CRITICALITY ISSUES WITH THE 30B CANISTER WITH ENRICHMENTS GREATER THAN 5 WT% U-235

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ABSTRACT

Calculations are performed showing that 6 wt% U-235 fuel can be safely stored in the standard 30B UF6 cylinder if, consistent with current cylinder criticality analysis, moderator exclusion is allowed. However, current USA and international regulations limit the use of moderator exclusion to 5 wt% U-235. A modification to the 30B UF6 cylinder is proposed using steel clad B4C rods traversing the length of the cylinder. Using 61 of these rods, it is shown that the cylinder is criticality safe for 6 wt% U-235 fuel. The rods reduce the capacity of the 30B cylinder by 13%. For higher enrichments, more B4C rods can be added with further reduction in capacity.

INTRODUCTION

The storage and shipping of UF6 between the enrichment facility and the fabrication plants uses the 30B cylinder. 10CFR71.55.g does not require analysis with water leakage into the cylinder as is required for all other packages per 10CFR71.55.b. This exception was allowed due to the use of these cylinders well before the current codification of 10CFR71. The exemption for the water in leakage is well supported by the many years of operation with thousands of 30B cylinders. Unfortunately, 10CFR71.55.g.4 specifically limits this moderator exemption to fuel that is "not more than 5 weight percent uranium-235." By 10CFR71.55, "(c) The Commission may approve exceptions to the requirements of paragraph (b) of this section if the package incorporates special design features that ensure that no single packaging error would permit leakage, and if appropriate measures are taken before each shipment to ensure that the containment system does not leak." From conversations with relevant NRC personnel, it is believed that the Commission is unlikely to approve a generic exemption for the 30B cylinder. Several arguments are given:

1. Exemptions are generally reserved for a single package or shipment rather than generic for a large number of packages and shipments.

2. The limit of 5 wt% is part of international agreements and the US NRC would have to convince the international community to agree to raise the enrichment limit.

3. The 30B has less protection to water in-leakage than many other cases for which the NRC has already rejected moderator exclusion. For example, welded shut spent fuel canisters have not been allowed moderator exclusion. (The 30B in contrast has a valve whose failure would allow water ingress.)

Rather than seek an exemption, 10CFR71 could be changed but for the same three reasons above there would be serious opposition and it is difficult to predict when, if ever, the rule would be changed.

The 30B canister is the only currently licensed method of shipping UF6 in the US. Although other cylinder designs have been made, current Certificates of Compliance needed for shipping are not available. However, <30" cylinders have been allowed in the past (either under a DOE certificate or a DOT Spec package), and there are no technical or regulatory limitations to reviewing and approving a proposed cylinder overpack design. It would take designing and submitting an application for a new overpack, and the NRC reviewing and approving it, which may take some time.

This paper will discuss shipping 6 wt% UF6 fuel under two assumptions: 1) The 5 wt% limit on the 30B moderator exclusion is lifted, or 2) the 5 wt% limit on the moderator exclusion is not lifted.

ASSUMING MODERATOR EXCLUSION

When crediting moderator exclusion the only criticality concern is for arrays of the 30B cylinders. Figure 1 shows a 30B cylinder and how they can be stacked. Figure 2 is provided to show more perspective with humans in the background.


Figure 1. 30B Canisters [1, 2]

**Figure 2. 30B Cylinder with external assay set up [3]**

Specifications for the 30B cylinder are given in a couple of standards, ISO 7195 and ANSI N14.1 [4, 5]. The standards are the same with regard to criticality and both standards specify a maximum enrichment of 5 wt%. The wall thickness is 0.5 +/- 0.0625 inches. Both standards require removal from service if the minimum wall thickness is less than 0.3125 inches. Figure 3 shows the key dimensions of the 30B cylinder.
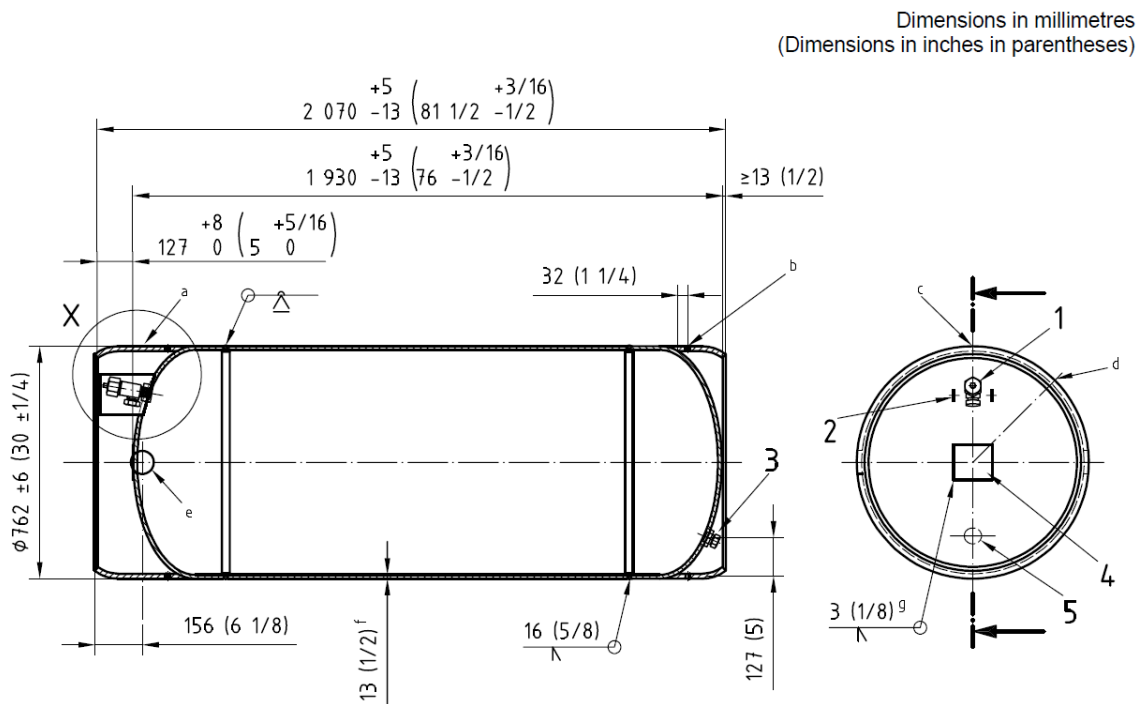
Figure 3. Dimensions of the 30B Cylinder [4]

ORNL performed criticality analysis for the 30B in 1991, reported in ORNL/TM-11947 [6]. This criticality analysis is the criticality analysis of record for the UX-30 overpack, Certificate of Compliance 9196 [7, 8]. In order to determine the impact of raising the enrichment limit to 6 wt% the ORNL analysis is reproduced using SCALE 6.1 and the ENDF/B-VII.0 cross section library [9].

The limiting criticality condition is with optimum moderation between the cylinders. Figure 4 shows k of an infinite array of 30B cylinders with 6 wt% fuel as a function of water density between the cylinders. ORNL showed that the maximum k stays the same as the distance between cylinders change (just the optimum water density changes) [6]. The maximum k occurs at 0.016 gm/cc water between the cylinders and is 0.9032 +/- 0.0001. For 5 wt% fuel the maximum k is 0.8524 +/- 0.001 so the change in enrichment is worth about 5% in k. The k of the array of containers is very sensitive to the thickness of the steel wall. The calculated k's shown on Figure 4 use the nominal wall thickness of 0.5 inches. The manufacturing uncertainty is 0.0625 inches. At the lower limit of the manufacturing tolerance, the calculated k at 0.016 gm/cc water between cylinders is 0.9324 +/- 0.0001. This 3% uncertainty dominates the statistical combination of uncertainties so the maximum 95/95 k is 0.9324 which is less than the criticality limit of 0.95. Therefore, following the approach of the criticality analysis of record, the 30B cylinder meets the criticality safety limits with 6 wt% fuel.
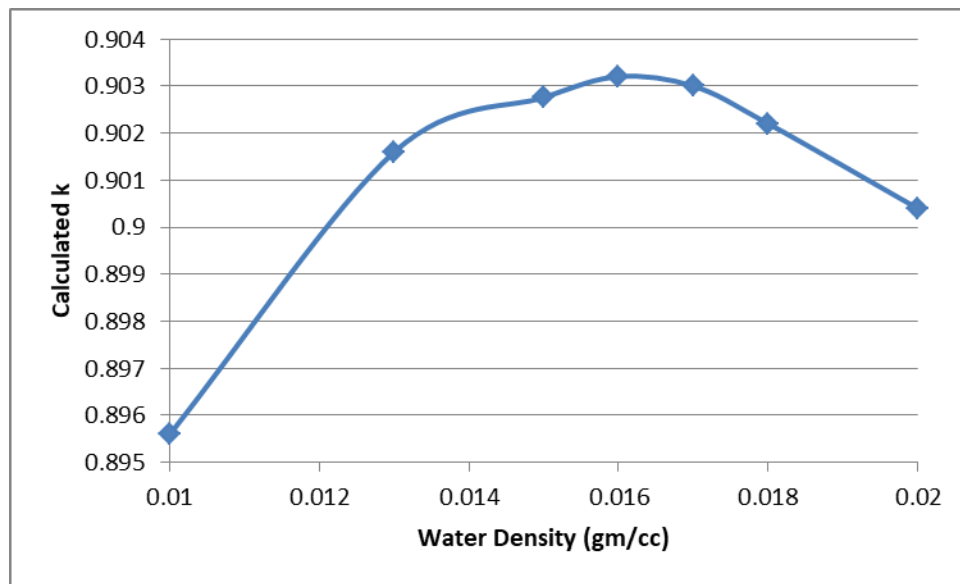
Figure 4. Calculated k as a function of water density

The ORNL analysis does not address the manufacturing tolerance in the cylinder wall thickness. As shown above, the wall thickness uncertainty is very important to the final 95/95 k. The standards [4, 5] also address a minimum wall thickness. This wall thickness is necessary for the pressure boundary. This is a requirement for any section of the wall. The criticality analysis done here ignores this parameter since unless the thinned area is large the criticality is controlled by the average thickness of the wall not at just the minimum point. Some recent presentations have been done assuming the minimum wall thickness [10, 11 and 12]. If the minimum

thickness of the wall must be assumed, then infinite stacking 30B cylinders would not be permitted without an overpack or other material between cylinders when using 6 wt% fuel. The calculated k for this case with 6 wt% fuel is 0.9956. The calculated k at 5 wt% using the minimum wall thickness with an infinite stack of cylinders is 0.9469. This finding agrees with a publication for PATRAM 2013 with a full (2.5 tons) cylinder [10]. In that publication the calculated k slightly exceeded 0.95. For transport, this is not a concern since the steel walls of the overpack result in an effective wall thickness greater than the nominal wall thickness of the 30B.

The criticality model used here is the same as presented in ORNL/TM-11947 which is the current criticality analysis of record. However, the calculated k for the 5 wt% fuel reported above is 3.3% higher than that found in ORNL/TM-11947. This analysis uses SCALE 6.1 and ENFD/B-VII.0 but the ORNL report used SCALE 4 and ENDF/B-IV. The input deck used for this analysis was run with SCALE 5.0 and the ENDF/B-IV cross section library and the calculated k was 0.817 which is identical to that reported in ORNL/TM-11947. Between ENDF/B-IV and ENDF/B-VII.0 the evaluations of Fluorine and Iron cross sections changed significantly. The Fluorine and then the Iron were removed from the model. When these two isotopes were removed from the model the difference between the ENDF/B-IV and ENDF/B-VII.0 results dropped from 3.3% to 0.5% in k. The evaluations of uranium were also changed and probably explain the final 0.5%. This analysis shows the worth of the Fluorine and Iron both changed about 8% with the cross section change from ENDF/B-IV to ENDF/B-VII.0.

In summary, using the methods for the criticality analysis of record, increasing the maximum enrichment from 5 wt% to 6 wt% does not result in any new restrictions. Using assumptions proposed by others [10] results in restrictions in stacking for both 5 wt% and 6 wt% filled 30B cylinders. The stacking restrictions would be more severe for the 6 wt% fuel. For transport, the overpack provides additional margin so that there is no need for stacking restrictions. Note that although the criticality analysis would allow infinite stacking for transport, the current COC for the UX-30 limits the stacking to 10 cylinders (CSI=5).

ASSUMING NO MODERATOR EXCLUSION

A 15 inch diameter homogeneous sphere of 6 wt% UF6 and water (75% water and 25% UF6) surrounded by water has a calculated k of 0.9503. This sphere contains only 37 kg of UF6. Since the modeled central void in a filled UF6 canister is greater than 18 inches in diameter, it is difficult to make an argument that such a collection of UF6 and water is not possible. This result suggests that the cylinder diameter for UF6 at 6 wt%, assuming no absorber material in the cylinder, needs to be less than 15 inches. By the way, a 16 inch sphere of 5 wt% UF6 and 70% water produces a k of 0.9537.

There is a 12B cylinder that is described in the standards [4, 5]. Due to leakage out of the sides of the 12B cylinder the critical mass is higher. The 12B cylinder can accept 5 wt% UF6 without moderator exclusion [4, 5]. The calculated k for 5 wt% UF6 in a 12B cylinder in a bath of water with optimum moderation on the inside is 0.9371. The calculated k for 6 wt% UF6 is 0.9759 which, as expected, is above the criticality limit. However, this calculation assumes the 12B is in an infinite bath of water. If the 12B cylinder is surrounded by a 1 cm thick B4C layer, the k of the cylinder in an infinite bath of water and 6 wt% fuel is only 0.9158. This means it is possible

to use the previously designed and approved 12B cylinder with 6 wt% fuel if it is kept in a boron-containing overpack or the room is designed for moderator exclusion.

The 12B cylinder allows loading of 208 kg of UF6 which is much better than derating the loading of the 30B (which would only allow 37 kg). However, using the 30B and 5 wt% fuel 2277 kg could be loaded. Thus using the 12B requires 11 times as many cylinders. This does not mean 11 times the number of truck deliveries since it is possible to design a truck package which is an array of 12B cylinders separated with absorbers. An overpack design, for a single cylinder or an array of cylinders, would have to be licensed. Normally this is major activity that would be expected to cost about $10 million and take about 10 years (without the overpack design established, these are just crude estimates based approximately on the cost to bring to market new fuel shipping containers.)

The 5 wt% UF6 limit on the moderator exclusion in the 30B is only for transport. The fuel enrichment and fabrication facilities may use the 30B cylinder with 6 wt% fuel taking moderator exclusion. In order to minimize the impact at the enrichment and fabrication it may be reasonable to create a new station where the 30B cylinder content is transferred to or from the shipping array.

Rather than use the 12B cylinder, a new cylinder could be designed using one or more absorber rods in the cylinder. This would allow a much higher capacity of UF6 per cylinder than the 12B can take. However, the newly designed cylinder without moderator exclusion will have a capacity less than the current capacity of the 30B. For example, the 30B canister could be modified to contain B4C absorber in steel tubes. A case was analyzed where 61 rods were placed in the 30B. Figure 5 shows the placement of the absorber rods in the 30B. Each rod is 2.4 cm diameter B4C cylinder clad by 0.5 cm thick carbon steel. The capacity of the new design 30B is 13% less or 1983 kg of UF6. The calculated k of an infinite array of these new canisters is 0.9167 with optimum moderation inside the canister (0.6 water volume fraction) and between canisters (0.02 water volume fraction).
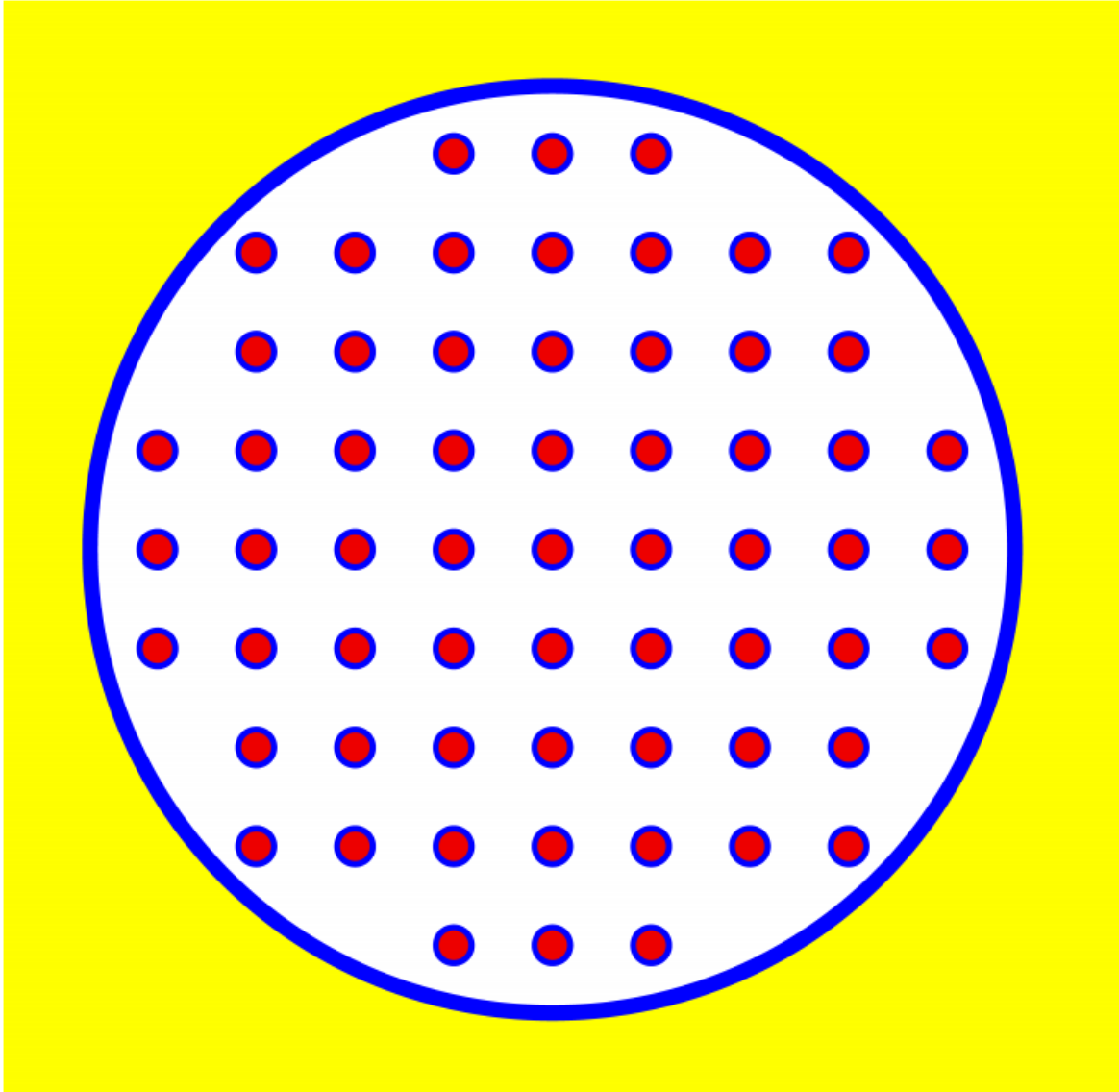
Figure 5. Possible Arrangement of Absorber Rods in a 30B Cylinder

A transportation canister vendor, Daher-NCSA, has announced it is developing a 30B cylinder for fuel up to 20 wt% U-235 that does not credit moderator exclusion. The design is still under development but maybe ready to deploy as soon as 2021. It, similar to the design shown on Figure 5 and will have some number of absorber rods (still under development). Figure 6 and Table 1 are from a one page brochure by Daher. The maximum UF6 capacity is expected to be 1600 kg. The same vendor is also developing a cylinder design for fuel up to 10 wt% U-235. They believes the high enrichment cylinders will not require drop testing but will be acceptable with their DN-30 overpack that was drop tested with a standard 30B cylinder. Daher is currently licensing their DN-30 overpack [13, 14] and hopes to have approval by the USNRC in 2019.
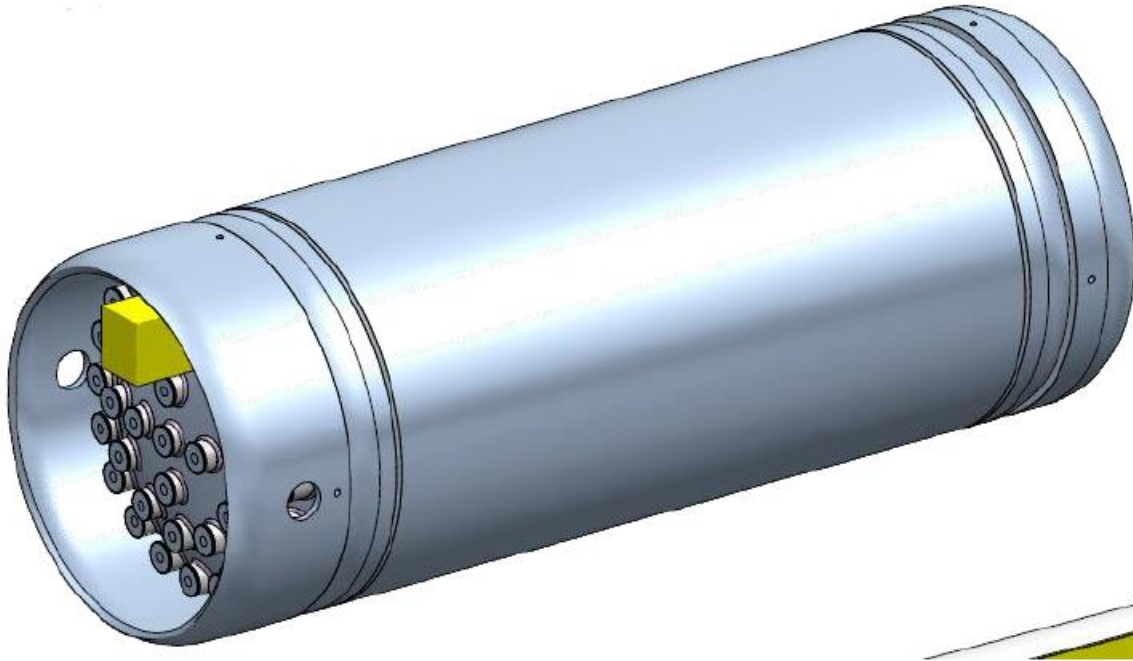
Figure 6. Daher 30B-20 Cylinder from Brochure (under design)

Table 1. Daher 30B-20 Technical Data

30B-20 cylinder Technical Data	
Nominal Diameter (mm)	762
Nominal Length (mm)	2060
Max. Net UF_6 Weight (kg)	1600
Max. Gross Weight (kg)	2710
Enrichment (wt. % ^{235}U)	max. 20

CONCLUSION

The 30B cylinder is criticality safe with 6 wt% fuel using moderator exclusion. However, due to difficulty in gaining a rule change or an exception from the NRC commissioners, it is believed that a new transport package for UF6 will be needed for 6 wt% fuel. A cask vendor is actively pursuing a new 30Bdesign that will solve this problem in a timely manner. The new 30B will have less capacity by about 30% which implies an increase in transport costs of about 30% per kg of UF6. But since 6 wt% fuel requires less UF6 for the same cycle energy and only a portion of a given core will use enrichments greater that 5 wt%, the transport cost increase would be minimal.

ACKNOWLEDGMENTS

REFERENCES

1.   http://us.areva.com/EN/home-2301/areva-nuclear-materials-tn-americas-packages.html

2.   https://www.wnti.co.uk/media/76713/WNTI%20-%20FS%20UF6%20-%20FINAL%20FINAL%205%208%2015%20-JK%20approved.pdf

3.   K. A. Miller, M. T. Swinhoe, H. O. Menlove, and J. B. Marlow, *Status Report on the Passive Neutron Enrichment Meter (PNEM) for UF6 Cylinder Assay*, LA-UR-12-21058, Los Alamos National Laboratory, Los Alamos, New Mexico, April 2012.

4.   *Nuclear energy — Packaging of uranium hexafluoride (UF6) for transport*, International Standard, ISO-7195 (2005).

5.   *Uranium Hexafluoride -Packaging for Transport*, ANSI N14.1-2001, American National Standards Institute, Inc., New York, New York, 2001.

6.   B. L. Broadhead, *Criticality Safety Review of 2 ½-, 10-, and 14-Ton UF$_6$ Cylinder*, ORNL/TM-11947, Oak Ridge National Laboratory, Oak Ridge, Tenn. (1991).

7.   Safety Analysis Report For Model UX-30 Package Rev. 3, Columbiana Hi Tech, Greensboro, NC, September 2014. NRC Adams Accession number: ML14279A158.

8.   *Certificate of Compliance for Radioactive Material Packages Certificate Number 9196*, Revision No. 29, Model: UX-30, U.S. Nuclear Regulatory Commission, Washington, DC, 2015.

9.   *Scale: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design*, ORNL/TM-2005/39, Version 6.1, June 2011. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-785. Includes 6.1.2 update dated 2/28/13.

10.   L. Begue, M. Milin, G. Caplin, and S. Evo,"Criticality Safety of Enriched UF6 Cylinders," Proceedings of the 17th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2013, August 18-23, 2013, San Francisco, CA, USA.

11.   Salaheddine Rezgui and Franz Hilbert, "Criticality Analyses of Enriched Uranium-Hexafluoride Containing Impurities," Proceedings of the 17th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2013, August 18-23, 2013, San Francisco, CA, USA.

12.   Gregory O'Connor, "Regulatory Criticality Safety Review Of Uranium Hexafluoride Transport Package Applications," Proceedings of the 17th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2013, August 18-23, 2013, San Francisco, CA, USA.

13.   DN30 Protective Structural Packaging for UF$_6$ Cylinders, Daher-TLI, slides for meeting with the US-NRC on April 4, 2017. NRC Adams Accession number: ML17144A081.

14.   *Summary of October 24, 2017, Meeting With Daher Nuclear Technologies GMBH*, Memorandum from Pierre Saverot to Anthony H. Hsia, November 7, 2017. NRC Adams Accession number: ML17312A303.