INTERNATIONAL

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Standard Practice for Qualification and Acceptance of Boron Based Metallic Neutron Absorbers for Nuclear Criticality Control for Dry Cask Storage Systems and Transportation Packaging[1]

This standard is issued under the fixed designation C1671; 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

1.1 This practice provides procedures for qualification and acceptance of neutron absorber materials used to provide criticality control by absorbing thermal neutrons in systems designed for nuclear fuel storage, transportation, or both.

1.2 This practice is limited to neutron absorber materials consisting of metal alloys, metal matrix composites (MMCs), and cermets, clad or unclad, containing the neutron absorber boron-10 (^{10}B).

1.3 *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.*

1.4 *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]

B557 Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products

B557M Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products (Metric)

C791 Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Boron Carbide

E8/E8M Test Methods for Tension Testing of Metallic Materials

E21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials

E456 Terminology Relating to Quality and Statistics

E1225 Test Method for Thermal Conductivity of Solids Using the Guarded-Comparative-Longitudinal Heat Flow Technique

E1461 Test Method for Thermal Diffusivity by the Flash Method

E2971 Test Method for Determination of Effective Boron-10 Areal Density in Aluminum Neutron Absorbers using Neutron Attenuation Measurements

3. Terminology

3.1 *Definitions:*

3.1.1 *acceptance test, n—for a neutron absorber material*, quality control, tests, and inspections conducted to determine whether a specific production lot meets selected specified material properties, characteristics, or both, so that the lot can be accepted.

3.1.2 *areal density, n—for neutron absorber materials with flat parallel surfaces*, the mass of boron-10 per unit area of a sheet, which is equivalent to the mass of boron-10 per unit volume in the material multiplied by the thickness of the material in which that isotope is contained.

3.1.3 *durability, n*—the ability of neutron absorber materials to withstand service conditions without physical changes that would render them unable to perform their design functions.

3.1.4 *lot, n*—a quantity of a product or material accumulated under conditions that are considered uniform for sampling purposes. **E456**

3.1.5 *moderator, n*—a material used to reduce neutron energy by scattering without appreciable capture.

3.1.6 *neutron absorber, n*—a nuclide that has a large thermal neutron absorption cross section (also known as a neutron poison).

3.1.7 *neutron absorber material, n*—a compound, alloy, composite, or other material that contains a neutron absorber.

[1] This practice is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.03 on Neutron Absorber Materials Specifications.

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[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.

3.1.8 *neutron attenuation test, n—for neutron absorber materials*, a process in which a material is placed in a thermal neutron beam, and the number of neutrons transmitted through the material in a specified period of time is counted. The neutron count can be converted to areal density by performing the same test on a series of appropriate calibration standards and comparing the results.

3.1.9 *neutron cross section, (barn), n*—a measure of the probability that a neutron will interact with a nucleus in the absorbing medium and is a function of the neutron energy.

3.1.10 *open porosity, n*—the volume fraction of all pores, voids, and channels within a solid mass that are interconnected with each other and communicate with the external surface, and thus are measurable by gas or liquid penetration. **C21, C242**

3.1.11 *packaging, n—in transport of radioactive material*, the assembly of components necessary to enclose the radioactive contents completely.[3]

3.1.12 *probability sampling, n*—a sample selection procedure in which the sampling units are selected by a chance process such that, at each step of the selection, a specified probability of selection can be attached to each sampling unit available for selection. **E456**

3.1.13 *qualification, n—for neutron absorber materials*, the process of evaluating, testing, or both, a material produced by a specific manufacturing process to demonstrate uniformity and durability for a specific application.

3.1.14 *systematic sampling, n*—a sample selection procedure in which every k^{th} element is selected from the universe or population, for example, u, $u + k$, $u + 2k$, $u + 3k$, etc., where u is in the interval 1 to k. **E456**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *designer, n*—the organization responsible for the design or the license holder for the dry cask storage system or transport packaging; the designer is usually the purchaser of the neutron absorber material, either directly or indirectly (through a fabrication subcontractor).

4. Significance and Use

4.1 For criticality control of nuclear fuel in dry storage and transportation, the most commonly used neutron absorber materials are borated stainless steel alloys, borated aluminum alloys, and boron carbide aluminum alloy composites. The boron used in these neutron absorber materials may be natural or enriched in the nuclide ^{10}B. The boron is usually incorporated either as an intermetallic phase (for example, AlB_2, TiB_2, CrB_2, etc.) in an aluminum alloy or stainless steel, or as a stable chemical compound particulate such as boron carbide (B_4C), typically in an aluminum MMC or cermet.

4.2 While other neutron absorbers continue to be investigated, ^{10}B has been most widely used in these applications, and it is the only thermal neutron absorber addressed in this standard.

4.3 In service, many neutron absorber materials are inaccessible and not amenable to a surveillance program. These neutron absorber materials are often expected to perform over an extended period.

4.4 Qualification and acceptance procedures demonstrate that the neutron absorber material has the necessary characteristics to perform its design functions during the service lifetime.

4.5 The criticality control function of neutron absorber materials in dry cask storage systems and transportation packagings is only significant in the presence of a moderator, such as during loading of fuel under water, or water ingress resulting from hypothetical accident conditions.

4.6 The expected users of this standard include designers, neutron absorber material suppliers and purchasers, government agencies, consultants and utility owners. Typical use of the practice is to summarize practices which provide input for design specification, material qualification, and production acceptance. Adherence to this standard does not guarantee regulatory approval; a government regulatory authority may require different tests or additional tests, and may impose limits or restrictions on the use of a neutron absorber material.

5. Procedure

5.1 *Determination of Service Conditions and Design Requirements for Neutron Absorber Material*—The designer shall specify the service conditions and design requirements, including environmental conditions, mechanical properties, and areal density or equivalent measure of neutron absorber content. Selection of environmental and service conditions that are important for neutron absorber material performance and qualification should take into consideration known failure modes and industry experience.

5.1.1 Environmental conditions to be considered include but are not limited to water chemistry, water temperature, paired dissimilar materials, hydrostatic pressure, duration of immersion, gamma and fast neutron flux, heat-up rate after draining, and maximum temperature.

5.1.2 For structural applications, specify the mechanical properties required by the structural analysis. For non-structural uses of the neutron absorber material, specify mechanical properties sufficient to assure material durability under the service conditions for which it is designed.

5.1.3 Specify other design properties, for example, thermal conductivity, surface finish, etc., as required for the application.

5.1.4 Product or feed material chemistry shall be specified.

5.2 *Neutron Absorber Material Qualification*—Qualification shall consist of three components: *(1)* verify durability for the intended service as defined in 5.2.5, *(2)* verify that the physical characteristics of components meet their design requirements defined in 5.2.6, and *(3)* verify that the uniformity of the ^{10}B distribution in the neutron absorber material is within acceptable bounds as specified by the designer as described in 5.2.6.

5.2.1 Qualification is needed:

5.2.1.1 When the neutron absorber material has not been previously qualified,

[3] "Regulations for the Safe Transport of Radioactive Material," *Safety Series Standards,* TS-R-1, International Atomic Energy Agency, Vienna, Austria.

5.2.1.2 When a new supplier is producing a qualified neutron absorber material, or

5.2.1.3 When any key process or process control, as defined in 5.2.7, is altered for production of a qualified neutron absorber material.

5.2.2 The key processes and process controls for producing neutron absorber material for qualification should be the same as those to be used for commercial production. Differences shall be justified in accordance with 5.2.7.

5.2.3 If a previously qualified material is manufactured by a new supplier, the designer should do a review of key process and controls and perform qualification testing demonstrating that the neutron absorbing material has the required properties. If the supplier has shown that process changes do not cause changes in the density, open porosity, composition, surface finish, or cladding (if applicable) of the neutron absorber material, the supplier should not be required to re-qualify the material with regard to thermal properties or resistance to degradation by corrosion and elevated temperatures.

5.2.4 If a neutron absorber material can not be qualified completely by reference to prior testing with similar neutron absorber materials for similar design functions and service conditions, complete the qualification by performing testing or portions thereof as described in 5.2.5 and 5.2.6.

5.2.5 *Environmental Qualification Tests*—For these tests, verify by visual and dimensional inspection, mechanical testing, neutron attenuation testing, etc., as appropriate, that the neutron absorber material does not undergo physical changes that would render it unable to perform its design functions.

5.2.5.1 For radiation and thermal testing, expose the neutron absorber material to the service conditions or equivalent accelerated conditions.

5.2.5.2 Corrosion testing shall consist of exposing test specimens of the neutron absorber material to simulate in-service immersion conditions.

5.2.5.3 If the neutron absorber material has open porosity, test it under simulated loading and service conditions using bounding pressure, temperature, time, and vacuum.

5.2.6 *Mechanical, Absorber Uniformity, and Other Qualification Testing:*

5.2.6.1 Perform tensile tests according to Test Methods B557, B557M, E8/E8M, or E21. Perform any other mechanical testing, for example, fracture toughness testing, bend testing, etc., in accordance with the appropriate ASTM test method. For neutron absorber materials where standardized testing is not appropriate, such as for laminates, develop the mechanical test appropriate for the materials.

NOTE 1—Most neutron absorbers are non-structural and are held in place during service by structural components. If the absorber material is intended as a structural member, other tests may be necessary to conform to a structural code (for example, ASME Boiler and Pressure Vessel Codes). It may also be necessary to consider the long term service temperature and the effect of aging on the tensile strength of aluminum or stainless steel alloy-based absorber materials.

5.2.6.2 Assess the uniformity of ^{10}B in the neutron absorber material by measuring either the neutron absorber density (g/cm^3) and thickness, or the areal density (g/cm^2). Two methods to assess uniformity include probability sampling or systematic sampling throughout the test material, provided that the systematic sampling method is conservative. Determine the lower tolerance limit of the measurements as described in Eq 1. Boron-10 areal density for aluminum based absorbers may be determined by neutron attenuation testing in accordance with Test Method E2971. Acceptance of Neutron absorbers shall meet a minimum 95 % confidence and 95 % probability criteria. If uniformity testing for areal density will be by means other than neutron attenuation, the user of the proposed method shall confirm that the proposed method is acceptable to the designer.

Using a goodness of fit test, determine if the set of measurement data is normally distributed. For a normal distribution, calculate the lower tolerance limit, T, for the areal density or neutron absorber density for each lot, that is, a number T such that at least a proportion, P, of the lot is greater than T with confidence γ. Usually, $P \geq 95\ \%$ and $\gamma \geq 95\ \%$. Calculate T as follows:

$$T = x(bar) - K*s \qquad (1)$$

where:

T = the lower tolerance limit, g/cm^2 for areal density or g/cm^3 for neutron absorber density,
K = the one-sided tolerance limit factor for a normal distribution with probability P and confidence γ,[4] dimensionless,
$x(bar)$ = the sample average, g/cm^2 or g/cm^3, and
s = the sample standard deviation, g/cm^2 or g/cm^3.

NOTE 2—If the data set is not normally distributed, then a nonparametric lower tolerance limit may be used. In this case, the method must be documented.

NOTE 3—The user is advised to consider the effect of the statistical uncertainty in neutron counting, which may contribute to the standard deviation of the measurements and thus affect the lower tolerance limit. In neutron attenuation testing, the fractional statistical uncertainty of counting is equal to the square root of the number of counts divided by the number of counts.

5.2.6.3 Verify other properties as required by the design, for example, thermal conductivity (Test Method E1225 or E1461), chemical analysis, surface finish, mechanical properties, etc.

5.2.6.4 Visual and dimensional inspection should be conducted as specified by the design requirements.

5.2.7 *Key Processes and Process Controls*—Identify key processes and process controls so that the product delivered for use will be consistent with the qualification test material in all respects that are important to the design function of the neutron absorber material. Prior to a change in any key process or process control, the supplier shall submit the proposed change and evaluation of its potential effects on the material properties to the designer who shall determine if any retesting is required. Re-testing need only evaluate those characteristics likely to be adversely affected by the change. The following paragraphs provide examples of key processes and process controls.

5.2.7.1 A change in a key process or process control that could adversely affect mechanical properties, for example, increasing the boron content over that qualified by testing,

[4] Natrella, M. G., "Experimental Statistics," *National Bureau of Standards Handbook,* No. 91, National Bureau of Standards, Washington, DC, 1963.