INTERNATIONAL

Designation: ~~C781 – 08 (Reapproved 2014)~~ C781 – 18

An American National Standard

Standard Practice for Testing Graphite ~~and Boronated Graphite~~ Materials for ~~High-Temperature~~ Gas-Cooled Nuclear Reactor Components[1]

This standard is issued under the fixed designation C781; 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.

1. ~~Scope~~ Scope*

1.1 This practice covers the application and limitations of test methods for measuring the properties of graphite ~~and boronated graphite~~ materials. These properties may be used for the design and evaluation of ~~high-temperature~~ gas-cooled reactor components.

1.2 The test methods referenced herein are applicable to materials used for replaceable and permanent components as defined in Section 7 and ~~Section 9, and~~ includes fuel elements; removable reflector elements and blocks; permanent side reflector elements and blocks; core support pedestals and elements; control rod, reserve shutdown, and burnable poison compacts; and neutron shield material. Specific aspects with respect to testing of irradiated materials are addressed.

1.3 This practice includes test methods that have been selected from ~~existing~~ ASTM ~~standards, ASTM standards that have been modified, and new ASTM standards~~ standards and guides that are specific to the testing of materials listed in 1.2. Comments on individual test methods for graphite ~~and boronated graphite~~ components are given in ~~Sections~~Section 8 ~~and~~ . ~~10, respectively.~~ The test methods are summarized in ~~Tables 1 and 2~~Table 1.

1.4 The values stated in SI units are to be regarded as standard. The values given in parentheses ~~are for information only.~~after SI units are provided for information only and are not considered standard.

1.5 *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]

C559 Test Method for Bulk Density by Physical Measurements of Manufactured Carbon and Graphite Articles
C561 Test Method for Ash in a Graphite Sample
C577 Test Method for Permeability of Refractories
C611 Test Method for Electrical Resistivity of Manufactured Carbon and Graphite Articles at Room Temperature
C625 Practice for Reporting Irradiation Results on Graphite
C651 Test Method for Flexural Strength of Manufactured Carbon and Graphite Articles Using Four-Point Loading at Room Temperature
C695 Test Method for Compressive Strength of Carbon and Graphite
~~C709 Terminology Relating to Manufactured Carbon and Graphite (Withdrawn 2017)[3]~~
C747 Test Method for Moduli of Elasticity and Fundamental Frequencies of Carbon and Graphite Materials by Sonic Resonance
C749 Test Method for Tensile Stress-Strain of Carbon and Graphite
C769 Test Method for Sonic Velocity in Manufactured Carbon and Graphite Materials for Use in Obtaining an Approximate Value of Young's Modulus

[1] This practice is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.F0 on Manufactured Carbon and Graphite Products.

Current edition approved ~~May 1, 2014~~Oct. 1, 2018. Published ~~July 2014~~November 2018. Originally approved in 1977. Last previous edition approved in ~~2008~~2014 as ~~C781 – 08.~~C781 – 08 (2014). DOI: ~~10.1520/C0781-08R14.~~10.1520/C0781-18.

[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] The last approved version of this historical standard is referenced on www.astm.org.

***A Summary of Changes section appears at the end of this standard**

TABLE 1 Summary of Test Methods for Graphite Components

NOTE 1—~~Designations under preparation will be added when approved.~~Graphite Components include: Fuel, Removable Reflector and Core Support Elements; Pebble Bed Reflector, Key and Sleeves and Dowel Pins, Permanent Side Reflector Elements and Dowel Pins, Core Support Pedestals and Dowels.

	~~Fuel, Removable Reflector, and Core Support Elements; Pebble Bed Reflector, Key and Sleeves; and Dowel Pins~~Test Method
Fabrication	
~~As Manufactured Bulk Density~~	~~C838~~
As Manufactured Bulk Density	C838
Mechanical Properties	
~~Compressive Strength~~	~~C695~~
Compressive Strength	C695
~~Tensile Properties~~	~~C749^A^~~
Tensile Properties	C749
~~Poisson's Ratio~~	~~E132^B^~~
Poisson's Ratio	E132, C747
~~Flexural Strength~~	~~C651^A^~~
Flexural Strength	C651, D7972
~~Fracture Toughness~~	~~B~~
Fracture Toughness	D7779
~~Modulus of Elasticity~~	~~C747~~
Modulus of Elasticity	C747, C769
Physical Properties	
~~Bulk Density–Machined Specimens~~	~~C559~~
Bulk Density–Machined Specimens	C559
~~Surface Area (BET)~~	~~C1274~~
Surface Area (BET)	C1274
~~Permeability~~	~~C577^A,B^~~
Permeability	C577^A,B^
~~Apparent Porosity~~	~~C1039~~
Apparent Porosity	C1039
~~Spectroscopic Analysis~~	~~B~~
Spectroscopic Analysis	B
~~Electrical Resistivity~~	~~C611~~
Electrical Resistivity	C611
Thermal Properties	
Linear Thermal Expansion	E228^A^
~~Thermal Conductivity~~	~~E1461^A^~~
Thermal Conductivity	E1461^A^
Chemical Properties	
~~Oxidative Mass Loss~~	~~C1179^B^~~
Oxidative Mass Loss	C1179, D7542
~~Sulfur Concentration~~	~~C816~~
Sulfur Concentration	C816
~~Ash Content~~	~~C561^A^~~
Ash Content	C561^A^
~~Equivalent Boron Content~~	~~C1233^A^~~
Equivalent Boron Content^C^	C1233^A^

^A^ Modification of this test method is required. See Section 8 for details.
^B^ New test methods are required. See Section 8 for details.
^C^ There is no identified need for determining this ~~property.~~property for core support pedestals and dowels.

~~**TABLE 2 Summary of Test Methods for Boronated Graphite Components**~~

~~NOTE 1—Designations under preparation will be added when approved.~~

	~~Compacts~~			~~Neutron Shield Material~~
	~~Control Rod~~	~~Burnable Poison~~	~~Reserve Shutdown~~	
~~Bulk Density~~	~~C838~~	~~C838~~	~~C838~~	~~D4292~~
~~Linear Thermal Expansion~~	~~A~~	~~E228^A^~~	~~E228^A^~~	~~B~~
~~Particle Size~~	~~C~~	~~C~~	~~C~~	~~D2862~~
~~Mechanical Strength:~~				
~~Compressive Strength~~	~~C695^A^~~	~~C695^A^~~	~~C695^A^~~	~~B~~
~~Impact Performance~~	~~B~~	~~B~~	~~B~~	~~C~~
~~Chemical Properties:~~				
~~Sulfur Concentration~~	~~C~~	~~C~~	~~C~~	~~C~~
~~Hafnium Concentration~~	~~C~~	~~C~~	~~C~~	~~C~~
~~Relative Oxidation Rate~~	~~C~~	~~C~~	~~C~~	~~C~~
~~Boron Analysis:~~				
~~Total Boron~~	~~C~~	~~C~~	~~C~~	~~C~~
~~Boron as Oxide~~	~~C~~	~~C~~	~~C~~	~~C~~
~~B_4C Particle Size~~	~~D2862^D^~~	~~D2862^D^~~	~~D2862^D^~~	~~D2862^D^~~

[A] Modification of this test method is required. See Section 10 for details.
[B] There is no identified need for determining this property.
[C] New test methods are required. See Section 10 for details.
[D] Additional test methods are required. See Section 10 for details.

C816 Test Method for Sulfur Content in Graphite by Combustion-Iodometric Titration Method
C838 Test Method for Bulk Density of As-Manufactured Carbon and Graphite Shapes
C1039 Test Methods for Apparent Porosity, Apparent Specific Gravity, and Bulk Density of Graphite Electrodes
C1179 Test Method for Oxidation Mass Loss of Manufactured Carbon and Graphite Materials in Air
C1233 Practice for Determining Equivalent Boron Contents of Nuclear Materials
C1274 Test Method for Advanced Ceramic Specific Surface Area by Physical Adsorption
D346 Practice for Collection and Preparation of Coke Samples for Laboratory Analysis
D1193 Specification for Reagent Water
D2854 Test Method for Apparent Density of Activated Carbon
D2862 Test Method for Particle Size Distribution of Granular Activated Carbon
D3104 Test Method for Softening Point of Pitches (Mettler Softening Point Method)
D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants
D4292 Test Method for Determination of Vibrated Bulk Density of Calcined Petroleum Coke
D5600 Test Method for Trace Metals in Petroleum Coke by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
D7219 Specification for Isotropic and Near-isotropic Nuclear Graphites
D7542 Test Method for Air Oxidation of Carbon and Graphite in the Kinetic Regime
D7775 Guide for Measurements on Small Graphite Specimens
D7779 Test Method for Determination of Fracture Toughness of Graphite at Ambient Temperature
D7846 Practice for Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters for Advanced Graphites
D7972 Test Method for Flexural Strength of Manufactured Carbon and Graphite Articles Using Three-Point Loading at Room Temperature
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E132 Test Method for Poisson's Ratio at Room Temperature
E228 Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer
E261 Practice for Determining Neutron Fluence, Fluence Rate, and Spectra by Radioactivation Techniques
E639 Test Method for Measuring Total-Radiance Temperature of Heated Surfaces Using a Radiation Pyrometer (Withdrawn 2011)[3]
E1461 Test Method for Thermal Diffusivity by the Flash Method
E1269 Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry
E2716 Test Method for Determining Specific Heat Capacity by Sinusoidal Modulated Temperature Differential Scanning Calorimetry

3. Terminology

3.1 *Definitions*—Terminology C709D4175 shall be considered as applying to the terms used in this practice.

4. Significance and Use

4.1 Property data obtained with the recommended test methods identified herein may be used for research and development, design, manufacturing control, specifications, performance evaluation, and regulatory statutes pertaining to high temperature gas-cooled reactors.nuclear reactors that utilize graphite.

4.2 The referenced test methods are applicable primarily to specimens in the non-irradiated and non-oxidized state. Many are also applicable to specimens in the irradiated or oxidized state, or both, provided the specimens meet allTesting irradiated specimens often requires specimen geometries that do not meet the requirements of the test method. The user is cautioned to consider standard. Specific instructions or recommendations with respect to testing non-conforming geometries can be found in STP 1578[4] and/or Guide D7775the instructions given in the test methods.. When testing irradiated specimens at elevated temperatures, the effects of annealing should be considered (see Note 1).

NOTE 1—Exposure to fast neutron radiation will result in atomic and microstructural changes to graphite. This radiation damage occurs when energetic particles, such as fast neutrons, impinge on the crystal lattice and displace carbon atoms from their equilibrium positions, creating a lattice vacancy and an interstitial carbon atom. The lattice strain that results from displacement damage causes significant structural and property changes in the graphite and is a function of the irradiation temperature and dose. When the temperature of the graphite is brought above the temperature at which it was irradiated,

[4] Tzelepi, N. and Carroll, M., Eds., *Graphite Testing for Nuclear Applications: The Significance of Test Specimen Volume and Geometry and the Statistical Significance of Test Specimen Population*, STP1578-EB, ASTM International, West Conshohocken, PA, 2014, https://doi.org/10.1520/STP1578-EB

enough energy is provided that the structure of the graphite will anneal back to its original condition. Therefore, measurement techniques that bring the specimen temperature above the irradiation temperature can result in property values that change during the measurement process. For this reason, measurements made on irradiated test specimens below the irradiation temperature will produce results that are representative of the irradiation damage. However, measurements made at temperatures above the irradiation temperature could include the effects of annealing.

4.3 Additional test methods are in preparation and will be incorporated. The user is cautioned to employ the latest revision.

5. Sample Selection

5.1 All test specimens should be selected from materials that are representative of those to be used in the intended application.

6. Test Reports

6.1 Test results should be reported in accordance with the reporting requirements included in the applicable test method. Where relevant, information on grade designation, lot number, billet number, orientation, and location (position of sample in the original billet) shall be provided.

6.2 Information on specimen irradiation conditions shall be reported in accordance with Practices C625 and E261 or referenced to source information of equivalent content.

GRAPHITE COMPONENTS

7. Description and Function

7.1 The following are identified as typical components of a graphite moderated gas-cooled reactor based on historical designs. This list is not intended to be inclusive of all possible components, which will depend upon the particular reactor design.

7.2 *Fuel and Removable Reflector Elements:*

7.2.1 ~~A~~ In manufactured carbons and graphites, a fuel element is a removable graphite element that contains channels for the passage of coolant gas, the fuel material (typically in the form of a compact containing coated particle fuel), the alignment dowel pins, and for the insertion of a handling machine pickup head. A fuel element may also contain channels for reactivity control material (control rods), reserve shutdown compacts, and burnable poison compacts, and nuclear instrumentation.

7.2.2 The fuel elements serve multiple functions, including *(1)* vertical and lateral mechanical support for the fuel elements and removable reflector elements above and adjacent to them, and for the fuel, reactivity control materials, and nuclear instrumentation within them, *(2)* moderation of fast neutrons within the core region, *(3)* a thermal reservoir and conductor for nuclear heat generated in the fuel, *(4)* a physical constraint for the flow of coolant gases, and *(5)* a guide for and containment of fuel material, reactivity control materials, and nuclear instrumentation.

7.2.3 A removable reflector element is a removable graphite element that contains channels for the alignment dowel pins and the insertion of a handling machine pickup head. A removable reflector element may also contain channels for the passage of coolant gas, reactivity control materials (control rods), neutron flux control materials (neutron shield materials), and nuclear instrumentation.

7.2.4 The primary function of the removable reflector elements that are located at the boundaries of the active reactor core (fuel elements) is to provide ~~for~~ moderation of fast neutrons escaping from and reflection of thermal neutrons back into the active core region.

7.2.5 Except for support, guide, and containment of fuel material, removable reflector elements may also serve any of the functions listed in ~~7.1.2~~7.2.2.

7.3 *Permanent Side Reflector Element:*

7.3.1 A permanent side reflector element is a graphite block that is designed to remain permanently in the core but may be removed for inspection and replacement, if necessary. A permanent side reflector element contains channels for alignment dowel pins. It may also contain channels for neutron flux control materials (boronated steel pins) and nuclear instrumentation, and recessed areas along its length on its outer periphery to provide channels for the passage of coolant gas between the element and the metallic lateral restraint for the reactor core.

7.3.2 The permanent side reflector elements encircle the active (fuel) elements and passive (removable reflector) elements of the reactor core and serve multiple functions, including *(1)* vertical and lateral mechanical support for the permanent side reflector elements above and beside them, *(2)* lateral mechanical support for the fuel, removable reflector, and core support elements, *(3)* moderation of fast neutrons within the reflector region, *(4)* reflection of thermal neutrons back into the core region, and *(5)* support, guide, and containment of nuclear instrumentation and neutron flux control materials (boronated steel pins) for reducing the neutron flux to metallic structures outside the permanent side reflector boundary.

7.4 *Core Support Pedestals and Elements:*

7.4.1 A core support pedestal is a graphite column that is designed to remain permanently in the core but can be removed for inspection and replacement, if necessary. A core support pedestal has a central reduced cross-section (dog bone shape) that at its upper end contains channels for the passage of coolant gas, alignment dowel pins, and for the insertion of a handling machine pickup head, and at its lower end contains a recessed region for locating it with respect to the metallic structure that supports the graphite core support assembly. A core support element is a graphite element that contains channels for alignment dowel pins and for the insertion of a handling machine pickup head. The core support elements may also contain channels for the passage of coolant gas, neutron flux control materials, and nuclear instrumentation.

7.4.2 The primary function of the core support pedestals is to provide for vertical mechanical support for core support elements and permanent side reflector elements above them. In addition, core support pedestals provide for lateral mechanical support for adjacent core support pedestals and permanent side reflector elements and physical constraint for the flow of coolant gases. The primary function of the core support elements is to provide for vertical mechanical support for core support, fuel, and removable reflector elements above them. In addition, core support elements provide for lateral mechanical support for adjacent core support and permanent side reflector elements and may provide for the physical constraint of coolant gases and for the support, guide, and containment of neutron flux control materials and nuclear instrumentation.

7.5 *Pebble Bed Modular Reactor Reflector Blocks:*

7.5.1 The fuel form of a pebble bed reactor is typically a 60 mm diameter sphere (pebble) containing graphite-carbon matrix and coated particle fuel.

7.5.2 The Pebble Bed reactor core structure consists of a graphite reflector supported and surrounded by a metallic core barrel. The graphite reflector is comprised of a large number of graphite blocks arranged in circular rings of separate columns. The graphite reflector can be subdivided into three subsystems, namely, the bottom, side, and top reflector. The side reflector may be split into an inner replaceable reflector and an outer permanent reflector. The graphite reflector blocks are interlinked within each circular ring by graphite keys set in machined channels in the reflector blocks. Certain Pebble Bed reactors designs have annular fuelled cores, and thus the reactor contains a central graphite column.

7.5.3 The primary function of the reflector blocks that are located at the boundary of the active reactor core (fuelled region) is to provide for moderation of fast neutrons escaping from, and reflection of thermal neutrons back into, the active core region.

7.5.4 Replaceable reflector blocks contain vertical channels for the reactivity control rods and reserve shutdown system. These channels contain graphite sleeves to eliminate cross flow of reactor coolant gas.

8. Test Methods

8.1 *Fabrication:*

8.1.1 *Coefficient of Thermal Expansion of Coke*—The method known as the flour-based graphitized rod CTE test is described in Annex A1.

8.1.2 *Bulk Density*—Determine bulk density on as-manufactured or machined specimens in accordance with Test Methods C838 and C559, respectively. Test Method C838 includes shaped articles other than right circular cylinders and rectangular parallelepipeds. Test Method C559 is used when a higher degree of accuracy is required. The procedures of Test Method C559 are modified in Annex A2 to provide for the measurement of bulk density of non-uniform specimens.

8.1.3 *Graphitization Temperature*—The graphitization temperature of a full-size billet is estimated from a laboratory correlation between Specific Electrical Resistivity (SER) (Test Method C611) and heat treatment temperature. The method is described in Annex A3.

8.2 *Mechanical Properties:*

8.2.1 *Compressive Strength*—Determine compressive strength in accordance with Test Method C695.

8.2.2 *Tensile Strength*—~~Determination of tensile properties may also be made~~ Determine tensile strength in accordance with Test ~~Methods~~Method C749 and Guide ~~E132~~D7775. ~~The procedures of Test Method C749 are modified in Annex A4 to provide for the measurement of the tensile stress-strain properties of specimens with glued ends, a convenient method that has been used in the past and verified for the testing of irradiated and non-irradiated (control) graphite specimens. The procedures of Test Method E132 are modified in Annex A5 to provide specimen geometries and measurements specifically adapted for measuring the Poisson's ratio of graphite.~~

8.2.3 *Flexural Strength*—Determine flexural strength in accordance with Test Method C651 or D7972.

8.2.4 *Fracture Toughness*—~~A test method for determining~~ Determine fracture toughness ~~is in preparation.~~in accordance with Test Method D7779.

8.2.5 *Modulus of ~~Elasticity—~~Elasticity and Poisson's Ratio*—Determine modulus of elasticity in accordance with Test Method C747. Poisson's ratio can be determined using Test Method E132. Sonic velocity (Test Method C769) may be used to give an approximate Young's Modulus.

8.3 *Physical Properties:*

8.3.1 *Bulk Density*—See 8.1.2.

8.3.2 *Surface Area*—The determination of the specific surface area (BET) shall be in accordance with Test Method C1274.

8.3.3 *Gaseous Permeability*—Test Method C577 for measuring gaseous permeability must be modified to permit the additional use of helium as the permeating medium and the use of alternative geometries for specimens and specimen holders. ~~A second method is also in preparation to provide for materials with lower permeability than those covered by Test Method C577.~~

8.3.4 *Apparent Porosity*—The determination of the apparent porosity shall be in accordance with Test Method C1039.

8.4 *Thermal Properties:*

8.4.1 *Coefficient of Thermal Expansion of Graphite*—Determine the linear coefficient of thermal expansion (CTE) of graphite of all grain sizes in (general) accordance with Test Method E228. Test specimens of cylindrical or prismatic geometry shall be used. The diameter or transverse-edge length, respectively, shall be no less than five times the maximum grain size of the graphite, and in no case smaller than 4 mm. The length of the test specimen shall be at least 25 mm, preferably 50 mm to 125 mm. The report shall include the temperature range over which the CTE was measured.

8.4.2 *Thermal Conductivity*—Calculate the thermal conductivity from the thermal diffusivity as determined by Test Method E1461. The required calculation is described in Annex ~~A6~~A4.

8.5 *Chemical Properties:*

8.5.1 *Oxidation*—Determine the oxidative mass loss in air in accordance with Test Method C1179. (A test method for the determination of oxidation rate in air is in preparation.)

8.5.2 *Chemical Impurities:*

8.5.2.1 The chemical impurities shall be measured in accordance with D5600. An ~~alternate~~alternative test method for determining impurity concentrations in nuclear graphite by spectroscopic methods is in preparation.

8.5.2.2 Determine sulfur concentration in accordance with Test Method C816.

8.5.2.3 A method for determining boron levels is described in Annex ~~A7~~A5.

~~8.5.3 *Ash Content*—Determination of ash shall be in accordance with Test Method C561.~~

8.5.3 *Equivalent Boron Content*—Test Method C1233 shall be used to calculate equivalent boron content. The elements specified in D7219 shall be measured for the determination of the equivalent boron content.

~~**BORONATED GRAPHITE COMPONENTS**~~

~~9. Description and Function~~

~~9.1 *Control Rod Compacts:*~~

~~9.1.1 The control rod compacts are dispersions of approximately 40-weight % boron as boron carbide (B_4C) in a graphite matrix. The compacts are in the form of short, thick-walled tubular elements and are enclosed within the annuli of thin-walled metallic containers. These assemblies are connected to form sections of control rods.~~

~~9.1.2 The function of the control rod compacts is to absorb neutrons when inserted within the core, thereby providing a means for controlling the nuclear reactions.~~

~~9.2 *Burnable Poison Compacts:*~~

~~9.2.1 The burnable poison compacts are dispersions of approximately 1-weight % boron as boron carbide (B_4C) in a graphite matrix. The compacts are in the form of solid cylinders and are enclosed within channels in fuel elements.~~

~~9.2.2 The function of the burnable poison is to reduce the magnitude of the long-term reactivity changes that accompany fuel burnup.~~

~~9.3 *Neutron Shield Material:*~~

~~9.3.1 Neutron shield material consists of granules containing dispersions of approximately 25–weight % boron as boron carbide (B_4C) in a graphite matrix. These granules are enclosed within metallic containers located above the core.~~

~~9.3.2 The function of the neutron shield material is to reduce the neutron flux to adjacent metallic components.~~

~~9.4 *Reserve Shutdown Compacts:*~~

~~9.4.1 The reserve shutdown compacts are dispersions of approximately 40–weight % boron as boron carbide (B_4C) in a graphite matrix. These compacts are in the form of spherical elements or short cylindrical elements with rounded ends and are gravity fed from storage hoppers above the core into channels within fuel elements when an emergency shutdown of the reactor is required.~~

~~9.4.2 The function of the reserve shutdown compacts is to absorb neutrons thereby providing a means for rapidly stopping the nuclear reactions.~~

~~10. Test Methods for Boronated Graphite~~

~~10.1 *Particle Size*—Determine particle size of neutron shield material in accordance with Test Method D2862. A new test method may be required for determining particle size in as-manufactured compacts.~~

~~10.2 *Bulk Density*—Determine bulk density on as-manufactured or machined specimens in accordance with Test Method C838. Determine apparent bulk density of neutron shield material in accordance with Test Method D2854.~~

~~10.3 *Linear Thermal Expansion*—Determine linear thermal expansion in general accordance with Test Method E228. Modifications to Test Method E228, which are in preparation and will be presented as an annex, are required to permit specimen geometries consistent with as-manufactured shapes.~~

~~10.4 *Mechanical Properties:*~~

~~10.4.1 Determine compressive strength in general accordance with Test Method C695. An exception is for control rod compacts, for which Test Method C695 is modified in Annex A8 to conform to specimen machining requirements for boron carbide-containing composite materials.~~