Designation: C922 – 14

Standard Specification for Sintered Gadolinium Oxide-Uranium Dioxide Pellets[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. It recognizes the diversity of manufacturing methods by which gadolinium 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. 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 oxide-uranium dioxide pellets for use in light-water reactors. It applies to gadolinium oxide-uranium dioxide pellets containing uranium of any ^{235}U concentration and any concentration of gadolinium oxide.

1.2 This specification recognizes the presence of reprocessed uranium in the fuel cycle and consequently defines isotopic limits for gadolinium 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. 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*) 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 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 71, and Title 49, Part 173.

1.4 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 and health practices and determine the applicability of regulatory limitations prior to use.*

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

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), 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

[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.

Current edition approved Jan. 1, 2014. Published February 2014. Originally approved in 1983. Last previous edition approved in 2008 as C922 – 08. DOI: 10.1520/C0922-14.

[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.

Code of Federal 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]

3. Terminology

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

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

4. Technical Requirements

4.1 *Major Constituents*—Gadolinium 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 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 *Gd_2O_3 Concentration*—The gadolinium oxide (Gd_2O_3) concentration shall be as specified in the purchase order.

4.3 *Nuclear Requirements:*

4.3.1 *Isotopic Content:* For (U,Gd)O_2 pellets with an isotopic content of ^{235}U between that of natural uranium and 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.[6]

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 shall be as specified by the buyer. These shall include diameter, length, perpendicularity, and, as required, other geometric parameters including surface finish.

4.4.2 *Pellet Density*—The density 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.[7] 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.

4.4.3 *Grain Size and Pore Morphology*—The performance of (U,Gd)O_2 fuel pellets may be affected by the grain size and pore morphology. These characteristics shall be mutually agreed upon between the buyer and the seller.

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 to criteria which maintain adequate fuel performance and 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.

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

[5] Available from U.S. Nuclear Regulatory Commission, Washington, DC 20555. Attention: Director, Division of Document Control, http://www.nrc.gov.

[6] The intent of the C996 isotopic limits is to indicate possible presence of reprocessed UF_6. Acceptance of (U,Gd)O_2 pellets with ^{236}U content above that specified for Enriched Commercial Grade UF_6, shall be based on fuel performance evaluation.

[7] X-ray diffraction studies may be used to establish the theoretical density of (U,Gd)O_2. In lieu 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 g/cm^3 and 7.41 g/cm^3 values for the density of Gd_2O_3 have been used for this interpolation.

(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 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*) by adequate correlation of manufacturing process or microstructure to in-reactor behavior, or both.

5. Lot Requirements

5.1 A pellet lot is defined as a group of pellets made from a single gadolinium oxide-uranium dioxide 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 Exposure of gadolinium oxide-uranium dioxide pellets to moist or oxidizing atmospheres may cause detectable errors. Sample and handle the sample under conditions which 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 by the seller, referee tests 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. 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 Gadolinium oxide-uranium dioxide 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 Nominal uranium enrichment,

8.2.5 Nominal gadolinium oxide (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 Uranium weight,

8.2.9 Purchase order number, and

8.2.10 Container ( ) of ( ).

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 ANSI/ASME NQA-1 are referenced as guides.

10. Keywords

10.1 burnable poison; gadolinia; nuclear fuel; nuclear fuel pellets; urania ; uranium dioxide

APPENDIX

(Nonmandatory Information)

X1. PELLET LOADABILITY TEST

X1.1 Randomly selected samples (the number of samples to be established by statistical considerations) shall be subjected to an axial load representative of fuel rod loading conditions at the fabrication plant. Each test sample shall consist of ten finished pellets. Samples shall be subjected to an axial load that is 125 % of the maximum load applied during pellet loading without producing a chip with a maximum linear dimension in excess of that agreed upon between the buyer and seller.