TRANSNUCLEAR
AN AREVA COMPANY

January 18, 2008
E-26016

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
One White Flint North
11555 Rockville Pike
Rockville, MD 20852

Subject: Revision 2 to Transnuclear, Inc. (TN) Application for Amendment 10 to the Standardized NUHOMS® System (Docket No. 72-1004; TAC NO. L24052)

Reference: Letter from Robert Grubb (TN) to NRC Document Control Desk, "Revision 1 to Transnuclear, Inc. (TN) Application for Amendment 10 to the Standardized NUHOMS® System (Docket No. 72-1004; TAC NO. L24052)," November 7, 2007 (E-25506)

Gentlemen:

The letter referenced above provided responses to a request for additional information (RAI) for Amendment 10 to CoC 1004 for the Standardized NUHOMS® System, and included a commitment to provide proposed Technical Specifications changes, including the revised UFSAR pages, on boron neutron absorber material for the 61BT, 32PT, and 24PTH dry shielded canister (DSC) designs not involved with Amendment 10, by January 28, 2008. The purpose of this submittal is to provide that supplemental information.

Enclosure 1 provides a listing of replacement pages for the CoC 1004 Amendment 10 Technical Specifications and the associated UFSAR, and Enclosure 2 provides those Amendment 10 replacement pages. As was done in the referenced Revision 1 submittal, in the Technical Specifications the changes are shown as bold font to distinguish them from the Amendment 10 Revision 0 changes and both Revision 0 and Revision 1 changes continue to be indicated by italicized text and revision bars. For the UFSAR, replacement pages are annotated as Revision 2, with changes indicated by revision bars.

Please note that certain UFSAR Appendix T pages (related to the 61BTH DSC) and Appendix U pages (related to the 32PTH1 DSC) are also included in Enclosures 1 and 2, showing changes made to achieve consistency in terminology and nomenclature between all of these sections related to boron neutron absorber material.

Should the NRC staff require additional information to support review of this application, please do not hesitate to contact Mr. Don Shaw at 410-910-6878 or me at 410-910-6930.

Sincerely,

Tara Neider for

Robert Grubb
Senior Vice President - Engineering

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cc: Jennifer Davis (NRC SFST) (11 paper copies of this cover letter and Enclosures 1 and 2, provided in a separate mailing)

Enclosures:

1. List of Replacement Pages for the CoC 1004 Amendment 10, Revision 2 Proposed Technical Specifications and UFSAR
2. Replacement Pages for the CoC 1004 Amendment 10, Revision 2 Proposed Technical Specifications and UFSAR

**Enclosure 1 to TN E-26016**

**List of Replacement Pages for the CoC 1004 Amendment 10, Revision 2 Proposed Technical Specifications and UFSAR**

Technical Specifications Page 5
Technical Specifications Page A-8
Technical Specifications Page A-9
Technical Specifications Page A-10
Technical Specifications Page A-22
Technical Specifications Page A-30

UFSAR Pages K.9-2 through K.9-15

UFSAR Page M.9-2 through M.9-12

UFSAR Page P.9-2 through P.9-13

UFSAR Page T.9-3
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UFSAR Page T.9-9

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UFSAR Page U.9-14

**Enclosure 2 to TN E-26016**

**Replacement Pages for the CoC 1004 Amendment 10, Revision 2 Proposed Technical Specifications and UFSAR**

LIST OF TABLES

the required burnup as a function of initial enrichment. The NUHOMS®-52B is designed for unirradiated fuel with an initial enrichment of less than or equal to 4.0 wt. % U-235.

The NUHOMS®-61BT has three basket configurations, based on the boron content in the poison plates as listed in Table 1-1k. The maximum lattice average enrichment authorized for Type A, B and C NUHOMS®-61BT DSC is 3.7, 4.1 and 4.4 wt. % U-235 respectively. ***Three alternate poison materials are allowed: (a) Borated Aluminum, or (b) a Boron Carbide/Aluminum Metal Matrix Composite (MMC), or (c) Boral®.***

***For the 61BT DSC, Borated Aluminum, MMC, or Boral® shall be supplied in accordance with UFSAR Sections K.9.1.7.1, K.9.1.7.2, K.9.1.7.3, K.9.1.7.5, K.9.1.7.6.5, and K.9.1.7.7.3, with the minimum B10 areal density specified in Table 1-1k. These sections of the FSAR are hereby incorporated into the NUHOMS® 1004 CoC.***

The NUHOMS®-61BTH DSC is designed for unirradiated fuel with a maximum lattice average enrichment of 5.0 wt. % U-235 as shown in Table 1-1t, taking credit for the boron content in the poison plates of the DSC basket, as shown in Table 1-1v for intact fuel and Table 1-1w for damaged fuel. The NUHOMS®-61BTH DSC (similar to 61BT DSC) is designated as Type 1 and Type 2 depending upon the rails used in the basket.

Each 61BTH DSC type is provided with six alternate basket configurations, based on the boron content in the poison plates, as listed in Table 1-1v or Table 1-1w (designated as "A" for the lowest B10 loading to "F" for the highest B10 loading). Three alternate poison materials are allowed: (a) Borated Aluminum, or (b) a Boron Carbide/Aluminum Metal Matrix Composite (MMC), or (c) Boral®.

For the 61BTH DSC, Borated Aluminum, MMC, or Boral® shall be supplied in accordance with UFSAR Sections T.9.1.7.1, T.9.1.7.2, T.9.1.7.3, T.9.1.7.5, T.9.1.7.6.5, and T.9.1.7.7.3, with the minimum B10 areal density specified in Table 1-1v or Table 1-1w. These sections of the FSAR are hereby incorporated into the NUHOMS® 1004 CoC.

The NUHOMS®-32PT is designed for unirradiated fuel with an initial fuel enrichment of up to 5.0 wt. % U-235 as shown in Table 1-1g, taking credit for Poison Rod Assemblies (PRAs), poison plates, and soluble boron in the DSC cavity water during loading operations. The required PRA locations are per Figures 1-5, or 1-6 or 1-7. A 32PT DSC basket may contain 0, 4, 8 or 16 PRAs and is designated a Type A, Type B, Type C or Type D basket, respectively. Each basket type is designed with up to three alternate configurations depending on the configuration of poison plates provided (16, 20 or 24) as shown in Table 1-1g. Table 1-1h specifies the minimum B10 content for poison plates. Specification 1.2.15a defines the

requirements for boron concentration in the DSC cavity water for the NUHOMS®-32PT design only. ***Two alternate poison materials are allowed: (a) Borated Aluminum, or (b) a Boron Carbide/Aluminum Metal Matrix Composite (MMC).***

***For the 32PT DSC, Borated Aluminum or MMC shall be supplied in accordance with UFSAR Sections M.9.1.7.1, M.9.1.7.2, M.9.1.7.5, M.9.1.7.6.5, and M.9.1.7.7.3, with the minimum B10 areal density specified in Table 1-1h. These sections of the FSAR are hereby incorporated into the NUHOMS® 1004 CoC.***

The NUHOMS®-24PHB is designed for unirradiated fuel with an assembly average initial enrichment of less than or equal to 4.5 wt. % U-235 as shown in Table 1-1i, taking credit for soluble boron in the DSC cavity water during loading operations. Specification 1.2.15b defines the requirements for boron concentration in the DSC cavity water for the NUHOMS®-24PHB design only.

The NUHOMS®-24PTH is designed for unirradiated fuel with an assembly average initial enrichment of less than or equal to 5.0 wt. % U-235, as shown in Table 1-1l, taking credit for soluble boron in the DSC cavity water during loading operations and the boron content in the poison plates of the DSC basket, as shown in Table 1-1p for intact fuel and Table 1-1q for damaged fuel. The 24PTH DSC basket is designated as Type 1, if it is provided with aluminum inserts and Type 2 if it does not contain the aluminum inserts. Each basket type is designed with three alternate configurations, based on the boron content in the poison plates, as listed in Table 1-1r. **For the 24PTH DSC, Borated Aluminum, MMC, or Boral® shall be supplied in accordance with UFSAR Sections P.9.1.7.1, P.9.1.7.2, P.9.1.7.3, P.9.1.7.5, P.9.1.7.6.5, and P.9.1.7.7.3, with the minimum B10 areal density specified in Table 1-1r. These sections of the FSAR are hereby incorporated into the NUHOMS® 1004 CoC.** Specification 1.2.15c defines the requirements for boron concentration in the DSC cavity water as a function of the DSC basket type for the various fuel classes authorized for storage in the 24PTH DSC for the NUHOMS®-24PTH design only.

The NUHOMS®-32PTH1 is designed for unirradiated fuel with an assembly average initial enrichment of less than or equal to 5.0 wt. % U-235, as shown in Table 1-1aa, taking credit for soluble boron in the DSC cavity water during loading operations and the boron content in the poison plates of the DSC basket, as shown in Table 1-1cc for intact fuel and Table 1-1dd for damaged fuel. The 32PTH1 DSC basket is designated as Type 1 or Type 2, depending upon the rails used in the basket. Each basket type is designed with five alternate configurations, based on the boron content in the poison plates, as listed in Table 1-1ff. Specification 1.2.15d defines the requirements for boron concentration in the DSC cavity water as a function of the DSC basket type for the various fuel

classes authorized for storage in the 32PTH1 DSC for the NUHOMS®-32PTH1 design only.

For the 32PTH1 DSC, Borated Aluminum, MMC, or Boral® shall be supplied in accordance with UFSAR Sections U.9.1.7.1, U.9.1.7.2, U.9.1.7.3, U.9.1.7.5, U.9.1.7.6.5, and U.9.1.7.7.3, with the minimum B10 areal density specified in Table 1-1ff. These sections of the FSAR are hereby incorporated into the NUHOMS® 1004 CoC.

The thermal design criterion of the fuel to be stored is that the total maximum heat generation rate per assembly and BPRA or Control Components be such that the fuel cladding temperature is maintained within established limits during normal and off-normal conditions. For the NUHOMS®-24P, 52B and 61BT systems, fuel cladding temperature limits were established based on methodology in PNL-6189 and PNL-4835. For the NUHOMS®-32PT, 24PHB and 24PTH systems, fuel cladding limits are based on ISG-11, Rev. 2 (Reference 3). *For the NUHOMS®-61BTH system,* NUHOMS®-61BT system with Framatome-ANP 9x9 Version 9x9-2 (FANP9 9x9-2) fuel assemblies, *and the NUHOMS®-32PTH1 system,* fuel cladding limits are based on ISG-11, Rev. 3 (Reference 4).

The radiological design criterion is that fuel stored in the NUHOMS® system must not increase the average calculated HSM or transfer cask surface dose rates beyond those calculated for the 24P, 24PHB, 52B, 61BT, or 32PT canister full of design basis fuel assemblies with or without BPRAs. The design value average HSM and cask surface dose rates for the 24P and 52B canisters were calculated to be 48.6 mrem/hr and 591.8 mrem/hr respectively based on storing twenty four (24) Babcock and Wilcox 15x15 PWR assemblies (without BPRAs) with 4.0 wt. % U-235 initial enrichment, irradiated to 40,000 MWd/MTU, and having a post irradiation time of five years. To account for BPRAs, the fuel assembly cooling required times are increased to maintain the above dose rate limits.

**Table 1-1k**
**B10 Specification for the NUHOMS®-61BT Poison Plates**

| NUHOMS®-61BT DSC Basket Type | Minimum B10 *Areal* Density, gm/cm² | |
|---|---|---|
| | **Borated** Aluminum or **MMC** | Boral® |
| A | .021 | .025 |
| B | .032 | .038 |
| C | .040 | .048 |

## Table 1-1r
## B10 Specification for the NUHOMS®-24PTH Poison Plates

| NUHOMS®-24PTH DSC Basket Type(1) | Minimum B10 *Areal* Density, gm/cm$^2$ | |
|---|---|---|
| | **Borated** Aluminum or MMC | Boral® |
| 1A or 2A | .007 | .009 |
| 1B or 2B | .015 | .019 |
| 1C or 2C | .032 | .040 |

(1) Basket Type 1 contains aluminum inserts in the R45 transition rails of the basket, Type 2 does not contain aluminum inserts.

## Table 1-1s

## (DELETED)

K.9.1.4 Components

No change.

K.9.1.5 Shielding Integrity

No change.

K.9.1.6 Thermal Acceptance

The analyses to ensure that the NUHOMS®-61BT DSCs are capable of performing their heat transfer function are presented in Section K.4.

K.9.1.7 Poison Acceptance

> ***CAUTION***
>
> *Sections K.9.1.7.1 through K.9.1.7.3 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of these sections is shown in bold type to distinguish it from other sections.*

The neutron absorber used for criticality control in the DSC basket may consist any of the following types of material:

(a) Borated Aluminum

(b) Boron carbide / Aluminum metal matrix composite (MMC)

(c) Boral®

The 61BT DSC safety analyses do not rely upon the tensile strength of these materials. The radiation and temperature environment in the cask is not sufficiently severe to damage these metallic/ceramic materials. To assure performance of the neutron absorber's design function only the presence of B10 and the uniformity of its distribution need to be verified, with testing requirements specific to each material. The boron content of these three types of materials is given in Table K.9-1, Table K.9-2 and Table K.9-3, respectively.

References to metal matrix composites throughout this chapter are not intended to refer to Boral®, which is described later in this section.

K.9.1.7.1 **Borated Aluminum**

**See the Caution in Section K.9.1.7 before deletion or modification to this section.**

**The material is produced by direct chill (DC) or permanent mold casting with boron precipitating as a uniform fine dispersion of discrete $AlB_2$ or $TiB_2$ particles in the matrix of**

**aluminum or aluminum alloy. For extruded products, the $TiB_2$ form of the alloy shall be used. For rolled products, either the $AlB_2$, the $TiB_2$, or a hybrid may be used.**

**Boron is added to the aluminum in the quantity necessary to provide the specified minimum B10 areal density in the final product, with sufficient margin to minimize rejection, typically 10 % excess. The amount required to achieve the specified minimum B10 areal density will depend on whether boron with the natural isotopic distribution of the isotopes B10 and B11, or boron enriched in B10 is used. In no case shall the boron content in the aluminum or aluminum alloy exceed 5% by weight.**

**The criticality calculations take credit for 90% of the minimum specified B10 areal density of borated aluminum. The basis for this credit is the B10 areal density acceptance testing, which shall be as specified in Section K.9.1.7.5. The specified acceptance testing assures that at any location in the material, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.**

**Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings"[9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surface, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

K.9.1.7.2 <u>Boron Carbide / Aluminum Metal Matrix Composites (MMC)</u>

**See the Caution in Section K.9.1.7 before deletion or modification to this section.**

**The material is a composite of fine boron carbide particles in an aluminum or aluminum alloy matrix. The material shall be produced by either direct chill casting, permanent mold casting, powder metallurgy, or thermal spray techniques. It is a low-porosity product, with a metallurgically bonded matrix. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding shall not exceed 50% by volume.**

**Prior to use in the 61BT DSC, MMCs shall pass the qualification testing specified in Section K.9.1.7.6, and shall subsequently be subject to the process controls specified in Section K.9.1.7.7.**

**The criticality calculations take credit for 90% of the minimum specified B10 areal density of MMCs. The basis for this credit is the B10 areal density acceptance testing, which is specified in Section K.9.1.7.5. The specified acceptance testing assures that at any location in the final product, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.**

**Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surfaces, or**

**cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

K.9.1.7.3 **Boral®**

**See the Caution in Section K.9.1.7 before deletion or modification to this section.**

**This material consists of a core of aluminum and boron carbide powders between two outer layers of aluminum, mechanically bonded by hot-rolling an "ingot" consisting of an aluminum box filled with blended boron carbide and aluminum powders. The core, which is exposed at the edges of the sheet, is slightly porous. The average size of the boron carbide particles in the finished product is approximately 85 microns before rolling. The nominal boron carbide content shall be limited to 65% (+ 2% tolerance limit) of the core by weight.**

**The criticality calculations take credit for 75% of the minimum specified B10 areal density of Boral®. B10 areal density will be verified by chemical analysis and by certification of the B10 isotopic fraction for the boron carbide powder, or by neutron transmission testing. Areal density testing is performed on an approximately 1 $cm^2$ area of a coupon taken near one of the corners of the sheet produced from each ingot. If the measured areal density is below that specified, all the material produced from that ingot will be either rejected, or accepted only on the basis of alternate verification of B10 areal density for each of the final pieces produced from that ingot.**

**Visual inspections shall verify that the Boral® core is not exposed through the face of the sheet at any location.**

K.9.1.7.4 Thermal Conductivity Testing

The poison plate material will be qualification tested to verify that the thermal conductivity equals or exceeds the values listed in Section K.4.3. Acceptance testing of the material in production may be done at only one temperature in that range to verify that the conductivity equals or exceeds the corresponding value in Section K.4.3.

Testing may be by ASTM E1225 [9.3], ASTM E1461 [9.4] , or equivalent method, performed on a sample of specimens removed from coupons adjacent to the final plates (see Section K.9.1.7.4.1 for more detail on coupons).

K.9.1.7.4.1 Test Coupons

The poison plates are manufactured in a variety of sizes. Coupons will be removed between every other plate or at the end of the plate so that there is at least one coupon contiguous with each plate. Coupons will generally be the full width of the plate. Thermal conductivity coupons may be removed from the full width coupon. The minimum dimension of the coupon shall be as required for acceptance test specimens; 1 to 2 inches is generally adequate.

K.9.1.7.5 **Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission**

| |
|---|
| ***CAUTION*** |
| *Section K.9.1.7.5 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.* |

**Neutron Transmission acceptance testing procedures shall be subject to approval by the Certificate Holder. Test coupons shall be removed from the rolled or extruded production material at locations that are systematically or probabilistically distributed throughout the lot. Test coupons shall not exhibit physical defects that would not be acceptable in the finished product, or that would preclude an accurate measurement of the coupon's physical thickness.**

**A lot is defined as all the pieces produced from a single ingot or heat or from a group of billets from the same heat. If this definition results in lot size too small to provide a meaningful statistical analysis of results, an alternate larger lot definition may be used, so long as it results in accumulating material that is uniform for sampling purposes.**

**The sampling rate for neutron transmission measurements shall be such that there is at least one neutron transmission measurement for each 2000 square inches of final product in each lot.**

**The B10 areal density is measured using a collimated thermal neutron beam of up to 1.2 centimeter diameter. A beam size greater than 1.2 centimeter diameter but no larger than 1.7 centimeter diameter may be used if computations are performed to demonstrate that the calculated $k_{effective}$ of the system is still below the calculated Upper Subcritical Limit (USL) of the system assuming defect areas the same area as the beam.**

**The neutron transmission through the test coupons is converted to B10 areal density by comparison with transmission through calibrated standards. These standards are composed of a homogeneous boron compound without other significant neutron absorbers. For example, boron carbide, zirconium diboride or titanium diboride sheets are acceptable standards. These standards are paired with aluminum shims sized to match the effect of neutron scattering by aluminum in the test coupons. Uniform but non-homogeneous materials such as metal matrix composites may be used for standards, provided that testing shows them to provide neutron attenuation equivalent to a homogeneous standard.**

**Alternatively, digital image analysis may be used to compare neutron radioscopic images of the test coupon to images of the standards. The area of image analysis shall be up to 1.1 $cm^2$. The method shall demonstrate sufficient sensitivity to distinguish between areal density at the specified minimum, and 1% above and below the minimum.**

**The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. The following illustrates one acceptable method.**

**The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The minimum B10 areal densities determined by neutron transmission are converted to volume density, i.e., the minimum B10 areal density is divided by the thickness at the location of the neutron transmission measurement or the maximum thickness of the coupon. The lower tolerance limit of B10 volume density is then determined, defined as the mean value of B10 volume density for the sample, less K times the standard deviation, where K is the one-sided tolerance limit factor with 95% probability and 95% confidence [9.6]. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the value of K for a normal distribution may be used. Otherwise, use a non-parametric (distribution-free) method of determining the one-sided tolerance limit.**

**Finally, the minimum specified value of B10 areal density is divided by the lower tolerance limit of B10 volume density to arrive at the minimum plate thickness which provides the specified B10 areal density.**

**Any plate which is thinner than this minimum or the minimum design thickness, whichever is greater, shall be treated as non-conforming, with the following exception. Local depressions are acceptable, so long as they total no more than 0.5% of the area on any given plate, and the thickness at their location is not less than 90% of the minimum design thickness.**

**Non-conforming material shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

K.9.1.7.6 Specification for Qualification Testing of Metal Matrix Composites

K.9.1.7.6.1 Applicability and Scope

Metal matrix composites (MMCs) shall consist of fine boron carbide particles in an aluminum or aluminum alloy matrix. The ingot shall be produced by either powder metallurgy (PM), thermal spray techniques, or by direct chill (DC) or permanent mold casting. In any case, the final MMC product shall have density greater than 98% of theoretical, a metallurgically bonded matrix, and boron carbide content no greater than 40% by volume. (For MMCs with an integral aluminum cladding, the maximum boron carbide content shall be no greater than 50% by volume and the density shall be greater than 97% of theoretical density.) Boron carbide particles for the products considered here typically have an average size in the range 10-40 microns, although the actual specification may be by mesh size, rather than by average particle size. No more than 10% of the particles shall be over 60 microns. The material shall have negligible interconnected porosity exposed at the surface or edges.

Prior to initial use in a spent fuel dry storage or transport system, such MMCs shall be subjected to qualification testing that will verify that the product satisfies the design function. Key process controls shall be identified per Section K.9.1.7.7 so that the production material is equivalent to

or better than the qualification test material. Changes to key processes shall be subject to qualification before use of such material in a spent fuel dry storage or transport system.

ASTM test methods and practices are referenced below for guidance. Alternative methods may be used with the approval of the certificate holder.

K.9.1.7.6.2 Design Requirements

In order to perform its design functions the product must have at a minimum sufficient strength and ductility for manufacturing and for the normal and accident conditions of the storage/ transport system. This is demonstrated by the tests in Section K.9.1.7.6.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section K.9.1.7.6.5.

K.9.1.7.6.3 Durability

There is no need to include accelerated radiation damage testing in the qualification. Such testing has already been performed on MMCs, and the results confirm what would be expected of materials that fall within the limits of applicability cited above. Metals and ceramics do not experience measurable changes in mechanical properties due to fast neutron fluences typical over the lifetime of spent fuel storage, about $10^{15}$ neutrons/cm$^2$.

The need for thermal damage and corrosion (hydrogen generation) testing shall be evaluated case-by-case based on comparison of the material composition and environmental conditions with previous thermal or corrosion testing of MMCs.

Thermal damage testing is not required for MMCs consisting only of boron carbide in an aluminum 1100 matrix, because there is no reaction between aluminum and boron carbide below 842°F, well above the basket temperature under normal conditions of storage or transport[1].

Corrosion testing is not required for full density MMCs consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[2].

K.9.1.7.6.4 Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity

At least three samples, one each from the two ends and middle of the test material production run shall be subject to:

a) room temperature tensile testing (ASTM- B557[3]) demonstrating that the material has the following tensile properties:

1 Sung, C., "Microstructural Observation of Thermally Aged and Irradiated Aluminum/Boron Carbide ($B_4C$) Metal Matrix Composite by Transmission and Scanning Electron Microscope," 1998.

2 Boralyn testing submitted to the NRC under docket 71-1027, 1998.

3 ASTM B557 Standard Test Methods of Tension Testing Wrought and Cast Aluminum and Magnesium-Alloy Products.

- Minimum yield strength, 0.2% offset: 1.5 ksi
- Minimum ultimate strength: 5 ksi
- Minimum elongation in 2 inches: 0.5%

  (Alternatively show that the material fails in a ductile manner, e.g., by scanning electron microscopy of the fracture surface or by bend testing.)

and

b) testing (ASTM-B311[4]) to verify more than 98% (or 97% for MMCs with integral aluminum cladding) of theoretical density. Testing or examination for exposed interconnected porosity shall be performed by a means to be approved by the Certificate Holder.

K.9.1.7.6.5 **Required Tests and Examinations to Demonstrate B10 Uniformity**

*CAUTION*

*Section K.9.1.7.6.5 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

**Uniformity of the boron distribution shall be verified either by:**

**a) Neutron radioscopy or radiography (ASTM E94[5], E142[6], and E545[7]) of material from the ends and middle of the test material production run, verifying no more than 10% difference between the minimum and maximum B10 areal density, or**

**b) Quantitative testing for the B10 areal density, B10 density, or the boron carbide weight fraction, on locations distributed over the test material production run, verifying that one standard deviation in the sample is less than 10% of the sample mean. Testing may be performed by a neutron transmission method similar to that specified in Section K.9.1.7.5, or by chemical analysis for boron carbide content in the composite.**

K.9.1.7.6.6 Approval of Procedures

Qualification procedures shall be subject to approval by the Certificate Holder.

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4 ASTM B311, Test Method for Density Determination for Powder Metallurgy (P/M) Materials Containing Less than Two Percent Porosity

5 ASTM E94, Recommended Practice for Radiographic Testing

6 ASTM E142, Controlling Quality of Radiographic Testing

7 ASTM E545, Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing

K.9.1.7.7 Specification for Process Controls for Metal Matrix Composites

K.9.1.7.7.1 Applicability and Scope

The applicability of this section is the same as that of Section K.9.1.7.6. It addresses the process controls to ensure that the material delivered for use is equivalent to the qualification test material.

Key processing changes shall be subject to qualification prior to use of the material produced by the revised process. The Certificate Holder shall determine whether a complete or partial re-qualification program per Section K.9.1.7.7 is required, depending on the characteristics of the material that could be affected by the process change.

K.9.1.7.7.2 Definition of Key Process Changes

Key process changes are those which could adversely affect the uniform distribution of the boron carbide in the aluminum, reduce density, or reduce the mechanical strength or ductility of the MMC.

K.9.1.7.7.3 **Identification and Control of Key Process Changes**

***CAUTION***

*Section K.9.1.7.7.3 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

**The manufacturer shall provide the Certificate Holder with a description of materials and process controls used in producing the MMC. The Certificate Holder and manufacturer shall identify key process changes as defined in Section K.9.1.7.7.2.**

**An increase in nominal boron carbide content over that previously qualified shall always be regarded as a key process change. The following are examples of other changes that may be established as key process changes, as determined by the Certificate Holder's review of the specific applications and production processes:**

**a) Changes in the boron carbide particle size specification that increase the average particle size by more than 5 microns or that increase the amount of particles larger than 60 microns from the previously qualified material by more than 5% of the total distribution but less than the 10% limit,**

**b) Change of the billet production process, e.g., from vacuum hot pressing to cold isostatic pressing followed by vacuum sintering,**

**c) Change in the nominal matrix alloy,**

**d) Changes in mechanical processing that could result in reduced density of the final product, e.g., for PM or thermal spray MMCs that were qualified with extruded material, a change to direct rolling from the billet,**

**e) For MMCs using a 6000 series aluminum matrix, changes in the billet formation process that could increase the likelihood of magnesium reaction with the boron carbide, such as an increase in the maximum temperature or time at maximum temperature, and**

**f) Changes in powder blending or melt stirring processes that could result in less uniform distribution of boron carbide, e.g., change in duration of powder blending.**

**In no case shall process changes be accepted if they result in a product outside the limits in Sections K.9.1.7.6.1 and K.9.1.7.6.4.**

## K.9.2 <u>Maintenance Program</u>

NUHOMS®-61BT system is a totally passive system and therefore will require little, if any, maintenance over the lifetime of the ISFSI. Typical NUHOMS®-61BT system maintenance tasks will be performed in accordance with Section 4.

## K.9.3 References


9.1 ASME Boiler and Pressure Vessel Code, Section III, 1998 Edition including 1999 addenda.

9.2 ANSI N14.5-1997, "American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials," February 1998.

9.3 ASTM E1225, "Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique."

9.4 ASTM E1461, "Thermal Diffusivity of Solids by the Flash Method."

9.5 "Aluminum Standards and Data, 2003" The Aluminum Association.

9.6 Natrella, "Experimental Statistics," Dover, 2005.

9.7 ASTM D 3553, "Fiber Content by Digestion of Reinforced Metal Matrix Composites."

9.8 AAR Advanced Structures, "Boral®, The Proven Neutron Absorber."

9.9 AAR Advanced Structures, Boral® Product Performance Report 624.

**Table K.9-1**
**Specified Boron Content**
**Borated Aluminum (90% credit)**

| Reference | Section K.6 Analysis | Specified Minimum |
|---|---|---|
| **Boron Content (wt. % Boron)** | **B10 Content ($g/cm^2$)** | **B10 Content ($g/cm^2$)** |
| 1.1 | 0.019 | 0.021 |
| 1.6 | 0.029 | 0.032 |
| 2.1 | 0.036 | 0.040 |
| **For Damaged Fuel** | | |
| 2.1 | 0.036 | 0.040 |

**Table K.9-2**
**Specified Boron Carbide Content**
**MMC (90% credit)**

| Reference | Section K.6 Analysis | Specified Minimum |
|---|---|---|
| **Boron Carbide Content (volume %)** | **B10 Content ($g/cm^2$)** | **B10 Content ($g/cm^2$)** |
| 8 | 0.019 | 0.021 |
| 12 | 0.029 | 0.032 |
| 15 | 0.036 | 0.040 |
| **For Damaged Fuel** | | |
| 15 | 0.036 | 0.040 |

**Table K.9-3**
**Specified B10 Areal Density**
**Boral® (75% credit)**

| Section K.6 Analysis | Specified Minimum |
|---|---|
| **B10 Content ($g/cm^2$)** | **B10 Content ($g/cm^2$)** |
| 0.019 | 0.025 |
| 0.029 | 0.039 |
| 0.036 | 0.048 |
| **For Failed Fuel** | |
| 0.036 | 0.048 |

M.9.1.4 Component Tests

No changes associated with this amendment.

M.9.1.5 Shielding Integrity Tests

No changes associated with this amendment.

M.9.1.6 Thermal Acceptance Tests

The analyses to ensure that the NUHOMS®-32PT DSCs are capable of performing their heat transfer function are presented in Section M.4.

M.9.1.7 Poison Acceptance

| **_CAUTION_** |
| --- |
| *Sections M.9.1.7.1 and M.9.1.7.2 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of these sections is shown in bold type to distinguish it from other sections.* |

The neutron absorber used for criticality control in the DSC basket may consist any of the following types of material:

(a) Borated Aluminum

(b) Boron carbide / Aluminum metal matrix composite (MMC)

The 32PT DSC safety analyses do not rely upon the tensile strength of these materials. The radiation and temperature environment in the cask is not sufficiently severe to damage these metallic/ceramic materials. To assure performance of the neutron absorber's design function only the presence of B10 and the uniformity of its distribution need to be verified, with testing requirements specific to each material. The boron content for these materials corresponds to a minimum areal density of 7.0 mg B10/cm$^2$.

M.9.1.7.1 **Borated Aluminum**

**See the Caution in Section M.9.1.7 before deletion or modification to this section.**

**The material is produced by direct chill (DC) or permanent mold casting with boron precipitating as a uniform fine dispersion of discrete $AlB_2$ or $TiB_2$ particles in the matrix of aluminum or aluminum alloy. For extruded products, the $TiB_2$ form of the alloy shall be used. For rolled products, either the $AlB_2$, the $TiB_2$, or a hybrid may be used.**

**Boron is added to the aluminum in the quantity necessary to provide the specified minimum B10 areal density in the final product, with sufficient margin to minimize rejection, typically 10 % excess. The amount required to achieve the specified minimum B10 areal density will depend on whether boron with the natural isotopic distribution of the isotopes B10 and B11, or boron enriched in B10 is used. In no case shall the boron content in the aluminum or aluminum alloy exceed 5% by weight.**

**The criticality calculations take credit for 90% of the minimum specified B10 areal density of borated aluminum. The basis for this credit is the B10 areal density acceptance testing, which shall be as specified in Section M.9.1.7.5. The specified acceptance testing assures that at any location in the material, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.**

**Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings"[9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surface, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

M.9.1.7.2 Boron Carbide / Aluminum Metal Matrix Composites (MMC)

**See the Caution in Section M.9.1.7 before deletion or modification to this section.**

**The material is a composite of fine boron carbide particles in an aluminum or aluminum alloy matrix. The material shall be produced by either direct chill casting, permanent mold casting, powder metallurgy, or thermal spray techniques. It is a low-porosity product, with a metallurgically bonded matrix. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding shall not exceed 50% by volume.**

**Prior to use in the 32PT DSC, MMCs shall pass the qualification testing specified in Section M.9.1.7.6, and shall subsequently be subject to the process controls specified in Section M.9.1.7.7.**

**The criticality calculations take credit for 90% of the minimum specified B10 areal density of MMCs. The basis for this credit is the B10 areal density acceptance testing, which is specified in Section M.9.1.7.5. The specified acceptance testing assures that at any location in the final product, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.**

**Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion,**

**isolated pores, or discoloration are acceptable. Widespread blisters, rough surfaces, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

M.9.1.7.3 Not Used

M.9.1.7.4 Thermal Conductivity Testing of Poison Plates

The poison plate material shall be qualification tested to verify that the thermal conductivity equals or exceeds the values listed in Section M.4.3. Acceptance testing of the material in production may be done at only one temperature in that range to verify that the conductivity equals or exceeds the corresponding value in Section M.4.3.

Testing may be by ASTM E1225 [9.3], ASTM E1461 [9.4], or equivalent method, performed on coupons as defined in Section M.9.1.7.4.1.

M.9.1.7.4.1 Test Coupon and Lot Definitions

Sample taken from the plate material is a test coupon. Test coupons will be removed so that there is at least one coupon contiguous with each plate. These coupons will be used for thermal conductivity testing. The minimum dimension of the coupon shall be as required for the acceptance test procedures.

A lot is defined as all the plates produced from a single cast ingot, or all the plates produced from a single heat.

M.9.1.7.5 Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission

| ***CAUTION*** |
|---|
| *Section M.9.1.7.5 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.* |

**Neutron Transmission acceptance testing procedures shall be subject to approval by the Certificate Holder. Test coupons shall be removed from the rolled or extruded production material at locations that are systematically or probabilistically distributed throughout the lot. Test coupons shall not exhibit physical defects that would not be acceptable in the finished product, or that would preclude an accurate measurement of the coupon's physical thickness.**

**A lot is defined as all the pieces produced from a single ingot or heat or from a group of billets from the same heat. If this definition results in lot size too small to provide a**

**meaningful statistical analysis of results, an alternate larger lot definition may be used, so long as it results in accumulating material that is uniform for sampling purposes.**

**The sampling rate for neutron transmission measurements shall be such that there is at least one neutron transmission measurement for each 2000 square inches of final product in each lot.**

**The B10 areal density is measured using a collimated thermal neutron beam of up to 1.2 centimeter diameter. A beam size greater than 1.2 centimeter diameter but no larger than 1.7 centimeter diameter may be used if computations are performed to demonstrate that the calculated $k_{effective}$ of the system is still below the calculated Upper Subcritical Limit (USL) of the system assuming defect areas the same area as the beam.**

**The neutron transmission through the test coupons is converted to B10 areal density by comparison with transmission through calibrated standards. These standards are composed of a homogeneous boron compound without other significant neutron absorbers. For example, boron carbide, zirconium diboride or titanium diboride sheets are acceptable standards. These standards are paired with aluminum shims sized to match the effect of neutron scattering by aluminum in the test coupons. Uniform but non-homogeneous materials such as metal matrix composites may be used for standards, provided that testing shows them to provide neutron attenuation equivalent to a homogeneous standard.**

**Alternatively, digital image analysis may be used to compare neutron radioscopic images of the test coupon to images of the standards. The area of image analysis shall be up to 1.1 $cm^2$. The method shall demonstrate sufficient sensitivity to distinguish between areal density at the specified minimum, 1% above and below the minimum.**

**The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. The following illustrates one acceptable method.**

**The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The minimum B10 areal densities determined by neutron transmission are converted to volume density, i.e., the minimum B10 areal density is divided by the thickness at the location of the neutron transmission measurement or the maximum thickness of the coupon. The lower tolerance limit of B10 volume density is then determined, defined as the mean value of B10 volume density for the sample, less K times the standard deviation, where K is the one-sided tolerance limit factor with 95% probability and 95% confidence [9.12]. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the value of K for a normal distribution may be used. Otherwise, use a non-parametric (distribution-free) method of determining the one-sided tolerance limit.**

**Finally, the minimum specified value of B10 areal density is divided by the lower tolerance limit of B10 volume density to arrive at the minimum plate thickness which provides the specified B10 areal density.**

**Any plate which is thinner than this minimum or the minimum design thickness, whichever is greater, shall be treated as non-conforming, with the following exception. Local depressions are acceptable, so long as they total no more than 0.5% of the area on any**

**given plate, and the thickness at their location is not less than 90% of the minimum design thickness.**

**Non-conforming material shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

M.9.1.7.6 Specification for Qualification Testing of Metal Matrix Composites

M.9.1.7.6.1 Applicability and Scope

Metal matrix composites (MMCs) shall consist of fine boron carbide particles in an aluminum or aluminum alloy matrix. The ingot shall be produced by either powder metallurgy (PM), thermal spray techniques, or by direct chill (DC) or permanent mold casting. In any case, the final MMC product shall have density greater than 98% of theoretical, a metallurgically bonded matrix, and boron carbide content no greater than 40% by volume. (For MMCs with an integral aluminum cladding, the maximum boron carbide content shall be no greater than 50% by volume and the density shall be greater than 97% of theoretical density.) Boron carbide particles for the products considered here typically have an average size in the range 10-40 microns, although the actual specification may be by mesh size, rather than by average particle size. No more than 10% of the particles shall be over 60 microns. The material shall have negligible interconnected porosity exposed at the surface or edges.

Prior to initial use in a spent fuel dry storage or transport system, such MMCs shall be subjected to qualification testing that will verify that the product satisfies the design function. Key process controls shall be identified per Section M.9.1.7.7 so that the production material is equivalent to or better than the qualification test material. Changes to key processes shall be subject to qualification before use of such material in a spent fuel dry storage or transport system.

ASTM test methods and practices are referenced below for guidance. Alternative methods may be used with the approval of the certificate holder.

M.9.1.7.6.2 Design Requirements

In order to perform its design functions the product must have at a minimum sufficient strength and ductility for manufacturing and for the normal and accident conditions of the storage/ transport system. This is demonstrated by the tests in Section M.9.1.7.6.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section M.9.1.7.6.5.

M.9.1.7.6.3 Durability

There is no need to include accelerated radiation damage testing in the qualification. Such testing has already been performed on MMCs, and the results confirm what would be expected of materials that fall within the limits of applicability cited above. Metals and ceramics do not experience measurable changes in mechanical properties due to fast neutron fluences typical over the lifetime of spent fuel storage, about $10^{15}$ neutrons/cm$^2$.

The need for thermal damage and corrosion (hydrogen generation) testing shall be evaluated case-by-case based on comparison of the material composition and environmental conditions with previous thermal or corrosion testing of MMCs.

Thermal damage testing is not required for MMCs consisting only of boron carbide in an aluminum 1100 matrix, because there is no reaction between aluminum and boron carbide below 842°F, well above the basket temperature under normal conditions of storage or transport[1].

Corrosion testing is not required for full density MMCs consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[2].

M.9.1.7.6.4 Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity

At least three samples, one each from the two ends and middle of the test material production run shall be subject to:

a) room temperature tensile testing (ASTM- B557[3]) demonstrating that the material has the following tensile properties:

- Minimum yield strength, 0.2% offset: 1.5 ksi
- Minimum ultimate strength: 5 ksi
- Minimum elongation in 2 inches: 0.5%

(Alternatively show that the material fails in a ductile manner, e.g., by scanning electron microscopy of the fracture surface or by bend testing.)

and

b) testing (ASTM-B311[4]) to verify more than 98% (or 97% for MMCs with integral aluminum cladding) of theoretical density. Testing or examination for exposed interconnected porosity shall be performed by a means to be approved by the Certificate Holder.

M.9.1.7.6.5 Required Tests and Examinations to Demonstrate B10 Uniformity

***CAUTION***

*Section M.9.1.7.6.5 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

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1 Sung, C., "Microstructural Observation of Thermally Aged and Irradiated Aluminum/Boron Carbide ($B_4C$) Metal Matrix Composite by Transmission and Scanning Electron Microscope," 1998.

2 Boralyn testing submitted to the NRC under docket 71-1027, 1998.

3 ASTM B557 Standard Test Methods of Tension Testing Wrought and Cast Aluminum and Magnesium-Alloy Products.

4 ASTM B311, Test Method for Density Determination for Powder Metallurgy (P/M) Materials Containing Less than Two Percent Porosity

**Uniformity of the boron distribution shall be verified either by:**

a) **Neutron radioscopy or radiography (ASTM E94[5], E142[6], and E545[7]) of material from the ends and middle of the test material production run, verifying no more than 10% difference between the minimum and maximum B10 areal density, or**

b) **Quantitative testing for the B10 areal density, B10 density, or the boron carbide weight fraction, on locations distributed over the test material production run, verifying that one standard deviation in the sample is less than 10% of the sample mean. Testing may be performed by a neutron transmission method similar to that specified in Section M.9.1.7.5, or by chemical analysis for boron carbide content in the composite.**

M.9.1.7.6.6 Approval of Procedures

Qualification procedures shall be subject to approval by the Certificate Holder.

M.9.1.7.7 Specification for Process Controls for Metal Matrix Composites

M.9.1.7.7.1 Applicability and Scope

The applicability of this section is the same as that of Section M.9.1.7.6. It addresses the process controls to ensure that the material delivered for use is equivalent to the qualification test material.

Key processing changes shall be subject to qualification prior to use of the material produced by the revised process. The Certificate Holder shall determine whether a complete or partial re-qualification program per Section M.9.1.7.7 is required, depending on the characteristics of the material that could be affected by the process change.

M.9.1.7.7.2 Definition of Key Process Changes

Key process changes are those which could adversely affect the uniform distribution of the boron carbide in the aluminum, reduce density, or reduce the mechanical strength or ductility of the MMC.

5 ASTM E94, Recommended Practice for Radiographic Testing

6 ASTM E142, Controlling Quality of Radiographic Testing

7 ASTM E545, Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing

M.9.1.7.7.3 Identification and Control of Key Process Changes

> ***CAUTION***
>
> *Section M.9.1.7.7.3 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

**The manufacturer shall provide the Certificate Holder with a description of materials and process controls used in producing the MMC. The Certificate Holder and manufacturer shall identify key process changes as defined in Section M.9.1.7.7.2.**

**An increase in nominal boron carbide content over that previously qualified shall always be regarded as a key process change. The following are examples of other changes that may be established as key process changes, as determined by the Certificate Holder's review of the specific applications and production processes:**

**a) Changes in the boron carbide particle size specification that increase the average particle size by more than 5 microns or that increase the amount of particles larger than 60 microns from the previously qualified material by more than 5% of the total distribution but less than the 10% limit,**

**b) Change of the billet production process, e.g., from vacuum hot pressing to cold isostatic pressing followed by vacuum sintering,**

**c) Change in the nominal matrix alloy,**

**d) Changes in mechanical processing that could result in reduced density of the final product, e.g., for PM or thermal spray MMCs that were qualified with extruded material, a change to direct rolling from the billet,**

**e) For MMCs using a 6000 series aluminum matrix, changes in the billet formation process that could increase the likelihood of magnesium reaction with the boron carbide, such as an increase in the maximum temperature or time at maximum temperature, and**

**f) Changes in powder blending or melt stirring processes that could result in less uniform distribution of boron carbide, e.g., change in duration of powder blending.**

**In no case shall process changes be accepted if they result in a product outside the limits in Sections M.9.1.7.6.1 and M.9.1.7.6.4.**

M.9.1.7.8 $B_4C$ Linear Density Testing for Poison Rod Assemblies (PRAs)

The PRAs are shown in Figure M.1-2, and additional physical requirements are listed in Table M.2-4. The $B_4C$ poison is inserted into the stainless steel tubes shown in Figure M.1-2. Table M.2-4 specifies the minimum $B_4C$ content per unit length in the axial direction of the rods for the various PRA designs. The minimum $B_4C$ content per unit length is consistent with the criticality analysis (Section M.6) with an additional 25% margin.

Pellets or powder representing each powder lot shall be tested per ASTM C751 [9.6] or ASTM C750 (Type 2) [9.7] (or equivalent). Density and diameter shall be measured to verify conformance to the specification requirements.

Deviations from the specified dimensions or density may be accepted, so long as the resulting minimum $B_4C$ mass per unit length is maintained.

Justification for Durability of $B_4C$ Pellets:

$B_4C$ is essentially inert and will not be attacked even by hot hydrofluoric or nitric acids[9.8]. It is insoluble in water [9.9], resistant to steam at temperatures of 200 to 300°C [9.10] and has a melting point of 2450°C [9.10]. Mechanically, $B_4C$ is extremely hard (Mohs hardness of 9.3 vs. 10 for diamond) and is used in abrasion- and wear-resistant applications and in bullet-proof tiles. It has a compressive strength of 398,000 psi In the PRAs, the $B_4C$ pellets are sealed within stainless steel. With this configuration there is nothing that could cause the material to degrade. In the unlikely event that a pellet were to crack or break, the total mass would be confined by the steel to the same dimensions.

The irradiation-induced swelling is due to neutron capture by the $^{10}B$ isotope. Using data from [9.11] and by determining the neutron absorption in the $B_4C$ ($^{10}B$ capture) from the shielding analyses, the swelling is determined to be negligible ~ 0.00002%. Finally, according to [9.11], the first intergranular cracks do not start to appear until fluences are 5.5 orders of magnitude greater than those calculated for 50 year operation.

## M.9.2 Maintenance Program

NUHOMS®-32PT system is a totally passive system and therefore requires little, if any, maintenance over the lifetime of the ISFSI. Typical NUHOMS®-32PT system maintenance tasks are performed in accordance with the FSAR.

## M.9.3 References


9.1 ASME Boiler and Pressure Vessel Code, Section III, 1998 Edition including 1999 addenda.

9.2 ANSI N14.5-1997, "American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials," February 1998.

9.3 ASTM E1225, "Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique."

9.4 ASTM E1461, "Thermal Diffusivity of Solids by the Flash Method."

9.5 "Aluminum Standards and Data, 2003" The Aluminum Association.

9.6 ASTM C751, "Standard Specification for Nuclear-Grade Boron Carbide Pellets."

9.7 ASTM C750, "Standard Specification for Nuclear-Grade Boron Carbide Powder."

9.8 The Merck Index, *9th edition, Merck & Co., 1976.*

9.9 *Grant (ed.),* Hackh's Chemical Dictionary, *4th edition, McGraw-Hill, 1969.*

9.10 *Lipp, A., "Boron Carbide: Production, Properties, Application," Reprint from* Technische Rundschau, *Nos. 14, 28, 33 (1995) and 7 (1966).*

9.11 *Stoto, T. et al., "Swelling and Microcracking of Boron Carbide Subjected to Fast Neutron Irradiations,"* Journal of Applied Physics, *Vol. 68, No.7, October 1, 1990, pp. 3198-3206.*

9.12 Natrella, "Experimental Statistics," Dover, 2005.

9.13 Not Used.

9.14 SNT-TC-1A, "American Society for Nondestructive Testing, Personnel Qualification and Certification in Nondestructive Testing," 1992.

P.9.1.4 Component Tests

No change.

P.9.1.5 Shielding Integrity Tests

No change.

P.9.1.6 Thermal Acceptance Tests

The analyses to ensure that the NUHOMS®-24PTH system is capable of performing their heat transfer function are presented in Section P.4.

P.9.1.7 Poison Acceptance

| CAUTION |
| --- |
| *Sections P.9.1.7.1 through P.9.1.7.3 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of these sections is shown in bold type to distinguish it from other sections.* |

The neutron absorber used for criticality control in the DSC basket may consist any of the following types of material:

(a) Borated Aluminum

(b) Boron carbide / Aluminum metal matrix composite (MMC)

(c) Boral®

The 24PTH DSC safety analyses do not rely upon the tensile strength of these materials. The radiation and temperature environment in the cask is not sufficiently severe to damage these metallic/ceramic materials. To assure performance of the neutron absorber's design function only the presence of B10 and the uniformity of its distribution need to be verified, with testing requirements specific to each material. The boron content for these materials is given in Table P.9-1.

References to metal matrix composites throughout this chapter are not intended to refer to Boral®, which is described later in this section.

P.9.1.7.1 **Borated Aluminum**

**See the Caution in Section P.9.1.7 before deletion or modification to this section.**

**The material is produced by direct chill (DC) or permanent mold casting with boron precipitating as a uniform fine dispersion of discrete $AlB_2$ or $TiB_2$ particles in the matrix of aluminum or aluminum alloy. For extruded products, the $TiB_2$ form of the alloy shall be used. For rolled products, either the $AlB_2$, the $TiB_2$, or a hybrid may be used.**

**Boron is added to the aluminum in the quantity necessary to provide the specified minimum B10 areal density in the final product, with sufficient margin to minimize rejection, typically 10 % excess. The amount required to achieve the specified minimum B10 areal density will depend on whether boron with the natural isotopic distribution of the isotopes B10 and B11, or boron enriched in B10 is used. In no case shall the boron content in the aluminum or aluminum alloy exceed 5% by weight.**

**The criticality calculations take credit for 90% of the minimum specified B10 areal density of borated aluminum. The basis for this credit is the B10 areal density acceptance testing, which shall be as specified in Section P.9.1.7.5. The specified acceptance testing assures that at any location in the material, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.**

**Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings"[9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surface, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

P.9.1.7.2 Boron Carbide / Aluminum Metal Matrix Composites (MMC)

**See the Caution in Section P.9.1.7 before deletion or modification to this section.**

**The material is a composite of fine boron carbide particles in an aluminum or aluminum alloy matrix. The material shall be produced by either direct chill casting, permanent mold casting, powder metallurgy, or thermal spray techniques. It is a low-porosity product, with a metallurgically bonded matrix. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding shall not exceed 50% by volume.**

**Prior to use in the 24PTH DSC, MMCs shall pass the qualification testing specified in Section P.9.1.7.6, and shall subsequently be subject to the process controls specified in Section P.9.1.7.7.**

**The criticality calculations take credit for 90% of the minimum specified B10 areal density of MMCs. The basis for this credit is the B10 areal density acceptance testing, which is specified in Section P.9.1.7.5. The specified acceptance testing assures that at any location in the final product, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.**

**Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surfaces, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

P.9.1.7.3 **Boral®**

**See the Caution in Section P.9.1.7 before deletion or modification to this section.**

**This material consists of a core of aluminum and boron carbide powders between two outer layers of aluminum, mechanically bonded by hot-rolling an "ingot" consisting of an aluminum box filled with blended boron carbide and aluminum powders. The core, which is exposed at the edges of the sheet, is slightly porous. The average size of the boron carbide particles in the finished product is approximately 85 microns before rolling. The nominal boron carbide content shall be limited to 65% (+ 2% tolerance limit) of the core by weight.**

**The criticality calculations take credit for 75% of the minimum specified B10 areal density of Boral®. B10 areal density will be verified by chemical analysis and by certification of the B10 isotopic fraction for the boron carbide powder, or by neutron transmission testing. Areal density testing is performed on an approximately 1 $cm^2$ area of a coupon taken near one of the corners of the sheet produced from each ingot. If the measured areal density is below that specified, all the material produced from that ingot will be either rejected, or accepted only on the basis of alternate verification of B10 areal density for each of the final pieces produced from that ingot.**

**Visual inspections shall verify that the Boral® core is not exposed through the face of the sheet at any location.**

P.9.1.7.4 Thermal Conductivity Testing of Poison Plates

The poison plate material shall be qualification tested to verify that the thermal conductivity equals or exceeds the values listed in Section P.4.3. Acceptance testing of the material in production may be done at only one temperature in that range to verify that the conductivity equals or exceeds the corresponding value in Section P.4.3.

Testing may be by ASTM E1225 [9.3], ASTM E1461 [9.4], or equivalent method, performed on coupons as defined in Section P.9.1.7.4.1.

P.9.1.7.4.1 Test Coupon and Lot Definitions

A sample taken from the plate material is a test coupon. Test coupons will be removed so that there is at least one coupon contiguous with each plate. These coupons will be used for neutron thermal conductivity testing. The minimum dimension of the coupon shall be as required for the acceptance test procedures.

A lot is defined as all the plates produced from a single cast ingot, or all the plates produced from a single heat.

P.9.1.7.5 Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission

> ***CAUTION***
>
> *Section P.9.1.7.5 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

**Neutron Transmission acceptance testing procedures shall be subject to approval by the Certificate Holder. Test coupons shall be removed from the rolled or extruded production material at locations that are systematically or probabilistically distributed throughout the lot. Test coupons shall not exhibit physical defects that would not be acceptable in the finished product, or that would preclude an accurate measurement of the coupon's physical thickness.**

**A lot is defined as all the pieces produced from a single ingot or heat or from a group of billets from the same heat. If this definition results in lot size too small to provide a meaningful statistical analysis of results, an alternate larger lot definition may be used, so long as it results in accumulating material that is uniform for sampling purposes.**

**The sampling rate for neutron transmission measurements shall be such that there is at least one neutron transmission measurement for each 2000 square inches of final product in each lot.**

**The B10 areal density is measured using a collimated thermal neutron beam of up to 1.2 centimeter diameter. A beam size greater than 1.2 centimeter diameter but no larger than 1.7 centimeter diameter may be used if computations are performed to demonstrate that the calculated $k_{effective}$ of the system is still below the calculated Upper Subcritical Limit (USL) of the system assuming defect areas the same area as the beam.**

**The neutron transmission through the test coupons is converted to B10 areal density by comparison with transmission through calibrated standards. These standards are composed of a homogeneous boron compound without other significant neutron absorbers. For example, boron carbide, zirconium diboride or titanium diboride sheets are acceptable standards. These standards are paired with aluminum shims sized to match the effect of neutron scattering by aluminum in the test coupons. Uniform but non-homogeneous materials such as metal matrix composites may be used for standards, provided that testing shows them to provide neutron attenuation equivalent to a homogeneous standard.**

**Alternatively, digital image analysis may be used to compare neutron radioscopic images of the test coupon to images of the standards. The area of image analysis shall be up to 1.1 $cm^2$. The method shall demonstrate sufficient sensitivity to distinguish between areal density at the specified minimum, 1% above and below the minimum.**

**The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. The following illustrates one acceptable method.**

**The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The minimum B10 areal densities determined by neutron transmission are converted to volume density, i.e., the minimum B10 areal density is divided by the thickness at the location of the neutron transmission measurement or the maximum thickness of the coupon. The lower tolerance limit of B10 volume density is then determined, defined as the mean value of B10 volume density for the sample, less K times the standard deviation, where K is the one-sided tolerance limit factor for a normal distribution with 95% probability and 95% confidence [9.6]. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the value of K for a normal distribution may be used. Otherwise, use a non-parametric (distribution-free) method of determining the one-sided tolerance limit.**

**Finally, the minimum specified value of B10 areal density is divided by the lower tolerance limit of B10 volume density to arrive at the minimum plate thickness which provides the specified B10 areal density.**

**Any plate which is thinner than this minimum or the minimum design thickness, whichever is greater, shall be treated as non-conforming, with the following exception. Local depressions are acceptable, so long as they total no more than 0.5% of the area on any given plate, and the thickness at their location is not less than 90% of the minimum design thickness.**

**Non-conforming material shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

P.9.1.7.6 Specification for Qualification Testing of Metal Matrix Composites

P.9.1.7.6.1 Applicability and Scope

Metal matrix composites (MMCs) shall consist of fine boron carbide particles in an aluminum or aluminum alloy matrix. The ingot shall be produced by either powder metallurgy (PM), thermal spray techniques, or by direct chill (DC) or permanent mold casting. In any case, the final MMC product shall have density greater than 98% of theoretical, a metallurgically bonded matrix, and boron carbide content no greater than 40% by volume. (For MMCs with an integral aluminum cladding, the maximum boron carbide content shall be no greater than 50% by volume and the density shall be greater than 97% of theoretical density.) Boron carbide particles for the products considered here typically have an average size in the range 10-40 microns, although the actual specification may be by mesh size, rather than by average particle size. No more than 10% of the particles shall be over 60 microns. The material shall have negligible interconnected porosity exposed at the surface or edges.

Prior to initial use in a spent fuel dry storage or transport system, such MMCs shall be subjected to qualification testing that will verify that the product satisfies the design function. Key process controls shall be identified per Section P.9.1.7.7 so that the production material is equivalent to or better than the qualification test material. Changes to key processes shall be subject to qualification before use of such material in a spent fuel dry storage or transport system.

ASTM test methods and practices are referenced below for guidance. Alternative methods may

be used with the approval of the certificate holder.

P.9.1.7.6.2 Design Requirements

In order to perform its design functions the product must have at a minimum sufficient strength and ductility for manufacturing and for the normal and accident conditions of the storage/ transport system. This is demonstrated by the tests in SectionP.9.1.7.6.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section P.9.1.7.6.5.

P.9.1.7.6.3 Durability

There is no need to include accelerated radiation damage testing in the qualification. Such testing has already been performed on MMCs, and the results confirm what would be expected of materials that fall within the limits of applicability cited above. Metals and ceramics do not experience measurable changes in mechanical properties due to fast neutron fluences typical over the lifetime of spent fuel storage, about $10^{15}$ neutrons/$cm^2$.

The need for thermal damage and corrosion (hydrogen generation) testing shall be evaluated case-by-case based on comparison of the material composition and environmental conditions with previous thermal or corrosion testing of MMCs.

Thermal damage testing is not required for MMCs consisting only of boron carbide in an aluminum 1100 matrix, because there is no reaction between aluminum and boron carbide below 842°F, well above the basket temperature under normal conditions of storage or transport[1].

Corrosion testing is not required for full density MMCs consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[2].

P.9.1.7.6.4 Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity

At least three samples, one each from the two ends and middle of the test material production run shall be subject to:

a) room temperature tensile testing (ASTM- B557[3]) demonstrating that the material has the following tensile properties:

- Minimum yield strength, 0.2% offset: 1.5 ksi
- Minimum ultimate strength: 5 ksi
- Minimum elongation in 2 inches: 0.5%

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1 Sung, C., "Microstructural Observation of Thermally Aged and Irradiated Aluminum/Boron Carbide ($B_4C$) Metal Matrix Composite by Transmission and Scanning Electron Microscope," 1998.

2 Boralyn testing submitted to the NRC under docket 71-1027, 1998.

3 ASTM B557 Standard Test Methods of Tension Testing Wrought and Cast Aluminum and Magnesium-Alloy Products.

(Alternatively show that the material fails in a ductile manner, e.g., by scanning electron microscopy of the fracture surface or by bend testing.)

and

b) testing (ASTM-B311[4]) to verify more than 98% (or 97% for MMCs with integral aluminum cladding) of theoretical density. Testing or examination for exposed interconnected porosity shall be performed by a means to be approved by the Certificate Holder.

P.9.1.7.6.5 Required Tests and Examinations to Demonstrate B10 Uniformity

> ***CAUTION***
>
> *Section P.9.1.7.6.4 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

**Uniformity of the boron distribution shall be verified either by:**

**a) Neutron radioscopy or radiography (ASTM E94[5], E142[6], and E545[7]) of material from the ends and middle of the test material production run, verifying no more than 10% difference between the minimum and maximum B10 areal density, or**

**b) Quantitative testing for the B10 areal density, B10 density, or the boron carbide weight fraction, on locations distributed over the test material production run, verifying that one standard deviation in the sample is less than 10% of the sample mean. Testing may be performed by a neutron transmission method similar to that specified in Section P.9.1.7.5, or by chemical analysis for boron carbide content in the composite.**

P.9.1.7.6.6 Approval of Procedures

Qualification procedures shall be subject to approval by the Certificate Holder.

P.9.1.7.7 Specification for Process Controls for Metal Matrix Composites

P.9.1.7.7.1 Applicability and Scope

The applicability of this section is the same as that of Section P.9.1.7.6. It addresses the process controls to ensure that the material delivered for use is equivalent to the qualification test material.

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4 ASTM B311, Test Method for Density Determination for Powder Metallurgy (P/M) Materials Containing Less than Two Percent Porosity

5 ASTM E94, Recommended Practice for Radiographic Testing

6 ASTM E142, Controlling Quality of Radiographic Testing

7 ASTM E545, Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing

Key processing changes shall be subject to qualification prior to use of the material produced by the revised process. The Certificate Holder shall determine whether a complete or partial re-qualification program per Section P.9.1.7.7 is required, depending on the characteristics of the material that could be affected by the process change.

P.9.1.7.7.2 Definition of Key Process Changes

Key process changes are those which could adversely affect the uniform distribution of the boron carbide in the aluminum, reduce density, or reduce the mechanical strength or ductility of the MMC.

P.9.1.7.7.3 Identification and Control of Key Process Changes

***CAUTION***

*Section P.9.1.7.7.3 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

**The manufacturer shall provide the Certificate Holder with a description of materials and process controls used in producing the MMC. The Certificate Holder and manufacturer shall identify key process changes as defined in Section P.9.1.7.7.2.**

**An increase in nominal boron carbide content over that previously qualified shall always be regarded as a key process change. The following are examples of other changes that may be established as key process changes, as determined by the Certificate Holder's review of the specific applications and production processes:**

a) **Changes in the boron carbide particle size specification that increase the average particle size by more than 5 microns or that increase the amount of particles larger than 60 microns from the previously qualified material by more than 5% of the total distribution but less than the 10% limit,**

b) **Change of the billet production process, e.g., from vacuum hot pressing to cold isostatic pressing followed by vacuum sintering,**

c) **Change in the nominal matrix alloy,**

d) **Changes in mechanical processing that could result in reduced density of the final product, e.g., for PM or thermal spray MMCs that were qualified with extruded material, a change to direct rolling from the billet,**

e) **For MMCs using a 6000 series aluminum matrix, changes in the billet formation process that could increase the likelihood of magnesium reaction with the boron carbide, such as an increase in the maximum temperature or time at maximum**

**temperature, and**

f) **Changes in powder blending or melt stirring processes that could result in less uniform distribution of boron carbide, e.g., change in duration of powder blending.**

**In no case shall process changes be accepted if they result in a product outside the limits in Sections P.9.1.7.6.1 and P.9.7.6.4.**

## P.9.2 Maintenance Program

NUHOMS®-24PTH system is a totally passive system and therefore requires little, if any, maintenance over the lifetime of the ISFSI. Typical NUHOMS®-24PTH system maintenance tasks are performed in accordance with the FSAR.

## P.9.3 References


9.1 ASME Boiler and Pressure Vessel Code, Section III, 1998 Edition including 2000 addenda.

9.2 ANSI N14.5-1997, "American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials," February 1998.

9.3 ASTM E1225, "Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique."

9.4 ASTM E1461, "Thermal Diffusivity of Solids by the Flash Method."

9.5 "Aluminum Standards and Data, 2003" The Aluminum Association.

9.6 Natrella, "Experimental Statistics," Dover, 2005.

9.7 Not Used.

9.8 SNT-TC-1A, "American Society for Nondestructive Testing, Personnel Qualification and Certification in Nondestructive Testing," 1992.

9.9 AAR Advanced Structures, "Boral®, The Proven Neutron Absorber."

9.10 AAR Advanced Structures, Boral® Product Performance Report 624.

**Table P.9-1**
**B10 Specification for the NUHOMS®-24PTH Poison Plates**

| Poison Type | 24PTH Basket Type | Minimum Poison Loading (B10 mg/cm$^2$) | % Credit Used in Criticality Analysis |
|---|---|---|---|
| Borated Aluminum /MMC | 1A or 2A | 7 | 90 |
| | 1B or 2B | 15 | |
| | 1C or 2C | 32 | |
| Boral® | 1A or 2A | 9 | 75 |
| | 1B or 2B | 19 | |
| | 1C or 2C | 40 | |

T.9.1.7 Poison Acceptance

> ***CAUTION***
>
> *Sections T.9.1.7.1 through T.9.1.7.3 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of these sections is shown in bold type to distinguish it from other sections.*

The neutron absorber used for criticality control in the DSC basket may consist any of the following types of material:

(a) Borated Aluminum

(b) Boron carbide / Aluminum metal matrix composite (MMC)

(c) Boral®

The 61BTH DSC safety analyses do not rely upon the tensile strength of these materials. The radiation and temperature environment in the cask is not sufficiently severe to damage these metallic/ceramic materials. To assure performance of the neutron absorber's design function only the presence of B10 and the uniformity of its distribution need to be verified, with testing requirements specific to each material. The boron content of these three types of materials is given in Table T.9-1, Table T.9-2 and Table T.9-3, respectively.

References to metal matrix composites throughout this chapter are not intended to refer to Boral®, which is described later in this section.

T.9.1.7.1 **Borated Aluminum**

**See the Caution in Section T.9.1.7 before deletion or modification to this section.**

**The material is produced by direct chill (DC) or permanent mold casting with boron precipitating as a uniform fine dispersion of discrete $AlB_2$ or $TiB_2$ particles in the matrix of aluminum or aluminum alloy. For extruded products, the $TiB_2$ form of the alloy shall be used. For rolled products, either the $AlB_2$, the $TiB_2$, or a hybrid may be used.**

**Boron is added to the aluminum in the quantity necessary to provide the specified minimum B10 areal density in the final product, with sufficient margin to minimize rejection, typically 10 % excess. The amount required to achieve the specified minimum B10 areal density will depend on whether boron with the natural isotopic distribution of the isotopes B10 and B11, or boron enriched in B10 is used. In no case shall the boron content in the aluminum or aluminum alloy exceed 5% by weight.**

**The criticality calculations take credit for 90% of the minimum specified B10 areal density of borated aluminum. The basis for this credit is the B10 areal density acceptance testing, which shall be as specified in Section T.9.1.7.5. The specified acceptance testing assures that at any location in the material, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.**

**Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings"[9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surface, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

T.9.1.7.2 <u>Boron Carbide / Aluminum Metal Matrix Composites (MMC)</u>

**See the Caution in Section T.9.1.7 before deletion or modification to this section.**

**The material is a composite of fine boron carbide particles in an aluminum or aluminum alloy matrix. The material shall be produced by either direct chill casting, permanent mold casting, powder metallurgy, or thermal spray techniques. It is a low-porosity product, with a metallurgically bonded matrix. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding shall not exceed 50% by volume.**

**Prior to use in the 61BTH DSC, MMCs shall pass the qualification testing specified in Section T.9.1.7.6, and shall subsequently be subject to the process controls specified in Section T.9.1.7.7.**

**The criticality calculations take credit for 90% of the minimum specified B10 areal density of MMCs. The basis for this credit is the B10 areal density acceptance testing, which is specified in Section T.9.1.7.5. The specified acceptance testing assures that at any location in the final product, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.**

**Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surfaces, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

T.9.1.7.3 <u>Boral®</u>

**See the Caution in Section T.9.1.7 before deletion or modification to this section.**

**This material consists of a core of aluminum and boron carbide powders between two outer layers of aluminum, mechanically bonded by hot-rolling an "ingot" consisting of an aluminum box filled with blended boron carbide and aluminum powders. The core, which is exposed at the edges of the sheet, is slightly porous. The average size of the boron carbide particles in the finished product is approximately 85 microns before rolling. The nominal boron carbide content shall be limited to 65% (+ 2% tolerance limit) of the core by weight.**

ASTM test methods and practices are referenced below for guidance. Alternative methods may be used with the approval of the certificate holder.

T.9.1.7.6.2 Design Requirements

In order to perform its design functions the product must have at a minimum sufficient strength and ductility for manufacturing and for the normal and accident conditions of the storage/ transport system. This is demonstrated by the tests in Section T.9.1.7.6.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section T.9.1.7.6.5.

T.9.1.7.6.3 Durability

There is no need to include accelerated radiation damage testing in the qualification. Such testing has already been performed on MMCs, and the results confirm what would be expected of materials that fall within the limits of applicability cited above. Metals and ceramics do not experience measurable changes in mechanical properties due to fast neutron fluences typical over the lifetime of spent fuel storage, about $10^{15}$ neutrons/$cm^2$.

The need for thermal damage and corrosion (hydrogen generation) testing shall be evaluated case-by-case based on comparison of the material composition and environmental conditions with previous thermal or corrosion testing of MMCs.

Thermal damage testing is not required for MMCs consisting only of boron carbide in an aluminum 1100 matrix, because there is no reaction between aluminum and boron carbide below 842°F, well above the basket temperature under normal conditions of storage or transport[1].

Corrosion testing is not required for full density MMCs consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[2].

T.9.1.7.6.4 Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity

At least three samples, one each from the two ends and middle of the test material production run shall be subject to:

a) room temperature tensile testing (ASTM- B557[3]) demonstrating that the material has the following tensile properties:

- Minimum yield strength, 0.2% offset: 1.5 ksi
- Minimum ultimate strength: 5 ksi
- Minimum elongation in 2 inches: 0.5%

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1 Sung, C., "Microstructural Observation of Thermally Aged and Irradiated Aluminum/Boron Carbide ($B_4C$) Metal Matrix Composite by Transmission and Scanning Electron Microscope," 1998.

2 Boralyn testing submitted to the NRC under docket 71-1027, 1998.

3 ASTM B557 Standard Test Methods of Tension Testing Wrought and Cast Aluminum and Magnesium-Alloy Products.

(Alternatively show that the material fails in a ductile manner, e.g., by scanning electron microscopy of the fracture surface or by bend testing.)

and

b) testing (ASTM-B311[4]) to verify more than 98% (or 97% for MMCs with integral aluminum cladding) of theoretical density. Testing or examination for exposed interconnected porosity shall be performed by a means to be approved by the Certificate Holder.

T.9.1.7.6.5 Required Tests and Examinations to Demonstrate B10 Uniformity

> ***CAUTION***
>
> *Section T.9.1.7.6.5 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

**Uniformity of the boron distribution shall be verified either by:**

**a) Neutron radioscopy or radiography (ASTM E94[5], E142[6], and E545[7]) of material from the ends and middle of the test material production run, verifying no more than 10% difference between the minimum and maximum B10 areal density, or**

**b) Quantitative testing for the B10 areal density, B10 density, or the boron carbide weight fraction, on locations distributed over the test material production run, verifying that one standard deviation in the sample is less than 10% of the sample mean. Testing may be performed by a neutron transmission method similar to that specified in Section 9.1.7.5, or by chemical analysis for boron carbide content in the composite.**

T.9.1.7.6.6 Approval of Procedures

Qualification procedures shall be subject to approval by the Certificate Holder.

4 ASTM B311, Test Method for Density Determination for Powder Metallurgy (P/M) Materials Containing Less than Two Percent Porosity

5 ASTM E94, Recommended Practice for Radiographic Testing

6 ASTM E142, Controlling Quality of Radiographic Testing

7 ASTM E545, Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing

U.9.1.7 Poison Acceptance

| CAUTION |
| --- |
| *Sections U.9.1.7.1 through U.9.1.7.3 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of these sections is shown in bold type to distinguish it from other sections.* |

The neutron absorber used for criticality control in the DSC basket may consist any of the following types of material:

(a) Borated Aluminum

(b) Boron carbide / Aluminum metal matrix composite (MMC)

(c) Boral®

The 32PTH1 DSC safety analyses do not rely upon the tensile strength of these materials. The radiation and temperature environment in the cask is not sufficiently severe to damage these metallic/ceramic materials. To assure performance of the neutron absorber's design function only the presence of B10 and the uniformity of its distribution need to be verified, with testing requirements specific to each material. The boron content for these materials is given in Table U.9-1.

References to metal matrix composites throughout this chapter are not intended to refer to Boral®, which is described later in this section.

U.9.1.7.1 **Borated Aluminum**

**See the Caution in Section U.9.1.7 before deletion or modification to this section.**

**The material is produced by direct chill (DC) or permanent mold casting with boron precipitating as a uniform fine dispersion of discrete $AlB_2$ or $TiB_2$ particles in the matrix of aluminum or aluminum alloy. For extruded products, the $TiB_2$ form of the alloy shall be used. For rolled products, either the $AlB_2$, the $TiB_2$, or a hybrid may be used.**

**Boron is added to the aluminum in the quantity necessary to provide the specified minimum B10 areal density in the final product, with sufficient margin to minimize rejection, typically 10 % excess. The amount required to achieve the specified minimum B10 areal density will depend on whether boron with the natural isotopic distribution of the isotopes B10 and B11, or boron enriched in B10 is used. In no case shall the boron content in the aluminum or aluminum alloy exceed 5% by weight.**

**The criticality calculations take credit for 90% of the minimum specified B10 areal density of borated aluminum. The basis for this credit is the B10 areal density acceptance testing, which shall be as specified in Section U.9.1.7.5. The specified acceptance testing assures that at any location in the material, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.**

**Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and**

**Castings"[9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surface, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

U.9.1.7.2 **Boron Carbide / Aluminum Metal Matrix Composites (MMC)**

**See the Caution in Section U.9.1.7 before deletion or modification to this section.**

**The material is a composite of fine boron carbide particles in an aluminum or aluminum alloy matrix. The material shall be produced by either direct chill casting, permanent mold casting, powder metallurgy, or thermal spray techniques. It is a low-porosity product, with a metallurgically bonded matrix. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding shall not exceed 50% by volume.**

**Prior to use in the 32PTH1 DSC, MMCs shall pass the qualification testing specified in Section U.9.1.7.6, and shall subsequently be subject to the process controls specified in Section U.9.1.7.7.**

**The criticality calculations take credit for 90% of the minimum specified B10 areal density of MMCs. The basis for this credit is the B10 areal density acceptance testing, which is specified in Section U.9.1.7.5. The specified acceptance testing assures that at any location in the final product, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.**

**Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surfaces, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.**

U.9.1.7.3 **Boral®**

**See the Caution in Section U.9.1.7 before deletion or modification to this section.**

**This material consists of a core of aluminum and boron carbide powders between two outer layers of aluminum, mechanically bonded by hot-rolling an "ingot" consisting of an aluminum box filled with blended boron carbide and aluminum powders. The core, which is exposed at the edges of the sheet, is slightly porous. The average size of the boron carbide particles in the finished product is approximately 85 microns before rolling. The nominal boron carbide content shall be limited to 65% (+ 2% tolerance limit) of the core by weight.**

**The criticality calculations take credit for 75% of the minimum specified B10 areal density of Boral®. B10 areal density will be verified by chemical analysis and by certification of the**

U.9.1.7.5 **Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission**

> ***CAUTION***
>
> *Section U.9.1.7.5 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

**Neutron Transmission acceptance testing procedures shall be subject to approval by the Certificate Holder. Test coupons shall be removed from the rolled or extruded production material at locations that are systematically or probabilistically distributed throughout the lot. Test coupons shall not exhibit physical defects that would not be acceptable in the finished product, or that would preclude an accurate measurement of the coupon's physical thickness.**

**A lot is defined as all the pieces produced from a single ingot or heat or from a group of billets from the same heat. If this definition results in lot size too small to provide a meaningful statistical analysis of results, an alternate larger lot definition may be used, so long as it results in accumulating material that is uniform for sampling purposes.**

**The sampling rate for neutron transmission measurements shall be such that there is at least one neutron transmission measurement for each 2000 square inches of final product in each lot.**

**The B10 areal density is measured using a collimated thermal neutron beam of up to 1.2 centimeter diameter. A beam size greater than 1.2 centimeter diameter but no larger than 1.7 centimeter diameter may be used if computations are performed to demonstrate that the calculated $k_{effective}$ of the system is still below the calculated Upper Subcritical Limit (USL) of the system assuming defect areas the same area as the beam.**

**The neutron transmission through the test coupons is converted to B10 areal density by comparison with transmission through calibrated standards. These standards are composed of a homogeneous boron compound without other significant neutron absorbers. For example, boron carbide, zirconium diboride or titanium diboride sheets are acceptable standards. These standards are paired with aluminum shims sized to match the effect of neutron scattering by aluminum in the test coupons. Uniform but non-homogeneous materials such as metal matrix composites may be used for standards, provided that testing shows them to provide neutron attenuation equivalent to a homogeneous standard.**

**Alternatively, digital image analysis may be used to compare neutron radioscopic images of the test coupon to images of the standards. The area of image analysis shall be up to 1.1 $cm^2$. The method shall demonstrate sufficient sensitivity to distinguish between areal density at the specified minimum, 1% above and below the minimum.**

be used with the approval of the certificate holder.

U.9.1.7.6.2 Design Requirements

In order to perform its design functions the product must have at a minimum sufficient strength and ductility for manufacturing and for the normal and accident conditions of the storage/ transport system. This is demonstrated by the tests in Section U.9.1.7.6.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section U.9.1.7.6.5.

U.9.1.7.6.3 Durability

There is no need to include accelerated radiation damage testing in the qualification. Such testing has already been performed on MMCs, and the results confirm what would be expected of materials that fall within the limits of applicability cited above. Metals and ceramics do not experience measurable changes in mechanical properties due to fast neutron fluences typical over the lifetime of spent fuel storage, about $10^{15}$ neutrons/$cm^2$.

The need for thermal damage and corrosion (hydrogen generation) testing shall be evaluated case-by-case based on comparison of the material composition and environmental conditions with previous thermal or corrosion testing of MMCs.

Thermal damage testing is not required for MMCs consisting only of boron carbide in an aluminum 1100 matrix, because there is no reaction between aluminum and boron carbide below 842°F, well above the basket temperature under normal conditions of storage or transport[1].

Corrosion testing is not required for full density MMCs consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[2].

U.9.1.7.6.4 Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity

At least three samples, one each from the two ends and middle of the test material production run shall be subject to:

a) room temperature tensile testing (ASTM- B557[3]) demonstrating that the material has the following tensile properties:

- Minimum yield strength, 0.2% offset: 1.5 ksi
- Minimum ultimate strength: 5 ksi
- Minimum elongation in 2 inches: 0.5%

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1 Sung, C., "Microstructural Observation of Thermally Aged and Irradiated Aluminum/Boron Carbide ($B_4C$) Metal Matrix Composite by Transmission and Scanning Electron Microscope," 1998.

2 Boralyn testing submitted to the NRC under docket 71-1027, 1998.

3 ASTM B557 Standard Test Methods of Tension Testing Wrought and Cast Aluminum and Magnesium-Alloy Products.

(Alternatively show that the material fails in a ductile manner, e.g., by scanning electron microscopy of the fracture surface or by bend testing.)

and

b) testing (ASTM-B311[4]) to verify more than 98% (or 97% for MMCs with integral aluminum cladding) of theoretical density. Testing or examination for exposed interconnected porosity shall be performed by a means to be approved by the Certificate Holder.

U.9.1.7.6.5 **Required Tests and Examinations to Demonstrate B10 Uniformity**

| CAUTION |
|---|
| *Section U.9.1.7.6.5 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.* |

**Uniformity of the boron distribution shall be verified either by:**

**a) Neutron radioscopy or radiography (ASTM E94[5], E142[6], and E545[7]) of material from the ends and middle of the test material production run, verifying no more than 10% difference between the minimum and maximum B10 areal density, or**

**b) Quantitative testing for the B10 areal density, B10 density, or the boron carbide weight fraction, on locations distributed over the test material production run, verifying that one standard deviation in the sample is less than 10% of the sample mean. Testing may be performed by a neutron transmission method similar to that specified in Section U.9.1.7.5, or by chemical analysis for boron carbide content in the composite.**

U.9.1.7.6.6 Approval of Procedures

Qualification procedures shall be subject to approval by the Certificate Holder.

U.9.1.7.7 Specification for Process Controls for Metal Matrix Composites

U.9.1.7.7.1 Applicability and Scope

The applicability of this section is the same as that of Section U.9.1.7.6. It addresses the process controls to ensure that the material delivered for use is equivalent to the qualification test

4 ASTM B311, Test Method for Density Determination for Powder Metallurgy (P/M) Materials Containing Less than Two Percent Porosity

5 ASTM E94, Recommended Practice for Radiographic Testing

6 ASTM E142, Controlling Quality of Radiographic Testing

7 ASTM E545, Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing

material.

Key processing changes shall be subject to qualification prior to use of the material produced by the revised process. The Certificate Holder shall determine whether a complete or partial re-qualification program per Section U.9.1.7.7 is required, depending on the characteristics of the material that could be affected by the process change.

U.9.1.7.7.2 Definition of Key Process Changes

Key process changes are those which could adversely affect the uniform distribution of the boron carbide in the aluminum, reduce density, or reduce the mechanical strength or ductility of the MMC.

U.9.1.7.7.3 **Identification and Control of Key Process Changes**

***CAUTION***

*Section U.9.1.7.7.3 is incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications (paragraph 1.2.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

**The manufacturer shall provide the Certificate Holder with a description of materials and process controls used in producing the MMC. The Certificate Holder and manufacturer shall identify key process changes as defined in Section U.9.1.7.7.2.**

**An increase in nominal boron carbide content over that previously qualified shall always be regarded as a key process change. The following are examples of other changes that may be established as key process changes, as determined by the Certificate Holder's review of the specific applications and production processes:**

**a) Changes in the boron carbide particle size specification that increase the average particle size by more than 5 microns or that increase the amount of particles larger than 60 microns from the previously qualified material by more than 5% of the total distribution but less than the 10% limit,**

**b) Change of the billet production process, e.g., from vacuum hot pressing to cold isostatic pressing followed by vacuum sintering,**

**c) Change in the nominal matrix alloy,**

**d) Changes in mechanical processing that could result in reduced density of the final product, e.g., for PM or thermal spray MMCs that were qualified with extruded material, a change to direct rolling from the billet,**

**e) For MMCs using a 6000 series aluminum matrix, changes in the billet formation process that could increase the likelihood of magnesium reaction with the boron**

**carbide, such as an increase in the maximum temperature or time at maximum temperature, and**

**f) Changes in powder blending or melt stirring processes that could result in less uniform distribution of boron carbide, e.g., change in duration of powder blending.**

**In no case shall process changes be accepted if they result in a product outside the limits in Sections U.9.1.7.6.1 and U.9.1.7.6.4.**

**Table U.9-1**
**B10 Specification for the NUHOMS® 32PTH1 Poison Plates**

| Poison Type | 32PTH1 Basket Type | Minimum Poison Loading (B10 mg/cm$^2$) | % Credit Used in Criticality Analysis |
|---|---|---|---|
| Borated Aluminum /MMC | 1A or 2A | 7 | 90 |
| | 1B or 2B | 15 | |
| | 1C or 2C | 20 | |
| | 1D or 2D | 32 | |
| | 1E or 2E | 50 | |
| Boral® | 1A or 2A | 9 | 75 |
| | 1B or 2B | 19 | |
| | 1C or 2C | 25 | |
| | 1D or 2D | N/A | |
| | 1E or 2E | N/A | |