Enclosure 3 to E-48527

Standardized NUHOMS® Updated Final Safety Analysis Report Revision 15 Chapters which Contain TS Incorporated by Reference

K.9 Tests and Maintenance Program

K.9.1 Acceptance Tests

The pre-operational testing requirements for the *Standardized* NUHOMS® system are given in Section 9.0 with the exceptions described in the following sections. The NUHOMS®-61BT DSC has been enhanced to provide leaktight confinement and the basket includes an updated poison plate design. Additional acceptance testing of the NUHOMS®-61BT DSC welds and of the poison plates are described. AMD 11

K.9.1.1 Visual Inspection

No change *to Section 4.5.1*.

K.9.1.2 Structural.

The NUHOMS®-61BT DSC confinement welds are designed, fabricated, tested and inspected in accordance with ASME B&PV Code Subsection NB [9.1] with exceptions as listed in Section K.3.1. The following requirements are unique to the NUHOMS®-61BT DSC:

- The inner bottom cover weld is inspected in accordance with Article NB-5231.
- The outer bottom cover weld root and cover are penetrant tested.
- The canister shell longitudinal and circumferential welds are 100% radiographically inspected.
- The outer top cover plate weld root, middle and cover are penetrant tested.

The NUHOMS®-61BT DSC basket is designed, fabricated, and inspected in accordance with ASME B&PV Code Subsection NG [9.1] with exceptions as listed in Section K.3.1. The following requirements are unique to the NUHOMS®-61BT DSC:

- The fuel compartment wrapper welds are inspected in accordance with Article NG-5231.
- The fuel compartment welds are inspected in accordance with Article NG-5231.

K.9.1.3 Leak Tests

The NUHOMS®-61BT DSC confinement is leak tested to verify it is leaktight in accordance with ANSI N14.5 [9.2].

The leak tests are typically performed using the helium mass spectrometer method. Alternative methods are acceptable, provided that the required sensitivity is achieved.

K.9.1.4 Components

The Standardized NUHOMS® system does not include any components such as valves, rupture discs, pumps, or blowers. No other components of the Standardized NUHOMS® system require testing, except as discussed in this Appendix.

K.9.1.5 Shielding Integrity

No change to Section 4.3.9 and Appendix U, Section U.9.1.5.

K.9.1.6 Thermal Acceptance

No thermal acceptance testing is required to verify the performance of each storage unit other than that specified in the Technical Specifications for initial loading.

The heat transfer analysis for the basket includes credit for the thermal conductivity of neutron-absorbing materials, as specified in Section K.4.3. Because these materials do not have publicly documented values for thermal conductivity, testing of such materials will be performed in accordance with Section K.9.1.7.6.

K.9.1.7 Poison Acceptance

CAUTION
Sections K.9.1.7.1 through K.9.1.7.4 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 1) and shall not be deleted or altered in any way without 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.

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

K.9.1.7.1 Borated Aluminum

All changes on this page are AMD 13

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 primarily as a uniform fine dispersion of discrete AlB_2 or TiB_2 particles in the matrix of aluminum or aluminum alloy (other boron compounds, such as AlB_{12}, can also occur). 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. 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.9.1.7.7. 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.

K.9.1.7.2 **Boron Carbide / Aluminum Metal Matrix Composites (MMCs)**

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, *molten metal infiltration* or thermal spray techniques. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding *or produced by molten metal infiltration* shall not exceed 50% by volume.

The final MMC product shall have density greater than 98% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity. For MMC with an integral cladding, the final density of the core shall be greater than 97% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity of the core and cladding as a unit of the final product.

At least 50% by weight of the B_4C particles in MMCs shall be smaller than 40 microns. No more than 10% of the particles shall be over 60 microns.

Prior to use in the 61BT DSC, MMCs shall pass the qualification testing specified in Section K.9.1.7.8, and shall subsequently be subject to the process controls specified in Section K.9.1.7.9.

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.9.1.7.7. 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.

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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. Before rolling, at least 80% by weight of the B_4C particles in BORAL® shall be smaller than 200 microns. 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 a coupon taken from 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.

K.9.1.7.4 Visual Inspections of Neutron Absorbers

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

Neutron absorbers shall be 100% visually inspected in accordance with the Certificate Holder's QA procedures. *Blisters shall be treated as non-conforming. For clad MMCs and for BORAL®, visual inspection shall verify that there are no cracks through the cladding, exposed core on the face of the sheet, or solid aluminum at the edge of the sheet. Material that does not meet these criteria shall be reworked, repaired, or scrapped.*

K.9.1.7.5 Other Visual Inspections Criteria (non-Technical Specifications)

For borated aluminum and MMCs, visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

K.9.1.7.6 Thermal Conductivity Testing

*Acceptance t*esting shall conform to ASTM E1225[1], ASTM E1461[2], or equivalent method, performed at roomtemperature on coupons taken from the rolled or extruded production material. Initial sampling shall be one test per lot, and may be reduced if the first five tests meet the specified minimum thermal conductivity. *For cast products, the lot shall be defined by the heat or ingot. For other products, the lot shall be defined as material produced in a single production campaign using the same heat or lots of aluminum and boron carbide feed materials.*

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If a thermal conductivity test result is below the specified minimum, at least four additional tests shall be performed on the material from that lot. If the mean value of those tests, including the original test, falls below the specified minimum, the associated lot shall be rejected.

After twenty five tests of a single type of material, with the same aluminum alloy matrix, the same boron content, and the same primary boron phase, e.g., B_4C, TiB_2, or AlB_2, if the mean value of all the test results less two standard deviations meets the specified thermal conductivity, no further testing of that material is required. This exemption may also be applied to the same type of material if the matrix of the material changes to a more thermally conductive alloy (e.g., from 6000 to 1000 series aluminum), or if the boron content is reduced without changing the boron phase.

The measured thermal conductivity values shall satisfy the minimum required conductivities as specified in Section K.4.3.

In cases where the specified thickness of the neutron absorber may vary, the equations introduced in Section K.4.3 shall be used to determine the minimum required effective thermal conductivity.

The thermal conductivity test requirement does not apply to aluminum that is paired with the neutron absorber.

K.9.1.7.7 Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission

CAUTION

Portions of Section K.9.1.7.7 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 1) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

a) 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

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

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

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.

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The B10 areal density is measured using a collimated thermal neutron beam up to 1.1 inch diameter.

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.

Standards will be calibrated, traceable to nationally recognized standards, or by attenuation of a monoenergetic neutron beam correlated to the known cross section of B10 at that energy.

The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the one-sided tolerance limit for a normal distribution may be used for this purpose. Otherwise, a non-parametric (distribution-free) method of determining the one-sided tolerance limit may be used. Demonstration of the one-sided tolerance limit shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

b) The following illustrates one acceptable method and is intended to be utilized as an example. Therefore, the following text is not part of the Technical Specifications. The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The B10 areal densities determined by neutron transmission are converted to volume density, i.e., the 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].

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 the statistically derived minimum thickness from K.9.1.7.7 a) 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. Edge effects due to manufacturing

operations such as shearing, deburring, and chamfering need not be included in this determination.

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

K.9.1.7.8 Specification for Qualification Testing of Metal Matrix Composites

All changes on this page are AMD 13

CAUTION

Portions of Section K.9.1.7.8.4 and Section K.9.1.7.8.5 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 1) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

K.9.1.7.8.1 Applicability and Scope

MMCs acceptable for use in the 61BT DSC are described in Section K.9.1.7.2.

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.9.1.7.9 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.9.1.7.8.2 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.9.1.7.8.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section K.9.1.7.8.5.

K.9.1.7.8.3 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.

Thermal damage and corrosion (hydrogen generation) testing shall be performed unless such tests on materials of the same chemical composition have already been performed and found acceptable. The following paragraphs illustrate two cases where such testing is not required.

Thermal damage testing is not required for unclad 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[3].

Corrosion testing is not required for MMCs (clad or unclad) consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[4].

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K.9.1.7.8.4 **Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity**

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

a) room temperature tensile testing (ASTM- B557[5]) 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%**

As an alternative to the elongation requirement, ductility may be demonstrated by bend testing per ASTM E290[6]. The radius of the pin or mandrel shall be no greater than three times the material thickness, and the material shall be bent at least 90 degrees without complete fracture.

b) Testing to verify more than 98% of theoretical density for non-clad MMCs and 97% for the matrix of clad MMCs. Testing or examination for interconnected porosity on the faces and edges of unclad MMC, and on the edges of clad MMC shall be performed by a means to be approved by the Certificate Holder. The maximum interconnected porosity is 0.5 volume %.

Delamination Testing of Clad MMC

c) Clad MMCs shall be subjected to thermal damage testing following water immersion to ensure that delamination does not occur under normal conditions of storage. *An example of such a test would be: (1) immerse a specimen at least 6 x 6 inches in water under pressure ≥30 psig for at least 24 hours, (2) place the specimen in a vacuum furnace preheated to at least 300°F and evacuate the furnace. Acceptance criterion: no blistering or delamination of the cladding.*

K.9.1.7.8.5 **Required Tests and Examinations to Demonstrate B10 Uniformity**

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

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

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

6 ASTM E290, Standard Methods for Bend Testing of Materials for Ductility

Uniformity of the boron distribution shall be verified either by:

a) Neutron radioscopy or radiography (ASTM E94[7], E142[8], and E545[9]) 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.9.1.7.7, or by chemical analysis for boron carbide content in the composite.

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K.9.1.7.8.6 Qualification Report

Qualification *report* shall be *prepared by, or* subject to approval by the Certificate Holder.

K.9.1.7.9 Specification for Process Controls for Metal Matrix Composites

> **CAUTION**
> Sections K.9.1.7.9.1 and K.9.1.7.9.2 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications *(paragraph 4.1 (*(Note 1)*)* and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

K.9.1.7.9.1 **Applicability and Scope**

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.9.1.7.8 is required, depending on the characteristics of the material that could be affected by the process change.

K.9.1.7.9.2 **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, reduce corrosion resistance, reduce the mechanical strength or ductility of the MMC.

K.9.1.7.9.3 Identification and Control of Key Process Changes

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.9.1.7.9.2.

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7 ASTM E94, Recommended Practice for Radiographic Testing

8 ASTM E142, Controlling Quality of Radiographic Testing

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

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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 are 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 *(d50)* 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 magnesium-alloyed 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,

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, and

g) For MMCs with an integral aluminum cladding, a change greater than 25% in the ratio of the nominal aluminum cladding thickness (sum of two sides of cladding) and the nominal matrix thickness could result in changes in the mechanical properties of the final product.

K.9.2 Maintenance Program

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 *Deleted.*

9.4 *Deleted.*

9.5 “Aluminum Standards and Data, 2003” The Aluminum Association.

9.6 Natrella, “Experimental Statistics,” Dover, 2005.

9.7 *Deleted.*

9.8 *Deleted.*

9.9 *Deleted.*

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Table K.9-1
B10 Specification for the NUHOMS® 61BT Poison Plates

Basket Type	*Specified Minimum B10 Areal Density for Borated Aluminum/MMC for 90% credit (g/cm^2)*	*Specified Minimum B10 Areal Density for BORAL® for 75% credit (g/cm^2)*
Type 1 DSC		
A	*0.021*	*0.025*
B	*0.032*	*0.038*
C	*0.040*	*0.048*
For Damaged Fuel		
C	*0.040*	*0.048*

Table K.9-2
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Table K.9-3
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M.9 Acceptance Tests and Maintenance Program

M.9.1 Acceptance Tests

The acceptance requirements for the NUHOMS®-32PT system are given in the *U*FSAR except as described in the following sections. The NUHOMS®-32PT DSC has been enhanced to provide leaktight confinement and the basket includes an updated poison plate design. Additional acceptance testing of the NUHOMS®-32PT DSC welds and poison plates are described.

All changes on this page are AMD 11

M.9.1.1 Visual Inspection

Visual examinations are performed at the fabricator's facility to ensure that the NUHOMS®-32PT system components conform to the fabrication specifications and drawings.

Visual examination of all finished absorber plates and rods are done to ensure that they are free of cracks, porosity, blisters, or foreign substances. Dimensional inspections of the plates and rods are done to ensure that their functional requirements listed in M.9.17.1 are met.

M.9.1.2 Structural Tests

The NUHOMS®-32PT DSC confinement welds are designed, fabricated, tested and inspected in accordance with ASME B&PV Code Section III, Subsection NB [9.1] with exceptions as listed in Section M.3.1. The following requirements are unique to the NUHOMS®-32PT DSC:

- The inner bottom cover weld is inspected in accordance with Article NB-5231,
- The outer bottom cover weld root and cover are penetrant tested, and
- The outer top cover plate weld root and cover are penetrant tested.

The NUHOMS®-32PT DSC basket is designed, fabricated, and inspected in accordance with ASME B&PV Code Section III, Subsection NG [9.1] with exceptions as listed in Section M.3.1. The following requirement is unique to the NUHOMS®-32PT DSC basket:

- The fuel compartment welds are inspected in accordance with Article NG-5260.

M.9.1.3 Leak Tests

The NUHOMS®-32PT DSC confinement boundary is leak tested to verify that it is leaktight in accordance with ANSI N14.5 [9.2]. The personnel performing the leak test are qualified in accordance with SNT-TC-1A [9.14].

The leak tests are typically performed using the helium mass spectrometer method. Alternative methods are acceptable, provided that the required sensitivity is achieved.

M.9.1.4 Component Tests

The Standardized NUHOMS® system does not include any components such as valves, rupture discs, pumps, or blowers. No other components of the Standardized NUHOMS® system require testing, except as discussed in this Appendix.

M.9.1.5 Shielding Integrity Tests

No changes to Section 4.3.9 and Appendix U, Section U.9.1.5.

M.9.1.6 Thermal Acceptance Tests

No thermal acceptance testing is required to verify the performance of each storage unit other than that specified in the Technical Specifications for initial loading.

The heat transfer analysis for the basket includes credit for the thermal conductivity of neutron absorbing materials, as specified in Section M.4.3. Because these materials do not have publicly documented values for thermal conductivity, testing of such materials will be performed in accordance with Section M.9.1.7.6.

M.9.1.7 Poison Acceptance

CAUTION Sections M.9.1.7.1 through M.9.1.7.4 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 2) and shall not be deleted or altered in any way without 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 is given in Table M.9-1.

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 primarily as a uniform fine dispersion of discrete AlB_2 or TiB_2 particles in the

matrix of aluminum or aluminum alloy (other boron compounds, such as AlB_{12}, can also occur). 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. 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.9.1.7.7. 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.

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

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, *molten metal infiltration,* or thermal spray techniques. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding *or produced by molten metal infiltration* shall not exceed 50% by volume.

The final MMC product shall have density greater than 98% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity. For MMC with an integral cladding, the final density of the core shall be greater than 97% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity of the core and cladding as a unit of the final product.

At least 50% by weight of the B_4C particles in MMCs shall be smaller than 40 microns. No more than 10% of the particles shall be over 60 microns.

Prior to use in the 32PT DSC, MMCs shall pass the qualification testing specified in Section M.9.1.7.8, and shall subsequently be subject to the process controls specified in Section M.9.1.7.9.

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.9.1.7.7. 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.

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M.9.1.7.3 **Not Used**

M.9.1.7.4 **Visual Inspections of Neutron Absorbers**

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

Neutron absorbers shall be 100% visually inspected in accordance with the Certificate Holder's QA procedures. Blisters shall be treated as non-conforming. For *clad MMCs*, visual inspection shall verify that there are no cracks through the cladding, exposed core on the face of the sheet, or solid aluminum at the edge of the sheet. *Material that does not meet the following acceptance criteria shall be reworked, repaired, or scrapped.*

M.9.1.7.5 Other Visual Inspections Criteria (non-Technical Specifications)

For borated aluminum and MMCs, visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

M.9.1.7.6 Thermal Conductivity Testing of Poison Plates

Acceptance testing shall conform to ASTM E1225[1], ASTM E1461[2], or equivalent method, performed at room temperature on coupons taken from the rolled or extruded production material. *Initial sampling shall be one test per lot, and may be reduced if the first five tests meet the specified minimum thermal conductivity. For cast products, the lot shall be defined by the heat or ingot. For other products, the lot shall be defined as material produced in a single production campaign using the same heat or lots of aluminum and boron carbide feed materials.*

If a thermal conductivity test result is below the specified minimum, at least four additional tests shall be performed on the material from that lot. If the mean value of those tests, including the original test, falls below the specified minimum, the associated lot shall be rejected.

After *twenty five* tests of a single type of material, with the same aluminum alloy matrix, the same boron content, and the same primary boron phase, e.g., B_4C, TiB_2, or AlB_2, if the mean value of all the test results less two standard deviations meets the specified thermal conductivity, no further testing of that material is required. This exemption may also be applied to the same type of material if the matrix of the material changes to a more thermally conductive alloy (e.g., from 6000 to 1000 series aluminum), or if the boron content is reduced without changing the boron phase.

The measured thermal conductivity values shall satisfy the minimum required conductivities as specified in Section M.4.3

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

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

In cases where the specified thickness of the neutron absorber may vary, the equations introduced in Section M.4.3 shall be used to determine the minimum required effective thermal conductivity.

The thermal conductivity test requirement does not apply to aluminum that is paired with the neutron absorber.

M.9.1.7.7 Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission

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> ***CAUTION***
> *Portions of Section M.9.1.7.7 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 2) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

a) **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 *1.1 inch* diameter.

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. *Standards will be calibrated, traceable to nationally recognized standards, or by attenuation of a monoenergetic neutron beam correlated to the known cross section of B10 at that energy.*

The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the one-sided tolerance limit for a normal distribution may be used for this purpose. Otherwise, a non-parametric (distribution-free) method of determining the one-sided tolerance limit may be used. Demonstration of the one-sided tolerance limit shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

b) The following illustrates one acceptable method and is intended to be utilized as an example. Therefore, the following text is not part of the Technical Specifications. The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The B10 areal densities determined by neutron transmission are converted to volume density, i.e., the 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].

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 the statistically derived minimum thickness from M.9.1.7.7a) 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. Edge effects due to manufacturing operations such as shearing, deburring, and chamfering need not be included in this determination.

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

M.9.1.7.8 Specification for Qualification Testing of Metal Matrix Composites

CAUTION

Portions of Section M.9.1.7.8.4 and Section M.9.1.7.8.5 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 2) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

M.9.1.7.8.1 Applicability and Scope

MMCs acceptable for use in the 32PT DSC are described in Section M.9.1.7.2.

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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.9.1.7.9 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 *C*ertificate *H*older.

M.9.1.7.8.2 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.9.1.7.8.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section M.9.1.7.8.5.

M.9.1.7.8.3 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.

Thermal damage and corrosion (hydrogen generation) testing shall be performed unless such tests on materials of the same chemical composition have already been performed and found acceptable. The following paragraphs illustrate two cases where such testing is not required.

Thermal damage testing is not required for unclad 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[3].

Corrosion testing is not required for full density MMCs (clad or unclad) consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[4]

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

[4] Boralyn testing submitted to the NRC under docket 71-1027, 1998

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M.9.1.7.8.4 Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity

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

a) **room temperature tensile testing (ASTM- B557[5]) 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%**

As an alternative to the elongation requirement, ductility may be demonstrated by bend testing per ASTM E290[6]. The radius of the pin or mandrel shall be no greater than three times the material thickness, and the material shall be bent at least 90 degrees without complete fracture.

b) **Testing to verify more than 98% of theoretical density for non-clad MMCs and 97% for the matrix of clad MMCs. Testing or examination for interconnected porosity on the faces and edges of unclad MMC, and on the edges of clad MMC shall be performed by a means to be approved by the Certificate Holder. The maximum interconnected porosity is 0.5 volume %.**

c) ***Delamination Testing of Clad MMC***
Clad MMCs shall be subjected to thermal damage testing following water immersion to ensure that delamination does not occur under normal conditions of storage. *An example of such a test would be: (1) immerse a specimen at least 6 x 6 inches in water under pressure ≥30 psig for at least 24 hours, (2) place the specimen in a vacuum furnace preheated to at least 300°F and evacuate the furnace. Acceptance criterion: no blistering or delamination of the cladding.*

M.9.1.7.8.5 Required Tests and Examinations to Demonstrate B10 Uniformity

Uniformity of the boron distribution shall be verified either by:

a) **Neutron radioscopy or radiography (ASTM E94[7], E142[8], and E545[9]) 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**

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5 ASTM B557 Standard Test Methods of Tension Testing Wrought and Cast Aluminum and Magnesium-Alloy Products
6 ASTM E290, Standard Methods for Bend Testing of Materials for Ductility
7 ASTM E94, Recommended Practice for Radiographic Testing
8 ASTM E142, Controlling Quality of Radiographic Testing
9 ASTM E545, Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing

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.9.1.7.7, or by chemical analysis for boron carbide content in the composite.**

M.9.1.7.8.6 *Qualification Report*

Qualification *report* shall be *prepared by, or* subject to approval by the Certificate Holder.

M.9.1.7.9 Specification for Process Controls for Metal Matrix Composites

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CAUTION
Sections M.9.1.7.9.1 and M.9.1.7.9.2 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 2) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

M.9.1.7.9.1 **Applicability and Scope**

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.9.1.7.8 is required, depending on the characteristics of the material that could be affected by the process change.

M.9.1.7.9.2 **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, reduce corrosion resistance, reduce the mechanical strength or ductility of the MMC.

M.9.1.7.9.3 **Identification and Control of Key Process Changes**

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.9.1.7.9.2.

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 are 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 *(d50)* 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,

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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 magnesium-alloyed 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,

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, and

g) For MMCs with an integral aluminum cladding, a change greater than 25% in the ratio of the nominal aluminum cladding thickness (sum of two sides of cladding) and the nominal matrix thickness could result in changes in the mechanical properties of the final product.

M.9.1.7.10 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 *U*FSAR.

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M.9.3 References

9.1 ASME Boiler and Pressure Vessel Code, Section III, *2004* Edition *through 2006* addenda.

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

9.3 *Deleted.*

9.4 *Deleted.*

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.

Table M.9-1
B10 Specification for the NUHOMS® - 32PT Poison Plates

Poison Type	32PT Basket Type	Minimum Poison Loading (B10 g/cm^2)	% Credit Used in Criticality Analysis
Borated Aluminum /MMC	A/B/C/D	0.007	90
Borated Aluminum /MMC	A1	0.015	90
Borated Aluminum /MMC	A2	0.020	90

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P.9 Acceptance Tests and Maintenance Program

P.9.1 Acceptance Tests

The acceptance requirements for the NUHOMS®-24PTH system are given in the UFSAR except as described in the following sections. The NUHOMS®-24PTH DSC has been enhanced to provide leaktight confinement and the basket includes an updated poison plate design. The requirements for the poison plate material acceptance tests and the NUHOMS®-24PTH DSC welds for the 24PTH system are described.

P.9.1.1 Visual Inspection

Visual examinations are performed at the fabricator's facility to ensure that the NUHOMS®-24PTH system components conform to the fabrication specifications and drawings.

P.9.1.2 Structural Tests

The NUHOMS®-24PTH DSC confinement welds are designed, fabricated, tested and inspected in accordance with ASME B&PV Code Section III, Subsection NB [9.1] with exceptions as listed in Section P.3.1. The following requirements are unique to the NUHOMS®-24PTH DSC:

- The inner bottom cover weld is inspected in accordance with Article NB-5231 when the weld joint design is per Figure NB-4243-1,
- The outer bottom cover weld is penetrant tested, and
- The outer top cover plate weld root and cover are penetrant tested.

The NUHOMS®-24PTH DSC basket is designed, fabricated, and inspected in accordance with ASME B&PV Code Section III, Subsection NG [9.1] with exceptions as listed in Section P.3.1.

P.9.1.3 Leak Tests

The NUHOMS®-24PTH DSC confinement boundary is leak tested to verify that it is leaktight in accordance with the criteria of ANSI N14.5 [9.2]. The personnel performing the leak test are qualified in accordance with SNT-TC-1A [9.8].

The leak tests are typically performed using the helium mass spectrometer method. Alternative methods are acceptable, provided that the required sensitivity is achieved.

P.9.1.4 Component Tests

The NUHOMS® system does not include any components such as valves, rupture discs, pumps, or blowers. No other components of the NUHOMS® system require testing, except as discussed in this chapter.

P.9.1.5 Shielding Integrity Tests

The transfer cask poured lead shielding integrity will be confirmed via gamma scanning prior to first use. The detector and examination grid will be matched to provide coverage of the entire lead-shielded surface area. For example, for a 6"x 6" grid, the detector will encompass a 6"x 6" square. The acceptance criterion is attenuation greater than or equal to that of a test block matching the cask through-wall configuration with lead and steel thicknesses equal to the design minima less 5%.

The radial neutron shielding is provided by filling the neutron shield shell with water during operations. No testing is necessary. The neutron shield material in the lid and bottom end is a proprietary polymer resin. The shielding performance of the resin will be assured by written procedures controlling temperature, measuring, and mixing of the components, degassing of the resin, and verification of the mass or volume of resin installed.

The gamma and neutron shielding materials of the storage system itself are limited to concrete HSM components and steel shield plugs in the DSC. The integrity of these shielding materials is ensured by the control of their fabrication in accordance with the appropriate ASME, ASTM or ACI criteria. No additional acceptance testing is required.

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P.9.1.6 Thermal Acceptance Tests

No thermal acceptance testing is required to verify the performance of each storage unit other than that specified in the Technical Specifications for initial loading.

The heat transfer analysis for the basket includes credit for the thermal conductivity of neutron-absorbing materials, as specified in Section P.4.3. Because these materials do not have publicly documented values for thermal conductivity, testing of such materials will be performed in accordance with Section P.9.1.7.6.

P.9.1.7 Poison Acceptance

CAUTION
Sections P.9.1.7.1 through P.9.1.7.4 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 3) and shall not be deleted or altered in any way without 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 *a*luminum

(b) Boron carbide/*a*luminum metal matrix composite (MMC)

(c) BORAL®

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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 primarily as a uniform fine dispersion of discrete AlB_2 or TiB_2 particles in the matrix of aluminum or aluminum alloy (other boron compounds, such as AlB_{12}, can also occur). 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. 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.9.1.7.7. 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.

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, *molten metal infiltration,* or thermal spray techniques. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding *or produced by molten metal infiltration* shall not exceed 50% by volume.

The final MMC product shall have density greater than 98% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity. For MMC with an integral cladding, the final density of the core shall be greater than 97% of theoretical density demonstrated by qualification testing, with no more than

0.5 volume % interconnected porosity of the core and cladding as a unit of the final product.

At least 50% by weight of the B_4C particles in MMCs shall be smaller than 40 microns. No more than 10% of the particles shall be over 60 microns.

Prior to use in the 24PTH DSC, MMCs shall pass the qualification testing specified in Section P.9.1.7.8, and shall subsequently be subject to the process controls specified in Section P.9.1.7.9.

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.9.1.7.7. 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.

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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. Before rolling, at least 80% by weight of the B_4C particles in BORAL® shall be smaller than 200 microns. 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 a coupon taken from 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.

P.9.1.7.4 Visual Inspections of Neutron Absorbers

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

Neutron absorbers shall be 100% visually inspected in accordance with the Certificate Holder's QA procedures. *Blisters shall be treated as non-conforming. For clad MMCs and for BORAL®, visual inspection shall verify that there are no cracks through the cladding, exposed core on the face of the sheet, or solid aluminum at the edge of the sheet.* Material that does not meet *these* acceptance criteria shall be reworked, repaired, or scrapped.

P.9.1.7.5 Other Visual Inspections Criteria (non-Technical Specifications)

For borated aluminum and MMCs, visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

P.9.1.7.6 Thermal Conductivity Testing of Poison Plates

*Acceptance t*esting shall conform to ASTM E1225[1], ASTM E1461[2], or equivalent method, performed at room temperature on coupons taken from the rolled or extruded production material. Initial sampling shall be one test per lot, and may be reduced if the first five tests meet the specified minimum thermal conductivity. *For cast products, the lot shall be defined by the heat or ingot. For other products, the lot shall be defined as material produced in a single production campaign using the same heat or lots of aluminum and boron carbide feed materials.*

If a thermal conductivity test result is below the specified minimum, at least four additional tests shall be performed on the material from that lot. If the mean value of those tests, including the original test, falls below the specified minimum, the associated lot shall be rejected.

After *twenty five* tests of a single type of material, with the same aluminum alloy matrix, the same boron content, and the same primary boron phase, e.g., B_4C, TiB_2, or AlB_2, if the mean value of all the test results less two standard deviations meets the specified thermal conductivity, no further testing of that material is required. This exemption may also be applied to the same type of material if the matrix of the material changes to a more thermally conductive alloy (e.g., from 6000 to 1000 series aluminum), or if the boron content is reduced without changing the boron phase.

The measured thermal conductivity values shall satisfy the minimum required conductivities as specified in Section P.4.3.

In cases where the specified thickness of the neutron absorber may vary, the equations introduced in Section P.4.3 shall be used to determine the minimum required effective thermal conductivity.

The thermal conductivity test requirement does not apply to aluminum that is paired with the neutron absorber.

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

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

P.9.1.7.7 Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission

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CAUTION

Portions of Section P.9.1.7.7 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 3) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

a) 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 1.1 inch diameter.

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. Standards will be calibrated, traceable to nationally recognized standards, or by attenuation of a monoenergetic neutron beam correlated to the known cross section of B10 at that energy.

The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the one-sided tolerance limit for a normal distribution may be used for this purpose. Otherwise, a non-parametric (distribution-free) method of determining the one-sided tolerance limit may be used. Demonstration of the one-sided

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

b) The following illustrates one acceptable method and is intended to be utilized as an example. Therefore, the following text is not part of the Technical Specifications. The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The B10 areal densities determined by neutron transmission are converted to volume density, i.e., the 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].

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 the statistically derived minimum thickness from P.9.1.7.7 a) 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. Edge effects due to manufacturing operations such as shearing, deburring, and chamfering need not be included in this determination.

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

P.9.1.7.8 Specification for Qualification Testing of Metal Matrix Composites

CAUTION
Portions of Section P.9.1.7.8.4 and Section P.9.1.7.8.5 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 3) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

P.9.1.7.8.1 Applicability and Scope

Metal matrix composites (MMCs) acceptable for use in the 24PTH DSC are described in Section P.9.1.7.2.

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.9.1.7.9 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.

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

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P.9.1.7.8.2 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.9.1.7.8.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section P.9.1.7.8.5.

P.9.1.7.8.3 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.

Thermal damage and corrosion (hydrogen generation) testing shall be performed unless such tests on materials of the same chemical composition have already been performed and found acceptable. The following paragraphs illustrate two cases where such testing is not required.

Thermal damage testing is not required for unclad 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[3].

Corrosion testing is not required for full density MMCs (clad or unclad) consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[4].

P.9.1.7.8.4 **Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity**

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

a) **room temperature tensile testing (ASTM- B557[5]) demonstrating that the material has the following tensile properties:**
   - **Minimum yield strength, 0.2% offset: 1.5 ksi**
   - **Minimum ultimate strength: 5 ksi**

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

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

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

- **Minimum elongation in 2 inches: 0.5%**

As an alternative to the elongation requirement, ductility may be demonstrated by bend testing per ASTM E290[6]. The radius of the pin or mandrel shall be no greater than three times the material thickness, and the material shall be bent at least 90 degrees without complete fracture.

b) Testing to verify more than 98% of theoretical density for non-clad MMCs and 97% for the matrix of clad MMCs. Testing or examination for interconnected porosity on the faces and edges of unclad MMC, and on the edges of clad MMC shall be performed by a means to be approved by the Certificate Holder. The maximum interconnected porosity is 0.5 volume %.

c) *Delamination Testing of Clad MMC*

Clad MMCs shall be subjected to thermal damage testing following water immersion to ensure that delamination does not occur under normal conditions of storage. An example of such a test would be: (1) immerse a specimen at least 6 x 6 inches in water under pressure ≥30 psig for at least 24 hours, (2) place the specimen in a vacuum furnace preheated to at least 300°F and evacuate the furnace. Acceptance criterion: no blistering or delamination of the cladding.

P.9.1.7.8.5 **Required Tests and Examinations to Demonstrate B10 Uniformity**

Uniformity of the boron distribution shall be verified either by:

a) Neutron radioscopy or radiography (ASTM E94[7], E142[8], and E545[9]) 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.9.1.7.7, or by chemical analysis for boron carbide content in the composite.

P.9.1.7.8.6 *Qualification Report*

Qualification *report* shall be *prepared by, or* subject to approval by the Certificate Holder.

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[6] ASTM E290, Standard Methods for Bend Testing of Materials for Ductility
[7] ASTM E94, Recommended Practice for Radiographic Testing
[8] ASTM E142, Controlling Quality of Radiographic Testing
[9] ASTM E545, Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing

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P.9.1.7.9 Specification for Process Controls for Metal Matrix Composites

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CAUTION

Sections P.9.1.7.9.1 and P.9.1.7.9.2 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 3) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

P.9.1.7.9.1 **Applicability and Scope**

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.9.1.7.8 is required, depending on the characteristics of the material that could be affected by the process change.

P.9.1.7.9.2 **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, reduce corrosion resistance, reduce the mechanical strength or ductility of the MMC.

P.9.1.7.9.3 Identification and Control of Key Process Changes

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.9.1.7.9.2.

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 are 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 *(d50)* 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 magnesium-alloyed 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,

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, and

g) For MMCs with an integral aluminum cladding, a change greater than 25% in the ratio of the nominal aluminum cladding thickness (sum of two sides of cladding) and the nominal matrix thickness could result in changes in the mechanical properties of the final product.

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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 *U*FSAR.

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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 *Deleted*.

9.4 *Deleted*.

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

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

9.7 *Deleted*.

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

9.9 *Deleted.*

9.10 *Deleted*.

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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	

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T.9 Acceptance Tests and Maintenance Program

T.9.1 Acceptance Tests

The pre-operational testing requirements for the NUHOMS® system are given in Chapter 9.0, with the exceptions described in the following sections. The NUHOMS®-61BTH DSC has been enhanced to provide leaktight confinement and the basket includes an updated poison plate design. Additional acceptance testing of the NUHOMS®-61BTH DSC welds and of the poison plates are described.

T.9.1.1 Visual Inspection

Visual inspections are performed at the fabricator's facility to ensure that the DSC, the Transfer Cask and the HSM conform to the drawings and specifications. The visual inspections include weld, dimensional, surface finish, and cleanliness inspections. Visual inspections specified by codes applicable to a component are performed in accordance with the requirements and acceptance criteria of those codes.

All weld inspection is performed using qualified processes and qualified personnel according to the applicable code requirements, e.g., ASME or AWS. Non-destructive examination (NDE) requirements for welds are specified on the drawings provided in Chapter T.1; acceptance criteria are as specified by the governing code. NDE personnel are qualified in accordance with SNT-TC-1A [9.2].

The confinement welds on the DSC are inspected in accordance with ASME B&PV Code Subsection NB [9.1] including alternatives to ASME Code specified in Section T.3.1.2.3.

DSC non-confinement welds are inspected to the NDE acceptance criteria of ASME B&PV Code Subsection NG or NF, based on the applicable code for the components welded.

T.9.1.2 Structural

The DSC confinement boundary except the inner top cover/shield plug to the DSC shell weld is pressure tested at the fabricator’s shop in accordance with ASME Article NB-6300. The test pressure is set between 14.5 to 16.0 psig for 61BTH DSC with Type 1 basket for future 10CFR71 application. This bounds the 1.1xDSC design pressure of 10 psig. The test pressure is set between 18.5 to 20.0 psig for 61BTH DSC with Type 2 basket for future 10CFR71 application. This bounds the 1.1xDSC design pressure of 15 psig.

The inner top cover/shield plug to the DSC shell weld is also pressure tested using a test pressure of between 14.5 to 16.0 psig for 61BTH DSC with Type 1 basket and between 18.5 to 20.0 psig for 61BTH DSC with Type 2 basket. This pressure test is performed at the field after the fuel assemblies are loaded in the DSC. This test is in accordance with the alternatives to the ASME Code specified in Section T.3.1.2.3.

HSM-H reinforcement and concrete are tested as described in Section 3.4.2.

T.9.1.3 Leak Tests

DSC confinement welds in the DSC shell and bottom are leak tested at the fabricator's shop to an acceptance criterion of $1x10^{-7}$ ref cm^3/s, i.e., "leaktight" as defined in ANSI N14.5 [9.4]. Personnel performing the leak test are qualified in accordance with SNT-TC-1A [9.2].

The weld between the DSC shell and inner top cover and the siphon/vent cover welds are also leak tested to an acceptance criteria of 1×10^{-7} ref cm^3/s in the field after the fuel assemblies are loaded in the canister.

T.9.1.4 Components

The Standardized NUHOMS® system does not include any components such as valves, rupture discs, pumps, or blowers. No other components of the NUHOMS® system require testing, except as discussed in this chapter.

T.9.1.5 Shielding Integrity

The Transfer Cask poured lead shielding integrity will be confirmed via gamma scanning prior to first use. The detector and examination grid will be matched to provide coverage of the entire lead-shielded surface area. For example, for a 6" × 6" grid, the detector will encompass a 6" × 6" square. The acceptance criterion is attenuation greater than or equal to that of a test block matching the cask through-wall configuration with lead and steel thicknesses equal to the design minima less 5%.

The radial neutron shielding is provided by filling the neutron shield shell with water during operations. No testing is necessary. The neutron shield material in the lid and bottom end is a proprietary polymer resin. The shielding performance of the resin will be assured by written procedures controlling temperature, measuring, and mixing of the components, degassing of the resin, and verification of the mass or volume of resin installed.

The gamma and neutron shielding materials of the storage system itself are limited to concrete HSM components and steel shield plugs in the DSC. The integrity of these shielding materials is ensured by the control of their fabrication in accordance with the appropriate ASME, ASTM or ACI criteria. No additional acceptance testing is required.

T.9.1.6 Thermal Acceptance

No thermal acceptance testing is required to verify the performance of each storage unit other than that specified in the Technical Specifications for initial loading.

The heat transfer analysis for the basket includes credit for the thermal conductivity of neutron-absorbing materials, as specified in Section T.4.3. Because these materials do not have publicly documented values for thermal conductivity, testing of such materials will be performed in accordance with Section T.9.1.7.6.

T.9.1.7 Poison Acceptance

> ***CAUTION***
>
> *Sections T.9.1.7.1 through T.9.1.7.4 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 4) and shall not be deleted or altered in any way without approval from the NRC. The text of these sections is shown in bold type to distinguish it from other sections.*

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

(a) Borated *a*luminum

(b) Boron carbide / *a*luminum 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.

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 *primarily* as a uniform fine dispersion of discrete AlB_2 or TiB_2 particles in the matrix of aluminum or aluminum alloy *(other boron compounds, such as AlB_{12}, can also occur)*. 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. 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.9.1.7.7. 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.

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

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, *molten metal infiltration,* or thermal spray techniques. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding *or produced by molten metal infiltration* shall not exceed 50% by volume.

The final MMC product shall have density greater than 98% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity. For MMC with an integral cladding, the final density of the core shall be greater than 97% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity of the core and cladding as a unit of the final product.

At least 50% by weight of the B_4C particles in MMCs shall be smaller than 40 microns. No more than 10% of the particles shall be over 60 microns.

Prior to use in the 61BTH DSC, MMCs shall pass the qualification testing specified in Section T.9.1.7.8, and shall subsequently be subject to the process controls specified in Section T.9.1.7.9.

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.9.1.7.7. 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.

T.9.1.7.3 **BORAL®**

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. Before rolling, at least 80% by weight of the B_4C particles in BORAL® shall be smaller than 200 microns. 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 a coupon taken from 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.

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T.9.1.7.4 **Visual Inspections of Neutron Absorbers**

See the Caution in Section T.9.1.7.7 before deletion or modification to this section.

Neutron absorbers shall be 100% visually inspected in accordance with the Certificate Holder's QA procedures. Blisters shall be treated as non-conforming. *For clad MMCs and f*or BORAL®, visual inspection shall verify that there are no cracks through the cladding, exposed core on the face of the sheet, or solid aluminum at the edge of the sheet. *Material that does not meet these criteria shall be reworked, repaired, or scrapped.*

T.9.1.7.5 Other Visual Inspections Criteria (non-Technical Specifications)

For borated aluminum and MMCs, visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

T.9.1.7.6 Thermal Conductivity Testing

*Acceptance t*esting shall conform to ASTM E1225[1], ASTM E1461[2], or equivalent method, performed at room temperature on coupons taken from the rolled or extruded production material. Initial sampling shall be one test per lot, and may be reduced if the first five tests meet the specified minimum thermal conductivity. *For cast products, the lot shall be defined by the heat or ingot. For other products, the lot shall be defined as material produced in a single production campaign using the same heat or lots of aluminum and boron carbide feed materials.*

If a thermal conductivity test result is below the specified minimum, at least four additional tests shall be performed on the material from that lot. If the mean value of those tests, including the original test, falls below the specified minimum, the associated lot shall be rejected.

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

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

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After twenty five tests of a single type of material, with the same aluminum alloy matrix, the same boron content, and the *same primary* boron phase, e.g., B_4C, TiB_2, or AlB_2, if the mean value of all the test results less two standard deviations meets the specified thermal conductivity, no further testing of that material is required. This exemption may also be applied to the same type of material if the matrix of the material changes to a more thermally conductive alloy (e.g., from 6000 to 1000 series aluminum), or if the boron content is reduced without changing the boron phase.

The measured thermal conductivity values shall satisfy the minimum required conductivities as specified in Section T.4.3.

In cases where the specified thickness of the neutron absorber may vary, the equations introduced in Section T.4.3 shall be used to determine the minimum required effective thermal conductivity.

The thermal conductivity test requirement does not apply to aluminum that is paired with the neutron absorber.

T.9.1.7.7 Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission

CAUTION

Portions of T.9.1.7.7 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 4) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

a) **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 *1.1 inch* diameter.

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. Standards will be calibrated, traceable to nationally recognized standards, or by attenuation of a monoenergetic neutron beam correlated to the known cross section of B10 at that energy.

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The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the one-sided tolerance limit for a normal distribution may be used for this purpose. Otherwise, a non-parametric (distribution-free) method of determining the one-sided tolerance limit may be used. Demonstration of the one-sided tolerance limit shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

b) The following illustrates one acceptable method and is intended to be utilized as an example. Therefore, the following text is not part of the Technical Specifications. The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The B10 areal densities determined by neutron transmission are converted to volume density, i.e., the 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].

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 the statistically derived minimum thickness from T.9.1.7.7 a) 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. Edge effects due to manufacturing operations such as shearing, deburring, and chamfering need not be included in this determination.

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

T.9.1.7.8 Specification for Qualification Testing of Metal Matrix Composites

> ***CAUTION***
>
> *Portions of Section T.9.1.7.8.4 and Section T.9.1.7.8.5 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 4) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

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T.9.1.7.8.1 Applicability and Scope

Metal matrix composites (MMCs) acceptable for use in the 61BTH DSC are described in Section T.9.1.7.2.

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 T.9.1.7.9 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.

T.9.1.7.8.2 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.9.1.7.8.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section T.9.1.7.8.5.

T.9.1.7.8.3 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.

Thermal damage and corrosion (hydrogen generation) testing shall be performed unless such tests on materials of the same chemical composition have already been performed and found acceptable. The following paragraphs illustrate two cases where such testing is not required.

Thermal damage testing is not required for unclad 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[3].

Corrosion testing is not required for MMCs (clad or unclad) consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[4].

All changes on this page are AMD 13

T.9.1.7.8.4 Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity

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

a) room temperature tensile testing (ASTM- B557[5]) 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%**

As an alternative to the elongation requirement, ductility may be demonstrated by bend testing per ASTM E290[6]. The radius of the pin or mandrel shall be no greater than three times the material thickness, and the material shall be bent at least 90 degrees without complete fracture.

b) Testing to verify more than 98% of theoretical density for non-clad MMCs and 97% for the matrix of clad MMCs. Testing or examination for interconnected porosity on the faces and edges of unclad MMC, and on the edges of clad MMC shall be performed by a means to be approved by the Certificate Holder. The maximum interconnected porosity is 0.5 volume %.

*c) **Delamination Testing of Clad MMC***

Clad MMCs shall be subjected to thermal damage testing following water immersion to ensure that delamination does not occur under normal conditions of storage. *An example of such a test would be: (1) immerse a specimen at least 6 x 6 inches in water under pressure ≥30 psig for at least 24 hours, (2) place the specimen in a vacuum furnace preheated to at least 300°F and evacuate the furnace. Acceptance criterion: no blistering or delamination of the cladding.*

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

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

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

6 ASTM E290, Standard Methods for Bend Testing of Materials for Ductility

All changes on this page are AMD 13

T.9.1.7.8.5 **Required Tests and Examinations to Demonstrate B10 Uniformity**

Uniformity of the boron distribution shall be verified either by:

a) Neutron radioscopy or radiography (ASTM E94[7], E142[8], and E545[9]) 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 *T*.9.1.7.7, or by chemical analysis for boron carbide content in the composite.

T.9.1.7.8.6 *Qualification Report*

Qualification *report* shall be *prepared by, or* subject to approval by the Certificate Holder.

T.9.1.7.9 Specification for Process Controls for Metal Matrix Composites

CAUTION
Sections T.9.1.7.9.1 and T.9.1.7.9.2 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 4) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

T.9.1.7.9.1 **Applicability and Scope**

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 T.9.1.7.8 is required, depending on the characteristics of the material that could be affected by the process change.

T.9.1.7.9.2 **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, reduce corrosion resistance, reduce the mechanical strength or ductility of the MMC.

7 ASTM E94, Recommended Practice for Radiographic Testing

8 ASTM E142, Controlling Quality of Radiographic Testing

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

T.9.1.7.9.3 Identification and Control of Key Process Changes

All changes on this page are AMD 13

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 T.9.1.7.9.2.

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 are 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 *(d50)* 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 magnesium-alloyed 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,

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, and

g) For MMCs with an integral aluminum cladding, a change greater than 25% in the ratio of the nominal aluminum cladding thickness (sum of two sides of cladding) and the nominal matrix thickness could result in changes in the mechanical properties of the final product.

T.9.2 Maintenance Program

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

T.9.3 References

9.1 ASME Boiler and Pressure Vessel Code, Section III, *2004* Edition with *2006* Addenda.

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

9.3 *Deleted*.

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

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

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

9.7 *Deleted*.

9.8 *Deleted*.

9.9 *Deleted*.

9.10 *Deleted*.

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Table T.9-1
B10 Specification for the NUHOMS® 61BTH Poison Plates

Basket Type	*Specified Minimum B10 Areal Density for Borated Aluminum/MMC for 90% Credit (g/cm^2)*	*Specified Minimum B10 Areal Density for BORAL® for 75% Credit (g/cm^2)*
Type 1 DSC		
A	*0.021*	*0.025*
B	*0.032*	*0.038*
C	*0.040*	*0.048*
D	*0.048*	*0.058*
E	*0.055*	*0.066*
F	*0.062*	*0.075*
Type 2 DSC		
A	*0.022*	*0.027*
B	*0.032*	*0.038*
C	*0.042*	*0.050*
D	*0.048*	*0.058*
E	*0.055*	*0.066*
F	*0.062*	*0.075*

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Table T.9-2
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U.9 Acceptance Tests and Maintenance Program

U.9.1 Acceptance Tests

The pre-operational testing requirements for the NUHOMS® system are given in Chapter 9.0, with the exceptions described in the following sections. The NUHOMS®-32PTH1 DSC has been enhanced to provide leaktight confinement and the basket includes an updated poison plate design. Additional acceptance testing of the NUHOMS®-32PTH1 DSC welds and of the poison plates are described.

U.9.1.1 Visual Inspection

Visual inspections are performed at the fabricator's facility to ensure that the DSC, the Transfer Cask and the HSM conform to the drawings and specifications. The visual inspections include weld, dimensional, surface finish, and cleanliness inspections. Visual inspections specified by codes applicable to a component are performed in accordance with the requirements and acceptance criteria of those codes.

All weld inspection is performed using qualified processes and qualified personnel according to the applicable code requirements, e.g., ASME or AWS. Non-destructive examination (NDE) requirements for welds are specified on the drawings provided in Chapter U.1; acceptance criteria are as specified by the governing code. NDE personnel are qualified in accordance with SNT-TC-1A [9.2].

The confinement welds on the DSC are inspected in accordance with ASME B&PV Code Subsection NB [9.1] including alternatives to ASME Code specified in Section U.3.1.2.3.

DSC non-confinement welds are inspected to the NDE acceptance criteria of ASME B&PV Code Subsection NG or NF, based on the applicable code for the components welded.

U.9.1.2 Structural

The DSC confinement boundary except the inner top cover/shield plug to the DSC shell weld is pressure tested at the fabricator's shop in accordance with ASME Article NB-6300. The test pressure is set between 21.5 to 23.0 psig for 32PTH1 DSC for future 10CFR71 application. This bounds the 1.1xDSC design pressure of 15 psig.

The inner top cover/shield plug to the DSC shell weld is also pressure tested using a test pressure between 21.5 to 23.0 psig for 32PTH1 DSC at the field after the fuel assemblies are loaded in the DSC. This test is in accordance with the alternatives to the ASME Code specified in Section U.3.1.2.3.

HSM-H reinforcement and concrete are tested as described in Section U.3.4.2.

U.9.1.3 Leak Tests

DSC confinement welds in the DSC shell and bottom are leak tested at the fabricator's shop to an acceptance criterion of 1×10^{-7} ref cm^3/s, i.e., "leaktight" as defined in ANSI N14.5 [9.4].

Personnel performing the leak test are qualified in accordance with SNT-TC-1A [9.2].

The weld between the DSC shell and inner top cover/shield plug and the siphon/vent cover welds are also leak tested to an acceptance criteria of 1 x 10^{-7} ref cm^3/s in the field after the fuel assemblies are loaded in the canister.

U.9.1.4 Components

The NUHOMS® System does not include any components such as valves, rupture discs, pumps, or blowers. No other components of the NUHOMS® System require testing, except as discussed in this chapter.

U.9.1.5 Shielding Integrity

The Transfer Cask poured lead shielding integrity will be confirmed via gamma scanning prior to first use. The detector and examination grid will be matched to provide coverage of the entire lead-shielded surface area. For example, for a 6” × 6” grid, the detector will encompass a 6” × 6” square. The acceptance criterion is attenuation greater than or equal to that of a test block matching the cask through-wall configuration with lead and steel thicknesses equal to the design minima less 5%.

The radial neutron shielding is provided by filling the neutron shield shell with water during operations. No testing is necessary. The neutron shield material in the lid and bottom end is a proprietary polymer resin. The shielding performance of the resin will be assured by written procedures controlling temperature, measuring, and mixing of the components, degassing of the resin, and verification of the mass or volume of resin installed.

The gamma and neutron shielding materials of the storage system itself are limited to concrete HSM components and steel shield plugs in the DSC. The integrity of these shielding materials is ensured by the control of their fabrication in accordance with the appropriate ASME, ASTM or ACI criteria. No additional acceptance testing is required.

U.9.1.6 Thermal Acceptance

No thermal acceptance testing is required to verify the performance of each storage unit other than that specified in the Technical Specifications for initial loading.

The heat transfer analysis for the basket includes credit for the thermal conductivity of neutron-absorbing materials, as specified in Section U.4.3. Because these materials do not have publicly documented values for thermal conductivity, testing of such materials will be performed in accordance with Section U.9.1.7.6.

U.9.1.7 Poison Acceptance

> ***CAUTION***
>
> *Sections U.9.1.7.1 through U.9.1.7.4 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specifications 4.1 (Note 5) and shall not be deleted or altered in any way without approval from the NRC. The text of these sections is shown in bold type to distinguish it from other sections.*

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

(a) Borated *a*luminum

(b) Boron carbide / *a*luminum 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 *primarily* as a uniform fine dispersion of discrete AlB_2 or TiB_2 particles in the matrix of aluminum or aluminum alloy *(other boron compounds, such as AlB_{12}, can also occur)*. 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. 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.*7*. 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.

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, *molten metal infiltration,* or thermal spray techniques. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding *or produced by molten metal infiltration* shall not exceed 50% by volume.

The final MMC product shall have density greater than 98% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity. For MMC with an integral cladding, the final density of the core shall be greater than 97% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity of the core and cladding as a unit of the final product.

At least 50% by weight of the B_4C particles in MMCs shall be smaller than 40 microns. No more than 10% of the particles shall be over 60 microns.

Prior to use in the 32PTH1 DSC, MMCs shall pass the qualification testing specified in Section U.9.1.7.8, and shall subsequently be subject to the process controls specified in Section U.9.1.7.9.

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.9.1.7.7. 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.

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. Before rolling, at least 80% by weight of the B_4C particles in BORAL® shall be smaller than 200 microns. 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 a coupon taken from 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.

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U.9.1.7.4 Visual Inspections of Neutron Absorbers

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

Neutron absorbers shall be 100% visually inspected in accordance with the Certificate Holder's QA procedures. Blisters shall be treated as non-conforming. *For clad MMCs and f*or BORAL®, visual inspection shall verify that there are no cracks through the cladding, exposed core on the face of the sheet, or solid aluminum at the edge of the sheet. *Material that does not meet these criteria shall be reworked, repaired, or scrapped.*

U.9.1.7.5 Other Visual Inspections Criteria (non-Technical Specifications)

For borated aluminum and MMCs, visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4, "Quality Control, Visual Inspection of Aluminum Mill Products" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

U.9.1.7.6 Thermal Conductivity Testing

*Acceptance t*esting shall conform to ASTM E1225[1], ASTM E1461[2], or equivalent method, performed at room temperature on coupons taken from the rolled or extruded production material. Initial sampling shall be one test per lot, and may be reduced if the first five tests meet the specified minimum thermal conductivity. *For cast products, the lot shall be defined by the heat or ingot. For other products, the lot shall be defined as material produced in a single production campaign using the same heat or lots of aluminum and boron carbide feed materials.*

If a thermal conductivity test result is below the specified minimum, at least four additional tests shall be performed on the material from that lot. If the mean value of those tests, including the original test, falls below the specified minimum, the associated lot shall be rejected.

After twenty five tests of a single type of material, with the same aluminum alloy matrix, the same boron content, and the same primary boron phase, e.g., B_4C, TiB_2, or AlB_2, if the mean value of all the test results less two standard deviations meets the specified thermal conductivity, no further testing of that material is required. This exemption may also be applied to the same type of material if the matrix of the material changes to a more thermally conductive alloy (e.g., from 6000 to 1000 series aluminum), or if the boron content is reduced without changing the boron phase.

The measured thermal conductivity values shall satisfy the minimum required conductivities as

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

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

specified in Section U.4.3.

In cases where the specified thickness of the neutron absorber may vary, the equations introduced in Section U.4.3 shall be used to determine the minimum required effective thermal conductivity.

The thermal conductivity test requirement does not apply to aluminum that is paired with the neutron absorber.

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U.9.1.7.7 **Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission**

CAUTION

Portions of Section U.9.1.7.7 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 5) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

a) **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 *1.1 inch* diameter.

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.

Standards will be calibrated, traceable to nationally recognized standards, or by attenuation of a monoenergetic neutron beam correlated to the known cross section of B10 at that energy.

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The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the one-sided tolerance limit for a normal distribution may be used for this purpose. Otherwise, a non-parametric (distribution-free) method of determining the one-sided tolerance limit may be used. Demonstration of the one-sided tolerance limit shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

b) The following illustrates one acceptable method and is intended to be utilized as an example. Therefore, the following text is not part of the Technical Specifications. The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The B10 areal densities determined by neutron transmission are converted to volume density, i.e., the 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].

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 the statistically derived minimum thickness from U.9.1.7.7 a) 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. Edge effects due to manufacturing operations such as shearing, deburring, and chamfering need not be included in this determination.

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

U.9.1.7.8 Specification for Qualification Testing of Metal Matrix Composites

CAUTION

Portions of Section U.9.1.7.8.4, and Section U.9.1.7.8.5, are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 5) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

U.9.1.7.8.1 Applicability and Scope

Metal matrix composites (MMCs) acceptable for use in the 32PTH1 DSC are described in Section U.9.1.7.2.

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 U.9.1.7.9 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.

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U.9.1.7.8.2 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.9.1.7.8.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section U.9.1.7.8.5.

U.9.1.7.8.3 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.

Thermal damage and corrosion (hydrogen generation) testing shall be performed unless such tests on materials of the same chemical composition have already been performed and found acceptable. The following paragraphs illustrate two cases where such testing is not required.

Thermal damage testing is not required for unclad 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[3].

Corrosion testing is not required for MMCs (clad or unclad) consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[4].

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

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

U.9.1.7.8.4 **<u>Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity</u>**

All changes on this page are AMD 13

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

a) room temperature tensile testing (ASTM- B557[5]) 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%**

As an alternative to the elongation requirement, ductility may be demonstrated by bend testing per ASTM E290[6]. The radius of the pin or mandrel shall be no greater than three times the material thickness, and the material shall be bent at least 90 degrees without complete fracture.

b) Testing to verify more than 98% of theoretical density for non-clad MMCs and 97% for the matrix of clad MMCs. Testing or examination for interconnected porosity on the faces and edges of unclad MMC, and on the edges of clad MMC shall be performed by a means to be approved by the Certificate Holder. The maximum interconnected porosity is 0.5 volume %.

c) Delamination Testing of Clad MMC

Clad MMCs shall be subjected to thermal damage testing following water immersion to ensure that delamination does not occur under normal conditions of storage. *An example of such a test would be: (1) immerse a specimen at least 6 x 6 inches in water under pressure ≥30 psig for at least 24 hours, (2) place the specimen in a vacuum furnace preheated to at least 300 °F and evacuate the furnace. Acceptance criterion: no blistering or delamination of the cladding.*

U.9.1.7.8.5 **<u>Required Tests and Examinations to Demonstrate B10 Uniformity</u>**

Uniformity of the boron distribution shall be verified either by:

a) Neutron radioscopy or radiography (ASTM E94[7], E142[8], and E545[9]) 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,

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5 ASTM B557 Standard Test Methods of Tension Testing Wrought and Cast Aluminum and Magnesium-Alloy Products.
6 ASTM E290, Standard Methods for Bend Testing of Materials for Ductility.
7 ASTM E94, Recommended Practice for Radiographic Testing.
8 ASTM E142, Controlling Quality of Radiographic Testing.
9 ASTM E545, Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing.

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.9.1.7.7, or by chemical analysis for boron carbide content in the composite.

U.9.1.7.8.6 *Qualification Report*

Qualification *reports* shall be *prepared by, or* subject to approval by the Certificate Holder.

U.9.1.7.9 Specification for Process Controls for Metal Matrix Composites

CAUTION

Sections U.9.1.7.9.1 and U.9.1.7.9.2 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 5) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

U.9.1.7.9.1 Applicability and Scope

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.9.1.7.8 is required, depending on the characteristics of the material that could be affected by the process change.

U.9.1.7.9.2 **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, reduce corrosion resistance, reduce the mechanical strength or ductility of the MMC.

U.9.1.7.9.3 Identification and Control of Key Process Changes

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.9.1.7.9.2.

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 are 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 *(d50)* 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,

All changes on this page are AMD 13

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 magnesium-alloyed 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,

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, and

g) For MMCs with an integral aluminum cladding, a change greater than 25% in the ratio of the nominal aluminum cladding thickness (sum of two sides of cladding) and the nominal matrix thickness could result in changes in the mechanical properties of the final product.

All changes on this page are AMD 13

U.9.2 Maintenance Program

The NUHOMS®-32PTH1 system is a totally passive system and therefore will require little, if any, maintenance over the lifetime of the ISFSI. Typical NUHOMS®-32PTH1 system maintenance tasks will be performed in accordance with the UFSAR.

U.9.3 References

9.1 ASME Boiler and Pressure Vessel Code, Section III, 1998 Edition *through* 2000 Addenda.

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

9.3 Deleted.

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

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

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

9.7 Deleted.

9.8 Deleted.

9.9 Deleted.

9.10 Deleted.

All changes on this page are AMD 13

All changes on this page are AMD 11

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	

Y.9 Acceptance Tests and Maintenance Program

Y.9.1 Acceptance Tests

The pre-operational testing requirements for the Standardized NUHOMS® system are given in Chapter 9, with the exceptions described in the following sections. The NUHOMS®-69BTH DSC has been enhanced to provide leaktight confinement and the basket includes an updated poison plate design. Additional acceptance testing of the NUHOMS®-69BTH DSC welds and of the poison plates are described.

Y.9.1.1 Visual Inspection

Visual inspections are performed at the fabricator's facility to ensure that the DSC, the Transfer Cask and the HSM conform to the drawings and specifications. The visual inspections include weld, dimensional, surface finish, and cleanliness inspections. Visual inspections specified by codes applicable to a component are performed in accordance with the requirements and acceptance criteria of those codes.

All weld inspection is performed using qualified processes and qualified personnel according to the applicable code requirements, e.g., ASME or AWS. Non-destructive examination (NDE) requirements for welds are specified on the drawings provided in Appendix Y.1; acceptance criteria are as specified by the governing code. NDE personnel are qualified in accordance with SNT-TC-1A [9.2].

The confinement welds on the DSC are inspected in accordance with ASME B&PV Code Subsection NB [9.1] including alternatives to ASME Code specified in Section Y.3.1.2.3.

DSC non-confinement welds are inspected to the NDE acceptance criteria of ASME B&PV Code Subsection NG or NF, based on the applicable code for the components welded.

Y.9.1.2 Structural

The DSC confinement boundary except the inner top cover/shield plug to the DSC shell weld is pressure tested at the fabricator's shop in accordance with ASME Article NB-6300. The test pressure is set between 16.5 to 18.0 psig for the 69BTH DSC, which bounds the 1.1xDSC design pressure of 15 psig.

The inner top cover/shield plug to the DSC shell weld is also pressure tested between 16.5 to 18.0 psig for 69BTH DSC. This pressure test is performed at the field after the fuel assemblies are loaded in the DSC. This test is in accordance with the alternatives to the ASME Code specified in Section Y.3.1.2.3.

HSM-H reinforcement and concrete are tested as described in Chapter 3, Section 3.4.2.

Y.9.1.3 Leakage Tests

The DSC canister confinement boundary is tested using two procedures described below. Personnel performing the leakage test are qualified in accordance with SNT-TC-1A [9.2].

Procedure 1 is accomplished during fabrication:

Upon completion of all canister shell welding and attachment of the inner bottom cover plate to the shell, a temporary seal plate is placed over the open end of the DSC. A bag or other enclosure is placed around the outside of the entire DSC and it is filled with helium. The DSC cavity is evacuated and a helium leakage test is performed using a port in the seal plate. This test is used to show that the entire DSC confinement boundary tested is leak tight ($1x10^{-7}$ ref cm^3/s).

Procedure 2 of the testing occurs after the DSC has been loaded with fuel assemblies:

The DSC cavity has been dried, back filled with helium and the inner top cover plate and the vent and drain port cover plates have been welded in place. After these welds are completed, a temporary test cover is installed or the outer top cover plate is welded in place with at least the root pass of the full weld. The cavity between inner top cover plate and the temporary test cover or outer top cover plate is evacuated and a helium leakage test is performed using a test port in the temporary test cover or in the outer top cover plate. The leakage test thus includes the weld attaching the inner top cover plate to the canister shell, the vent and drain port cover plate welds and the base metal of the inner top cover plate and vent and drain port cover plates. The vent and drain ports are filled with helium prior to welding the vent and drain port covers. This test verifies that the tested welds and cover plates are leak tight ($1x10^{-7}$ ref cm^3/s).

Y.9.1.4 Components

The Standardized NUHOMS® system does not include any components such as valves, rupture discs, pumps, or blowers. No other components of the NUHOMS® system require testing, except as discussed in this chapter.

Y.9.1.5 Shielding Integrity

The Transfer Cask poured lead shielding integrity will be confirmed via gamma scanning prior to first use. The detector and examination grid will be matched to provide coverage of the entire lead-shielded surface area. For example, for a 6″ × 6″ grid, the detector will encompass a 6″ × 6″ square. The acceptance criterion is attenuation greater than or equal to that of a test block matching the cask through-wall configuration with lead and steel thicknesses equal to the design minima less 5%.

The radial neutron shielding is provided by filling the neutron shield shell with water during operations. No testing is necessary. The neutron shield material in the lid and bottom end is a proprietary polymer resin. The shielding performance of the resin will be assured by written procedures controlling temperature, measuring, and mixing of the components, degassing of the resin, and verification of the mass or volume of resin installed. The gamma and neutron shielding materials of the storage system itself are limited to concrete HSM components and steel shield plugs in the DSC. The integrity of these shielding materials is ensured by the control of their fabrication in accordance with the appropriate ASME, ASTM or ACI criteria. No additional acceptance testing is required.

Y.9.1.6 Thermal Acceptance

No thermal acceptance testing is required to verify the performance of each storage unit other than that specified in the Technical Specifications for initial loading.

The heat transfer analysis for the basket includes credit for the thermal conductivity of neutron-absorbing materials, as specified in Section Y.4.3. Because these materials do not have publicly documented values for thermal conductivity, testing of such materials will be performed in accordance with Section Y.9.1.7.6.

Y.9.1.7 Poison Acceptance

CAUTION
Sections Y.9.1.7.1 through Y.9.1.7.4 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 6) and shall not be deleted or altered in any way without 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 69BTH 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 Y.9-1.

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

Y.9.1.7.1 **Borated Aluminum**

See the Caution in Section Y.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 primarily as a uniform fine dispersion of discrete AlB_2 or TiB_2 particles in the matrix of aluminum or aluminum alloy (other boron compounds, such as AlB_{12}, can also occur). 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. 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 Y.9.1.7.7. 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.

Y.9.1.7.2 **Boron Carbide / Aluminum Metal Matrix Composites (MMCs)**

See the Caution in Section Y.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, molten metal infiltration, or thermal spray techniques. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding or produced by molten metal infiltration shall not exceed 50% by volume.

The final MMC product shall have density greater than 98% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity. For MMC with an integral cladding, the final density of the core shall be greater than 97% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity of the core and cladding as a unit of the final product.

At least 50% by weight of the B_4C particles in boron carbide shall be smaller than 40 microns. No more than 10% of the particles shall be over 60 microns.

Prior to use in the 69BTH DSC, MMCs shall pass the qualification testing specified in Section Y.9.1.7.8, and shall subsequently be subject to the process controls specified in Section Y.9.1.7.9.

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 Y.9.1.7.7. 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.

Y.9.1.7.3 **BORAL®**

See the Caution in Section Y.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. Before rolling, at least 80% by weight of the B_4C particles in BORAL® shall be smaller than 200 microns. 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 a coupon taken from 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.

Y.9.1.7.4 **Visual Inspections of Neutron Absorbers**

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

Neutron absorbers shall be 100% visually inspected in accordance with the Certificate Holder's QA procedures. Blisters shall be treated as non-conforming. For clad MMCs and for BORAL®, visual inspection shall verify that there are no cracks through the cladding, exposed core on the face of the sheet, or solid aluminum at the edge of the sheet. Material that does not meet these criteria shall be reworked, repaired, or scrapped.

Y.9.1.7.5 Other Visual Inspections Criteria (non-Technical Specifications)

For borated aluminum and MMCs, visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

Y.9.1.7.6 Thermal Conductivity Testing

Acceptance testing shall conform to ASTM E1225[1], ASTM E1461[2], or equivalent method, performed at room temperature on coupons taken from the rolled or extruded production material. Initial sampling shall be one test per lot, and may be reduced if the first five tests meet the specified minimum thermal conductivity. For cast products, the lot shall be defined by the heat or ingot. For other products, the lot shall be defined as material produced in a single production campaign using the same heat or lots of aluminum and boron carbide feed materials.

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

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

If a thermal conductivity test result is below the specified minimum, at least four additional tests shall be performed on the material from that lot. If the mean value of those tests, including the original test, falls below the specified minimum, the associated lot shall be rejected.

After twenty five tests of a single type of material, with the same aluminum alloy matrix, the same boron content, and the same primary boron phase, e.g., B_4C, TiB_2, or AlB_2, if the mean value of all the test results less two standard deviations meets the specified thermal conductivity, no further testing of that material is required. This exemption may also be applied to the same type of material if the matrix of the material changes to a more thermally conductive alloy (e.g., from 6000 to 1000 series aluminum), or if the boron content is reduced without changing the boron phase.

The measured thermal conductivity values shall satisfy the minimum required conductivities as specified in Section Y.4.3

In cases where the specified thickness of the neutron absorber may vary, the equations introduced in Section Y.4.3 shall be used to determine the minimum required effective thermal conductivity.

The thermal conductivity test requirement does not apply to aluminum that is paired with the neutron absorber.

Y.9.1.7.7 Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission

CAUTION

Portions of Section Y.9.1.7.7 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 6) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

a) 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 up to 1.1 inch diameter.

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. Standards will be calibrated, traceable to nationally recognized standards, or by attenuation of a monoenergetic neutron beam correlated to the known cross section of B10 at that energy.

The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the one-sided tolerance limit for a normal distribution may be used for this purpose. Otherwise, a non-parametric (distribution-free) method of determining the one-sided tolerance limit may be used. Demonstration of the one-sided tolerance limit shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

b) The following illustrates one acceptable method and is intended to be utilized as an example. Therefore, the following text is not part of the Technical Specifications. The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The B10 areal densities determined by neutron transmission are converted to volume density, i.e., the 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].

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 the statistically derived minimum thickness from Y.9.1.7.7a) 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.

Y.9.1.7.8 Specification for Qualification Testing of Metal Matrix Composites

> ***CAUTION***
>
> *Portions of Section Y.9.1.7.8.4, and all of Section Y.9.1.7.8.5, are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 6) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

Y.9.1.7.8.1 Applicability and Scope

MMCs acceptable for use in the 69BTH DSC are described in Section Y.9.1.7.2.

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 Y.9.1.7.9 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.

Y.9.1.7.8.2 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 Y.9.1.7.8.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section Y.9.1.7.8.5.

Y.9.1.7.8.3 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 and corrosion (hydrogen generation) testing shall be performed unless such tests on materials of the same chemical composition have already been performed and found acceptable. The following paragraphs illustrate two cases where such testing is not required.

Thermal damage testing is not required for unclad 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[3].

Corrosion testing is not required for full density MMCs (clad or unclad) consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[4].

Y.9.1.7.8.4 **Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity**

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

a) room temperature tensile testing (ASTM- B557[5]) 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%**

As an alternative to the elongation requirement, ductility may be demonstrated by bend testing per ASTM E290[6]. The radius of the pin or mandrel shall be no greater than three times the material thickness, and the material shall be bent at least 90 degrees without complete fracture.

b) Testing to verify more than 98% of theoretical density for non-clad MMCs and 97% for the matrix of clad MMCs. Testing or examination for interconnected porosity on the faces and edges of unclad MMC, and on the edges of clad MMC shall be performed by a means to be approved by the Certificate Holder. The maximum interconnected porosity is 0.5 volume %.

c) Delamination Testing of Clad MMC

Clad MMCs shall be subjected to thermal damage testing following water immersion to ensure that delamination does not occur under normal conditions of storage. An example of such a test would be: (1) immerse a specimen at least 6 x 6 inches in water under pressure ≥30 psig for at least 24 hours, (2) place the specimen in a vacuum furnace preheated to at least 300 °F and evacuate the furnace. Acceptance criterion: no blistering or delamination of the cladding.

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

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

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

6 ASTM E290, Standard Methods for Bend Testing of Materials for Ductility

Y.9.1.7.8.5 **Required Tests and Examinations to Demonstrate B10 Uniformity**

Uniformity of the boron distribution shall be verified either by:

a) Neutron radioscopy or radiography (ASTM E94[7], E142[8], and E545[9]) 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 Y.9.1.7.7, or by chemical analysis for boron carbide content in the composite.

Y.9.1.7.8.6 Qualification Report

Qualification report shall be prepared by, or subject to approval by the Certificate Holder.

Y.9.1.7.9 Specification for Process Controls for Metal Matrix Composites

CAUTION
Sections Y.9.1.7.9.1 and Y.9.1.7.9.2 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 6) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

Y.9.1.7.9.1 **Applicability and Scope**

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 Y.9.1.7.8 is required, depending on the characteristics of the material that could be affected by the process change.

Y.9.1.7.9.2 **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, reduce corrosion resistance, reduce the mechanical strength or ductility of the MMC.

7 ASTM E94, Recommended Practice for Radiographic Testing

8 ASTM E142, Controlling Quality of Radiographic Testing

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

Y.9.1.7.9.3 Identification and Control of Key Process Changes

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 Y.9.1.7.9.2.

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 are 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 (d50) 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 magnesium-alloyed 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,

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, and

g) For MMCs with an integral aluminum cladding, a change greater than 25% in the ratio of the nominal aluminum cladding thickness (sum of two sides of cladding) and the nominal matrix thickness could result in changes in the mechanical properties of the final product.

Y.9.2 Maintenance Program

The NUHOMS®-69BTH system is a totally passive system and therefore will require little, if any, maintenance over the lifetime of the ISFSI. Typical NUHOMS®-69BTH system maintenance tasks will be performed in accordance with the UFSAR.

Y.9.3 References

9.1 ASME Boiler and Pressure Vessel Code, Section III, 2004 Edition through 2006 Addenda.

9.2 SNT-TC-1A, “American Society for Nondestructive Testing, Personnel Qualification and Certification in Nondestructive Testing,” 1992.

9.3 Not Used.

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

9.5 “Aluminum Standards and Data, 2003,” The Aluminum Association.

9.6 Natrella, “Experimental Statistics,” Dover, 2005.

Table Y.9-1
B10 Specification for the NUHOMS®-69BTH Poison Plates

Poison Type	Basket Type	Specified Minimum B10 Areal Density for 90% Credit (g/cm^2)	% Credit Used in Criticality Analysis
Borated Aluminum Alloy / MMC	A	0.021	90
	B	0.031	
	C	0.039	
	D	0.046	
	E	0.053	
	F	0.061	
BORAL®	A	0.025	75
	B	0.037	
	C	0.047	
	D	0.055	
	E	0.064	
	F	0.073	

Z.9 Acceptance Tests and Maintenance Program

Z.9.1 Acceptance Tests

The pre-operational testing requirements for the Standardized NUHOMS® system are given in Chapter 9, with the exceptions described in the following sections. The NUHOMS®-37PTH DSC has been enhanced to provide leaktight confinement and the basket includes an updated poison plate design. Additional acceptance testing of the NUHOMS®-37PTH DSC welds and of the poison plates are described.

Z.9.1.1 Visual Inspection

Visual inspections are performed at the fabricator's facility to ensure that the DSC, the transfer cask and the HSM conform to the drawings and specifications. The visual inspections include weld, dimensional, surface finish, and cleanliness inspections. Visual inspections specified by codes applicable to a component are performed in accordance with the requirements and acceptance criteria of those codes.

All weld inspection is performed using qualified processes and qualified personnel according to the applicable code requirements, e.g., ASME or AWS. Non-destructive examination (NDE) requirements for welds are specified on the drawings provided in Appendix Z.1; acceptance criteria are as specified by the governing code. NDE personnel are qualified in accordance with SNT-TC-1A [9.2].

The confinement welds on the DSC are inspected in accordance with ASME B&PV Code Subsection NB [9.1] including alternatives to ASME Code specified in Section Z.3.1.2.3.

DSC non-confinement welds are inspected to the NDE acceptance criteria of ASME B&PV Code Subsection NG or NF, based on the applicable code for the components welded.

Z.9.1.2 Structural

The DSC confinement boundary except the inner top cover/shield plug to the DSC shell weld is pressure tested at the fabricator's shop in accordance with ASME Article NB-6300. The test pressure is set between 16.5 to 18.0 psig for 37PTH DSC, which bounds the 1.1xDSC design pressure of 15 psig.

The inner top cover/shield plug to the DSC shell weld is also pressure tested between 16.5 to 18.0 psig for 37PTH DSC. This pressure test is performed at the field after the fuel assemblies are loaded in the DSC. This test is in accordance with the alternatives to the ASME Code specified in Section Z.3.1.2.3.

HSM-H reinforcement and concrete are tested as described in Chapter 3, Section 3.4.2.

Z.9.1.3 Leakage Tests

The DSC canister confinement boundary is tested using two procedures described below. Personnel performing the leakage test are qualified in accordance with SNT-TC-1A [9.2].

Procedure 1 is accomplished during fabrication:

Upon completion of all canister shell welding and attachment of the inner bottom cover plate to the shell, a temporary seal plate is placed over the open end of the DSC. A bag or other enclosure is placed around the outside of the entire DSC and it is filled with helium. The DSC cavity is evacuated and a helium leakage test is performed using a port in the seal plate. This test is used to show that the entire DSC confinement boundary tested is leak tight ($1x10^{-7}$ ref cm^3/s).

Procedure 2 of the testing occurs after the DSC has been loaded with fuel assemblies:

The DSC cavity has been dried, back filled with helium and the inner top cover plate and the vent and drain port cover plates have been welded in place. After these welds are completed, a temporary test cover is installed or the outer top cover plate is welded in place with at least the root pass of the full weld. The cavity between inner top cover plate and the temporary test cover or outer top cover plate is evacuated and a helium leakage test is performed using a test port in the temporary test cover or in the outer top cover plate. The leakage test thus includes the weld attaching the inner top cover plate to the canister shell, the vent and drain port cover plate welds and the base metal of the inner top cover plate and vent and drain port cover plates. The vent and drain ports are filled with helium prior to welding the vent and drain port covers. This test verifies that the tested welds and cover plates are leak tight ($1x10^{-7}$ ref cm^3/s).

Z.9.1.4 Components

The Standardized NUHOMS® system does not include any components such as valves, rupture discs, pumps, or blowers. No other components of the NUHOMS® system require testing, except as discussed in this chapter.

Z.9.1.5 Shielding Integrity

The transfer cask poured lead shielding integrity will be confirmed via gamma scanning prior to first use. The detector and examination grid will be matched to provide coverage of the entire lead-shielded surface area. For example, for a 6″ × 6″ grid, the detector will encompass a 6″ × 6″ square. The acceptance criterion is attenuation greater than or equal to that of a test block matching the cask through-wall configuration with lead and steel thicknesses equal to the design minima less 5%.

The radial neutron shielding is provided by filling the neutron shield shell with water during operations. No testing is necessary. The neutron shield material in the lid and bottom end is a proprietary polymer resin. The shielding performance of the resin will be assured by written procedures controlling temperature, measuring, and mixing of the components, degassing of the resin, and verification of the mass or volume of resin installed.

The gamma and neutron shielding materials of the storage system itself are limited to concrete HSM components and steel shield plugs in the DSC. The integrity of these shielding materials is ensured by the control of their fabrication in accordance with the appropriate ASME, ASTM or ACI criteria. No additional acceptance testing is required.

Z.9.1.6 Thermal Acceptance

No thermal acceptance testing is required to verify the performance of each storage unit other than that specified in the Technical Specifications for initial loading.

The heat transfer analysis for the basket includes credit for the thermal conductivity of neutron-absorbing materials, as specified in Section Z.4.3. Because these materials do not have publicly documented values for thermal conductivity, testing of such materials will be performed in accordance with Section Z.9.1.7.6.

Z.9.1.7 Poison Acceptance

CAUTION
Sections Z.9.1.7.1 through Z.9.1.7.4 below are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 7) and shall not be deleted or altered in any way without 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 37PTH 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 0.0020 g/cm^2 for Borated Aluminum and MMC, and 0.0025 g/cm^2 for BORAL®.

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

Z.9.1.7.1 **Borated Aluminum**

See the Caution in Section Z.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 primarily as a uniform fine dispersion of discrete AlB2 or TiB2 particles in the matrix of aluminum or aluminum alloy (other boron compounds, such as AlB12, can also occur). For extruded products, the TiB2 form of the alloy shall be used. For rolled products, either the AlB2, the TiB2, 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. 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 Z.9.1.7.7. 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.

Z.9.1.7.2 **Boron Carbide/Aluminum Metal Matrix Composites (MMCs)**

See the Caution in Section Z.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, molten metal infiltration, or thermal spray techniques. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding or produced by molten metal infiltration shall not exceed 50% by volume.

The final MMC product shall have density greater than 98% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity. For MMC with an integral cladding, the final density of the core shall be greater than 97% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity of the core and cladding as a unit of the final product.

At least 50% by weight of the B4C particles in boron carbide shall be smaller than 40 microns. No more than 10% of the particles shall be over 60 microns.

Prior to use in the 37PTH DSC, MMCs shall pass the qualification testing specified in Section Z.9.1.7.8, and shall subsequently be subject to the process controls specified in Section Z.9.1.7.9.

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 Z.9.1.7.7. 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.

Z.9.1.7.3 **BORAL®**

See the Caution in Section Z.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. Before rolling, at least 80% by weight of the B_4C particles in BORAL® shall be smaller than 200 microns. 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 a coupon taken from 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.

Z.9.1.7.4 **Visual Inspections of Neutron Absorbers**

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

Neutron absorbers shall be 100% visually inspected in accordance with the Certificate Holder's QA procedures. Blisters shall be treated as non-conforming. For clad MMCs and for BORAL®, visual inspection shall verify that there are no cracks through the cladding, exposed core on the face of the sheet, or solid aluminum at the edge of the sheet. Material that does not meet these criteria shall be reworked, repaired, or scrapped.

Z.9.1.7.5 Other Visual Inspections Criteria (non-Technical Specifications)

For borated aluminum and MMCs, visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products" [9.5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

Z.9.1.7.6 Acceptance Testing

Acceptance testing shall conform to ASTM E1225[1], ASTM E1461[2], or equivalent method, performed at room temperature on coupons taken from the rolled or extruded production material. Initial sampling shall be one test per lot, and may be reduced if the first five tests meet the specified minimum thermal conductivity. For cast products, the lot shall be defined by the

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[1] ASTM E1225, "Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique"

[2] ASTM E1461, "Thermal Diffusivity of Solids by the Flash Method"

heat or ingot. For other products, the lot shall be defined as material produced in a single production campaign using the same heat or lots of aluminum and boron carbide feed materials.

If a thermal conductivity test result is below the specified minimum, at least four additional tests shall be performed on the material from that lot. If the mean value of those tests, including the original test, falls below the specified minimum, the associated lot shall be rejected.

After twenty five tests of a single type of material, with the same aluminum alloy matrix, the same boron content, and the same primary boron phase, e.g., B_4C, TiB_2, or AlB_2, if the mean value of all the test results less two standard deviations meets the specified thermal conductivity, no further testing of that material is required. This exemption may also be applied to the same type of material if the matrix of the material changes to a more thermally conductive alloy (e.g., from 6000 to 1000 series aluminum), or if the boron content is reduced without changing the boron phase.

The measured thermal conductivity values shall satisfy the minimum required conductivities as specified in Section Z.4.3

In cases where the specified thickness of the neutron absorber may vary, the equations introduced in Section Z.4.3 shall be used to determine the minimum required effective thermal conductivity.

The thermal conductivity test requirement does not apply to aluminum that is paired with the neutron absorber.

Z.9.1.7.7 Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission

CAUTION
Portions of Section Z.9.1.7.7 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 7) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

a) 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 up to 1.1 inch diameter.

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. Standards will be calibrated, traceable to nationally recognized standards, or by attenuation of a monoenergetic neutron beam correlated to the known cross section of B10 at that energy.

The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the one-sided tolerance limit for a normal distribution may be used for this purpose. Otherwise, a non-parametric (distribution-free) method of determining the one-sided tolerance limit may be used. Demonstration of the one-sided tolerance limit shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

b) The following illustrates one acceptable method and is intended to be utilized as an example. Therefore, the following text is not part of the Technical Specifications. The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The B10 areal densities determined by neutron transmission are converted to volume density, i.e., the 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].

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 the statistically derived minimum thickness from Z.9.1.7.7 a) 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.

Z.9.1.7.8 Specification for Qualification Testing of Metal Matrix Composites

> ***CAUTION***
>
> *Portions of Section Z.9.1.7.8.4, and all of Section Z.9.1.7.8.5, are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 7) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

Z.9.1.7.8.1 Applicability and Scope

Metal matrix composites (MMCs) acceptable for use in the 37PTH DSC are described in Section Z.9.1.7.2.

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 Z.9.1.7.9 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.

Z.9.1.7.8.2 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 Z.9.1.7.8.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section Z.9.1.7.8.5.

Z.9.1.7.8.3 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 and corrosion (hydrogen generation) testing shall be performed unless such tests on materials of the same chemical composition have already been performed and found acceptable. The following paragraphs illustrate two cases where such testing is not required.

Thermal damage testing is not required for unclad 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[3].

Corrosion testing is not required for full density MMCs (clad or unclad) consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear[4].

Z.9.1.7.8.4 Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity

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

a) room temperature tensile testing (ASTM- B557[5]) 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%**

As an alternative to the elongation requirement, ductility may be demonstrated by bend testing per ASTM E290[6]. The radius of the pin or mandrel shall be no greater than three times the material thickness, and the material shall be bent at least 90 degrees without complete fracture.

b) Testing to verify more than 98% of theoretical density for non-clad MMCs and 97% for the matrix of clad MMCs. Testing or examination for interconnected porosity on the faces and edges of unclad MMC, and on the edges of clad MMC shall be performed by a means to be approved by the Certificate Holder. The maximum interconnected porosity is 0.5 volume %.

c) Delamination Testing of Clad MMC

Clad MMCs shall be subjected to thermal damage testing following water immersion to ensure that delamination does not occur under normal conditions of storage. An example of such a test would be: (1) immerse a specimen at least 6 x 6 inches in water under pressure ≥30 psig for at least 24 hours, (2) place the specimen in a vacuum furnace preheated to at least

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

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

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

6 ASTM E290, Standard Methods for Bend Testing of Materials for Ductility

300°F and evacuate the furnace. Acceptance criterion: no blistering or delamination of the cladding.

Z.9.1.7.8.5 **Required Tests and Examinations to Demonstrate B10 Uniformity**

Uniformity of the boron distribution shall be verified either by:

a) Neutron radioscopy or radiography (ASTM E94[7], E142[8], and E545[9]) 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 Z.9.1.7.7, or by chemical analysis for boron carbide content in the composite.

Z.9.1.7.8.6 Qualification Report

Qualification report shall be prepared by, or subject to approval by the Certificate Holder.

Z.9.1.7.9 Specification for Process Controls for Metal Matrix Composites

CAUTION

Sections Z.9.1.7.9.1 and Z.9.1.7.9.2 are incorporated by reference into the NUHOMS® CoC 1004 Technical Specification 4.1 (Note 7) and shall not be deleted or altered in any way without approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.

Z.9.1.7.9.1 **Applicability and Scope**

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 Z.9.1.7.8 is required, depending on the characteristics of the material that could be affected by the process change.

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7 ASTM E94, Recommended Practice for Radiographic Testing

8 ASTM E142, Controlling Quality of Radiographic Testing

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

Z.9.1.7.9.2 **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, reduce corrosion resistance, reduce the mechanical strength or ductility of the MMC.

Z.9.1.7.9.3 Identification and Control of Key Process Changes

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 Z.9.1.7.9.2.

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 are 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 (d50) 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 magnesium-alloyed 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,

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, and

g) For MMCs with an integral aluminum cladding, a change greater than 25% in the ratio of the nominal aluminum cladding thickness (sum of two sides of cladding) and the nominal matrix thickness could result in changes in the mechanical properties of the final product.

Z.9.2 Maintenance Program

The NUHOMS®-37PTH system is a totally passive system and therefore will require little, if any, maintenance over the lifetime of the ISFSI. Typical NUHOMS®-37PTH system maintenance tasks will be performed in accordance with the UFSAR.

Z.9.3 References

9.1 ASME Boiler and Pressure Vessel Code, Section III, 2004 Edition through 2006 Addenda.

9.2 SNT-TC-1A, “American Society for Nondestructive Testing, Personnel Qualification and Certification in Nondestructive Testing,” 1992.

9.3 Not Used.

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

9.5 “Aluminum Standards and Data, 2003,” The Aluminum Association.

9.6 Natrella, “Experimental Statistics,” Dover, 2005.