



Standard Specification for Sintered Gadolinium Oxide-Uranium Dioxide Pellets¹

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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 ²³⁵U 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 UO₂. Such commercial grade UO₂ is defined so that, regarding fuel design and manufacture, the product is essentially equivalent to that made from unprocessed uranium. UO₂ 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:

C 696 Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Uranium Dioxide Powders and Pellets²

C 753 Specification for Nuclear-Grade, Sinterable Uranium Dioxide Powder²

C 859 Terminology Relating to Nuclear Materials²

C 888 Specification for Nuclear-Grade Gadolinium Oxide (Gd₂O₃) Powder²

C 968 Test Methods for Analysis of Sintered Gadolinium Oxide-Uranium Dioxide Pellets²

C 996 Specification for Uranium Hexafluoride Enriched to Less than 5 % ²³⁵U²

C 1233 Practice for Determining the Equivalent Boron Content of Nuclear Materials²

E 105 Practice for Probability Sampling of Materials³

2.2 ANSI Standard:

NQA-1 Quality Assurance Program Requirements for Nuclear Facilities⁴

2.3 U.S. Government Documents:

Code of Federal Regulations (Latest Edition), Title 10, Part 50, Energy (10 CFR 50) Domestic Licensing of Production and Utilization Facilities⁵

Code of Federal Regulations, Title 10, Part 71, Packaging and Transportation of Radioactive Material⁵

Code of Federal Regulations, Title 49, Part 173, General Requirements for Shipments and Packaging⁵

² Annual Book of ASTM Standards, Vol 12.01.

³ Annual Book of ASTM Standards, Vol 14.02.

⁴ Available from the American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

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

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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Regulatory Guide NUREG 1.126, An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification, Rev. 1 March 1978⁶

3. Terminology

3.1 *Definitions*—For definitions of terms, refer to Terminology C 859.

4. Technical Requirements

4.1 *Major Constituents*—Gadolinium oxide-uranium dioxide pellets shall be fabricated using major constituents that meet the requirements of Specifications C 753 and C 888.

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 C 968 (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

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

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 *Gd₂O₃ Concentration*—The gadolinium oxide (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 between that of natural uranium and 5 %, the isotopic limits of Specification C 996 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 C 996 shall apply. The specific isotopic measurements required by Specification C 996 may be waived, provided that the seller can otherwise demonstrate compliance with Specification C 996, for instance, through the seller’s quality assurance records.²³⁶U content greater than one specified in Specification C 996 for Commercial grade UF₆ may be agreed between the buyer and the seller since it is not a safety concern.⁷

4.3.2 For (U,Gd)O₂ 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 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.⁸ Density measurements shall be made by the method stated in Specification C 753 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 behavior of gadolinium oxide-uranium dioxide 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 Gd₂O₃ in UO₂ 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 Gd₂O₃, UO₂, and UO₂/Gd₂O₃ solid solution regions, or the maximum particle size of Gd₂O₃ and UO₂ particles, or some combination thereof, 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:

(1) *Axial Cracks, including those leading to the Pellet*

⁷ The intent of the C 996 isotopic limits is to indicate possible presence of reprocessed UF₆. Acceptance of (U,Gd)O₂ pellets with ²³⁶U content above that specified for Enriched Commercial Grade UF₆ shall be based on fuel performance evaluation.

⁸ X-ray diffraction studies may be used to establish the theoretical density of (U,Gd)O₂. In lieu 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 g/cc and 7.41 g/cc values for the density of Gd₂O₃ have been used for this interpolation.

⁶ Available from U.S. Nuclear Regulatory Commission, Washington, DC 20555. Attention: Director, Division of Document Control.

Ends— $\frac{1}{2}$ the pellet length.

(2) *Circumferential Cracks*— $\frac{1}{3}$ 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*—30% of the pellet length.

(2) *Pellet Ends*— $\frac{1}{3}$ of the pellet end surface (may be inspected as $\frac{1}{3}$ 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 estimate of the stability shall consist of either (a) conformance to the thermal stability test as specified in US NRC 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 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, weigh, and handle the sample under conditions which assure that the sample is representative of the lot. Sampling plans to meet acceptance criteria shall be mutually agreed upon between the buyer and the seller. Practice E 105 is referenced as a guide.

6.2 The buyer or his representative 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 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 When requested by the buyer, the seller shall make available records of all data obtained from tests 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 Section 4 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, or both, 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 following information:

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 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 Subject randomly selected samples (the number of samples to be established by statistical considerations) to an axial load test 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 10% greater than the maximum load applied during pellet loading. The finished pellets shall withstand the compressive load of 19-MPa (2755-psi) or more without producing chips in excess of 0.40 mm. If chips in excess of 0.40 mm are produced at the applied load, the pellet lot shall be subject to rejection.

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