RAI: M8

Include an acceptance plan for the neutron poison plates in the SAR and include it by reference into the proposed Technical Specifications. Correlate the acceptance testing of the neutron absorber with expected performance. Indicate how the acceptance tests indicate an adequate percentage of H and B in the absorber material. Describe the significance of the density measurement, and the sensitivity of measurements to the percentage of critical components (H & B).

This information is needed to determine compliance with 10 CFR 72.124(a).

Response: M8

An acceptance plan will be provided in new SAR Section A9.7.3 with acceptance testing located in new SAR Section A9.7.4. Qualification testing of new Metal Matrix Composites will be located in new SAR Section A9.7.5 and process controls for Metal Matrix Composites will be located in new SAR Section A9.7.6.

The information in these new sections may be used to determine compliance with 10 CFR 72.124(a).

These new sections are based on Transnuclear's response to NRC RAI questions 9.1 through 9.11 for the NUHOMS HD CoC 1030 Amendment 1 application (TN Letter E-27377, Dated December 15, 2008, TAC NO. L24153).

Note there is no hydrogen in the metallic neutron absorbers. Therefore the acceptance testing does not determine the percentage or density of H in the absorber material.

Regulation 10 CFR 72.44(c) requires that Technical Specifications include requirements in the following categories:

- Functional and operating Limits and monitoring instruments and limiting control setting
- Limiting conditions
- Surveillance Requirements
- Design Features
- Administrative controls

A review of these categories, as described in 10 CFR 72.44(c), concluded that the regulation does not require fabrication acceptance testing of the neutron absorber plates to be included in the Technical Specifications. Note that the minimum areal Boron-10 density design feature requirement is already specified in proposed Technical Specification 4.3.

Although NUREG-1745, “Standard Format and Content for Technical Specifications for 10 CFR Part 72 Cask Certificates of Compliance”, is not directly applicable to site specific Technical Specifications, it was reviewed to determine if it called for the inclusion fabrication acceptance testing of the neutron absorber plates in the Technical Specifications. The review concluded that NUREG-1745 did not call for fabrication acceptance testing of the neutron absorber plates to be included in Technical Specifications.

Finally, it is NSPM’s understanding that Technical Specifications (both the Prairie Island Nuclear Generating Plant’s and the Site Specific ISFSI’s) are to be written focusing on the operational controls, limits and design needed to ensure safe operation (see Technical Specification Content Discussion above). This would not include fabrication acceptance testing of the neutron absorber plates.

Since the information needed to demonstrate compliance with 10 CFR 72.124(a) will be added in SAR Sections A9.7.3 through A9.7.6, and for the reasons above, NSPM does not propose to include fabrication acceptance testing of the neutron absorber plates into the proposed Technical Specifications.

The following will be added to the SAR:

A9.7.3 NEUTRON ABSORBER REQUIREMENTS

The neutron absorber used for criticality control in the TN-40HT 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 TN-40HT 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 visual inspections, thermal conductivity testing, and the presence / uniformity of B10 need to be verified with testing requirements specific to each material.

References to metal matrix composites throughout this chapter are not intended to refer to borated aluminum or Boral®.

A9.7.3.1 Boron Aluminum Alloy (Borated Aluminum)

Description

The material is produced by direct chill (DC) or permanent mold casting with boron precipitating as a uniform fine dispersion of discrete aluminum diboride (AlB_2) or Titanium diboride (TiB_2) particles in the matrix of aluminum or aluminum alloy. For extruded products, the TiB_2 form of the alloy shall be used. For rolled products, 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 boron may have the natural isotopic distribution or may be enriched in B10.

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 A9.7.4.3.

Requirements

The boron content in the aluminum or aluminum alloy shall not exceed 5% by weight.

The neutron absorbers shall be 100% visually inspected in accordance with the inspection requirements described in Section A9.7.4.1.

The thermal conductivity of the material shall be tested in accordance with the testing requirements in Section A9.7.4.2.

The minimum B10 areal density specified in Table A3.3-17 shall be confirmed via neutron transmission testing as described in Section A9.7.4.3.

A9.7.3.2 BORON CARBIDE / ALUMINUM METAL MATRIX COMPOSITES (MMC)

Description

The material is a composite of fine boron carbide particles in an aluminum or aluminum alloy matrix. The material shall be produced by either direct chill casting, permanent mold casting, powder metallurgy, or thermal spray techniques. It is a low-porosity product, with a metallurgically bonded matrix.

The 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 A9.7.4.3.

Requirements

For non-clad MMC products, the boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding shall not exceed 50% by volume.

Non-clad MMC products shall have a density greater than 98% of theoretical density , 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, with no more than 0.5 volume % interconnected porosity of the core and cladding as a unit of the final product.

Boron carbide particles for the products considered here typically have an average size in the range 10-40 microns, although the actual specification may be by mesh size, rather than by average particle size. No more than 10% of the particles shall be over 60 microns.

The neutron absorbers shall be 100% visually inspected in accordance with the inspection requirements described in Section A9.7.4.1.

The thermal conductivity of the material shall be tested in accordance with the testing requirements in Section A9.7.4.2.

The minimum B10 areal density specified in Table A3.3-17 shall be confirmed via neutron transmission testing as described in Section A9.7.4.3.

The MMCs material shall be qualified in accordance with the requirements specified in Section A9.7.5, and shall subsequently be subject to the process controls specified in Section A9.7.6.

A9.7.3.3 BORAL®

Description

This material consists of a core of aluminum and boron carbide powders between two outer layers of aluminum, mechanically bonded by hot-rolling an “ingot” consisting of an aluminum box filled with blended boron carbide and aluminum powders. The core, which is exposed at the edges of the sheet, is slightly porous. The average size of the boron carbide particles in the finished product is approximately 50 microns after rolling.

The criticality calculations take credit for 75% of the minimum specified B10 areal density of Boral®.

<u>Requirements</u>

The nominal boron carbide content shall be limited to 65% (+ 2% tolerance limit) of the core by weight.

The neutron absorbers shall be 100% visually inspected in accordance with the inspection requirements described in Section A9.7.4.1.

The thermal conductivity of the material shall be tested in accordance with the testing requirements in Section A9.7.4.2.

The minimum B10 areal density specified in Table A3.3-17 shall be confirmed via chemical analysis and by certification of the B10 isotopic fraction for the boron carbide powder, or by neutron transmission testing described in Section A9.7.4.3. Areal density testing shall be 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.

A9.7.4 NEUTRON ABSORBERS ACCEPTANCE TESTING

A9.7.4.1 VISUAL INSPECTIONS OF NEUTRON ABSORBERS

For borated aluminum and MMCs, visual inspections shall follow the recommendations in Aluminum Standards and Data (Reference 6), Chapter 4 “Quality Control, Visual Inspection of Aluminum Mill Products and Castings”. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surface, or cracking shall be treated as non-conforming. Inspection of MMCs with an integral aluminum cladding shall also include verification that the matrix is not exposed through the faces of the aluminum cladding and that solid aluminum is not present at the edges.

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.

A9.7.4.2 THERMAL CONDUCTIVITY TESTING OF NEUTRON ABSORBERS

Testing shall conform to ASTM E1225 (Reference 7), ASTM E1461 (Reference 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 A9.7-1, 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 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 A3.3.2.2 considers a dual plate basket construction base model with 0.125” thick neutron absorber with a 0.312” thick aluminum 1100 plate. This model gives the bounding values for the maximum component temperatures. Either a dual plate basket construction or an alternate single plate (borated aluminum or MMC) construction basket may be utilized. For the dual plate construction, 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. In either construction type, 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 at least 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 A9.7-2.

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. The neutron absorber material need not be tested for thermal conductivity if the nominal thickness of the aluminum 1100 plate is 0.359 inch or greater.

A9.7.4.3 Neutron Transmission Testing of Neutron Absorbers

Neutron Transmission acceptance testing procedures shall be subject to approval by Transnuclear . 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 a 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 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. The calibration of the standards shall be evaluated for acceptance in accordance with Transnuclear 's QA procedures.

Alternatively, digital image analysis may be used to compare neutron radioscopic images of the test coupon to images of the standards. The area of image analysis shall be up to 0.75 sq. inch.

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 Transnuclear 's QA procedures.

The following illustrates one acceptable method and is intended to be utilized as an example. 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 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 (Reference 9).

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

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

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

A9.7.5 Qualification Testing of Metal Matrix Composites

A9.7.5.1 APPLICABILITY AND SCOPE

Prior to initial use in a spent fuel dry storage system, new 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 A9.7.6 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 system.

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

A9.7.5.2 DURABILITY

There is no need to include accelerated radiation damage testing in the qualification. Metals and ceramics do not experience measurable changes in mechanical properties due to fast neutron fluences typical over the lifetime of spent fuel storage.

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 (Reference 10), well above the basket temperature under normal conditions of storage or transport.

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 (Reference 11).

A9.7.5.3 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.

A9.7.5.4 REQUIRED 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:

a) room temperature tensile testing (ASTM- B557 (Reference 12)) 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; and
   - has minimum elongation in two inches no less than 0.5%.

   As an alternative to the elongation requirement, ductility may be demonstrated by bend testing per ASTM E290 (Reference 13). 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 by ASTM-B311 (Reference 14) to verify more than 98% 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 method to be approved by Transnuclear. The maximum interconnect porosity is 0.5 volume %.

And

c) For MMCs with an integral aluminum cladding, thermal durability testing demonstrating that after a 24 hour soak in either pure or borated water, followed by a 30 day heat treatment at a minimum temperature of 825°F in an inert environment, that the specimens are free of blisters and delamination and pass the mechanical testing requirements described in test ‘a’ of this section.

A9.7.5.5 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 (Reference 15), E142 (Reference 16), and E545 (Reference 17)) 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 A9.7.4.3, or by chemical analysis for boron carbide content in the composite.

A9.7.5.6 APPROVAL OF PROCEDURES

Qualification procedures shall be subject to approval by Transnuclear.

A9.7.6 PROCESS CONTROLS FOR METAL MATRIX COMPOSITES

This section provides process controls to ensure that the material delivered for use is equivalent to the qualification test material.

A9.7.6.1 APPLICABILITY AND SCOPE

Key processing changes shall be subject to qualification prior to use of the material produced by the revised process. Transnuclear shall determine whether a complete or partial re-qualification program per Section A9.7.5 is required, depending on the characteristics of the material that could be affected by the process change.

A9.7.6.2 DEFINITION OF KEY PROCESS CHANGES

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

A9.7.6.3 IDENTIFICATION AND CONTROL OF KEY PROCESS CHANGES

The manufacturer shall provide Transnuclear with a description of materials and process controls used in producing the MMC. Transnuclear and the manufacturer shall identify key process changes as defined in Section A9.7.6.2.

An increase in nominal boron carbide content over that previously qualified shall always be regarded as a key process change.

The following are examples of other changes that may be established as key process changes, as determined by Transnuclear's review of the specific applications and production processes:

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

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

(c) Change in the nominal matrix alloy;

(d) Changes in mechanical processing that could result in reduced density of the final product, e.g., for powder metallurgy or thermal spray MMCs that were qualified with extruded material, or 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.

References Added to SAR Section A9.8

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

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

10. 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)

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

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

13. ASTM E290, “Standard Test Methods for Bend Testing of Material for Ductility”

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

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

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

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

18. Thermal Conductivity Measurements of Boron Carbide/Aluminum Specimens, Oct 1998, testing by Precision Measurements and Instruments Corp. for Transnuclear, Inc., Purchase Order Number 98037

19. Eagle Picher Report AAQR06, “Qualification of Thermal Conductivity, Borated Aluminum 1100”, May 2001

Table A9.7-1
Thermal Conductivity 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:
References 18 and 19

TABLE A9.7-2
SAMPLE DETERMINATION OF THERMAL CONDUCTIVITY ACCEPTANCE CRITERION

Single Plate Model	Al 1100	n absorber	total
thickness (inch)	0	0.437	0.437
conductivity at 70°F (Btu/hr-in-°F)	n/a	**9.11**	n/a
conductance (Btu/hr-°F)	0	3.98	3.98*

Dual Plate Construction	Al 1100	n absorber	total	
thickness (inch)	0.312	0.125	0.437	as modeled
conductivity at 70°F (Btu/h-.in-°F)	11.09	**4.17**	n/a	
conductance (Btu/hr-°F)	3.46	0.52	3.98	
thickness (inch)	0.187	0.250	0.437	thicker neutron absorber
conductivity at 70°F (Btu/hr-in-°F)	11.09	**7.62**	n/a	
conductance (Btu/hr-°F)	2.07	1.91	3.98	
thickness (inch)	0.359	0.078	0.437	thinner neutron absorber
conductivity at 70°F (Btu/hr-in-°F)	11.09	**0**	n/a	
conductance (Btu/hr-°F)	3.98	0	3.98	

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

RAI: M10

Provide an acceptance plan for the neutron shield material. Provide data or analyses to show that the neutron shield material (both resin and polypropylene) will retain adequate properties for the application during the storage period. Include the testing procedure, and data that were collected to determine the maximum temperature that the resin can withstand without degradation. This plan should be included by reference to the SAR in the proposed CoC.

The neutron shield material is a borated polyester resin compound that surrounds the gamma shield shell. It is subject to thermal and radiation fields during service, which have the potential for degrading properties of the material including its thermal conductivity.

This information is needed to determine compliance with 10 CFR 72.126(6).

Response: M10

An acceptance plan will be provided in new SAR Section A9.7.7.

The information in these new sections may be used to determine compliance with 10 CFR 72.126(6).

<u>Acceptance of neutron shielding materials</u>

Because the top polypropylene neutron shield is a standard industrial plastic plate, the only acceptance planned is verification of supplier certification to confirm that the material is polypropylene.

<u>Demonstration of durability for neutron shielding materials</u>

Both the polypropylene and the proprietary polyester resin proposed for use in the TN-40HT have been used since 1995 in the TN-40, TN-32, and TN-68 casks with no evidence of degradation of their shielding functions, i.e., no reported increase in dose rates on the cask exterior.

Radiation:

Radiation can cause degradation of polymers by cross-linking or by chain scission. Radiation can also cause radiation-assisted oxidation, which can facilitate chain scission in the polymer. In oxygen-starved conditions, bond repair or crosslinking can be significant mechanisms that prevent chain scission; for this reason, on thick sections such as the TN-40HT neutron shields, most of the damage is confined to a surface layer. The anti-oxidant additive in the radial neutron shield further limits radiation-assisted oxidation.

The threshold for radiation dose damage for polymers is typically greater than 1×10^6 rad. (See page 11 of NASA SP8053, “Nuclear and Space Radiation Effects on Materials”, June 1970). To evaluate the radiation damage to the neutron shield, note that the energy absorption of polymers and tissue is similar. Therefore, the gamma radiation energy absorbed by the polypropylene shield may be approximated as the rad equivalent of the surface dose in rem. The absorbed neutron energy may be estimated as half the neutron dose rate to account for the tissue quality factor. Based on SAR Table A7A.2-1, the accident dose rate at the radial surface of the gamma shield is 116 mrem/hr gamma, and 1980 mrem/hr neutron. This is approximately equivalent to 1.1 rad/hr for the radial neutron shield and less for the less for the top shield. At the end of 40 years, assuming that the radiation field remains constant, this would result in absorbed energy in the radial shield of about 3.9 x 10^5 rad. This is well below the threshold of 1 x 10^6 rad.

Thermal durability:

Public sources of information on polypropylene generally establish the melting point of polypropylene near 327° F (for example, CRC Handbook of tables for Applied Engineering Science, 2nd Edition, Table 1-80) and the long term maximum service temperature at 170° F. Published continuous use temperatures apply to typical industrial applications where the material must retain most of its mechanical properties and dimensional stability. In the case of the top neutron shield, because the material is entirely enclosed in a steel shell, the polypropylene could in fact melt, and still perform its shielding function. On this basis, Table A3.3-3 of the SAR assigns a maximum use temperature of 300° F for the polypropylene, 27° F below its melting point. According to the same table, the normal temperature of the top neutron shield is 191° F, well below the limit.

More information on the durability of the radial shielding resin may be found in Appendix 9A of the TN-68 Storage Safety Analysis Report, Docket 72-1027

The RAI questions says that the "plan should be included by reference to the SAR in the proposed CoC". However, the plan is being submitted as part of a License Amendment Request to the site specific License SNM-2506. Therefore there is no CoC. In the event that the intent of the RAI question was that the plan should be included into the Technical Specification by reference, the following discussion is provided.

Regulation 10 CFR 72.44(c) requires that Technical Specifications include requirements in the following categories:

- Functional and operating Limits and monitoring instruments and limiting control setting
- Limiting conditions
- Surveillance Requirements
- Design Features
- Administrative controls

A review of these categories, as described in 10 CFR 72.44(c), concluded that the regulation does not require the radial neutron shield acceptance plan be included in the Technical Specifications.

Although NUREG-1745, "Standard Format and Content for Technical Specifications for 10 CFR Part 72 Cask Certificates of Compliance", is not directly applicable to site specific Technical Specifications, it was reviewed to determine if it called for the inclusion of the radial neutron shield acceptance plan in the Technical Specifications. The review concluded that NUREG-1745 did not call for the radial neutron shield acceptance plan to be included in Technical Specifications.

Finally, it is NSPM's understanding that Technical Specifications (both the Prairie Island Nuclear Generating Plant's and the Site Specific ISFSI's) are to be written focusing on the operational controls, limits and design needed to ensure safe operation (see Technical Specification Content Discussion above). This would not include the radial neutron shield acceptance plan.

Since the information needed to demonstrate compliance with 10 CFR 72.126(6) will be added in SAR Section A9.7.7, and for the reasons above, NSPM does not propose to include the radial neutron shield acceptance plan into the proposed Technical Specifications.

The following will be added to the SAR:

A9.7.7 Radial Neutron Shielding Tests

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

<u>Testing Requirements</u>

Chemical analysis shall be performed 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. The acceptance values for the chemical composition of the polyester resin are listed in the following table. Note that the chemical composition used in the shielding models (i.e. listed in Table A7A.4-3) are included in the following table for comparison.

Table A7A.4-3 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	2.11			
Total	100.0%		100%	

A density measurement shall be performed on every mixed batch of the polyester resin The minimum polymer density measured shall be greater than 1.547 g/cm^3.

<u>Process Controls</u>

Qualification tests of the personnel and procedure used for mixing and pouring the polyester resin shall be performed. Qualification testing shall include verification that the chemical composition and density is achieved, and the process is performed in such a manner as to prevent voids.

RAI: A8.1

Section A8.2.8.2.1, Dynamic Impact Loads.

Considering the approach similar to that for the NUHOMS-HD storage system (Docket 72- 1030), perform a transient dynamic impact dynamic analysis of the cask for the 18-inch handling end-drop accident to define applicable loading conditions for cask component evaluations.

A comprehensive review of the EPRI NP-7551 target hardness method and its benchmarking for TN-40HT application may involve long lead-time without certitude for closure. The staff will review other justifiable methods, including the NUHOMS-HD approach, for determining loading conditions for cask components.

The information requested is needed for evaluating the cask for complying with the 10 CFR 72.122(b) requirements for protection against environmental conditions and natural phenomena.

Response: A8.1

Transient dynamic analysis of the cask for the 18-inch end-drop using LS-DYNA was performed to determine decelerations and will be added to new SAR Section A4A.10. The calculation to determine decelerations using EPRI NP-7551 will be removed from Section A8.2.8.2.1.

SAR Section A8.2.8.2.1 will be replaced with the following:

> The peak decelerations in the cask and basket during the 18 inch end drop were calculated by a dynamic nonlinear analysis described in Section A4A.10. The analysis showed a maximum acceleration in the TN40HT cask body of 44.1g. This occurred in the bottom plate. The highest acceleration in the basket and fuel

was 28.8g. However, since the basket and fuel were not modeled explicitly, the maximum acceleration (28.8g) must be multiplied by the dynamic load factor of 1.52 resulting in a maximum loading of 43.8g.

The following will be added to new SAR Section A4A.10.

A4A.10 TN-40HT STORAGE CASK END DROP ANALYSIS

The purpose of this section is to determine the rigid body accelerations for the TN-40HT Cask during a vertical drop height of 18 inches on concrete.

The rigid body transfer cask accelerations were predicted numerically by the LS-DYNA 3D explicit nonlinear dynamic analysis finite element solver, Version 971 (Reference 18). The methodology used in performing this analysis is based on work conducted at the Lawrence Livermore National Laboratory (LLNL), where an analysis methodology was developed and validated through comparisons with test data (Reference 19 and Reference 20).

The results of these analyses are used as input to the detailed analyses for the cask body, internal basket and fuel assemblies.

A4A.10.1 FINITE ELEMENT MODEL DESCRIPTION

The ANSYS finite element model of the TN-40HT Cask developed for the cask stress analysis (Appendix A4A.3) was simplified for use in the dynamic impact analysis. The TN-40HT Cask model consists of the cask body, simplified basket structure, concrete pad and soil. Each of these components was modeled using 3D 8-node brick elements. Fully integrated selectively-reduced solid elements were used for all elements to reduce the risk of hourglassing problems.

The finite element model was developed with ANSYS and transferred to LS-DYNA. Modifications were made to the LS-DYNA input file to add the material definitions, non-reflecting boundaries and equation of state into LS-DYNA. Features of the cask, such as the trunnions and neutron shield were neglected in terms of stiffness but their weight was lumped into the density of the cask.

The fuel and basket were modeled as a solid cylinder inside the cask walls with elastic material properties approximately equivalent to that of the structure as a whole.

The geometry of the cask finite element model including the cask internals, concrete and base soil is shown in Figure A4A.10-1 and Figure A4A.10-2.

Only ½ of the cask, internals, concrete and soil were modeled, because the entire arrangement is symmetric about the *x-y* plane. The concrete modeled was 16'-8" long, 6'-8" wide, and 3' thick, and the soil modeled was 66'-8" long, 18'-9" wide, and 39'-2" deep.

A4A.10.2 MATERIAL PROPERTIES

The material properties required to perform the analysis include modulus of elasticity, E, Poison's Ratio, v, and material density (ρ) for the cask body, basket, concrete, and soil. The concrete pad requires a more detailed material model since all of the significant nonlinear deformations occur in the concrete. Material properties used for the concrete and soil were based on those developed at Lawrence Livermore National Labs (Reference 19 and Reference 20).

All material properties were taken at room temperature. This is considered conservative because the cask loaded with spent fuel will typically reach temperatures higher than room temperature, and the lower modulus of elasticity at higher temperatures tends to soften the impact and consequently lower the computed g-loads.

<u>TN-40HT Cask Material</u>

The cask material properties were the same at those used in Appendix A4A.3. All cask materials were modeled as elastic.

Cask Component	Elastic Modulus (psi)	Density (lb-sec^2/in^4)	Poisson's Ratio
Lid Outer Plate	27.8X10^6	8.230x10^{-4}	0.3
Shield Plate	29.0X10^6	8.230x10^{-4}	0.3
Shell Flange	27.8X10^6	7.324x10^{-4}	0.3
Shell	29.0X10^6	9.394x10^{-4}	0.3
Bottom Plate	29.0X10^6	7.324x10^{-4}	0.3
Inner Liner	27.8X10^6	7.324X10^{-4}	0.3

<u>Fuel and Basket Material</u>

The basket structure material properties were the same as those used in Reference 20 except for density. The density of the basket was adjusted to calibrate the overall weight of the cask and basket assembly. The basket was modeled as elastic.

$E = 2.8X10^6$ psi
$v = 0.3$
$\rho = 3.215X10^{-4}$ lb sec^2/in^4

Total modeled weight of the cask and basket is 121,174 lbs since it is a half model. Therefore the total modeled weight is 242,348 lbs. Total actual weight of the cask and basket is 242,400 lbs.

Concrete Material

The concrete was modeled using material law 16 in LS-DYNA, which was developed specifically for granular type materials. The concrete data used in the analysis was originally designed by LLNL for the Shippingport Station Decommissioning Project in 1988. This model was also used in the LLNL (Reference 19) cask drop analysis. Material constants were implemented into Material Model 16, Mode II.B in LS-DYNA. The material represents 4,200 psi compressive strength concrete. A summary of the input used in the analysis is as follows.

$\rho = 2.09675\times10^{-4}$ lb sec^2 / in^4
$v = 0.22$
$a_0 = 1606$
$a_1 = 0.418$
$a_2 = 8.35\times10^{-5}$ psi^{-1}
$b_1 = 0$
$a_{0f} = 0.0$ psi
$a_{1f} = 0.385$

Effective Plastic Strain versus Scale Factor for Concrete Material

Effective Plastic Strain	**Scale Factor, *v***
0	0
0.00094	0.289
0.00296	0.465
0.00837	0.629
0.01317	0.774
0.0234	0.893
0.04034	1.0
1.0	1.0

The maximum principal stress tensile failure cutoff was set at 870 psi. Strain rate effects were neglected in the analysis. Dilger (Reference 21) suggests that the major impact of strain rate effects is in the softening part of the stress-strain curve. Since the purpose of these analyses is primarily to predict the peak accelerations, the strain rate effects on the material behavior may be neglected.

The pressure-volume behavior of the concrete was modeled with the following tabulated pressure versus volumetric strain rate relationship using the equation of state feature in LS-DYNA.

Tabulated Pressure versus Volumetric Strain Rate for the Concrete Material

Volumetric Strain, ε	Pressure (psi)
0	0
-0.006	4,600
-0.075	5,400
-0.01	6,200
-0.012	6,600
-0.02	7,800
-0.038	10,000
-0.06	12,600
-0.0755	15,000
-0.097	18,700

An unloading bulk modulus of 700,000 psi was assumed to be constant at any volumetric strain, as was assumed in Reference 19.

One percent deformation was assumed in the concrete pad to account for the pad reinforcement.

The material properties used for the reinforcing bar are as follows.

$E = 30\times10^6$ psi
$v = 0.3$
$S_y = 30{,}000$ psi
Tangent Modulus, $E_T = 30\times10^4$ psi

Soil Material

The Lawrence Livermore National Labs report (Reference 20) and Brookhaven National Laboratory report (Reference 23) indicates that the stiffness of the soil has little impact on the peak accelerations predicted in the cask. Thus the same soil model was assumed as that used in the Livermore report. The soil material properties assumed for the analysis are:

E = 6,000 psi
v = 0.45
ρ = 2.0368 x 10^{-4} lb-sec^2 / in^4

A4A.10.3 BOUNDARY CONDITIONS

Only ½ of the cask was modeled with symmetry boundary conditions used to simulate the full structure. Non-reflecting boundaries were applied to the bottom and sides of the modeled soil not aligned with the plane of symmetry (bottom, left side, right side, and back) to prevent artificial stress waves from reflecting back into the model. Both dilatation and shear waves were damped as described in the LS-DYNA *BOUNDARY command.

An automatic surface to surface (contact_automatic_single_surface) contact definition was applied between all parts except the soil. The contact definition has a 0.5 penalty stiffness scale factor to prevent excessive contact stiffness leading to unrealistic part accelerations. A surface to surface (contact_surface_to_surface) contact definition was applied between the concrete and the soil with soft contact option 2. Soft contact option 2 was necessary between the soil and concrete as the materials have very different material stiffness. A conservatively low coefficient of friction (static and kinetic) of 0.25 was applied between all contact surfaces. It is conservative to use a low value for the coefficient of friction because less energy is absorbed due to friction resulting in greater impact acceleration forces.

A4A.10.4 INITIAL CONDITIONS AND LOADING

The analysis begins with a 1" gap between the cask and concrete to allow for at least 5 ms of zero acceleration other than gravity. An initial velocity was applied to all parts of the cask model. The initial velocity was computed by equating potential and kinetic energies. Due to the initial 1" gap and gravitational acceleration, initial velocities were computed 1" shorter than the drop heights.

V = potential energy = mgh
T = kinetic energy = $\frac{1}{2}mv^2$

For an 18" Drop:

$mgh = ½mv^2$

$$\Rightarrow v = \sqrt{2gh} = \sqrt{2(386.4)(18-1)} = 114.62 \text{ in./sec.}$$

A gravitational acceleration of 386.4 in/sec^2 was applied to the cask and basket model.

A4A.10.5 RESULTS OF LS-DYNA ANALYSES

The resulting rigid body acceleration time histories were computed by LS-DYNA. The rigid body accelerations were computed for the bottom plate, circumferential shell, and basket representation. The parts can be seen in Figure A4A.10-3.

The peak filtered accelerations and corresponding time history plot for different parts of the TN-40HT cask 18" end drop are listed below. All results were filtered with a 4th order low pass butterworth filter with a 350Hz cutoff frequency.

Results Summary

Part	Peak Acceleration (g)	Time History Figure Number
Shell	41.5	A4A.10-4
Bottom Plate	44.1	A4A.10-5
Basket Representation	28.8	A4A.10-6

Based on the Results shown in the above table, the maximum acceleration in the TN-40HT cask during the 18 inch accident condition end drop event is 44.1g and occurs in the bottom plate. Also from this table, the highest acceleration in the basket and fuel is 28.8g. However, since the basket and fuel were not modeled explicitly, the maximum acceleration (28.8g) must be multiplied by the appropriate dynamic load factor (DLF). The maximum DLF for a triangular load is 1.52 (Reference 24). This results in a maximum loading of 43.8g.

References:

18. LS-DYNA Keyword User's Manual, Volumes 1 & 2, Version 9.71s, Rev. 7600.398 August 17, 2006, Livermore Software Technology Corporation.

19. Witte, M. et. Al. Evaluation of Low-Velocity Impact Testing of Solid Steel Billet onto Concrete Pads and Application to Generic ISFSI Storage Cask for Tipover and Side Drop.

Lawrence Livermore National Laboratory. UCRL-ID-126295, Livermore, California. March 1997.

20. NUREG/CR-6608, UCRL-1D-12911," Summary and Evaluation of Low-Velocity Impact Tests of Solid Steel/Billet onto Concrete Pad," LLNL, February, 1998

21. Dilger, etc., Ductility of Plain and Confined Concrete under Different Stain Rates, ACI Journal, January-February, 1984.

22. Not Used.

23. BNL-NUREG-71196-2003-CP, “Impact Analysis of Spent Fuel Dry Casks Under Accidental Drop Scenarios,” BNL, 2003.

24. Methods for Impact Analysis of Shipping Containers, NUREG/CR-3966, UCID-20639, LLNL, 1987.

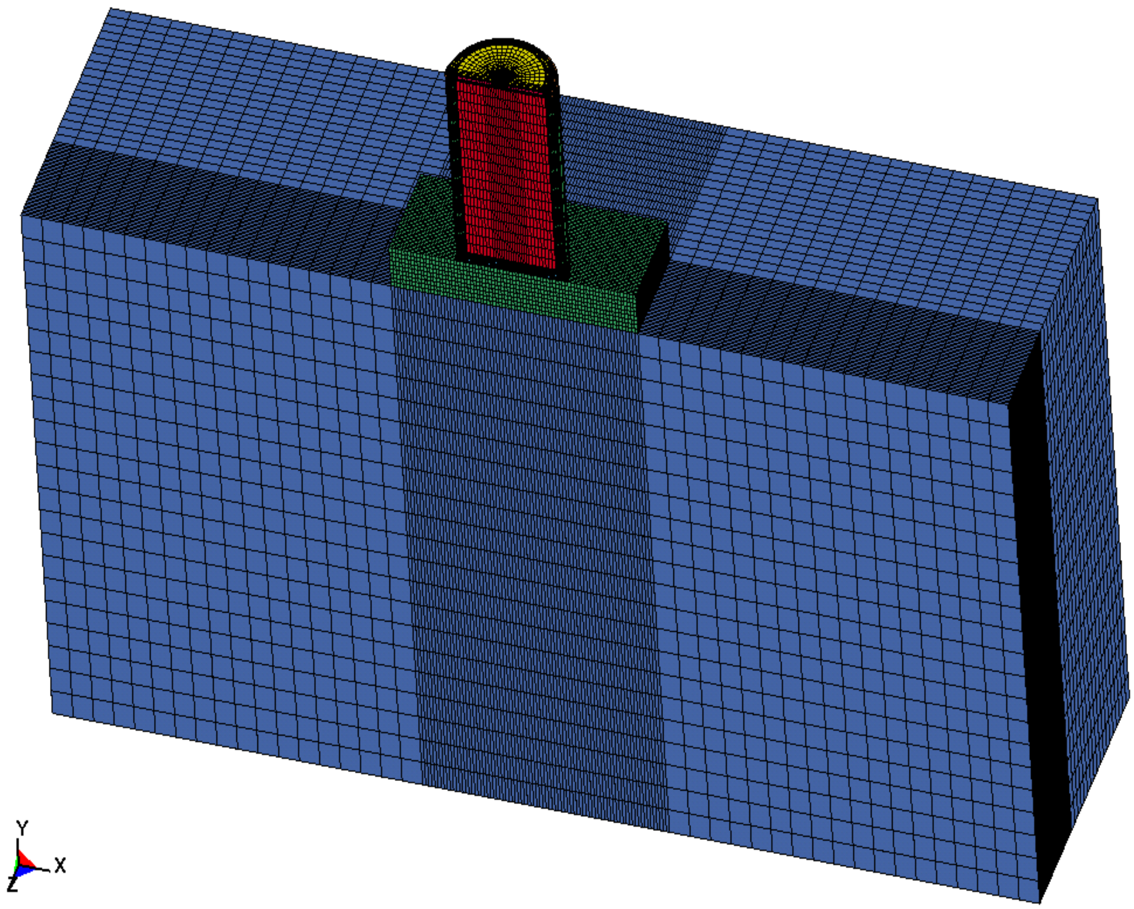

FIGURE A4A.10-1
OVERVIEW OF FINITE ELEMENT MODEL

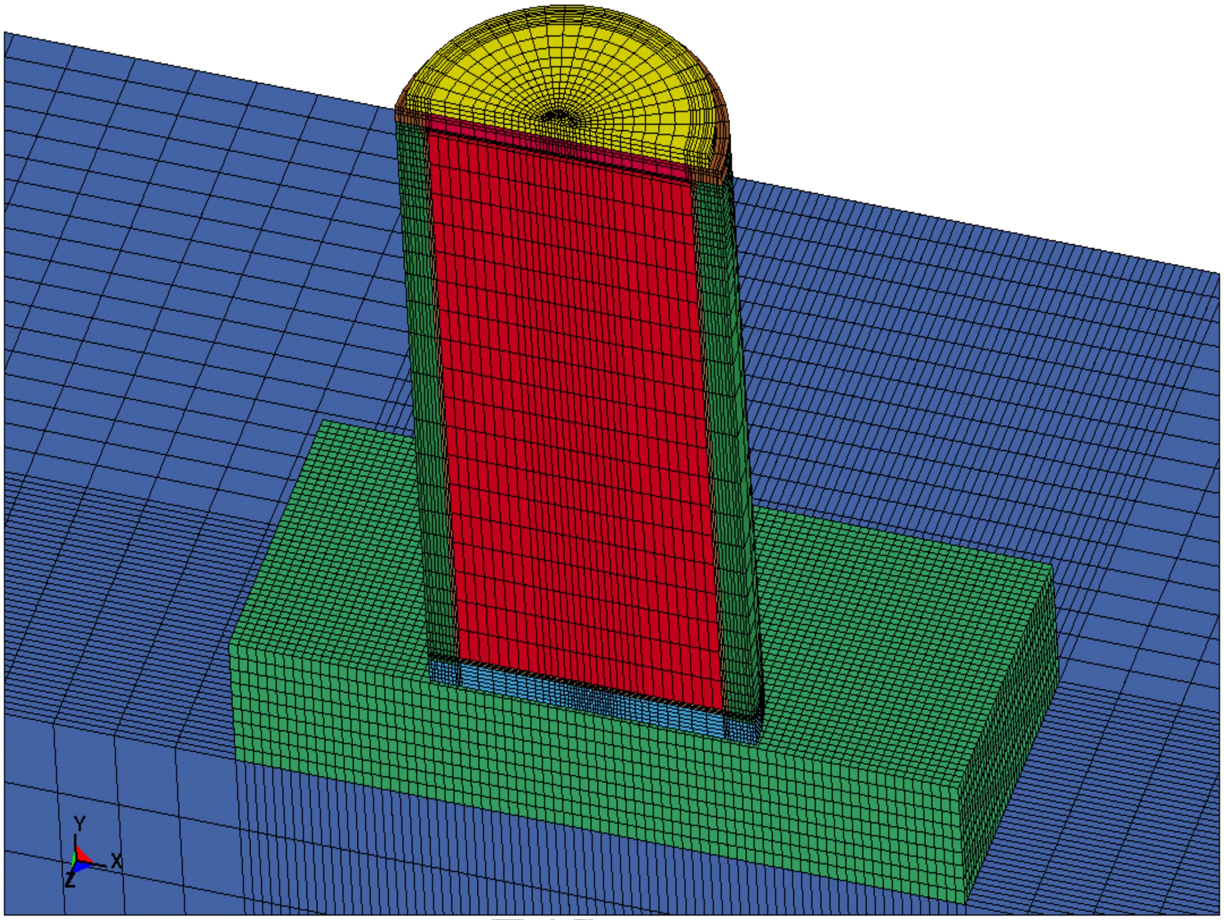

FIGURE A4A.10-2
OVERVIEW OF TN-40HT CASK FINITE ELEMENT MODEL

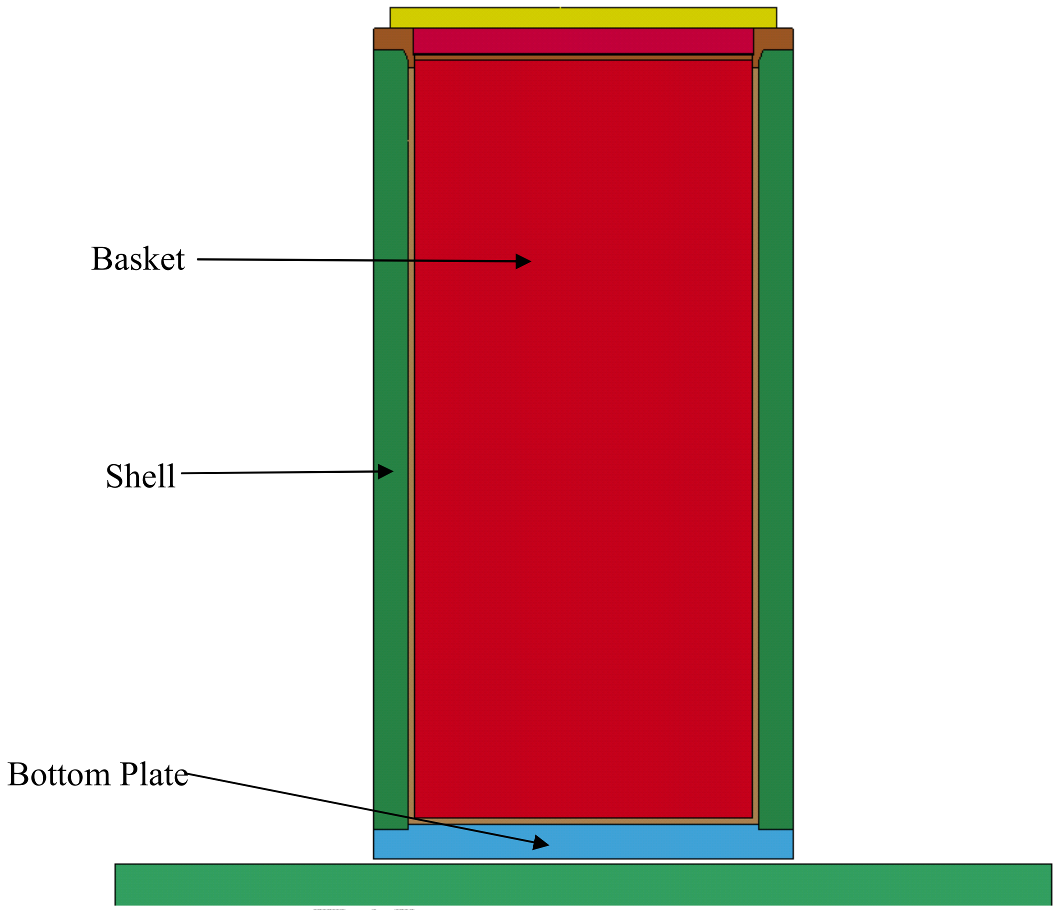

FIGURE A4A.10-3
PARTS ANALYZED FOR ACCELERATION TIME HISTORY

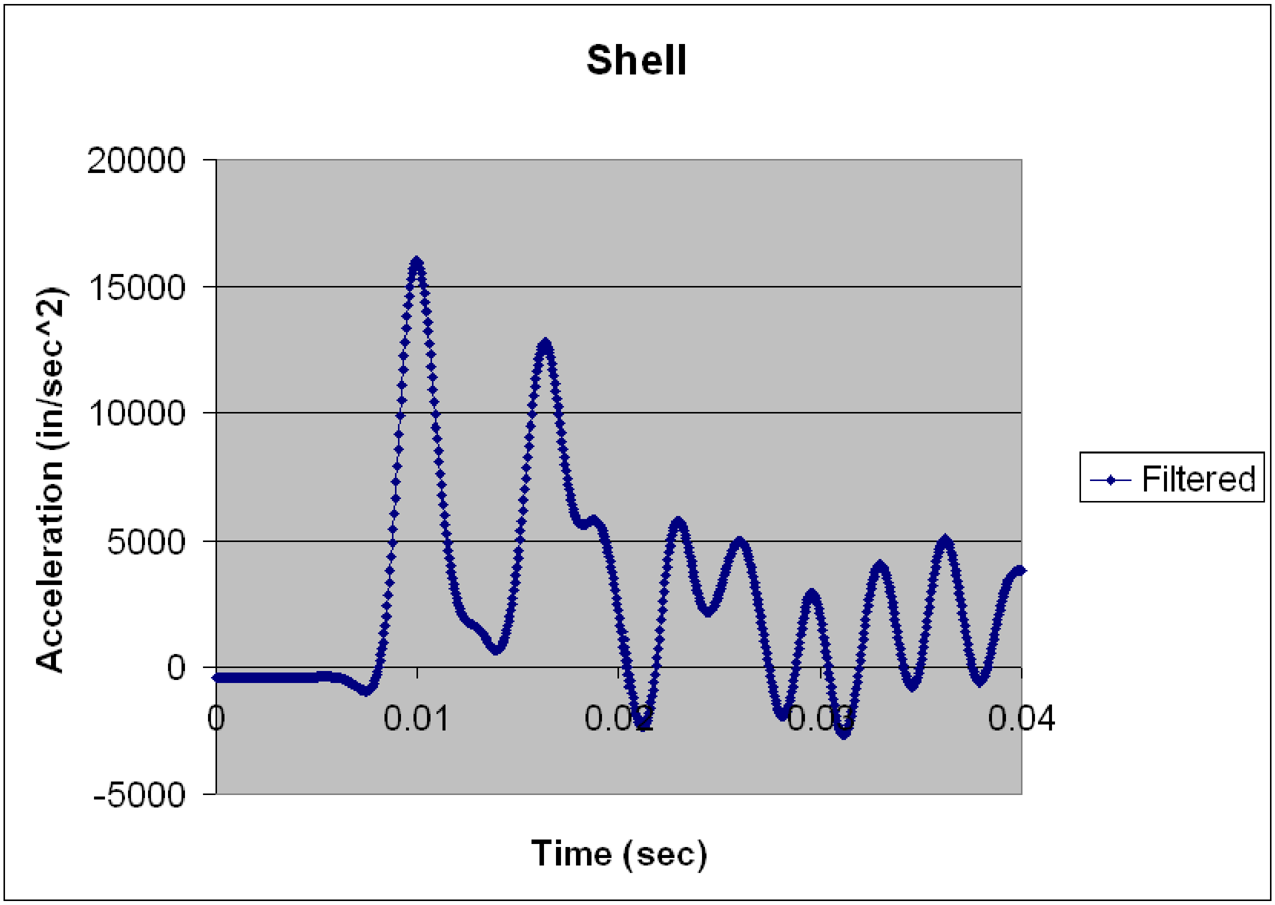

FIGURE A4A.10-4
CASK SHELL ACCELERATION TIME HISTORY (350HZ FILTER)

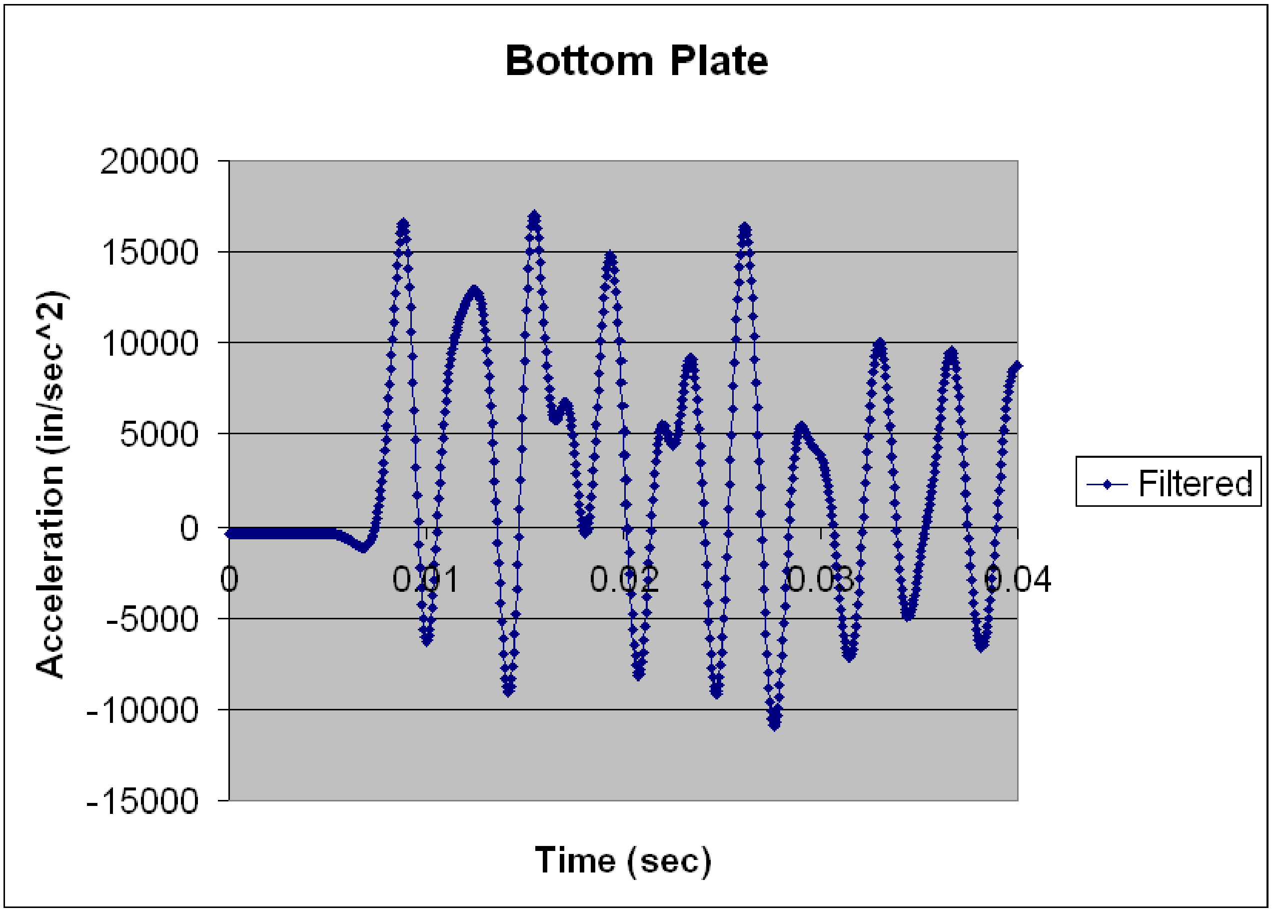

FIGURE A4A.10-5
CASK BOTTOM PLATE ACCELERATION TIME HISTORY (350HZ FILTER)

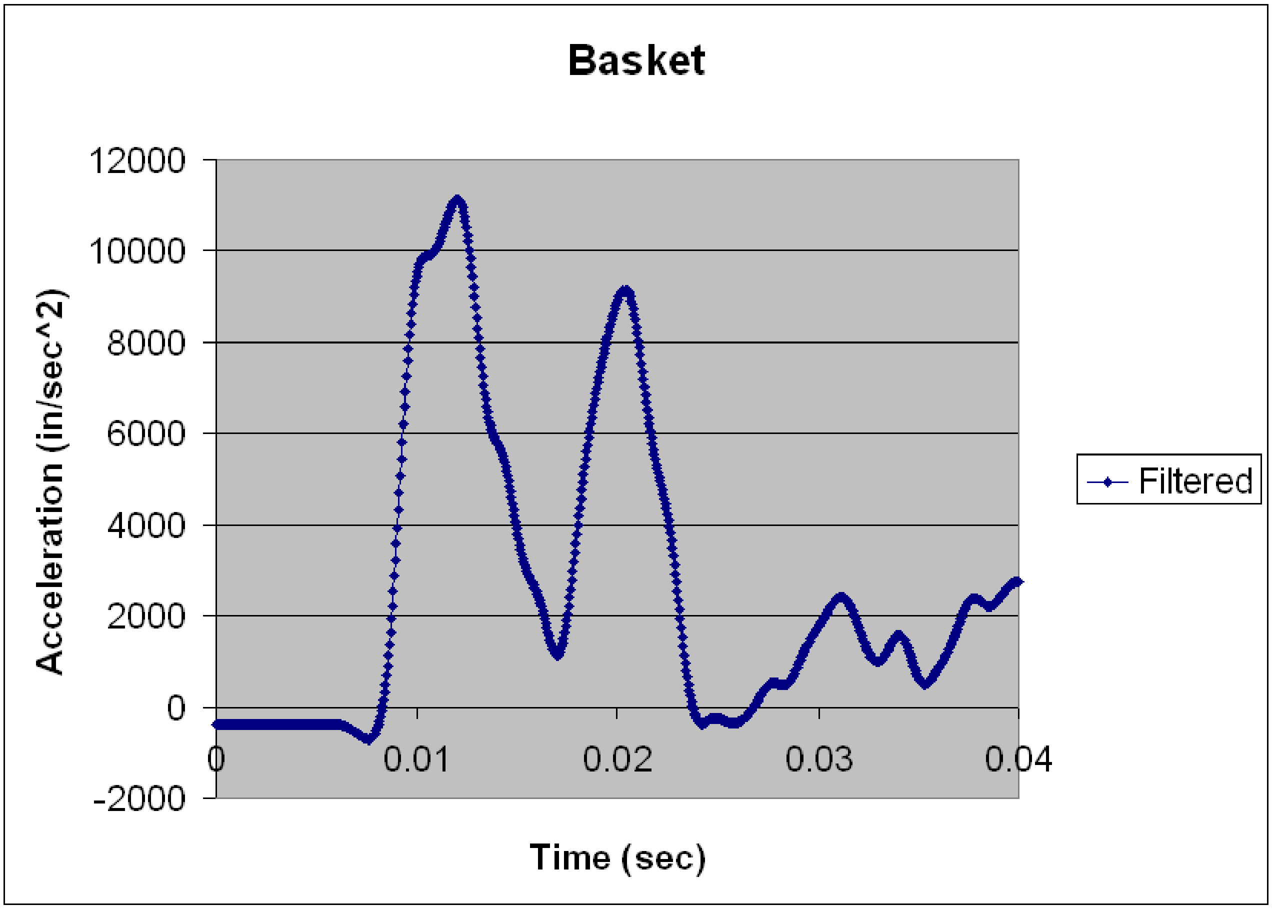

FIGURE A4A.10-6

<u>CASK BASKET ACCELERATION TIME HISTORY (350HZ FILTER)</u>