Designation: C996 – 15

# Standard Specification for Uranium Hexafluoride Enriched to Less Than 5 % $^{235}U$[1]

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## 1. Scope

1.1 This specification covers nuclear grade uranium hexafluoride ($UF_6$) that either has been processed through an enrichment plant, or has been produced by the blending of Highly Enriched Uranium with other uranium to obtain uranium of any $^{235}U$ concentration below 5 % and that is intended for fuel fabrication. The objectives of this specification are twofold: *(1)* To define the impurity and uranium isotope limits for Enriched Commercial Grade $UF_6$ so that, with respect to fuel design and manufacture, it is essentially equivalent to enriched uranium made from natural $UF_6$; and *(2)* To define limits for Enriched Reprocessed $UF_6$ to be expected if Reprocessed $UF_6$ is to be enriched without dilution with Commercial Natural $UF_6$. For such $UF_6$, special provisions, not defined herein, may be needed to ensure fuel performance and to protect the work force, process equipment, and the environment.

1.2 This specification is intended to provide the nuclear industry with a standard for enriched $UF_6$ that is to be used in the production of sinterable $UO_2$ powder for fuel fabrication. In addition to this specification, the parties concerned may agree to other appropriate conditions.

1.3 The scope of this specification does not comprehensively cover all provisions for preventing criticality accidents or requirements for health and safety or for shipping. Observance of this specification does not relieve the user of the obligation to conform to all applicable international, federal, state, and local regulations for processing, shipping, or in any other way using $UF_6$ (see, for example, TID-7016, DP-532, and DOE O474.1).

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

C761 Test Methods for Chemical, Mass Spectrometric, Spectrochemical, Nuclear, and Radiochemical Analysis of Uranium Hexafluoride

C787 Specification for Uranium Hexafluoride for Enrichment

C859 Terminology Relating to Nuclear Materials

C1052 Practice for Bulk Sampling of Liquid Uranium Hexafluoride

C1703 Practice for Sampling of Gaseous Uranium Hexafluoride

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.2 *ANSI/ASME Standards:*[3]

ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications

ANSI N14.1 Nuclear Materials—Uranium Hexafluoride—Packaging for Transport

2.3 *U.S. Government Documents:*

Inspection, Weighing, and Sampling of Uranium Hexafluoride Cylinders, Procedure for Handling and Analysis of Uranium Hexafluoride, Vol. 1, DOE Report ORO-671-1, latest revision[4]

Nuclear Safety Guide, U.S. NRC Report TID-7016, Rev. 2, 1978

Clarke, H. K., Handbook of Nuclear Safety, DOE Report DP-532[4]

Code of Federal Regulations, Title 10, Part 50, (Appendix B)[4]

[1] This specification is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.02 on Fuel and Fertile Material Specifications.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[4] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401.

2.4 *Other Document:*

The $UF_6$ Manual: Good Handling Practices for Uranium Hexafluoride, United States Enrichment Corporation Report USEC-651, latest revision[5]

## 3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 Terms shall be defined in accordance with Terminology C859 except for the following:

3.1.2 *Commercial Natural $UF_6$*—$UF_6$ from natural unirradiated uranium (containing 0.711 ± 0.004 g $^{235}U$ per 100 g U).

3.1.2.1 *Discussion*—It is recognized that some contamination with reprocessed uranium may occur during routine processing. This is acceptable provided that the $UF_6$ meets the requirements for Commercial Natural $UF_6$ as specified in Specification C787.

3.1.3 *Reprocessed $UF_6$*—any $UF_6$ made from uranium that has been exposed in a neutron irradiation facility and subsequently chemically separated from the fission products and transuranic isotopes so generated.

3.1.4 *Highly Enriched Uranium*—any form of uranium having a $^{235}U$ content of 20 % or greater.

3.1.5 *Enriched Commercial Grade $UF_6$*—$UF_6$ enriched from Commercial Natural $UF_6$ or Derived Enriched $UF_6$ that meets the specification limits for Enriched Commercial Grade $UF_6$.

3.1.6 *Enriched Reprocessed $UF_6$*—$UF_6$ enriched from Reprocessed $UF_6$, any mixture of Reprocessed $UF_6$ and Commercial Natural $UF_6$ or Derived Enriched $UF_6$, exceeding the applicable limits of Sections 4 and 5 for Enriched Commercial Grade $UF_6$. The wide range of irradiation levels, cooling times, reprocessing, conversion, and enrichment processes, and fuel cycle choices for combination with unirradiated $UF_6$, together with the varying acceptance limits of different fuel fabrication facilities, make it not practical to specify the exact radionuclide composition of Enriched Reprocessed $UF_6$.

3.1.7 *Derived Enriched $UF_6$*—any $UF_6$ obtained from the blending of Highly Enriched Uranium with any other uranium.

3.2 For enriched $UF_6$ transactions, "buyer" usually represents the electric power utility company or the fuel fabricator, and "seller" usually represents the isotopic enrichment facility.

## 4. Safety, Health Physics, and Criticality Requirements

4.1 The $UF_6$ concentration shall not be less than 99.5 g $UF_6$ per 100 g of sample in order to limit the potential hydrogen content for nuclear criticality safety.

4.2 The total absolute vapor pressure shall not exceed the values given below:

380 kPa at 80°C (55 psia at 176°F), or
517 kPa at 93°C (75 psia at 200°F), or
862 kPa at 112°C (125 psia at 235°F)

Additionally, if a measurement is taken over solid $UF_6$, the vapor pressure shall not exceed the values given below:

50 kPa at 20°C (7 psia at 68°F), or
69 kPa at 35°C (10 psia at 95°F)

The purpose of the pressure check is to limit the hydrogen fluoride, air, or other volatile components that might cause overpressure when heating the shipping container, such as to obtain a liquid sample or withdraw the contents.

4.2.1 If the temperature differs from 20°C or 35°C, a temperature correction must be performed which takes the change in vapor pressure of $UF_6$ into account. For example, an acceptable correction would be that the pressure must remain below $P_{UF6}(T) + 39.3$ kPa, where $P_{UF6}(T)$ is the vapor pressure of pure $UF_6$ over solid at temperature T and $P_{UF6}(T)$ is given according to $\text{Log } P_{UF6} = 12.77 - (2562.46/T)$, with P in Pascal and T in K.[6] Other methods or equations to assure that the pressure limits above are met are acceptable provided that validated temperature compensation is made.

4.3 The total hydrocarbon, chlorocarbon, and partially substituted halohydrocarbon content shall not exceed 0.01 mol % of the $UF_6$. The reason for the exclusion of these materials is to prevent a vigorous reaction with $UF_6$ upon heating. It is essential that contamination of the $UF_6$ containers, such as by vacuum pump oil, be prevented since it is not practical to obtain a sample without heating the $UF_6$. An alternative means of demonstrating compliance with this requirement, other than by direct measurement, may be agreed upon between the parties concerned.

4.3.1 Measures should be taken to minimize contamination by hydrocarbons, chlorocarbons and halohydrocarbons in the receiving cylinder before filling.

4.3.2 Also, it is good practice to minimize contact of hydrocarbon, chlorocarbon, and partially substituted halohydrocarbon during UF6 processing.

4.3.3 If $UF_6$ has been liquefied, either during filling or during sampling of the final shipping container, compliance can be assumed. If the $UF_6$ has not been liquefied, compliance must be demonstrated. An alternative means of demonstrating compliance with this requirement, other than by direct measurement, may be agreed upon between the parties concerned.

4.3.4 For fully substituted chlorofluorocarbons, a maximum limit may be agreed upon between the parties concerned.

4.4 For Enriched Commercial Grade $UF_6$ meeting the requirements of Section 5, (*1*) the gamma activity from fission products is expected to be below the detection limits of the measurement methodology; and (*2*) the alpha activity from neptunium and plutonium is expected to be below the detection limits of commonly used measurement methodology. Therefore unless otherwise agreed upon between the buyer and seller, measurements are not required, except for Derived Enriched $UF_6$ resulting from blending with reprocessed uranium.

4.5 For Enriched Reprocessed $UF_6$, the gamma radiation from fission products shall not exceed $4.4 \times 10^5$ MeVBq/kgU ($4.4 \times 10^5$ MeV/sec kgU).

[5] Available from United States Enrichment Corporation, 6903 Rockledge Drive, Bethesda, MD 20817.

[6] *Comprehensive Nuclear Materials*, Volume 2, The U-F System, Ed. R.J.M. Konings, p. 209, Elsevier 2012.

4.5.1 For Enriched Reprocessed $UF_6$, the alpha activity from neptunium and plutonium shall be less than 3300 Bq/kgU (200 000 dpm/kgU).

## 5. Chemical, Physical, and Isotopic Requirements

5.1 Both Enriched Commercial Grade $UF_6$ and Enriched Reprocessed $UF_6$ must meet the specification criteria except as differentiated in 4.4, 4.5, 5.4, and 5.5. For certain isotopes, including artificially created radioactive species, two groups of limits are set. Limits for Enriched Commercial Grade $UF_6$ are set so as to have no special impact on the use of this material in existing facilities. For Enriched Reprocessed $UF_6$, higher limits are indicated to correspond with Specification C787, and lower limits may be agreed upon by the buyer and seller according to the composition of the feed material presented for enrichment.

5.2 The $UF_6$ content shall be reported as $gUF_6/100$ g sample.

5.3 The following impurities shall not exceed these values:

| Element | µg/gU |
|---|---|
| Boron | 4 |
| Silicon | 250 |

For fully substituted chlorofluorocarbons a maximum limit may be agreed upon between the parties concerned.

5.4 Enriched Commercial Grade $UF_6$ shall comply with the limits given in 5.5. For evaluating Enriched Commercial Grade $UF_6$, the measured concentration of $^{236}U$ will be used as an indicator for contamination with reprocessed uranium, on the assumption that there is no opportunity for contamination with irradiated uranium that has not been processed to remove the majority of fission products. Uranium isotopic concentrations shall be determined and reported for $^{234}U$, $^{235}U$, and $^{236}U$.

5.5 *Radionuclides*—The following values represent limits obtainable from the enrichment of $UF_6$ feed materials at the corresponding limits of Specification C787. For purposes of determining conformance with these limits, the observed values shall be rounded to the nearest significant digit indicated in accordance with the rounding method of Practice E29. For example, for $^{234}U$ in Enriched Commercial Grade $UF_6$ the observed value would be rounded to the nearest $0.1 \times 10^3$ $\mu g^{234}U/g^{235}U$.

| | Enriched Commercial Grade $UF_6$ | Enriched Reprocessed $UF_6$ |
|---|---|---|
| $^{232}U$ | 0.0001 µg/gU, see 5.5.1, 5.5.2, and 5.5.3 | 0.050 µg/gU, see Note 1 |
| $^{234}U$ | $11.0 \times 10^3$ $\mu g/g^{235}U$, see Note 2 | 2000 µg/gU, see Note 1 |
| $^{236}U$ | 250 µg/gU, see 5.5.3 | see Note 1 |
| $^{99}Tc$ | 0.01 µg/gU, see 5.5.4 | 5 µg/gU, see Note 1 |

5.5.1 If the $^{236}U$ measurement result is less than 125 µg/gU, then measurement of $^{232}U$ is not required unless agreed upon between the buyer and seller.

5.5.2 If the $^{236}U$ measurement result is greater than 125 but less than 250 µg/gU, then measurement and reporting of $^{232}U$ is required for routine acceptance of the $UF_6$.

5.5.3 The buyer may consider acceptance of the lot above 250 µg/gU on the basis of the total significance of all the measured levels of radionuclides to determine the suitability for intended use in the fuel fabrication and irradiation. If the $^{236}U$ measurement result is greater than 250 µg/gU, then measurement of $^{232}U$ and notification of results before shipment are required.

5.5.4 The buyer and seller may agree to waive the requirement to measure $^{99}Tc$, provided that adequate capability to meet the $^{99}Tc$ limit for Enriched Commercial grade $UF_6$ can be demonstrated through quality assurance records. Such records shall include the results of the seller's periodic measurements of $^{99}Tc$ in the $UF_6$.

NOTE 1—Enrichment of Reprocessed $UF_6$ feed material at the limit of Specification C787 could be expected to reach these limits. Defining these limits does not imply that any fuel fabrication plant designed for Enriched Commercial Grade $UF_6$ could handle Enriched Reprocessed $UF_6$ without dilution with Enriched Commercial Grade $UF_6$ and other special precautions. With respect to the variability of Reprocessed $UF_6$ from various fuel histories and the demands that would be placed on the fuel fabricators and users, it could be necessary for the seller and buyer to agree on lower limits after enrichment than implied by Specification C787 feed limits.

NOTE 2—A $^{234}U$ content greater than $10.0 \times 10^3$ $\mu g/g^{235}U$ shall require agreement in advance between the parties (for example, supplier, receiver) to accept the material. It is recognized that some applications may not allow for the limit in the table due to licensing, regulatory, or contractual limitations.

## 6. Sampling

6.1 A representative sample of sufficient size to perform tests prescribed shall be taken while the material is liquid and homogeneous. Relevant sample procedures are given in Practice C1052, USEC Report USEC-651, and DOE Report ORO-671-1.

6.2 Alternatively, if the cylinder is filled in the gas phase, a representative sample may be taken during the transfer according to Practice C1703. It will have to be demonstrated that Gas sampling is equivalent to Liquid sampling as representative of the bulk material in cylinder. Otherwise, the use of this alternative technique should be agreed between buyer and seller.

6.3 All samples shall be clearly identified including the seller's lot number. It shall be stated whether samples have been taken in liquid or gas phase and whether they have been taken during or after filling.

6.4 All containers used for a lot shall be positively identified as containing material from a particular homogeneous lot.

## 7. Test Methods for Chemical and Isotopic Analysis

7.1 Chemical and isotopic analysis shall conform to Test Methods C761, or demonstrated equivalent, as mutually agreed upon between the buyer and seller.

## 8. Packaging, Handling, and Shipping

8.1 Procedures for packaging, handling, and shipping $UF_6$ are given in ANSI N14.1, USEC Report USEC-651, and DOE Report ORO-671-1 or appropriate national or international procedures.

8.2 Cylinders used for transport of Reprocessed $UF_6$ shall not be used for Enriched Commercial Grade $UF_6$ unless decontaminated internally before filling with Enriched Commercial Grade $UF_6$. Appropriate documentation shall be provided as agreed between buyer and seller to confirm that a cylinder has been used exclusively for enriched commercial grade $UF_6$ or has been internally decontaminated.

## 9. Quality Assurance

9.1 Quality assurance requirements shall be agreed upon between the buyer and the seller when specified in the purchase order. Code of Federal Regulations, Title 10, Part 50 (Appendix B) and ANSI/ASME NQA-1 are referenced as guides.

## 10. Keywords

10.1 low enriched uranium; nuclear fuel; uranium enrichment; uranium hexafluoride