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CHAPTER 9

ACCEPTANCE CRITERIA AND MAINTENANCE PROGRAM

9.1 Acceptance Criteria

9.1.1 Visual Inspection

Visual inspections are performed at the Fabricator's facility to ensure that the casks conform to the drawings and specifications. The visual inspection includes verifying that all specified coatings are applied and the cask is clean and free of defects. (Visual inspection requirements on welds are discussed in Chapter 3.) Upon arrival at the loading facility, the casks are again inspected to ensure that the casks have not been damaged during shipment. Visual inspections which indicate conditions which are not in conformance with the drawings and specifications will be repaired or evaluated for the effect of the condition on the safety function of the components in accordance with 10CFR72.48 by the user.

9.1.2 Structural

The structural analyses performed on the cask are presented in Chapter 3. To ensure that the cask can perform its design function, all structural materials are chemically and physically tested to ensure that the required properties are met. All welding is performed using qualified processes and qualified personnel according to the ASME Boiler and Pressure Vessel Code[(1)]. Base materials and welds are examined in accordance with ASME Boiler and Pressure Vessel code requirements. NDE requirements for welds are specified on the drawings provided in Chapter 1. All weld-related NDE is performed in accordance with written and approved procedures. Inspection personnel are qualified in accordance with SNT-TC-1A[(2)].

The confinement welds are designed, fabricated, tested and inspected in accordance with ASME B&PV Code Subsection NB. Exceptions to the code taken regarding the containment vessel are described in Chapter 7. The basket is designed, fabricated and inspected in accordance with the ASME B&PV Code Subsection NG. Exceptions to the code taken regarding the basket are described in Section 3.1.2.3. Noncontainment welds are inspected to the NDE acceptance criteria of ASME B&PV Code Subsection NF.

A pressure test is performed on the cask assembly (containment vessel installed in gamma shield shell) at a test pressure of 125 psig, which is 1.25 times the design pressure of 100 psig. The test pressure is held for a minimum of 10 minutes. The test will be performed in accordance with ASME B&PV Code, Section III, Subsection NB, Paragraph NB-6200 or NB-6300. Visible joints/surfaces are visually examined for possible leakage after application of pressure. Temporary gaskets and seals may be used in place of the metallic seals during the test.

In addition, a bubble leak test is performed at 4.5 psig or greater on the resin enclosure. The purpose of this test is to identify any potential leak passages in the enclosure welds. The bubble leak test pressure is set at 1.5 times the relief valve set pressure.

The lifting trunnions are fabricated and tested in accordance with ANSI N14.6[(3)] and are designed for nonredundant (single failure proof) lifting. A load test of 3 times the design lift load is applied to the trunnions for a period of ten minutes to ensure that the trunnions can perform satisfactorily. The periodic load test or examination of the trunnions, including removal and inspection of the bolts in accordance with ANSI N14.6 will not be performed while the cask is in storage or prior to return of the cask from storage for unloading. This is justified since the cask will only be lifted a few times and there are no cyclic loads on the trunnions.

9.1.3 Leak Tests

Leakage tests are performed on the containment system and overpressure system at the Fabricator's facility. These tests are usually performed using the helium mass spectrometer method. Alternative methods are acceptable, provided that the required sensitivity is achieved. The leakage tests are performed in accordance with ANSI N14.5[(4)]. Personnel performing the leakage tests are qualified in accordance with SNT-TC-1A.

The containment boundary permissible leakage rate is less than or equal to 1×10^{-5} ref cm^3/sec. In order to assure the leakage rate of the containment boundary is less than 1×10^{-5} ref cm^3/sec, the total leak rate (of the inner seals and the outer seals) at standard conditions is less than 1×10^{-5} ref cm^3/sec. The sensitivity of the leakage test procedure is at least 5×10^{-6} ref cm^3/sec.

Although the overpressure system is not important to safety, it is also leak tested in accordance with ANSI N14.5. The permissible leakage rate for the overpressure system shall be less than or equal to 1×10^{-5} ref cm^3/sec. The sensitivity of the leakage test procedure shall be no less than 5×10^{-6} ref cm^3/sec.

9.1.4 Components

9.1.4.1 Valves

There are no valves performing a function important to safety. The TN-68 design incorporates quick-connect couplings for ease of draining and venting. However, these couplings do not form part of the containment boundary. They are covered by bolted closures with metallic o-ring seals.

9.1.4.2 Gaskets

The lid and all containment penetrations are sealed using double metallic o-ring seals. The inside o-ring forms part of the containment boundary. Metallic o-rings are not temperature sensitive, and are therefore tested at room temperature. Metallic o-rings of the same type as

those to be used for storage are installed for the fabrication leakage test described in Section 9.1.3. The tested o-rings are replaced before loading the cask. Upon completion of cask loading, the seals are tested in accordance with Technical Specifications Surveillance Requirement 3.1.3.1.

9.1.5 Shielding Integrity

The analyses performed to ensure shielding integrity are presented in Chapter 5.
The radial neutron shield is protected from damage or loss by the aluminum and steel enclosure. The material is a proprietary borated reinforced polymer.

The resin's primary function is neutron shielding, which is provided primarily by its hydrogen content. The resin includes boron to reduce secondary gamma radiation which occurs when neutrons are captured by hydrogen. Both neutrons and capture gammas are a small component of the radial dose rate. The resin also provides some gamma shielding, which is a function of the overall resin density, but is not sensitive to composition.

The shielding performance of the material can be adequately verified by chemical analysis and verification of density. Uniformity is assured by installation process control.

The following are acceptance values for density and chemical composition for the resin. The values used in the shielding calculations of Chapter 5 are included for comparison.

Chapter 5 values		Acceptance Testing Values		
Element	nominal wt %	Element	wt %	acceptance range (wt %)
H	5.05	H	5.05	-10 / +20
B	1.05	B	1.05	± 20
C	35.13	C	35.13	± 20
Al	14.93	Al	14.93	± 20
O	41.73	O+Zn (balance)	43.84	± 20
Zn				
Total	97.89%		100%	

The nominal resin density used in Chapter 5 calculations is 1.58 g/cm^3. However, because zinc is not included, the sum of the individual elements is only 97.89%, and the effective density used in the shielding calculations is 1.58*0.9789 = 1.547 g/cm^3. Therefore, the minimum resin density in acceptance testing is 1.547 g/cm^3.

Density testing will be performed on every mixed batch of resin. Chemical analysis will be made on the first batch mixed with a given set of components, and thereafter whenever a new lot of one of the major components is introduced. Major components are aluminum oxide, zinc borate and the polyester resin, which combined make up 92% of the resin by weight.

Qualification tests of the personnel and procedure used for mixing and pouring the polyester resin used for radial neutron shielding are performed. Qualification testing includes verification that the chemical composition and density is achieved, and the process is performed in such a manner as to prevent voids.Tests are performed at loading to ensure that the radiation dose limits are not exceeded for each cask.

9.1.6 Thermal Acceptance

The heat transfer analysis for the basket includes credit for the thermal conductivity of neutron-absorbing materials, as specified in Section 4.2 part 12. Because these materials do not have publicly documented values for thermal conductivity, testing of such materials will be performed in accordance with Section 9.4.1.

9.1.7 Neutron Absorber Tests

The neutron absorber used for criticality control in the TN-68 basket may consist any of the following types of material:

(a) Boron-aluminum alloy (borated aluminum)

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

(c) Boral®

The boron content of these materials is given by Table 9.1-1.

The neutron absorber plates may be monolithic, or they may consist of paired plates, one containing boron in the specified areal density, and the other composed of aluminum or aluminum alloy to make up the balance of the specified thickness and thermal conductance.

The TN-68 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 the presence of B10 and the uniformity of its distribution shall be verified by acceptance testing as specified in Section 9.3.2, with the exception of the materials for units TN-68-1 through 44, which may be accepted by the testing described in Section 9.5.

9.1.7.1 Boron Aluminum Alloy (Borated Aluminum)

The material is an ingot metallurgy product with boron precipitating as a uniform fine dispersion of discrete AlB_2 or TiB_2 particles in the matrix of 1000 or 6000 series aluminum.

Boron is added to the aluminum in the quantity necessary to provide the specified minimum B10 areal density in the final product, with sufficient margin to minimize rejection, typically 10 % excess. The amount will depend on whether boron with the natural isotopic distribution of the

isotopes B10 and B11, or boron enriched in B10 is used. Practical manufacturing considerations limit the boron content in aluminum to 5% by weight.

The minimum specified B10 areal density of borated aluminum is 111% (1/0.90) of the areal density used in the criticality calculations in Chapter 6.   The basis for this 90% credit is the B10 areal density acceptance testing, which assures that at any location in the material, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.

Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings"(5). In particular, blisters and widespread rough surface conditions such as die chatter or porosity will not be acceptable, while local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

9.1.7.2 Boron Carbide / Aluminum Metal Matrix Composites (MMC)

The material is a composite of fine boron carbide particles in an aluminum 1000 or 6000 series matrix. The material may be produced by, either direct chill casting, powder metallurgy, or thermal spray techniques. In either case it is a low-porosity product, with a metallurgically bonded matrix. Practical manufacturing considerations limit the boron carbide content to 35% by volume.

Prior to use in the TN-68, MMCs shall pass the qualification testing specified in Section 9.4.3, and shall subsequently be subject to the process controls specified in Section 9.4.4.
Again, 90% credit is taken for the B10 areal density, based on the areal density acceptance testing and the qualification testing required for this class of materials.

Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings" (5).   In particular, blisters and widespread rough surface conditions such as die chatter or porosity will not be acceptable, while local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

9.1.7.4 Boral®

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 is slightly porous.
The minimum specified B10 areal density of Boral® is 111% (1/0.90) of the areal density used in the criticality calculations in Chapter 6.   The basis for this 90% credit is the testing documented in reference 6 and the manufacturer's acceptance testing program, described here.

Areal density of B10 will be verified by chemical analysis and by certification of the B10 isotopic fraction for the boron carbide powder, or by neutron transmission testing. A coupon is

taken from the corners of the sheet produced from each ingot. Areal density testing is performed on an approximately 1 cm^2 area of the thinnest coupon. If the measured areal density is below that specified, then all 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.

A Boral® lot is defined as a group of consecutively rolled ingots, with a single final thickness and boron carbide loading, using the same lot of boron carbide powder. The sampling rate for areal density testing will be at least 20% and will be sufficient that the lower tolerance limit for the lot will exceed the specified minimum areal density. The lower tolerance limit is defined as the mean value of areal density for the sample, less K times the standard deviation, where K is the one-sided tolerance limit factor for the sample size, a normal distribution, and 95% probability and 95% confidence. The statistical verification is not required if the lot is subjected to 100% inspection.

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

9.2 Maintenance Program

Because of their passive nature, the storage casks will require little, if any, maintenance over the lifetime of the ISFSI. Typical maintenance tasks could involve occasional recalibration of pressure monitoring instrumentation and repainting of some casks with corrosion-inhibiting coatings. No special maintenance techniques are necessary.

Two identical pressure transducers/switches are provided. If the instrument malfunctions, the second switch can be connected. The pressure transducers/switches are not replaced unless they are malfunctioning.

All the gaskets used for the containment boundary are metallic o-rings. They are designed to maintain their sealing capability until the cask is reopened. If a leak is detected by a drop in pressure in the overpressure system, all the gaskets can be replaced. For a drop in pressure that is consistent with the maximum allowable leak rate (see Figure 7.1-1), the overpressure system can be re-pressurized at the time of transducer/switch maintenance.

9.3 Marking

The TN-68 is marked with the model number, unique identification number, and empty weight in accordance with 10 CFR 72.236(k). The unit identification number has the form TN-68-XX-Y-Z, where XX is a sequential number corresponding to a specific cask, Y is blank or a letter from A to G indicating B10 areal density in the basket neutron absorber plates (see Table 9.1-1) and Z is blank or the letter Q indicating that the basket is outfitted to accommodate damaged fuel.

9.4 Specification for Neutron Absorbers

9.4.1 Specification for Thermal Conductivity Testing of Neutron Absorbers

Testing shall conform to ASTM E1225(7), ASTM E1461(8), or equivalent method, performed at room temperature on coupons taken from the rolled or extruded production material. Previous testing of borated aluminum and metal matrix composite, Table 9.4-1, shows that thermal conductivity increases slightly with temperature. Initial sampling shall be one test per lot, defined by the heat or ingot, and may be reduced if the first five tests meet the specified minimum thermal conductivity.

If a thermal conductivity test result is below the specified minimum, additional tests may be performed on the material from that lot. If the mean value of those tests falls below the specified minimum (Ch 4, Section 4.2, item 12), 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 boron appearing in the same 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 thermal analysis in Chapter 4 considers a base model with 0.31” thick neutron absorber. This model gives the bounding values for the maximum component temperatures. The dual plate basket construction alternate model described in Section 4.3.1 assumes a 3/16 inch thick neutron absorber paired with a 1/8 inch thick aluminum ll00 plate to make a total thickness of 0.31”. The specified thickness of the neutron absorber may vary, and the thermal conductivity acceptance criterion for the neutron absorber will be based on the nominal thickness specified. To maintain the thermal performance of the basket, the minimum thermal conductivity shall be such that the total thermal conductance (sum of conductivity * thickness) of the neutron absorber and the aluminum 1100 plate shall equal the conductance assumed in the analysis for the base model. Samples of the acceptance criteria for various neutron absorber thicknesses are highlighted in Table 9.4-2.

The aluminum 1100 plate does not need to be tested for thermal conductivity; the material may be credited with the values published in the ASME Code Section II part D.

9.4.2 <u>Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission</u>

Measurement of B10 areal density by neutron transmission may be done either directly on the finished product, or on test coupons removed from the finished product. Measurements shall be made (equivalently, coupons shall be taken) at locations that are well-distributed throughout the lot. Measurements shall not be made where there is physical damage, such as severe surface defects, that would preclude an accurate measurement of the product's physical thickness or its areal density.

A lot is defined as all the pieces produced from a single ingot or heat. If this definition results in lot size too small to provide a meaningful statistical analysis of results (<25), an alternate larger lot definition may be used. For example, for powder metallurgical metal matrix composites, an acceptable alternate lot definition would be a group of billets produced using the same process, in a single production campaign, from the same batch of powder. Batch would be defined as a mix of the same lots of boron carbide and aluminum powders blended using the same process. 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. A PWR basket with 32 compartments will have about 60,000 square inches of neutron absorber, and a BWR basket with 61 compartments about 90,000 square inches, assuming 144 inch length and no neutron absorber at the basket periphery.

The B10 areal density is measured using an approximately 1 cm^2 collimated thermal neutron beam. The neutron transmission through the test coupons is converted to B10 areal density by comparison with transmission through calibrated standards. These standards are composed of a homogeneous boron compound without other significant neutron absorbers, for example, zirconium diboride or titanium diboride. 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. The nominal value of B10 areal density thus determined is reduced by 3 standard deviations, based on the number of neutrons counted, in order to conservatively account for statistical variations in testing. The resulting value is called the "minimum B10 areal density."

Equivalently, digital image analysis may be used to compare neutron radioscopic images of the test coupon to images of the standards. The area of image analysis shall be approximately 1 cm^2, though the neutron beam may be larger. The determination of the standard deviation for each measurement may be based on the number of pixel images analyzed, rather than the neutron count.

The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The minimum B10 areal densities determined by neutron transmission are converted to volume density, i.e., the minimum B10 areal density is divided by the thickness at the location of the neutron transmission measurement or the maximum thickness of the coupon. The lower tolerance limit of B10 volume density is then determined, defined as the mean value

of B10 volume density for the sample, less K times the standard deviation, where K is the one-sided tolerance limit factor for a normal distribution with 95% probability and 95% confidence. Finally, the minimum specified value of B10 areal density is divided by the lower tolerance limit of B10 volume density to arrive at the minimum plate thickness which provides the specified B10 areal density.

Any plate which is thinner than this minimum or the minimum thickness specified on the procurement drawing, 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 specified on the drawing.

9.4.3 Specification for Qualification Testing of Metal Matrix Composites

9.4.3.1 Applicability and Scope

This specification applies to metal matrix composites (MMC) consisting of fine boron carbide particles in an aluminum 1000 or 6000 series matrix. The ingot may be produced by either powder metallurgy (PM), thermal spray techniques, or by direct chill (DC) casting. In any case it shall have porosity no greater than 2%, a metallurgically bonded matrix, and boron carbide content no greater than 35% by volume. Boron carbide particles for the products considered here typically have an average size in the range 10-40 microns, although the actual specification may be by mesh size, rather than by average particle size. No more than 10% of the particles are over 60 microns. Limitations on fines are established as required by the billet formation process. 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 manufacturing process results in a product that satisfies the design function. Subsequently, the material for use in a spent fuel dry storage or transport system shall be manufactured under the same process limitations, other than production scale, used to control the manufacturing of the test material. Upon any major changes to manufacturing processes, as specified in Section 9.4.4, qualification testing shall be repeated before use of such material in a spent fuel dry storage or transport system.

This specification does not apply to Boral®, described in Section 9.1.7.4.

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

9.4.3.2 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. It must be free of macrosegregation, e.g., alternating zones of higher and low boron carbide density; the validity of acceptance testing coupons for B10 areal density depends in part upon the assumption that the small area tested will be reasonably representative of the much larger area of the delivered piece.

Depending on the specific application, other design requirements may include specified minimum thermal conductivity and tensile strength, and the ability to take a surface finish such as anodizing.

9.4.3.3 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 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 testing is not required for MMCs consisting only of boron carbide in an aluminum 1100 matrix, because there is no reaction between aluminum and boron carbide below 842 °F(9), well above the basket temperature under normal conditions of storage or transport.

Corrosion testing is not required for full density MMCs consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear(15).

9.4.3.4 Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity

At least three samples, one each from the two ends and middle of the test material production run shall be subjected to room temperature tensile testing (ASTM- B557(10)) demonstrating that the material

- has a 0.2% offset yield strength no less than 1.5 ksi
- has an ultimate strength no less than 5.0 ksi
- has elongation no less than 1%, or can be shown to fail in a ductile manner, e.g., by scanning electron microscopy of the fracture surface, and

For PM or thermal spray MMCs, density testing by ASTM-B311(11) or by measuring and weighing shall verify no more than 2% porosity.

9.4.3.5 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(12), E142(13), and E545(14)) 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 (Note that the sensitivity of these techniques may be insufficient for areal densities greater than 20 mg B10/cm^2), or

(b) Quantitative testing for the B10 areal density, or the boron carbide weight fraction, on at least 25 locations distributed over the test material production run, verifying that one standard deviation in the sample is less than 5% of the sample mean. Testing may be performed by a neutron transmission method similar to that specified in Section 9.4.2 or by chemical (gravimetric and/or titrimetric) analysis for boron carbide content in the composite.

9.4.3.6 Testing for Other Design Properties

If the design depends upon the thermal conductivity of the material, at least one specimen from the test material shall be subject to thermal conductivity testing (ASTM E1225[7] or ASTM E1461[8]) to verify that the material has the specified minimum thermal conductivity at all temperatures specified in the design.

9.4.4 Specification for Process Controls for Metal Matrix Composites

9.4.4.1 Applicability and Scope

The applicability of this section is the same as that of Section 9.4.3. This section addresses the process controls to ensure that the material delivered for use has the same characteristics as the qualification test material.

Major processing changes shall be subject to a complete program of qualification testing per Section 9.4.3 prior to use of the material produced by the revised process.

9.4.4.2 Definition of Major Process Changes

Major process changes are those which could adversely affect the uniform distribution of the boron carbide in the aluminum, increase porosity, or reduce the mechanical strength or ductility of the MMC. In the case where the design takes credit for thermal conductivity of the material, major process changes include those that could reduce thermal conductivity.

9.4.4.3 Identification and Control of Major Process Changes

The manufacturer shall provide the certificate holder with a complete specification for materials and process controls used in producing the MMC for qualification testing. The certificate holder and manufacturer shall by mutual agreement establish limits beyond which changes in the processing shall require re-qualification of the process. Major process changes include:

(a) Increase in boron carbide content,

(b) Changes in the boron carbide particle size specification that increase the average particle size by more than 5 microns, or that increase the tolerance for course or fine particles.

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

(d) Change in the matrix alloy, including change in any specified modifications of the matrix alloy, except reduction of trace contaminants,

(e) For PM or thermal spray MMCs that were qualified with extruded material, elimination of extrusion, e.g., direct rolling from the billet, near net shape sintering, etc.,

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

(g) Changes in powder blending or melt stirring processes that could result in less uniform distribution of boron carbide.

9.5 Alternate Acceptance Testing for Neutron Absorbers on TN-68-01 through -44

Neutron absorber material for the first forty-four TN-68 casks consisted either of borated aluminum (1.7% boron, minimum 30 mg B10/cm^2), or Boralyn® MMC (15% B_4C, minimum 36 mg B10/cm^2). These materials were manufactured prior to October 2004, and were subject to the original TN-68 neutronic acceptance testing described here.

9.5.1 Test Coupons

Each neutron absorber plate is 10.4 inches wide by ~42, 55, and 69 inches long. Coupons the full width of the plate (10.4 inches) will be removed between each finished plate and at the ends of the "stock plate". The thermal conductivity coupon may be removed from one of the neutronic inspection coupons. The minimum dimension of the coupon shall be as required for neutron transmission measurements; 1 to 2 inches is adequate for the typical 1 cm diameter neutron beam.

9.5.2 Acceptance Testing

Effective boron 10 content is verified by neutron transmission testing of these coupons. The transmission through the coupons is compared with transmission through calibrated standards composed of a homogeneous boron compound without other significant neutron absorbers, for example zirconium diboride or titanium diboride. These standards are paired with aluminum shims sized to match the scattering by aluminum in the neutron absorber plates. Provision shall be made so that the neutron transmission test is not always made in the same location on the coupon. Thus, the random placement of the coupons in the test fixture results in testing at two locations across the plate width. The effective B10 content of each coupon, minus 3σ based on the number of neutrons counted for that coupon, must be greater than the specified areal density. Rejection of a given coupon shall result in rejection of the contiguous plate(s).

Macroscopic uniformity of B10 distribution is verified by neutron radioscopy of the coupons. The acceptance criterion is that there be uniform luminance across the coupon. This inspection shall cover the entire coupon.

Normal sampling of coupons for neutron transmission measurements and radioscopy shall be 100%. Reduced sampling (50%) may be introduced based upon acceptance of all coupons in the first 25% of the lot. A rejection during reduced inspection will require a return to 100% inspection of the lot. A lot is defined as all the plates produced from a single casting or powder metal billet.

9.6 References

1. ASME Boiler and Pressure Vessel Code, Section III, 1995 Edition including 1996 addenda.

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

3. ANSI N14.6, "American National Standard for Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds or More for Nuclear Materials," New York, 1986.

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

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

6. “Topical Report: Credit for 90% of the ^{10}B in BORAL,” AAR Report 1829, AAR Manufacturing, Oct 2004

7. ASTM E1225, “Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique”

8. ASTM E1461, “Thermal Diffusivity of Solids by the Flash Method”

9. Pyzak and Beaman, “Al-B-C Phase Development and Effects on Mechanical Properties of B_4C/Al Derived Composites,” J. Am. Ceramic Soc., 78[2], 302-312 (1995)

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

11. ASTM B311, “Test Method for Density Determination for Powder Metallurgy (P/M) Materials Containing Less Than Two Percent Porosity”

12. ASTM E94, “Recommended Practice for Radiographic Testing”

13. ASTM E142, “Controlling Quality of Radiographic Testing”

14. ASTM E545, “Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing”

15. “Hydrogen Generation Analysis Report for TN-68 Cask Materials,” Test Report No. 61123-99N, Rev 0, Oct 23, 1998, National Technical Systems

Table 9.1-1
Boron Content of Neutron Absorbers

Basket Designator "Y"	Specified areal density g B10/cm^2	Maximum fuel enrichment (note 1)	Nom wt % boron in enriched borated aluminum 0.3 inch thick (notes 2, 3)	Nominal vol % B_4C in MMC, 0.3 inch thick (notes 2, 3)	Boral® nominal core thickness, inch (note 2)
none	30	3.70	1.55	11.0	0.064
A	35	3.95	1.80	12.9	0.073
B	40	4.05	2.06	14.7	0.082
C	45	4.15	2.32	16.5	0.092
D	50	4.30	2.58	18.4	Note 4
E	55	4.40	2.84	20.2	
F	60	4.50	3.09	22.1	
G	70	4.70	3.61	25.8	

Notes:

1. Lattice average enrichment limit for undamaged fuel, pellet enrichment limit for damaged fuel
2. The neutron absorber manufacturer may increase the amount of boron to provide margin against rejection of the product
3. If a neutron absorber thinner than 0.3 inch is paired with an aluminum plate, the boron content varies in inverse proportion to the thickness to maintain the same areal density
4. Use of Boral® in this range is not anticipated due to thermal conductivity limitations

Table 9.4-1
Thermal Conductivity as a Function of Temperature for Sample Neutron Absorbers

Temperature °C	Material			
	1	2	3	4
20	193	170	194	194
100	203	183	207	201
200	208	-	-	
250	-	201	218	206
300	211	204	220	203
314	-	-	-	202
342	-	-	-	202

Units: W/mK

Materials:

1) Boralyn® MMC, aluminum 1100 with 15% B_4C
2) Borated aluminum 1100, 2.5% boron as TiB_2
3) Borated aluminum 1100, 2.0% boron as TiB_2
4) Borated aluminum 1100, 4.3% boron as AlB_2

Sources:

Thermal Conductivity Measurements of Boron Carbide/Aluminum Specimens, Oct 1998, testing by Precision Measurements and Instruments Corp. for Transnuclear, Inc.

Qualification of Thermal Conductivity, Borated Aluminum 1100, Eagle Picher Report AAQR06, May 2001

Table 9.4-2
Sample Determination of Thermal Conductivity Acceptance Criterion

Base Model	Al 1100	n absorber	total	
thickness (inch)	0	0.31	0.31	as modeled
conductivity at 70°F (Btu/hr-in-°F)	n/a	**7.94**	n/a	
conductance (Btu/hr-°F)	0	2.46	2.46	

Dual Plate Construction	Al 1100	n absorber	total	
thickness (inch)	0.1225	0.1875	0.31	as modeled
conductivity at 70°F (Btu/h-.in-°F)	11.09	**7.94**	n/a	
conductance (Btu/hr-°F)	1.36	1.49	2.85	

thickness (inch)	0.06	0.25	0.31	thicker neutron absorber
conductivity at 70°F (Btu/hr-in-°F)	11.09	**8.72**	n/a	
conductance (Btu/hr-°F)	0.67	2.18	2.85	

thickness (inch)	0.185	0.125	0.31	thinner neutron absorber
conductivity at 70°F (Btu/hr-in-°F)	11.09	**6.40**	n/a	
conductance (Btu/hr-°F)	2.05	0.80	2.85	

The acceptance criterion is identified by boldface type for each thickness.

The neutron absorber material need not be tested for thermal conductivity if the nominal thickness of the aluminum 1100 in the paired plates is 0.237 inch or greater. The conductance of such plate is equal to 2.46 Btu/hr-°F at the lowest conductivity for Al-1100 (10.4 Btu/hr-in-°F @ 400°F) and satisfies the above criteria for the base model.