Designation: ~~C922 – 14~~ C922 – 21

Standard Specification for Sintered Gadolinium Oxide-Uranium Dioxide Pellets for Light Water Reactors[1]

This standard is issued under the fixed designation C922; 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 specification for gadolinium oxide-uranium dioxide ~~pellets.~~(U,Gd)O_2 pellets for light water reactor use. It recognizes the diversity of manufacturing methods by which ~~gadolinium~~(U,Gd)O_2 ~~oxide-uranium 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.~~ 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 ~~gadolinium~~(U,Gd)O_2 ~~oxide-uranium dioxide pellets for use in light-water reactors.~~ pellets. It applies to ~~gadolinium~~(U,Gd)O_2 ~~oxide-uranium dioxide~~ pellets containing uranium (U) of any ^{235}U concentration and any concentration of gadolinium ~~oxide.~~oxide (Gd_2O_3) for use in nuclear reactors.

1.2 This specification recognizes the presence of reprocessed ~~uranium~~U in the fuel cycle and consequently defines isotopic limits for ~~gadolinium~~(U,Gd)O_2 ~~oxide-uranium dioxide~~ 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 ~~uranium.~~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 (~~1~~*a*) provisions for preventing criticality ~~accidents or~~ accidents, (~~2~~*b*) requirements for health and ~~safety.~~ 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 applicable international, federal, state, and local regulations pertaining to possessing, shipping, processing, or using source or special nuclear material. Examples of U.S. Governmental 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 *Units*—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~~ safety, health, and ~~health~~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]

C753 Specification for Nuclear-Grade, Sinterable Uranium Dioxide Powder
C859 Terminology Relating to Nuclear Materials
C888 Specification for Nuclear-Grade Gadolinium Oxide (Gd_2O_3) Powder
C968 Test Methods for Analysis of Sintered Gadolinium Oxide-Uranium Dioxide Pellets
C996 Specification for Uranium Hexafluoride Enriched to Less Than 5 % ^{235}U
E105 Practice for Probability Sampling of Materials
E112 Test Methods for Determining Average Grain Size

2.2 *ANSI Standard:*[3]

ANSI/ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications

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

Code of Federal ~~Regulations (Latest Edition),~~ Regulations, Title 10, Part ~~50,~~50 Domestic Licensing of Production and Utilization Facilities
Code of Federal Regulations Title 10, Part 70, Domestic Licensing of Special Nuclear Material
Code of Federal ~~Regulations,~~Regulations Title 10, Part 71, Packaging and Transportation of Radioactive Material
Code of Federal ~~Regulations,~~Regulations Title 49, Part 173, Shippers—General Requirements for Shipments and Packagings
~~Regulatory Guide 1.126, An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification, current version~~[5]

2.4 *NRC Guide*[5]

Regulatory Guide 1.126 An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification, current version

3. Terminology

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

3.1 *Definitions:*

3.1.1 For definitions of terms, refer to Terminology C859.

4. Technical Requirements

4.1 *Major Constituents*—~~Gadolinium~~(U,Gd)O_2 ~~oxide-uranium dioxide~~ pellets shall be fabricated using major constituents that meet the requirements of Specifications C753 and C888.

4.2 *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 C968 (latest edition) or demonstrated equivalent as mutually agreed to between the seller and the buyer.

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

[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 National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.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/fdsys/browse/collectionCfr.action?collectionCode=CFR.~~ 20401-0001, http://www.access.gpo.gov.

[5] Available from ~~U.S. Nuclear Regulatory Commission, Washington, DC 20555. Attention: Director, Division of Document Control,~~ U. S. Nuclear Regulatory Commission (NRC), 11555 Rockville Pk., Rockville, MD 20852, http://www.nrc.gov.

TABLE 1 Impurity Elements and Maximum Concentration Limits

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

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
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

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. The thorium measurements required by Table 1 may be waived, provided that the seller can otherwise demonstrate compliance with this specification, for instance, through the seller's quality assurance records.

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

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

4.2.4 *Gd_2O_3 Concentration*—The ~~gadolinium oxide (Gd~~Gd_2O_3~~)~~ concentration shall be as specified in the purchase order.

4.3 *Nuclear Requirements:*

4.3.1 *Isotopic ~~Content:~~ Content*—For $(U,Gd)O_2$ pellets with an isotopic content of ^{235}U ~~between that of natural uranium and~~ below 5 %, the isotopic limits of Specification C996 shall apply, unless otherwise agreed upon between the buyer and the seller. If the ^{236}U content is greater than enriched commercial grade UF_6 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 otherwise demonstrate compliance with Specification C996, for instance, through the seller's quality assurance records. ~~A ^{236}U content greater than the one specified in Specification C996 for Commercial grade UF_6 may be agreed upon between the buyer and the seller.~~

~~4.3.2 For $(U,Gd)O_2$ pellets not having an assay in the range set forth in 4.3.1, the isotopic requirements shall be as agreed upon between the buyer and the seller.~~

4.4 *Physical Characteristics:*

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

4.4.2 *Pellet Density*—The density and tolerance of sintered pellets shall be as specified by the buyer. The theoretical density for UO_2 of natural isotopic content shall be considered to be 10.96 g/cm^3. The theoretical density for the $(U,Gd)O_2$ shall be determined as agreed upon between the buyer and the ~~seller.~~seller (see Note 1). Density measurements shall be made by the method stated in Specification C753 for the geometric method, an immersion density technique, or by a demonstrated equivalent method as mutually agreed upon between the buyer and the seller.

NOTE 1—X-ray diffraction studies may be used to establish the theoretical density of $(U,Gd)O_2$. Instead of x-ray diffraction data, the theoretical density of the $(U,Gd)O_2$ pellets is often taken as the molar interpolation of the values for UO_2 and Gd_2O_3. Both 8.33 and 7.41 g/cm^3 values for the density of Gd_2O_3 have been used for this interpolation.

4.4.3 *Grain Size and Pore Morphology*—~~The performance of (U,Gd)O~~Because there is no~~, fuel pellets may be affected by the~~ unique structure for ensuring satisfactory performance, the pellet grain size and pore ~~morphology. These characteristics~~ 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.

4.4.4 *Pellet Homogeneity*—The homogeneity of Gd_2O_3 in UO_2 shall be determined for the sintered pellets by a procedure and to a standard and specification mutually agreed upon between the buyer and the seller. The characteristics to be measured in order to verify this homogeneity (for instance, the fractions of Gd_2O_3, UO_2, and UO_2/Gd_2O_3 solid solution regions, or the maximum particle size of Gd_2O_3 and UO_2 particles or any other characteristic representative of the homogeneity of the pellets) shall be defined by agreement between the buyer and the seller, and their values shall be as specified.

4.4.5 *Pellet Integrity*—Pellets shall be inspected and sorted to criteria ~~which~~that maintain adequate fuel performance and ensure ~~that excessive breakage will not occur during fuel-rod loading. Acceptable test methods include~~ general pellet integrity during subsequent handling. Acceptable inspection methods include lateral surface inspection using automated equipment, a visual (1×) comparison with pellet standards, or other methods, ~~for example, loadability tests, approved by both~~ as mutually a greed u p on 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.

~~4.4.5.1 *Surface Cracks*—The suggested limits for surface cracks are defined as follows:~~
~~*(1) Axial Cracks, including those leading to the Pellet Ends*—½ the pellet length.~~
~~*(2) Circumferential Cracks*—⅓ of the pellet circumference.~~

~~4.4.5.2 *Chips*—The limits for chips (missing material) are as follows:~~
~~*(1) Cylindrical Surface Chips*~~
~~(a)*Cylindrical Surface Area*—the total area of all chips shall be less than 5% of the pellet cylindrical surface area.~~
~~(b)*Maximum Linear Dimension*—the maximum linear dimension shall be established to maintain adequate fuel performance in the intended application and shall be agreed upon between the buyer and the seller.~~
~~*(2) Pellet Ends*—⅓ of the pellet end surface (may be inspected as ⅓ of missing circumference at the pellet end).~~

4.5 *Cleanliness and Workmanship*—The surface of finished pellets shall be visually free of ~~loose chips,~~ macroscopic inclusions, and foreign material such as oil and grinding media.

4.6 *Identification*—Pellets may be identified as to enrichment and ~~gadolinia~~Gd_2O_3 concentration by either marking or coding.

4.7 *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 estimation of the stability shall consist of either (*a*) conformance to the thermal stability test as specified in US NRC Regulatory Guide ~~1.126~~1.126, or (*b*) ~~by adequate correlation of manufacturing process or microstructure to in-reactor behavior, or both.~~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 below a certain threshold to be accepted, for example less than 2 % of the TD (theoretical density). Pellet density determination shall be performed as indicated in 4.4.2.