to hold the 2S cylinder securely. The BU-D is a Type AF-96 drum type package with a German package approval that has been validated by the USDOT for import/export. Therefore, the BU-D packaging conforms to requirements of the German approval certificate and the IAEA requirements for Type A packaging. (A USDOT validation is not required for using the BU-D as a Type A packaging for a domestic shipment.)



Figure 1: BU-D Type AF-96 Packaging

Even though the BU-D is a Type A packaging, a technical evaluation was performed to confirm that the BU-D meets the USDOT Type A regulations [7]. The evaluation identified all applicable DOT requirements and showed by cross-reference to the ADR and TS-R-1 that the BU-D/2S UF₆ Cylinder combination package fulfills the requirements for Type A packaging. Figure 2 shows a small portion of the analysis table.

<p><i>The components for the BU-D package are designed for a temperature range of -40°C to +70°C. The 2S cylinder container specification requires a maximum operating temperature of 250°F (120°C).</i></p>	
<p>173.412(d), Closure [6.4.7.7] (639) [6.4.7.8] (640) [6.4.7.9] (641)</p>	<p>The packaging must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by pressure that may arise within the package during normal transport. Special form Class 7 (radioactive) material, as demonstrated in accordance with § 173.469, may be considered as a component of the containment system. If the containment system forms a separate unit of the package, it must be securely closed by a positive fastening device that is independent of any other part of the package.</p>
<p><i>The BU-D package containment is provided by the inner container with lid, the gasket and 12 (M10-1.5 x 25) threaded fasteners and a 2S cylinder container conforming to specification in ANSI N14.1. An unintentional opening and impairment by internal pressure during normal transport can be excluded. There is no radioactive material in special form and the containment is part of the package.</i></p>	
<p>173.412(e), Radiolytic Decomposition [6.4.7.10] (642)</p>	<p>For each component of the containment system account is taken, where applicable, of radiolytic decomposition of materials and the generation of gas by chemical reaction and radiolysis.</p>
<p><i>Generation of gas by radiolysis can be excluded because of the low radiation from unirradiated uranium and the metal packaging materials. The packaging design also conforms to the requirements for packages containing uranium hexafluoride, excluding the possibility for generation of gas by UF₆ reacting with metals or air in the containment system during all conditions of transport.</i></p>	

Figure 2: Excerpt from Analysis Table of CN-12006-101

Fissile Material Packaging

The BU-D transport package was designed to meet the TS-R-1 and ADR [4] requirements for a fissile material package. However, to meet the terms of the General License, it was necessary to verify that the Criticality Safety Index (CSI) limit could be met. The general license under 10CFR71.22 allows transport of up to 108 grams ²³⁵U for 5.0 wt.% enriched material. Hence, a maximum of 3.22 kg UF₆ can be transported in a Type A package. The design capacity of a 2S cylinder is 2.22 kg UF₆, which gives approximately 75 grams ²³⁵U assuming 5 wt.% enrichment. Therefore the CSI for a Type A package containing a full, single 2S cylinder as specified in §71.22(e) is calculated as follows:

$$CSI = 10 \left[\frac{75 \text{ g}}{108 \text{ g}} \right] = 7.0$$

For a shipment of multiple packagings, a maximum of 7 packages containing one 2S cylinder could be transported by nonexclusive use conveyance and a maximum of 14 packages could be transported by exclusive use conveyance. It is not possible to place more than a one 2S cylinder in a package because the general license applies only to packages with a CSI less than or equal to 10.

Uranium Hexafluoride Packaging

It was necessary to demonstrate that the BU-D packaging used in combination with an engineered protective shipping packaging (PSP) insert for a standard 2S cylinder satisfied the particular USDOT requirements for transporting uranium hexafluoride. The technical evaluation [7] and a thermal analysis [8] specifically for the BU-D / 2S cylinder configuration demonstrated that these requirements were met.

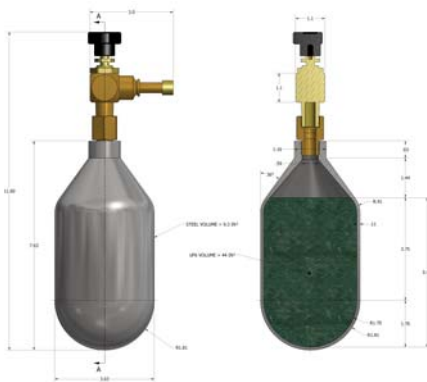


Figure 3: 2S Cylinder

The first requirement was that the package must withstand a hydraulic test at an internal pressure of at least 1.4 MPa (200 psi) without leakage. The ANSI N14.1 design and test criteria satisfy this requirement.

The second requirement in §173.420 is that the package shall survive the Type A 1.2-meter free drop test. The BU-D packaging is a Type A package that has been tested with contents exceeding the mass of the engineered foam protective shipping package (PSP) insert containing a 2S cylinder. It has been shown to meet both the 9-meter hypothetical drop test conditions and 1.2 meter normal condition drop requirements. The 1.2-meter drop is considered a low velocity impact and only minimum damage is expected during the impact event. According the BU-D Safety Analysis Report [6] after the drop test from 1.2 meters only slight deformation of the container structure is expected because the stiffness of the outer drum. The predicted local deformation is minimal. Therefore, it will not impair the ability of the package to meet the other normal conditions of transport requirements.

During impact, the UF6 cylinder valves are considered the most critical component because of their importance to containment. In general the larger UF6 cylinders (i.e., 30B and 48Y) require more protection during impact because of the difficulty in preventing the valve from rotating with respect to the massive cylinder. However, for smaller cylinder types such as the 2S where maximum gross weight of the 2S cylinder is less than 10 pounds, the relative difference in mass between the cylinder body and valve is much less which results in more uniform forces being applied to the cylinder and valve body during impact conditions. Therefore, it is possible to fully protect the 2S cylinder during impact by using packing foam that completely encapsulating the cylinder and valve. This packing method ensures that impact loads are uniformly reacted by the packing foam while preventing rotation of the valve.

The third requirement in §173.420 is that the package survives the HAC thermal test. Daher-TLI designed a close-fitting packing insert made of insulating foam that provided thermal protection for the 2S cylinder. A thermal analysis was performed [8] to supplement the actual thermal test data in the BU-D safety analysis report [6]. In the Daher-TLI thermal analysis, the calculation method was the same as described in the BU-D SAR, except that a more recent version of the heating code was used. The model in the SAR was modified to replace the contents with the 2S cylinder and protective shipping packaging. The analysis concluded that the foam insert successfully reduces the heat load to the 2S valve. Figure 5 shows sample figures from CN-12006-301.

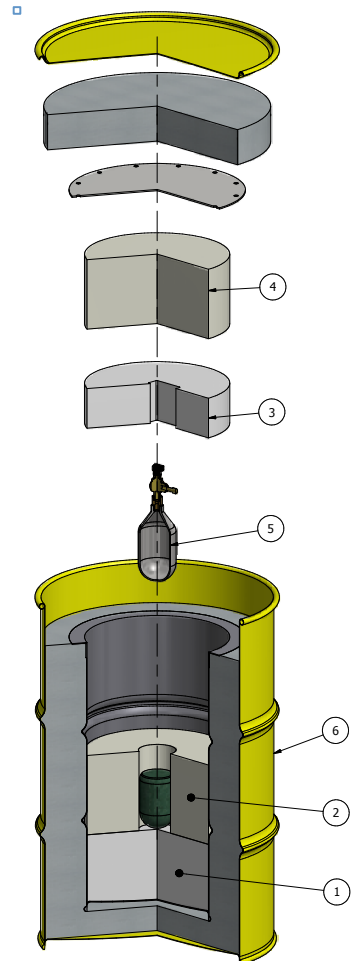


Figure 4: BU-D / 2S Cylinder with inserts

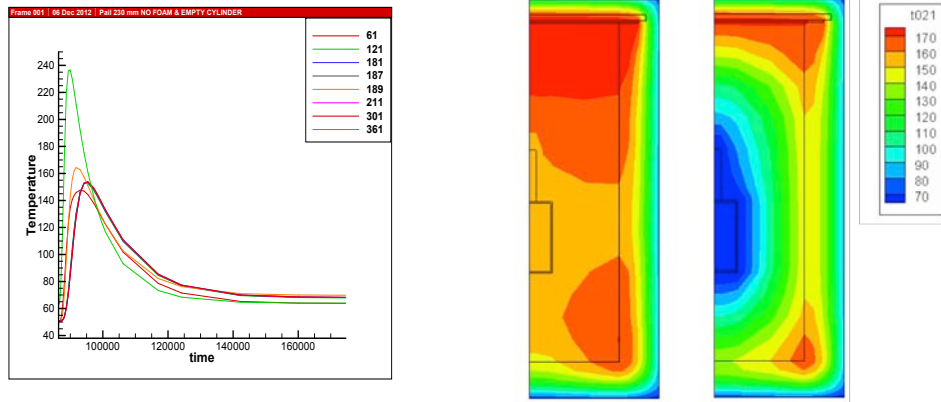


Figure 5: Figures from Thermal Analysis CN-12006-301

CONCLUSION

USDOT regulations provide a way for domestic transport of small quantities of fissile and non-fissile uranium hexafluoride. It was determined that 49CFR173.417 allows transport of fissile material in Type A packaging limited to quantities specified by 10CFR71.22, and it allows transport of uranium hexafluoride under the restrictions of 49 CFR 173.420. The foreign made BU-D Type AF shipping package was ideally suited for serving as a protective overpack for the 2S cylinder.

REFERENCES

1. AMERICAN NATIONAL STANDARD FOR NUCLEAR MATERIALS – Uranium Hexafluoride – Packaging for Transport, No. ANSI N14.1, 2001
2. UNITED STATES CODE OF FEDERAL REGULATIONS, Title 49, Transportation, Part 173--Shippers--General Requirements for Shipments and Packagings, No. 49CFR173, July 2013
3. UNITED STATES CODE OF FEDERAL REGULATIONS, Title 10, Energy, Part 71— Packaging and Transportation of Radioactive Material, No. 10CFR71, July 2013
4. EUROPEAN AGREEMENT CONCERNING THE INTERNATIONAL CARRIAGE OF DANGEROUS GOODS BY ROAD (ADR), Economic Commission for Europe Committee on Inland Transport, No. ECE/TRANS/225, 2013
5. German Certificate of Approval No. D/4305/AF-96, Revision 8
6. Safety analysis report NCS 0601, Rev. 1 of NCS dated October 2008
7. Packaging Requirements Evaluation of BU-D for Shipment of UF₆ 2S Cylinders, TLI Engineering Services, December 17, 2012, CN-12006-101
8. Thermal Evaluation of BU-D for Shipment of UF₆ Type 2S Cylinders, TLI Engineering Services, December 18, 2012, CN-12006-301

END NOTES

1. The Model 2000MED packaging is available for shipping 1S UF₆ cylinders containing non-fissile or fissile excepted UF₆.