



Designation: C922 – 21

Standard Specification for Sintered Gadolinium Oxide-Uranium Dioxide Pellets for Light Water Reactors¹

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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

INTRODUCTION

This specification is intended to provide the nuclear industry with a general specification for gadolinium oxide-uranium dioxide (U,Gd) O_2 pellets for light water reactor use. It recognizes the diversity of manufacturing methods by which (U,Gd) 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. 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 (U,Gd) O_2 pellets. It applies to (U,Gd) O_2 pellets containing uranium (U) of any ^{235}U concentration and any concentration of gadolinium oxide (Gd_2O_3) 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 (U,Gd) O_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 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 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 *Units*—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 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 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

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.

- 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, Title 10, Part 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 Title 10, Part 71, Packaging and Transportation of Radioactive Material
 Code of Federal Regulations Title 49, Part 173, Shippers—General Requirements for Shipments and Packagings
 2.4 NRC Guide⁵
 Regulatory Guide 1.126 An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification, current version

3. Terminology

3.1 Definitions:

3.1.1 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
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 *Major Constituents*—(U,Gd)O₂ 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 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. 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 *Gd₂O₃ Concentration*—The Gd₂O₃ concentration shall be as specified in the purchase order.

4.3 Nuclear Requirements:

4.3.1 *Isotopic Content*—For (U,Gd)O₂ 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 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 otherwise demonstrate compliance with Specification C996, for instance, through the seller’s quality assurance records.

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 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 UO₂ of natural isotopic content shall be considered to be 10.96 g/cm³. The theoretical density for the (U,Gd)O₂ shall be determined as agreed upon between the buyer and the 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)O₂. Instead of x-ray diffraction data, the theoretical density of the (U,Gd)O₂ pellets is often taken as the molar interpolation of the values for UO₂ and Gd₂O₃. Both 8.33 and 7.41 g/cm³ values for the density of Gd₂O₃ have been used for this interpolation.

4.4.3 *Grain Size and Pore Morphology*—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.

4.4.4 *Pellet Homogeneity*—The homogeneity of Gd₂O₃ in UO₂ shall be determined for the sintered pellets by a procedure and to a standard and specification mutually agreed upon

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, Washington, DC 20401-0001, <http://www.access.gpo.gov>.

⁵ Available from U. S. Nuclear Regulatory Commission (NRC), 11555 Rockville Pk., Rockville, MD 20852, <http://www.nrc.gov>.

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 that maintain adequate fuel performance and ensure 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, 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.

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

4.6 *Identification*—Pellets may be identified as to enrichment and 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, 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 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.

5. Lot Requirements

5.1 A pellet lot is defined as a group of pellets made from a single Gd_2O_3 - UO_2 powder lot 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 (U,Gd) O_2 pellets may be hygroscopic and retain water after exposure to a moist atmosphere. Sample and handle the sample under conditions that 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 they become necessary, and, when required, acceptance testing by the buyer.

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

6.5 The referee sample shall be identified clearly and retained by the seller until the lot has been accepted formally by the buyer.

7. Testing and Certification

7.1 The seller shall test the sample described in Section 6 to ensure conformance of the pellet lot 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 all 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 lot basis and shall be contingent upon the material properties meeting the requirements of Section 4 or 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 (U,Gd) O_2 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 Gd_2O_3 concentration, weight %,
- 8.2.6 Distinctive cautionary marking for presence of a neutron absorber,
- 8.2.7 Gross, tare, and net oxide weights,
- 8.2.8 U weight,
- 8.2.9 Purchase order number, and
- 8.2.10 Container () of () (total number of containers).