Designation: C 1008 – 99

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Specification for Sintered (Uranium-Plutonium) Dioxide Pellets—Fast Reactor Fuel[1]

This standard is issued under the fixed designation C 1008; 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-plutonium) dioxide pellets for fast reactor use. It recognizes the diversity of manufacturing methods by which (uranium-plutonium) dioxide 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 specific reactor systems. It does not recognize the possible problems associated with the reprocessing of such pellets. It is therefore anticipated that the buyer may supplement this specification with additional requirements for specific applications.

1. Scope

1.1 This specification is for finished sintered (uranium-plutonium) dioxide pellets. It applies to (uranium-plutonium) dioxide pellets containing plutonium additions in the range from 10 to 40 weight % and uranium of any ^{235}U content. The isotopic composition of the plutonium component will be as normally produced by in-reactor neutron irradiation of uranium having less than 5 % ^{235}U or by in-reactor neutron irradiation of recycled plutonium mixed with uranium.

1.2 This specification does not include (*1*) provisions for preventing criticality accidents or (*2*) requirements for health and safety. Observance of this specification does not relieve the user of the obligation to be aware of and conform to all applicable international, federal, state, and local regulations pertaining to possessing, processing, shipping, or using source or special nuclear material. Examples of U.S. government documents are Code of Federal Regulations Title 10, Part 50 — Domestic Licensing of Production and Utilization Facilities; Title 10, Part 71 — Packaging and Transportation of Radioactive Material; and Title 49, Part 173 — General Requirements for Shipments and Packaging.

1.3 The following safety hazards 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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 698 Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Mixed Oxides ($(U, Pu)O_2$)[2]

C 753 Specification for Nuclear-Grade, Sinterable Uranium Dioxide Powder[2]

C 757 Specification for Nuclear-Grade Plutonium Dioxide Powder, Sinterable[2]

C 859 Terminology Relating to Nuclear Materials[2]

C 1165 Test Method for Determining Plutonium by Controlled-Potential Coulometry in H_2SO_4 at a Platinum Working Electrode[2]

C 1204 Test Method for Uranium in the Presence of Plutonium by Iron (II) Reduction in Phosphoric Acid Followed by Chromium (VI) Titration[2]

C 1206 Test Method for Plutonium by Iron (II)/Chromium (VI) Amperometric Titration[2]

E 105 Practice for Probability Sampling of Materials[3]

2.2 *ANSI Standard:*

ANSI/ASME NQA-1 Quality Assurance Program Requirements for Nuclear Facility Applications[4]

2.3 *U.S. Government Documents:*

Code of Federal Regulations, Title 10, (Energy) Part 50, Domestic Licensing of Production and Utilization Facilities (10 CFR 50)[5]

U.S. Department of Transportation, Title 49, Transportation,

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[1] This specification is under the jurisdiction of ASTM Committee C-26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.02 on Fuel and Fertile Material Specifications.

Current edition approved Jan. 10, 1999. Published March 1999. Originally published as C 1008 – 84. Last previous edition C 1008 – 92.

[2] *Annual Book of ASTM Standards*, Vol 12.01.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

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

[5] Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

Chapter 1, Materials Transportation Bureau, applicable parts[5]

U.S. Nuclear Regulatory Commission, Title 10, Part 71, Packaging and Transportation of Radioactive Material[5]

3. Terminology

3.1 *Definitions*—Definitions shall be in accordance with Terminology C 859.

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 shall be as stated in Test Methods C 698 (latest edition) or demonstrated equivalent as mutually agreed upon between the buyer and the seller.

4.1.1 *Uranium and Plutonium Content*—Individual powders shall meet the requirements of Specifications C 753 and C 757. The uranium and plutonium contents combined shall be a minimum of 87.7 weight % on a dry weight basis compensated for the americium-241 content. (Dry weight is defined as the sample weight minus the moisture content.) The plutonium content shall be that specified by the buyer.

4.1.2 *Impurity Content*— The impurity content shall not exceed the individual element limit specified in Table 1, based on the heavy metal content (uranium plus plutonium). The summation of the contribution of each of the impurity elements listed in Table 1 shall not exceed 5000 µg/g (U + Pu). If an element analysis is reported as "less than" a given concentration, this" less than" value shall be used in the determination of the total impurities.

4.1.3 *Stoichiometry*— The oxygen-to-heavy-metal ratio of sintered fuel pellets shall be within the range from 1.94 to 2.01. The nominal value and allowable tolerances shall be agreed upon between the buyer and the seller.

4.1.4 *Moisture Content*— The moisture content shall not exceed 30 µg/g total weight.

4.1.5 *Gas Content*— The gas content, exclusive of moisture, shall not exceed, at standard temperature and pressure, 0.18 L/kg of the heavy metal content.

4.1.6 *Americium-241 Content*—The americium-241 content shall be measured and reported, along with the date of analysis.

TABLE 1 Impurity Elements and Maximum Concentration Limits

Elements	Maximum Concentration Limit (µg/g of U + Pu)
Aluminum	900
Calcium	250
Carbon	300
Chlorine	25
Chromium	500
Fluorine	25
Iron	1600
Magnesium	150
Nickel	500
Nitride nitrogen	200
The sum of copper, zinc, and silicon	1400
The sum of silver, manganese, molybdenum, lead, and tin	400

The americium-241 content or activity is important to the handling of UO_2-PuO_2 and will vary with time. The maximum acceptable americium-241 content on a given date shall be agreed upon between the buyer and seller. The date of separation of plutonium from this isotope shall be considered.

4.1.7 The uranium, thorium, and americium contents or activity, or both, are important in the handling of plutonium dioxide (PuO_2) containing materials and will vary with time. The dates of separation of the plutonium used from these elements and the analysis dates shall be considered. Methods of reporting shall be agreed upon between the seller and the buyer.

4.2 *Nuclear Requirements*:

4.2.1 *Isotopic Content*— The isotopic content of the americum, uranium, and plutonium in the (uranium-plutonium) dioxide pellets shall be determined. The ^{234}U, ^{235}U, ^{236}U, and ^{238}U content of the uranium shall be reported as a mass percentage with respect to total uranium, and the ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu content of the plutonium shall be reported on a Pu mass % or on a (Pu + Am) mass % basis. The equivalent plutonium content based on uranium and plutonium isotopic concentrations shall be as specified by the buyer.

4.2.2 *Equivalent Plutonium at a Given Date*—The equivalent plutonium of the (uranium-plutonium) dioxide pellets shall be considered as the sum of the fissile isotopes of uranium, plutonium, and americium. Debits in fissile inventory will be considered, as necessary, for poisons, for example, U236 or Am241. The dates of isotopic analyses in support of these determinations will be recorded by the seller and reported to the buyer. The permissible tolerances of the plutonium content (either as americum, uranium plus plutonium, or as the individual elements) and their evaluation criteria shall be as agreed upon between the buyer and the seller.

4.3 *Physical Characteristics*:

4.3.1 *Dimensions*—The dimensions of the pellet shall be as specified by the buyer. These shall include diameter, length, perpendicularity, and, as required, other geometric parameters including surface finish.

4.3.2 *Pellet Density*— The density of sintered pellets shall be as specified by the buyer. The theoretical density for uranium dioxide (UO_2) of natural isotopic content shall be considered as 10.96 g/cm^3. The theoretical density for PuO_2 shall be considered as 11.46 g/cm^3. The theoretical density for the uranium-plutonium dioxide ($(U, Pu)O_2$) pellets shall be calculated by linear interpolation between these values. Density measurements shall be made by the method stated in Annex A1 (for the geometric method) or by a demonstrated equivalent method as mutually agreed upon between the buyer and the seller.

4.3.3 *Grain Size and Pore Morphology*—The performance of pellets (including irradiation swelling and densification) may be affected by the pellet grain size and pore morphology. These characteristics shall be mutually agreed upon between the buyer and the seller.

4.3.4 *Plutonium Oxide Homogeneity and Size*:

4.3.4.1 *Plutonium Homogeneity Within a Pellet Lot*—Homogeneity of the Pu content shall be demonstrated through analysis of representative samples taken from multiple pellets.

Sample size shall not exceed the nominal equivalent of a fuel pellet. The range of the Pu content shall not exceed 0.2 % absolute. Alternative methods and criteria that may be agreed upon between the buyer and the seller are possible for evaluation of plutonium homogeneity within a lot.

4.3.4.2 *Plutonium Oxide Particle Size and Distribution Within a Pellet*—No more than 5 % of the nominal PuO_2 content within a pellet shall be present in PuO_2 rich particles with equivalent diameters of 200 µm or greater. When α-autoradiography is used to determine the value, due allowance shall be permitted for the halo effect. The area percentage and volume percentage shall be considered equivalent provided the homogeneity requirements of 4.3.4.1 are satisfied.

4.3.5 *Pellet Integrity*— Pellets shall be inspected to criteria that ensure that excessive breakage will not occur during fuel rod loading. Acceptable test methods include a visual (1X) comparison with pellet standards, or other methods, for instance, loadability tests, approved by both the buyer and the seller.

4.3.5.1 *Surface Cracks*— The suggested limits for surface cracks are defined as follows:

(1) Radial cracks on the pellet ends—½ the pellet radius.

(2) Circumferential cracks—½the circumference.

(3) Axial cracks—½ the pellet length.

4.3.6 *Chips*—The limits for chips are as follows:

4.3.6.1 *Pellet Ends*— 25 % of the surface area of the load bearing surface of the pellet end. Alternative criteria may be agreed upon between the buyer and the seller for evaluation of chips.

4.3.6.2 *Circumferential Chips*—10 % of the pellet circumferential surface area.

4.3.7 *Cleanliness and Workmanship*—The surface of finished pellets shall be visually (1X) free of loose chips, macroscopic inclusions and foreign materials, such as oil and grinding media.

4.4 *Identification*— Pellet identity shall be maintained as to total fissile and total Pu content by marking, coding, or alternative methods.

5. Lot Requirements

5.1 A pellet lot is defined as a group of pellets made from a single blend of UO_2 and PuO_2 powder lots 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 (Uranium-plutonium) dioxide pellets may be hygroscopic and retain sufficient water after exposure to a moist atmosphere to cause detectable errors. Sampling, weighing of the sample, and handling the sample shall be done under conditions that assure that the sample is representative of the lot. Sampling plans to meet acceptance criteria shall be mutually agreed upon between the buyer and the seller. Practice E 10 is referenced as a guide.

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

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

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 shipped with or preceding the lot. The referee sample shall be clearly identified and retained at the seller's plant until the lot has been formally accepted by the buyer.

7. Testing and Certification

7.1 The seller shall test the sample described in Section 6 to assure conformance of the pellet to the requirements of Section 4. All testing shall be conducted by techniques mutually agreed upon between the buyer and the seller.

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

7.3 When requested by the buyer, the seller shall make available records of all data obtained from tests certifying that the pellets meet 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 lot basis and shall be contingent upon the material properties meeting the requirements of Section 4 or of Section 4 as modified by contract documentation.

7.5 *Referee*—The buyer and the 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 (Uranium-plutonium) dioxide pellets shall be packaged in sealed containers to prevent loss or damage, or both, of material and contamination from airborne or container materials. The exact size and type of packaging shall be as mutually agreed upon between the buyer and seller.

8.2 Each container referred to in 8.1 shall bear labels on the lid and side that include the following information:

8.2.1 Seller's name,

8.2.2 Material in container,

8.2.3 Lot numbers,

8.2.4 Plutonium content and enrichment,

8.2.5 Uranium content and enrichment,

8.2.6 Gross, tare, net oxide weights,

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 NQA-1 are referenced as guides.

10. Keywords

10.1 breeder reactor; fast reactor; mixed oxide fuels; nuclear fuel; nuclear fuel pellets; plutonium; uranium

ANNEX

(Mandatory Information)

A1. DENSITY DETERMINATION

A1.1 Determine the geometrical density of the fired and unfired pellets as follows:

A1.1.1 *Diameter*—Record the average of four readings taken at equally spaced intervals along a 180° helix 1.6 mm (1/16 in.) from each end of the pellet using a blade micrometer and reading to the nearest 0.0051 mm (0.0002 in.).

A1.1.2 *Length*—Record the average of three readings taken from end-to-end of the pellet at equally spaced intervals along a vertically bisecting plane using a micrometer and reading to the nearest 0.0127 mm (0.001 in.).

A1.1.3 *Weight*—Weigh to the nearest 0.001 g.

A1.1.4 *Density*—Calculate the density of each pellet to the nearest 0.01 g/cm^3.

A1.2 Alternatively, the density of the pellet may be obtained by an immersion technique as agreed between the buyer and seller.