



Standard Specification for Uranium Hexafluoride for Enrichment¹

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1. Scope

1.1 This specification covers uranium hexafluoride (UF_6) intended for feeding to an enrichment plant. Included are specifications for UF_6 derived from unirradiated natural uranium and UF_6 derived from irradiated uranium that has been reprocessed and converted to UF_6 for enrichment and subsequent reuse. The objectives of this specification are twofold: (1) To define the impurity and uranium isotope limits for Commercial Natural UF_6 feedstock; and (2) To define additional limits for Reprocessed UF_6 (or any mixture of Reprocessed UF_6 and Commercial Natural UF_6). For such UF_6 , special provisions may be needed to ensure that no extra hazard arises to the work force, process equipment, or the environment.

1.2 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 international, federal, state, and local regulations for processing, shipping, or in any other way using UF_6 (see, for example, TID-7016, DP-532, ORNL-NUREG-CSD-6, and DOE O 474.1).

1.3 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
- C859 Terminology Relating to Nuclear Materials
- C996 Specification for Uranium Hexafluoride Enriched to

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.

Less Than 5 % ^{235}U

C1052 Practice for Bulk Sampling of Liquid Uranium Hexafluoride

C1295 Test Method for Gamma Energy Emission from Fission and Decay Products in Uranium Hexafluoride and Uranyl Nitrate Solution

C1703 Practice for Sampling of Gaseous Uranium Hexafluoride

2.2 ANSI Standard:

N14.1 Packaging of Uranium Hexafluoride for Transport³

2.3 U.S. Government Documents:

Inspection, Weighing, and Sampling of Uranium Hexafluoride Cylinders, Procedures for Handling and Analysis of Uranium Hexafluoride, Vol. 1, Department of Energy Report ORO-671-1, latest revision⁴

The UF_6 Manual: Good Handling Practices for Uranium Hexafluoride, United States Enrichment Corporation Report USEC-651, latest revision⁵

Nuclear Safety Guide, U.S. Nuclear Regulatory Commission Report TID-7016, Rev. 2, 1978, and ORNL-NUREG-CSD-6⁴

Clarke, H. K., Handbook of Nuclear Safety, Department of Energy Report DP-532⁴
Control and Accountability of Nuclear Materials, DOE Directive O 474.1⁴

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 .

³ Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

⁴ Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

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

3.1.3 *Reprocessed UF₆*—any UF₆ 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.

3.1.3.1 *Discussion*—The requirements for Reprocessed UF₆ given in this specification are intended to be typical of reprocessed spent fuel that has achieved burnup levels of up to 50 000 Megawatt days per tonne of uranium in light water reactors and has been cooled for ten years after discharge. It is recognized that different limits would be necessary to accommodate different fuel histories.

4. Safety, Health Physics, and Criticality Requirements

4.1 The UF₆ concentration shall be not less than 99.5 g UF₆ 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 UF₆, then 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 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 UF₆ into account. For example, an acceptable correction would be that the pressure must remain below $P_{\text{UF}_6}(T) + 39.3 \text{ kPa}$, where $P_{\text{UF}_6}(T)$ is the vapor pressure of pure UF₆ over solid at temperature T and $P_{\text{UF}_6}(T)$ is given according to $\text{Log } P_{\text{UF}_6} = 12.77 - (2562.46/T)$, 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 UF₆. The reason for the exclusion of these materials is to prevent a vigorous reaction with UF₆ upon heating or with stronger-fluorinating agents which may be present in enrichment plants. It is essential that contamination of the UF₆ containers, such as by vacuum pump oil, be prevented since it is not practical to obtain a sample without heating the UF₆. For fully substituted chlorofluorocarbons a maximum limit may be agreed upon between the parties concerned.

4.3.1 Measures should be taken to minimize contamination by hydrocarbons, chlorocarbons, and partially substituted halohydrocarbons in the receiving cylinder before filling and it is good practice to minimize such contact during UF₆ processing.

4.3.2 If UF₆ has been liquefied, either during filling or during sampling of the final shipping container, compliance

can be assumed. If the UF₆ 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.

4.4 For Reprocessed UF₆ the gamma radiation from fission products shall not exceed $1.1 \times 10^5 \text{ MeV Bq/kgU}$ ($1.1 \times 10^5 \text{ MeV/sec kgU}$). The measurements are made in accordance with Test Method C1295 or equivalent. The purpose of this requirement is to limit the gamma dose from fission products to which plant workers might be exposed to a level less than 20 % of the gamma dose from aged natural uranium, and to limit the quantity of fission products in effluent from enrichment and fuel fabrication plants.

4.5 For Reprocessed UF₆, the alpha activity from neptunium (Np) and plutonium (Pu) isotopes may be specified in either of two ways as agreed upon between the parties concerned:

4.5.1 The total alpha activity from Np and Pu in the cylinder shall be limited to $25\,000 \text{ Bq/kgU}$ (1.5×10^6 disintegrations per minute per kilogram of uranium). This criterion is concerned with both the volatile components and those that remain on the inner surfaces and in the heel, so it can be measured practically only by sampling from the inflow during the filling of the shipping container; or

4.5.2 The volatile alpha activity from Np and Pu in the liquid sample from the shipping container shall be limited to 3300 Bq/kgU (0.2×10^6 disintegrations per minute per kilogram of uranium). To prevent nonvolatile particles from being included in this measurement, the liquid sample must be filtered through a porous nickel filter as described in Test Methods C761.

5. Chemical, Physical, and Isotopic Requirements

5.1 Plants preparing UF₆ will have to control the purity of process chemicals and also employ low corrosion equipment to be successful in meeting the specifications for most impurities. Both Commercial Natural UF₆ and Reprocessed UF₆ will have to meet the same specification criteria for most elements. In addition, Reprocessed UF₆ must meet additional specification limits for artificially created radioactive species. For evaluating Commercial Natural UF₆, the measured concentration of ²³⁶U 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. Provided that this isotope does not exceed the concentration limit for Commercial Natural UF₆ listed in 5.5, the expected concentrations of artificial isotopes would be so far below normal detection limits that measurements to determine compliance with the separate limits are not appropriate. Uranium hexafluoride that fails to meet Commercial Natural UF₆ limits would require further testing to determine its acceptability as Reprocessed UF₆.

5.2 The UF₆ content shall be reported as gUF₆/100 g of sample.

5.3 The total of all the following listed elements that form nonvolatile fluorides shall not exceed 300 µg/g of uranium:

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

aluminum	iron	sodium
arsenic	lead	strontium
barium	lithium	thorium
beryllium	magnesium	tin
bismuth	manganese	zinc
cadmium	nickel	zirconium
calcium	potassium	
chromium	silver	
copper		

NOTE 1—The list of nonvolatile fluorides and their limits were determined based upon their vapor pressure and likelihood to remain in the UF₆ heel following transfer. These elements form fluorides with a vapor pressure below 101.3 kPa at 300°C and are always nonvolatile. Additionally some elements may form both volatile and nonvolatile compounds and that is why in 5.4 we specifically limit the volatile component of each element.

5.3.1 If the concentration of an impurity element is given as a less-than value (this is a concentration expressed as being less than the lower detection limit of the analytical method), this less-than value shall be taken as the concentration of that element in determining the total impurity content.

5.4 The volatile component of the following elements shall not exceed the values listed below:

Element	Value, µg/g of uranium
antimony	1
arsenic	3 (see Note 2)
boron	1
bromine	5
chlorine	100
chromium	10 (see Note 2)
molybdenum	5 (see Note 2)
niobium	1
phosphorus	50
ruthenium	1
silicon	100
tantalum	1
titanium	1
tungsten	2
vanadium	2

NOTE 2—Total chromium, molybdenum, and arsenic are usually expected to be well below 10µg/gU, 5µg/gU, and 3µg/gU, respectively. If the total value of the element (noted hereafter as $E_{(total)}$) is found to be above the limit in 5.4, the volatile component may be determined by either of the following techniques as described in Test Method C761:

by measuring the insoluble component of the Element, and deducing the volatile component by: $E_{(volatile)} = E_{(total)} - E_{(nonvolatile)} = E_{(total)} - E_{(insoluble)}$

or, by vapor transfer of a sample UF₆ (taken according to Practice C1052) from its original sample container to a new container. Measuring the Element in the hydrolysed UF₆ of the new container will yield the volatile component of the Element initially present, providing the transfer has been made in the vapor phase $E_{(volatile)} = E_{(total)} - E_{(nonvolatile)} = E_{(after\ gas\ transfer)}$

If $E_{(total)}$ exceeds the value in 5.4, then agreement in advance between the parties (for example, supplier, receiver) shall be required to accept the material.

5.5 *Minor Isotopes*—These items shall not exceed the limits given as micrograms per gram of total uranium (µg/gU).

	Commercial Natural UF ₆	Reprocessed UF ₆
²³² U	0.00001	0.005
²³⁴ U	62	480.0 (see Note 3)
²³⁶ U	20	8400.0

5.5.1 It is recognized that variability in natural uranium does occur and affects the ²³⁴U level. ²³⁴U levels in the range of 56–62 µg/gU have been identified in a small part of natural

uranium production. For compliance with Specification C996 after enrichment, a ²³⁴U content of 56 µg/gU or less in Commercial Natural UF₆ is generally required to yield Enriched Commercial Grade UF₆ that does not exceed $10.0 \times 10^3 \mu\text{g}^{234}\text{U/g}^{235}\text{U}$ (Specification C996 requires agreement in advance between the parties to accept Enriched Commercial Grade UF₆ above $10.0 \times 10^3 \mu\text{g}^{234}\text{U/g}^{235}\text{U}$). A ²³⁴U content of 57–62 µg/gU will yield Enriched Commercial Grade UF₆ that may exceed this level, but will generally comply with the limit in Specification C996 of $11.0 \times 10^3 \mu\text{g}^{234}\text{U/g}^{235}\text{U}$. Therefore, prior to any delivery of Commercial Natural UF₆ containing ²³⁴U above 56 µg/gU, the ²³⁴U level shall be reported and shall require agreement in advance between the parties (for example, converter, enricher) to accept the material.

5.5.2 Values at or below the above limit for ²³²U in Commercial Natural UF₆ may be assumed without measurement provided that it can be demonstrated that the material meets the ²³⁶U limits.

5.5.3 For Commercial Natural UF₆, isotopic concentrations shall be reported for ²³⁴U, ²³⁵U, and ²³⁶U unless it can be otherwise demonstrated that the UF₆ conforms to the appropriate isotopic specifications (for example, through the seller's quality assurance records). For Commercial Natural UF₆ from verifiable natural uranium sources the analysis of ²³⁶U is not normally required unless otherwise agreed upon between the buyer and seller.

5.5.4 Unirradiated UF₆ at any ²³⁵U concentration other than that of Commercial Natural UF₆ might be delivered as feed material if this is acceptable to the enricher. Renegotiation of the impurity limits may be needed under these circumstances.

5.5.5 For Reprocessed UF₆, isotopic concentrations shall be measured and reported for ²³²U, ²³⁴U, ²³⁵U, and ²³⁶U.

NOTE 3—If the ²³⁴U level (expressed here in wt %) in reprocessed UF₆ exceeds the following limit: $(0.036 \times \text{wt } \%^{235}\text{U}) - 0.004$, then in order to ensure compliance with Specification C996, an acceptance between the parties shall be required prior to any delivery. For example, for wt % ²³⁵U = 1 %, then a value above 320 µg ²³⁴U/gU will require an acceptance.

5.6 *Technetium*—⁹⁹Tc shall not exceed the following limits given as micrograms per gram of total uranium (µg/gU).

	Commercial Natural UF ₆	Reprocessed UF ₆
⁹⁹ Tc	0.001	0.500

5.6.1 For Commercial Natural UF₆ from verifiable (for example, through the seller's quality assurance records) natural uranium sources, the analysis of ⁹⁹Tc is not normally required unless otherwise agreed upon between the buyer and seller.

5.6.2 For Reprocessed UF₆ the concentration of ⁹⁹Tc shall be measured and reported.

6. Sampling

6.1 A representative sample of sufficient size to perform the 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. 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 cylinders used for a lot shall be positively identified as containing material from a particular homogeneous lot.

7. Methods of 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 Commercial Natural UF_6 unless decontaminated internally before filling with Commercial Natural UF_6 . Appropriate documentation shall be provided as agreed between buyer and seller to confirm that a cylinder has been used exclusively for Commercial Natural UF_6 or has been internally decontaminated.

9. Keywords

9.1 low enriched uranium; natural uranium; nuclear fuel; reprocessed uranium; uranium enrichment; uranium hexafluoride

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