



Designation: C776 – 17 (Reapproved 2022)

Standard Specification for Sintered Uranium Dioxide Pellets for Light Water Reactors¹

This standard is issued under the fixed designation C776; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This specification is intended to provide the nuclear industry with a general standard for uranium dioxide (UO_2) pellets for light water reactor use. It recognizes the diversity of manufacturing methods by which UO_2 pellets are produced and the many special requirements for chemical and physical characterization which may be imposed by the operating conditions to which the pellets will be subjected in different light water reactors. Therefore, it is anticipated that the purchaser may supplement this specification with additional requirements for specific applications.

1. Scope

1.1 This specification is for finished sintered UO_2 pellets. It applies to UO_2 pellets containing uranium (U) of any ^{235}U concentration for use in nuclear reactors.

1.2 This specification recognizes the presence of reprocessed U in the fuel cycle and consequently defines isotopic limits for UO_2 pellets made from commercial grade UO_2 . Such commercial grade UO_2 is defined so that, regarding fuel design and manufacture, the product is essentially equivalent to that made from unirradiated U. UO_2 falling outside these limits cannot necessarily be regarded as equivalent and may thus need special provisions at the fuel fabrication plant or in the fuel design.

1.3 This specification does not include (a) provisions for preventing criticality accidents, (b) requirements for health and safety, (c) avoidance of hazards, or (d) shipping precautions and controls. Observance of this specification does not relieve the user of the obligation to be aware of and conform to all federal, state, and local regulations pertaining to possessing, shipping, processing, or using source or special nuclear material. Examples of U.S. Government documents are Code of Federal Regulations (Latest Edition), Title 10, Part 50, Title 10, Part 70, Title 10, Part 71, and Title 49, Part 173.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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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1.5 The following precautionary caveat pertains only to the technical requirements portion, Section 4, of this specification: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability or regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 ASTM Standards:²

- C696 Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Uranium Dioxide Powders and Pellets
- C753 Specification for Nuclear-Grade, Sinterable Uranium Dioxide Powder
- C859 Terminology Relating to Nuclear Materials
- C996 Specification for Uranium Hexafluoride Enriched to Less Than 5 % ^{235}U
- C1233 Practice for Determining Equivalent Boron Contents of Nuclear Materials
- E105 Guide for Probability Sampling of Materials
- E112 Test Methods for Determining Average Grain Size

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.

2.2 ASME Standard:³

ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications

2.3 U.S. Government Documents:

Code of Federal Regulations (Latest Edition), Title 10, Part 50 Domestic Licensing of Production and Utilization Facilities⁴

Code of Federal Regulations, Title 10, Part 70 Domestic Licensing of Special Nuclear Material⁴

Code of Federal Regulations, Title 10, Part 71 Packaging and Transportation of Radioactive Material⁴

Code of Federal Regulations, Title 49, Part 173 General Requirements for Shipments and Packaging⁴

Regulatory Guide NUREG 1.126 An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification, Rev. 1 March 1978⁵

3. Terminology

3.1 *Definitions*—For definitions of terms, refer to Terminology C859.

TABLE 1 Impurity Elements and Maximum Concentration Limits

Element	Maximum Concentration Limit (µg/g U)
Aluminum (Al)	250
Carbon (C)	100
Calcium (Ca) + magnesium (Mg)	200
Chlorine (Cl)	25
Chromium (Cr)	250
Cobalt (Co)	100
Fluorine (F)	15
Hydrogen (H, total from all sources)	1.3
Iron (Fe)	500
Nickel (Ni)	250
Nitrogen (N)	75
Silicon (Si)	500
Thorium (Th)	10

4. Technical Requirements

4.1 *Chemical Requirements*—All chemical analyses shall be performed on portions of the representative sample prepared in accordance with Section 6. Analytical chemistry methods used shall be as stated in Test Methods C696 (latest edition) or demonstrated equivalent as mutually agreed upon between the seller and the buyer.

4.1.1 *Uranium Content*—The U content shall be a minimum of 87.7 weight % on a dry weight basis. (Dry weight is defined as the sample weight minus the moisture content.)

4.1.2 *Impurity Content*—The impurity content shall not exceed the individual element limit specified in Table 1 on a U weight basis. The summation of the contribution of each of the impurity elements listed in Table 1 shall not exceed 1500 µg/g.

If an element analysis is reported as “less than” a given concentration, this “less than” value shall be used in the determination of total impurities.

4.1.3 *Stoichiometry*—The oxygen-to-uranium ratio of sintered fuel pellets shall be within the range from 1.99 to 2.02.

4.1.4 *Moisture Content*—The moisture content limit is included in the total hydrogen limit (see Table 1).

4.2 Nuclear Requirements:

4.2.1 Isotopic Content:

4.2.1.1 For UO₂ pellets with an isotopic content of ²³⁵U below 5 %, the isotopic limits of Specification C996 shall apply, unless otherwise agreed upon between the buyer and the seller. If the ²³⁶U content is greater than the Enriched Commercial Grade UF₆ requirements, the isotopic analysis requirements of Specification C996 shall apply. The specific isotopic measurements required by Specification C996 may be waived, provided that the seller can demonstrate compliance with Specification C996, for instance, through the seller’s quality assurance records.

4.2.1.2 For UO₂ pellets not having an assay in the range set forth in 4.2.1.1, the isotopic requirements shall be as agreed upon between the buyer and the seller.

4.2.2 *Equivalent Boron Content*—For light water reactor use, the total equivalent boron content (EBC) shall not exceed 4.0 µg/g on a U basis. The total EBC is the sum of the individual EBC values. For purpose of EBC calculation B, Gd, Eu, Dy, Sm, and Cd shall be included in addition to elements listed in Table 1. The method of performing the calculation shall be as indicated in Practice C1233. For fast reactor use, the above limitation on EBC does not apply.

4.3 Physical Characteristics:

4.3.1 *Dimensions*—The dimensions of the pellet and their tolerances shall be specified by the buyer. These shall include diameter, length, perpendicularity, and, as agreed upon between the buyer and seller, other parameters including end-face configuration and surface finish. The diameter can be determined by three (3) multiple-point measurements at a minimum: middle and the two extremities of the pellet. Length measurements shall be made between the furthest extremities of the pellet on the land area.

4.3.2 *Pellet Density*—The density and tolerance of sintered pellets shall be as specified by the buyer. The theoretical density (TD) for UO₂ shall be considered as 10.96 g/cm³. Density measurements shall be made by the method stated in Specification C753 (for the geometric method), by an immersion density technique, or by demonstrated equivalent method as mutually agreed upon between the buyer and the seller, or combinations thereof.

4.3.3 *Grain Size and Pore Size Distribution*—Because there is no unique structure for ensuring satisfactory performance, the pellet grain size and pore size distribution shall be mutually agreed upon between the buyer and the seller. The mean grain size can be measured as described in Test Method E112 or equivalent.

4.3.4 *Pellet Integrity*—Pellets shall be inspected and sorted to criteria which maintain adequate fuel performance and ensure general pellet integrity during subsequent handling.

³ Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, <http://www.asme.org>.

⁴ Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

⁵ Available from U.S. Nuclear Regulatory Commission, Washington, DC 20555. Attention: Director, Division of Document Control.

Acceptable inspection methods include lateral surface inspection using automated equipment, a visual (1×) comparison with pellet standards, or other methods, as mutually agreed upon between the buyer and the seller. Surface defects to be inspected for include chips, cracks, pits, end-capping, lips, inclusions, unground surfaces, blisters, spots/discoloration, and protrusions. Specific acceptance criteria and limits relative to the above characteristics shall be mutually agreed upon between the buyer and seller.

4.3.5 *Cleanliness and Workmanship*—The surfaces of finished pellets shall be visually free of macroscopic inclusions and foreign material such as oil and grinding media.

4.4 *Identification*—Pellets may be identified as to enrichment by either marking or coding.

4.5 *Irradiation Stability (Densification)*—An estimate of the fuel pellet irradiation stability shall be obtained (maximum densification anticipated) unless adequate allowance for such effects is factored into the fuel rod design. The estimate of the stability shall consist of either (a) conformance to the thermal stability test as specified in the applicable US NRC Regulatory Guide NUREG 1.126, or (b) equivalent test or qualification method as agreed upon between the buyer and the seller. Such methods typically consist of resintering the pellets at around 1700 °C for a minimum of 24 hours and calculating the density change. The mean density change must be positive and below a certain threshold to be accepted, for example less than 2 % of the TD. Pellet density determination shall be performed as indicated in 4.3.2.

5. Lot Requirements

5.1 A pellet lot is defined as a group of pellets made from a single UO₂ powder lot as defined in Specification C753 using one set of process parameters.

5.2 The identity of a pellet lot shall be retained throughout processing without mixing with other established lots.

5.3 Conformance to this specification shall be established for each pellet lot.

6. Sampling

6.1 UO₂ pellets may be hygroscopic and retain water after exposure to a moist atmosphere. Sampling and handling the sample shall be done under conditions which assure that the sample is representative of the lot. Practice E105 is referenced as a guide.

6.2 The buyer shall have the option to take a representative sample of pellets from each pellet lot for the purpose of determining chemical, nuclear, or physical properties.

6.3 The lot sample shall be of sufficient size to perform quality assurance testing and referee testing in the event it becomes necessary, and, when required, acceptance testing at the buyer's plant.

6.4 The lot sample for acceptance testing at the buyer's plant, when required, shall be packaged in a separate container, clearly identified by lot number, and shall be shipped preceding the shipment or with the lot.

6.5 The referee sample shall be clearly identified and retained by the manufacturer per requirements established by the buyer.

7. Testing and Certification

7.1 The seller shall sample pellets as described in Section 6 to assure conformance of the pellet lot to the requirements of Section 4. All testing shall be conducted by techniques mutually agreed to between the buyer and the seller (and manufacturer if different from the seller).

7.2 The seller shall provide to the buyer documentation certifying that the pellets meet all the requirements of Section 4.

7.3 For a time period to be agreed upon by the buyer and the seller, the seller shall maintain and make available upon request all results used to certify that pellets meet the requirements of Section 4.

7.4 *Lot Acceptance*—Acceptance testing may be performed by the buyer on either the sample provided by the seller or on a sample taken at the buyer's plant. Acceptance shall be on a pellet lot basis and shall be contingent upon the material properties meeting the requirements of Section 4, or modified Section 4 by contract documentation.

7.5 *Referee*—The buyer and seller shall agree to a third party as a referee in the event of a dispute in analytical results.

8. Packaging and Shipping

8.1 UO₂ pellets shall be packaged in sealed containers to prevent loss or damage of material and contamination from airborne or container materials. The exact size and type of packaging shall be mutually agreed upon between the buyer and the seller.

8.2 Each container in 8.1 shall bear labels on the lid and side that include the required information to satisfy the appropriate transportation and regulatory requirements, including as a minimum the following:

- 8.2.1 Seller's name,
- 8.2.2 Material in container,
- 8.2.3 Lot number,
- 8.2.4 U enrichment,
- 8.2.5 Gross, tare, net oxide weights,
- 8.2.6 U weight,
- 8.2.7 Purchase order number, and
- 8.2.8 Container () of () (total number of containers).

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 ASME NQA-1 are referenced as guides.

10. Keywords

10.1 light water reactors; nuclear fuel; nuclear fuel pellets; urania; uranium dioxide