Designation: C 833 – 95a

Standard Specification for Sintered (Uranium-Plutonium) Dioxide Pellets[1]

This standard is issued under the fixed designation C 833; 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 thermal 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 that 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 purchaser may supplement this specification with additional requirements for specific applications.

1. Scope

1.1 This specification covers finished sintered (uranium-plutonium) dioxide pellets. It applies to uranium-plutonium dioxide pellets containing plutonium additions up to 10 % weight. The isotopic composition of the diluent uranium shall be of any ^{235}U composition. The isotopic composition of the plutonium component shall be as normally prepared by in-reactor neutron irradiation of uranium having less than 5 % ^{235}U.

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 international, federal, state, and local regulations on possessing, shipping, processing, or using source or special nuclear materials. Guidance is provided in CFR Title 10, TID-7016, and DP-532 (see 2.3).

1.3 All terms used herein are as defined in Terminology C 859.

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:*

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]

C 1233 Practice for Determining Equivalent Boron Contents of Nuclear Material[2]

E 105 Practice for Probability Sampling of Materials[3]

2.2 *ANSI Standard:*[4]

NQA-1 Quality Assurance Program Requirements for Nuclear Facilities

2.3 *U.S. Government Documents:*[5]

CFR Title 10, Chapter 1 Nuclear Safety Guide (Title 49 Transportation, Chapter 1 Materials Transportation Bureau) Nuclear Safety Guide, U.S. AEC Report TID-7016 Handbook of Nuclear Safety, AEC Report DP-532

CFR 10, Chapter 1, Regulatory Guide 1.126 An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification

3. Terminology

3.1 *Definitions:*

[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.

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[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 West 42nd St., 13th Floor, New York, NY 10036.

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

3.1.1 For definitions of terms, refer to 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 to between the buyer and the seller.

4.1.1 *Uranium and Plutonium Content*—Individual powders may be specified as in Specifications C 753 and C 757, which also reference Test Methods C 1165, C 1204, and C 1206. The uranium and plutonium contents combined 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). 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 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.

NOTE 1—Higher impurity limits should be acceptable for restricted burnups and linear power ratings if there is evidence to substantiate the relaxation. Higher impurity levels of 450 ppm aluminum, 250 ppm carbon, 250 ppm nitrogen, and 450 ppm silicon have been supported for burnups of less than 35 000 MWd/t. The extension of the burnup limit may be determined by agreement between the buyer and seller as supporting data are accumulated.

4.1.3 *Stoichiometry*—The oxygen-to-heavy metal ratio of sintered fuel pellets shall be within the range from 1.98 to 2.02.

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

4.1.5 *Gas Content*—The gas content, exclusive of moisture, shall not exceed, at standard temperature and pressure, 0.05 L/kg of the heavy metal content.

4.1.6 *Americium-241 Content*—The americium-241 content shall be measured by the seller and reported to the buyer. The americium-241 content or activity is important in the handling of UO_2-PuO_2 pellets and will vary with time. The maximum acceptable americium-241 content on a given date along with the date of analysis shall be agreed upon between the buyer and seller. The dates of separation of plutonium from this isotope and the analysis dates shall be considered; methods of reporting shall be agreed upon between the buyer and seller.

TABLE 1 Impurity Elements and Maximum Concentration Limits

Element	Maximum Concentration Limit (µg/g of U + Pu)
Aluminum	250
Carbon	100
Calcium + magnesium	200
Chlorine	25
Chromium	250
Cobalt	100
Fluorine	15
Hydrogen (total from all sources)	1.3
Iron	500
Nickel	250
Nitride/nitrogen	75
Silicon	250
Thorium	10

4.2 *Nuclear Requirements*:

4.2.1 *Isotopic Content*—The isotopic content of the uranium and of the plutonium in the (uranium-plutonium) dioxide pellets shall be measured and the date of measurement recorded. The ^{234}U, ^{235}U, ^{236}U, and ^{238}U content of the uranium shall be reported on a U % weight basis, and the ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu content of the plutonium shall be reported on a Pu % weight or on (Pu + Am) % weight basis. The plutonium equivalent content based on uranium, plutonium, and americium isotopic concentration shall be as specified by the buyer.

4.2.2 *Plutonium Equivalent*—The Plutonium equivalent content of the (uranium-plutonium) dioxide fuel shall be considered as defined by the plutonium content with adjustment (credit or debit) for the actual isotopic composition of plutonium, americium, and uranium as of a "reference date." The permissible tolerances of the equivalent plutonium content (either as uranium plus plutonium or as the individual elements) shall be as agreed upon between the buyer and the seller.

4.2.3 *Equivalent Boron Content*—For thermal reactor use, the total equivalent boron content (EBC) shall not exceed 4.0 µg/g on a heavy metal basis. The total EBC is the sum of the individual EBC values. Practice C 1233 contains a list of elements to be considered in calculating the total EBC. The specific elements to be used in calculating the total EBC as well as the values of the cross sections will depend on individual reactor characteristics. Practice C 1233 should be considered as an example only. Specific elements and their EBC factors shall be determined by agreement between the buyer and the seller. The EBC of each element shall be calculated individually using the following equation:

$$\text{EBC of Element} = (\text{EBC factor}) \times (\mu\text{g element/g heavy metal}) \quad (1)$$

4.2.4 *Reactivity*—An integral test of reactivity may be performed and correlated to total EBC by a method agreed upon between the buyer and the seller. If this is done, a total EBC need not be determined.

4.3 *Physical Characteristics*:

4.3.1 *Dimensions*—The dimensions of the pellet shall be 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 UO_2 shall be considered to be 10.96 g/cm^3. The theoretical density for PuO_2 shall be considered to be 11.46 g/cm^3. The theoretical density for the (U, Pu)O_2 pellets shall be calculated by linear interpolation between these values. Density measurements shall be made by the method stated in Specification C 753 (for the geometric method) or by demonstrated equivalent method as mutually agreed upon between the buyer and the seller.

4.3.3 *Grain Size and Pore Morphology*—Because there is no unique structure for ensuring satisfactory performance, the

pellet grain size and pore morphology 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. The range of the Pu content shall not exceed a range to be agreed upon between the buyer and the seller.

4.3.4.2 *Plutonium-Oxide Particle Size and Distribution Within a Pellet*—No more than 5 % of the nominal PuO_2 content shall be present in PuO_2-rich particles with equivalent diameters of 200 µm or greater. The method for determining the homogeneity shall be agreed upon between the buyer and the seller. The area percentage and volume percentage shall be considered equivalent provided the homogeneity requirements of 4.3.4.1 are satisfied.

NOTE 2—This specification is for particles of plutonium oxide only. In the case where the particle is composed of a homogeneously produced plutonium oxide/uranium oxide, the equivalent to the above mentioned shall be specified according to plutonium content in the particle as agreed upon between the buyer and seller.

4.3.5 *Pellet Integrity*—Pellets shall be inspected according to criteria that ensure that excessive breakage will not occur during fuel rod loading. Acceptable test methods include a visual (1×) comparison with pellet standards or other methods, for example, 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*—½the pellet radius.

(*2*) *Circumferential Cracks*—½ circumference.

(*3*) *Axial Cracks*—½ the pellet length.

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

(*1*) *Pellet Ends*—20 % of the surface area of the loadbearing surface of the pellet end.

(*2*) *Circumferential Chips*—10 % of the pellet circumferential surface area.

4.3.6 *Cleanliness and Workmanship*—The surfaces of finished pellets shall be visually free of loose chips, oil, macroscopic inclusions, and foreign materials.

4.3.7 *Pellet Solubility Test*—When requested by the buyer, a pellet solubility test shall be performed in accordance with a procedure agreed upon between the buyer and the seller.

4.4 *Identification*—Pellets shall be possible to identify as to total fissile and total plutonium content by, for example, marking or coding. Other identification can be used (for example, total plutonium and "reference date").

4.5 *Irradiation Stability (Densification)*—An estimate of the fuel pellet irradiation stability shall be obtained unless adequate allowance for such effects are 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 Regulatory Guide (NUREG 1.126), or (*b*) by adequate correlation of manufacturing process or microstructure to in-reactor behavior, or both.

5. Lot Requirements

5.1 A (UO_2-PuO_2) powder lot is defined as a quantity of (UO_2-PuO_2) powder that is manufactured to produce uniform isotopic, chemical, physical, and sinterability characteristics.

5.2 A pellet lot is defined as a group of pellets made from a single (UO_2-PuO_2) powder lot using one set of blending and pelletizing process parameters.

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

5.4 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 ensure that the sample is representative of the pellet or powder lot. Sampling plans shall be mutually agreed upon between the buyer and the seller. Practice E 105 is recommended as a guide.

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

6.3 The pellet lot sample shall be of sufficient size to perform quality assurance testing by the seller, referee tests in the event they become necessary, and, furthermore, archive retention and acceptance testing when agreed upon between buyer and seller.

6.4 The pellet lot sample for acceptance testing by the buyer, when required, shall be packaged in a separate container, clearly identified by pellet lot number, and shipped preceding or with the pellet lot. This referee sample shall be identified clearly and retained by the seller until the lot has been formally accepted by the buyer.

7. Testing and Certification

7.1 The manufacturer shall test the sample described in Section 6 to ensure 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 the buyer documentation that certifies that the pellets meet the requirements of Section 4.

7.3 When requested by the buyer, the seller shall supply records of data obtained from tests conducted to certify that pellets meet the requirements of Section 4.

7.4 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 Section 4 as modified by contract documentation.

7.5 The buyer and the seller shall agree upon a third party as a referee in the event of a discrepancy in analytical results.

8. Packaging and Shipping

8.1 (Uranium-plutonium) dioxide pellets shall be packaged in sealed containers to prevent loss of or damage to 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 the seller.

8.2 Each container described 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 pellet lot numbers,
8.2.4 fissile plutonium content,
8.2.5 uranium content and enrichment,
8.2.6 gross, tare, and net oxide weights,
8.2.7 uranium and plutonium weights,
8.2.8 purchase order number, and
8.2.9 container ( ) of ( ) (total number of containers).

9. Quality Assurance

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

10. Keywords

10.1 mixed oxide fuel; plutonium; thermal reactors; uranium-plutonium

APPENDIX

(Nonmandatory Information)

X1. PELLET LOADABILITY TEST

X1.1 Subject randomly selected samples (the number of samples to be established by statistical considerations) from each production lot of pellets to an axial stress test. Each individual sample shall consist of ten finished pellets. Samples shall be subjected to an axial stress of up to 25 MPa (3625 psi), and the stress level at which a 0.40-mm (1/64-in.) or larger chip is produced shall be recorded. If the sample of 10 pellets withstands a 25 MPa stress without chipping, the chip loading for that sample shall be recorded as 25 MPa. For acceptance of the lot, the finished pellets shall withstand an average of 19 MPa (2755 psi) axial compressive stress or more without producing chips in excess of 0.40 mm. If the average stress to produce chips is less than 19 MPa or if any single sample produces chips at less than 13 MPa (1855 psi), the lot is subject to rejection or retest.

X1.2 Retesting a lot of pellets requires the selection of additional samples of ten finished pellets each, (the number to be established by statistical considerations), and subjecting these samples to the axial loading test. The acceptance criterion for the lot shall be based on the grand average of all samples (original and retest) equaling 19 MPa (2755 psi) or more with no more than one sample producing chips at less than 13 MPa (1855 psi).