Designation: ~~C833 – 17~~ C833 – 23

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

This standard is issued under the fixed designation C833; 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 ((U, Pu)O_2) pellets for light water reactor use. It recognizes the diversity of manufacturing methods by which (U, Pu)O_2 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 different light water reactors. 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 and ground (U, Pu)O_2 pellets for use in light water reactors. It applies to (U, Pu)O_2 pellets containing ~~plutonium additions up to 15 weight % (wt%; that is, 0.15 g Pu / g (U + Pu + Am)).~~ a plutonium mass fraction up to 15 % (that is, mass of Pu divided by the sum of masses U, Pu, and Am yielding 0.15 or less).

1.2 Pellets produced under this specification are available in four grades.

1.2.1 *Grade R*—^{240}Pu ~~content of /~~ (Pu + Am) ~~(that is, g~~isotope mass fraction ^{240}~~Pu / g (Pu + Am))~~ is at least ~~19 %.~~19 %.

1.2.2 *Grade F*—^{240}Pu ~~content of /~~ (Pu + Am) isotope mass fraction is at least ~~7 %~~ 7 % and less than ~~19 %.~~19 %.

1.2.3 *Grade N1*—^{240}Pu ~~content of /~~ (Pu + Am) isotope mass fraction is less than ~~7 %.~~7 %.

1.2.4 *Grade N2*—^{240}Pu /^{239}Pu isotope mass fraction does not exceed ~~0.10.~~0.10 (10 %).

1.3 There is no discussion of or provision for preventing criticality incidents, nor are health and safety requirements, the avoidance of hazards, or shipping precautions and controls discussed. 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; Code of Federal Regulations Title 10, Part 71—Packaging and Transportation of Radioactive Material; and Code of Federal Regulations Title 49, Part 173—General Requirements for Shipments and Packaging.

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

~~1.5 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.*~~

1.5 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, health, and environmental practices and determine the applicability of 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]

B243 Terminology of Powder Metallurgy
C698 Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Mixed Oxides ((U, Pu)O_2)
C753 Specification for Nuclear-Grade, Sinterable Uranium Dioxide Powder
C757 Specification for Nuclear-Grade Plutonium Dioxide Powder for Light Water Reactors
C859 Terminology Relating to Nuclear Materials
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

2.2 *ASME Standard:*[3]

ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications

2.3 *U.S. Government Documents:*[4]

USNRC Regulatory Guide 1.126 An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification
Code of Federal Regulations Title 10, Part 50 Domestic Licensing of Production and Utilization Facilities
Code of Federal Regulations Title 10, Part 71 Packaging and Transportation of Radioactive Material
Code of Federal Regulations Title 49, Part 173 General Requirements for Shipments and Packaging

3. Terminology

3.1 *Definitions*—Definitions of terms are as given in Terminologies B243 and C859.

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 C698 (latest edition) or demonstrated equivalent as mutually agreed to between the buyer and the seller.

4.1.1 *Uranium and Plutonium Content*—Unless agreed upon by the buyer and seller, individual powders shall meet the requirements of Specifications C753 and C757. The combined U and Pu ~~contents combined~~mass fractions shall be a minimum of ~~87.7 wt%~~87.7 % on a dry weight basis compensated for the Americium 241 (^{241}Am) content. (Dry weight is defined as the sample weight minus the moisture content). The content shall be that specified by the buyer, up to the limits covered in this specification (that is, 15 wt%).

[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 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.gpo.gov.

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 (U + Pu + Am). The summation of the contribution of each of the impurity elements listed in Table 1 shall not exceed 1500 µg/g (U + Pu + Am). Some other elements such as those listed in Table 2 may also be of concern for the buyer and should be measured and reported if requested. 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. Impurity elements measured and their associated limits may differ from what is listed in this specification as agreed upon between the buyer and seller.

4.1.3 *Stoichiometry*—The oxygen-to-heavy metal ratio (O/(U + Pu + Am)) of sintered fuel pellets shall be within the range from 1.98 to 2.02. The nominal value and allowable tolerance shall be agreed upon between the buyer and seller.

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 be determined as agreed upon between the buyer and the seller. Typical methods include calculation based on C, N_2, and H_2 contents or determination by high temperature vacuum extraction, or combinations thereof.

4.1.6 *Americium-241 Content*—The ^{241}Am content shall be measured by the seller and reported to the buyer. The ^{241}Am content or activity is important in the handling of (U, Pu)O_2 pellets and subsequent helium generation from alpha decay during irradiation and will vary with time. The maximum acceptable ^{241}Am content on a given date along with the date of analysis shall be agreed upon between the buyer and seller. The analysis dates shall be reported; methods of reporting shall be agreed upon between the buyer and seller.

4.2 *Nuclear Requirements:*

4.2.1 *Isotopic Content*—The isotopic content of the U and Pu in the (U, Pu)O_2 pellets shall be determined and the date of the determination recorded. The ^{234}U, ^{235}U, ^{236}U, and ^{238}U content of the uranium shall be reported on a U basis, and the ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, and ^{241}Am content of the Pu shall be reported on a Pu or Pu + Am basis. The equivalent Pu content based on U and Pu isotopic concentrations shall be as agreed upon between the buyer and seller.

4.2.2 *Plutonium Equivalent at a Given Date*—(U, Pu)O_2 fuel shall be considered as defined by the Pu content with adjustment (credit or debit) for the actual isotopic composition of Pu and Am. The dates of isotopic analyses in support of these determinations shall be recorded by the seller and reported to the buyer. The allowable tolerances of the Pu equivalent content (either as Pu + Am or as the individual elements) shall be as agreed upon between the buyer and seller.

TABLE 1 Impurity Elements and Maximum Concentration Limits[A]

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

[A]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.
[B]Any additional potential impurities, added by the fabrication process for example, beyond those listed here shall be evaluated (for example, in terms of equivalent boron) and associated limits established and agreed upon between the buyer and seller.

TABLE 2 Additional Impurity Elements

Element	
Beryllium (Be)	Silver (Ag)
Bismuth (Bi)	Sodium (Na)
Copper (Cu)	Sulfur (S)
Indium (In)	Tantalum (Ta)
Lead (Pb)	Thorium (Th)
Lithium (Li)	Tin (Sn)
Manganese (Mn)	Titanium (Ti)
Molybdenum (Mo)	Tungsten (W)
Neptunium (Np)	Vanadium (V)
Niobium (Nb)	Zinc (Zn)
Phosphorous (P)	Zirconium (Zr)
Potassium (K)	

4.2.3 *Equivalent Boron Content*—For light water reactor use, the total equivalent boron content (EBC) shall not exceed 4.0 µg/g on a heavy metal basis (µg/g of (U + Pu + Am)). The method of performing the calculation shall be as indicated in Practice C1233. For the purposes of EBC calculation, B, Gd, Eu, Dy, Sm, and Cd shall be included.

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 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 UO_2 shall be considered to be 10.96 g/cm^3. The TD for PuO_2 shall be considered to be 11.46 g/cm^3. After confirming the pellets are stoichiometric per 4.1.3, the TD for the (U, Pu)O_2 pellets shall be calculated by linear interpolation between these values based on the Pu content. 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 expressed in microns can be measured as indicated in Test Method E112 or equivalent.

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 analyses of multiple pellets. Each sample for analysis should be one pellet or a fragment thereof. The range of the equivalent Pu content shall not exceed ±5.0 % relative or ±0.2 % ~~absolute,~~ absolute for Pu content less than 5 %, whichever is less restrictive in accordance with fuel management method. Alternative methods and criteria that may be agreed upon between the buyer and the seller are possible for evaluation of Pu homogeneity within a lot.

4.3.4.2 *Plutonium-Rich Cluster*[5] *Size and Distribution Within a Pellet*—Criteria for the distribution of Pu-rich clusters shall be determined in consideration of the following: (*a*) reactivity initiated accidents, (*b*) power peaks (that is, hot spots), and (*c*) fission gas release during ~~irradiation as well as (~~irradiation. ~~d) solubility in nitric acid solutions if applicable.~~ Acceptance criteria typically involve limiting the percentage of clusters above a certain effective diameter that make up the sample cross-section.

For pellets produced by a master mix (that is, dual-blend) process, a maximum acceptable effective diameter[6] of Pu-rich clusters shall be determined. Recommended values are below 550 µm if composed of pure PuO_2. In the case where the cluster is composed

[5] Sometimes referred to as *island* or *zone*.

[6] Depending on the specification, effective diameter of Pu-rich clusters can be calculated based on: (*1*) the square root of the surface area of the cluster, or (*2*) a circle having an equivalent area as the cluster.