Division of Spent Fuel Storage and Transportation
Interim Staff Guidance-23

Issue: **Application of ASTM Standard Practice C1671-07 when performing technical reviews of spent fuel storage and transportation packaging licensing actions.**

Introduction:

The standard review plans for storage of spent nuclear fuel and transportation of fissile materials do not address, in detail, the technical considerations for crediting the neutron absorber content of metal matrix composites used for preventing nuclear criticality. The Division of Spent Fuel Storage and Transportation (SFST) considers the application of acceptance criteria and methodology described in the recently developed American Standard for Testing and Materials (ASTM) standard practice C1671-07, "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] with some exceptions, additions, and clarifications appropriate for staff use in their review activities. This Interim Staff Guidance (ISG) provides guidance to the staff and is not a regulatory requirement. Alternative approaches are acceptable if technically supportable.

Discussion:

<u>Use of ASTM C1671-07</u>
The staff considers the terminology and statements within ASTM Standard Practice C1671-07 as acceptable guidance with some additions, clarifications and exceptions delineated below, for reviewing spent nuclear fuel storage cask and transportation packages, and therefore appropriate for use by the Spent Fuel Storage and Transportation (SFST) staff.

<u>Clarification regarding use of Section 5.2.1.3 of ASTM C1671-07</u>
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. This clarification *does not* extend to long-term use (e.g., a year or more) of neutron absorbing materials in spent fuel pools, where minor contaminants accrued during fabrication can significantly influence the corrosion behavior of such materials.

<u>Exception to Section 5.2.3 of ASTM C1671-07</u>
The staff does not accept the following language in Section 5.2.3: "Requalification for a qualified neutron absorber material produced by a new supplier may consist of review of key processes and process controls to verify that they have been adequately replicated by the new supplier."

The staff considers a review of key processes and process controls alone insufficient to ensure that qualified neutron absorbers produced by a new supplier will meet the same specifications as those produced by the previous supplier.

Clarification regarding use of Section 5.2.5.1 of ASTM C1671-07

Section 5.2.5.1 of C1671-07 requires that the neutron absorber material be exposed to "service conditions or equivalent accelerated conditions" as part of the qualifying tests. The staff should ensure that the service life adequately represents the term of the license or Certificate of Compliance, e.g., 5 or 20 years, or longer if subsequent renewals will be requested. The staff is cautioned that the effects of accelerated testing may not exactly match the actual effects encountered under operating conditions over the entire service life. Hence, for accelerated tests, the computed test period should represent a period longer than the anticipated service life. The staff should confirm that the service life for the neutron absorbing materials is specified in the Safety Analysis Report and Certificate of Compliance, or the Technical Specifications of the application.

Additional guidance regarding use of Section 5.2.5.3 of ASTM C1671-07

The following additional guidance applies to Section 5.2.5.3: Neutron absorbing materials should undergo testing to simulate submersion and subsequent cask drying conditions, as part of a qualifying test program.

Clad aluminum/boron carbide neutron absorbers with core porosities between one and three-percent have exhibited blistering after simulated cask or package drying events. This blistering was due to flash steaming of water that was trapped in pores. The staff is concerned that blistering could have an impact on retrievability and (during loading in the spent fuel pool) on the effective neutron multiplication factor, k_{eff}.

Clarification regarding use of Section 5.2.6.2 of ASTM C1671-07

If a coupon contiguous to every plate of neutron absorbing material is not examined during acceptance testing, the qualifying (or re-qualifying) neutron attenuation program should be done with a sufficient number of samples to ensure that the neutron absorbing properties of the materials meet the minimum required areal density of the neutron absorber.

Clarification regarding use of Section 5.2.6.2 and 5.3.4.1 of ASTM C1671-07

The following additional guidance applies to Section 5.2.6.2: The "credit" taken for the amount of boron-10 (^{10}B) present in the neutron absorbing material for the calculation of the effective neutron multiplication factor, $k_{eff,}$ must be clearly stated in Chapter 8 of a Part 71 application, and the proposed Technical Specifications in a Part 72 application.

Based on recommendations in NUREG-1567[3] and NUREG-1609[4], NUREG-1617[5] it has been the staff's practice to limit the credit for neutron absorber materials to only 75-percent of the minimum amount of boron-10 (^{10}B) confirmed by acceptance tests. The staff has permitted up to 90-percent credit in certain cases where the absorber materials are shown by neutron attenuation testing of production lots to be effectively homogeneous, and the boron carbide particle size is sufficiently small to preclude neutron streaming.

If 90-percent credit is taken for the efficacy of the neutron absorber, then methods other than neutron attenuation should be used only as verification or partial substitution for attenuation tests. Benchmarking of other methods, against neutron attenuation testing, should be done periodically throughout acceptance testing, under appropriate attenuation conditions and with proper sample sizes. This should be done to confirm the adequacy of the proposed methods, as direct measurements of neutron attenuation are the most reliable method of measuring the expected neutron absorbing behavior of the poison plates.

For neutron absorbing materials for which 75-percent credit is taken, direct neutron attenuation measurements should be required only as part of a qualification program. Once qualified, other methods which have been validated by attenuation measurements, such as wet chemistry analyses, are sufficient to verify the minimum areal density of the neutron absorbing material during acceptance testing.

Exception to Section 5.2.6.2(1) of ASTM C1671-07

The staff does not accept the following language in Section 5.2.6.2(1): “If materials with discrete absorber particles or phases are used for calibration standards, then the size of the particles containing the neutron absorber should be small enough so that neutron streaming and self-shielding is insignificant.”

Only homogenous neutron absorbing materials such as zirconium diboride (ZrB_2) with uniform absorption properties should be considered for neutron attenuation testing standards, as homogenous materials preclude, or at least minimize, any neutron streaming effects which may occur in heterogeneous materials. This exception to ASTM C1671-07 precludes the use of materials such as boron carbide reinforced aluminum matrix composites as calibration standards for neutron absorption.

Additional guidance regarding use of Section 5.2.6.2 of ASTM C1671-07

Section 5.2.6.2 states: “If uniformity testing for areal density will be by means other than neutron attenuation, the user of the proposed method should confirm that the proposed method is acceptable to the designer.”

The applicant should confirm that use of a uniformity testing method other than neutron attenuation is acceptable to the NRC, not just the designer.

Additional guidance regarding use of Section 5.2.6.2(2) of ASTM C1671-07

The following additional guidance applies to Section 5.2.6.2(2): The size of the collimated neutron beam should be specified for attenuation testing, and limited to 2.54-cm diameter, with a tolerance of 10-percent.

A neutron beam 1-cm diameter is often used for attenuation measurements. There have been requests for relief to increase the size of the neutron beam. The staff conducted an independent criticality study using a typical spent nuclear fuel transportation package to determine if neutron attenuation measurements using beam sizes in excess of 1-cm are unable to detect localized regions in the neutron absorbing material deficient in neutron absorber. In the study, it was assumed that the neutron absorber (^{10}B) arranged itself into a “checkerboard” fashion of alternating boron-rich and boron-deficient regions where the boron concentration was 50-percent greater and 50-percent less than the average amount of boron in a homogenous plate of boron and aluminum. The staff considers this hypothetical configuration bounding of any possible “real-life” defects which might occur in actual manufacturing. In the simulations, two models were considered. One model permitted a non-constant density, where boron was removed from boron-deficient regions and directly added to adjacent regions. In the second model, the quantity of aluminum and carbon were adjusted in each of the regions so that the overall mass density of the plate remained uniform. The sizes of the boron-rich and boron deficient regions were then gradually increased, and changes in k_{eff} were observed. This is plotted in Figure 1.

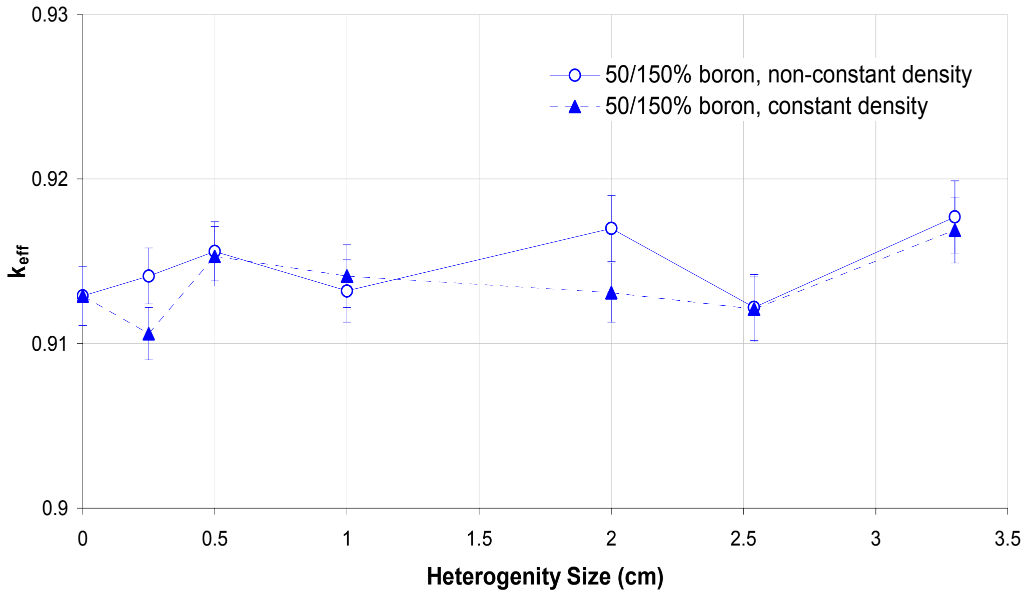

Figure 1: Plot of the Effective Neutron Multiplication Factor, k_{eff}, as a Function of Heterogeneity size

The results of the study showed no significant difference in k_{eff} when the size of the heterogeneities (the length of each boron deficit or rich region) increased from 1 cm to 2.54 cm. It should be noted that this study was conducted on a single transportation package design. The staff considers the heterogeneities introduced in the neutron absorbing materials sufficiently exaggerated that this study suitably reflects the basis for a general determination.

As such, the staff regards collimated neutron beams with nominal diameters between 1 and 2.54 cm, with tolerances of 10-percent, as sufficiently capable of detecting defects within the neutron absorbing material, and should be considered acceptable for the purposes of qualification and acceptance testing of neutron absorbing materials.

<u>Additional guidance regarding use of Section 5.2.6.3 of ASTM C1671-07</u>
The following additional guidance applies to Section 5.2.6.3: A visual inspection procedure which describes the nominal inspection criteria should be specified in the applicant's acceptance tests. Visual inspection should be conducted on all of the neutron absorbing materials intended for service.

Special consideration should be given to visual inspection of plate materials containing more than 30 volume percent boron carbide. Plate materials with high loadings of boron carbide (> 30 volume percent) are subject to edge cracking during rolling operations, and the procedures used for inspection of these edge effects need to be closely reviewed to determine the adequacy of the specified procedures.

As part of the visual inspection of the neutron absorbing material, it is important to ensure that there are no defects that might lead to problems in service; such as delaminations that could appear on clad neutron absorbing materials. The concern is that any gross defect on the plate or plate edge may lead to separations, especially from vibrations during transportation; this could lead to a lack of absorber capability over the missing or misplaced region within a plate material.

Additional guidance regarding use of Section 5.2.6.3 of ASTM C1671-07

The following additional guidance applies to Section 5.2.6.3: The maximum permissible thickness deviation of the neutron absorbing material should be specified, and actions to be taken if the thickness is outside the permissible limits.

During the production of neutron absorbing materials, minor deviations from the specified physical dimensions are expected. These deviations, and in particular, variations of the neutron absorbing material thickness should be discussed in the application, either in the Technical Specifications or package drawings which are referenced in the Certificate of Compliance. The applicant should specify the maximum permissible thickness deviation, and the actions taken if the thickness is outside the permissible limits. This is done to ensure adequate performance of the neutron absorbing materials. In the past, the staff have allowed acceptance testing where a minimum plate thickness is specified, which permitted local depressions, so long as the depressions were no more than 0.5-percent of the area on any given plate, and the thickness at their location is not less than 90-percent of the minimum design thickness.

Clarification regarding use of Sections 5.2.7 and 5.3 of ASTM C1671-07

When implementing Sections 5.2.7 and 5.3, a description of the key process, operations process controls, and the acceptance testing steps of neutron absorbing materials should be included in Chapter 8 of a Part 71 application, and the proposed Technical Specifications in a Part 72 application.

Additional guidance regarding use of Section 5.2.7.1 of ASTM C1671-07

In addition to the guidance provided in Section 5.2.7.1, a change of the matrix alloy, or a change in the material's heat treatment which may cause an undesirable reaction to occur within the matrix itself or between the matrix and a secondary phase should also be considered key processes.

Heat treatments which cause the precipitation of water-soluble aluminum carbide (Al_4C_3) or embrittling $Al_xB_yC_z$ phases could degrade the mechanical properties of the material.

Additional guidance regarding use of Section 5.4 of ASTM C1671-07

The following additional guidance applies to Section 5.4: Title 10 CFR Part 71 and Part 72 applications, neutron absorbing materials intended for criticality control should always have a safety classification of "A", under the guidance of NUREG/CR-6407.[7]

Regulatory Basis:

> 10 CFR 71.33(b)(4): The application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package. The description must include extent of reflection, the amount and identity of nonfissile materials used as neutron absorbers or moderators, and the atomic ratio of moderator to fissile constituents;

10 CFR 71.55(b): Except as provided in paragraph (c) or (g) of this section, a package used for the shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, or liquid contents were to leak out of the containment system so that, under the following conditions, maximum reactivity of the fissile material would be attained: (1) The most reactive credible configuration consistent with the chemical and physical form of the material; (2) Moderation by water to the most reactive credible extent; and (3) Close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may additionally be provided by the surrounding material of the packaging.

10 CFR 71.55(e): A package used for the shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in § 71.73 ("Hypothetical accident conditions"), the package would be subcritical. For this determination, it must be assumed that: (1) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents; (2) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents; and (3) There is full reflection by water on all sides, as close as is consistent with the damaged condition of the package.
10 CFR 71.59(a)(2) A fissile material package must be controlled by either the shipper or the carrier during transport to assure that an array of such packages remains subcritical. To enable this control, the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close full reflection on all sides of the stack by water: two times "N" damaged packages, if each package were subjected to the tests specified in § 71.73 ("Hypothetical accident conditions") would be subcritical with optimum interspersed hydrogenous moderation

10 CFR 71.64(a)(1)(iii): A package for the shipment of plutonium by air subject to § 71.88(a)(4), in addition to satisfying the requirements of §§ 71.41 through 71.63, as applicable, must be designed, constructed, and prepared for shipment so that under the tests specified in § 71.74 ("Accident conditions for air transport of plutonium") -- A single package and an array of packages are demonstrated to be subcritical in accordance with this part, except that the damaged condition of the package must be considered to be that which results from the plutonium accident tests in § 71.74, rather than the hypothetical accident tests in § 71.73.

10 CFR 72.124(b): Methods of criticality control. When practicable, the design of an ISFSI or MRS must be based on favorable geometry, permanently fixed neutron absorbing materials (poisons), or both. Where solid neutron absorbing materials are used, the design must provide for positive means of verifying their continued efficacy. For dry spent fuel storage systems, the continued efficacy may be confirmed by a demonstration or analysis before use, showing that significant degradation of the neutron absorbing materials cannot occur over the life of the facility.

10 CFR 72.154(a): The licensee, applicant for a license, certificate holder, and applicant for a Certificate of Compliance shall establish measures to ensure that purchased material, equipment, and services, whether purchased directly or

through contractors and subcontractors, conform to the procurement documents. These measures must include provisions, as appropriate, for source evaluation and selection, objective evidence of quality furnished by the contractor or subcontractor, inspection at the contractor or subcontractor source, and examination of products upon delivery.

10 CFR 72.236(c): (Certificate of Compliance holder only) The spent fuel storage cask must be designed and fabricated so that the spent fuel is maintained in a subcritical condition under credible conditions.

Applicability:

This guidance applies to reviews of dry cask storage and transport package designed for fissile material conducted in accordance with NUREG-1536[2], "Standard Review Plan for Dry Cask Storage Systems" (January 1997); NUREG-1567[3], "Standard Review Plan for Spent Fuel Dry Storage Facilities" (March 2000); NUREG-1609[4], "Standard Review Plan for Transportation Packages for Radioactive Material" (March 1999); NUREG-1617[5], "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel" (March 2000); and Interim Staff Guidance 15 (ISG-15)[6], "Materials Evaluation" (January 2001).

Technical Review Guidance:

- Clarification on use of Section 5.2.1.3:
  This clarification describes certain physical properties of the neutron absorbing material which, when shown not to change, would not require requalification with regards to corrosion or thermal degradation behavior.

- Exception to Section 5.2.3:
  New suppliers should re-qualify the neutron absorbing material.

- Clarification on use of Section 5.2.5.1:
  The staff should ensure that accelerated testing can justify the expected material performance, potentially over a service life that is beyond the licensing time period.

- Additional guidance on use of Section 5.2.5.3:
  Testing should be added to simulate vacuum drying after submersion.

- Clarification on use of Section 5.2.6.2:
  Acceptance testing sampling is dependent on the statistical validity of qualification testing.

- Clarification on use of Section 5.2.6.2 and 5.3.4.1:
  Methods other than neutron attenuation may be appropriate for acceptance testing of the neutron absorbing material, depending on the amount of "credit" taken for the neutron absorber.

- Exception to Section 5.2.6.2(1):
  Heterogeneous materials are not permitted to be used as neutron attenuation calibration standards.

- Additional guidance on use of Section 5.2.6.2:
  The applicant should confirm that its use of any alternative method for measuring the areal density of ^{10}B is acceptable to the regulatory authority.

- Additional guidance on use of Section 5.2.6.2(2):
  The neutron beam diameter used for attenuation measurements is limited to 1-inch with 10-percent tolerance.

- Additional guidance on use of Section 5.2.6.3:
  A visual inspection procedure for 100-percent of the plates of neutron absorbing material should be specified in the application.

- Additional guidance on use of Section 5.2.6.3:
  Maximum possible thickness variations in the neutron absorbing material should be discussed in the application.

- Clarification of use of Sections 5.2.7 and 5.3:
  Key processes and testing criteria should be placed in Chapter 8 of the Part 71 application or in the Technical Specifications of a Part 72 application.

- Additional guidance on use of Section 5.2.7.1:
  Changes to processing which may adversely affect the microstructure of the matrix may require re-qualification of the neutron absorbing material.

- Additional guidance on use of Section 5.4:
  For Part 71 and Part 72 applications, neutron absorbing materials should be given a safety classification of "A", under the guidance of NUREG/CR-6407.[7]

Recommendations:

The staff recommends that the ASTM Standard Designation C1671-07, along with the qualifying statements found in this document, be considered for use in the evaluation of licensing actions which rely upon boron-based metallic neutron absorber materials for nuclear criticality control in dry cask storage systems and transportation packaging.

References:

[1] ASTM C 1671-07, "Standard Practice for Qualification and Acceptance of Boron Based Metallic Neutron Absorber Materials for Nuclear Criticality Control for Dry Cask Storage Systems and Transportation Packaging," ASTM International, August 2007.

[2] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," Spent Fuel Project Office, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, D.C. January 1997.

[3] NUREG-1567, “Standard Review Plan for Spent Fuel Dry Storage Facilities,” Spent Fuel Project Office, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, D.C. March 2000.

[4] NUREG-1609, “Standard Review Plan for Transportation Packages for Radioactive Material” Spent Fuel Project Office, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, D.C. March 1999.

[5] NUREG-1617, “Standard Review Plan for Transportation Packages for Spent Nuclear Fuel,” Spent Fuel Project Office, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, D.C. March 2000.

[6] Interim Staff Guidance 15 (ISG-15), “Materials Evaluation,” Spent Fuel Project Office, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, D.C. January 2000.

[7] NUREG/CR-6407, “Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety,” Idaho National Engineering Laboratory, ID. February 1996.

Approved: ________________/Draft/________________ **June 23 , 2009**
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