TRANSNUCLEAR

APPENDIX M, Rev. 7A

of

NUHOMS® FSAR

NON-PROPRIETARY

Enclosure #4

to

NUH03-04-57

Supplemental Submittal

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M.1 General Discussion

This Appendix M to the NUHOMS® Final Safety Analysis Report (FSAR) addresses the Important to Safety aspects of storing spent fuel in the NUHOMS®-32PT system. The NUHOMS®-32PT system consists of a NUHOMS®-32PT Dry Shielded Canister (DSC) stored in a Model 80 or Model 102 NUHOMS® Horizontal Storage Module (HSM) and transferred in a OS197 or OS197H Transfer Cask (TC). There is no change to the HSM or the TC as described in the NUHOMS® FSAR.

The format of this Appendix follows the guidance provided in NRC Regulatory Guide 3.61 [1.1]. The analysis presented in this Appendix shows that the NUHOMS®-32PT system meets all the requirements of 10CFR72 [1.1]. A separate analysis will be submitted to address the safety related aspects of transporting spent fuel in the NUHOMS®-32PT DSC in accordance with 10CFR71 [1.3].

The NUHOMS®-32PT system provides confinement, shielding, criticality control and passive heat removal independent of any other facility structures or components. The NUHOMS®-32PT DSC also maintains structural integrity of the fuel during storage.

Note: References to sections or chapters within this Appendix are identified with a prefix M (e.g., Section M.2.3 or Chapter M.2). References to sections or chapters of the FSAR outside of this Appendix (main body of the FSAR) are identified with the applicable FSAR section or chapter number (e.g., Section 2.3 or Chapter 2).

M.1.1 Introduction

The NUHOMS® System provides a modular canister based spent fuel storage and transport system. The system includes DSCs, HSMs, and the TC.

This Appendix M provides the supporting safety analysis for the addition of the 32PT DSC system. Only those features that are being revised or added to the NUHOMS® System are addressed and evaluated in this Appendix. The HSM and TC designs remain unchanged. The NUHOMS®-32PT DSC is similar to the existing 24P DSCs with the following exceptions:

- The basket has a capability to store 32, rather than 24, Pressurized Water Reactor (PWR) fuel assemblies.
- The canister shell thickness is reduced from 0.625 inches to 0.5 inches.
- The canister has been upgraded to provide a leak tight confinement.
- The basket represents a new design.
- The canister shell length and the thickness of the top and bottom end closure assemblies have been modified to accommodate the new basket design and the revised payload.

The NUHOMS®-32PT DSC system is designed to store intact standard PWR fuel assemblies with or without Burnable Poison Rod Assemblies (BPRAs). The NUHOMS®-32PT DSC system is designed for a maximum heat load of 24 kW/canister and a maximum of 1.2 kW/assembly when heat load zoning is considered. The fuel which may be stored in the NUHOMS®-32PT DSC is presented in Section M.2.

M.1.2 General Description of the NUHOMS®-32PT DSC

M.1.2.1 NUHOMS®-32PT DSC Characteristics

Each NUHOMS®-32PT DSC consists of a fuel basket and a canister body (shell, canister inner bottom and top cover plates and shield plugs). A sketch of the 32PT DSC components is shown in Figure M.1-1. A set of reference drawings is presented in Section M.1.5.

As shown in Table M.1-1, the 32PT DSC system consists of four design configurations or Types as follows:

- 32PT-S100, Short Canister (186.2 inch length)
- 32PT-L100, Long Canister (192.2 inch length)
- 32PT-S125, Short Canister (186.2 inch length)
- 32PT-L125, Long Canister (192.2 inch length)

These four design configurations allow flexibility to accommodate the payload fuel types described in Section M.2, with and without BPRAs. Dimensions and estimated weights of the NUHOMS®-32PT DSC are shown in Table M.1-1.

The thickness for the individual plate components of the top and bottom end cover plates has been increased to accommodate the higher internal pressure, while the top and bottom end shield plug thickness has been reduced relative to the 24P DSC configuration. The NUHOMS®-32PT DSC shell thickness is 0.50 inches instead of 0.625 inches as used for the NUHOMS®-24P or –52B DSC designs. The materials used to fabricate the DSC are shown in the Parts List on Drawings NUH-32PT-1001-SAR, -1002-SAR, -1003-SAR, -1004-SAR, and -1006-SAR.

The confinement vessel for the NUHOMS®-32PT DSC consists of a shell which is a welded stainless steel cylinder with an integrally-welded, stainless steel bottom closure assembly; and a stainless steel top closure assembly, which includes the vent and drain system.

There are no penetrations through the confinement vessel. The draining and venting systems are covered by the seal welded outer top closure plate and vent and siphon port plugs. To preclude air in-leakage, the canister cavity is inerted and pressurized above atmospheric pressure with helium. The NUHOMS®-32PT DSCs are designed and tested to meet the leak tight criteria of ANSI N14.5-1997.

The basket structure consists of a grid assembly of welded stainless steel plates or tubes that make up a grid of 32 fuel compartments. Each fuel compartment accommodates aluminum and/or neutron absorbing plates (which are made of either borated aluminum or metal matrix composites such as Boralyn®, Metamic® or equivalent) that provide the necessary criticality control and heat conduction paths from the fuel assemblies to the canister shell. The space between the fuel compartment grid assembly and the perimeter of the DSC shell is bridged by transition rail structures. The transition rails are solid aluminum segments that support the fuel

compartment grid assembly and transfer mechanical loads to the DSC shell. They also provide the thermal conduction path from the basket assembly to the canister shell wall, making it efficient in rejecting heat from its payload. This method of construction forms a robust structure of compartment assemblies which provides for storage of 32 fuel assemblies. The nominal clear dimension of each fuel compartment opening is 8.7 in. x 8.7 in., which provides clearance around the fuel assemblies.

During dry storage of the spent fuel in the NUHOMS®-32PT system, no active systems are required for the removal and dissipation of the decay heat from the fuel. The NUHOMS®-32PT DSC is designed to transfer the decay heat from the fuel to the basket, from the basket to the canister body and ultimately to the ambient via the HSM or TC.

Each canister is identified by a Mark Number as follows: WWW32PT-XXX-YYY-ZZZ, where: XXX is the canister type designation (S100/L100/S125/L125), YYY is the basket type designation (A/B/C/D) and WWW and ZZZ are designated by TN. Each canister is also marked with the patent number.

M.1.2.2 Operational Features

M.1.2.2.1 General Features

The NUHOMS®-32PT DSCs are designed to safely store 32 intact standard PWR fuel assemblies with or without BPRAs. The NUHOMS®-32PT DSC is designed to maintain the fuel cladding temperature below allowable limits during storage, short-term accident conditions, short-term off-normal conditions and fuel transfer operations.

The criticality control features of the NUHOMS®-32PT DSC are designed to maintain the neutron multiplication factor k-effective less than the upper subcritical limit equal to 0.95 minus benchmarking bias and modeling bias under all conditions.

M.1.2.2.2 Sequence of Operations

The sequence of operations to be performed in loading fuel into the NUHOMS®-32PT DSCs is presented in Chapter M.8.

M.1.2.2.3 Identification of Subjects for Safety and Reliability Analysis

M.1.2.2.3.1 Criticality Prevention

Criticality is controlled by geometry, soluble boron in spent fuel pool and by utilizing fixed neutron poison material in the fuel basket. If required, depending on fuel assembly design and initial enrichment, Poison Rod Assemblies (PRAs), as shown in Figure M.1-2 are also used for criticality control. The 32PT basket may contain 0, 4, 8 or 16 PRAs and is called a Type A, Type B, Type C, or Type D, respectively. These features are only necessary during the loading and unloading operations that occur in the loading pool (underwater). However, the PRAs are left in place following the completion of the DSC draining and drying operations which are discussed in M.8.1.3. During storage, with the DSC cavity dry and sealed from the environment, criticality control measures within the installation are not necessary because of the low reactivity of the

fuel in the dry NUHOMS®-32PT DSC and the assurance that no water can enter the DSC cavity during storage.

M.1.2.2.3.2 Chemical Safety

There are no chemical safety hazards associated with operations of the NUHOMS®-32PT system.

M.1.2.2.3.3 Operation Shutdown Modes

The NUHOMS®-32PT DSC system is a totally passive system so that consideration of operation shutdown modes is unnecessary.

M.1.2.2.3.4 Instrumentation

No change.

M.1.2.2.3.5 Maintenance Techniques

No change.

M.1.2.3 Cask Contents

The NUHOMS®-32PT DSC system is designed to store 32 intact standard PWR fuel assemblies with or without BPRAs. Each NUHOMS®-32PT DSC is designed for a maximum heat load of 24 kW/canister and 1.2 kW/assembly if zoning for heat load is used. The fuel that may be stored in the NUHOMS®-32PT DSC is presented in Chapter M.2.

Chapter M.5 provides the shielding analysis. Chapter M.6 covers the criticality safety of the NUHOMS®-32PT DSC system and its contents, listing material densities, moderator ratios, and geometric configurations.

M.1.3 Identification of Agents and Contractors

Transnuclear, Inc. (TN) provides the design, analysis, licensing support and quality assurance for the NUHOMS®-32PT system. Fabrication of the NUHOMS®-32PT system cask is done by one or more qualified fabricators under TN's quality assurance program described in Chapter M.13. This program is written to satisfy the requirements of 10 CFR 72, Subpart G and covers control of design, procurement, fabrication, inspection, testing, operations and corrective action. Experienced TN operations personnel provide training to utility personnel prior to first use of the NUHOMS®-32PT system and prepare generic operating procedures.

Managerial and administrative controls, which are used to ensure safe operation of the casks, are provided by the host utility. NUHOMS®-32PT system operations and maintenance are performed by utility personnel. Decommissioning activities will be performed by utility personnel in accordance with site procedures.

TN provides specialized services for the nuclear fuel cycle that support transportation, storage and handling of spent nuclear fuel, radioactive waste and other radioactive materials. TN is the holder of Certificate of Compliance 1004.

M.1.4 Generic Cask Arrays

No change.

M.1.5 Supplemental Data

The following Transnuclear drawings are enclosed:

1. NUHOMS®-32PT Transportable Storage Canister for PWR Fuel, Main Assembly, Drawing NUH-32PT-1001NP-SAR.

2. NUHOMS®-32PT Transportable Storage Canister for PWR Fuel, Shell Assembly, Drawing NUH-32PT-1002NP-SAR.

3. NUHOMS®-32PT Transportable Storage Canister for PWR Fuel, Basket Assembly Option 1, Drawing NUH-32PT-1003NP-SAR.

4. NUHOMS®-32PT Transportable Storage Canister for PWR Fuel, Basket Assembly Option 2, Drawing NUH-32PT-1004NP-SAR.

5. NUHOMS®-32PT Transportable Storage Canister for PWR Fuel, Aluminum Transition Rails, Drawing NUH-32PT-1006NP-SAR.

Figure Withheld Under 10 CFR 2.390

TRANSNUCLEAR

NUHOMS® 32PT TRANSPORTABLE STORAGE CANISTER FOR PWR FUEL MAIN ASSEMBLY

NUH-32PT-100THP-SAR | NONE | 1 OF 3 | 2

Figure Withheld Under 10 CFR 2.390

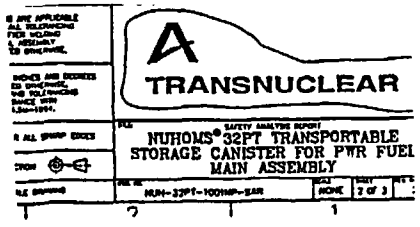


Figure Withheld Under 10 CFR 2.390

TRANSNUCLEAR

NUHOMS® 32PT TRANSPORTABLE STORAGE CANISTER FOR PWR FUEL MAIN ASSEMBLY

NUH-32PT-100TRP-SAR | NONE | 3 OF 3 | 2

Figure Withheld Under 10 CFR 2.390

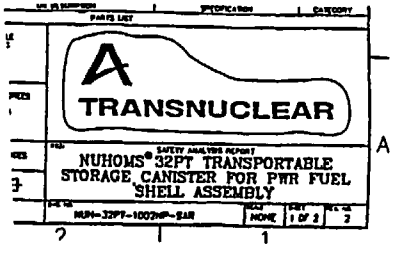


Figure Withheld Under 10 CFR 2.390

TRANSNUCLEAR

NUHOMS® 32PT TRANSPORTABLE STORAGE CANISTER FOR PWR FUEL SHELL ASSEMBLY

NUH-32PT-1002NP-SAR | NONE | 2 OF 2 | 2

Figure Withheld Under 10 CFR 2.390

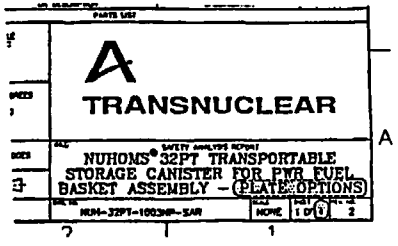


Figure Withheld Under 10 CFR 2.390

TRANSNUCLEAR

NUHOMS® 32PT TRANSPORTABLE STORAGE CANISTER FOR PWR FUEL BASKET ASSEMBLY – (PLATE OPTIONS)

NUH-32PT-1003NP-SAR | NONE | 2 OF 6 | 2

Figure Withheld Under 10 CFR 2.390

TRANSNUCLEAR

NUHOMS® 32PT TRANSPORTABLE STORAGE CANISTER FOR PWR FUEL BASKET ASSEMBLY – (PEATE OPTIONS)

NUH-32PT-1003NP-SAR | NONE | 2

Figure Withheld Under 10 CFR 2.390

TRANSNUCLEAR

SAFETY ANALYSIS REPORT

NUHOMS® 32PT TRANSPORTABLE STORAGE CANISTER FOR PWR FUEL BASKET ASSEMBLY- (PLATE-OPTIONS)

NUH-32PT-100.SAR | NONE | 2

Figure Withheld Under 10 CFR 2.390

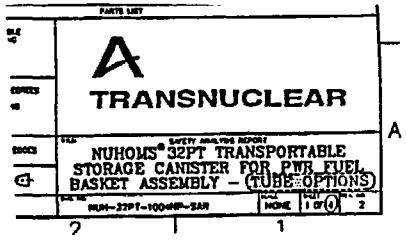


Figure Withheld Under 10 CFR 2.390

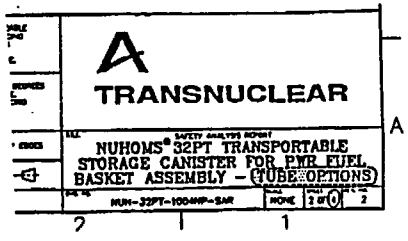


Figure Withheld Under 10 CFR 2.390

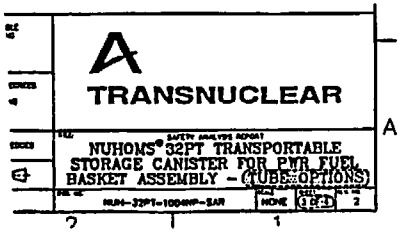


Figure Withheld Under 10 CFR 2.390

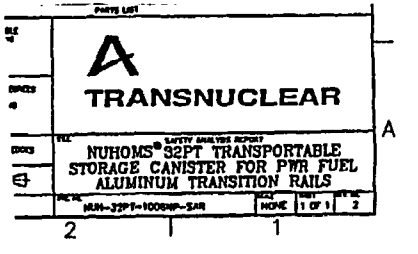
TRANSNUCLEAR

NUHOMS® 32PT TRANSPORTABLE STORAGE CANISTER FOR PWR FUEL BASKET ASSEMBLY – (TUBE OPTIONS)

NUH-32PT-100HP-SAR | NONE | 4 OF 4 | 2

A

Figure Withheld Under 10 CFR 2.390



M.1.6 References

1.1 U.S. Nuclear Regulatory Commission, Regulatory Guide 3.61, Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Cask, February, 1989.

1.2 10CFR72, Rules and Regulations, Title 10, Chapter 1, Code of Federal Regulations - Energy, U.S. Nuclear Regulatory Commission, Washington, D.C., "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste."

1.3 10CFR71, Rules and Regulations, Title 10, Chapter 1, Code of Federal Regulations - Energy, U.S. Nuclear Regulatory Commission, Washington, D.C., "Packaging and Transportation of Radioactive Material."

Table M.1-1
Nominal Dimensions and Weight of the NUHOMS®-32PT DSC

	32PT DSC Design Configuration			
	32PT-S100	32PT-S125	32PT-L100	32PT-L125
Canister Length (in.)	186.2	186.2	192.2	192.2
Outside Diameter (in)	67.19	67.19	67.19	67.19
Cavity Length (in.)	169.6	167.1	175.6	173.1
Cavity Diameter (in)	66.19	66.19	66.19	66.19
Nominal DSC Loaded Weight, Dry (kips)	88.2 (1) 98.3 (2)	90.3 (1) 100.4 (2)	89.2 (1) 99.3 (2)	91.3 (1) 101.4 (2)

Notes:
1. Based on fuel weight of 1,365 lbs. per assembly. This is the limit for any 32PT DSC for which the maximum lift weight of the loaded transfer cask is to remain under 100 tons.
2. Based on fuel weight of 1,682 lbs per assembly.

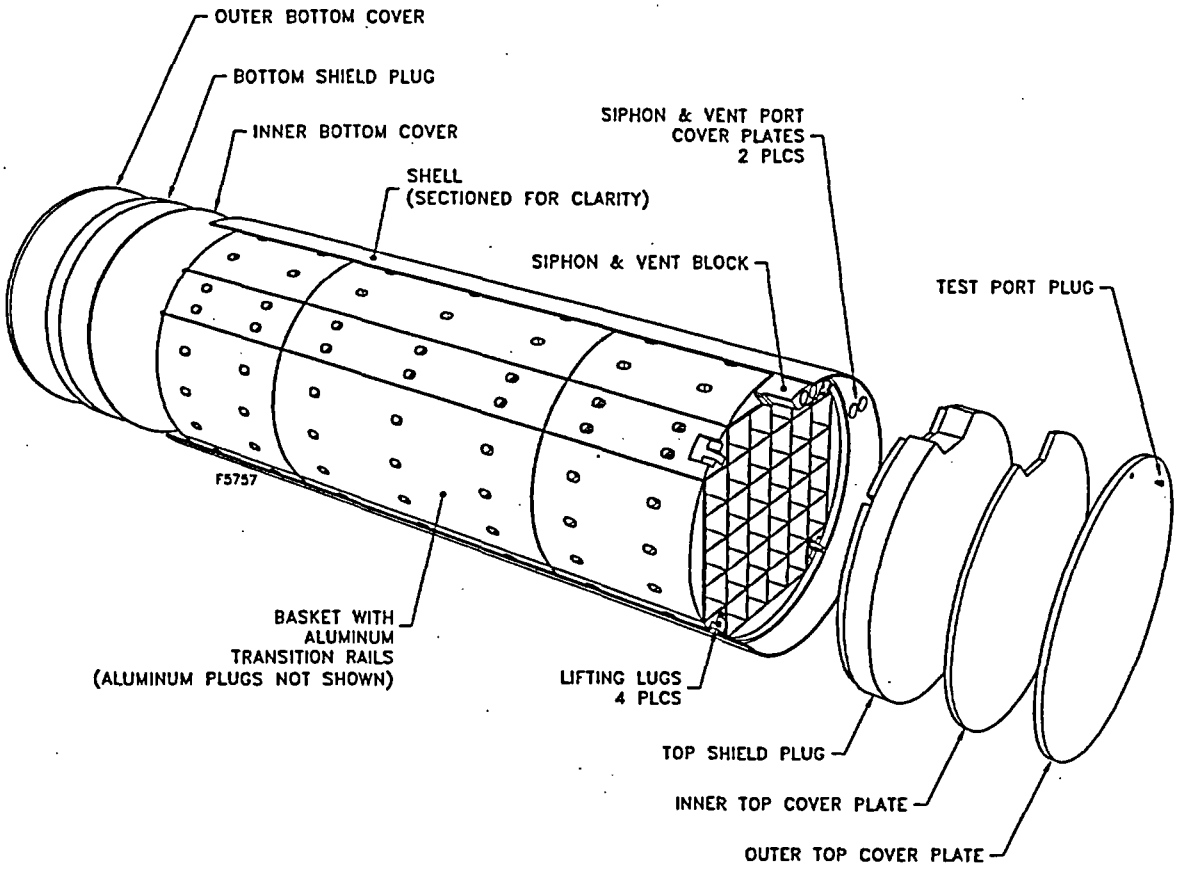
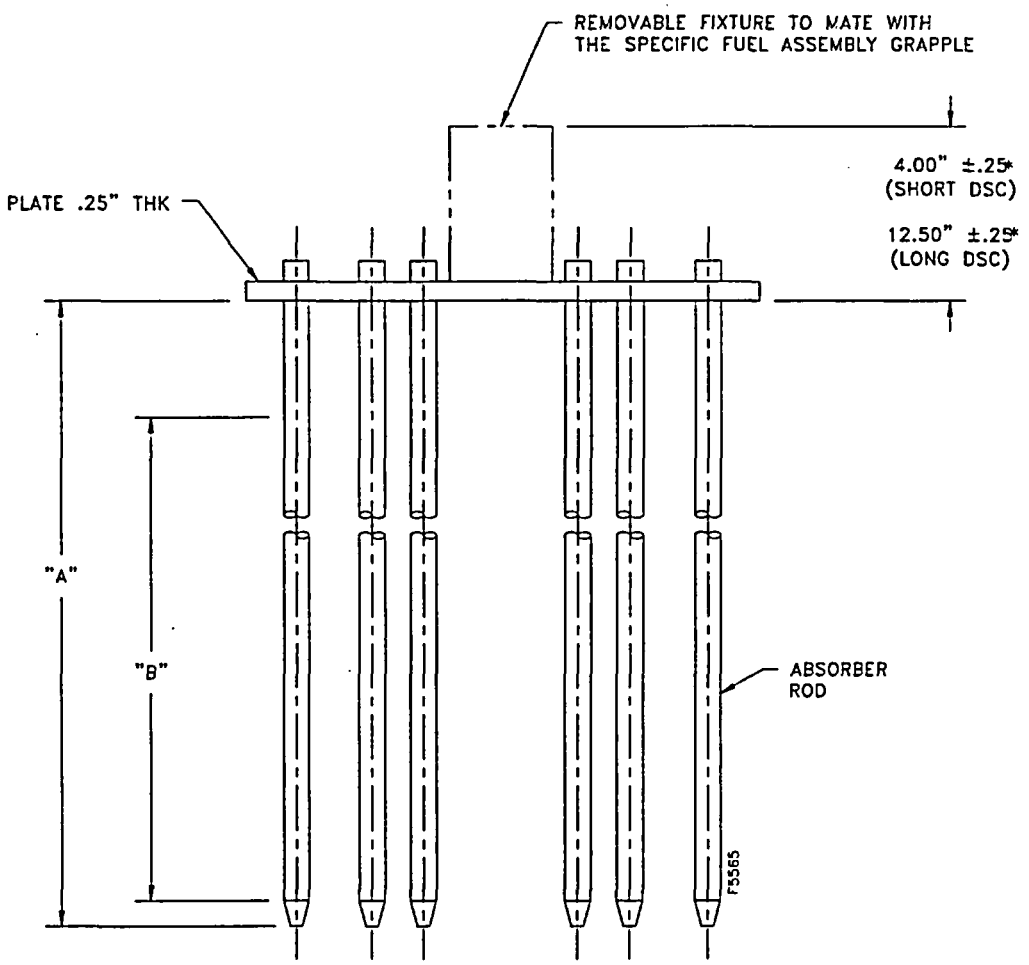


Figure M.1-1
NUHOMS®-32PT DSC Components



*THESE DIMENSIONS ARE FOR USE WITH WESTINGHOUSE 17x17 FUEL ASSEMBLIES. DIMENSIONS WILL VARY AS REQUIRED BY FUEL ASSEMBLY TYPE.

DIMENSION	FUEL ASSEMBLY TYPE				
	WE 17x17	B&W 15x15	WE 15x15	CE 14x14	WE 14x14
ABSORBER ROD OD NOMINAL (in)	.362	.438	.450	.975	.432
MINIMUM ABSORBER ROD DIMENSION "A" (IN)	156	160	156	143	156
MINIMUM B_4C PELETS STACK HEIGHT, "B" (IN)	151	151	150	129	150
CLAD THICKNESS NOMINAL (in)	.018	.022	.023	.049	.022
No. OF RODS	24	16	20	5	16
MATERIAL	304 SST	304 SST	304 SST	304 SST	304 SST

Figure M.1-2
Poison Rod Assemblies (PRAs)

M.2 Principal Design Criteria

This section provides the principal design criteria for the NUHOMS®-32PT system. The NUHOMS®-32PT Dry Shielded Canister (DSC) is handled, transferred and stored in the same manner as the existing NUHOMS®-24P DSC. There is no change to the NUHOMS® OS197 or the NUHOMS® OS197H Transfer Cask (TC), or the standard NUHOMS® Horizontal Storage Module (HSM). Only those principal design criteria that have changed from the existing FSAR, Chapter 3, are described in this chapter. Section M.2.1 presents a general description of the spent fuel to be stored. Section M.2.2 provides the design criteria for environmental conditions and natural phenomena. This section contains an assessment of the local damage due to the design basis environmental conditions and natural phenomena and the general loadings and design parameters used for analysis in subsequent chapters. Section M.2.3 provides a description of the systems that have been designated as important to safety. Section M.2.4 discusses decommissioning considerations. Section M.2.5 summarizes the NUHOMS®-32PT DSC design criteria.

M.2.1 Spent Fuel To Be Stored

There are four design configurations for the NUHOMS®-32PT DSC, two "short" canister configurations (the 32PT-S100 and 32PT-S125), and two "long" canister configurations (the 32PT-L100 and 32PT-L125). The main difference between the –S100/-L100 and –S125/-L125 configuration designs are the thicknesses of shield plugs and DSC cover plates. The basket layout for these two configurations is identical except for the length of the components. Each of the DSC configurations is designed to store 32 intact standard PWR fuel assemblies. The 32PT-L100 and 32PT-L125 are also designed to store 32 intact standard PWR fuel assemblies with or without BPRAs. The NUHOMS®-32PT DSCs can store intact PWR fuel assemblies and BPRAs with the characteristics described in Table M.2-1. The NUHOMS®-32PT DSC may store PWR fuel assemblies arranged in any of three alternate heat zoning configurations with a maximum decay heat of 1.2kW per assembly and a maximum heat load of 24 kW per canister. The heat load zoning configurations are shown in Figure M.2-1 through Figure M.2-3. The NUHOMS®-32PT DSC is inerted and backfilled with helium at the time of loading. The maximum fuel assembly weight with a BPRA is 1682 lbs. which is the same as the NUHOMS®-24P DSC design.

The maximum fuel cladding temperature limit of 400°C (752°F) is applicable to normal conditions of storage and all short term operations from spent fuel pool to ISFSI pad including vacuum drying and helium backfilling of the NUHOMS®-32PT DSC per Interim Staff Guidance (ISG) No. 11, Revision 2 [2.7]. In addition, ISG-11 does not permit thermal cycling of the fuel cladding with temperature differences greater than 65°C (117°F) during DSC drying, backfilling and transfer operations.

The maximum fuel cladding temperature limit of 570°C (1058°F) is applicable to accidents or off-normal thermal transients [2.7].

Calculations were performed to determine the fuel assembly type which was most limiting for each of the analyses including shielding, criticality, heat load and confinement. These evaluations are performed in Chapter M.5, M.6, M.4 and M.7. The fuel assembly types considered are listed in Table M.2-2. It was determined that the B&W 15x15 is the enveloping fuel design for the shielding source term calculation because of its total assembly weight and highest initial heavy metal loading. For criticality safety, the B&W 15x15 assembly is the most reactive assembly type for a given enrichment. This assembly is used to determine the most reactive configuration in the DSC. Using this most reactive configuration, criticality analysis for all other fuel assembly classes is performed to determine the maximum enrichment allowed as a function of number of Poison Rod Assemblies (PRAs). For thermal analysis, the WE 14x14 fuel assembly is limiting, since it results in the lowest fuel conductivity. The confinement analyses is based on B&W 15x15 fuel assembly, since it results in the smaller free volume inside the DSC cavity more than a 14x14 fuel assembly.

All four NUHOMS®-32PT DSC design configurations have the same minimum boron content for the poison neutron plates. The minimum boron-10 content for the poison plates is 0.0070

g/cm^2. The criticality analysis is based on 90% credit or 0.0063 g/cm^2 of B10. The use of 90% credit is allowed because poison material coupons are to be tested via neutron transmission plus statistical analysis of the neutron transmission results. A basket may contain 0, 4, 8, or 16 PRAs and is designated a Type A, Type B, Type C or Type D basket, respectively.

For calculating the maximum internal pressure in the NUHOMS®-32PT DSC, it is assumed that 1% of the fuel rods are damaged for normal conditions, up to 10% of the fuel rods are damaged for off normal conditions, and 100% of the fuel rods will be damaged following a design basis accident event. A minimum of 100% of the fill gas and 30% of the fission gases (e.g., H-3, Kr and Xe) within the ruptured fuel rods are assumed to be available for release into the DSC cavity, consistent with NUREG-1536 [2.1].

The maximum design basis internal pressures for the NUHOMS®-32PT DSC are 15, 20 and 105 psig for normal, off-normal and accident conditions of storage, respectively.

M.2.1.1 General Operating Functions

No change.

M.2.2 Design Criteria for Environmental Conditions and Natural Phenomena

The NUHOMS®-32PT DSC is handled and stored in the same manner as the existing NUHOMS®-24P System. The environmental conditions and natural phenomena are the same as described in the existing FSAR, Chapter 3. Updated criteria are given in the applicable section. Table M.2-20 summarizes the design criteria for the 32PT DSC. This table also summarizes the applicable codes and standards utilized for design. Design criteria for the NUHOMS® HSM and TC remain the same as shown in Table 3.2-1 of the FSAR.

M.2.2.1 Tornado Wind and Tornado Missiles

No change.

M.2.2.2 Water Level (Flood) Design

No change.

M.2.2.3 Seismic Design

No change.

M.2.2.4 Snow and Ice Loading

No change.

M.2.2.5 Combined Load Criteria

The NUHOMS®-32PT system is subjected to the same loads as the existing NUHOMS®-24P or -52B System. The criteria applicable to the HSM and the TC are the same as those found in the existing FSAR, Chapter 3. The criteria applicable to the NUHOMS®-32PT DSC are found in the following subsections.

M.2.2.5.1 NUHOMS®–32PT DSC Structural Design Criteria

The NUHOMS®-32PT DSC is designed using the ASME Boiler and Pressure Vessel Code [2.2] criteria given in the existing FSAR, Chapter 3, except as noted in the following sections. A summary of the NUHOMS®-32PT DSC load combinations is presented in Table M.2-15.

M.2.2.5.1.1 NUHOMS®–32PT DSC Shell Stress Limits

The stress limits for the NUHOMS®-32PT DSC shell are taken from the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, Article NB-3200 [2.2] for normal condition loads (Level A) and NB-3225, Appendix F for accident condition loads (Level D). The stress limits for Level B and Level C are taken from ASME, Section III, Subsection NB, Paragraph NB-3223 and 3224.

Stress criteria for Level A through Level D service loading conditions are given in Table M.2-16. Local yielding is permitted at the point of contact where the Level D load is applied. If elastic stress limits cannot be met, the plastic system analysis approach and acceptance criteria of Appendix F of ASME Section III are used.

The allowable stress intensity value, S_m, as defined by the Code is based on the temperature calculated for each service load condition or a bounding temperature.

M.2.2.5.1.2 NUHOMS®–32PT DSC Basket Stress Limits

The basket fuel support grid wall thickness is established to meet heat transfer, nuclear criticality, and structural requirements. The basket structure provides sufficient rigidity to maintain a subcritical configuration under the applied loads.

No credit is taken for neutron poison plates in any of the stress or stability analyses.

Normal Conditions

Normal Condition Stress Criteria for Steel Elements

As summarized in Table M.2-17, the normal condition stress criteria for the fuel support structure, and the R90 transition rail cover plates is based on Subsection NG [2.2] of the ASME Code, Section III.

Normal Condition Stress Criteria for Aluminum Transition Rails

The solid aluminum transition rail bodies (R90 and R45) perform their function (support of the fuel grid) by remaining in place. The loads on the rail bodies are primarily bearing from the fuel grid (transmitted through the cover plate on the R90 rails). "Failure" of the transition rail would require that the rail no longer provide support to the fuel grid. Since the solid aluminum rail bodies are constrained between the DSC shell and the fuel support grid, this cannot occur.

Therefore, for deadweight and handling condition loads, stress in the aluminum bodies will be compared to the allowable bearing stress, equal to Sy, from NG-3227.1(a). Values of S_y are taken from Table M.3.3-4 for annealed 6061 aluminum material at temperature (as described in Section M.3.3, these yield stresses are lower bound values).

Normal Condition Stability Criteria

Stability criteria are addressed in two parts:

A. Under axial loads, the DSC shell and transfer/transport cask provide overall/global stability to the 32PT basket structure. Thus, only local stability effects are specifically addressed. For local (panel) stability under axial loads, the allowable stress in the fuel support grid and transition rail panels are taken as the smallest of the following three values:

- The normal condition (Level A) primary membrane stress allowable, P_m,

- Two-thirds of the material yield stress at temperature, 2/3 S_y,

- The critical buckling value determined using Table 35, Case 1a of [2.3] for a rectangular plate under equal uniform compression on two opposite edges, with all edges simply supported.

$$\sigma_{CR} = K\frac{E}{1-\upsilon^2}\left(\frac{t}{b}\right)^2$$

B. Under lateral loads, stability of the basket structure is demonstrated using hand calculations to evaluate the fuel support grid "ligaments" as columns using the stability criteria of NF-3322.1(c)(2) for stainless steel compression members.

Accident Conditions

Accident Condition Stress Criteria for Steel Elements

As summarized in Table M.2-17 the accident condition stress criteria for the fuel support structure is based on Appendix F of the ASME Code, Section III. Criteria are provided for both linear elastic and elastic-plastic stress analyses.

Accident Condition Criteria for Aluminum Transition Rails

For accident condition loading (i.e., the postulated drops), the solid transition rail bodies must support the fuel support grid such that stresses and displacements in the fuel grid are acceptable. Since, the solid rail bodies are captured between the fuel grid and the DSC shell, large displacements of the rails are prevented. Thus, no additional checks (of the solid aluminum) are required for accident/drop loading. Qualification of the fuel grid (and R90 transition rail cover plate) will demonstrate that the rails perform their intended function.

Accident Condition Stability Criteria

Similar to the normal condition evaluations, stability criteria are addressed in two parts:

A. Accident condition axial stresses in the fuel support grid panels are calculated and compared to the lesser of:

1. The accident condition (Level D) primary membrane stress allowable, P_m,

2. 90% of the material yield stress at temperature, $.9S_y$,

3. The critical buckling value determined using Table 35, Case 1a of [2.3] for a rectangular plate under equal uniform compression on two opposite edges, with all edges simply supported.

$$\sigma_{CR} = K\frac{E}{1-\upsilon^2}\left(\frac{t}{b}\right)^2$$

B. Under lateral loads, stability of the basket structure is demonstrated using detailed finite element models and the Collapse Load criteria from F-1341.3. These criteria establish the allowable load as 90% of the Limit Analysis Collapse Load where the Limit Analysis Collapse Load is the maximum load determined using elastic-perfectly plastic material properties with a yield stress equal to the lesser of $2.3S_m$ or $0.7S_u$.

In addition, supplementary hand calculations were performed using the criteria of F-1334.3(b) for members under axial compression. Further confirmatory finite element analyses were performed using the LS-DYNA computer code.

M.2.3 Safety Protection Systems

M.2.3.1 General

The NUHOMS®-32PT DSC is designed to provide storage of spent fuel for at least 40 years. The DSC cavity is inerted and backfilled with helium and the internal pressure is always above atmospheric during the storage period as a precaution against in-leakage of air, which could be harmful to the fuel. Since the confinement vessel consists of a steel cylinder with an integrally-welded bottom closure, and a seal welded top closure that is verified to be leak tight after loading, the DSC cavity gas cannot escape.

Only those features that are not addressed in the existing FSAR, Chapter 3, or have been revised, are addressed in this Section. Those features include the thermal and nucleonic performance of the poison plates, and their acceptance. Components of the NUHOMS®-32PT DSC that are "Important to Safety" and "Not Important to Safety" are listed in Table M.2-18.

M.2.3.2 Protection By Multiple Confinement Barriers and Systems

The NUHOMS®-32PT DSC provides a leak tight confinement of the spent fuel. Although similar to the existing NUHOMS®-24P DSC, sealing of the NUHOMS®-32PT DSC involves leak testing in accordance with ANSI N14.5 [2.4] after loading and sealing the canister, as described in Section M.9.

M.2.3.3 Protection By Equipment and Instrumentation Selection

No change.

M.2.3.4 Nuclear Criticality Safety

M.2.3.4.1 Control Methods for Prevention of Criticality

The design criterion for criticality is that an upper subcritical limit (USL) of 0.95 minus benchmarking bias and modeling bias will be maintained for all postulated arrangements of fuel within the DSC. The intact fuel assemblies are assumed to stay within their basket compartment based on the DSC and basket geometry.

The control method used to prevent criticality is incorporation of poison material in the basket material, soluble boron in the pool and favorable geometry. The quantity and distribution of boron in the poison material is controlled by specific manufacturing and acceptance criteria of the poison plates and PRAs. The acceptance criteria of the plates and PRAs is described in Section M.9.

The basket has been designed to assure an ample margin of safety against criticality under the conditions of fresh fuel in a DSC flooded with borated pool water. The method of criticality control is in accordance with the requirements of 10CFR72.124.

The criticality analyses are described in Section M.6.

M.2.3.4.2 Error Contingency Criteria

Provision for error contingency is built into the criterion used in Section M.2.3.4.1 above. The criterion used in the criticality analysis is common practice for licensing submittals. Because conservative assumptions are made in modeling, it is not necessary to introduce additional contingency for error.

M.2.3.4.3 Verification Analysis-Benchmarking

The verification analysis-benchmarking used in the criticality safety analysis is described in Section M.6.

M.2.3.5 Radiological Protection

No change.

M.2.3.6 Fire and Explosion Protection

No change.

M.2.4 Decommissioning Considerations

No change.

M.2.5 Summary of NUHOMS®-32PT DSC Design Criteria

The additional principal design criteria for the NUHOMS®-32PT DSC are presented in Table M.2-19. The NUHOMS®-32PT DSC is designed to store 32 intact standard PWR fuel assemblies with or without BPRAs with assembly average burnup, initial enrichment and cooling time as described in Table M.2-1. The maximum total heat generation rate of the stored fuel is limited to 1.2 kW per fuel assembly and 24 kW per NUHOMS®-32PT DSC in order to keep the maximum fuel cladding temperature below the limit [2.7]necessary to ensure cladding integrity. The fuel cladding integrity is assured by the NUHOMS®-32PT DSC and basket design which limits fuel cladding temperature and maintains a nonoxidizing environment in the cask cavity as described in Section M.4.

The NUHOMS®-32PT DSC (shell and closure) is designed and fabricated as a Class 1 component in accordance with the rules of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, and the alternative provisions to the ASME Code as described in Table M.3.1-1.

The NUHOMS®-32PT DSC is designed to maintain a subcritical configuration during loading, handling, storage and accident conditions. A combination of fixed neutron absorbers, soluble boron in the pool and favorable geometry are employed to maintain the upper subcritical limit of 0.9411. The fixed neutron absorbers are in the form of borated metallic plates and PRAs which are inserted in the guide tubes of certain assemblies in the basket. The basket is designed and fabricated in accordance with the rules of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NG, Article NG-3200 and the alternative provisions to the ASME Code as described in Table M.3.1-1.

The NUHOMS®-32PT DSC design, fabrication and testing are covered by TN's Quality Assurance Program, which conforms to the criteria in Subpart G of 10CFR72.

The NUHOMS®-32PT DSC is designed to withstand the effects of severe environmental conditions and natural phenomena such as earthquakes, tornadoes, lightning and floods. Section M.11 describes the NUHOMS®-32PT DSC behavior under these accident conditions.

M.2.6 References

2.1 NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," 1997.

2.2 American Society of Mechanical Engineers, ASME Boiler And Pressure Vessel Code, Section III, Division 1 - Subsections NB, NG and NF, 1998 edition including 2000 Addenda.

2.3 Young, W.C., "Roark's Formulas for Stress and Strain," 6th Edition, McGraw-Hill Book Company, New York, 1989.

2.4 ANSI N14.5-1997, "Leakage Tests on Packages for Shipment," February 1998.

2.5 Deleted.

2.6 Deleted.

2.7 Interim Staff Guidance No. 11, Revision 2, "Cladding Considerations for the Transportation and storage of Spent Fuel", dated July 30, 2002.

Table M.2-1
Intact PWR Fuel Assembly Characteristics

PHYSICAL PARAMETERS:	
Fuel Class	B&W 15x15, WE 17x17, CE 15x15, WE 15x15, CE 14x14 and WE 14x14 assemblies that are enveloped by the fuel assembly design characteristics listed in Table M.2-2.
Fuel Cladding Material	Zircaloy
Fuel Damage	Cladding damage in excess of pinhole leaks or hairline cracks is not authorized to be stored as "Intact PWR Fuel."
Burnable Poison Rod Assemblies (BPRAs)	Standard BPRA designs for the B&W 15x15 and Westinghouse 17x17 class assemblies as listed in Appendix J of the FSAR.
Maximum Assembly plus BPRA Weight	-1365 lbs for 32PT-S100 & 32PT-L100 DSC System -1682 lbs for 32PT-S125 & 32PT-L125 DSC System
BPRA Damage	BPRAs with cladding failures are acceptable for loading.
THERMAL/RADIOLOGICAL PARAMETERS:	
Fuel Burnup and Cooling Time without BPRAs	Per Table M.2-5, Table M.2-6, Table M.2-7, Table M.2-8, Table M.2-9; and Figure M.2-1 or Figure M.2-2 or Figure M.2-3.
Fuel Burnup and Cooling Time with BPRAs	Per Table M.2-10, Table M.2-11, Table M.2-12, Table M.2-13, Table M.2-14; and Figure M.2-1 or Figure M.2-2 or Figure M.2-3.
Initial Enrichment	Per Table M.2-3; and Figure M.2-4 or Figure M.2-5 or Figure M.2-6, as applicable.
B&W 15x15 BPRA Burnup and Cooling Time	BPRA Burnup shall not exceed that of a BPRA irradiated in fuel assemblies with a total Burnup of 36,000 MWd/MTU. -Minimum Cooling Time 5 years
WE 17x17 BPRA Burnup and Cooling Time	BPRA Burnup shall not exceed that of a BPRA irradiated in fuel assemblies with a total Burnup of 36,000 MWd/MTU. -Minimum Cooling Time 10 years

Table M.2-2
PWR Fuel Assembly Design Characteristics

Assembly Class	B&W 15x15	WE 17x17	CE 15x15	WE 15x15	CE 14x14	WE 14x14
DSC Configuration	Max Unirradiated Length (in)					
32PT-S100/32PT-L100	165.75	165.75	165.75	165.75	165.75	165.75
32PT-S125/32PT-L125	171.71[1]	171.71[1]	171.71	171.71	171.71	171.71
Fissile Material	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2
Maximum MTU/Assembly[2]	0.475	0.475	0.475	0.475	0.475	0.475
Maximum Number of Fuel Rods	208	264	216	204	176	179
Maximum Number of Guide/ Instrument Tubes	17	25	9	21	5	17

(1) Maximum Assembly + BPRA Length (unirradiated)
(2) The maximum MTU/assembly is based on the shielding analysis. The listed value is higher than the actual.

Table M.2-3
Initial Enrichment and Number of PRAs for Various Fuel Assembly Types

Assembly Class	Assembly Type	Maximum Initial Enrichment, wt. % U-235			
		0 PRAs Type A Basket	4 PRAs Type B Basket	8 PRAs Type C Basket	16 PRAs Type D Basket
WE 17x17(1)	Westinghouse 17x17 LOPAR/Std	3.40	4.00	4.50	5.00
	Westinghouse 17x17 OFA/Vantage 5				
B&W 15x15(1)	B&W 15x15 Mark B	3.30	3.90	NA	5.00
CE 15x15	CE 15x15 Palisades	3.40	Not Evaluated	Not Evaluated	Not Evaluated
	Exxon/ANF 15x15 CE				
WE 15x15	Westinghouse 15x15 Std/ZC	3.40	4.00	4.60	5.00
	Exxon/ANF 15x15 WE				
CE 14x14	CE 14x14 Std/Generic	3.80	4.60	5.00	Not Evaluated
	CE 14x14 Fort Calhoun				
WE 14x14	Westinghouse 14x14 ZCA/ZCB	4.00	5.00	Not Evaluated	Not Evaluated
	Westinghouse 14x14 OFA				
	Exxon/ANF 14x14 WE				

(1) With or without BPRAs. BPRAs shall not be stored in basket locations where a PRA is requested.

Table M.2-4
Poison Rod Assembly (PRA) Description

Assembly Class	Minimum Number of Rods/PRA	Modeled B_4C Content per Rod (g/cm) (75% Credit)	Minimum B_4C Content per Rod (g/cm)
WE 17x17	24	0.59	0.79
B&W 15x15	16	0.72	0.96
WE 15x15	20	0.72	0.96
CE 14x14	5	3.14	4.19
WE 14x14	16	0.72	0.96

Table M.2-5
PWR Fuel Qualification Table for 1.2 kW per Assembly for the NUHOMS®-32PT DSC (Fuel w/o BPRAs)
(Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Initial Enrichment wt % U-235																													
	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
28				5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
30						5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
32							5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
34								5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
36									5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
38											5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
39											5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
40			Not Analyzed									5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
41												5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
42												6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5
43													6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5	5	5	5
44														6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
45														6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup are correctly accounted for during fuel qualification.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment less than 2.0 and greater than 5.0 wt.% U-235 is unacceptable for storage.
- Fuel with a burnup greater than 45 GWd/MTU is unacceptable for storage
- Fuel with a burnup less than 10 GWd/MTU is acceptable for storage after 5-years cooling
- Example: An assembly with an initial enrichment of 3.75 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for storage after a six-year cooling time as defined by 3.7 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table.

Table M.2-6
PWR Fuel Qualification Table for 0.87 kW per Assembly for the NUHOMS®-32PT DSC (Fuel w/o BPRAs)

(Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Initial Enrichment wt % U-235																													
	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
28				5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
30						5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
32							6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
34								6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5
36									6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
38											7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	6	6	6
39											7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
40			Not Analyzed									8	8	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
41												8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7	7	7
42												8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
43													9	9	9	9	9	9	9	8	8	8	8	8	8	8	8	8	8	8	8
44														9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8	8
45														10	10	10	10	10	10	9	9	9	9	9	9	9	9	9	9	9	9

- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup are correctly accounted for during fuel qualification.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment less than 2.0 and greater than 5.0 wt.% U-235 is unacceptable for storage.
- Fuel with a burnup greater than 45 GWd/MTU is unacceptable for storage
- Fuel with a burnup less than 10 GWd/MTU is acceptable for storage after 5-years cooling.
- Example: An assembly with an initial enrichment of 3.75 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for storage after a eight-year cooling time as defined by 3.7 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table.

Table M.2-7
PWR Fuel Qualification Table for 0.7 kW per Assembly for the NUHOMS®-32PT DSC (Fuel w/o BPRAs)

(Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Initial Enrichment wt % U-235																													
	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
28				6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5
30						6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
32							7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	6	6
34								8	8	8	8	8	8	8	8	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
36									9	9	9	9	9	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
38											10	10	10	10	10	10	10	9	9	9	9	9	9	9	9	9	9	9	9	9	9
39											11	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
40			Not Analyzed									11	11	11	11	11	11	11	11	11	11	11	11	11	11	10	10	10	10	10	10
41												12	12	12	12	12	12	12	12	12	12	11	11	11	11	11	11	11	11	11	11
42												13	13	13	13	13	13	13	13	12	12	12	12	12	12	12	12	12	12	12	12
43													14	14	14	14	14	14	14	13	13	13	13	13	13	13	13	13	13	13	13
44														15	15	15	15	15	15	15	14	14	14	14	14	14	14	14	14	14	14
45														16	16	16	16	16	16	16	15	15	15	15	15	15	15	15	15	15	15

- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup are correctly accounted for during fuel qualification.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment less than 2.0 and greater than 5.0 wt.% U-235 is unacceptable for storage.
- Fuel with a burnup greater than 45 GWd/MTU is unacceptable for storage
- Fuel with a burnup less than 10 GWd/MTU is acceptable for storage after 5-years cooling.
- Example: An assembly with an initial enrichment of 3.75 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for storage after a thirteen-year cooling time as defined by 3.7 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table.

Table M.2-8
PWR Fuel Qualification Table for 0.63 kW per Assembly for the NUHOMS®-32PT DSC (Fuel w/o BPRAs)

(Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Initial Enrichment wt % U-235																													
	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25		6	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
28				7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
30						7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
32							8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7
34								9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
36									11	11	11	11	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
38											13	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	11	11	11	11
39											14	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	12	12	12	12
40			Not Analyzed									15	15	14	14	14	14	14	14	14	14	14	14	14	14	14	14	13	13	13	13
41												16	16	16	16	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	14
42												17	17	17	17	17	17	16	16	16	16	16	16	16	16	16	16	16	16	16	16
43													18	18	18	18	18	18	18	18	18	17	17	17	17	17	17	17	17	17	17
44														20	19	19	19	19	19	19	19	19	19	19	18	18	18	18	18	18	18
45														21	21	21	21	20	20	20	20	20	20	20	20	20	20	20	20	19	19

- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup are correctly accounted for during fuel qualification.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment less than 2.0 and greater than 5.0 wt.% U-235 is unacceptable for storage.
- Fuel with a burnup greater than 45 GWd/MTU is unacceptable for storage
- Fuel with a burnup less than 10 GWd/MTU is acceptable for storage after 5-years cooling.
- Example: An assembly with an initial enrichment of 3.75 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for storage after a sixteen-year cooling time as defined by 3.7 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table.

Table M.2-9
PWR Fuel Qualification Table for 0.6 kW per Assembly for the NUHOMS®-32PT DSC (Fuel w/o BPRAs)

(Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Initial Enrichment wt % U-235																													
	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5	5
28				7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	6	6	6	6	6	6	6
30						8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
32							9	9	9	9	9	9	9	9	9	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
34								10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	9	9	9	9	9
36									12	12	12	12	12	12	12	12	12	11	11	11	11	11	11	11	11	11	11	11	11	11	11
38											14	14	14	14	14	14	14	14	14	13	13	13	13	13	13	13	13	13	13	13	13
39											15	15	15	15	15	15	15	15	15	15	15	15	14	14	14	14	14	14	14	14	14
40			Not Analyzed									17	16	16	16	16	16	16	16	16	16	16	16	16	16	15	15	15	15	15	15
41												18	18	18	18	18	17	17	17	17	17	17	17	17	17	17	17	17	17	17	16
42												19	19	19	19	19	19	19	19	19	18	18	18	18	18	18	18	18	18	18	18
43													21	20	20	20	20	20	20	20	20	20	20	20	20	19	19	19	19	19	19
44														22	22	22	22	21	21	21	21	21	21	21	21	21	21	21	21	20	20
45														23	23	23	23	23	23	23	23	22	22	22	22	22	22	22	22	22	22

- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup are correctly accounted for during fuel qualification.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment less than 2.0 and greater than 5.0 wt.% U-235 is unacceptable for storage.
- Fuel with a burnup greater than 45 GWd/MTU is unacceptable for storage
- Fuel with a burnup less than 10 GWd/MTU is acceptable for storage after 5-years cooling.
- Example: An assembly with an initial enrichment of 3.75 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for storage after a nineteen-year cooling time as defined by 3.7 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table.

Table M.2-10
PWR Fuel Qualification Table for 1.2 kW per Assembly for the NUHOMS®-32PT DSC (Fuel w/ BPRAs)

(Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Initial Enrichment wt % U-235																													
	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
28				5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
30						5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
32							5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
34								5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
36									5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
38											5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
39											5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
40			Not Analyzed									5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
41												6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
42												6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5
43													6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5
44														6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
45														6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup are correctly accounted for during fuel qualification.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment less than 2.0 and greater than 5.0 wt.% U-235 is unacceptable for storage.
- Fuel with a burnup greater than 45 GWd/MTU is unacceptable for storage
- Fuel with a burnup less than 10 GWd/MTU is acceptable for storage after 5-years cooling
- Example: An assembly with an initial enrichment of 3.75 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for storage after a six-year cooling time as defined by 3.7 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table.

Table M.2-11
PWR Fuel Qualification Table for 0.87 kW per Assembly for the NUHOMS®-32PT DSC (Fuel w/ BPRAs)

(Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Initial Enrichment wt % U-235																													
	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
28				5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
30						5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
32							6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
434								6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
36									7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
38											7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6
39											7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
40			Not Analyzed									8	8	8	8	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
41												8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7
42												9	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
43													9	9	9	9	9	9	9	9	9	9	8	8	8	8	8	8	8	8	8
44														9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
45														10	10	10	10	10	10	10	10	10	9	9	9	9	9	9	9	9	9

- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup are correctly accounted for during fuel qualification.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment less than 2.0 and greater than 5.0 wt.% U-235 is unacceptable for storage.
- Fuel with a burnup greater than 45 GWd/MTU is unacceptable for storage
- Fuel with a burnup less than 10 GWd/MTU is acceptable for storage after 5-years cooling.
- Example: An assembly with an initial enrichment of 3.75 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for storage after a eight-year cooling time as defined by 3.7 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table.

Table M.2-12
PWR Fuel Qualification Table for 0.7 kW per Assembly for the NUHOMS®-32PT DSC (Fuel w/ BPRAs)

(Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Initial Enrichment wt % U-235																														
	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
28				6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
30						6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
32							7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
34								8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7	7	7	7	7	7	7
36									9	9	9	9	9	9	9	9	9	9	8	8	8	8	8	8	8	8	8	8	8	8	8
38											10	10	10	10	10	10	10	10	10	10	10	10	9	9	9	9	9	9	9	9	9
39											11	11	11	11	11	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
40			Not Analyzed									12	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
41												13	13	12	12	12	12	12	12	12	12	12	12	12	12	12	12	11	11	11	11
42												14	14	13	13	13	13	13	13	13	13	13	13	13	12	12	12	12	12	12	12
43													15	14	14	14	14	14	14	14	14	14	14	14	13	13	13	13	13	13	13
44														16	15	15	15	15	15	15	15	15	15	15	15	14	14	14	14	14	14
45														17	17	16	16	16	16	16	16	16	16	16	16	16	15	15	15	15	15

- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup are correctly accounted for during fuel qualification.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment less than 2.0 and greater than 5.0 wt.% U-235 is unacceptable for storage.
- Fuel with a burnup greater than 45 GWd/MTU is unacceptable for storage
- Fuel with a burnup less than 10 GWd/MTU is acceptable for storage after 5-years cooling.
- Example: An assembly with an initial enrichment of 3.75 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for storage after a thirteen-year cooling time as defined by 3.7 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table.

Table M.2-13
PWR Fuel Qualification Table for 0.63 kW per Assembly for the NUHOMS®-32PT DSC (Fuel w/ BPRAs)

(Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Initial Enrichment wt % U-235																													
	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
28				7	7	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
30						7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
32							8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
34								10	10	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
36									11	11	11	11	11	11	11	11	11	11	11	10	10	10	10	10	10	10	10	10	10	10	10
38											13	13	13	13	13	13	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
39											14	14	14	14	14	14	14	13	13	13	13	13	13	13	13	13	13	13	13	13	13
40			Not Analyzed									15	15	15	15	15	15	15	14	14	14	14	14	14	14	14	14	14	14	14	14
41												16	16	16	16	16	16	16	16	16	16	16	15	15	15	15	15	15	15	15	15
42												18	18	17	17	17	17	17	17	17	17	17	17	17	16	16	16	16	16	16	16
43													19	19	19	19	18	18	18	18	18	18	18	18	18	18	18	18	17	17	17
44														20	20	20	20	20	20	20	19	19	19	19	19	19	19	19	19	19	19
45														22	21	21	21	21	21	21	21	21	21	20	20	20	20	20	20	20	20

- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup are correctly accounted for during fuel qualification.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment less than 2.0 and greater than 5.0 wt.% U-235 is unacceptable for storage.
- Fuel with a burnup greater than 45 GWd/MTU is unacceptable for storage
- Fuel with a burnup less than 10 GWd/MTU is acceptable for storage after 5-years cooling.
- Example: An assembly with an initial enrichment of 3.75 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for storage after a seventeen-year cooling time as defined by 3.7 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table.

Table M.2-14
PWR Fuel Qualification Table for 0.6 kW per Assembly for the NUHOMS®-32PT DSC (Fuel w/ BPRAs)

(Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Initial Enrichment wt % U-235																														
	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
28				7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6
30						8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7	7	7	7	7
32							9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8	8	8	8	8	8
34								11	11	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
36									12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	11	11	11	11	11
38											15	15	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	13	13
39											16	16	16	16	16	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
40			Not Analyzed									17	17	17	17	17	17	17	17	16	16	16	16	16	16	16	16	16	16	16	16
41												19	18	18	18	18	18	18	18	18	18	18	18	17	17	17	17	17	17	17	17
42												20	20	20	20	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
43													21	21	21	21	21	21	21	21	20	20	20	20	20	20	20	20	20	20	20
44														23	22	22	22	22	22	22	22	22	22	22	22	21	21	21	21	21	21
45														24	24	24	24	24	23	23	23	23	23	23	23	23	23	23	23	23	22

- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup are correctly accounted for during fuel qualification.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment less than 2.0 and greater than 5.0 wt.% U-235 is unacceptable for storage.
- Fuel with a burnup greater than 45 GWd/MTU is unacceptable for storage
- Fuel with a burnup less than 10 GWd/MTU is acceptable for storage after 5-years cooling.
- Example: An assembly with an initial enrichment of 3.75 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for storage after a nineteen-year cooling time as defined by 3.7 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table.

Table M.2-15
Summary of 32PT-DSC Load Combinations

Load Case	Horizontal DW		Vertical DW		Internal Pressure	External Pressure	Thermal Condition	Lifting Loads	Other Loads	Service Level
	DSC	Fuel	DSC	Fuel						
Non-Operational Load Cases										
NO-1 Fab. Leak Testing	--	--	--	--	--	14.7 psi	70°F	--	155 kip axial	Test
NO-2 Fab. Leak Testing	--	--	--	--	18 psi				155 kip axial	Test
NO-3 DSC Uprighting	x	--	--	--	--	--	70°F	x	--	B
NO-4 DSC Vertical Lift	--	--	x	--	--	--	70°F	x	--	B
Fuel Loading Load Cases										
FL-1 DSC/Cask Filling	--	--	Cask	--	--	Hydrostatic	100°F Cask	x	x	A
FL-2 DSC/Cask Filling	--	--	Cask	--	Hydrostatic	Hydrostatic	100°F Cask	x	x	A
FL-3 DSC/Cask Xfer	--	--	Cask	--	Hydrostatic	Hydrostatic	100°F Cask	--	--	A
FL-4 Fuel Loading	--	--	Cask	x	Hydrostatic	Hydrostatic	100°F Cask	--	--	A
FL-5 Xfer to Decon	--	--	Cask	x	Hydrostatic	Hydrostatic	100°F Cask	--	--	A
FL-6 Inner Cover plate Welding	--	--	Cask	x	Hydrostatic	Hydrostatic	100°F Cask	--	--	A
FL-7 Fuel Deck Seismic Loading	--	--	Cask	x	Hydrostatic	Hydrostatic	100°F Cask	--	Note 10	D
Draining/Drying Load Cases										
DD-1 DSC Blowdown	--	--	Cask	x	Hydrostatic+ 20 psi	Hydrostatic	100°F Cask	--	--	B
DD-2 Vacuum Drying	--	--	Cask	x	0 psia	Hydrostatic+ 14.7psi	100°F Cask	--	--	B
DD-3 Helium Backfill	--	--	Cask	x	18 psi	Hydrostatic	100°F Cask	--	--	B
DD-4 Final Helium Backfill	--	--	Cask	x	3.5 psi	Hydrostatic	100°F Cask	--	--	B
DD-5 Outer Cover Plate Weld	--	--	Cask	x	3.5 psi	Hydrostatic	100°F Cask	--	--	B
Transfer Trailer Loading										
TL-1 Vertical Xfer to Trailer	--	--	Cask	x	15 psi	--	0°F Cask	--	--	A
TL-2 Vertical Xfer to Trailer	--	--	Cask	x	15 psi	--	100°F Cask	--	--	A
TL-3 Laydown	Cask	X	--	--	15 psi	--	0°F Cask	--	--	A
TL-4 Laydown	Cask	X	--	--	15 psi	--	100°F Cask	--	--	A

Table M.2-15
Summary of 32PT-DSC Load Combinations

(continued)

Load Case	Horizontal DW		Vertical DW		Internal Pressure	External Pressure	Thermal Condition	Handling Loads	Other Loads	Service Level
	DSC	Fuel	DSC	Fuel						
Transfer To/From ISFSI										
TR-1 Axial Load – Cold	Cask	X	--	--	15.0 psi	--	0°F Cask	1g Axial	--	A
TR-2 Transverse Load - Cold	Cask	X	--	--	15.0 psi	--	0°F Cask	1g Transverse	--	A
TR-3 Vertical Load – Cold	Cask	X	--	--	15.0 psi	--	0°F Cask	1g Vertical	--	A
TR-4 Oblique Load – Cold	Cask	X	--	--	15.0 psi	--	0°F Cask	½ g Axial + ½ g Trans + ½ g Vert.	--	A
TR-5 Axial Load – Hot	Cask	X	--	--	15.0 psi	--	100°F Cask	1g Axial	--	A
TR–6 Transverse Load - Hot	Cask	X	--	--	15.0 psi	--	100°F Cask	1g Trans.	--	A
TR-7 Vertical Load – Hot	Cask	X	--	--	15.0 psi	--	100°F Cask	1g Vertical	--	A
TR-8 Oblique Load – Hot	Cask	X	--	--	15.0 psi	--	100°F Cask	½ g Axial + ½ g Trans + ½ g Vert.	--	A
TR-9 25g Corner Drop	Note 1	Note 1	Note 1	Note 1	20 psi	--	100°F[2] Cask		25g Corner Drop	D
TR-10 75g Side Drop	Note 1	Note 1	--	--	20 psi	--	100°F[2] Cask		75g Side Drop	D
TR-11 Top or Bottom End Drops	Note 12									
HSM LOADING										
LD-1 Normal Loading - Cold	Cask	X	--	--	15.0 psi	--	0°F Cask	+80 Kip	--	A
LD-2 Normal Loading – Hot	Cask	X	--	--	15.0 psi	--	100° F Cask	+80 Kip	--	A
LD-3 Normal Loading – Hot	Cask	X	--	--	15.0 psi	--	117° F w/shade[5]	+80 Kip	--	A
LD-4 Off-Normal Loading – Cold	Cask	X	--	--	20.0 psi	--	0° F Cask	+80 Kip	--	B
LD-5 Off-Normal Loading - Hot	Cask	X	--	--	20.0 psi	--	100° F Cask	+80 Kip	--	B
LD-6 Off-Normal Loading – Hot	Cask	X	--	--	20.0 psi	--	117° F w/shade[5]	+80 Kip	--	B
LD-7 Accident Loading	Cask	X	--	--	20.0 psi	--	117° F w/shade[5]	+80 Kip	--	C/D

Table M.2-15
Summary of 32PT-DSC Load Combinations
(continued)

Load Case	Horizontal DW		Vertical DW		Internal Pressure	External Pressure	Thermal Condition	Handling Loads	Other Loads	Service Level
	DSC	Fuel	DSC	Fuel						
HSM STORAGE										
HSM-1 Off-Normal	HSM	X	--	--	15.0 psi	--	-40° F HSM	--	--	B
HSM-2 Normal Storage	HSM	X	--	--	15.0 psi	--	0° F HSM	--	--	A
HSM-3 Off-Normal	HSM	X	--	--	15.0 psi	--	117° F HSM	--	--	B
HSM-4 Off-Normal Temp. + Failed Fuel	HSM	X	--	--	20.0 psi	--	117° F HSM	--		C
HSM-5 Blocked Vent Storage	HSM	X	--	--	105.0 psi	--	117° F HSM/BV[4]	--	--	D
HSM-6 B.V. + Failed Fuel Storage	HSM	X	--	--	105.0 psi	--	117° F HSM/BV[4]	--		D
HSM-7 Earthquake Loading – Cold	HSM	X	--	--	15.0 psi	--	0° F HSM	--	EQ	C
HSM-8 Earthquake Loading – Hot	HSM	X	--	--	15.0 psi	--	100°F HSM	--	EQ	C
HSM-9 Flood Load (50' H_2O) – Cold	HSM	X	--	--	0 psi	22 psi	0° F HSM	--	Flood[3]	C
HSM-10 Flood Load (50' H_2O) – Hot	HSM	X	--	--	0 psi	22 psi	100°F HSM	--	Flood[3]	C

HSM Unloading	Horizontal DW		Vertical DW		Internal Pressure	External Pressure	Thermal Condition	Handling Loads	Other Loads	Service Level
	DSC	Fuel	DSC	Fuel						
UL-1 Normal Unloading – Cold	HSM	X	--	--	15.0 psi	--	0°F HSM	-60 Kip	--	A
UL-2 Normal Unloading – Hot	HSM	X	--	--	15.0 psi	--	100° F HSM	-60 Kip	--	A
UL-3 Normal Unloading – Hot	HSM	X	--	--	15.0 psi	--	117° F HSM	-60 Kip	--	A
UL-4 Off-Normal Unloading – Cold	HSM	X	--	--	20.0 psi	--	0° F HSM	-60 Kip	--	B
UL-5 Off-Normal Unloading – Hot	HSM	X	--	--	20.0 psi	--	100° F HSM	-60 Kip	--	B
UL-6 Off-Normal Unloading – Hot	HSM	X	--	--	20.0 psi	--	117° F HSM	-60 Kip	--	B
UL-7 Off-Normal Unloading – Hot	HSM	X	--	--	20.0 psi	--	100° F HSM	-80 Kip	--	C
UL-8 Accident Unloading – Hot	HSM	X	--	--	105.0 psi	--	100° F HSM	-80 Kip	--	D

HSM Unloading / Reflood	Horizontal DW		Vertical DW		Internal Pressure[13]	External Pressure	Thermal Condition	Handling Loads	Other Loads	Service Level
	DSC	Fuel	DSC	Fuel						
RF-1 32PT-DSC Reflood	--	--	Cask	X	105.0 psi (max)	Hydrostatic	100° F Cask	--	--	D

Table M.2-15
Summary of 32PT-DSC Load Combinations

Summary of 32PT-DSC Load Combinations Notes:

1. Drop acceleration includes gravity effects.
2. For Level D events, stress allowables are based considering the maximum temperature of the component (Thermal stresses are not limited for level D events and maximum temperatures give minimum allowables) or the actual temperature distribution (basket).
3 Flood load is an external pressure equivalent to 50 feet (164m) of water.
4. BV = HSM Vents are blocked.
5. At temperature over 100° F (38°C) a sunshade is required over the TC. Temperatures for these cases are enveloped by the 100° F (without sunshade) case.
6. Not used.
7. Not used.
8. Not used.
9. Not used.
10. Fuel deck seismic loads are assumed enveloped by handling loads.
11. Not used.
12. The 75g top end drop and bottom end drop are not credible events, therefore these drop analyses are not required. However, consideration of 60g end drops and the 75g side drop conservatively envelop the effects of a 25g corner drop.
13. Reflood pressure is limited to 20psi. For analysis purposes a 105psi pressure is considered.

Table M.2-16
Summary of Stress Criteria for Subsection NB Pressure Boundary Components
(e.g., Shells and Cover Plates)

Service Level	Stress Category
Level A[(1)(2)]	$P_m \le 1.0S_m$ $P_L \le 1.5S_m$ $P_m\ (or\ P_L) + P_b \le 1.5S_m$ $P_m\ (or\ P_L) + P_b + Q \le 3.0S_m$
Level B[(1)(3)]	$P_m \le 1.0S_m$ $P_L \le 1.5S_m$ $P_m\ (or\ P_L) + P_b \le 1.5S_m$ $P_m\ (or\ P_L) + P_b + Q \le 3.0S_m$
Level C[(4)]	$P_m \le \max(1.2S_m, 1.0S_y)$ $P_L \le \max(1.8S_m, 1.5S_y)$ $P_m\ (or\ P_L) + P_b \le \max(1.8S_m, 1.5S_y)$ $P_m\ (or\ P_L) + P_b + Q \le note\ 4$ $F_p \le 1.5S_y$ $\sigma_1 + \sigma_2 + \sigma_3 \le 4.0S_m$
Carbon Steel Components (e.g., Shield Plugs)	
Level D[(4)] Elastic Analysis	$P_m \le 0.7S_u$ $P_m\ (or\ P_L) + P_b \le 1.0S_u$
Level D[(4)] Plastic Analysis	$P_m \le 0.7S_u$ $P_m\ (or\ P_L) + P_b \le 0.9S_u$
Austenitic Steel Components (e.g., Shell)	
Level D[(4)] Elastic Analysis	$P_m \le \min(2.4S_m, 0.7S_u)$ $P_m\ (or\ P_L) + P_b \le \min(3.6S_m, 1.0S_u)$
Level D[(4)] Plastic Analysis	$P_m \le \max(0.7S_u, S_y + (S_u - S_y)/3)$ $P_m\ (or\ P_L) + P_b \le 0.9S_u$

Notes:
1. The secondary stress limit may be exceeded provided the criteria of NB-3228.5 are satisfied.
2. There are no specific limits on primary stresses for Level A events. However, the stresses due to primary loads during normal service must be computed and combined with the effects of other loadings in satisfying other limits. See NB-3222.1.
3. The 10% increase in allowables from NB-3223(a) may be applicable for load combinations for which the pressure exceeds the design pressure.
4. Evaluation of secondary stresses not required for Level C and D events.

Table M.2-17
Summary of Stress Criteria for Subsection NG Components

Service Level	Stress Category (5)
Level A/B[1]	$P_m \le 1.0S_m$ $P_m + P_b \le 1.5S_m$ $P_m + P_b + Q \le 3.0S_m$ (*note* 4)
Level C[2][3] Elastic Analysis	$P_m \le 1.5S_m$ $P_m + P_b \le 2.25S_m$
Level D[2][6] Elastic Analysis	$P_m \le \min(2.4S_m, 0.7S_u)$ $P_m + P_b \le \min(3.6S_m, 1.0S_u)$
Level D[2][6] Plastic Analysis	$P_m \le \max(0.7S_u, S_y + 1/3(S_u - S_y))$ $P_m + P_b \le 0.9S_u$

Notes:

1. There are no pressure loads on the basket, therefore the 10% increase permitted by NG-3223(a) for pressures exceeding the design pressure does not apply.
2. Evaluation of secondary stresses not required for Level C and D events.
3. Criteria listed are for elastic analyses, other analysis methods permitted by NG-3224.1 are acceptable if performed in accordance with the appropriate paragraph of NG-3224.1.
4. This limit may be exceeded provided the requirements of NG-3228.3 are satisfied, see NG-3222.2 and NG-3228.3.
5. As appropriate, the special stress limits of NG-3227 are applicable.
6. Level D criteria are taken from ASME Code, Section III, Appendix F. Acceptable criteria for stability are from Section III of the ASME Code Appendix F.

Table M.2-18
Classification of NUHOMS®-32PT DSC Components

IMPORTANT TO SAFETY	NOT IMPORTANT TO SAFETY
Canister Assembly	Siphon tube
	Quick connect coupling
Canister shell	Male connector
Bottom shield plug	Alignment key
Inner bottom cover	Canister lifting lug
Outer bottom cover	Electroless nickel coating
Grapple ring and support	
Top shield plug	
Inner top cover plate	
Outer top cover plate	
Siphon/vent port cover plate	
Siphon vent block	
Support ring	
Test port plug	
Weld filler metal	
Storage Basket Assembly	
Poison plate	
Basket plate	
Weld stud, washer, hex nut	
Basket rails	
Weld filler metal	

Table M.2-19
Additional Design Criteria for NUHOMS®-32PT DSC

The Gross Weight (rounded) of the NUHOMS®-32PT DSC:	
32PT-S100	88,200 (1) lbs. / 98,300 (2) lbs.
32PT-S125	90,300 (1) lbs. / 100,400(2) lbs.
32PT-L100	89,200 (1) lbs. / 99,300 (2) lbs.
32PT-L125	91,300 (1) lbs./ 101,400 (2) lbs.
Payload Capacity:	up to 32 intact PWR assemblies (acceptable assemblies listed in Table M.2-2) and up to 16 BPRAs
Spent Fuel Characteristics:	See Table M.2-1 through Table M.2-3.

(1) Based on fuel weight of 1365 lbs. per assembly.
(2) Based on fuel weight of 1682 lbs. per assembly.

Table M.2-20
Summary of NUHOMS®-32PT Component Design Loadings[1]

Component	Design Load Type	FSAR Section Reference	Design Parameters	Applicable Codes
32PT-DSC:	---	---	---	ASME Code, 1998 Edition with 2000 Addenda, Section III, Subsection NB and Appendix F (Shell) and Subsections NG, NF and Appendix F (Basket) with exceptions noted in Table M.3.1-2.
	Flood	M.2.2.2	Maximum water height: 50 ft.	10CFR72.122(b)
	Seismic	M.2.2.3	Horizontal ground acc: 0.25g Vertical ground acc.: 0.17g	NRC Reg. Guides 1.60 & 1.61
	Dead Load	M.3.6.1.2 M.3.6.1.3	Maximum enveloping weight of loaded 32PT DSCs: 101,400 lbs.	ANSI 57.9-1984
	Normal and Off-Normal Pressure	M.3.6.1.2 M.3.6.1.3	Enveloping internal pressure of ≤15 psig (Normal) and < 20 psig (Off-Normal)	10CFR72.122(h)
	Test Pressure	M.3.6.1.2	Enveloping internal pressure of 18 psig applied w/o DSC outer top cover plate	10CFR72.122(h)
	Normal and Off-Normal Operating Temperature	M.3.6.1.2 M.3.6.1.3 M.3.6.2.2 M.4.4 M.4.5	DSC with spent fuel rejecting 24 kW (PWR) decay heat. Ambient air temperature -40°F to 117°F	ANSI 57.9-1984
	Normal Handling Loads	M.3.6.1.2 M.3.6.1.3	1. Hydraulic ram load of 80,000 lb.(DSC HSM insertion) 60,000 lb (DSC HSM extraction) 2. Transfer (to/from ISFSI) Loads of: 2a. +/-1.0g axial 2b. +/-1.0g transverse 2c. +/-1.0g vertical 2d. +/-0.5g axial +/-0.5g transverse +/-0.5g vertical	ANSI 57.9-1984
	Off-Normal Handling Loads	M.3.6.1.2	Hydraulic ram load of: 80,000 lb (DSC HSM insertion) 80,000 lb (DSC HSM extraction)	ANSI-57.9-1984

Table M.2-20
Summary of NUHOMS®-32PT Component Design Loadings(1)
(Continued)

Component	Design Load Type	FSAR Section Reference	Design Parameters	Applicable Codes
	Accidental Cask Drop Loads	M.3.7.5	Equivalent static deceleration of 75g for horizontal side drops, and 25g oblique corner drop	10CFR72.122(b)
	Accident Internal Pressure	M.4	Enveloping internal pressure of ≤105 psig based on 100% fuel cladding rupture and fill gas release, 30% fission gas release, and ambient air temperature of 117°F	10CFR72.122(h)

Note:
(1) The design criteria for the HSM (including the DSC Steel Support Structure) and the TC remain unchanged from the FSAR (FSAR Table 3.2-1). These components have been evaluated for the effect of the higher weight of the 32PT-DSC.

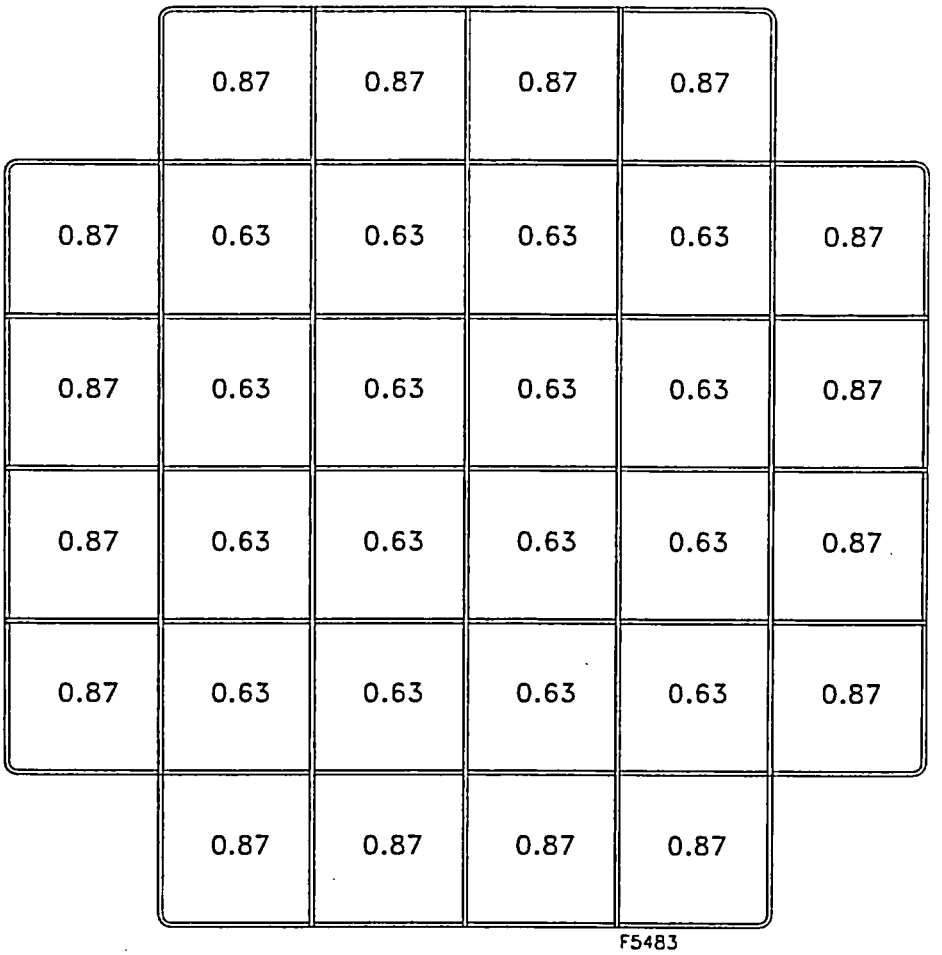


Figure M.2-1
Heat Load Zoning Configuration 1

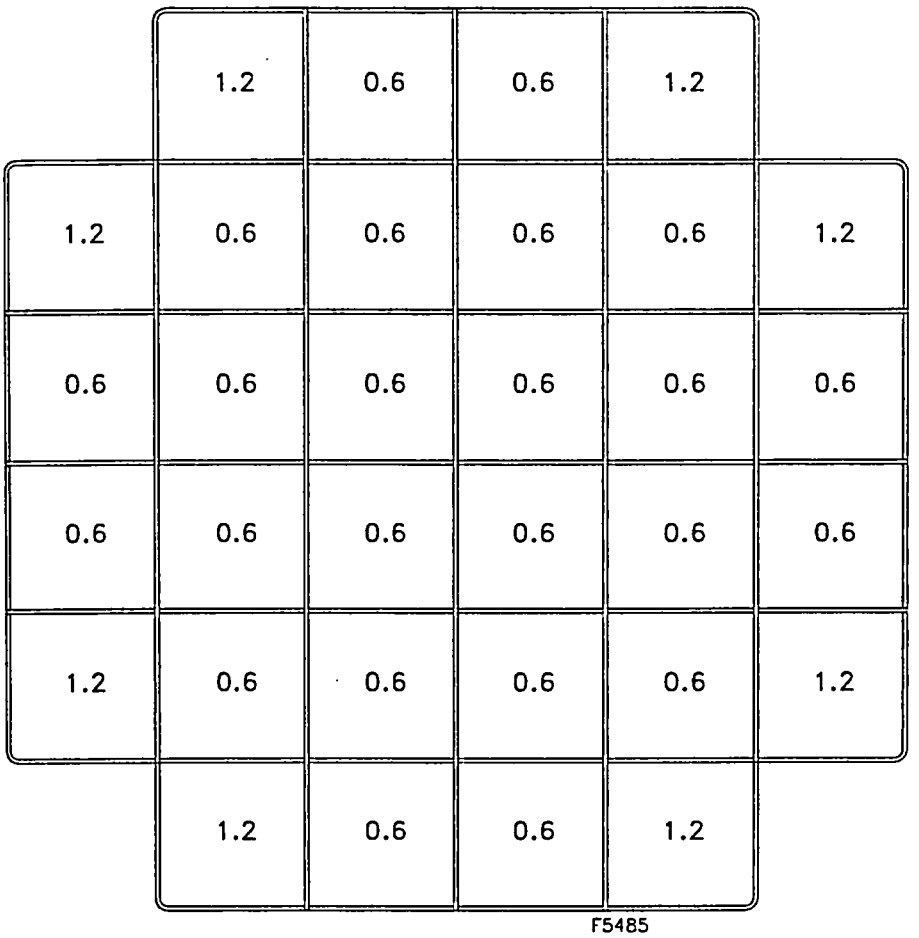


Figure M.2-2
Heat Load Zoning Configuration 2

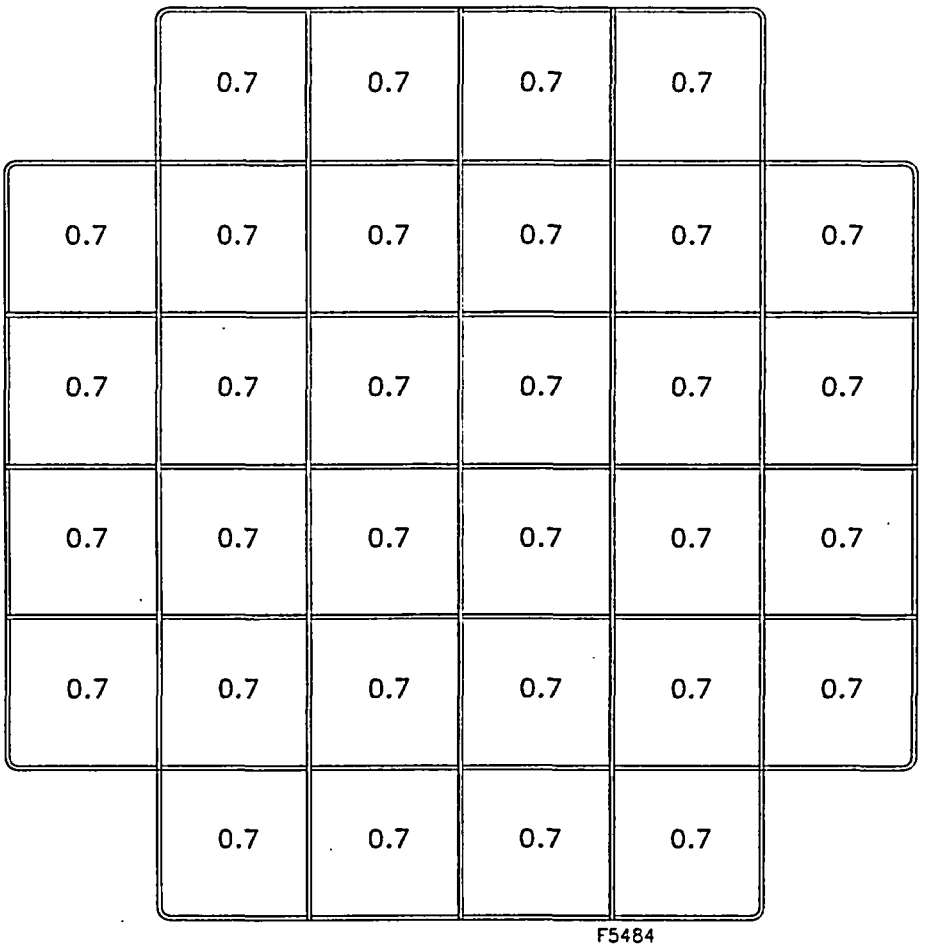


Figure M.2-3
Heat Load Zoning Configuration 3

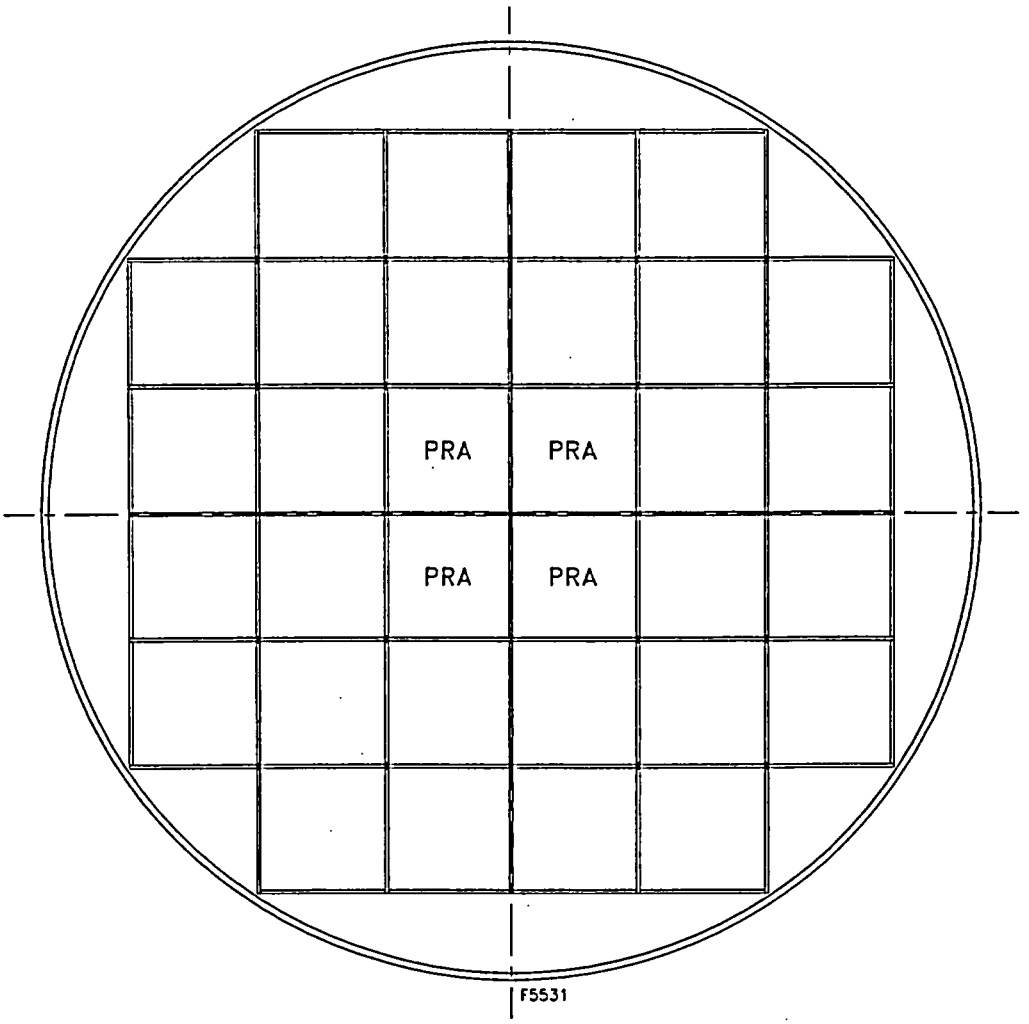
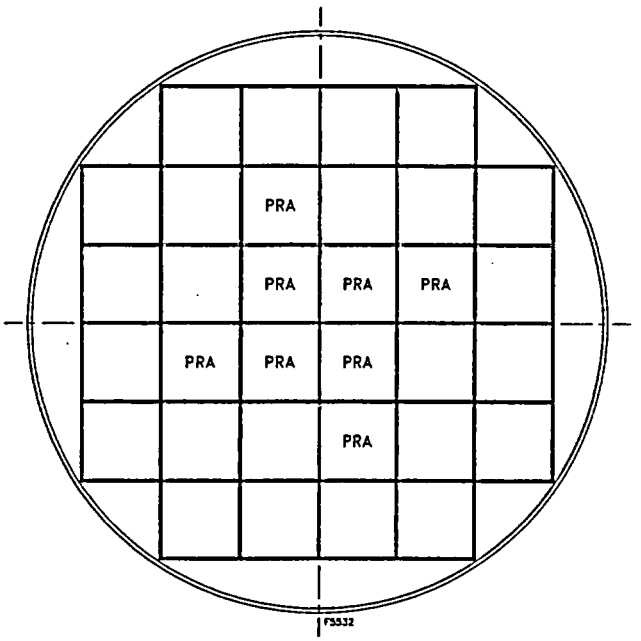


Figure M.2-4
Required PRA Locations for Configurations with Four PRAs
(Basket Type B)



OR

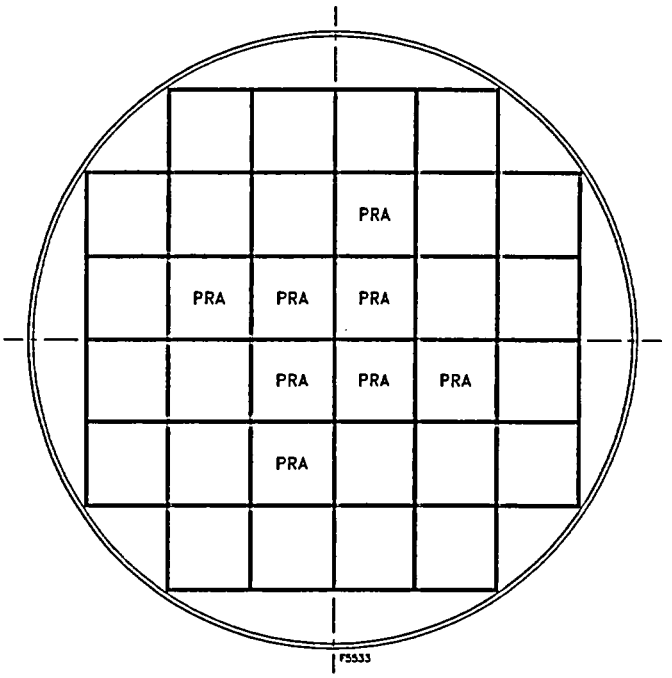


Figure M.2-5
Required PRA Locations for Configurations with Eight PRAs
(Basket Type C)

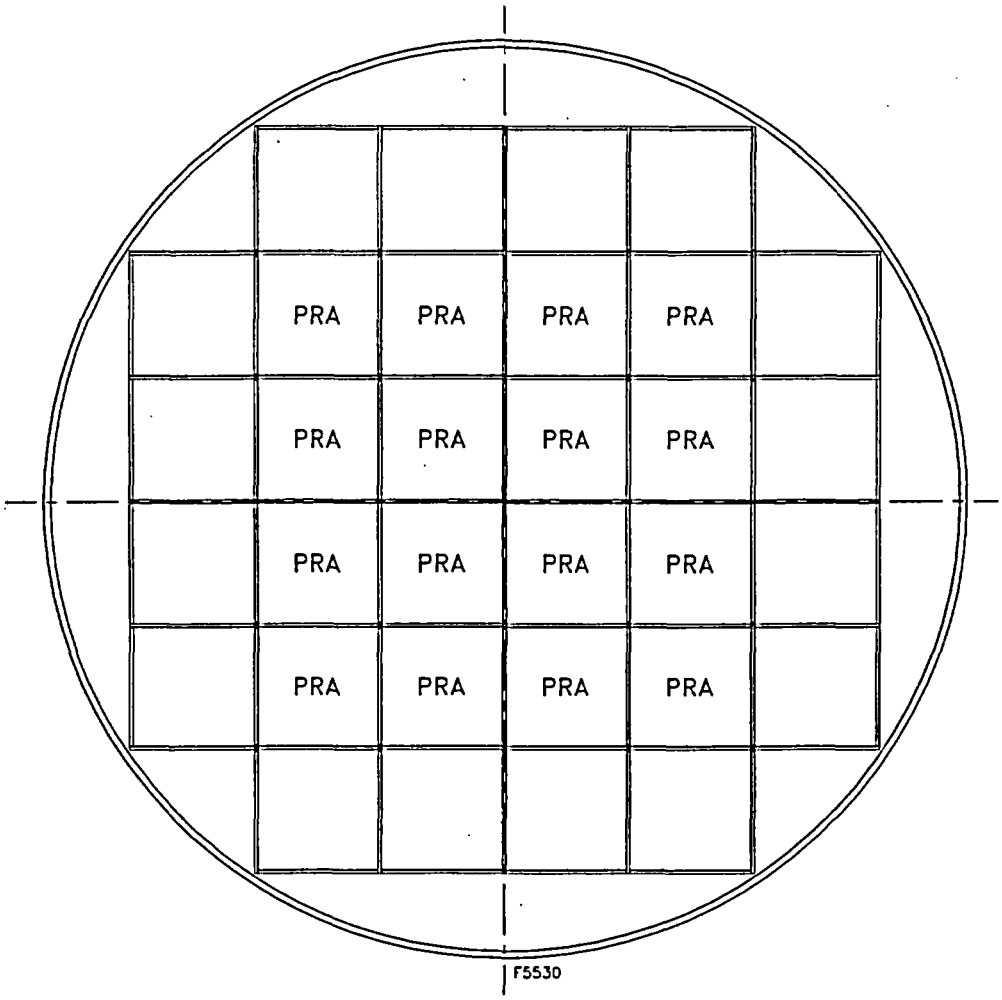


Figure M.2-6
Required PRA Locations for Configurations with Sixteen PRAs
(Basket Type D)

M.3 Structural Evaluation

M.3.1 Structural Design

M.3.1.1 Discussion

This section describes the structural evaluation of the NUHOMS®-32PT system. The NUHOMS®-32PT system consists of the NUHOMS® HSM, the OS197 and OS197H TCs, and he 32PT DSC basket and shell assemblies. No changes have been made to the HSM or the OS197 or OS197H TCs to accommodate the 32PT DSC. Where the new components have an effect on the structural evaluations presented in the FSAR, the changes are included in this section. Sections that do not effect the evaluations presented in the FSAR include a statement that there is no change to the FSAR. In addition, a complete evaluation of the 32PT DSC shell and basket components has been performed and is summarized in this section.

The 32PT DSC shell assembly is shown on drawings NUH-32PT-1001-SAR and NUH-32PT-1002-SAR. These drawings are provided in Section M.1.5. The NUHOMS®-32PT DSC shell assembly is the same as the NUHOMS®-24P DSC with the following exceptions:

- The nominal DSC shell thickness has been reduced to 0.5 inch thick from 0.625 inch thick.
- The nominal thickness of the outer top cover plate has been increased from 1.25 inches to 1.50 inches.
- The nominal thickness of the inner top cover plate has been increased from 0.75 inches to 1.25 inches.
- The nominal thickness of the inner bottom cover plate has been increased from 0.75 inches to 1.75 inches and has been designed for the internal pressure loads without credit taken for the structural support of the bottom shield plug and outer bottom cover plate.
- The nominal thickness of the top shield plug has been reduced from 8.25 inches to 6.25 inches for the 32PT-S100 and 32PT-L100 and to 7.5 inches for the 32PT-S125 and 32PT-L125.
- The nominal thickness of the bottom shield plug has been reduced from 6.25 inches to 4.00 inches for the 32PT-S100 and 32PT-L100 and to 5.25 inches for the 32PT-S125 and 32PT-L125.
- An optional configuration has been added for the inner bottom cover plate that allows the use of a forging to provide the same structural function as the plate design. The forging may be a single piece comprising the full thickness of the bottom end components.
- A test port has been added to the top cover plate to allow testing of the inner top cover plate welds and vent and siphon port cover plate welds to a leak tight criteria.

The NUHOMS®-32PT basket is a welded assembly of stainless steel plates or tubes that make up a fuel support assembly grid designed to accommodate up to 32 PWR fuel assemblies. The basket structure consists of the fuel support structure, the transition rails, aluminum heat transfer material, and neutron absorbing material.

The 32PT basket assembly is shown on drawings NUH-32PT-1003-SAR, -1004-SAR and -1006-SAR. These drawings are provided in Section M.1.5.

- The fuel support structure is fabricated from high strength (Type XM-19) stainless steel and contains 32 square fuel compartments in a box arrangement.
- The transition rails provide the transition between the "rectangular" fuel support grid and the cylindrical internal diameter of the DSC shell. There are two sizes of transition rails. The large rails are referred to as the R90 transition rails. The smaller transition rails are referred to as the R45 transition rails.

The thermal analysis results for the basket components are presented in Chapter M.4. These thermal analysis results correspond to the basket configuration with solid aluminum transition rails, shown in drawing NUH-32PT-1006-SAR. The stress evaluations documented in Chapter M.3 are generally based on bounding temperatures/thermal profiles that correspond to a welded stainless steel transition rail configuration which is not approved for use with a NUHOMS®-32PT basket. A detailed reconciliation of the Chapter M.4 thermal results with those used in Chapter M.3 was performed. The discussion below is a summary of this reconciliation. In cases where the Chapter M.4 maximum temperatures/thermal profiles are used, it is so noted.

Blocked Vent: Maximum temperatures and temperature gradients corresponding to the thermal analysis results documented in Chapter M.4 are lower for all basket components than the temperatures and temperature gradients used in the stress analysis. Therefore, the Chapter M.4 thermal results have no impact on the stress evaluations documented in this chapter for the blocked vent condition.

Vacuum Drying: The maximum temperatures corresponding to the thermal analysis results documented in Chapter M.4 are lower for all basket components than the maximum temperatures used in the stress analysis. The temperature gradients for the solid aluminum rail components are also lower. Therefore, the Chapter M. 4 thermal results have no impact on the stress evaluations of the solid aluminum rail components. The temperature gradient across the XM-19 steel grid component increases, causing an increase in the stress of about 1.0 ksi. The maximum thermal stress intensity in the grid component is small (4.33 ksi, from Table M.3.4-2). Considering that the only other load for this condition is deadweight (0.06 ksi, from Table M.3.6-5), the margin to allowable (84.6 ksi, from Table M.3.3-3, at 800°F) remains very large (4.33+1.1+0.06=5.39 ksi versus 84.6 ksi). Therefore, the impact of the revised thermal results is negligible.

Storage and Transfer Conditions: The maximum temperatures corresponding to the thermal analysis results documented in Chapter M.4 are lower for all basket components than the maximum temperatures used in the stress analysis. The temperature gradients for the solid aluminum rail components are also lower. Therefore, the Chapter M.4 thermal results have no

impact on the stress evaluations of the solid aluminum rail components. The temperature gradient across the XM-19 steel grid component increases, causing a maximum (envelope of all transfer/storage cases) stress increase of 1.55 ksi. The maximum thermal stress intensity in the grid component is small (4.95 ksi, from Table M.3.4-2). The controlling stress intensity (which includes the thermal stress) for the grid component is 18.3 ksi (from Table M.3.6-6). Considering the incremental stress, the revised stress intensity is 19.85 ksi versus 84.6 ksi allowable. Therefore, considering the large margin available, the impact of the Chapter M.4 thermal results is negligible.

Accident Transfer Case (117°F ambient, loss of sunshade, loss of neutron shield): The maximum temperature for the accident transfer case has increased. As shown in Table M.4-14, the maximum temperature for the steel grid is 852°F. The structural evaluation used allowable for the steel grid at 800°F. An exception to the material temperature limits of ASME Section II, Part D for the XM-19 grid plate material is added to Table M.3.1-2. This is a post-drop accident condition, where the only primary loads on the basket are due to deadweight and the expected reduction in material strength is small (less than 1 ksi by extrapolation, from Table M.3.3-3). Therefore, this case is not a concern considering that the deadweight stress is small.

The shell assembly temperatures used in the structural analysis are bounded by the thermal results documented in M.4 and, thus, there is no impact on the shell assembly. The calculated pressures due to the increased temperatures for the postulated post-drop accident transfer case (117°F ambient, loss of sunshade, loss of neutron shield) bound the pressures used in the structural evaluations.

Therefore, the thermal analysis results presented in Chapter M.4 have negligible impact on the DSC structural analysis results as presented in this Chapter.

Two fabrication designs are evaluated for the transition rails:

- Single Piece Solid Aluminum Rails: The transition rails are solid sections of 6061 aluminum alloy. The large (R90) rails include an XM-19 "cover plate" between the fuel support grid and the aluminum body. The structural evaluation of the rails uses properties for annealed aluminum (no credit is taken for enhanced properties obtained by heat treatment).

- Multi-Piece Solid Aluminum Rails: Optionally, the large (R90) transition rails may be made from 3 equal width sections of 6061 aluminum alloy. XM-19 cover plate is not changed. Analysis properties are the same as used for the solid rails.

The fuel support grid structure contains aluminum alloy 1100 plates as heat transfer material and, neutron absorbing plates. No credit is taken for the structural capacity of the aluminum heat transfer plates or neutron absorbing materials in the structural evaluation of the support grid structure.

The connections between the transition rails and fuel support structure are not required to maintain structural capacity of the basket assembly. These connections are primarily to simplify fabrication and are designed to allow free thermal expansion of the connected parts.

The basket structure is open at each end such that longitudinal fuel assembly loads are applied directly to the DSC/cask body and not to the basket structure. The fuel assemblies are laterally supported by the XM-19 fuel support structure. The basket is laterally supported by the basket transition rails and the DSC inner shell.

Inside the TC, the DSC rests on two 3" wide rails ("cask rails"), attached to the inside of the TC at +/-18.5° from the bottom centerline of the DSC. In the HSM, the DSC is supported by rails located at +/-30° from the bottom centerline of the DSC.

The nominal open dimension of each fuel compartment cell is 8.70 in. x 8.70 in. which provides clearance around the fuel assemblies. The overall basket length is less than the DSC cavity length to allow for thermal expansion and tolerances.

M.3.1.2 Design Criteria

Design criteria for the DSC shell and basket are provided in Section M.2.2.

M.3.1.2.1 DSC Shell Assembly Confinement Boundary

The primary confinement boundary consists of the DSC shell, the inner top cover plate, the inner bottom cover plate, the siphon vent block, the siphon/vent port cover plates, and the associated welds. Figure M.3.1-1 provides a graphic representation of the 32PT-DSC confinement boundary. The outer top cover plate forms the redundant confinement boundary.

The welds made during fabrication of the 32PT-DSC that affect the confinement boundary of the DSC include the inner bottom cover plate to shell weld and the circumferential and longitudinal seam welds applied to the shell. These welds are inspected (radiographic or ultrasonic inspection, and liquid penetrant inspection) according to the requirements of Subsection NB of the ASME Code.

The top inner cover plate and associated welds, the welds applied to the vent and siphon port covers, and the closure welds applied to the vent & siphon block, define the primary confinement boundary at the top end of the 32PT-DSC. These welds are in accordance with the alternative ASME Code Section III requirements of ASME Code Case N-595-2. These welds are applied using a multiple-layer technique and are liquid penetrant (PT) examined in accordance with Code Case N-595-2 [3.1] and Section III NB-5000.

During fabrication, leak tests of the 32PT-DSC shell assembly are performed in accordance with ANSI N14.5-1997 [3.13] to demonstrate that the shell is leaktight (1×10^{-7} std. cm^3/sec). The DSC inner top cover closure welds, including the vent and siphon pressure boundary welds, are also leak tested after fuel loading to demonstrate that the ANSI N14.5 leaktight criteria is met following installation of the outer cover plate root pass weld.

The basis for the allowable stresses for the confinement boundary is ASME Code Section III, Division I, Subsection NB Article NB-3200 [3.1] for normal (Level A) condition loads , off-normal (Level B) condition loads and off-normal/accident (Level C) condition loads, and Appendix F for accident (Level D) condition loads. See Section M.2.2 for additional design criteria.

M.3.1.2.2 DSC Basket

The basket is designed to meet heat transfer, nuclear criticality, and structural requirements. The basket structure provides sufficient rigidity to maintain a subcritical configuration under the applied loads. The Type XM-19 stainless steel members in the NUHOMS®-32PT basket are the primary structural components. The aluminum heat transfer plates and neutron poison plates are the primary heat conductors, and provide the necessary criticality control. The transition rails provide support to the fuel compartment grid for mechanical loads and also transfer heat from the fuel compartments to the DSC shell.

The stress analyses of the basket do not take credit for the neutron absorbing/heat transfer plate material.

The basket structural design criteria is provided in Section M.2.2. The basis for the allowable stresses for the stainless steel components in the basket assembly is Section III, Division 1, Subsection NG of the ASME Code [3.1]:

- Normal conditions are evaluated using criteria from NG-3200.
- Accident conditions are classified as Level D events and are evaluated using stress and stability criteria from Section III, Appendix F of the ASME Code [3.1].

M.3.1.2.3 Alternatives to the ASME Code for the 32PT DSC

The primary confinement boundary of the NUHOMS®-32PT DSC consists of the DSC shell, the inner top cover plate, the inner bottom cover plate, the siphon vent block, and the siphon/vent port cover plate. Even though the ASME B&PV code is not strictly applicable to the DSC, it is TN's intent to follow Section III, Subsection NB of the Code as closely as possible for design and construction of the confinement vessel. The DSC may, however, be fabricated by other than N-stamp holders and materials may be supplied by other than ASME Certificate Holders. Thus the requirements of NCA are not imposed. TN's quality assurance requirements, which are based on 10CFR72 Subpart G and NQA-1 are imposed in lieu of the requirements of NCA-3800. The SAR is prepared in place of the ASME design and stress reports. Surveillances are performed by TN and utility personnel rather than by an Authorized Nuclear Inspector (ANI).

The basket is designed, fabricated and inspected in accordance with the ASME Code Subsection NG. The following alternative provisions to the ASME Code Section III requirements are taken:

The poison rod assemblies, poison plates, and aluminum heat transfer plates are not considered for structural integrity. Therefore, these materials are not required to be Code materials. The quality assurance requirements of NQA-1 is imposed in lieu of NCA-3800. The basket is not Code stamped. Therefore, the requirements of NCA are not imposed. Fabrication and inspection surveillances are performed by TN and utility personnel rather than by an ANI.

A complete list of the alternatives to the ASME Code and corresponding justification for the NUHOMS®-32PT DSC and basket is provided in Table M.3.1-1 and Table M.3.1-2.

Table M.3.1-1
Alternatives to the ASME Code for the NUHOMS®-32PT DSC Confinement Boundary

Reference ASME Code Section/Article	Code Requirement	Alternatives, Justification & Compensatory Measures
NCA	All	Not compliant with NCA. TN Quality Assurance requirements, which are based on 10CFR72 Subpart G, are used in lieu of NCA-4000. Fabrication oversight is performed by TN and utility personnel in lieu of an Authorized Nuclear Inspector.
NB-1100	Requirements for Code Stamping of Components	The NUHOMS®-32PT DSC shell is designed & fabricated in accordance with the requirements of ASME Code, Section III, Subsection NB and the alternative provisions described in this table. However, Code Stamping is not required. As Code Stamping is not required, the fabricator is not required to hold an ASME "N" or "NPT" stamp, or to be ASME Certified.
NB-2130	Material must be supplied by ASME approved material suppliers.	All materials designated as ASME on the SAR drawings are obtained from ASME approved Material Organization with ASME CMTR's. Material is certified to meet all ASME Code criteria but is not eligible for certification or Code Stamping if a non-ASME fabricator is used. As the fabricator is not required to be ASME certified, material certification to NB-2130 is not possible. Material traceability & certification are maintained in accordance with TN's NRC approved QA program.
NB-4121	Material Certification by Certificate Holder	
NB-4243 and NB-5230	Category C weld joints in vessels and similar weld joints in other components shall be full penetration joints. These welds shall be examined by UT or RT and either PT or MT	The joints between the top outer and inner cover plates and containment shell are designed and fabricated per ASME Code Case N-595-2, which provides alternative requirements for the design and examination of spent fuel canister closures. This includes the inner top cover plate weld around the vent & siphon block and the vent and siphon block welds to the shell. The closure welds are partial penetration welds and the root and final layer are subject to PT examination (in lieu of volumetric examination) in accordance with the provisions of ASME Code Case N-595-2. The 32PT closure system employs austenitic stainless steel shell, lid materials, and welds. Because austenitic stainless steels are not subject to brittle failure at the operating temperatures of the DSC, crack propagation is not a concern. Thus, multi-level PT examination provides reasonable assurance that flaws of interest will be identified. The PT examination is done by qualified personnel, in accordance with Section V and the acceptance standards of Section III, Subsection NB-5000. This alternative does not apply to other shell confinement welds, i.e., the longitudinal and circumferential welds applied to the DSC shell, and the inner bottom cover plate-to-shell weld which comply with NB-4243 and NB-5230.

Table M.3.1-1
Alternatives to the ASME Code for the NUHOMS®-32PT DSC Confinement Boundary
(Concluded)

Reference ASME Code Section/Article	Code Requirement	Alternatives, Exception, Justification & Compensatory Measures
NB-6100 and 6200	All pressure retaining components and completed systems shall be pressure tested. The preferred method shall be hydrostatic test.	The NUHOMS®-32PT DSC is pressure tested in accordance with ASME Code Case N-595-2. The shield plug support ring and the vent and siphon block are not pressure tested due to the manufacturing sequence. The support ring is not a pressure-retaining item and the vent and siphon block weld is helium leak tested after fuel is loaded to the same criteria as the inner top closure plate-to-shell weld (ANSI N14.5-1997 leaktight criteria).
NB-7000	Overpressure Protection	No overpressure protection is provided for the NUHOMS®-32PT DSC . The function of the NUHOMS®-32PT DSC is to contain radioactive materials under normal, off-normal and hypothetical accident conditions postulated to occur during transportation and storage. The NUHOMS®-32PT DSC is designed to withstand the maximum possible internal pressure considering 100% fuel rod failure at maximum accident temperature. The NUHOMS®-32PT DSC is pressure tested in accordance with ASME Code Case N-595-2.
NB-8000	Requirements for nameplates, stamping & reports per NCA-8000	The NUHOMS®-32PT DSC nameplate provides the information required by 10CFR71, 49CFR173 and 10CFR72 as appropriate. Code stamping is not required for the NUHOMS®-32PT DSC. In lieu of code stamping, QA data packages are prepared in accordance with the requirements of 10CFR71, 10CFR72 and TN's approved QA program.

Table M.3.1-2
Alternatives to the ASME Code Exceptions for the NUHOMS®-32PT DSC Basket Assembly

Reference ASME Code Section/Article	Code Requirement	Alternatives, Exception, Justification & Compensatory Measures
NG-1100	Requirements for Code Stamping of Components	The NUHOMS®-32PT DSC baskets are designed & fabricated in accordance with the ASME Code, Section III, Subsection NG as described in the SAR, but Code Stamping is not required. As Code Stamping is not required, the fabricator is not required to hold an ASME N or NPT stamp or be ASME Certified.
NG-2000	Use of ASME Material	The poison material and aluminum plates are not used for structural analysis, but to provide criticality control and heat transfer. They are not ASME Code Class 1 material. Material properties in the ASME Code for Type 6061 aluminum are limited to 400°F to preclude the potential for annealing out the hardening properties. Annealed properties (as published by the Aluminum Association and the American Society of Metals) are conservatively assumed for the solid aluminum rails for use above the Code temperature limits.
NG-2130	Material must be supplied by ASME approved material suppliers.	All materials designated as ASME on the SAR drawings are obtained from ASME approved Material Organization with ASME CMTR's. Material is certified to meet all ASME Code criteria, but is not eligible for certification or Code Stamping if a non-ASME fabricator is used. As the fabricator is not required to be ASME certified, material certification to NG-2130 is not possible. Material traceability & certification are maintained in accordance with TN's NRC approved QA program.
NG-4121	Material Certification by Certificate Holder	
NG-8000	Requirements for nameplates, stamping & reports per NCA-8000	The NUHOMS®-32PT DSC nameplate provides the information required by 10CFR71, 49CFR173 and 10CFR72 as appropriate. Code stamping is not required for the NUHOMS®-32PT DSC. In lieu of Code stamping, QA Data packages are prepared in accordance with the requirements of 10CFR71, 10CFR72 and TN's approved QA program.
NCA	All	Not compliant with NCA as no Code stamp is used. TN Quality Assurance requirements, which are based on 10CFR72 Subpart G, are used in lieu of NCA-4000. Fabrication oversight is performed by TN and utility personnel in lieu of an Authorized Nuclear Inspector.
NG-3000/ Section II, Part D, Table 2A	Maximum temperature limit for XM-19 plate material is 800°F	Not compliant with ASME Section II Part D Table 2A material temperature limit for XM-19 steel for the postulated transfer accident case (117°F, loss of sunshade, loss of neutron shield). This is a post-drop accident scenario, where the calculated maximum steady state temperature is 852°F, the expected reduction in material strength is small (less than 1 ksi by extrapolation), and the only primary stresses in the basket grid are deadweight stresses. The recovery actions following the postulated drop accident are as described in Section 8.2.5 of the FSAR.

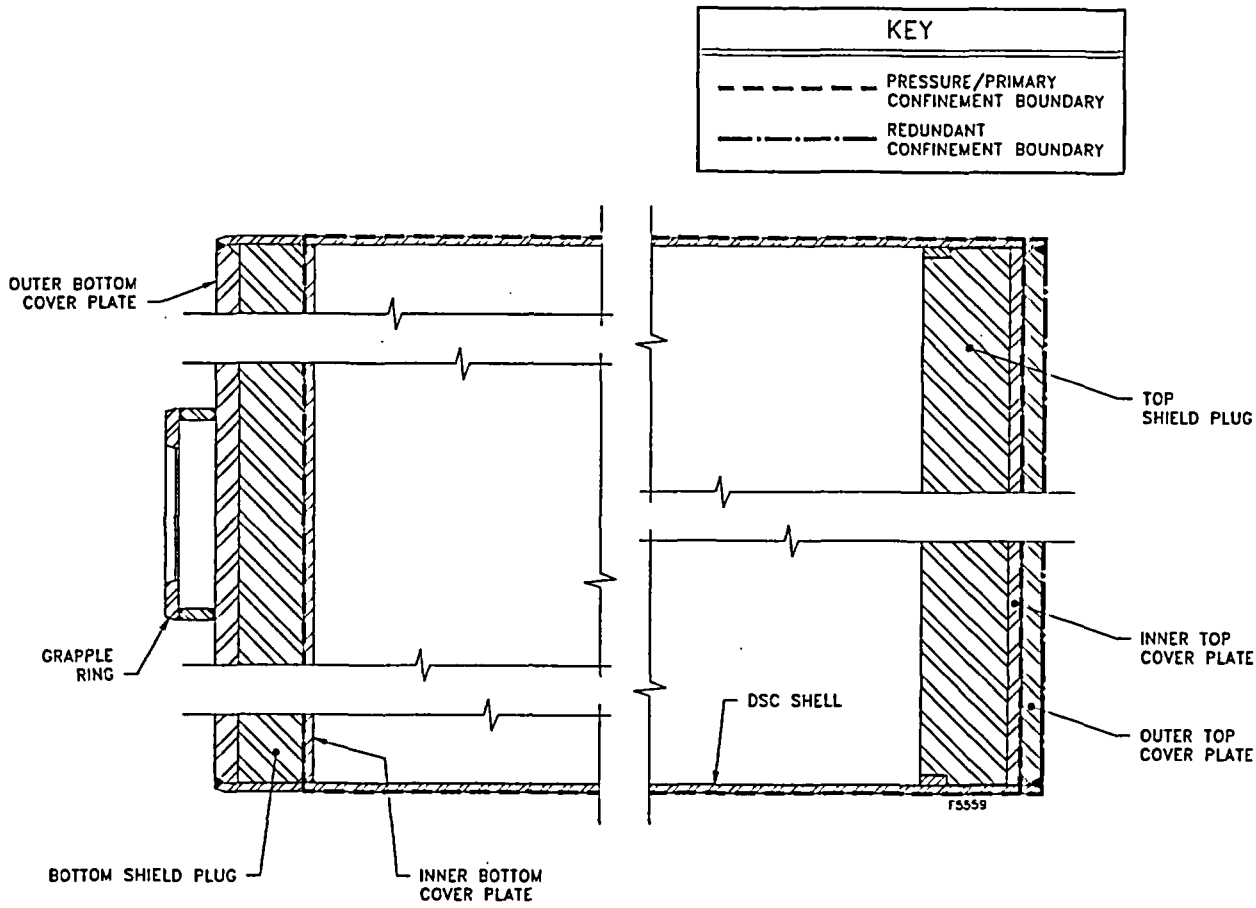


Figure M.3.1-1
32PT-DSC Pressure and Confinement Boundaries

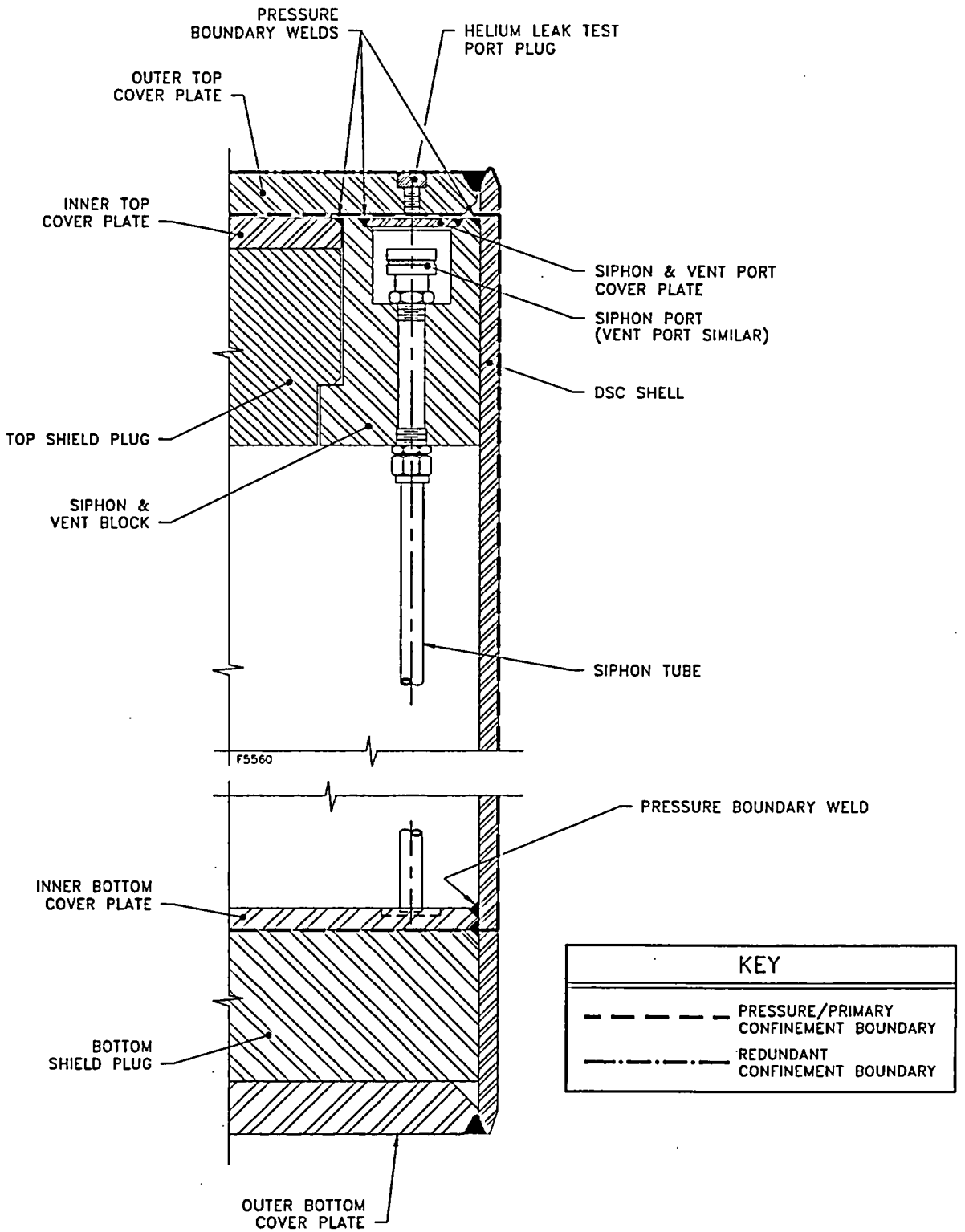


Figure M.3.1-1
32PT-DSC Pressure and Confinement Boundaries
(Concluded)

M.3.2 Weights and Centers of Gravity

Table M.3.2-1 shows the weights of the various components of the NUHOMS®-32PT system including basket, DSC, standard HSM and OS197 and OS197H TC. The dead weights of the components are determined based on nominal dimensions.

Table M.3.2-1
Summary of the NUHOMS®-32PT System Component Nominal Weights

Component Description	CALCULATED WEIGHT (kips)			
	32PT-S100	32PT-S125	32PT-L100	32PT-L125
DSC Shell Assembly[1]	13.06	14.28	13.24	14.46
DSC Top Shield Plug Assembly[2]	8.71	9.93	8.71	9.93
DSC Internal Basket Assembly	22.74	22.40	23.55	23.21
Total Empty Weight	**44.52**	**46.62**	**45.51**	**47.61**
32 PWR Spent Fuel Assemblies	≤ 43.68[3] ≤ 53.82[4]	≤ 43.68[3] ≤ 53.82[4]	≤ 43.68[3] ≤ 53.82[4]	≤ 43.68[3] ≤ 53.82[4]
Total Loaded DSC Weight (Dry)	**88.20[3]** **98.34[4]**	**90.30[3]** **100.44[4]**	**89.19[3]** **99.33[4]**	**91.29[3]** **101.43[4]**
Water in Loaded DSC	6.81[5] 13.61[7]	5.38[5] 10.75[7]	6.40[6] 14.23[7]	5.12[6] 11.37[7]
Total Loaded DSC Weight (Wet)	**95.0[8]** **111.9[9]**	**95.7[8]** **111.2[9]**	**95.6[8]** **113.6[9]**	**96.4[8]** **112.8[9]**
Cask Spacer	1.10	1.10	0.79	0.79
OS197 (OS197H) TC Empty Weight[10]	106.67 111.25	106.67 111.25	106.67 111.25	106.67 111.25
Total Loaded TC Weight	**196.0[8]** **210.7[9]**	**198.1[8]** **212.8[9]**	**196.6[8]** **211.4[9]**	**198.7[8]** **213.5[9]**
HSM Single Module Weight Maximum (Empty)	**263.0**	**263.0**	**263.0**	**263.0**
HSM Single Module Weight Maximum (Loaded)	**351.2**	**363.4**	**352.1**	**364.4**

Notes:

1. Excludes top cover plates and shield plug.
2. Includes top cover plates and shield plug.
3. Based on a fuel weight of 1,365 lbs per assembly. This is a limit for any 32PT DSCs for which the maximum lift weight of the loaded TC is to remain under 100 tons.
4. Based on B&W 15x15 fuel (with control components) weight of 1,682 lbs per assembly.
5. Based on DSC water volume reduced to 50% of capacity to ensure that the maximum lift weight of the loaded TC is under 100 tons.
6. Based on DSC water volume reduced to 45% of capacity to ensure that the maximum lift weight of the loaded TC is under 100 tons.
7. Based on 100% water volume in DSC.
8. Based on fuel assembly weight of 1,365 lbs and 50% water reduction in DSC.
9. Based on fuel assembly weight of 1,682 lbs. and 100% water in DSC.
10. Includes cask top cover plate. The first figure is when the neutron shield is not filled with demineralized water to ensure that the maximum lift weight of the loaded cask is under 100 tons. The second figure is when the neutron shield is filled with demineralized water.

M.3.3 Mechanical Properties of Materials

M.3.3.1 Material Properties

The DSC shell and inner and outer top and bottom cover plates are fabricated from Type 304 stainless steel. The properties for the material are from ASME Code Section II Part D [3.2] and are listed in Table M.3.3-1.

The top and bottom shield plugs are fabricated from A36 carbon steel. The properties from ASME Code Section II Part D [3.2], as listed in Table M.3.3-2, are applied to this material.

The fuel support grid in the 32PT basket is fabricated with Type XM-19 high strength stainless steel. The properties of this material are from ASME Code Section II, Part D [3.2] and are listed in Table M.3.3-3.

The aluminum transition rails use solid sections (e.g., machined plates) of Type 6061 aluminum. The large (R90) rails include a 1/4" thick XM-19 plate (same material and thickness as the fuel support structure) while the small (R45) transition rails are solid aluminum parts with no cover plates. Analysis properties are taken from [3.3] for annealed aluminum. Use of properties for annealed material ensures that no credit is taken for enhanced properties obtained by heat treatment. The selection of properties for annealed material is based on the possibility that the maximum temperature in the rails may exceed the temperatures for which strength properties are provided (for aluminum) in the ASME Code (see Table M.3.3-4). This is acceptable for the following reasons:

1. The transition rails are not pressure boundary parts. Loading on the rails is primarily bearing and the transition rails are "captured" between the fuel support structure and the DSC shell. Deformation of the transition rails (to conform to the inside diameter of the DSC shell) will distribute the applied loads and will not adversely impact the basket structure.

2. For applications where the aluminum properties result from heat treatment, it is necessary to limit the maximum temperature to values below which the effects of the heat treatment are maintained. Heat treatment provides significant differences in strength properties at low temperatures. However, as temperature increases, the effect(s) of heat treatment on strength properties decreases. The strength properties used in the design of the 32PT are based on annealed aluminum. Thus, changes in strength which may occur under exposure to temperatures exceeding 400°F have no adverse impact on the properties used in the design.

For the stress analyses of the 32PT basket, properties for the aluminum rails are taken directly from Table M.3.3-5. For elastic-plastic analyses, the plastic slope of the aluminum is taken as 0.01E. This approximates elastic-perfectly plastic properties while providing a small stiffness to enhance analytical stability.

Table M.3.3-6 provides additional material properties.

M.3.3.2 Materials Durability

The materials used in the fabrication of the NUHOMS®-32PT system are shown in Table M.3.3-1 through Table M.3.3-5. Essentially all of the materials meet the appropriate requirements of the ASME Code, ACI Code, and appropriate ASTM Standards. The durability of the shell assembly and basket assembly stainless steel components is well beyond the design life of the applicable components. The aluminum material used in the basket is only relied upon for its thermal conductivity and bearing strength properties. The poison material selected for criticality control of the NUHOMS®-32PT system has been tested and is currently in use for similar applications. Additionally, the NUHOMS®-32PT basket assembly resides in an inert helium gas environment for the majority of the design life. The materials used in the NUHOMS®-32PT system will maintain the required properties for the design life of the system.

Table M.3.3-1
ASME Code Materials Data For SA-240 Type 304 Stainless Steel

Materials Data, SA-240 Type 304 (18Cr-8Ni) Stainless Steel

Temp. (°F)	E (ksi)	S_m (ksi)	S_y (ksi)	S_u (ksi)	α_{AVG} (x 10^{-6}°F^{-1})
-100	29,100	--	--	--	--
-20	--	20.0	30.0	75.0	--
70	28,300	--	--	--	8.5
100	--	20.0	30.0	75.0	8.6
200	27,600	20.0	25.0	71.0	8.9
300	27,000	20.0	22.4	66.2	9.2
400	26,500	18.7	20.7	64.0	9.5
500	25,800	17.5	19.4	63.4	9.7
600	25,300	16.4	18.4	63.4	9.8
650	--	16.2	18.0	63.4	9.9
700	24,800	16.0	17.6	63.4	10.0
750	--	15.6	17.2	63.3	10.0
800	24,100	15.2	16.9	62.8	10.1
Reference Section II-D	Table TM-1 Group G	Table 2A	Table Y-1	Table U	18Cr-8Ni TE-1, Group 3

Table M.3.3-2
Materials Data For ASTM A36 Steel

(Properties are taken from ASME Code Section II for SA-36 Steel. The ASME material specification is identical to the ASTM A36 Steel specification.)

Temp. (°F)	E (ksi)	S_m (ksi)	S_y (ksi)	S_u (ksi)	α_{AVG} (x 10^{-6} °F^{-1})
-100	30,200	--	--	--	--
-20	--	19.3	36.0	58.0	--
70	29,500	19.3	36.0	58.0	--
100	--	19.3	36.0	58.0	6.5
200	28,800	19.3	33.0	58.0	6.7
300	28,300	19.3	31.8	58.0	6.9
400	27,700	19.3	30.8	58.0	7.1
500	27,300	19.3	29.3	58.0	7.3
600	26,700	17.7	27.6	58.0	7.4
650	--	17.4	26.7	58.0	7.5
700	25,500	17.3	25.8	58.0	7.6
750	--	--	--	--	7.7
800	24,200	--	--	--	7.8

Table M.3.3-3
ASME Code Materials Data For SA-240 Type XM-19 Stainless Steel

Materials Data, SA-240 Type XM-19 (22Cr-13Ni-5Mn)

Temp. (°F)	E (ksi)	S_m (ksi)	S_y (ksi)	S_u (ksi)	α_{AVG} (x 10^{-6}°F^{-1})
-100	29,100	--	--	--	--
-20	--	33.3	55.0	100.0	--
70	28,300	--	--	--	8.2
100	--	33.3	55.0	100.0	8.2
200	27,600	33.2	47.1	99.4	8.5
300	27,000	31.4	43.3	94.2	8.8
400	26,500	30.2	40.7	91.1	8.9
500	25,800	29.7	38.8	89.1	9.1
600	25,300	29.2	37.4	87.7	9.2
650	--	29.0	36.8	87.0	9.2
700	24,800	28.8	36.3	86.4	9.3
750	--	28.5	35.8	85.6	9.3
800	24,100	28.2	35.3	84.8	9.4
Reference	Table TM-1	Table 2A	Table Y-1	Table U	22Cr-13Ni-5Mn
Section II-D	Group G				TE-1, Group 4

Table M.3.3-4
ASME Code Properties for 6061 Aluminum

ASME Code Properties for 6061 Aluminum (Plate)

Temperature	Yield Strength (ksi)		E	α
(°F)	A96061-T451	A96061-T651	(ksi)	(x 10^{-6} °F^{-1})
75	16.0	35.0	10,000	12.1
100	16.0	35.0	--	12.4
150	15.7	34.6	--	12.7
200	15.5	33.7	9,600	13.0
250	15.3	32.4	--	13.1
300	15.3	27.4	9,200	13.3
350	15.3	20.0	--	13.4
400	11.6	13.3	8,700	13.6
450	--	--	--	13.8
500	--	--	8,100	13.9
550	--	--	--	14.1
600	--	--	--	14.2
Reference	Table Y-1 .250" - 3.00"	Table Y-1 .250" - 6.00"	Table TM-2 A96061	Table TE-2

Table M.3.3-5
Analysis Properties for Aluminum Transition Rails

6061-O Aluminum (Annealed)

Temperature (°F)	S_u, 6061-O (ksi)	S_y, 6061-O (ksi)	E (ksi)
75	18.0	8.0	9,900
212	18.0	8.0	9,500
300	15.0	8.0	9,100
350	12.0	8.0	8,900
400	10.0	7.5	8,600
450	8.5	6.0	8,300
500	7.0	5.5	7,900
600	5.0	4.2	6,800
700	3.6	3.0	5,500
800	2.8	2.2	--
900	2.2	1.6	--
1000	1.6	1.2	--

Note: Data from "Properties of Aluminum Alloys", ASM International/The Aluminum Association, 1999

Table M.3.3-6
Additional Material Properties

Material Property	Value	Reference
Aluminum Density (1100 and 6061)	0.098 lb/in^3	Section II, Part D, Table NF-2
Aluminum Melting Point (Alloy 1100)	1190°F - 1215°F	Section II, Part D, Table NF-2
Aluminum Melting Point (Alloy 6061)	1080°F - 1205°F	Section II, Part D, Table NF-2
Neutron Absorber Density	0.098 lb/in^3	Taken as equal to the density of pure aluminum
Steel Density	$\frac{493\ lb}{1728\ in^3} = .285\ lb/in^3$	

M.3.4 General Standards for Casks

M.3.4.1 Chemical and Galvanic Reactions

The materials of the 32PT DSC and basket have been reviewed to determine whether chemical, galvanic or other reactions among the materials, contents and environment might occur during any phase of loading, unloading, handling or storage. This review is summarized below:

The 32PT DSC is exposed to the following environments:

- During loading and unloading, the DSC is placed inside of the OS197 or OS197H TC. The annulus between the cask and DSC is filled with demineralized water and an inflatable seal is used to cover the annulus between the DSC and cask. The exterior of the DSC will not be exposed to pool water.

- The space between the top of the DSC and inside of the TC is sealed to prevent contamination. For PWR plants the pool water is borated. This affects the interior surfaces of the DSC, the shield plug, and the basket. The TC and DSC are kept in the spent fuel pool for a short period of time, typically about 6 hours to load or unload fuel, and 2 hours to lift the loaded TC/DSC out of the spent fuel pool.

- During storage, the interior of the DSC is exposed to an inert helium environment. The helium environment does not support the occurrence of chemical or galvanic reactions because both moisture and oxygen must be present for a reaction to occur. The DSC is thoroughly dried before storage by a vacuum drying process. It is then backfilled with helium, thus stopping corrosion. Since the DSC is vacuum dried, galvanic corrosion is also precluded as no water is present at the point of contact between dissimilar metals.

- During storage, the exterior of the DSC is protected by the concrete NUHOMS® HSM. The HSM is vented, so the exterior of the DSC is exposed to the atmosphere. The DSC shell and cover plates are fabricated from austenitic stainless steel and are resistant to corrosion.

The NUHOMS®-32PT DSC materials are shown in the Parts List on Drawings NUH-32PT-1001 through NUH-32PT-1006 provided in Section M.1.5. The DSC shell material is SA-240 Type 304 Stainless Steel. The top and bottom shield plug material is A36 carbon steel. The top shield plug is coated with a corrosion resistant electroless nickel coating.

The basket grid structure is composed of either plate or tube assemblies made from XM-19 stainless steel. Within the grid structure are plates of Type 1100 aluminum and neutron absorbing materials composed of either enriched borated aluminum alloy or Boralyn® plates. These plates are attached to the grid structure using corrosion resistant fasteners. Poison Rod Assemblies (PRAs) are also used with some fuel assembly loading options.

The transition rails provide the transition between the fuel compartment grid structure and the DSC shell. The transition rails are made of alloy Type 6061 aluminum. The transition rails are bolted to the grid structure.

Potential sources of chemical or galvanic reactions are the interaction between the aluminum, aluminum-based neutron poison and stainless steel within the basket and the pool water. Additionally, an interaction exists with the stainless steel top and bottom plates and the top shield plug.

Typical water chemistry in a PWR Spent Fuel pool is as follows:

pH (77°F)	4.5 - 9.0
Chloride, max	0.15 ppm
Fluoride, max	0.1 ppm
Dissolved Air, max	Saturated
Lithium, max	2.5 ppm
Boric Acid	2100 - 2600 ppm
Pool Temperature Range	40 - 120°F

A. Behavior of Aluminum in Borated Water

Aluminum is used for many applications in spent fuel pools. In order to understand the corrosion resistance of aluminum within the normal operating conditions of spent fuel storage pools, a discussion of each of the types of corrosion is addressed separately. None of these corrosion mechanisms is expected to occur in the short time period that the cask is submerged in the spent fuel pool.

General Corrosion

General corrosion is a uniform attack of the metal over the entire surfaces exposed to the corrosive media. The severity of general corrosion of aluminum depends upon the chemical nature and temperature of the electrolyte and can range from superficial etching and staining to dissolution of the metal. Figure M.3.4-1 shows a potential-pH diagram for aluminum in high purity water at 77°F and 140°F. The potential for aluminum coupled with stainless steel and the limits of pH for PWR pools are shown in the diagram to be well within the passivation domain at both temperatures. The passivated surface of aluminum (hydrated oxide of aluminum) affords protection against corrosion in the domain shown because the coating is insoluble, non-porous and adherent to the surface of the aluminum. The protective surface formed on the aluminum is known to be stable up to 275°F and in a pH range of 4.5 to 8.5.

The water aluminum reactions are self limiting because the surface of the aluminum becomes passive by the formation of a protective and impervious coating making further reaction impossible until the coating is removed by mechanical or chemical means.

The ability of aluminum to resist corrosion from boron ions is evident from the wide usage of aluminum in the handling of borax and in the manufacture of boric acid. Aluminum storage racks with Boral plates (aluminum 1100 exterior layer) in contact with 800 ppm borated water showed only small amounts of pitting after 17 years in the pool at the Yankee Rowe Power Plant. These racks maintained their structural integrity.

During immersion in the spent fuel pool, the 32PT-DSC basket temperatures are close to the water temperature, which is typically near 80°F, and the pH range is typically 4.0 to 6.5. Based on the above discussion, general corrosion is not expected on the aluminum after the protective coating has been formed.

Galvanic Corrosion

Galvanic corrosion is a type of corrosion which could cause degradation of dissimilar metals exposed to a corrosive environment for a long period of time.

Galvanic corrosion is associated with the current of a galvanic cell consisting of two dissimilar conductors in an electrolyte. The two dissimilar conductors of interest in this discussion are aluminum and stainless steel in borated water. There is little galvanic corrosion in borated water since the water conductivity is very low. There is also less galvanic current flow between the aluminum-stainless steel couple than the potential difference on stainless steel which is known as polarization. It is because of this polarization characteristic that stainless steel is compatible with aluminum in all but severe marine, or high chloride, environmental conditions [3.4].

Pitting Corrosion

Pitting corrosion is the forming of small sharp cavities in a metal surface. The first step in the development of corrosion pits is a local destruction of the protective oxide film. Pitting will not occur on commercially pure aluminum when the water is kept sufficiently pure, even when the aluminum is in electrical contact with stainless steel. Pitting and other forms of localized corrosion occur under conditions like those that cause stress corrosion, and are subject to an induction time which is similarly affected by temperature and the concentration of oxygen and chlorides. As with stress corrosion, at the low temperatures and low chloride concentrations of a spent fuel pool, the induction time for initiation of localized corrosion will be greater than the time that the DSC internal components are exposed to the aqueous environment.

Crevice Corrosion

Crevice corrosion is the corrosion of a metal that is caused by the concentration of dissolved salts, metal ions, oxygen or other gases in crevices or pockets remote from the principal fluid stream, with a resultant build-up of differential galvanic cells that ultimately cause pitting. Crevice corrosion could occur in the basket grid assembly plates around the stainless steel welds. However, due to the short time in the spent fuel pool, this type of corrosion is expected to be insignificant.

Intergranular Corrosion

Intergranular corrosion is corrosion occurring preferentially at grain boundaries or closely adjacent regions without appreciable attack of the grains or crystals of the metal itself. Intergranular corrosion does not occur with commercially pure aluminum and other common work hardened aluminum alloys.

Stress Corrosion

Stress corrosion is failure of the metal by cracking under the combined action of corrosion and stresses approaching the yield stress of the metal. During spent fuel pool operations, the 32PT-DSC is upright and there is negligible load on the basket assembly. The stresses on the basket are small, well below the yield stress of the basket materials.

B. Behavior of Austenitic Stainless Steel in Borated Water

The fuel compartments are made from XM-19 stainless steel and the transition rails that support the fuel compartments are made from solid aluminum. Stainless steel does not exhibit general corrosion when immersed in borated water. Galvanic attack can occur between the aluminum in contact with the stainless steel in the water. However, the attack is mitigated by the passivity of the aluminum and the stainless steel in the short time the pool water is in the DSC. Also the low conductivity of the pool water tends to minimize galvanic reactions.

Stress corrosion cracking in the Type XM-19 stainless steel welds of the basket is also not expected to occur, since the baskets are not highly stressed during normal operations. There may be some residual fabrication stresses as a result of welding of the stainless steel plates together.

Of the corrosive agents that could initiate stress corrosion cracking in the stainless steel basket welds, only the combination of chloride ions with dissolved oxygen occurs in spent fuel pool water. Although stress corrosion cracking can take place at very low chloride concentrations and at low temperatures such as those in spent fuel pools (less than 10 ppb and 160°F, respectively), the effect of low chloride concentration and low temperature greatly increases the induction time. That is, the time period during which the corrodent is breaking down the passive oxide film on the stainless steel surface is increased. Below 60°C (140°F), stress corrosion cracking of austenitic stainless steel does not occur at all. At 100°C (212 °F), chloride concentration on the order of 15% is required to initiate stress corrosion cracking [3.5]. At 288 °C (550 °F), with tensile stress at 100% of yield in PWR water that contains 100 ppm O_2, time to crack is about 40 days in sensitized 304 stainless steel [3.6]. Thus, the combination of low chlorides, low temperature and short time of exposure to the corrosive environment eliminates the possibility of stress corrosion cracking in the basket and DSC welds.

C. Behavior of Aluminum Based Neutron Poison in Borated Water

To investigate the use of borated aluminum in a spent fuel pool, tests were performed by Eagle Picher to evaluate its dimensional stability, corrosion resistance and neutron capture ability. These studies showed that borated aluminum performed well in a spent fuel pool environment.

The 1100 series aluminum component is a ductile metal having a high resistance to corrosion. Its corrosion resistance is provided by the buildup of a protective oxide film on the metal surface when exposed to a water or moisture environment. As stated above, for aluminum, once a stable film develops, the corrosion process is arrested at the surface of the metal. The film remains stable over a pH range of 4.5 to 8.5.

Tests were performed by Eagle Picher which concluded that borated aluminum exhibits a strong corrosion resistance at room temperature in either reactor grade deionized water or in 2000 ppm

borated water. The behavior is only slightly different than 1100 series aluminum, hence, satisfactory long-term usage in these environments is expected. Neutron irradiation up to 10^{17} n/cm^2 level did not cause any measurable dimensional changes or any other damage to the material.

At high temperature, the borated aluminum still exhibits high corrosion resistance in the pure water environment. However, at temperatures of 80°C, in 2000 ppm borated water, local pitting corrosion has been observed. At 100°C and room temperature, the pitting attack was less than at 80°C. In all cases, passivation occurs limiting the pit depth.

From tests on pure aluminum, it was found that borated aluminum was more resistant to uniform corrosion attack than pure aluminum. Local pitting corrosion, can occur over time, causing localized damage to the borated aluminum.

There are no chemical, galvanic or other reactions that could reduce the areal density of boron in the 32PT-DSC neutron poison plates.

D. Electroless Nickel Plated Carbon Steel

The carbon steel top shield plug of the DSC is plated with electroless nickel. This coating is identical to the coating used on the NUHOMS®-52B DSC. It has been evaluated for potential galvanic reactions in Transnuclear West's response to NRC Bulletin 96-04 [3.7]. In PWR pools, the reported corrosion rates are insignificant and are expected to result in a negligible rate of reaction for the NUHOMS® PWR systems.

Lubricants and Cleaning Agents

Lubricants and cleaning agents used on the NUHOMS®-32PT DSC should be selected for compatibility with the spent fuel pool water chemistry and the DSC materials. Never-seez or Neolube (or equivalent) is used to coat the threads and bolt shoulders of the closure bolts. The lubricant should be selected for its ability to maintain lubricity under long term storage conditions.

The DSC is cleaned in accordance with approved procedures to remove cleaning residues prior to shipment to the storage site. The basket is also cleaned prior to installation in the DSC. The cleaning agents and lubricants have no significant affect on the DSC materials and their safety related functions.

Hydrogen Generation

During the initial passivation state, small amounts of hydrogen gas may be generated in the 32PT DSC. The passivation stage may occur prior to submersion of the TC into the spent fuel pool. Any amounts of hydrogen generated in the DSC will be insignificant and will not result in a flammable gas mixture within the DSC.

The small amount of hydrogen which may be generated during DSC operations does not result in a safety hazard. In order for concentrations of hydrogen in the cask to reach flammability

levels, most of the DSC would have to be filled with water for the hydrogen generation to occur, and the lid would have to be in place with both the vent and drain ports closed. This does not occur during DSC loading or unloading operations.

An estimate of the maximum hydrogen concentration can be made, ignoring the effects of radiolysis, recombination, and solution of hydrogen in water. Testing was conducted by Transnuclear [3.9] to determine the rate of hydrogen generation for aluminum metal matrix composite in intermittent contact with 304 stainless steel. The samples represent the neutron poison plates paired with the basket compartment tubes. The test specimens were submerged in deionized water for 12 hours at 70 °F to represent the period of initial submersion and fuel loading, followed by 12 hours at 150 °F to represent the period after the fuel is loaded, until the water is drained. The hydrogen generated during each period was removed from the water and the test vessel and measured. Since the test was performed in deionized water, and the 32PT DSC will be used in borated water, the test results over-predict the hydrogen generation rates.

The test results were:

	12 hours @ 70°F		12 hours @ 150°F	
Aluminum MMC/SS304	$cm^3hr^{-1}dm^{-2}$	$ft^3hr^{-1}ft^{-2}$	$cm^3hr^{-1}dm^{-2}$	$ft^3hr^{-1}ft^{-2}$
	0.517	1.696E-4	0.489	1.604E-4

During the welding cycle, the most limiting case for hydrogen concentration is the 32PT-L100 DSC because it has the most aluminum surfaces. The total surface area of all aluminum components including the neutron absorber plates is 3495 ft^2. After 750 gallons of water has been drained, 1868 ft^2 of aluminum remains submerged. This surface area, combined with the test data at 150°F above result in a hydrogen generation rate of

$$(1.60\text{x}10^{-4}\ ft^3/ft^2hr)(1868\ ft^2) \quad = 0.30\ ft^3/hr$$

The minimum free volume of the DSC is 99.6 ft^3, which is equivalent to the 750 gallons of water drained from the DSC cavity. The following assumptions are made to arrive at a conservative estimate of hydrogen concentration:

- All generated hydrogen is released instantly to the plenum between the water and the shield plug, that is, no dissolved hydrogen is pumped out with the water, and no released hydrogen escapes through the open vent port, and
- The welding and backfilling process takes 8 hours to complete.

Under these assumptions, the hydrogen concentration in the space between the water and the shield plug is a function of the time water is in the DSC prior to backfilling with helium. The hydrogen concentration is (0.30 ft^3 H_2/hr)*(8 hr) / (99.6 ft^3) = 2.39%. Monitoring of the hydrogen concentration before and during welding operations is performed to ensure that the hydrogen concentration does not exceed 2.4%, which is well below the ignitable limit of 4%. If the hydrogen concentration exceeds 2.4%, welding operations are suspended and the DSC is purged with an inert gas. In an inert atmosphere, hydrogen will not be generated.

Effect of Galvanic Reactions on the Performance of the System

There are no significant reactions that could reduce the overall integrity of the DSC or its contents during storage. The DSC and fuel cladding thermal properties are provided in Section M.4. The emissivity of the fuel compartment is 0.46, which is typical for non-polished stainless steel surfaces. If the stainless steel is oxidized, this value would increase, improving heat transfer. The fuel rod emissivity value used is 0.80, which is a typical value for oxidized Zircaloy. Therefore, the passivation reactions would not reduce the thermal properties of the component cask materials or the fuel cladding.

There are no reactions that would cause binding of the mechanical surfaces or the fuel to basket compartment boxes due to galvanic or chemical reactions.

There is no significant degradation of any safety components caused directly by the effects of the reactions or by the effects of the reactions combined with the effects of long term exposure of the materials to neutron or gamma radiation, high temperatures, or other possible conditions.

M.3.4.2 Positive Closure

Positive closure is provided by the OS197 and OS197H TCs. No change.

M.3.4.3 Lifting Devices

The evaluations for the OS197 and OS197H TC trunnions are based on critical lift weights (with water in the DSC) of 208,500 lbs and 250,000 lbs, respectively. The maximum critical lift weight with a NUHOMS®-32PT DSC is approximately 224,000 lbs. Therefore, the OS197H cask is acceptable with any NUHOMS®-32PT DSC and the OS197 cask is acceptable with a NUHOMS®-32PT DSC where the total critical lift weight is not more than 208,500 lbs (with water drained from the DSC cavity, if needed, to meet the weight limit).

M.3.4.4 Heat and Cold

M.3.4.4.1 Summary of Pressures and Temperatures

Temperatures and pressures for the 32PT DSC and basket are calculated in Section M.4. Section M.4.4 provides the thermal evaluation of normal conditions. Section M.4.5 provides the thermal evaluation for off-normal conditions. Section M.4.6 provides the thermal evaluation of accident conditions. Section M.4.7 provides the thermal evaluation during vacuum drying operations. Section M.4 provides the calculated temperatures for the various components during storage, transfer and vacuum drying operations respectively.

Section M.4.4.4 also provides the maximum pressures during normal, off-normal and accident conditions which are used in the evaluations presented later in this Appendix.

M.3.4.4.2 Differential Thermal Expansion

To minimize thermal stress, clearance is provided between the poison plates and inside of the fuel cells, between the basket outer diameter and DSC cavity inside diameter, and in the axial

direction between the DSC cavity and all basket parts. Additionally, the connections between the transition rails and the fuel support grid and between the aluminum heat transfer plate material and the fuel support grid are made to permit relative axial growth.

- In the axial direction, required clearances are determined using hand calculations.
- In the "radial" direction, clearance between the fuel cells and the neutron absorbing and heat transfer plate materials, is evaluated using hand calculations.
- In the "radial" direction, clearance between the basket assembly (fuel support grid and transition rails) was included in the ANSYS thermal stress analyses described in Section M.3.4.4.3. The normal condition stress analyses are described in M.3.6 and the accident condition analyses are described in M.3.7. Thus, stresses due to any thermal interferences are included in the stress results.

As noted above, hand calculations are used to evaluate thermal expansion in the axial direction and between the fuel cells and the poison/heat transfer material. Sample calculations and results for the hand calculations are described below. Results from the ANSYS thermal stress evaluations are described in Section M.3.4.4.3.

Basket assembly temperatures for normal conditions are listed in Tables M.4-3 to M.4-5; off-normal temperatures are listed in Tables M.4-9 through M.4-11.

The thermal analyses of the basket for the handling/transfer conditions are described in Section M.4. As described there, thermal analyses are performed to determine the temperature distributions in the 32PT DSC for the following cases:

- Vacuum Drying
- Blocked Vent Storage
- On-Site Transfer at -40°F ambient
- On-Site Transfer at 0°F ambient
- On-Site Transfer at 100°F ambient
- On-Site Transfer at 117°F ambient
- HSM Storage at -40°F ambient
- HSM Storage at 0°F ambient
- HSM Storage at 70°F ambient
- HSM Storage at 100°F ambient
- HSM Storage at 117°F ambient

Based on the temperature distributions for the cases listed above, hand calculations are used to evaluate the effects of differential thermal expansion for the vacuum drying and -40°F storage cases. These cases are selected since they maximize the temperature differentials, and differential expansion, in the DSC and basket assembly.

The following calculations show the evaluation of relative radial growth between the fuel support grid and the heat transfer/neutron absorbing material. For these parts, the relative growth is evaluated between parts that are immediately adjacent to each other (i.e., between the

heat transfer/neutron absorbing material at the center of the basket and the XM-19 at the center of the basket), Thus the temperatures of the two materials are equal.

Radial Expansion

In the radial direction, the thermal expansion values for the fuel support grid and the heat transfer materials are evaluated at the maximum allowable material temperature of 800°F. This maximizes the relative expansion between the parts:

$$\begin{aligned}\Delta L_{GRID} &= \alpha_{XM19} L_{GRID} \Delta T \\ &= \left(9.40 \times 10^{-6}\,°F^{-1}\right)\left(8.825\text{ in}\right)\left(800°F - 70°F\right) \\ &= .061\text{ in} \\ \Delta L_{AL_N} &= \alpha_{1100} L_{GRID} \Delta T \\ &= \left(14.8 \times 10^{-6}\,°F^{-1}\right)\left(8.56\text{ in}\right)\left(800°F - 70°F\right) \\ &= .092\text{ in}\end{aligned}$$

Comparing the relative expansion of the heat transfer/neutron absorbing material and the Type XM-19 fuel grid to the design clearance:

$$\begin{aligned}\text{Design Clearance} &= \left(8.825\text{ in}\right) - \left(8.56\text{ in}\right) \\ &= 0.265\text{ in} \\ \text{Relative Growth} &= \Delta L_{AL_N} - \Delta L_{GRID} \\ &= .092\text{ in} - .061\text{ in} \\ &= .031\text{ in}\end{aligned}$$

The clearance is much larger than the differential growth. Thus there is no stress due to differential "radial" expansion between the heat transfer/neutron absorbing material(s) and the Type XM-19 fuel grid.

Axial Expansion

For the vacuum drying condition, axial thermal expansion of the basket components is calculated below using thermal results documented in Chapter M.4.

Component	T_{max} (°F)	T_{min} (°F)	α_{avg} (°F)	L	ΔL
Fuel Grid (XM-19)	656	—	9.2×10^{-6}	174.7 in	0.942 in
"	—	314	8.8×10^{-6}	174.7 in	0.375 in
"	Average Expansion:				0.658 in
Heat Transfer Material / Neutron Absorber	656	—	14.4×10^{-6}	174.7 in	1.474 in
16061 (Al.) T. Rails	352	—	13.4×10^{-6}	174.7 in	0.660 in
"	—	306	13.3×10^{-6}	174.7 in	0.548 in
DSC Cavity	—	215	8.9×10^{-6}	174.7 in	0.225 in

Relative expansion is determined by comparing values calculated above. For example, the "worst case" required clearances between the end of the DSC cavity and the structural parts of the basket assembly can be determined by comparing the cavity expansion to the expansion of the basket assembly calculated using the maximum component temperatures:

Relative Axial Thermal Growth (Vacuum Drying)	Component Growth	Cavity Growth	Required Clearance(1)
Fuel Grid to Cavity	0.942 in	0.225 in	0.72 in
6061 Transition Rails to Cavity	0.660 in	0.225 in	0.44 in

Notes: 1. Required Clearance is the room temperature clearance between the top of the listed component and the bottom of the top shield plug and is determined by subtracting the cavity expansion from the component expansion.

The differential axial growth between the Aluminum Alloy 1100 heat transfer material (and neutron absorbing material) and the fuel support grid is determined using similar methods. An average value of axial expansion is used since the overall growth of the fuel support grid will be related to the average grid temperature. A maximum value of aluminum expansion is used.

Relative Axial Thermal Growth (Vacuum Drying)	Fuel Support Grid Axial Growth	1100 Alloy Growth	Required Clearance(1)
Fuel Grid to Aluminum Heat Transfer Material (Alloy 1100)	$\Delta L = \frac{0.94\text{ in} + 0.38\text{ in}}{2} = 0.66\text{ in}$	1.47 in	0.81 in

Notes: 1. Required Clearance is the room temperature clearance between the neutron absorbing sheets and Alloy 1100 aluminum heat transfer material and the stop plates attached to the fuel grid.

M.3.4.4.3 Thermal Stress Calculations

The thermal stress calculations for the various system components other than the basket are provided in Sections 3.6 and 3.7 for normal, off-normal and accident conditions. The thermal stress calculations for the 32PT basket are presented below.

Thermal stresses are considered separately and in combination with other loads on the basket assembly. Only the separate thermal stresses are presented here. Thermal stresses in combination with other loads are addressed in the appropriate sections.

As noted in M.3.4.4.2, clearances are provided such that there is free thermal expansion in the axial direction.

Thermal stresses in the basket assembly are evaluated using the ANSYS [3.11] finite element model described in M.3.6.1.3. As described in M.3.6.1.3.1, the ANSYS model includes the fuel support grid, R90 transition rails, R45 transition rails, the DSC shell, and the cask ID and cask rails. For the evaluation of thermal stresses only (i.e., thermal stresses without deadweight or other loads), the cask ID and cask rails are removed from the solution by eliminating the contact elements between the shell OD and the cask ID with cask rails. For the evaluation of thermal loads combined with other loads (e.g., thermal plus deadweight), all contact elements are active and the effects of the cask and cask rails are included.

As listed below, a total of 30 thermal stress analyses were performed.

Condition / Ambient Temperature		Heat Load Zoning Configurations (see Figures M.1-1, M.1-2 and M.1-3)		
		1	2	3
Vacuum Drying		X	X	
Blocked Vent Storage		X		
On-Site Transfer	-40°F ambient	X	X	X
	0°F ambient	X	X	X
	100°F ambient	X	X	X
	117°F ambient	X	X	X
HSM Storage	-40°F ambient	X	X	X
	0°F ambient	X	X	X
	70°F ambient	X	X	X
	100°F ambient	X	X	X
	117°F ambient	X	X	X

Maximum thermal stresses (ANSYS nodal stress intensities) are summarized in Table M.3.4-2. These results apply directly to the single-piece solid R90 rail configuration and are conservative for the multi-piece R90 option (since decreasing stiffness reduces thermal stresses). As shown by the table, thermal stresses in the 32PT basket are low. Based on these results, the temperature distribution corresponding to 117°F ambient temperature, DSC in the TC, with heat load zoning configuration 1 was selected for combination with other loads.

Selection of a high temperature case ensures the application of lower allowable stresses (since allowable stresses decrease with temperature), and reduced structural stiffness (since stability is directly related to E and S_y).

Results of the thermal stress analysis are shown in Figure M.3.4-4 and Figure M.3.4-5. These figures show the applied temperature distribution and resulting thermal stresses for cold (-40°F in cask) and hot (117°F in cask) conditions.

Table M.3.4-1
Summary of Thermal Stress Results - 32PT Basket with Steel Transition Rails

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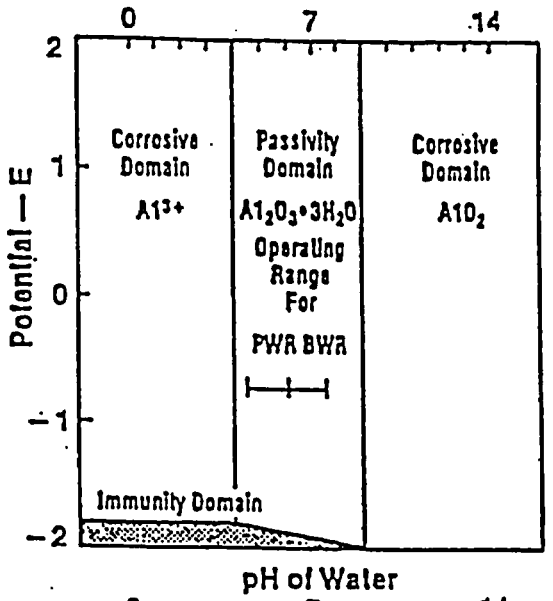
Table M.3.4-2
Summary of Thermal Stress Results - 32PT Basket with Aluminum Transition Rails

Operating Condition	Maximum Stress Intensities (ksi)			
	Fuel Grid	R90 Transition Rail (XM-19 Cover Plate)	R90 Transition Rail (Aluminum)	R45 Transition Rail (Aluminum)
Vacuum Drying	4.33	2.55	.55	1.40
Blocked Vent Storage	4.25	2.75	.60	1.40
On-Site Transfer & Storage[1]	4.95	2.50	.60	1.50

Note: 1. Includes all cases except for vacuum drying and blocked vent storage.

POTENTIAL VERSUS pH DIAGRAM FOR ALUMINUM-WATER SYSTEM

At 25°C (77°F):



At 60°C (140°F):

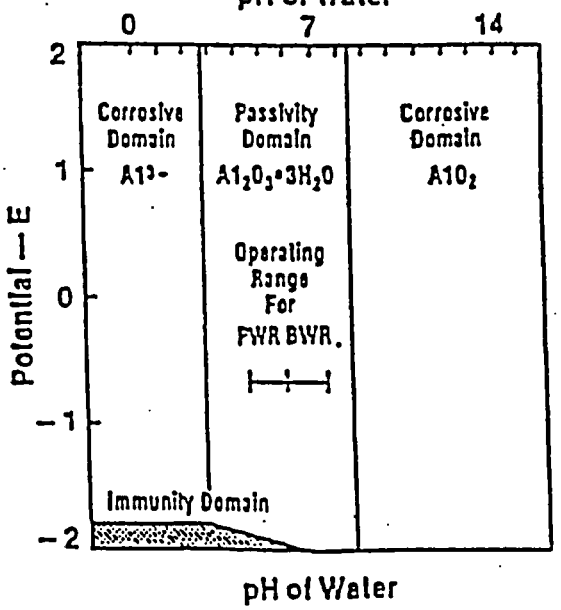


Figure M.3.4-1
Potential Versus pH Diagram for Aluminum-Water System

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Figure M.3.4-2
32PT Basket with Steel Transition Rails,
Temperatures and Stress Intensities, -40°F in Cask

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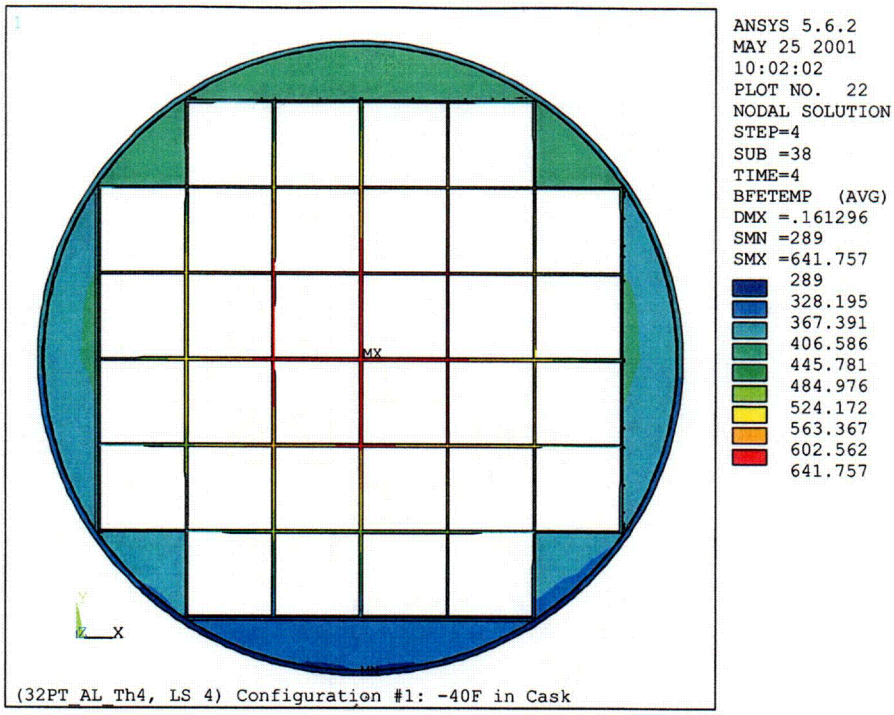
Figure M.3.4-3
32PT Basket with Steel Transition Rails,
Temperatures and Stress Intensities, 117°F in Cask



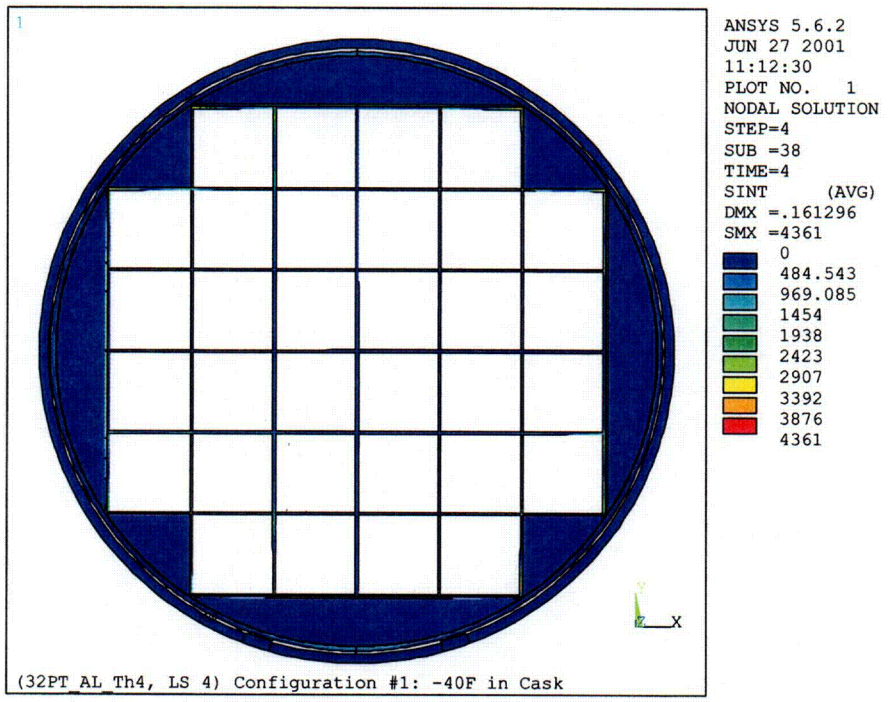
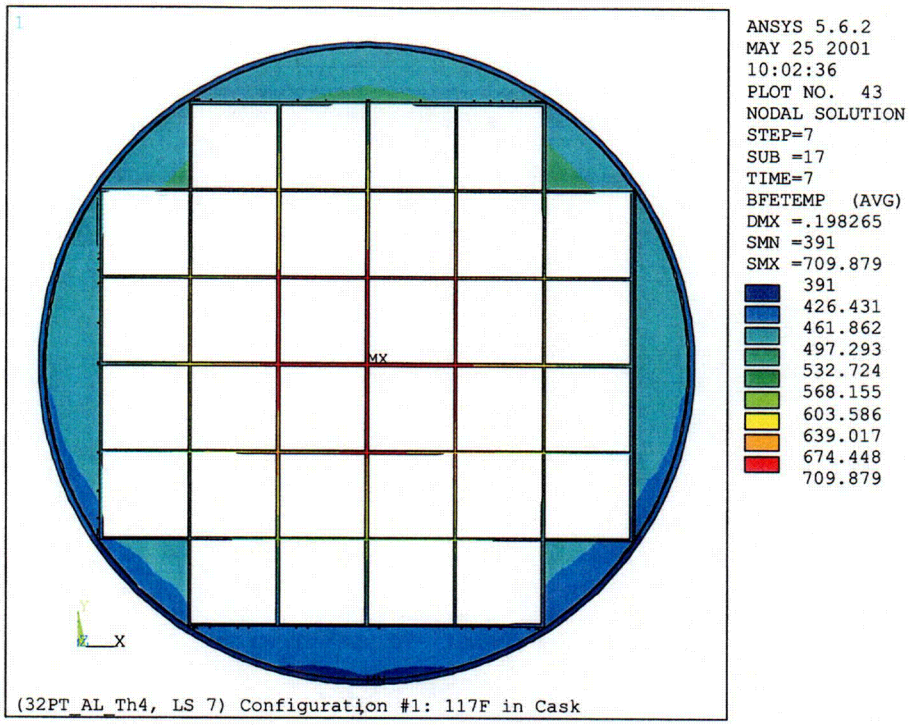


Figure M.3.4-4
32PT Basket with Aluminum Transition Rails,
Temperatures and Stress Intensities, -40°F in Cask



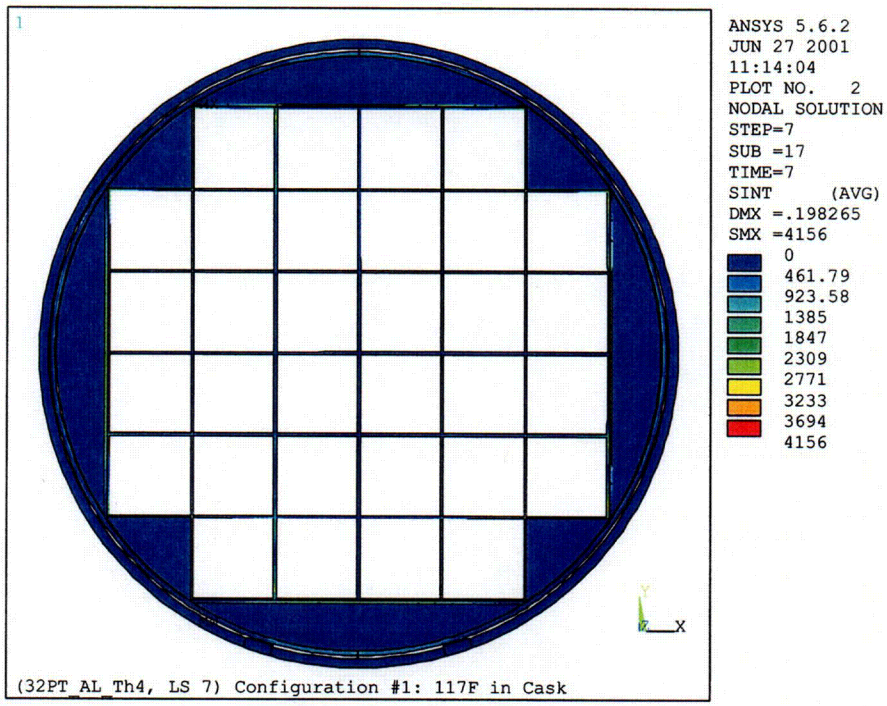


Figure M.3.4-5
32PT Basket with Aluminum Transition Rails,
Temperatures and Stress Intensities, 117°F in Cask

M.3.5 Fuel Rods

No change to the evaluation presented in the FSAR.

M.3.6 Structural Analysis (Normal and Off-Normal Operations)

In accordance with NRC Regulatory Guide 3.48 [3.12], the design events identified by ANSI/ANS 57.9-1984, [3.14] form the basis for the accident analyses performed for the standardized NUHOMS® System. Four categories of design events are defined. Design event Types I and II cover normal and off-normal events and are addressed in Section 8.1. Design event Types III and IV cover a range of postulated accident events and are addressed in Section 8.2. The purpose of this section of the Appendix is to present the structural analyses for normal and off-normal operating conditions for the NUHOMS®-32PT system using a format similar to the one used in Section 8.1 for analyzing the NUHOMS®-24P systems.

M.3.6.1 Normal Operation Structural Analysis

Table M.3.6-1 shows the normal operating loads for which the NUHOMS® safety-related components are designed. The table also lists the individual NUHOMS® components which are affected by each loading. The magnitude and characteristics of each load are described in Section M.3.6.1.1.

The method of analysis and the analytical results for each load are described in Sections M.3.6.1.2 through M.3.6.1.9.

M.3.6.1.1 Normal Operating Loads

The normal operating loads for the NUHOMS® System components are:

- Dead Weight Loads
- Design Basis Internal and External Pressure Loads
- Design Basis Thermal Loads
- Operational Handling Loads
- Design Basis Live Loads

These loads are described in detail in the following paragraphs.

A. Dead Weight Loads

Table M.3.2-1 shows the weights of various components of the NUHOMS®-32PT system. The dead weight of the component materials is determined based on nominal component dimensions.

B. Design Basis Internal and External Pressure

The maximum internal pressures of the NUHOMS®-32PT DSC for the storage and transfer mode are presented in Section M.4.

C. Design Basis Thermal Loads

The normal condition temperature distributions for the 32PT-DSC are presented in Section M.4. Stress analysis for normal thermal loads for the DSC shell assembly are provided in Section M.3.6.1.2C and in Section M.3.4.4 for the basket assembly.

D. Operational Handling Loads

There are two categories of handling loads: (1) inertial loads associated with on-site handling and transporting the DSC between the fuel handling/loading area and the HSM, and (2) loads associated with loading the DSC into, and unloading the DSC from, the HSM. These handling loads are described in Section 8.1.1.1C.

Based on the surface finish and the contact angle of the DSC support rails inside the HSM (described in Chapter 4), a bounding coefficient of friction is conservatively assumed to be 0.25. Therefore, the nominal ram load required to slide the DSC under normal operating conditions is approximately 29,400 lbs., calculated as follows:

$$P = \frac{0.25W}{Cos\theta} = 0.29W \quad = 0.29\ (101{,}400\ \text{lbs.}) \approx 29{,}400\ \text{lbs.}$$

Where:

P = Push/Pull Load,

W = Loaded DSC Weight ≈ 101,400 lbs. (See Table M.3.2-1), and

θ = 30 degrees, Angle of the Canister Support Rail.

However, the DSC bottom cover plate and grapple ring assembly are designed to withstand a normal operating insertion force equal to 80,000 pounds and a normal operating extraction force equal to 60,000 pounds. To insure retrievability for a postulated jammed DSC condition, the ram is sized with a capacity for a load of 80,000 pounds, as described in Section 8.1.2. These loads bound the friction force postulated to be developed between the sliding surfaces of the DSC and TC during worst case off-normal conditions.

E. Design Basis Live Loads

As discussed in Section 3.2.4, a live load of 200 pounds per square foot is conservatively selected to envelope all postulated live loads acting on the HSM, including the effects of snow and ice. Live loads which may act on the TC are negligible, as discussed in Section 3.2.4.

M.3.6.1.2 Dry Shielded Canister Analysis

The standardized NUHOMS®-32PT DSC shell assembly is analyzed for the normal, off-normal and postulated accident load conditions using two basic ANSYS [3.11] finite element models: a top-end half-length model of the DSC shell assembly and a bottom-end half-length model of the

DSC shell assembly. Typical models of the top and bottom halves of the DSC shell assembly are shown in Figures 8.1-14a and 8.1-14b.

These models are used to evaluate stresses in the NUHOMS®-32PT DSC due to:

- Dead Weight
- Design Basis Normal Operating Internal and External Pressure Loads
- Normal Operating Thermal Loads
- Normal Operation Handling Loads

The methodology used to evaluate the effects of these normal loads is addressed in the following paragraphs. Table M.3.6-2 summarizes the resulting stresses for normal operating loads.

Dead load analyses of the DSC are performed for both vertical and horizontal positions of the DSC. In the vertical position, the DSC shell supports its own empty weight and the entire weight of the top end components. When inside the TC, the weight of the fuel and the bottom end components is transferred to the TC by bearing through the inner bottom cover plate, shield plug and outer bottom cover plate. When in the horizontal position, the DSC is in the TC or in the HSM. In this position, the DSC shell assembly end components and the internal basket assembly bear against the DSC shell. The DSC shell assembly is supported by two rails located at ± 18.5° when in the TC and at ± 30° when in the HSM. This is shown schematically in Figure 8.1-13.

A. DSC Dead Load Analysis

Dead load stresses are obtained from static analyses performed using the ANSYS finite element models described above. Both, the top-end half and bottom-end half models are analyzed for a 1g load, using the appropriate finite element model and boundary conditions, for horizontal and vertical configurations. For the horizontal dead load analyses, the DSC is conservatively assumed to be supported on one rail. In addition, the fuel-loaded portions of the basket assembly bear on the inner surface of the DSC shell. DSC shell stresses in the region of the basket assembly resulting from the bearing load and from local deformations at the cask rails are evaluated using the ANSYS model described in Section M.3.6.1.3. The DSC shell assembly components are evaluated for primary membrane and membrane plus bending stress and for primary plus secondary stress range. Enveloping maximum stress intensities are summarized in Table M.3.6-2 for the NUHOMS®-32PT DSC.

B. DSC Normal Operating Design Basis Pressure Analysis

The NUHOMS®-32PT DSC shell assembly analytical models shown in Figure 8.1-14a and Figure 8.1-14b are used for the normal operating design pressure analyses. The calculated maximum internal pressures for the NUHOMS®-32PT DSC are shown in Section M.4. The design internal pressure of 20 psig is used. The resulting maximum stress intensities are reported in Table M.3.6-2.

C. DSC Normal Operating Thermal Stress Analysis

The thermal analysis of the DSC for the various conditions, as presented in Section M.4.0, provide temperature distributions for the DSC shell, along with maximum and minimum DSC component temperatures. These temperature distributions are imposed onto the DSC shell assembly ANSYS stress analysis models shown in Figure 8.1-14a and Figure 8.1-14b for thermal stress evaluation. Corresponding component temperatures are used to determine material properties and allowable stress values used in the stress analyses. DSC shell assembly materials are all Type 304 stainless steel with the exception of the shield plugs, which are made of A36 carbon steel. However, because these dissimilar materials are not mechanically fastened, allowing free differential thermal growth, the thermal stresses in the DSC shell components are due entirely to thermal gradients. The results of the thermal analysis show that for the range of normal operating ambient temperature conditions, the thermal gradients are primarily along the axial and tangential directions of the DSC and that no significant thermal gradients exist through the wall of the DSC. Stresses resulting from thermal gradients are classified as secondary stresses and are evaluated for Service Level A and B conditions. Maximum stress intensities resulting from the thermal stress analyses are summarized in Table M.3.6-2 for the NUHOMS®-32PT DSC.

D. DSC Operational Handling Load Analysis

To load the DSC into the HSM, the DSC is pushed out of the TC using a hydraulic ram. The applied force from the hydraulic ram, specified in Section M.3.6.1.1D, is applied to the center of the DSC outer bottom cover plate at the center of the grapple ring assembly. The ANSYS finite element model shown in Figure 8.1-14b is used to calculate the stresses in the DSC shell assembly. In the analysis, the ram load is applied to the cover plate in the form of two arcs, assuming that the load is concentrated at the barrel diameter of the ram, excluding the cutouts for extension of the grapple arms.

To unload the HSM, the DSC is pulled using grapples which fit into the grapple ring. For analysis of grapple pull loading, the 180° ANSYS finite element model of the bottom half DSC assembly is refined in the area of the grapple assembly and outer cover plate, as shown in Figure 8.1-15.

The controlling stresses from these analyses are tabulated in Table M.3.6-2.

E. Evaluation of the Results

The maximum calculated DSC shell stresses induced by normal operating load conditions are shown in Table M.3.6-2. The calculated stresses for each load case are combined in accordance with the load combinations presented in Table M.2-15. The resulting stresses for the controlling load combinations are reported in Section M.3.7.10 along with the ASME Code allowable stresses.

M.3.6.1.3 NUHOMS®-32PT Basket Structural Analysis

Stresses in the basket assembly are determined using a combination of hand calculations and a two dimensional (planar) ANSYS finite element model. The following loads are addressed:

- Dead Weight
- Thermal Stresses
- Handling/Transfer Loads
- Side Drops
- Seismic Loads

Thermal loads for the basket are addressed in Section M.3.4.4. The side drop loads are Level D loads and are addressed in Section M.3.7. The seismic loads are Level C loads, but are enveloped by the on-site handling loads as described in Section M.3.6.1.3.2.

M.3.6.1.3.1 ANSYS Finite Element Model Analysis

ANSYS is used for structural analysis of the 32PT basket for all normal and off-normal conditions.

A. ANSYS Finite Element Model Description

The ANSYS models of the 32PT basket assembly use Plane42 (2-D Structural Solid) elements to represent a unit length of the 32PT basket. A minimum of three (3) elements are used through the thickness of all parts except the cask shell and cask rails. The cask shell and cask rails, which are extremely rigid relative to the other parts of the structure, are included as "ground" and are fixed around their entire circumference. Therefore, the cask shell is modeled with only one through thickness element. Table M.3.6-3 lists the structural parts included in the model.

The geometry of the basket model is shown in Figures M.3.6-3, M.3.6-3A, M.3.6-4 and M.3.6-4A for the 32PT DSC with aluminum transition rails.

ANSYS contact elements, Contac48, 2-D Point-to-Surface Contact, are used between the separate parts of the structure. Since the components are modeled with actual thicknesses, the initial gap dimensions are determined by the geometry of the contacting surfaces. Contact elements are included between the following interfacing components:

- Fuel support grid to transition rails,
- Transition rails to DSC shell ID,
- DSC shell OD to cask ID and cask rail, and
- Between segments of the 3-piece R90 rails (as applicable).

Springs elements are provided between the fuel support grid and the transition rails. These springs, which act in parallel to the contact elements, are defined with non-linear stiffnesses such that low stiffness is active for motion of the rails away from the grid, allowing the transition rails to separate from the grid and a higher stiffness which is active for compression between the two structures.

Inertial loads are applied to the structure by including the appropriate weight density of the materials and applying accelerations. Fuel loads are applied using pressure loads on the fuel grid elements. Thermal effects are included by applying temperatures corresponding to the 117°F in cask temperature distribution, to each node in the model (see M.3.4.4.3).

For all stress analyses, 1g (deadweight) loads are applied and stresses determined. These deadweight stresses are classified as primary membrane and membrane plus bending stresses. Additional load steps are then used to apply temperatures corresponding to the 117°F ambient temperature condition. The thermal plus deadweight stresses are classified as primary plus secondary. Tables of the temperature-dependent material properties (e.g., S_y versus temperature) are included in the ANSYS model, such that the appropriate properties are applied at each point in the structure.

For each cell of the fuel support structure, stresses were linearized at the 12 locations shown in Figure M.3.6-5 using the ANSYS LPATH, and PRSECT commands. Maximum values are reported in this Appendix.

B. Material Properties

The material properties used in the ANSYS stress analyses for normal conditions are summarized in Table M.3.6-4. As listed in this table, linear elastic properties are used for the normal condition analyses. With the exception of the solid aluminum transition rails, properties for all materials are directly from the ASME Code. Properties for the aluminum rails are described in Section M.3.3.

M.3.6.1.3.2 Normal Condition Loading

Postulated loads on the 32PT basket structure for non-accident conditions are described in the following sections. The loads and load combinations for the 32PT basket structure are simplified by consideration that the basket is unaffected by either pressure loads or HSM insertion/retrieval loads.

A. Thermal

The analysis of the 32PT basket for thermal loads is described in Section M.3.4.4. As shown in Section M.3.4.4, thermal stresses are small.

B. Vertical Deadweight

Deadweight load conditions include: (1) vertical deadweight during fuel loading operations, (2) horizontal deadweight in the TC with support through the cask rails at ±18.5°, and (3) horizontal deadweight in the HSM with support through the HSM rails at ±30°.

Under axial loads, the fuel assemblies and fuel compartment are supported by the bottom of the cask. Thus, the fuel assemblies react directly against the bottom of the canister/cask and do not load the basket structure. Stresses under axial loading are from self weight of the basket structure. Maximum axial compressive stresses occur at the supported end of the basket.

Vertical deadweight was evaluated using hand calculations and by comparing the calculated axial compression stresses to stability allowables developed considering both stability criteria and the general membrane criteria (P_m) from Subsection NG (see M.2.2.5.1.2). Calculated stresses for the vertical deadweight condition also applied to the vacuum drying case.

Calculated stresses are listed in Table M.3.6-5 along with the appropriate compressive allowables. As shown by the table, stresses for this load condition are small.

C. Horizontal Deadweight

Horizontal deadweight cases were evaluated using the ANSYS model described in M.3.6.1.3.1. As appropriate the elements representing the support rails were located at either ±18.5° or ±30° from bottom center for support by the TC or HSM, respectively. Separate analyses were performed for the 32PT fuel grid supported by the solid 1-piece or 3-piece R90 transition rails. Thus, the following four (4) analysis cases were evaluated:

1. 32PT DSC with solid 1-piece R90 transition rails supported at ±18.5° (Figure M.3.6-10 and M.3.6-11)

2. 32PT DSC with solid 3-piece R90 transition rails supported at ±18.5° (Figure M.3.6-10A and M.3.6-11A)

3. 32PT DSC with solid 1-piece R90 transition rails supported at ±30° (Figure M.3.6-12 and M.3.6-13)

4. 32PT DSC with solid 3-piece R90 transition rails supported at ± 30° (Figure M.3.6-12A and M.3.6-13A)

Primary plus secondary stresses were evaluated by combining deadweight stresses with the thermal stresses resulting from the 117°F in cask temperature distribution. Maximum stresses are summarized in Table M.3.6-5 along with a comparison to Level A allowables from Subsection NG.

D. Vacuum Drying

As described above, the axial compression stresses under the vacuum drying condition are equal to the axial compression stresses under vertical deadweight.

As described in M.3.4.4.3, maximum stresses from the vacuum drying temperature distribution are listed in Tables M.3.4-1 and M.3.4-2. These thermal stresses are classified as secondary by the Code and, as shown by the tables, these stresses are small.

E. Handling/On-Site Transfer Loads

These cases include the loads associated with loading (and unloading) the 32PT DSC into an HSM and the inertial loads associated with on-site handling. The insertion/retrieval loads do not directly impact the 32PT basket assembly and do not require additional consideration. The inertia loads to be considered are:

- DW + 1g Axial
- DW + 1g Transverse.
- DW + 1g Vertical
- DW + 0.5g Axial + 0.5 Transverse + 0.5 Vertical

These loads are enveloped by a 2g resultant acceleration applied in the most critical orientation.

The 2.0g resultant axial load is evaluated using hand calculations and the same methodology used for the vertical deadweight analyses. Maximum compressive stresses resulting from this load case are listed in Table M.3.6-6 along with a comparison to the axial stability criteria described in M.2.2.5.1.2.

Loads transverse to the axis of the DSC are evaluated using the ANSYS models described in M.3.6.1.3.1. Loads are enveloped by selection of maximum stresses from the analysis load cases listed in Table M.3.6-7. Table M.3.6-7 lists the on-site handling analyses performed for the 32PT basket considering the basket transition rail configuration and DSC support conditions in the OS197, OS197H and HSM. Enveloping 32PT basket stresses are summarized in Table M.3.6-6 along with a comparison to Service Level A allowables.

F. Evaluation of Results

ANSYS plots showing typical analysis results for the 32PT basket are provided in Figure M.3.6-10, Figure M.3.6-11, Figure M.3.6-12 and Figure M.3.6-13 for baskets with solid aluminum 1-piece R90 aluminum transition rails and Figure M.3.6-10A, Figure M.3.6-11A, Figure M.3.6-12A and Figure M.3.6-13A for baskets with solid aluminum 3-piece R90 transition rails. These figures and summary tables in the previous sections show that the basket stress criteria is met.

Welds in the fuel support structure are sized to maintain full moment capacity of the plates across all welded connections.

Within the basket grid structure are plates of Type 1100 aluminum and neutron absorbing materials composed of either enriched borated aluminum alloy or Boralyn® plates which perform heat transfer and criticality functions. As shown in Section M.4, the maximum short term basket temperature is 791°F, which is well below the melting point of the aluminum plates (approximately 1200°F). As discussed in Section M.3.4, adequate clearance is provided for thermal expansion so that thermal stresses in the aluminum plates are negligible. The bounding normal or off-normal axial stress in the plates is 0.04 ksi, due to the 2g handling load, which is well below the yield stress value of 1.3 ksi (Type 1100 aluminum at 791°F). This ensures that the plates remain in position to perform their heat transfer and criticality functions. Under inertia loading in the transverse direction, the aluminum plates are supported along their length by either the grid structure or the fuel assemblies. Deflection of the aluminum plates in the transverse direction is limited by the gap between the grid structure and the fuel assembly and does not significantly affect the heat transfer function of the plates. The effect of this gap is bounded by the criticality evaluation.

M.3.6.1.4 DSC Support Structure Analysis

The DSC support structure is shown in Figures 4.2-6 and 4.2-7.

As presented in Section 8.1.1.4, the various components of the DSC support structure are subjected to normal operating loads including dead weight, thermal, and operational handling loads which are greater than or equal to the corresponding loads for the 32PT DSC. Therefore, the limiting DSC support structure components are acceptable.

M.3.6.1.5 HSM Design Analysis

The HSM loads evaluated in Section 8.1.1.5 bound the corresponding loads for the 32PT system. Therefore, there is no change to the structural evaluation of the HSM.

M.3.6.1.6 HSM Door Analyses

As discussed in Section M.3.6.1.5 there is no change to the structural evaluation of the HSM.

M.3.6.1.7 HSM Heat Shield Analysis

As discussed in Section M.3.6.1.5 there is no change to the structural evaluation of the HSM.

M.3.6.1.8 HSM Axial Retainer for DSC

As discussed in Section M.3.6.1.5 there is no change to the structural evaluation of the HSM.

M.3.6.1.9 On-Site TC Analysis

The on-site TC is evaluated for normal operating condition loads including:

- Dead Weight Load

- Thermal Loads
- Handling Loads
- Live Loads.

Section 8.1.1.9 provides the evaluation of the TCs for the normal operating loads. Thermal loads and live loads for the OS197 and OS197H TCs with the 32PT DSC are equivalent to or less than those evaluated in Section 8.1.1.9. The evaluations for the OS197 and OS197H casks are based on DSC maximum allowable wet payloads of 102,410 lbs. and 126,000 lbs., and maximum allowable DSC dry payload weights of 97,250 lbs. and 116,000 lbs., respectively. The maximum total cask payload with a dry-loaded NUHOMS®-32PT DSC is approximately 102,000 lbs., and wet loaded 32PT DSC is approximately 114,000 lbs. Therefore, the OS197H cask is acceptable with any NUHOMS®-32PT DSC and the OS197 cask is acceptable with a NUHOMS®-32PT DSC where the total cask wet payload is not more than 102,410 lbs. and the total cask dry payload is not more than 97,250 lbs. Water may be drained from the DSC cavity to meet the weight limit.

M.3.6.2 Off-Normal Load Structural Analysis

Table M.3.6-8 shows the off-normal operating loads for which the NUHOMS® safety-related components are designed. This section describes the design basis off-normal events for the NUHOMS® System and presents analyses which demonstrate the adequacy of the design safety features of a NUHOMS® System with the 32PT DSC.

For an operating NUHOMS® System, off-normal events could occur during fuel loading, cask handling, trailer towing, canister transfer and other operational events. Two off-normal events are defined which bound the range of off-normal conditions. The limiting off-normal events are defined as a jammed DSC during loading or unloading from the HSM and the extreme ambient temperatures of -40°F (winter) and +117°F (summer). These events envelope the range of expected off-normal structural loads and temperatures acting on the DSC, TC, and HSM. These off-normal events are described in Section 8.1.2.

M.3.6.2.1 Jammed DSC During Transfer

The interfacing dimensions of the top end of the TC and the HSM access opening sleeve are specified so that docking of the TC with the HSM is not possible should gross misalignments between the TC and HSM exist. Furthermore, beveled lead-ins are provided on the ends of the TC, DSC, and DSC support rails to minimize the possibility of a jammed DSC during transfer. Nevertheless, it is postulated that if the TC is not accurately aligned with respect to the HSM, the DSC binds or becomes jammed during transfer operations.

The interfacing dimensions and design features of the HSM access opening, DSC Support Structure and the OS197 and OS197H TCs, as described in Section 8.1.2, remain unchanged. The insertion and extraction forces applied on the NUHOMS®-32PT during loading and unloading operations are the same as those specified for the NUHOMS®-24P system. The discussion in Section 8.1.2B applies to the 32PT DSC. However, the NUHOMS®-32PT DSC

shell thickness is 0.5 inches (compared to 0.625 inches for the NUHOMS®-24P DSC shell) and the outside radius is 33.595 inches. Hence, the NUHOMS®-32PT DSC shell stresses, based on a force of 80 kips and a moment arm of 33.595 inches are calculated below.

Axial Sticking of the DSC

$$S_{mx} = \frac{M}{S}$$ (From Equation 8.1-9, Section 8.1.2.1)

Where:

M = 80 x 33.595 = 2690 in.-kip, Bending moment

S = 1734 in.^{3}, DSC section modulus

Therefore:

S_{mx} = 1.55 ksi

This magnitude of stress is negligible when compared to the allowable membrane stress of 17.5 ksi and is bounded by stresses for other handling loads as shown Table M.3.6-2.

There is no change to the structural evaluation of the HSM.

Binding of the DSC

As discussed in Section 8.1.2C, if axial alignment within system operating specifications is not achieved, it may be possible to pinch the DSC shell as shown in Figure 8.1-32. From Section 8.1.2C, the pinching force is taken as the product of the maximum ram loading of 80,000 pounds and the sine of a 1 degree angle, or 1,400 pounds.

The 1,400 pound load is conservatively assumed to be applied as a point load at a location away from the ends of the cask or DSC. The resulting maximum stresses are given by Table 31, Case 9a of Roark [3.10] as:

Membrane stress:

$$\sigma = \frac{0.4P}{t^2}$$

Bending stress:

$$\sigma' = \frac{2.4P}{t^2}$$

Therefore, the maximum membrane plus bending stress is:

$$\sigma + \sigma' = \frac{2.8P}{t^2}$$

For the DSC shell, t = 0.500 inch. Substituting for t and using a value of P equal to 1,400 pounds, the maximum extreme fiber stresses in the DSC shell are 15.7 ksi. This local stress is conservative in that small deformations create a larger contact area, i.e., not a point load, and the stress is actually lower than calculated. In addition, the deformations are limited by the gap

between the shell and basket. As such, this stress is considered a secondary stress and is enveloped by the handling stresses shown in Table M.3.6-2.

The tangential component of ram loading under the assumed condition is less than the 80,000 lbs force of the jammed condition, axial sticking, calculated above and as such is not considered further.

In both scenarios for a jammed DSC, the stress in the DSC shell is demonstrated to be much less than the ASME Code allowable stress and below the yield value of the material. Therefore, permanent deformation of the DSC shell does not occur. There is no potential for breach of the DSC containment pressure boundary and, therefore, no potential for release of radioactive material.

There is no change to the structural evaluation of the OS197 and OS197H TC as shown in the FSAR.

There is no change to the required corrective actions, as described in the FSAR, for the jammed DSC conditions.

M.3.6.2.2 Off-Normal Thermal Loads Analysis

As described in Section 8.1.2, the NUHOMS® System is designed for use at all reactor sites within the continental United States. Therefore, off-normal ambient temperatures of -40°F (extreme winter) and 117°F (extreme summer) are conservatively chosen. In addition, even though these extreme temperatures would likely occur for a short period of time, it is conservatively assumed that these temperatures occur for a sufficient duration to produce steady state temperature distributions in each of the affected NUHOMS® components. Each licensee should verify that this range of ambient temperatures envelopes the design basis ambient temperatures for the ISFSI site. The NUHOMS® System components affected by the postulated extreme ambient temperatures are the TC and DSC during transfer from the plant's fuel/reactor building to the ISFSI site, and the HSM during storage of a DSC.

Section M.4 provides the off-normal thermal analyses for storage and transfer mode for the NUHOMS®-32PT DSC. Maximum DSC shell assembly thermal stress analysis results for the normal and off-normal conditions are summarized in Table M.3.6-2. Basket assembly thermal results are summarized in Section M.3.4.4. The resulting stress intensities for the NUHOMS®-32PT are acceptable.

Table M.3.6-1
NUHOMS® Normal Operating Loading Identification

Load Type	AFFECTED COMPONENT				
	DSC Shell Assembly	DSC Basket	DSC Support Structure	Reinforced Concrete HSM	On-site TC
Dead Weight	X	X	X	X	X
Internal/External Pressure	X				
Normal Thermal	X	X	X	X	X
Normal Handling	X	X	X	X	X
Live Loads				X	X

Table M.3.6-2
Maximum NUHOMS®-32PT DSC Shell Assembly Stresses for Normal and Off-Normal Loads

DSC Components	Stress Type	Maximum Stress Intensity (ksi)[1]			
		Dead Weight	Internal Pressure[6]	Thermal[2]	Handling[4]
DSC Shell	Primary Membrane	2.65	8.90	N/A	4.10
	Membrane + Bending	6.00	9.18	N/A	6.00
	Primary + Secondary	7.00	16.29	41.75	55.63
Inner Top Cover Plate	Primary Membrane	0.58	0.74	N/A	1.68
	Membrane + Bending	1.67	16.76	N/A	1.84
	Primary + Secondary[5]	1.63	16.76	24.52	1.85
Outer Top Cover Plate	Primary Membrane	1.11	2.65	N/A	1.11
	Membrane + Bending	1.63	7.43	N/A	1.63
	Primary + Secondary[5]	1.17	7.22	23.69	1.17

See end of table for notes.

Table M.3.6-2
Maximum NUHOMS®-32PT DSC Shell Assembly Stresses for Normal and Off-Normal Loads
(concluded)

DSC Components	Stress Type	Maximum Stress Intensity (ksi)[1]			
		Dead Weight	Internal Pressure[6]	Thermal[2]	Handling[4]
Inner Bottom Cover Plate[9]	Primary Membrane	0.71	0.56	N/A	3.22
	Membrane + Bending	0.84	1.48	N/A	4.80
	Primary + Secondary[5]	0.83	1.51	36.41	49.26[8]
Outer Bottom Cover Plate	Primary Membrane	0.74	0.83	N/A	5.27
	Membrane + Bending	1.31	1.47	N/A	22.72
	Primary + Secondary[5]	1.18	1.15	30.81	39.97[8]

(1) Values shown are maximum irrespective of location.
(2) Envelope of Normal and Off-Normal ambient temperature conditions.
(3) Not used.
(4) Maximum of deadweight, 1g axial, 60 kips pull or 80 kips push (except as noted).
(5) Per Note 2 of Table NB3217-1, the stress at the intersection between a shell and a flat head may be classified as secondary (Q) if the bending moment at the edge is not required to maintain the bending stresses in the middle of the head within acceptable limits. Thus, the primary plus secondary stresses were computed in a finite element model that assumed moment transferring connections, whereas the primary membrane plus bending stresses were computed assuming pinned connections. All thermal stresses are classified as secondary.
(6) Due to the off-normal 20 psig internal pressure condition.
(7) Results are for the combination of deadweight, 15 psi internal pressure, the 1g vertical transfer load and thermal.
(8) Results are for the combination of deadweight, 20 psi internal pressure, the 80 kip ram push load and thermal.
(9) These stresses may also be applied to the single bottom and forging, when used.

Table M.3.6-3
NUHOMS®-32PT Basket Model Components, Element Types and Materials

Structural Component	ANSYS Element Type	Material
Fuel Support Structure	Plane42	Type XM-19 Stainless Steel
DSC Shell	Plane42	Type 304 Stainless Steel
R45 Transition Rails	Plane42	6061 Aluminum
R90 Transition Rails	Plane42	6061 Aluminum w/XM-19 Cover Plate
Cask Shell & Cask Rails	Plane42	Type 304 (Elastic)
DSC/Cask Shell Springs	Combin39	N/A

Table M.3.6-4
Material Properties Used in Normal Condition 32PT Basket Analyses

Component	Material	Normal Condition Stress Analysis Material Properties[2]	Evaluation Temperature[1]
Fuel Support Grid	1/4" Thick, Type XM-19 Stainless Steel	Elastic (Code Properties)	800°F (All conditions)
Solid Aluminum Transition Rails, R90 Cover Plates	1/4" Thick, Type XM-19 Stainless Steel	Elastic (Code Properties)	610°F/600°F (Vacuum Drying/Other)
Solid Aluminum Transition Rails, Aluminum Bodies	6061 Aluminum Alloy	Elastic[3]	500°F/450°F (Blocked Vent / Other)

Notes:
1. For the steel components, stress checks were performed at the enveloping temperatures listed. For the aluminum transition rails, stress checks were performed at temperatures corresponding to the maximum stress point. Temperatures listed are for the maximum stress points of the most highly loaded rail (the large R90 transition rail at the "bottom" of the basket).
2. ASME Code properties for Type XM-19 and Type 304 Stainless Steels from Tables M.3.3-3 and M.3.3-2, respectively.
3. Properties for 6061 Aluminum from Table M.3.3-5.

Table M.3.6-5
Summary of Results for 32PT Basket Assembly Deadweight Analyses

Vertical Deadweight

Component	Stress (Axial Compression)			Notes[1]
	Calculated	Allowable	Ratio	
Fuel Support Grid	.06 ksi	23.7 ksi	< .01	XM-19, 800°F
Aluminum Transition Rails	.02 ksi	4.2 ksi	< .01	6061 Al., ≈600°F

Notes: 1. For vacuum drying, the maximum transition rail temperature is less than 610°F. It occurs in the R90 rails and is localized at the point closest to the basket center, the average temperature is less than 600°F.

Horizontal Deadweight

Component	Stress Category	Stress Intensity		Stress Ratio	Notes
		Calculated	Allowable		
1-Piece R90 Transition Rails					
Fuel Support Grid	P_m	.57 ksi	28.2 ksi	.02	XM-19, 800°F
	$P_m + P_b$	2.72 ksi	42.3 ksi	.06	
	$P_m + P_b + Q$	7.41 ksi	84.6 ksi	.09	
Transition Rail Cover Plates	P_m	.30 ksi	28.2 ksi	.01	XM-19, 800°F
	$P_m + P_b$	2.50 ksi	42.3 ksi	.06	
	$P_m + P_b + Q$	2.50 ksi	84.6 ksi	.03	
6061 Aluminum Transition Rails	Maximum Stress	1.32 ksi	6.0 ksi	.22	Al. 6061, 450°F
3-Piece R90 Transition Rails					
Fuel Support Grid	P_m	.70 ksi	28.2 ksi	.02	XM-19, 800°F
	$P_m + P_b$	4.73 ksi	42.3 ksi	.11	
	$P_m + P_b + Q$	8.07 ksi	84.6 ksi	.10	
Transition Rail Cover Plates	P_m	.41 ksi	28.2 ksi	.01	XM-19, 800°F
	$P_m + P_b$	5.32 ksi	42.3 ksi	.13	
	$P_m + P_b + Q$	5.32 ksi	84.6 ksi	.06	
6061 Aluminum Transition Rails	Maximum Stress	1.72 ksi	6.0 ksi	.29	Al. 6061, 450°F

Table M.3.6-6
Summary of Results for 32PT Basket Assembly On-Site Handling (2.0g Loads)

Vertical Handling/Seismic

Component	Stress (Axial Compression)			Notes
	Calculated	Allowable	Ratio	
Fuel Support Grid	.11 ksi	23.7 ksi	< .01	XM-19, 800°F
Aluminum Transition Rails	.04 ksi	4.2 ksi	.01	6061 Al., 600°F

Horizontal/45° Handling/Seismic

Component	Stress Category	Stress Intensity		Stress Ratio	Notes
		Calculated	Allowable		
1-Piece R90 Transition Rails					
Fuel Support Grid	P_m	2.68 ksi	28.2 ksi	.10	XM-19, 800°F
	$P_m + P_b$	18.3 ksi	42.3 ksi	.43	
	$P_m + P_b + Q$	18.3 ksi	84.6 ksi	.22	
Transition Rail Cover Plates	P_m	2.19 ksi	28.2 ksi	.08	XM-19, 800°F
	$P_m + P_b$	11.1 ksi	42.3 ksi	.26	
	$P_m + P_b + Q$	11.1 ksi	84.6 ksi	.13	
6061 Aluminum Transition Rails	Maximum Stress	4.64 ksi	6.0 ksi	0.77	Al. 6061, 450°F
3-Piece R90 Transition Rails					
Fuel Support Grid	P_m	1.52ksi	28.2 ksi	.05	XM-19, 800°F
	$P_m + P_b$	20.7 ksi	42.3 ksi	.49	
	$P_m + P_b + Q$	20.7 ksi	84.6 ksi	.24	
Transition Rail Cover Plates	P_m	1.05 ksi	28.2 ksi	.04	XM-19, 800°F
	$P_m + P_b$	10.1 ksi	42.3 ksi	.24	
	$P_m + P_b + Q$	10.1 ksi	84.6 ksi	.12	
6061 Aluminum Transition Rails	Maximum stress	2.06 ksi	6.0 ksi	.56	Al. 6061, 450°F

Note: 1. For the steel components, stress checks were performed at the enveloping temperatures listed. For the aluminum transition rails, stress checks were performed at temperatures corresponding to the maximum stress point. Temperatures listed are for the maximum stress points of the most highly loaded rail (the large R90 transition rail at the "bottom" of the basket).

Table M.3.6-7
32PT Basket Analyses Used to Determine On-Site Handling Loads

Case	Resultant Load	Basket Assembly Configuration	Support Conditions
1	2g resultant load in the "vertical" orientation	32PT Basket Assembly with 1-piece R90 aluminum transition rails	HSM (Support Rails at ± 30)
2	2g resultant load in the "vertical" orientation	32PT Basket Assembly with 1-piece R90 aluminum transition rails	OS197 (Support Rails at ± 18.5°)
3	2g resultant load oriented 45° from bottom center	32PT Basket Assembly with 1-piece R90 aluminum transition rails	OS197 (Support Rails at ± 18.5°)
4	2.5g resultant load in the "vertical" orientation	32PT Basket Assembly with 3-piece R90 aluminum transition rails	HSM (Support Rails at ± 30
5	2.5g resultant load in the "vertical" orientation	32PT Basket Assembly with 3-piece R90 aluminum transition rails	OS197 (Support Rails at ± 18.5°)
6	2.0g g resultant load oriented 45° from bottom center	32PT Basket Assembly with 3-piece R90 aluminum transition rails	OS197 (Support Rails at ± 18.5°)

Table M.3.6-8
NUHOMS® Off-Normal Operating Loading Identification

Load Type	AFFECTED COMPONENT				
	DSC Shell Assembly	DSC Basket	DSC Support Structure	Reinforced Concrete HSM	On-site TC
Dead Weight	X	X	X	X	X
Internal/External Pressure	X				
Off-Normal Thermal	X	X	X	X	X
Off-Normal Handling	X	X	X	X	X

DELETED

Figure M.3.6-1
32PT Basket Model with Steel Transition Rails

DELETED

Figure M.3.6-2
32PT Basket Model with Steel Transition Rails

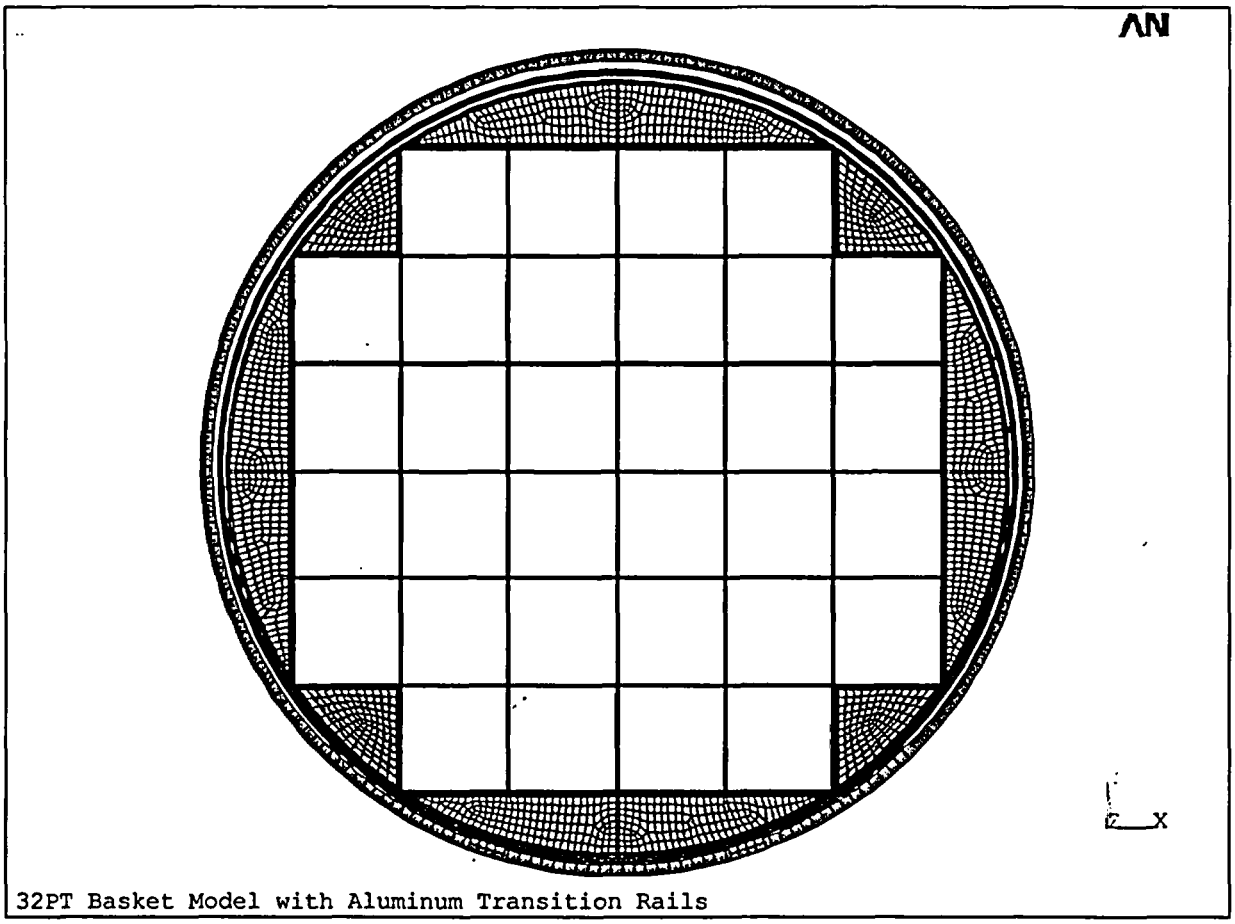


Figure M.3.6-3
32PT Basket Model with Aluminum Transition Rails (1-Piece R90)

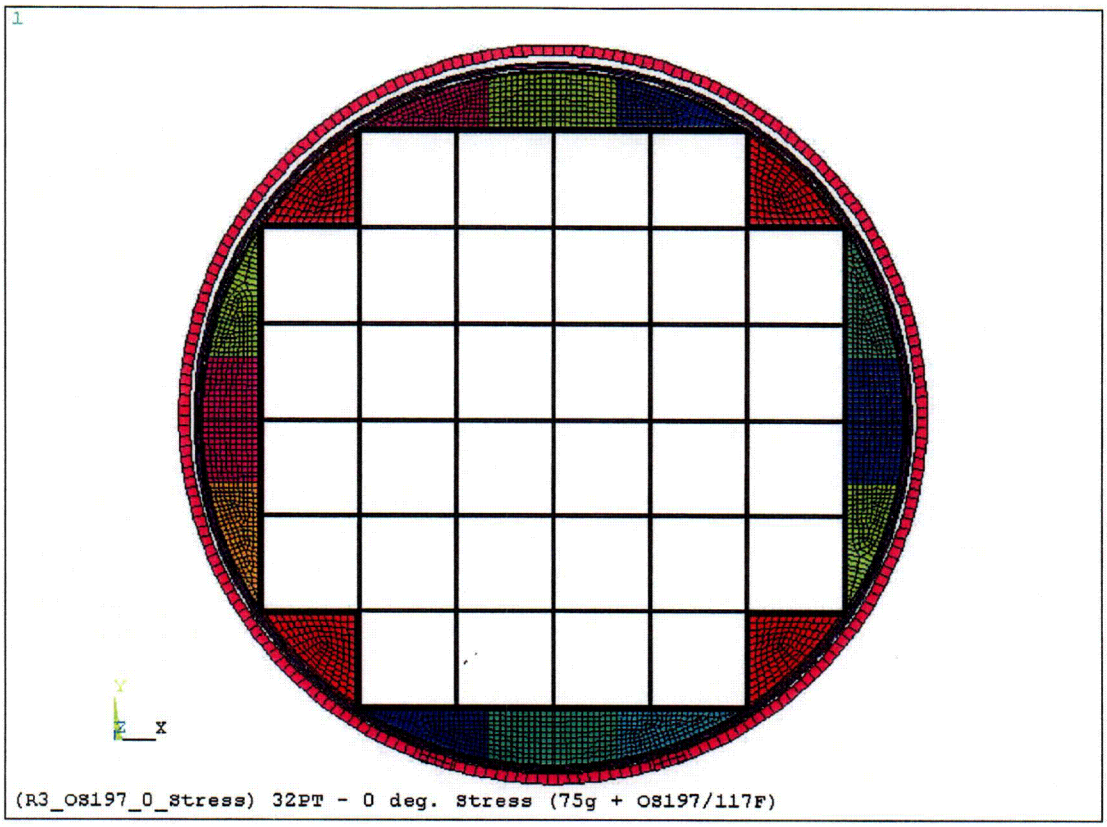


Figure M.3.6-3A
32PT Basket Model with Aluminum Transition Rails (3-Piece R90)

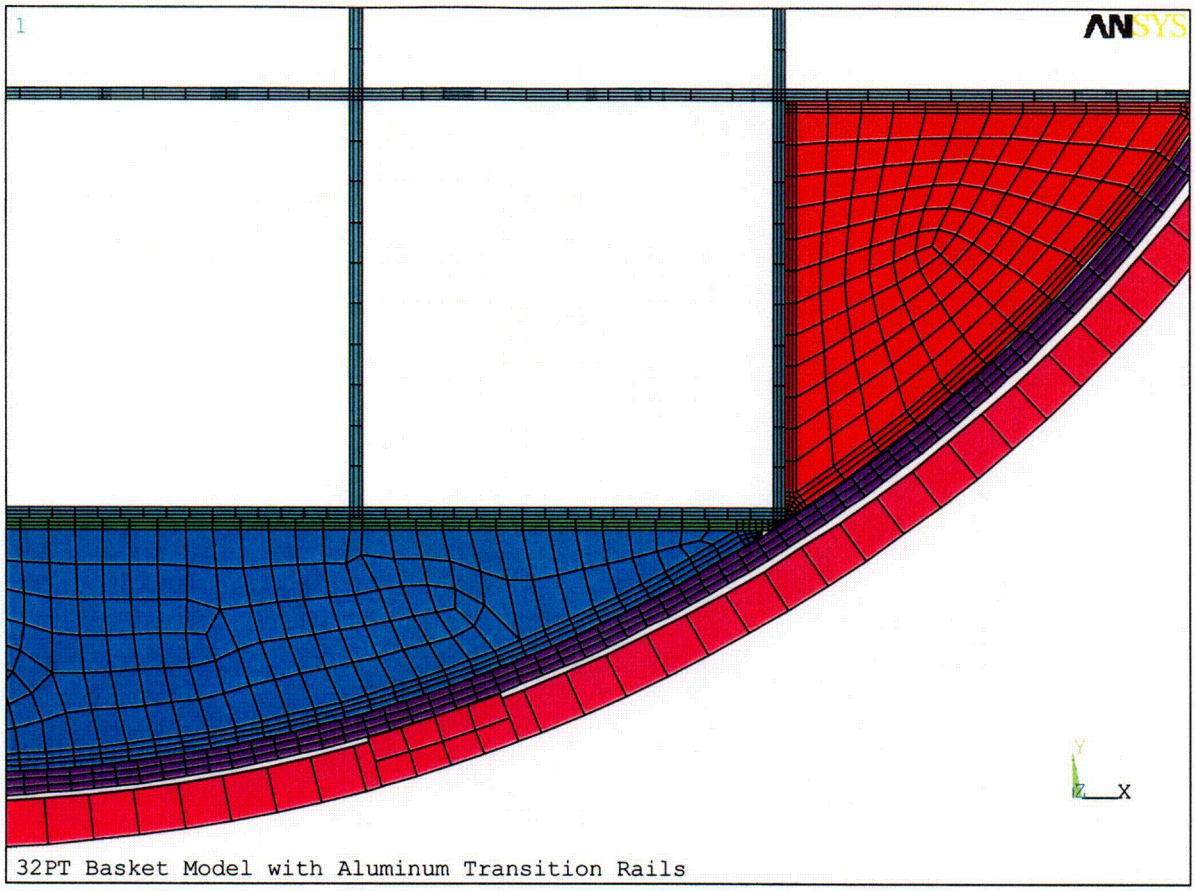


Figure M.3.6-4
32PT Basket Model with Aluminum Transition Rails (1-Piece R90)

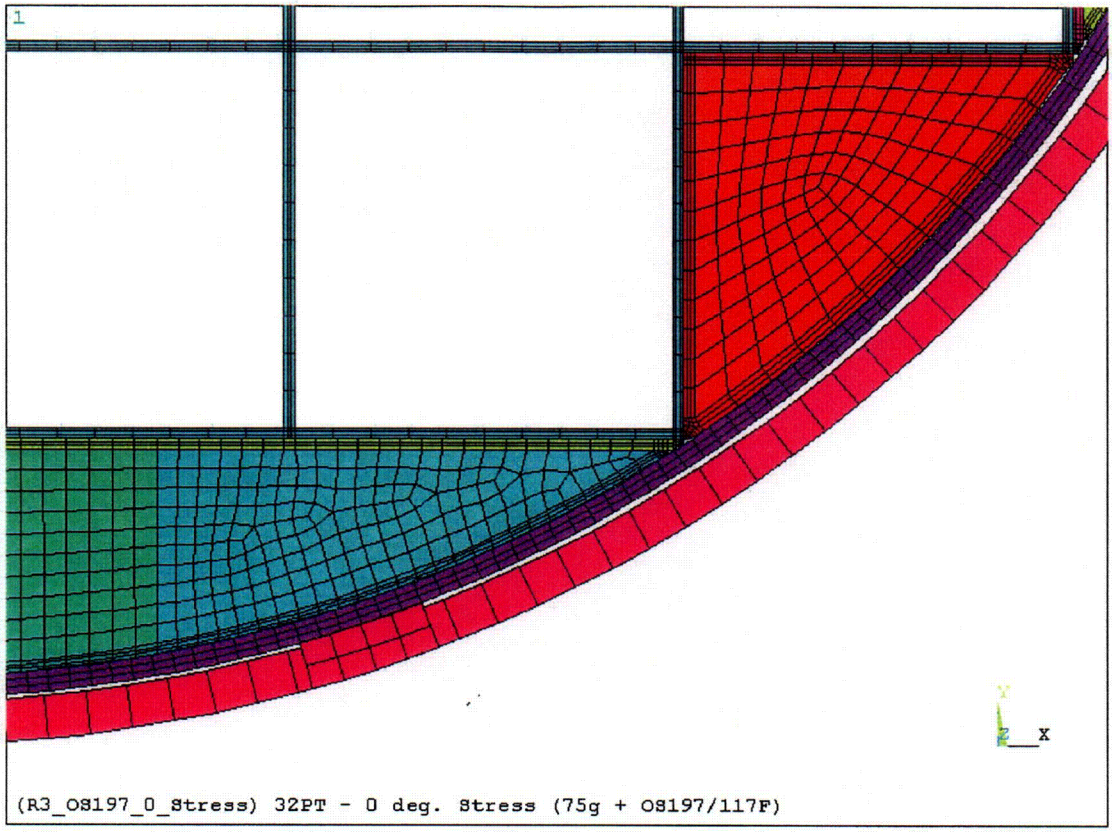


Figure M.3.6-4A
32PT Basket Model with Aluminum Transition Rails (3-Piece R90)

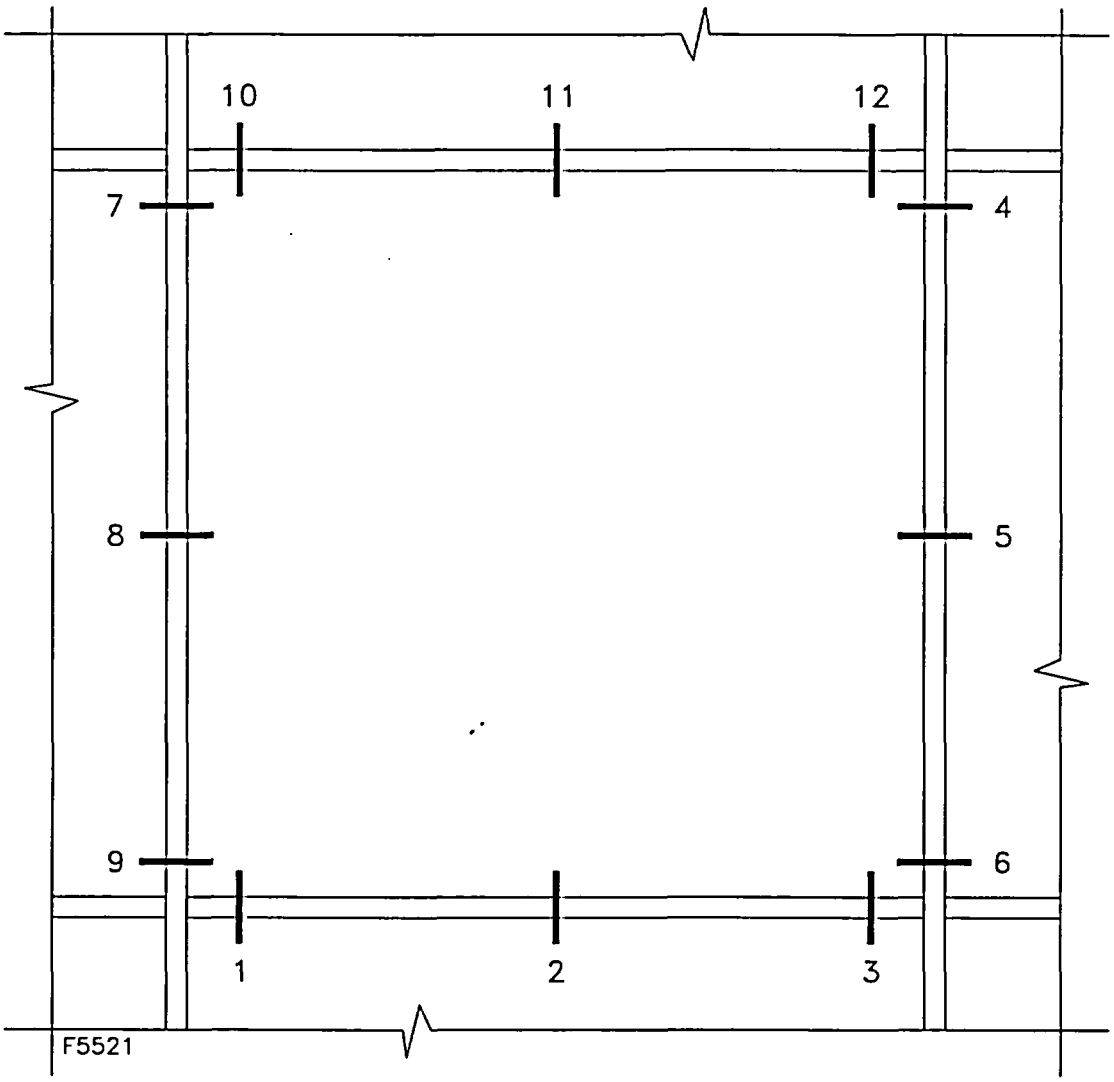


Figure M.3.6-5
Location and Numbering of Stress Cuts for 32PT Basket Analyses

DELETED

Figure M.3.6-6
Deadweight Stress Intensity, 32PT Basket with Steel Transition Rails
(Support Rails at ±18.5°)

DELETED

Figure M.3.6-7
Deadweight + Thermal Stress Intensity, 32PT Basket with Steel Transition Rails
(Support Rails at ±18.5°)

DELETED

Figure M.3.6-8
Deadweight Stress Intensity, 32PT Basket with Steel Transition Rails
(Support Rails at ±30°)

DELETED

Figure M.3.6-9
Deadweight + Thermal Stress Intensity, 32PT Basket with Steel Transition Rails
(Support Rails at ±30°)

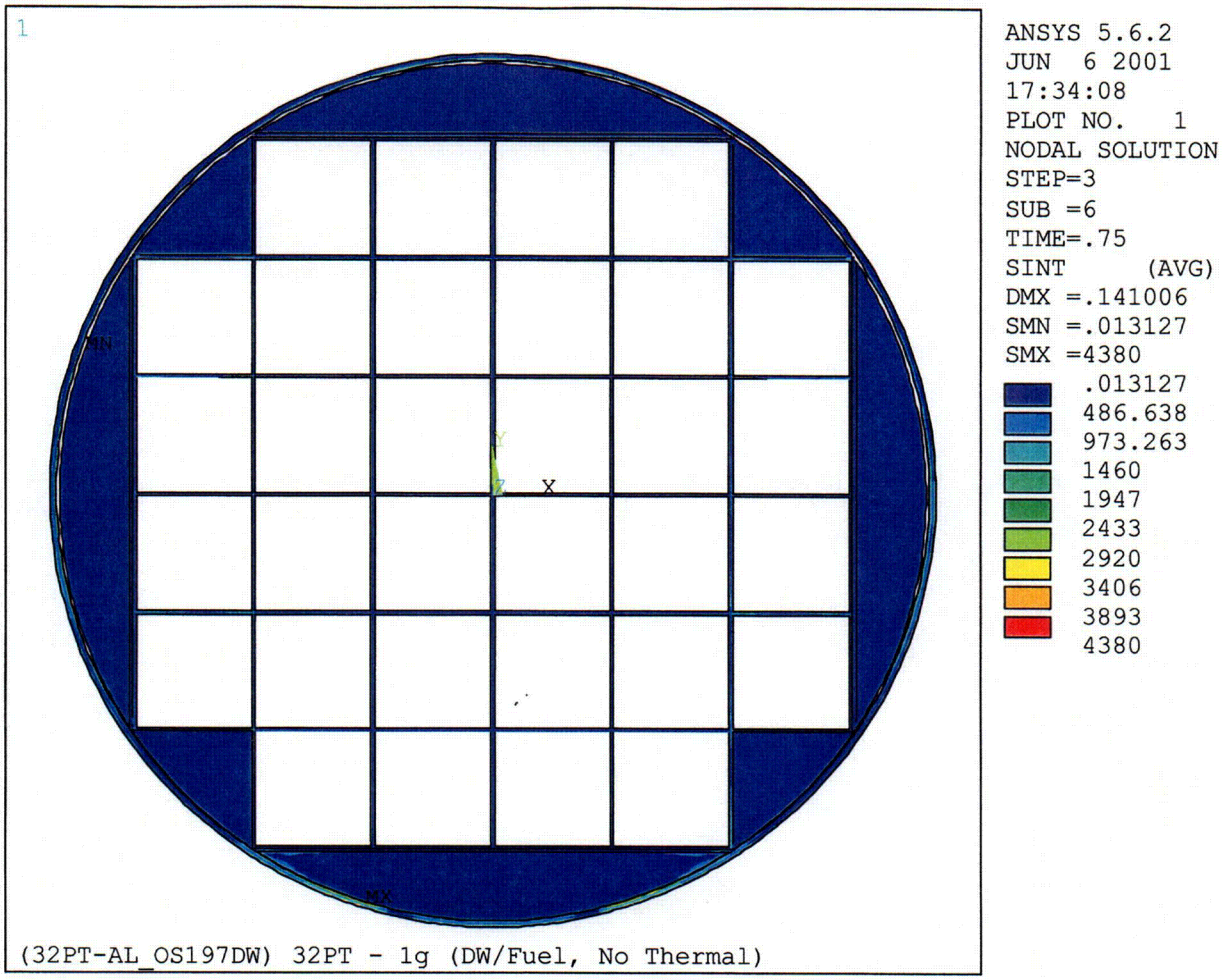


Figure M.3.6-10
Deadweight Stress Intensity, 32PT Basket with Aluminum Transition Rails (1- Piece R90)
(Support Rails at ±18.5°)

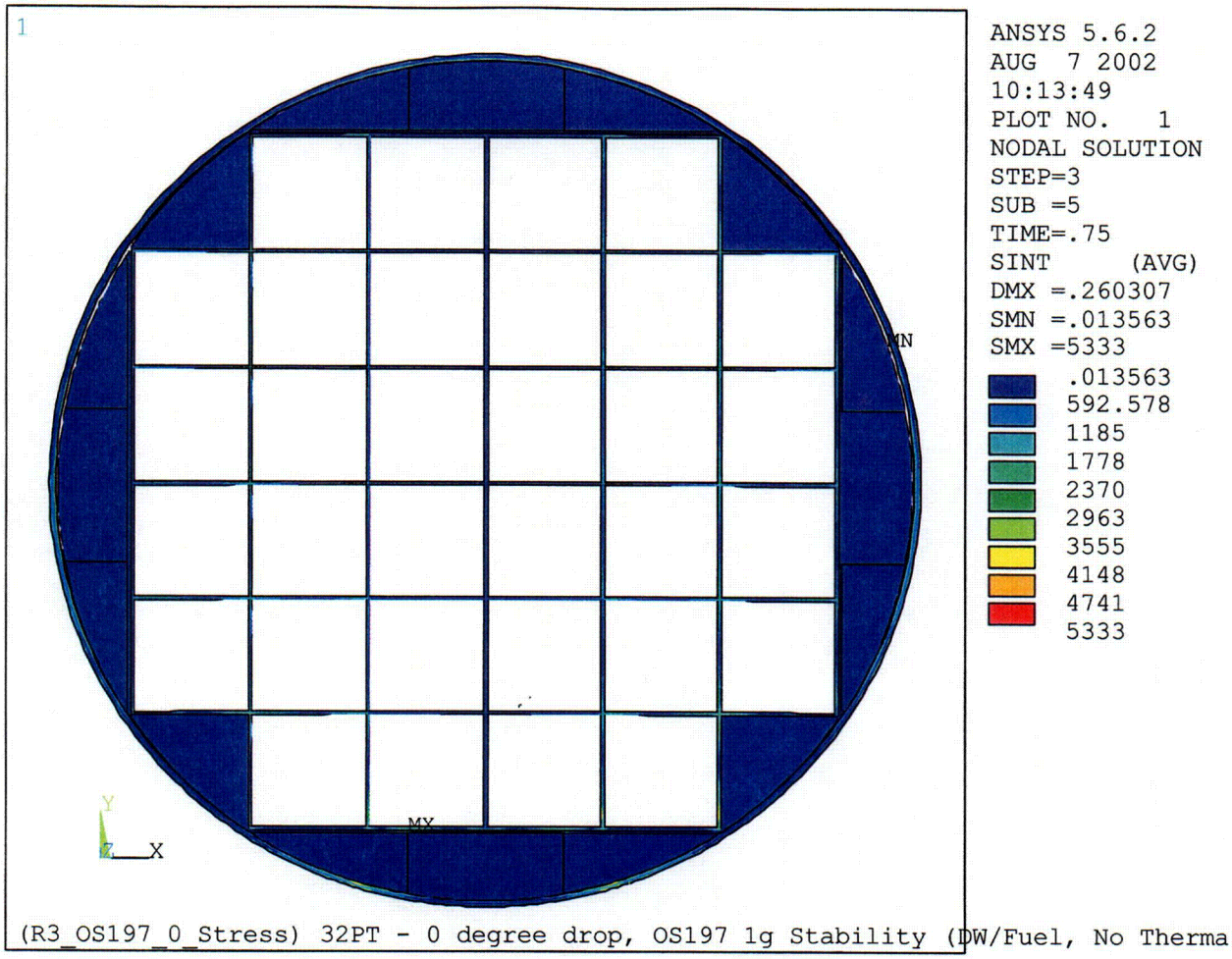


Figure M.3.6-10A
Deadweight Stress Intensity, 32PT Basket with Aluminum Transition Rails (3-Piece R90)
(Support Rails at ±18.5°)

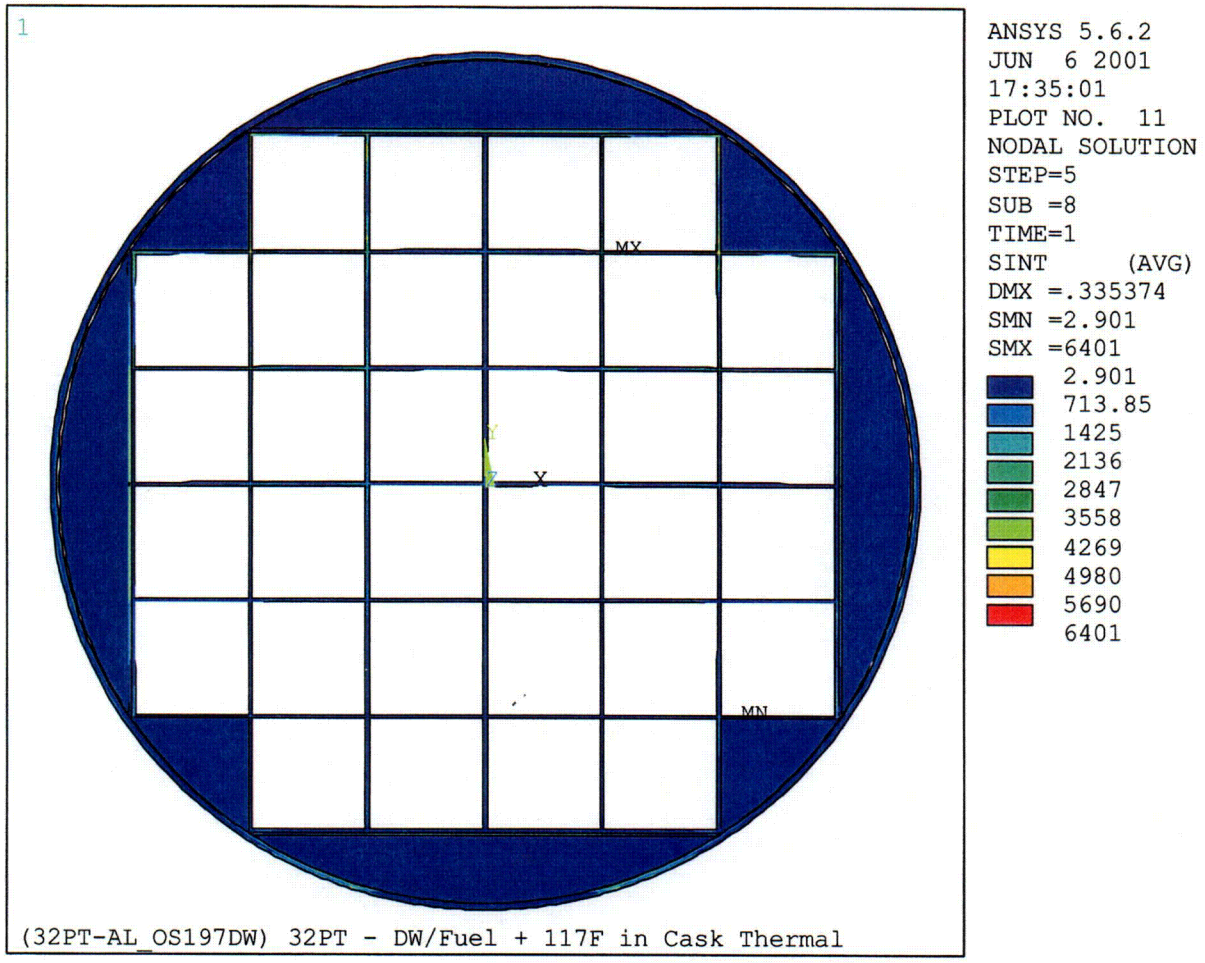


Figure M.3.6-11
Deadweight + Thermal Stress Intensity, 32PT Basket with Aluminum Transition Rails (1-Piece R90) (Support Rails at ±18.5°)

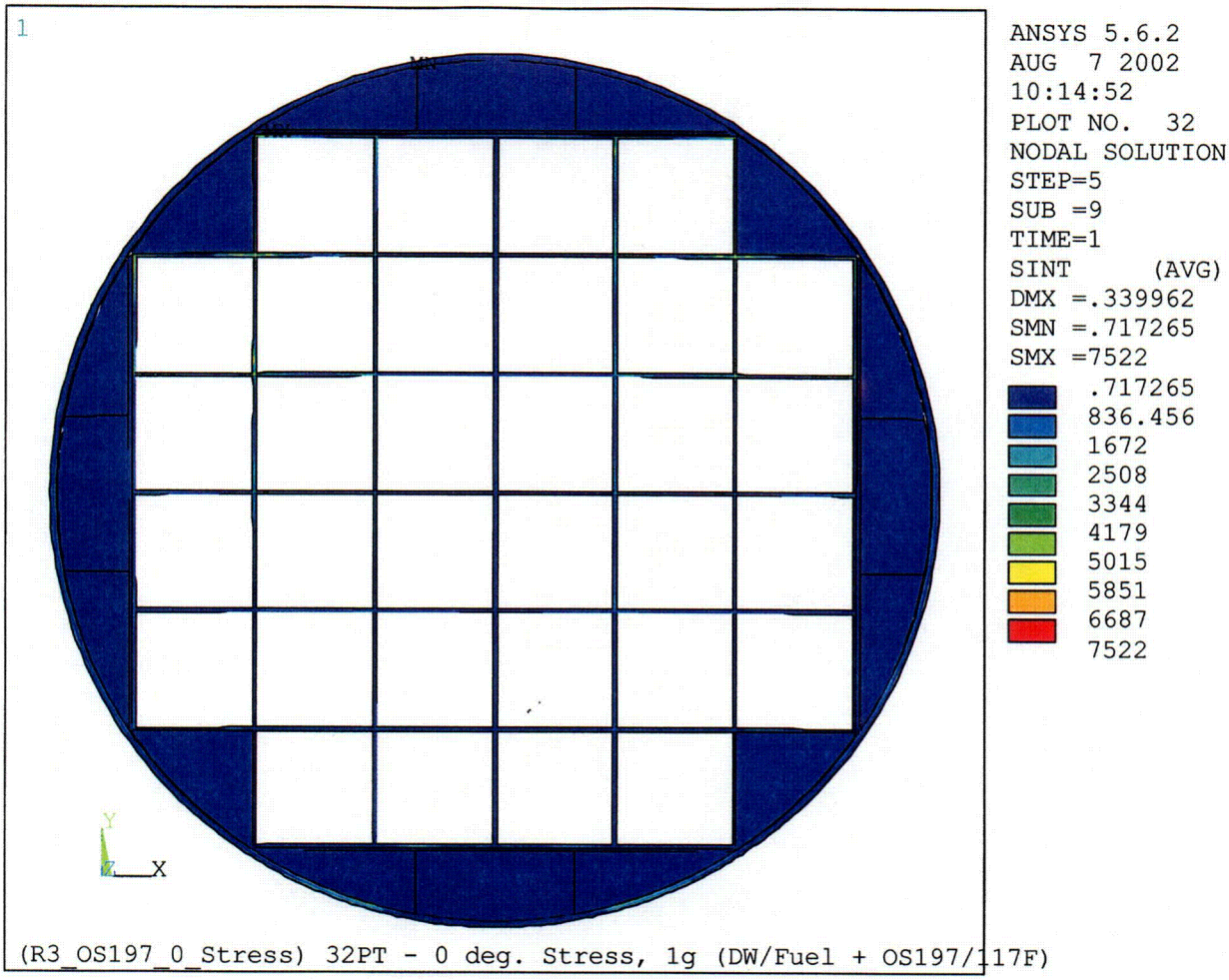


Figure M.3.6-11A
Deadweight + Thermal Stress Intensity, 32PT Basket with Aluminum Transition Rails (3-Piece R90) (Support Rails at ±18.5°)

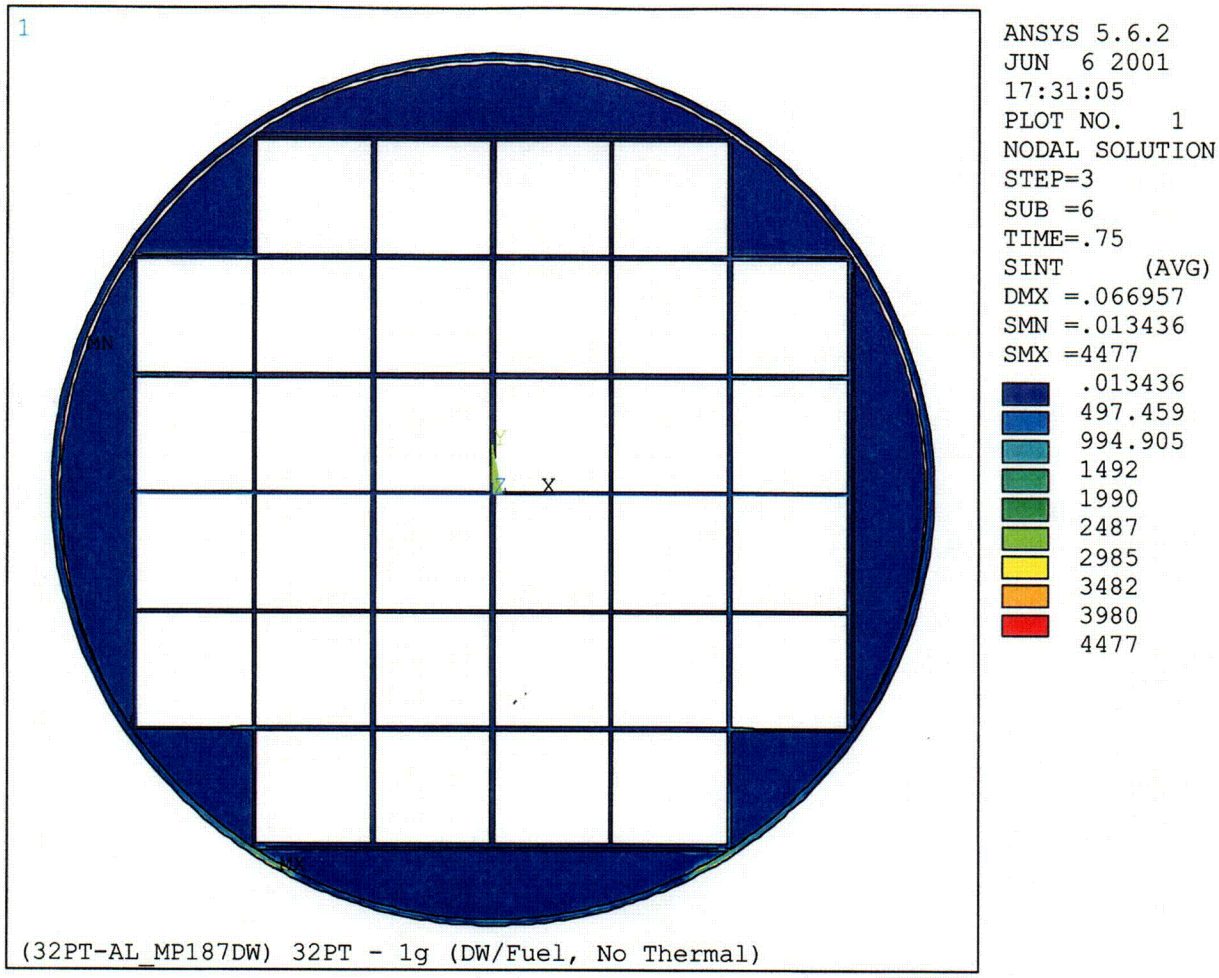


Figure M.3.6-12
Deadweight Stress Intensity, 32PT Basket with Aluminum Transition Rails (1-Piece R90) (Support Rails at ±30°)

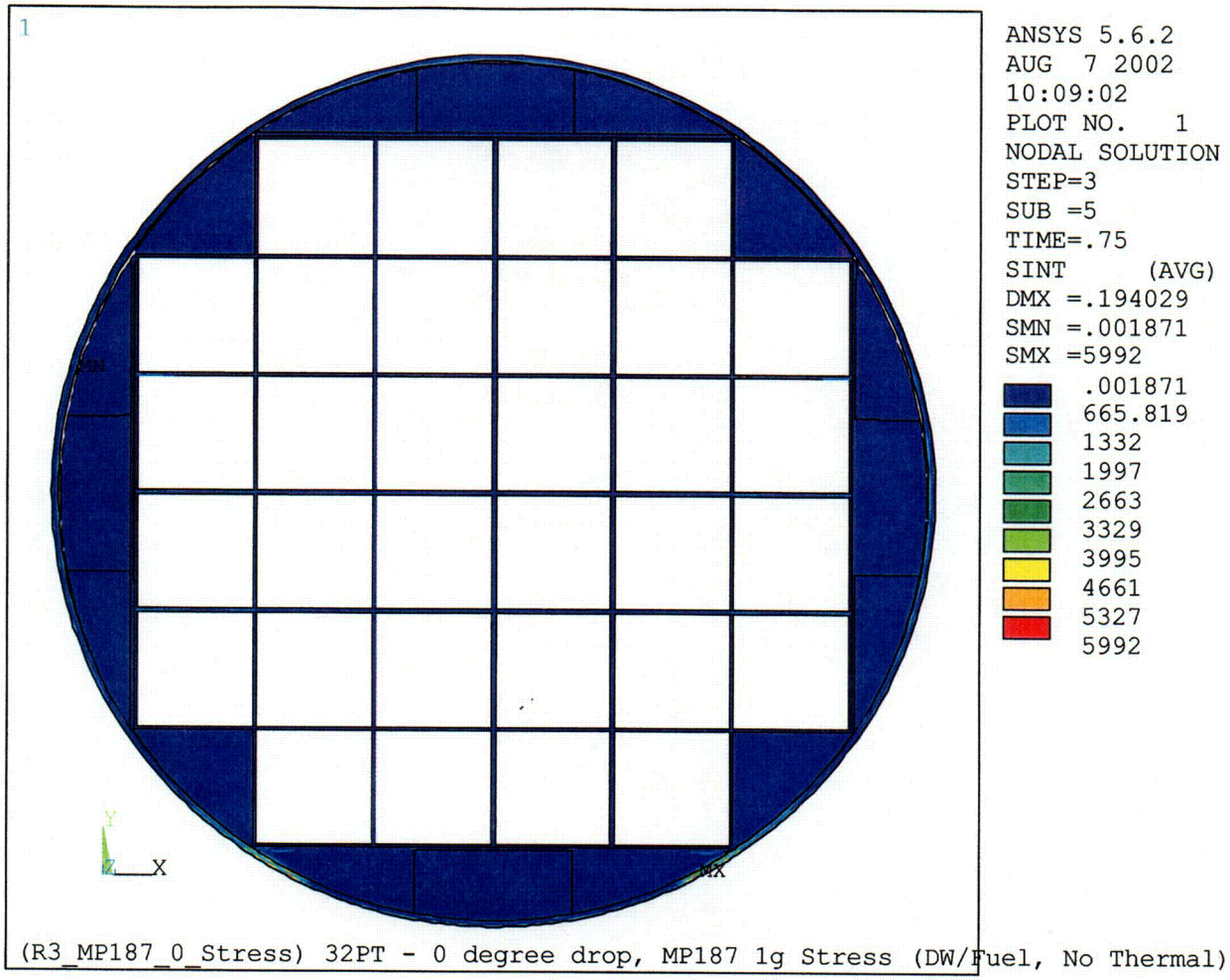


Figure M.3.6-12A
Deadweight Stress Intensity, 32PT Basket with Aluminum Transition Rails (3-Piece R90)
(Support Rails at ±30°)

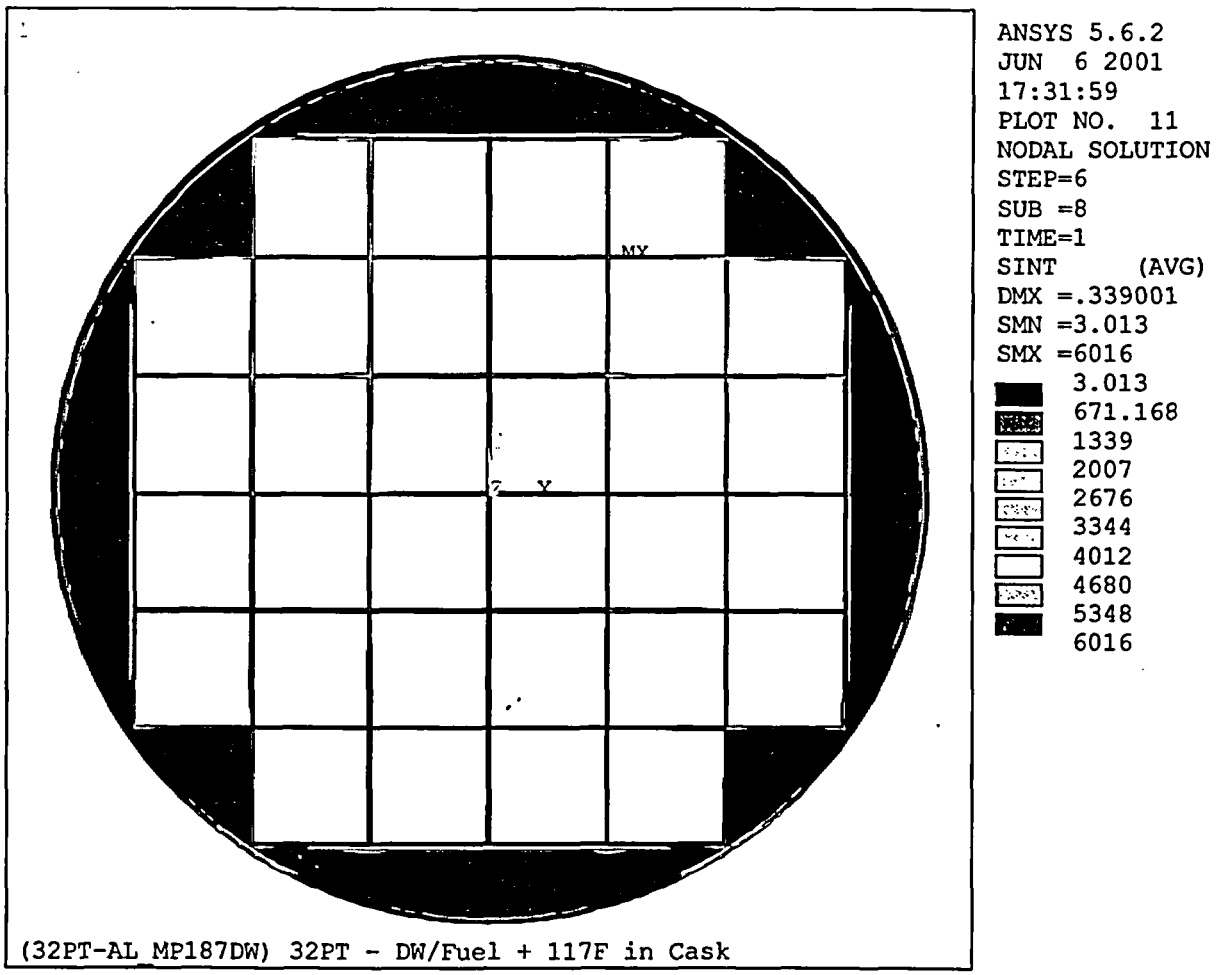


Figure M.3.6-13
Deadweight +Thermal Stress Intensity, 32PT Basket with Aluminum Transition Rails (1-Piece R90) (Support Rails at ±30°)

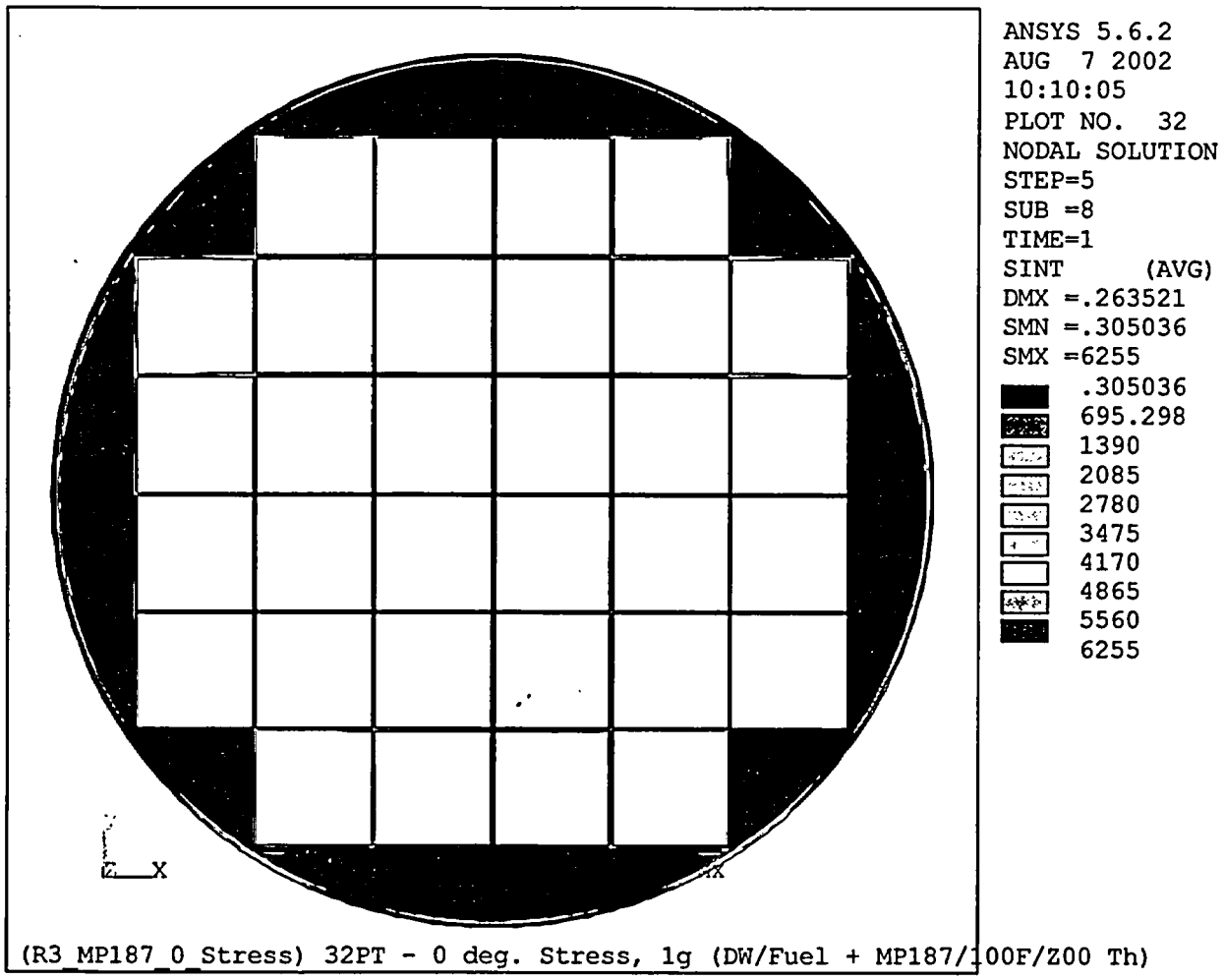


Figure M.3.6-13A
Deadweight+ Thermal Stress Intensity, 32PT Basket with Aluminum Rails (3-Piece R90)
(Support Rails at ±30°)

M.3.7 Structural Analysis (Accidents)

The design basis accident events specified by ANSI/ANS 57.9-1984, and other credible accidents postulated to affect the normal safe operation of the standardized NUHOMS® System are addressed in this section. Analyses are provided for a range of hypothetical accidents, including those with the potential to result in an annual dose greater than 25 mrem outside the owner controlled area in accordance with 10CFR72. The postulated accidents considered in the analysis of the 32PT DSC and the associated NUHOMS® components affected by each accident condition are the same as those shown in Table 8.2-1.

In the following sections, each accident condition is analyzed to demonstrate that the requirements of 10CFR72.122 are met and that adequate safety margins exist for the standardized NUHOMS® System design. The resulting accident condition stresses in the NUHOMS® System components are evaluated and compared with the applicable code limits set forth in Section 3.2. Where appropriate, these accident condition stresses are combined with those of normal operating loads in accordance with the load combination definitions in Tables 3.2-5, 3.2-6, and 3.2-7. Load combination results for the HSM, DSC, and TC and the evaluation for fatigue effects are presented in Section M.3.7.10.

The postulated accident conditions addressed in this section include:

- Reduced HSM air inlet and outlet shielding (M.3.7.1),
- Tornado winds and tornado generated missiles (M.3.7.2),
- Design basis earthquake (M.3.7.3),
- Design basis flood (M.3.7.4),
- Accidental TC drop with loss of neutron shield (M.3.7.5),
- Lightning effects (M.3.7.6),
- Debris blockage of HSM air inlet and outlet opening (M.3.7.7),
- Postulated DSC leakage (M.3.7.8), and
- Pressurization due to fuel cladding failure within the DSC (M.3.7.9).

M.3.7.1 Reduced HSM Air Inlet and Outlet Shielding

This postulated accident is the partial loss of shielding for the HSM air inlet and outlet vents provided by the adjacent HSM. All other components of the NUHOMS® System are assumed to be functioning normally.

There are no structural consequences that affect the safe operation of the NUHOMS® System resulting from the separation of the HSMs. The thermal effects of this accident results from the

blockage of HSM air inlet and outlet openings on the HSM side walls in contact with each other. This would block the ventilation air flow provided to the HSMs in contact from these inlet and outlet openings. The increase in spacing between the HSM on the opposite side from 6 inches to 12 inches will reduce the ventilation air flow resistance through the air inlet and outlet openings on these side walls, which will partially compensate the ventilation reduction from the blocked side. However, the effect on the DSC, HSM and fuel temperatures is bounded by the complete blockage of air inlet and outlet openings described in Section M.3.7.7.

M.3.7.2 Tornado Winds/Tornado Missile

The applicable design parameters for the design basis tornado (DBT) are specified in Section 3.2.1. The determination of the tornado wind and tornado missile loads acting on the HSM are detailed in Section 3.2.2. The end modules of an array utilize shield walls to resist tornado wind and missile loads. For this conservative generic analysis, the tornado loads are assumed to act on a single free-standing HSM (with two end shield walls and a rear shield wall). This case conservatively envelopes the effects of wind on an HSM array. The TC is also designed for the tornado wind and tornado missile loads defined in Section 3.2.2. Thus, the requirements of 10CFR72.122 are met.

For DBT wind and missile effects, the HSM is more stable when loaded with a heavier DSC since the overturning moment is not a function of the DSC weight while the resisting moment increases with the increased payload. The DSC weight does not have any effect on HSM sliding stability, since the weight terms on either side of the sliding equation presented in Section 8.2.2 cancel out. Since the weight of the NUHOMS®-32PT DSC is bounded by the DSC weights used in Section 8.2.2, there is no change to the structural evaluation of the HSM for DBT winds and missile effects.

M.3.7.3 Earthquake

As discussed in Section 3.2.3 and as shown in Figure 8.2-2, the peak horizontal ground acceleration of 0.25g and the peak vertical ground acceleration of 0.17g are utilized for the design basis seismic analysis of the NUHOMS® components. Based on NRC Reg. Guide 1.61 [3.15], a damping value of three percent is used for the DSC seismic analysis. Similarly, a damping value of seven percent for DSC support steel and concrete is utilized for the HSM. An evaluation of the frequency content of the loaded HSM is performed to determine the dynamic amplification factors associated with the design basis seismic response spectra for the NUHOMS® HSM and DSC. Since the weight of the NUHOMS®-32PT DSC is bounded by the DSC weights used in Section 8, there is no change to the seismic response of the HSM.

M.3.7.3.1 DSC Seismic Evaluation

The maximum calculated seismic accelerations for the DSC inside the HSM are 0.40g horizontally and 0.17g vertically. An analysis using these seismic loads shows that the DSC will not lift off the support rails inside the HSM. The resulting stresses in the DSC shell due to vertical and horizontal seismic loads are also determined and included in the appropriate load combinations. The seismic evaluation of the DSC is described in the paragraphs that follow.

The DSC basket and support structure are also subjected to the calculated DSC seismic reaction loads as discussed in Sections M.3.7.3.2 and M.3.7.3.4, respectively.

M.3.7.3.1.1 DSC Natural Frequency Calculation

Two natural frequencies, each associated with a distinct mode of vibration of the DSC are evaluated. These two modes are the DSC shell cross-sectional ovalling mode and the mode with the DSC shell bending as a beam.

M.3.7.3.1.1.1 DSC Shell Ovalling Mode

The natural frequency for the DSC shell ovalling mode is determined from the Blevins [3.16] correlation as follows.

$$f = \frac{\lambda_i}{2\pi R}\sqrt{\frac{E}{\mu(1-\nu^2)}} \quad \text{(Blevins, Table 12-1, Case 3)}$$

where: R = 33.34 in, DSC mean radius,

E = $26.5\text{x}10^6$ psi, Young's Modulus,

ν = 0.3, Poisson's ratio,

λi = $\lambda_i = 0.289\frac{t}{R}\frac{i(i^2-1)}{\sqrt{1+i^2}}$,

t = 0.5 in., Thickness of DSC shell, and

μ = 0.288/g lb/in^3, Steel mass density.

The lowest natural frequency corresponds to the case when i = 2.

Hence: λ_2 = 0.0116 sec.

Substituting gives: f = 10.9 Hertz

The resulting spectral accelerations in the horizontal and vertical directions for this DSC ovalling frequency are less than 1.0g and 0.68g, respectively.

M.3.7.3.1.1.2 DSC Beam Bending Mode

The DSC shell is conservatively assumed to be simply supported at the two ends of the DSC. The beam bending mode natural frequency of the DSC was calculated from the Blevins correlation:

$$f_i = \frac{\lambda_i^2}{2\pi L^2}\sqrt{\frac{EI}{m}} \quad \text{(Blevins, Table 8.1, Case 5)}$$

where: E = 26.5E6 psi, Young's Modulus,

I = 58,400 in.4, DSC moment of inertia,

L = 192.55 in., Total length of DSC,

m = 101,130/192.55 = 525/g lb/in, and

λ = $i\pi$; for lowest natural frequency, i = 1.

Substituting yields: f_1 = 45.1 Hertz.

The DSC spectral accelerations at this frequency correspond to the zero period acceleration. These seismic accelerations are bounded by those of the ovalling mode frequency that are used in the subsequent stress analysis of the DSC shell.

M.3.7.3.1.2 DSC Seismic Stress Analysis

With the DSC conservatively assumed to be resting on a single support rail inside the HSM, the stresses induced in the DSC shell are calculated due to the 1.0g horizontal and 0.68g vertical seismic accelerations, and increased by a factor of 1.5 to account for the effects of possible multimode excitation. Thus, the DSC shell is qualified to seismic accelerations of 1.5g horizontal and 1.0g vertical. The DSC shell stresses obtained from the analyses of vertical and horizontal seismic loads are summed absolutely. See Table M.3.7-9 for the Level C seismic stress evaluation of the NUHOMS®-32PT DSC. The seismic load combination includes deadweight + pressure + 1.5g horizontal and 1g vertical (load combinations HSM-7 and HSM-8 as shown in Table M.2-15).

As stated, in Section 4.2.3.2, an axial retainer is included in the design of the DSC support system inside the HSM to prevent sliding of the DSC in the axial direction during a postulated seismic event. The stresses induced in the DSC shell and bottom cover plate due to the restraining action of this retainer for a horizontal seismic load, applied along the axis of the DSC, are included in the seismic response evaluation of the DSC shell assembly.

The stability of the DSC against lifting off one of the support rails during a seismic event is evaluated by performing a rigid body analysis, using the 0.40g horizontal and 0.17g vertical input accelerations. The factor of 1.5 used in the DSC analysis to account for multimode behavior need not be included in the seismic accelerations for this analysis, as the potential for lift off is due to rigid body motion, and no frequency content effects are associated with this action. The horizontal equivalent static acceleration of 0.40g is applied laterally to the center of gravity of the DSC. The point of rigid body rotation of the DSC is assumed to be the center of the support rail, as shown in Figure M.3.7-1. The applied moment acting on the DSC is calculated by summing the overturning moments. The stabilizing moment, acting to oppose the applied moment, is calculated by subtracting the effects of the upward vertical seismic acceleration of 0.17g from the total weight of the DSC and summing moments at the support rail. Since the stabilizing moment calculated below is greater than that of the applied moment, the DSC will not lift off the DSC support structure inside the HSM.

Referring to Figure M.3.7-1, the factor of safety associated with DSC lift-off is calculated as follows:

$$M_{am} = yF_H,$$

and $$M_{sm} = (F_{v1} - F_{v2})x.$$

where: M_{am} = the applied seismic moment, and

M_{sm} = the stabilizing moment

All other variables are defined in Figure M.3.7-1.

Substituting yields: M_{am} = 1177.1 K-in.

and M_{sm} = 1410.2 K-in.

Thus, the factor of safety (SF) against DSC lift off from the DSC support rails inside the HSM obtained from this bounding analysis is:

$$SF = \frac{M_{sm}}{M_{am}} = 1.20$$

M.3.7.3.2 Basket Seismic Evaluation

Seismic loads on the 32PT basket are enveloped by the 2.0g loads used for the on-site handling evaluation described in Section M.3.6. Therefore, based on the following considerations, specific qualification/evaluation for seismic loads is not required for the 32PT basket assembly:

- seismic loads are enveloped by the on-site handling loads evaluated in Section M.3.6.1.3.2(E).
- the handling load evaluation is performed using Service Level A allowables, while seismic loads are classified as Service Level C loads.

Therefore, the qualification for on-site handling in Section M.3.6.1.3.2(E) also demonstrates qualification for seismic loading and no additional evaluation is required.

M.3.7.3.3 HSM Seismic Evaluation

The weight of the NUHOMS®-32PT DSC is bounded by the DSC weight used in Section 8.2.3.2(B). Therefore, there is no change to the HSM seismic evaluation.

M.3.7.3.4 DSC Support Structure Seismic Evaluation

The weight of the NUHOMS®-32PT DSC is bounded by the DSC weight used in Section 8.2.3.2(C). Therefore, there is no change to the DSC support structure seismic evaluation.

M.3.7.3.5 DSC Axial Retainer Seismic Evaluation

The weight of the NUHOMS®-32PT DSC is bounded by the DSC weight used in Section 8.2.3.2(C). Therefore, there is no change to the DSC Axial Retainer seismic evaluation.

M.3.7.3.6 TC Seismic Evaluation

The effects of a seismic event occurring when a loaded NUHOMS®-24P DSC is resting inside the TC are described in Section 8.2.3.2(D). The stabilizing moment to prevent overturning of the cask/trailer assembly due to the 0.25g horizontal and 0.17g vertical seismic ground accelerations is calculated and compared to the dead weight stabilizing moment. The results of this analysis show that there is a factor of safety of at least 2.0 against overturning that ensures that the cask/trailer assembly has sufficient margin for the design basis seismic loading. Since the weight of the NUHOMS®-32PT DSC is bounded by the DSC weights used in Section 8.2.3, and the TC was evaluated using peak spectrum amplification factors (See Section 8.2.3.2D) this factor of safety against overturning due to seismic remains bounding for the NUHOMS®-32PT DSC.

M.3.7.4 Flood

Since the source of flooding is site specific, the exact source, or quantity of flood water, should be established by the licensee. However, for this generic evaluation of the 32PT DSC and HSM, bounding flooding conditions are specified that envelop those that are postulated for most plant sites. As described in Section 3.2, the design basis flooding load is specified as a 50 foot static head of water and a maximum flow velocity of 15 feet per second. Each licensee should confirm that this represents a bounding design basis for their specific ISFSI site.

M.3.7.4.1 HSM Flooding Analysis

For flooding effects, the HSM is more stable when loaded with a heavier DSC since the overturning moment is not a function of the DSC weight while the resisting moment increases with the increased payload. Since the weight of the NUHOMS®-32PT DSC is bounded by the DSC weights used in Section 8.2.4, there is no change to the HSM flooding analysis.

M.3.7.4.2 DSC Flooding Analyses

The DSC is evaluated for the design basis fifty foot hydrostatic head of water producing external pressure on the DSC shell and outer cover plates. To conservatively determine design margin which exists for this condition, the maximum allowable external pressure on the DSC shell is calculated for Service Level A stresses using the methodology presented in NB-3133.3 of the ASME Code [3.1]. The resulting allowable pressure of 39.7 psi is 1.8 times the maximum external pressure of 21.7 psi due to the postulated fifty foot flood height. This demonstrates stability of the DSC under the worst case external pressure due to flooding.

The DSC shell stresses for the postulated flood condition are determined using the ANSYS analytical model shown in Figure 8.1-14a and Figure 8.1-14b. The 21.7 psig external pressure is applied to the model as a uniform pressure on the outer surfaces of the top cover plate, DSC shell and bottom cover plate. The maximum DSC shell primary membrane plus bending stress

intensity for the 21.7 psi external pressure is 3.00 ksi which is considerably less than the Service Level C allowable primary membrane plus bending stress of 32.6 ksi. The maximum primary membrane plus bending stress in the flat heads of the DSC occurs in the inner bottom cover plate. The maximum primary membrane plus bending stress in the inner bottom cover plate is 1.54 ksi. This value is considerably less than the ASME Service Level C allowable of 32.6 ksi for primary membrane plus bending. These stresses are combined using the load combinations shown in Table M.2-15.

M.3.7.5 Accidental Cask Drop

This section addresses the structural integrity of the standardized NUHOMS® on-site TC, the DSC and its internal basket assembly when subjected to postulated cask drop accident conditions.

Cask drop evaluations include the following:

- DSC Shell Assembly (M.3.7.5.2),
- Basket Assembly (M.3.7.5.3),
- On-Site TC (M.3.7.5.4), and
- Loss of the TC Neutron Shield (M.3.7.5.5).

The DSC shell assembly, TC, and loss of TC neutron shield evaluations are based on the approaches and results presented in Section 8.2. The 32PT DSC basket assembly cask drop evaluation is presented in more detail since the 32PT basket assembly is a new design.

A short discussion of the effect of the NUHOMS®-32PT DSC on the transfer operation, accident scenario and load definition is presented in Section M.3.7.5.1.

M.3.7.5.1 General Discussion

Cask Handling and Transfer Operation

Various TC drop scenarios have been evaluated in Section 8.2.5. The NUHOMS®-32PT DSC is heavier than the NUHOMS®-24P DSC. Therefore, the expected g loads for the postulated drop accidents would be lower. However, for conservatism, the g loads used for the NUHOMS®-24P analyses in Section 8.2.5 are also used for the NUHOMS®-32PT DSC analyses.

Cask Drop Accident Scenarios

In spite of the incredible nature of any scenario that could lead to a drop accident for the TC, a conservative range of drop scenarios are developed and evaluated. These bounding scenarios assure that the integrity of the DSC and spent fuel cladding is not compromised. Analyses of these scenarios demonstrate that the TC will maintain the structural integrity of the DSC pressure containment boundary. Therefore, there is no potential for a release of radioactive materials to the environment due to a cask drop. The range of drop scenarios conservatively selected for design are:

1. A horizontal side drop from a height of 80 inches.

2. A vertical end drop from a height of 80 inches onto the top or bottom of the TC (two cases). Vertical end drops for the NUHOMS® DSC are non-mechanistic. However, 60g vertical end drop analyses are performed as a means of enveloping the 25g corner drop (in conjunction with the 75g horizontal drop).

3. An oblique corner drop from a height of 80 inches at an angle of 30° to the horizontal, onto the top or bottom corner of the TC. This case is not specifically evaluated. The side drop and end drop cases envelope the corner drop.

Cask Drop Accident Load Definitions

Same as Section 8.2.5.1(C).

Cask Drop Surface Conditions

Same as 8.2.5.1(D).

M.3.7.5.2 DSC Shell Assembly Drop Evaluation

The shell assembly consists of the DSC shell, the shield plugs, and the top and bottom inner and outer cover plates. The shell assembly drop evaluation is presented in three parts:

1. DSC shell assembly horizontal drop analysis,

2. DSC shell assembly vertical drop analysis, and

3. DSC shell stability analysis.

M.3.7.5.2.1 DSC Shell Assembly Horizontal Drop Analysis

The DSC shell assembly is analyzed for the postulated horizontal side drop using the ANSYS 3-D models of the DSC shell assembly discussed in Section M.3.6.1.2. Half-symmetry (180°) models of the top end and bottom end sections of the DSC shell assembly are developed based on the models for the end drops shown in Figure 8.1-14a and Figure 8.1-14b. Each model includes one-half of the height of the cylindrical shell. Each of the DSC shell assembly components is modeled using ANSYS solid 3-D elements. The full weight of the DSC is conservatively assumed to drop directly onto a single TC rail. Elastic-plastic analyses are performed and stresses are determined for each DSC shell assembly component. The NUHOMS®-32PT DSC shell stresses in the region of the basket assembly are also analyzed for the postulated horizontal side drop conditions. This analysis and results are presented in Section M.3.7.5.3.1.

M.3.7.5.2.2 DSC Shell Assembly Vertical Drop Analysis

For this drop accident case, the TC is assumed to be oriented vertically and dropped onto a uniform surface. The vertical cask drop evaluation conservatively assumes that the TC could be dropped onto either the top or bottom surfaces. No credit is taken for the energy absorbing

capacity of the cask top or bottom cover plate assemblies during the drop. Therefore, the DSC is analyzed as though it is dropped on to an unyielding surface. The principal components of the DSC and internals affected by the vertical drop are the DSC shell, the inner and outer top cover plates, the shield plugs, and the inner and outer bottom cover plates.

M.3.7.5.2.3 DSC Shell Assembly Stress Analysis

The ANSYS analytical models of the DSC shell assembly as described in Section M.3.6.1.2 and shown in Figure 8.1-14a and Figure 8.1-14b are used to determine the vertical end drop accident stresses in the DSC shell, the inner cover plates, the outer cover plates, and the shield plugs. The models consist of 90° quarter symmetry models and include one-half of the height of the cylindrical shell. To capture the maximum stress state in the DSC assembly components, each model was analyzed for end drop loading on the opposite end (i.e., the bottom end model was analyzed for top end drop, and the top end model was analyzed for bottom end drop). In these drop orientations, the end plates are supported at the perimeter by the shell. For the top and bottom end drops, the nodal locations on the impacted end are restrained in the vertical direction. An equivalent static linear elastic analysis is conservatively used for the vertical end drop analyses. Inertia loadings based on forces associated with the 75g deceleration are statically applied to the models. Analyses show that the stresses in the DSC cover plates and shield plugs are low. These low stresses occur because for the bottom end drop, the inner and outer top cover plates are supported by the top shield plug. During a top end drop, the outer top cover plate is assumed to be supported by the unyielding impacted surface and is subjected to a uniform bearing load imposed by the DSC internals. The same is true for the DSC bottom outer cover plate and shield plug for the bottom end drop. The highest stresses occur in the DSC shell and bottom inner cover plate. The maximum stresses in the inner bottom cover plate result from the top end vertical drop condition, in which the inner bottom cover plate is supported only at the edges. The maximum DSC shell membrane stresses, which occur near the top end of the DSC shell area, result from the accelerated weight of the DSC shell and the bottom end (for top end drop case) or top end (for the bottom end drop case) assemblies.

A summary of the calculated stresses for the main components of the DSC and associated welds is provided in Table M.3.7-1.

M.3.7.5.2.4 DSC Shell Stability Analysis

The stability of the DSC shell for a postulated vertical drop impact is also evaluated. For Level D conditions, the allowable axial stress in the DSC shell is based on Appendix F of the ASME Code. The maximum axial stress in the DSC shell obtained from the 75g end drop analyses is 11.08 ksi. The allowable axial stress is 11.14 ksi. Therefore, buckling of the DSC shell for a 75g vertical deceleration load does not occur.

M.3.7.5.3 Basket Assembly Drop Evaluation

As discussed in previous chapters, the structural components of the basket assembly include the fuel support grid and the transition rails.

The DSC resides in the TC for all drop conditions. Horizontally, the DSC is supported in the TC by two cask rails that are integral to the cask wall. The effect of these cask rails are included in the horizontal drop evaluations.

Vertical drops are non-mechanistic for the 32PT horizontal storage system, therefore, as noted in Section M.3.7.5.1, no end drops are postulated. However, to provide an enveloping load for the postulated 25g corner drop, a 60g end drop is evaluated. For this drop, the end of the DSC/basket assembly is supported by the ends of the TC.

The stress evaluation of the 32PT DSC basket assembly is presented in three parts:

1. Basket assembly horizontal drop stress analyses, including evaluation of the fuel support grid and the transition rails: The ANSYS model described in Section M.3.6.1.3 is used for all stress analyses except for the 45° drop evaluation of the basket assembly with 3-piece R90 transition rails, where the LS-DYNA model described in Section M.3.7.12 is used.

2. Basket assembly horizontal drop stability analyses including the fuel support grid and the transition rails: The ANSYS model described in Section M.3.6.1.3 is used for all stability analyses except for the 45° drop evaluation of the basket assembly with 3-piece R90 transition rails, where the LS-DYNA model described in Section M.3.7.12 is used. The criteria of the ASME B&PV Code, Appendix F-1341.3 is used.

3. Basket assembly vertical drop analysis which includes a stress evaluation of the fuel support grid and transition rails using hand calculations as described in Section M.3.6.1.3 for vertical deadweight. The stress criteria used for the vertical drop analysis also provide assurance of structural stability.

Within the basket grid structure are plates of Type 1100 aluminum and neutron absorbing materials composed of either enriched borated aluminum alloy or Boralyn® plates which perform heat transfer and criticality functions and are not included in the finite element models. The hand-calculated bounding accident condition axial stress in the plates is 1.0 ksi, due to the 60g end drop, which is below the yield stress value of 1.5 ksi (Type 1100 aluminum at 720°F). This ensures that the plates remain in position to perform their heat transfer and criticality functions. For the 75g side drop loading, the aluminum plates are supported in the transverse direction along their length by either the grid structure or the fuel assemblies. Deflection of the aluminum plates in the transverse direction is limited by the gap between the grid structure and the fuel assembly and does not significantly affect the heat transfer function of the plates. The effect of this gap is bounded by the criticality evaluation.

M.3.7.5.3.1 Basket Assembly Horizontal Drop Analysis

M.3.7.5.3.1.1 Basket and Basket Rail Stress Analysis

The ANSYS and LS-DYNA models described in Section M.3.6.1.3 and in Section M.3.7.12, respectively, are used to perform stress analyses of the 32PT basket assembly for horizontal drop loads. The finite element models include the fuel support grid, transition rails, DSC shell, and

the effects of the TC rails. Contact elements between the parts of the structure are active for all the stress analyses.

Loads

Inertia loads corresponding to the drop accelerations are applied to the structure by including the appropriate weight density of the materials and applying accelerations. Fuel loads are applied using pressure loads (or nodal forces) on the fuel grid elements. As previously described, thermal effects are included by applying temperatures (corresponding to the 117°F ambient temperature condition, DSC in the TC case) to each node in the model. This includes thermal effects in the model and applies the temperature dependent material properties at different model locations.

Side drop orientations were selected to maximize both axial compression and bending stresses in the basket structure. Zero degree (0°) drop orientations were selected to maximize axial compression while an orientation of 45° (from vertical) was selected to maximize bending loads. Drops onto the TC rails were selected to maximize load concentrations. Table M.3.7-2 lists the stress analyses configurations performed for the postulated side drop.

Material Properties

The material properties used in the accident condition stress analyses are listed in Table M.3.7-3 for the 32PT basket structural components. The evaluations were performed using bilinear elastic-plastic material properties. For the steel components, the plastic slope was taken as 5% of the elastic modulus ($E_{tan} = 0.05E$) and Code values of yield stresses were used. For the aluminum transition rails, yield stresses were taken from Table M.3.3-5, and a lower bound plastic slope of 0.01E was used.

Results

Fuel grid stresses are linearized at the locations shown in Figure M.3.6-5. Enveloping stresses in each basket component are listed in Table M.3.7-4 for the postulated 75g side drop. The stresses are the maximum values in each component from the analyses listed in Table M.3.7-2. Table M.3.7-4 includes a comparison of the calculated stresses to Service Level D stress allowables for elastic-plastic analyses based on the stress criteria from Table M.2-17 and materials data from Table M.3.3-1 and Table M.3.3-3. As shown, all stress ratios are less than 1.0. Results are illustrated in Figure M.3.7-3 and Figure M.3.7-5 for the 1-piece R90 rail configuration and Figure M.3.7-3A and Figure M.3.7-5A for the 3-piece R90 rail configuration.

M.3.7.5.3.2 Basket Assembly Part71 End Drop Analysis

As noted in Section M.3.7.5.1, end drops are non-mechanistic for the 32PT system. End drop results are included to demonstrate margin for the postulated 25g corner drop.

Under axial loading, the fuel assemblies and basket assembly are supported by the bottom of the DSC/cask. The fuel assemblies react directly against the bottom or top end of the DSC/cask and do not load the basket structure. Stresses under axial loading result only from the self weight/inertia of the basket structure. In addition, since any connections between the fuel

support grid and transition rails are slotted (to allow for thermal expansion preventing thermal stresses), each part of the basket structure is loaded only by its own weight/inertia.

Compressive axial stresses are maximum at the "supported" end of the basket structure. Stresses are calculated using hand calculations and are summarized, and compared to the acceptance criteria, in Table M.3.7-5. As shown by the table, all stresses are well below the allowable values.

M.3.7.5.3.3 Basket Assembly Stability Analysis

Stability under axial loading is demonstrated by the results described in Section M.3.7.5.3.2 above. To demonstrate stability of the 32PT basket structure under side loading, a series of stability analyses were performed. As listed in Table M.3.7-3, the stability evaluations were performed using the criteria of ASME B&PV Code, Appendix F-1341.3 which establishes the allowable load as 90% of the Limit Analysis Collapse Load where the Limit Analysis Collapse Load is the maximum load determined using elastic-perfectly plastic material properties with a yield stress equal to the lesser of $2.3S_m$ or $0.7S_u$.

- For the basket configuration with 1-piece R90 transition rails, the stability analyses were performed using the ANSYS models described in Section M.3.6.1.3
- For the basket configuration with 3-piece R90 transition rails, stability analyses for 0° and 180° drop orientations were performed using the ANSYS models described in Section M.3.6.1.3. For the 45° drop orientation, the stability analysis was performed using the LS-DYNA model described in M.3.7.12.

The stability analyses performed for the 32PT basket assembly are listed in Table M.3.7-6. The results of the stability analyses are summarized in Table M.3.7-7. These analyses demonstrate stability of the structural components of the basket structure with ample margin for 75g loading.

LS-DYNA was also used to perform confirmatory stability analyses. The LS-DYNA confirmatory analyses used the same material properties and assumptions as the ANSYS analyses. Results of these analyses are listed in Table M.3.7-7A along with the ANSYS results. These confirmatory analyses are performed using the welded steel rail configuration and are included here for comparison purposes only. Displaced shape plots from the 0° and 180° analyses are included as Figure M.3.7-6 and Figure M.3.7-8, respectively. The plots show the geometry just past the stability load. Also included are displacement "time history" (load [time] vs. displacement) plots for the node locations indicated in the geometry plots (See Figure M.3.7-7 and Figure M.3.7-9). These "time history" plots clearly show the stability point of the structure.

M.3.7.5.3.3.1 Fuel Support Structure Stability Evaluation Using Hand Calculations

A confirmatory stability analyses for the fuel grid structure was performed using hand calculations, the column stability criteria of ASME B&PV Code, Appendix F-1334.3(b), and ASME Code yield stress values as listed in Table M.3-3. The criteria were developed for a material temperature of 600°F, which corresponds to the maximum temperature at the most highly loaded ligaments at the periphery of the fuel support grid.

The "bottom" span of the "center" ligament is selected as the critical location. The compressive load in this ligament is determined as follows:

- A load of 11.0 lb/in was applied to each fuel cell. This represents an enveloping load.
- The loads from the four (4) cells along the bottom edge of the basket are transferred directly into the transition rails without loading the "columns" of the fuel grid.
- The subject ligament is assumed to carry half the load in the central cells above the bottom row. Thus, there are 10 cells above the ligament, and 1/2 the load is carried by the subject ligament while the remaining load is carried by the adjacent columns. Therefore, the load from 5 fuel cells is applied to the subject ligament.

The self weight/inertia of the basket assembly was neglected.

The load on the subject ligament is:

$$P = (75g)(11.0\,{}^{lb}/_{in})(5\text{ cells})(1.0\text{ in})$$
$$= 4.13\,{}^{kip}/_{ligament}$$

The stress is:

$$f_a = \frac{(4.13\,{}^{kip}/_{ligament})}{0.25\text{ in}} = 16.5\text{ ksi}$$

The allowable under the side drop load is determined using the following equations from ASME B&PV Code, Appendix F-1334.3(b):

$$F_a = S_y\left(\frac{(1-\lambda^2/4)}{1.11+0.5\lambda+.17\lambda^2-0.28\lambda^3}\right)$$

where: $$\lambda = \left(\frac{Kl}{r}\right)\left(\frac{1}{\pi}\right)\left(\frac{S_y}{E}\right)^{1/2}$$

$$r = \frac{t}{(12)^{1/2}}$$

L = cell height of 8.825"

The allowable axial compression stress, F_a, is 19.0 ksi and the ratio of calculated to allowable stresses is:

$$\frac{16.5\,ksi}{19.0\,ksi} = 0.87$$

M.3.7.5.3.3.2 Results of Basket Stability Analysis

The results of the analyses indicate the structural capacity of the NUHOMS®-32PT basket assembly is higher than the postulated 75g side drop impact load. Thus, the 32PT basket assembly is stable under the postulated side drop loads.

M.3.7.5.4 On-site TC Horizontal and Vertical Drop Evaluation

An analysis has been performed in Section 8.2.5.2 to evaluate the OS197 and OS197H TCs for postulated horizontal and vertical drop accidents with a static equivalent deceleration of 75g's. The evaluations for the OS197 and OS197H casks are based on payload weights of 97,250 lbs and 116,000 lbs, respectively. The maximum total cask payload weight with a dry-loaded NUHOMS®-32PT DSC is approximately 102,000 lbs. Therefore, the OS197H cask is acceptable with any NUHOMS®-32PT DSC and the OS197 cask is acceptable with a NUHOMS®-32PT DSC where the total cask payload weight is not more than 97,250 lbs.

M.3.7.5.5 Loss of Neutron Shield

No impact on the structural evaluation.

M.3.7.6 Lightning

No impact on the structural evaluation.

M.3.7.7 Blockage of Air Inlet and Outlet Openings

This accident conservatively postulates the complete blockage of the HSM ventilation air inlet and outlet openings on the HSM side walls.

Since the NUHOMS® HSMs are located outdoors, there is a remote probability that the ventilation air inlet and outlet vent openings could become blocked by debris. The NUHOMS® design features such as the perimeter security fence and the redundant protected location of the air inlet and outlet vent openings reduces the probability of occurrence of such an accident. Nevertheless, for this conservative generic analysis, such an accident is postulated to occur and is analyzed.

The structural consequences due to the weight of the debris blocking the air inlet and outlet vent openings are negligible and are bounded by the HSM loads induced for a postulated tornado (Section 8.2.2) or earthquake (Section 8.2.3).

The thermal effects of this accident for the NUHOMS®-32PT DSC are described in Section M.4.0.

M.3.7.8 DSC Leakage

The 32PT DSC is leak tested to meet the leaktight ($1x10^{-7}$ std. cm^3/sec) of ANSI N145-1997 [3.13]. The analyses of the 32PT demonstrate that the pressure boundary is not breached since it meets the applicable stress limits for normal, off-normal and postulated accident conditions.

M.3.7.9 Accident Pressurization of DSC

The NUHOMS® 32PT DSC is evaluated and designed for the maximum accident pressures calculated in Section M.4.0. The pressure boundary stresses due to this pressure load are bounded by the results presented in Table M.3.7-10. Therefore, the 32PT-DSC is acceptable for this postulated accident condition.

M.3.7.10 Load Combinations

The load categories associated with normal operating conditions, off-normal conditions and postulated accident conditions are described and analyzed in previous sections. The load combination results for the NUHOMS® components important to safety are presented in this section. Fatigue effects on the TC and the DSC are also addressed in this section.

M.3.7.10.1 DSC Load Combination Evaluation

As described in Section 3.2, the stress intensities in the DSC at various critical locations for the appropriate normal operating condition loads are combined with the stress intensities experienced by the DSC during postulated accident conditions. It is assumed that only one postulated accident event occurs at any one time. The DSC load combinations summarized in Table 3.2-6 are expanded in Table M.2-15 for the 32PT DSC. Since the postulated cask drop accidents are by far the most critical, the load combinations for these events envelope all other accident event combinations. Table M.3.7-8 through Table M.3.7-10 tabulate the maximum stress intensity for each component of the DSC calculated for the enveloping normal operating, off-normal, and accident load combinations. For comparison, the appropriate ASME Code allowables are also presented in these tables.

M.3.7.10.2 DSC Fatigue Evaluation

Although the normal and off-normal internal pressures for the NUHOMS®-32PT DSC are higher relative to the NUHOMS®-24P DSC, the range of pressure fluctuations due to seasonal temperature changes are essentially the same as those evaluated for the NUHOMS®-24P DSC. Similarly, the normal and off-normal temperature fluctuations for the NUHOMS®-32PT DSC due to seasonal fluctuations are essentially the same as those calculated for the NUHOMS®-24P DSC. Therefore, the fatigue evaluation presented in Section 8.2.10.2 for the 24P DSC remains applicable to the NUHOMS®-32PT DSC.

M.3.7.10.3 TC Load Combination Evaluation

There is no change to the TC load combination evaluations. The evaluations performed in Sections 8.1 and 8.2 for the OS197 and OS197H casks are based on payloads of 97,250 lbs and 116,000 lbs, respectively. The maximum total cask payload with a dry-loaded NUHOMS®-32PT DSC is approximately 102,000 lbs. Therefore, the OS197H cask is acceptable with any NUHOMS®-32PT DSC and the OS197 cask is acceptable with a NUHOMS®-32PT DSC where the total cask payload is not more than 97,250 lbs.

M.3.7.10.4 TC Fatigue Evaluation

No change.

M.3.7.10.5 HSM Load Combination Evaluation

Since the weight of the NUHOMS®-32PT DSC is bounded by the DSC weights used in Sections 8.1 and 8.2, there is no change to the HSM load combination evaluation.

M.3.7.10.6 Thermal Cycling of the HSM

No change.

M.3.7.10.7 DSC Support Structure Load Combination Evaluation

See Section M.3.7.10.5 above.

M.3.7.11 Evaluation of Poison Rod Assemblies

The Poison Rod Assemblies (PRA) consist of Type 304 stainless steel tubes filled with Boron carbide pellets or Boron powder that are inserted into the fuel assemblies through the guide tubes. They each contain up to 24 rods depending on the type of fuel assembly and are held together at the top end with a support plate as shown schematically in Figure M.1-2.

The PRAs are near the fuel rods, so their temperature is conservatively assumed to be the same temperature as the fuel cladding. Table M.4-13 reports that the maximum fuel cladding temperature during the postulated accidental blocked vent condition remains below 800°F. Table M.4-16 reports that the maximum fuel cladding temperature during vacuum drying is 810°F, which is acceptable because vacuum drying is a short term event.

In the vertical direction, the PRAs are supported by the support plate at the top end of the fuel assembly. The most limiting vertical load occurs during the postulated 60g end drop (See Section M.3.7.5.1) where the PRAs are supported by the support plate. All longitudinal loading is due solely to the inertia of each tube and contents. The PRAs are continuously supported by the guide tubes, thus elastic stability is not limiting. The PRAs are an open system and are thus not pressurized, so there is no hoop component of stress. Using the geometry of the PRA cladding shown in Figure M.1-2, the maximum fuel assembly length is 171.71 inches (see Table M.2-2). Assuming that the PRA contents have a density of 2.5 lb/in^3, the maximum longitudinal stress (and stress intensity) in the PRA cladding is approximately 5.9 ksi. This stress intensity is well below the Type 304 Service Level D membrane allowable stress of 36.5 ksi at 800° F (See Tables M.3-2 and M.2-16).

In the horizontal direction, the PRAs are supported by the guide tubes during all normal, off-normal and postulated accident conditions; therefore, there are no limiting stresses associated with horizontal deadweight, transfer handling (with a horizontal load component), and the postulated side drop.

M.3.7.12 LS-DYNA Finite Element Model Analysis

An LS-DYNA (Version 960) model is used to evaluate stresses in the basket assembly with 3-piece R90 transition rails under 45° loading. LS-DYNA is used because its contact algorithm is a lot more robust than the one in ANSYS and, therefore, is better able to solve problems that include a large number of parts in contact with each other such as is the case for the 3-piece R90 transition rail configuration. The LS-DYNA model includes contact between all parts of the DSC, transfer cask, and basket, including the following:

- Fuel support grid to the four (4) R90 transition rail cover plates
- Fuel support grid to the four (4) R45 transition rails
- Each R90 transition rail cover plates to the three (3) parts of the adjacent 3-piece R90 transition rails
- The corners/ends of the R90 transition rail cover plates and the DSC Shell
- The DSC shell and the four R45 transition rails and the 12 pieces of the 3-piece R90 transition rail
- Between all adjacent sections of the 3-piece R90 transition rails
- The DSC shell and the Cask and Cask Rails.

The LS-DYNA model is based on the ANSYS model of the basket with the 3-piece R90 transition rails configuration. As noted above, contact was defined (modeled) between all parts that are in contact to each other. No connections were modeled between the transition rails, fuel grid, and/or R90 transition rails cover plates.

The LS-DYNA model uses plane stress elements to represent a unit length of the 32PT basket. The fuel support grid is modeled with four (4) elements through the thickness. A minimum of three (3) elements are used through the thickness of all other parts except the cask shell and the cask rails. The cask shell and cask rails are extremely rigid relative to the other parts of the structure and are modeled as rigid bodies and are fixed around their entire circumference. Therefore, the cask shell is modeled with only one through thickness element.

The geometry of the LS-DYNA basket model is shown in Figure M.3.7-10 and Figure M.3.7-11.

Inertial loads are applied to the structure by including the appropriate weight density of the materials and applying accelerations. Fuel loads are applied as forces to the nodes on the surfaces of the fuel grid elements. Thermal effects are included by applying temperatures corresponding to the 100°F in cask temperature distribution (fuel configuration 1) documented in Chapter M.4 and shown in Figure M.3.7-12.

Table M.3.7-1
Maximum NUHOMS®-32PT DSC Stresses for Drop Accident Loads

DSC Components	Stress Type	Calculated Stress (ksi)[1]	
		Vertical[3]	Horizontal
DSC Shell	Primary Membrane	14.54	36.47
	Membrane + Bending	39.64	55.83
Inner Top Cover Plate	Primary Membrane	2.41	25.08
	Membrane + Bending	5.87	39.19
Outer Top Cover Plate	Primary Membrane	2.22	34.46
	Membrane + Bending	5.12	55.25
Inner Bottom Cover Plate[4]	Primary Membrane	7.61	21.84
	Membrane + Bending	25.27	55.17
Outer Bottom Cover Plate	Primary Membrane	1.69	31.91
	Membrane + Bending	3.67	49.85
Inner Top Cover Plate Weld[2]	Primary	2.18	22.81
Outer Top Cover Plate Weld[2]	Primary	0.68	11.53

Notes:
(1) Values shown are maximums irrespective of location.
(2) Stress values are the envelope of drop loads with and without 20psig internal pressure.
(3) The vertical end drops are non-mechanistic for the NUHOMS® 32PT DSC. They are performed as a means of demonstrating qualification of the 25g corner drop. The analyses reported here are conservatively based on 75g deceleration.
(4) These stresses may also be applied to the single bottom end forging, when used.

Table M.3.7-2
List of Drop Condition ANSYS Stress Analyses of the 32PT Basket Assembly

Case	Load	DSC Configuration	Support Conditions	Analysis Code
1	75g Side Drop at 0°	32PT DSC with 1-piece aluminum transition rails	OS197 (Support Rails at ± 18.5°)	ANSYS
2	75g Side Drop at 45° from bottom center	32PT DSC with 1-piece aluminum transition rails	OS197 (Support Rails at ± 18.5°)	ANSYS
3	75g Side Drop at 180°	32PT with 1-Piece Aluminum Transition Rails	OS197 (Cask Rails Not Impacted)	ANSYS
4	75g Side Drop at 0°	32PT with 3-Piece R90 Aluminum Transition Rails	OS197 (±18.5°)	ANSYS
5	75g Side Drop at 45°	32PT with 3-Piece R90 Aluminum Transition Rails	OS197 (±18.5°)	LS-DYNA
6	75g Side Drop at 180°	32PT with 3-Piece R90 Aluminum Transition Rails	OS197 (Cask Rails Not Impacted)	ANSYS

Note: See Table M.3.7-6 for additional stability analyses performed for the 75g side drop load.

Table M.3.7-3
Summary of Material Properties for Drop Accident Analyses of the 32PT Basket Assembly

Component	Material	Drop Condition Analysis Material Properties		Evaluation Temperature
		Stress Analyses[1]	Stability Analyses[1,2]	
Fuel Support Grid	1/4" Thick, Type XM-19 Stainless Steel	Bilinear Elastic-Plastic S_y = Code S_y (Table M.3.3-3) E_{tan} =.05E_{Code} (Table M.3.3-3)	Bilinear Elastic-Perfectly Plastic (F-1341.3): S_y = min(2.3S_m,0.7S_u) E_{tan} = 0	800°F
Solid Aluminum Transition Rails, R90 Cover Plates	1/4" Thick, Type XM-19 Stainless Steel	Bilinear Elastic-Plastic S_y = Code S_y (Table M.3.3-3) E_{tan} =.05E_{Code} (Table M.3.3-3)	Bilinear Elastic-Perfectly Plastic (F-1341.3): S_y = min(2.3S_m,0.7S_u) E_{tan} = 0	600°
Solid Aluminum Transition Rails, Aluminum Bodies	6061 Aluminum Alloy	Bilinear Elastic-Plastic S_y = (Table M.3.3-5) E_{tan} =.01E (Table 3.3-5)	Bilinear Elastic-Plastic S_y = (Table M.3.3-5) E_{tan} =.01E (Table M.3.3-5)	Note 3

Notes:

1. Prior to application of drop loads, the structure was initialized to the temperatures corresponding to the 117°F in cask case.

2. For the steel components, stress checks were performed at the enveloping temperatures listed. For the aluminum transition rails, stress checks were performed at temperatures corresponding to the maximum stress point. Temperatures listed are for the maximum stress points of the most highly loaded rail (the large 90° transition rail at the "bottom" of the basket).

3. For accident condition loading, the transition rails support the fuel support grid such that stresses and displacements in the fuel grid are acceptable. Since the transition rails are entrapped between the fuel grid and the DSC shell, no additional checks (of the aluminum) are required for accident/drop loading. Qualification of the fuel grid (and R90 cover plate) demonstrate that the rails perform their intended function.

Table M.3.7-4
32PT Basket, Enveloping Stress Results - 75g Side Drops

Component	Stress Category	Stress Intensity		Stress Ratio	Notes
		Calculated	Allowable		
Basket with 1-Piece R90 Transition Rails					
Fuel Support Grid	P_m	26.2 ksi	59.4 ksi	.44	XM-19, 800°F(2)
	$P_m + P_b$	73.9 ksi	76.3 ksi	.97	
Transition Rail Cover Plates	P_m	7.63 ksi	59.4 ksi	0.13	XM-19, 800°F(2)
	$P_m + P_b$	64.4 ksi	76.3 ksi	.84	
Basket with 3-Piece R90 Transition Rails					
Fuel Support Grid	P_m	27.0	60.4	0.45	XM-19, 705°F(3)
	$P_m + P_b$	76.2	77.7	0.98	

Note: 1. Although all the listed values include thermal effects, evaluation of secondary stress not required for Level D events.

2. Allowable stress based on an enveloping temperature of 800°F.

3. Allowable stress based on maximum basket temperature (see Figure M.3.7-12).

Table M.3.7-5
32PT Basket, Enveloping Stress Results - 60g Part 71 End Drop

Component	Stress (Axial (Compression)			Notes
	Calculated	Allowable	Ratio	
Fuel Support Grid	3.30 ksi	31.8 ksi	.10	XM-19, 800°F
Aluminum Transition Rails	1.03 ksi	4.20 ksi	.25	6061 Al., 600°F

Table M.3.7-6
Drop Condition Stability Analyses for the 32PT Basket Assembly

Case	Load	DSC Configuration	Support Conditions	Analysis Code
1	Side Drop at 0°	32PT DSC with aluminum transition rails	OS197 (Support Rails at ± 18.5°)	ANSYS
2	Side Drop at 45° from bottom center	32PT DSC with aluminum transition rails	OS197 (Support Rails at ± 18.5°)	LS-DYNA
3	Side Drop at 180° from Bottom center	32PT DSC with aluminum transition rails	OS197 n/a (cask rails not impacted)	ANSYS

Table M.3.7-7
Summary of 32PT Basket Stability Analysis -- Side Drops

Drop Orientation[1]	Stability Analyses	
	3-Piece Aluminum Transition Rails	1-Piece Aluminum Transition Rails
0° (OS197)	83.6g	107.6g
45° (OS197)	81.0g	90.7g
180°	112g	88.4g

Notes: 1. The OS197 cask rails are at ± 18.5° from bottom center. The 180° drops do not impact cask rails.

Table M.3.7-7A
Summary of 32PT Analysis Confirmatory Stability Analysis[1]

Drop Orientation	ANSYS	LS-DYNA
0°	98.0g	98.6g
180°	99.9g	110.4g

Notes: 1. The confirmatory analyses were performed for the Type 304-SS transition rails configuration.

Table M.3.7-8
NUHOMS®-32PT DSC Enveloping Load Combination Results for Normal and Off-Normal Loads
(ASME Service Levels A and B)

DSC Components	Stress Type	Controlling Load Combination[1]	Stress (ksi)	
			Calculated	Allowable[2]
DSC Shell	Primary Membrane	DD-1	9.09	17.5
	Membrane + Bending	TR-8	21.24	26.3
	Primary + Secondary	TR-3	55.63	60.0
Inner Bottom Cover Plate[7]	Primary Membrane	LD-5	4.49	17.5
	Membrane + Bending	NO-1	23.07	40.5
	Primary + Secondary	LD-4	49.26	54.3
Outer Bottom Cover Plate	Primary Membrane	UL-5, UL-6	6.83	18.7
	Membrane + Bending	UL-5, UL-6	25.53	28.1
	Primary + Secondary	LD-4	39.97	54.3
Inner Top Cover Plate	Primary Membrane	TR-5	2.65	17.5
	Membrane + Bending	DD-1	16.83	26.3
	Primary + Secondary	DD-1	30.45	52.5
Outer Top Cover Plate	Primary Membrane	TR-7	4.21	17.5
	Membrane + Bending	TR-7	8.83	26.3
	Primary + Secondary	TR-7	27.38	52.5

See Table M.3.7-11 for notes.

Table M.3.7-9
NUHOMS®-32PT DSC Enveloping Load Combination Results for Accident Loads

(ASME Service Level C)

DSC Components	Stress Type	Controlling Load Combination[1]	Stress (ksi)	
			Calculated	Allowable[2]
DSC Shell	Primary Membrane	HSM-8	17.79	21.7
	Membrane + Bending	HSM-8	30.58	32.6
Inner Bottom Cover Plate[7]	Primary Membrane	HSM-8	5.58	22.4
	Membrane + Bending	HSM-8	7.01	33.7
Outer Bottom Cover Plate	Primary Membrane	UL-7	8.59	22.4
	Membrane + Bending	UL-7	33.06	35.0
Inner Top Cover Plate	Primary Membrane	HSM-8	5.07	21.7
	Membrane + Bending	HSM-8	14.95	32.6
Outer Top Cover Plate	Primary Membrane	HSM-8	10.23	21.7
	Membrane + Bending	HSM-8	19.06	32.6

See Table M.3.7-11 for notes.

Table M.3.7-10
NUHOMS®-32PT DSC Enveloping Load Combination Results for Accident Loads
(ASME Service Level D)[3]

DSC Components	Stress Type	Controlling Load Combination[1]	Stress (ksi)	
			Calculated	Allowable[2]
DSC Shell	Primary Membrane	TR-10	36.47	44.4
	Membrane + Bending	TR-10	55.83	61.0[4]
Inner Bottom Cover Plate[7]	Primary Membrane	TR-10	38.36	44.4
	Membrane + Bending	TR-10	56.65	59.6[5]
Outer Bottom Cover Plate	Primary Membrane	TR-10	32.74	44.4
	Membrane + Bending	TR-10	51.31	57.1
Inner Top Cover Plate	Primary Membrane	TR-10	25.08	44.4
	Membrane + Bending	TR-10	46.30	57.1
Outer Top Cover Plate	Primary Membrane	TR-10	36.85	44.4
	Membrane + Bending	TR-10	55.86	58.6[6]

See Table M.3.7-11 for notes.

Table M.3.7-11
DSC Enveloping Load Combination Table Notes

(1) See Table M.2-15 for load combination nomenclature.

(2) See Table M.2-16 and M.2-17 for allowable stress criteria. Material properties were obtained from Section M.3.3 at a design temperature of 500° F or as noted.

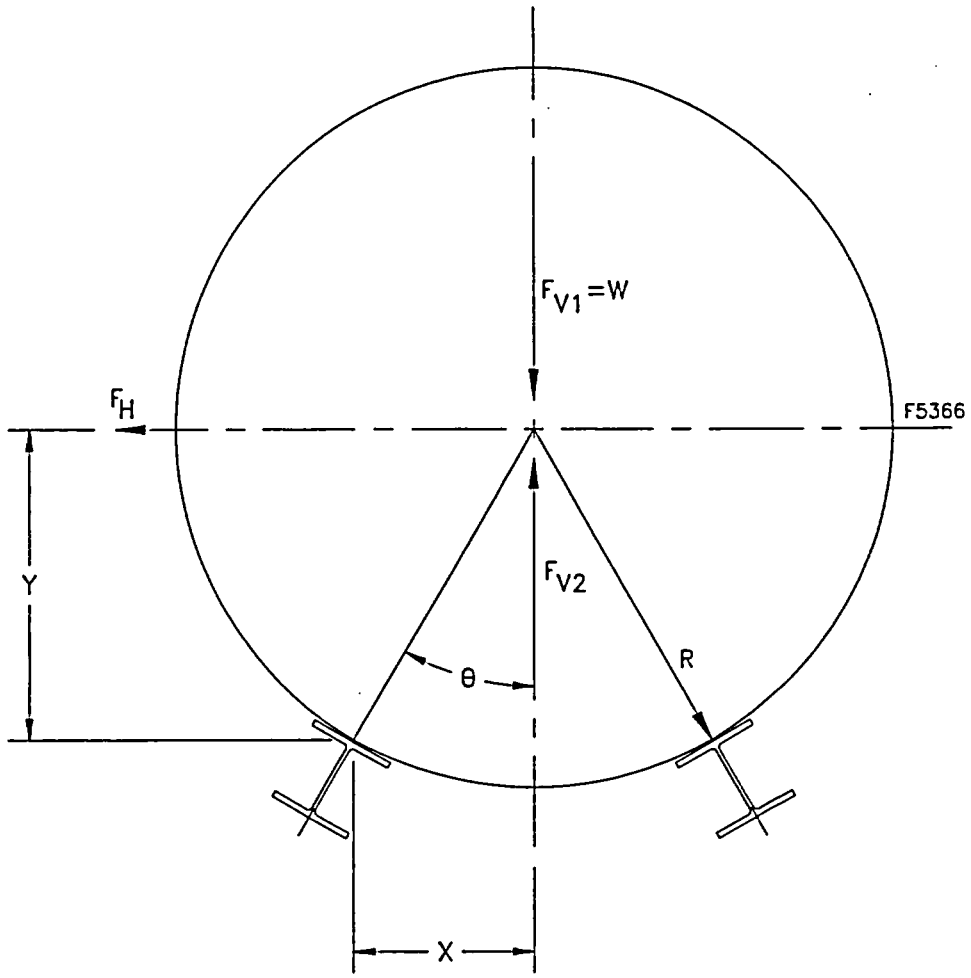
(3) In accordance with the ASME Code, thermal stresses need not be included in Service Level D load combinations.

(4) The maximum side drop membrane + bending stress is highly localized near the cask rail, at the outer bottom cover plate. The maximum temperature in this region is less than 266°F.

(5) The maximum side drop membrane + bending stress is highly localized over the cask rail. The maximum temperature in this region is less than 300°F.

(6) The maximum side drop membrane + bending stress is highly localized over the cask rail. The maximum temperature in this region is less than 350°F.

(7) These stresses may also be applied to the single bottom end forging, when used.



WHERE:

R = 33.595 in., DSC outer radius
θ = 30°
X = R Sin θ = 16.8 in.
Y = R Cos θ = 29.1 in.
F_{V1} = W = weight of DSC
F_{V2} = W(0.17g) = upward vertical seismic load
F_H = W(0.40g) = horizontal seismic load

Figure M.3.7-1
DSC Lift-Off Evaluation

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Figure M.3.7-2
0° Side Drop Stress Intensity, 32PT Basket with Steel Transition Rails
(Support Rails at ±18.5°)

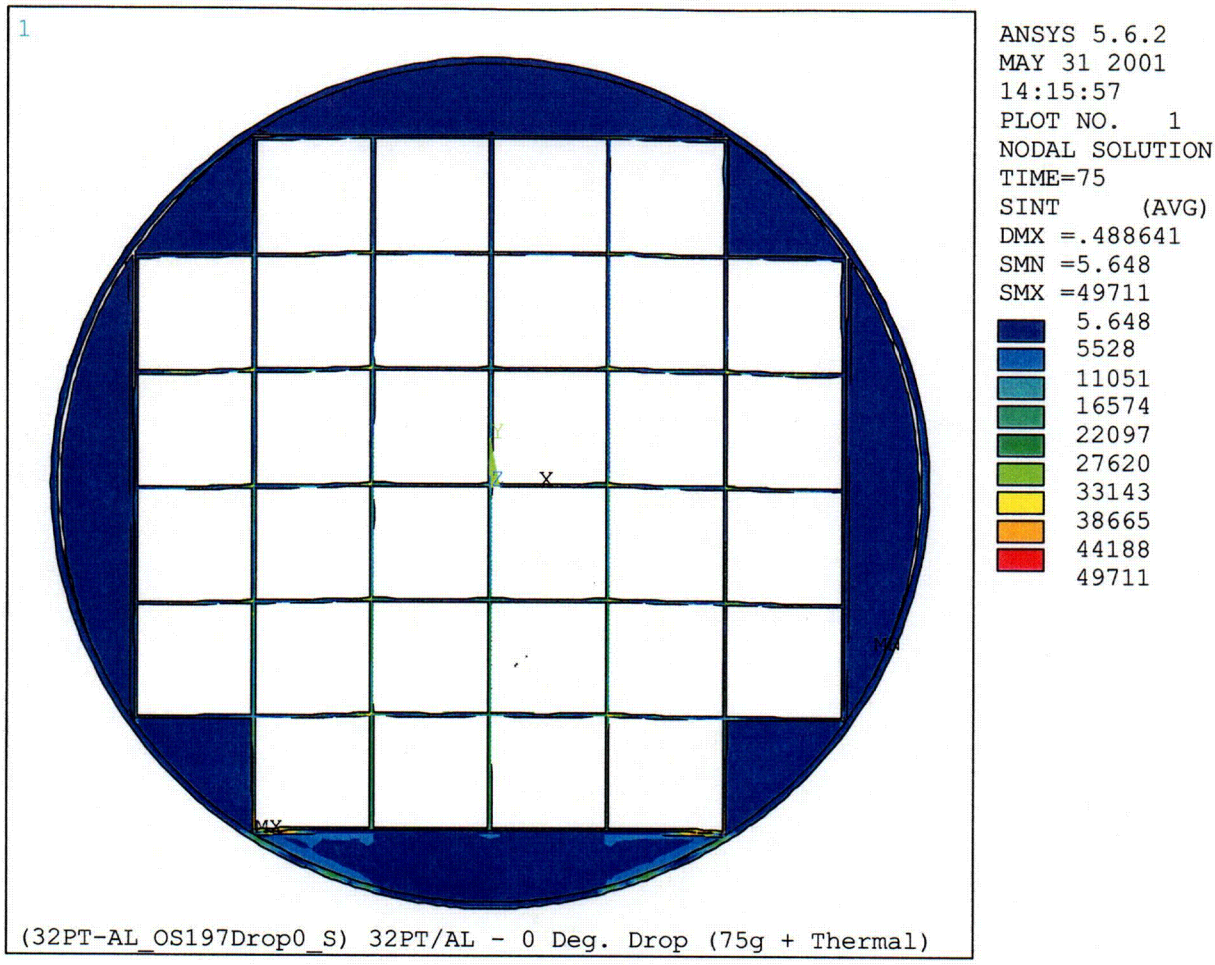

Figure M.3.7-3
0° Side Drop Stress Intensity, 32PT Basket with Aluminum Transition Rails (1-Piece R90)
(Support Rails at ±18.5°)

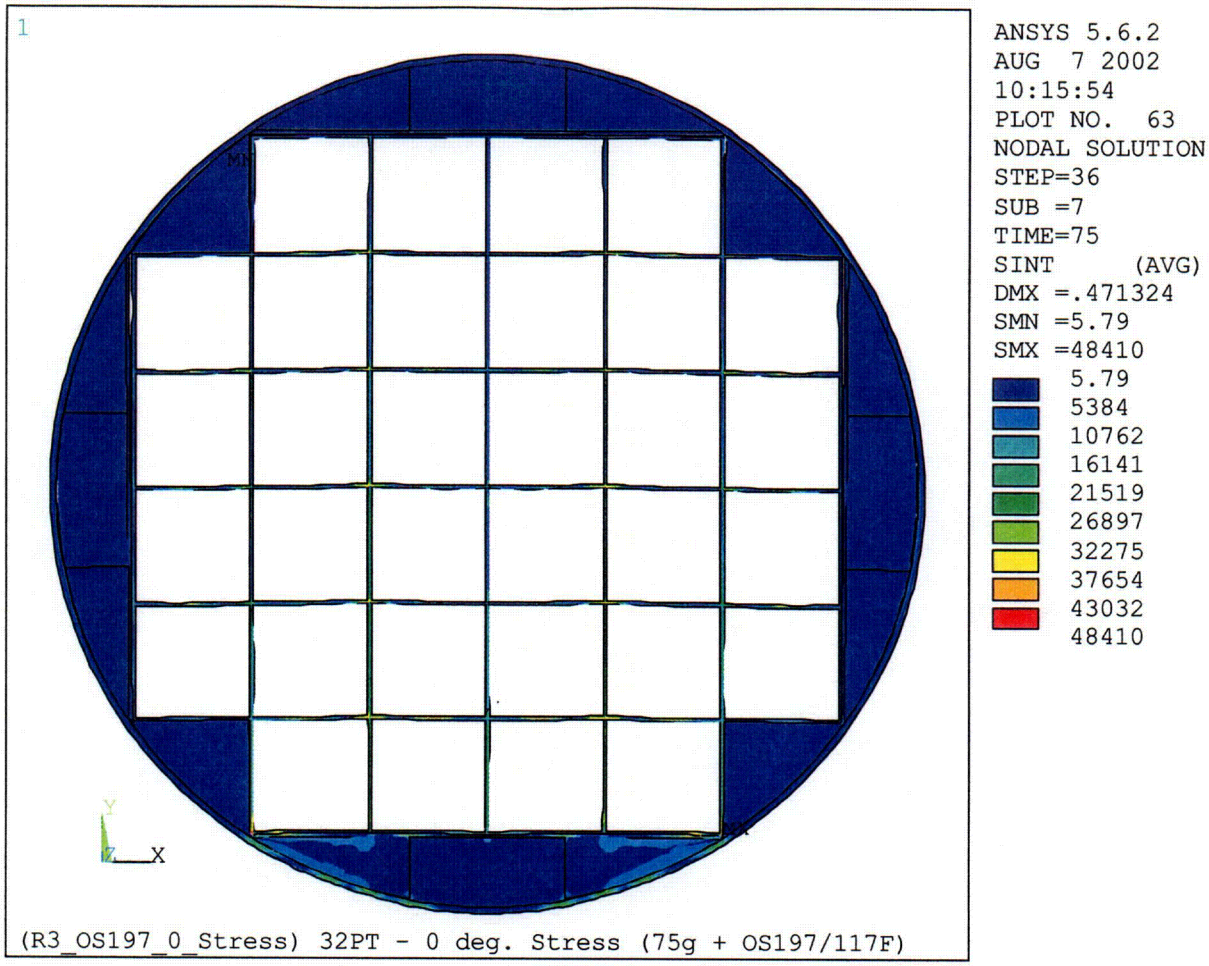

Figure M.3.7-3A
0° Side Drop Stress Intensity, 32PT Basket with Aluminum Transition Rails (3-Piece R90)
(Support Rails at ± 18.5°)

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Figure M.3.7-4
45° Side Drop Stress Intensity, 32PT Basket with Steel Transition Rails
(Support Rails at ±18.5°)

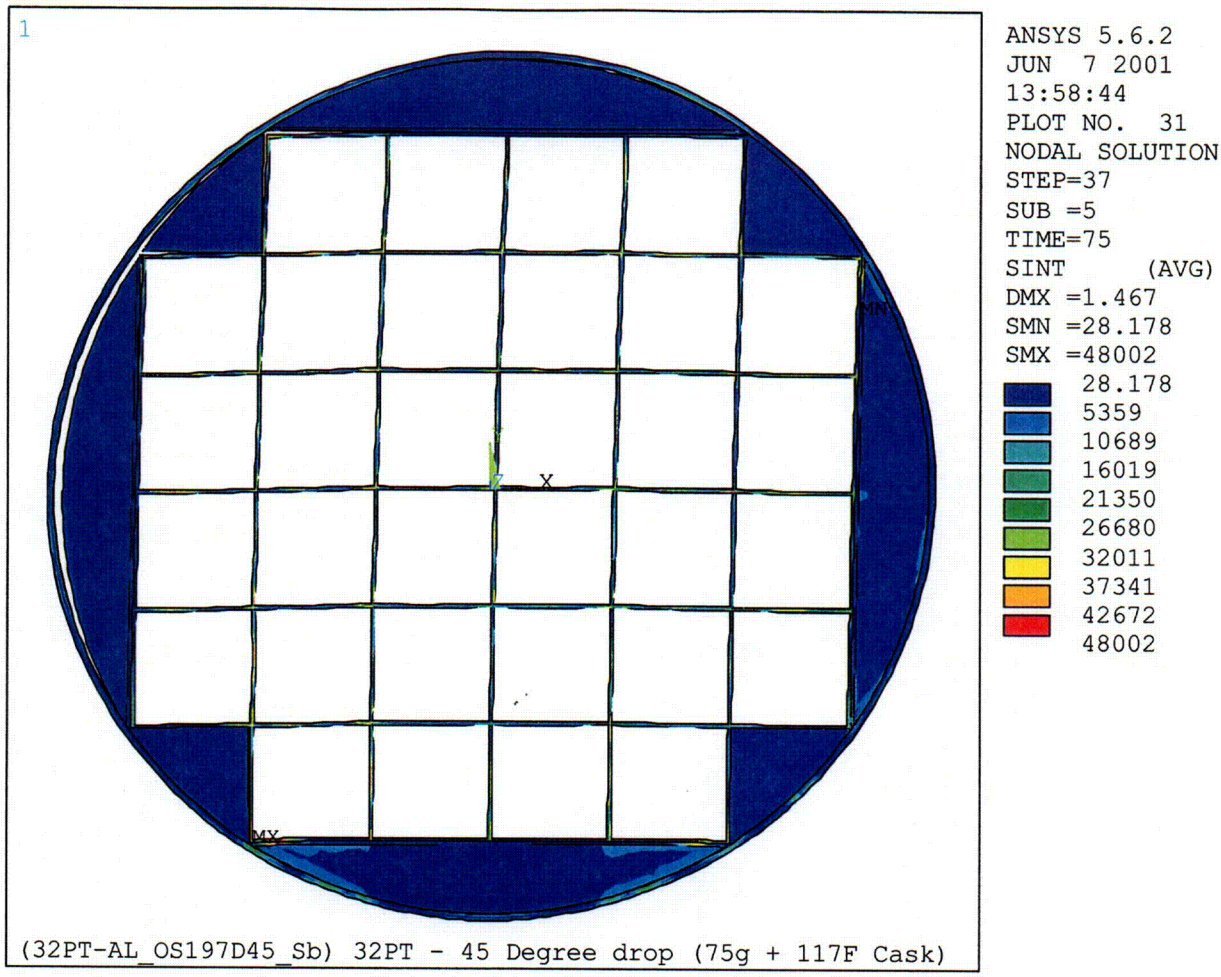
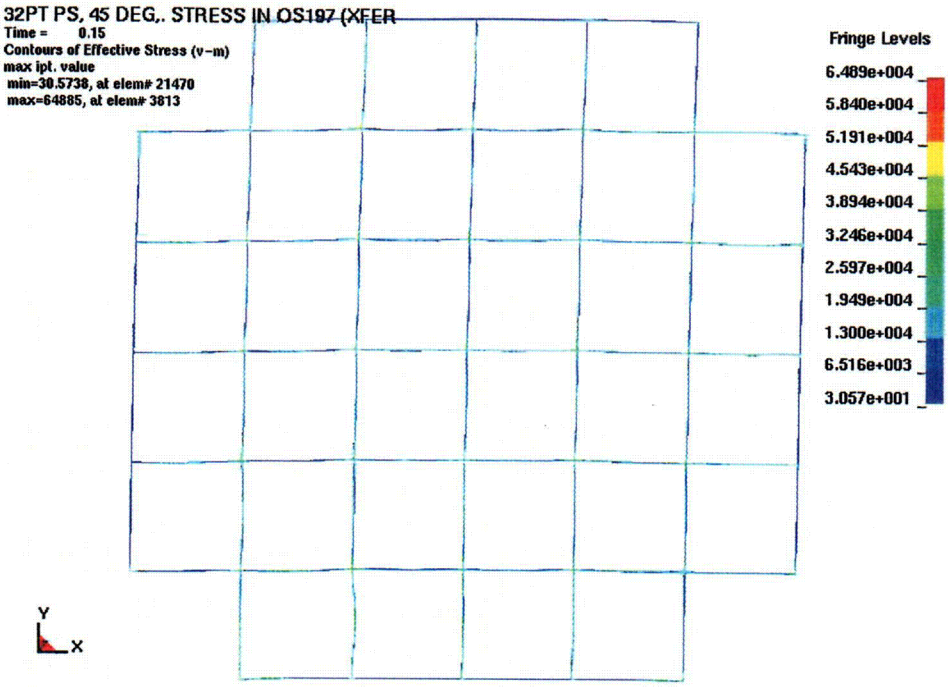


Figure M.3.7-5
45° Side Drop Stress Intensity, 32PT Basket with Aluminum Transition Rails (1-Piece R90)
(Support Rails at ±18.5°)



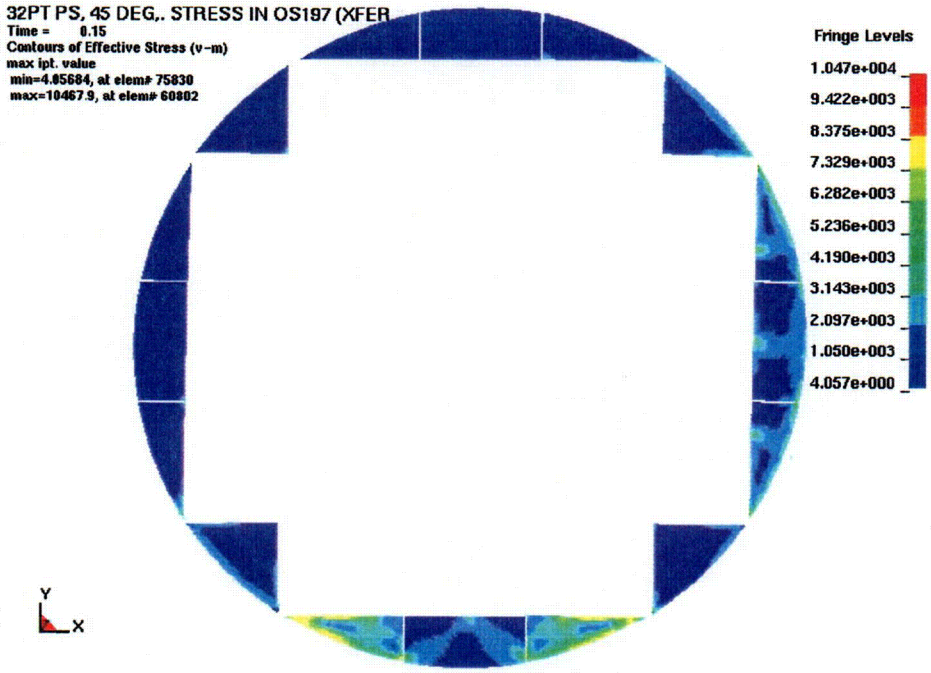


Figure M.3.7-5A
45° Side Drop Von Misses Effective Stresses, 32PT Basket with Aluminum Transition Rails (3-Piece R90) (Support Rails at ± 18.5°)

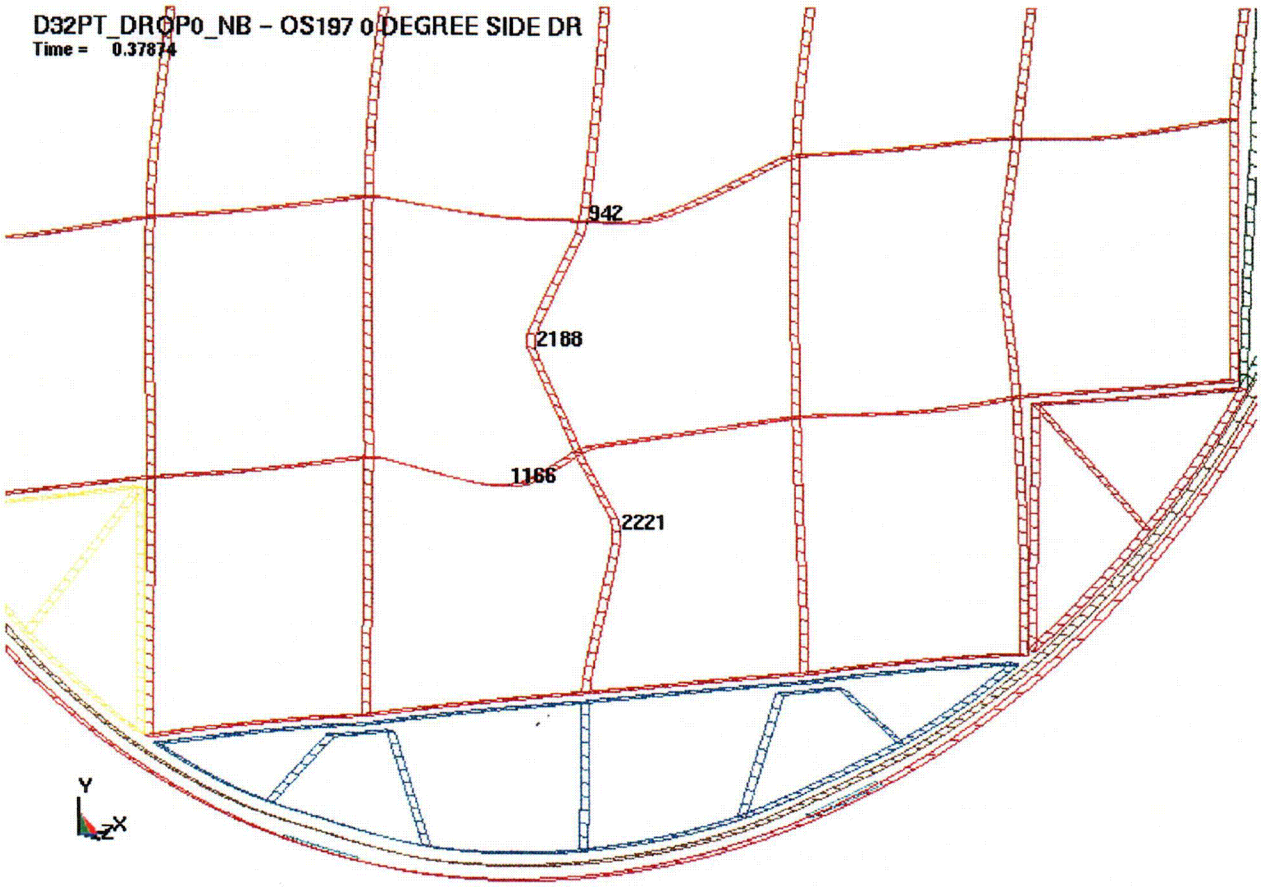
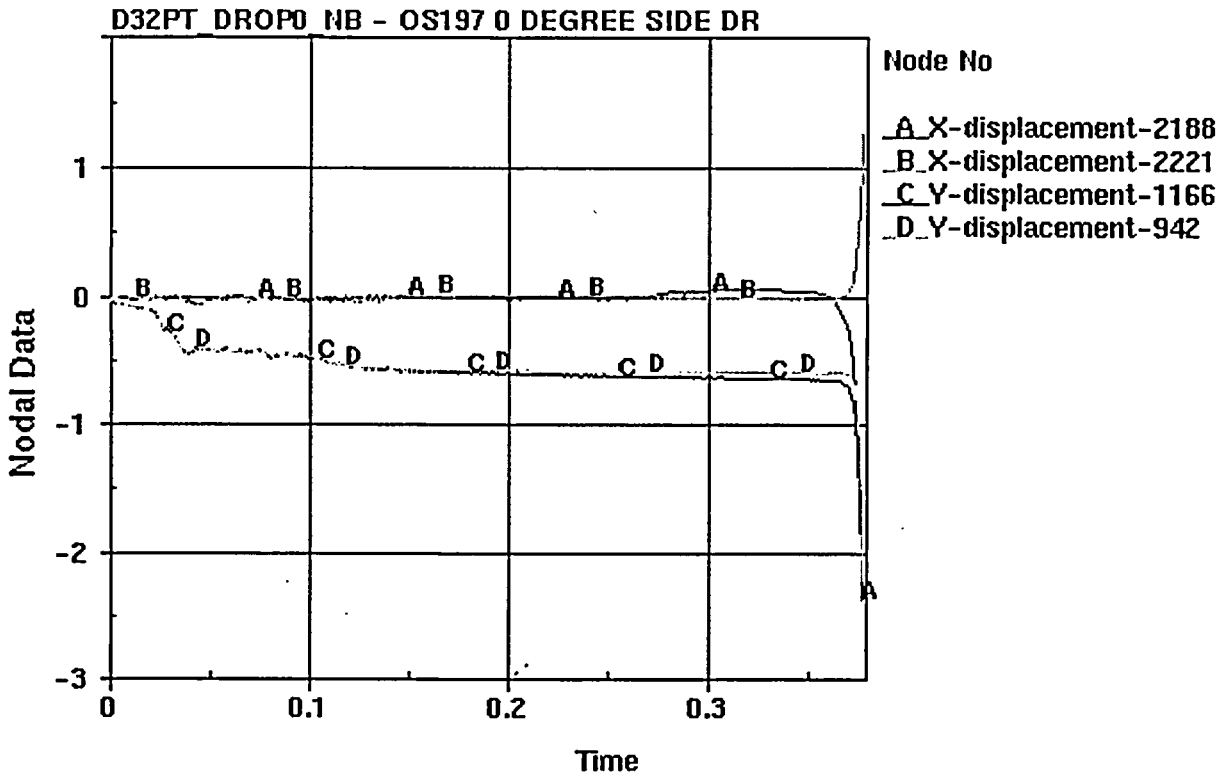


Figure M.3.7-6
Displaced Shape at 113g, LS-DYNA Confirmatory Stability Analysis for 0° Side Drop with Steel Transition Rails
(Support Rails at ±18.5°)

(See displacement time history on following page)



Time	g-load
0.10 sec.	1. g
0.15 sec.	26. g
0.20 sec.	50. g
0.25 sec.	75. g
0.30 sec.	90. g
0.35 sec.	105. g
0.40 sec.	120. g
0.45 sec.	135. g

Figure M.3.7-7
Displacement Time History, LS-DYNA Confirmatory Stability Analysis for 0° Side Drop with Steel Transition Rails

(See previous page for displaced shape and node locations)

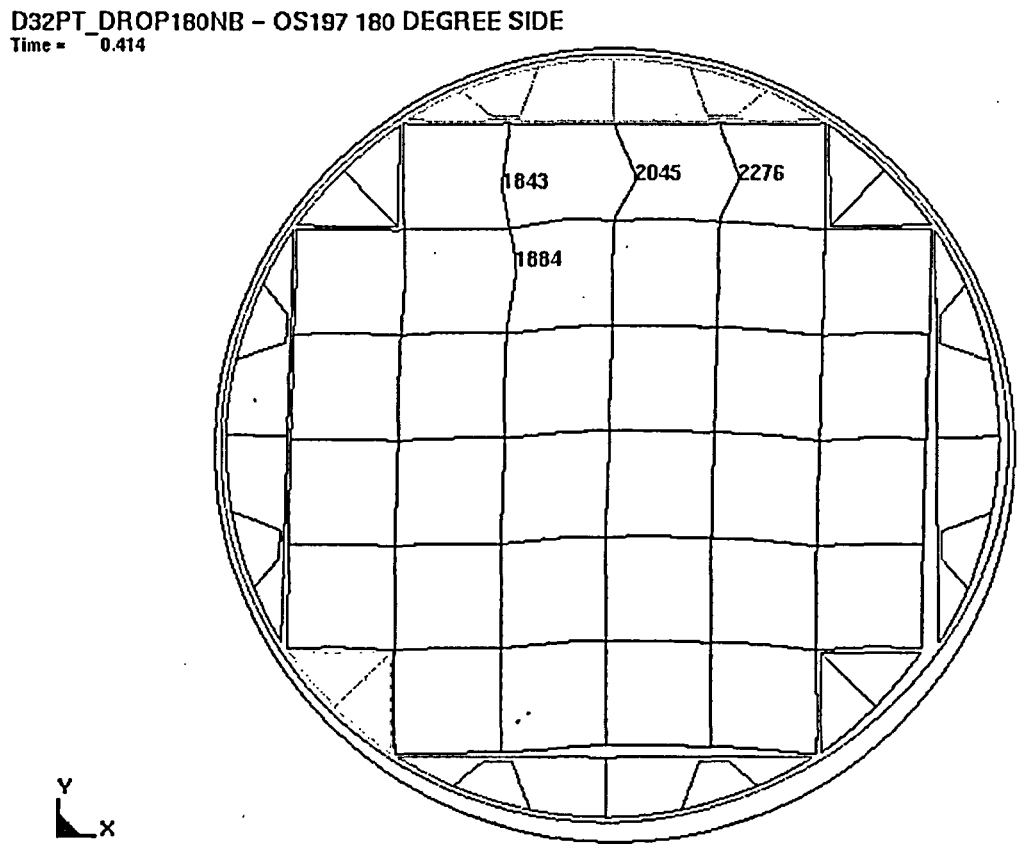
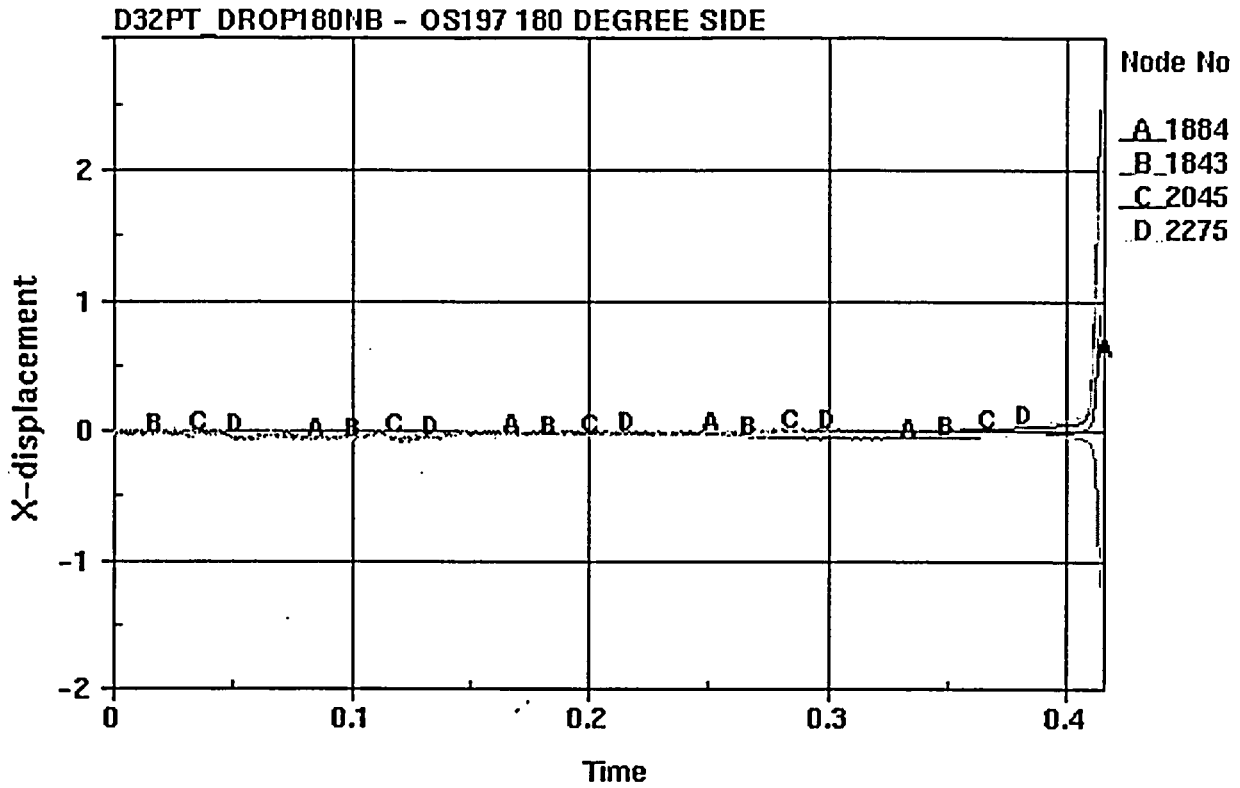


Figure M.3.7-8
Displaced Shape at 124g, LS-DYNA Confirmatory Stability Analysis for 180° Side Drop with Steel Transition Rails
(No Cask Rails at 180°)

(See displacement time history on following page)



Time	g-load
0.10 sec.	1. g
0.15 sec.	26. g
0.20 sec.	50. g
0.25 sec.	75. g
0.30 sec.	90. g
0.35 sec.	105. g
0.40 sec.	120. g
0.45 sec.	135. g

Figure M.3.7-9
Displacement Time History, LS-DYNA Confirmatory Stability Analysis for 180° Side Drop with Steel Transition Rails

(See previous page for displaced shape and node locations)

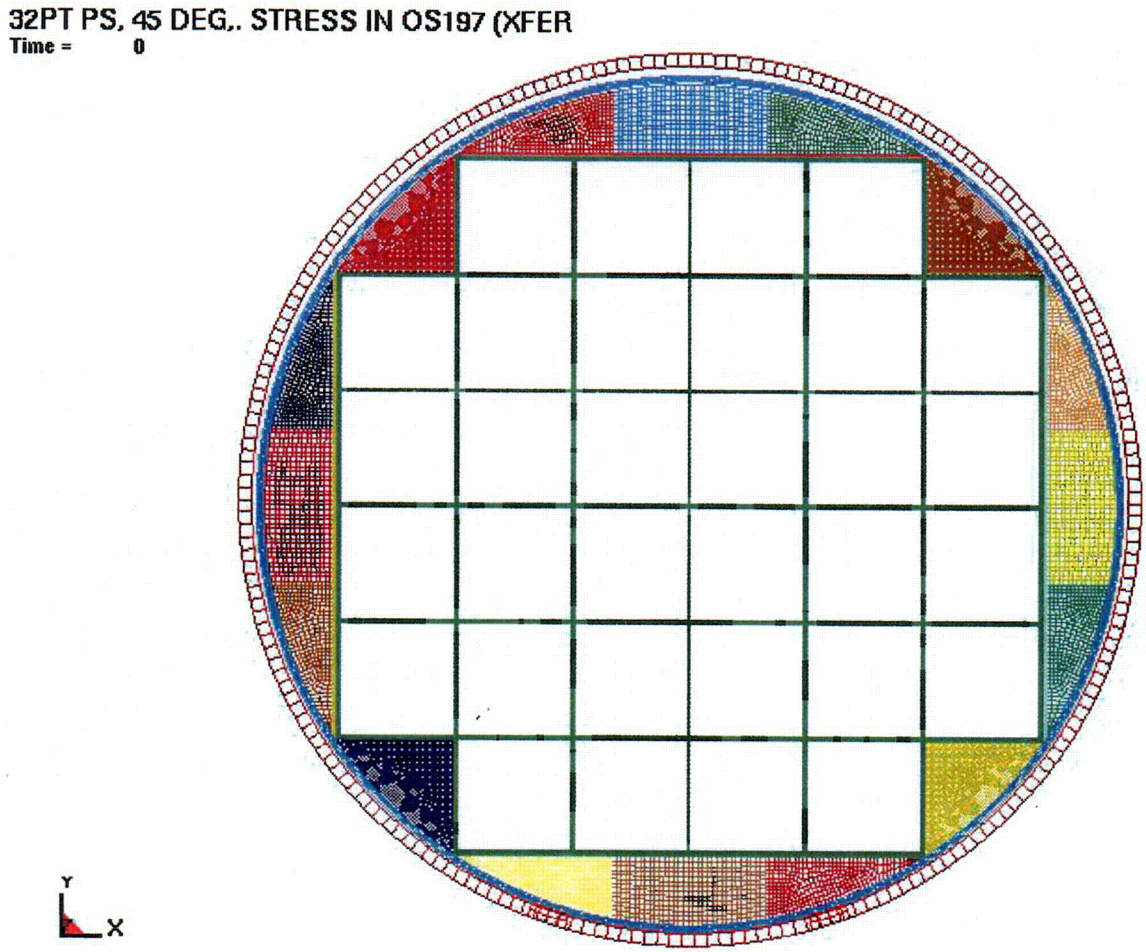


Figure M.3.7-10
LS-DYNA 32PT Basket Model with Aluminum Transition Rails (3-Piece R90)

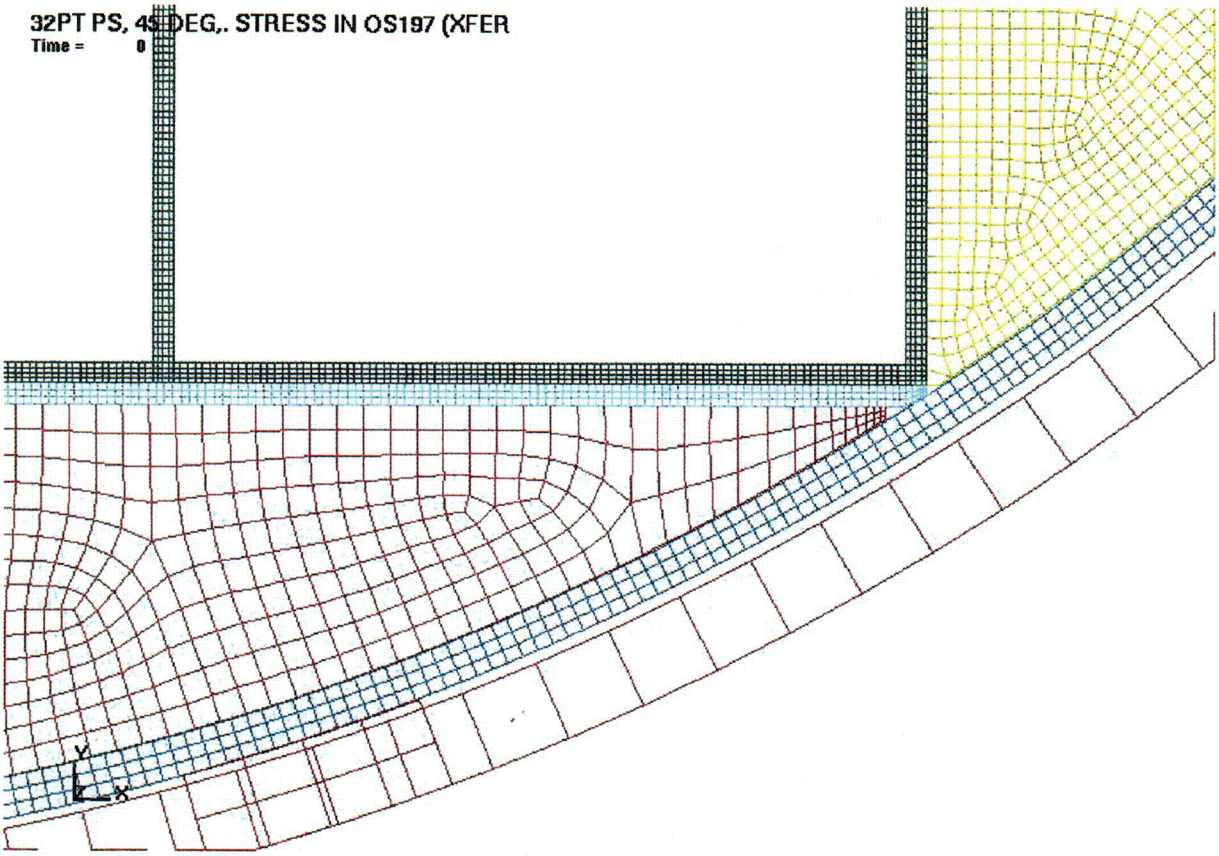


Figure M.3.7-11
LS-DYNA 32PT Basket Model with Aluminum Transition Rails (3-Piece R90) – Detailed View

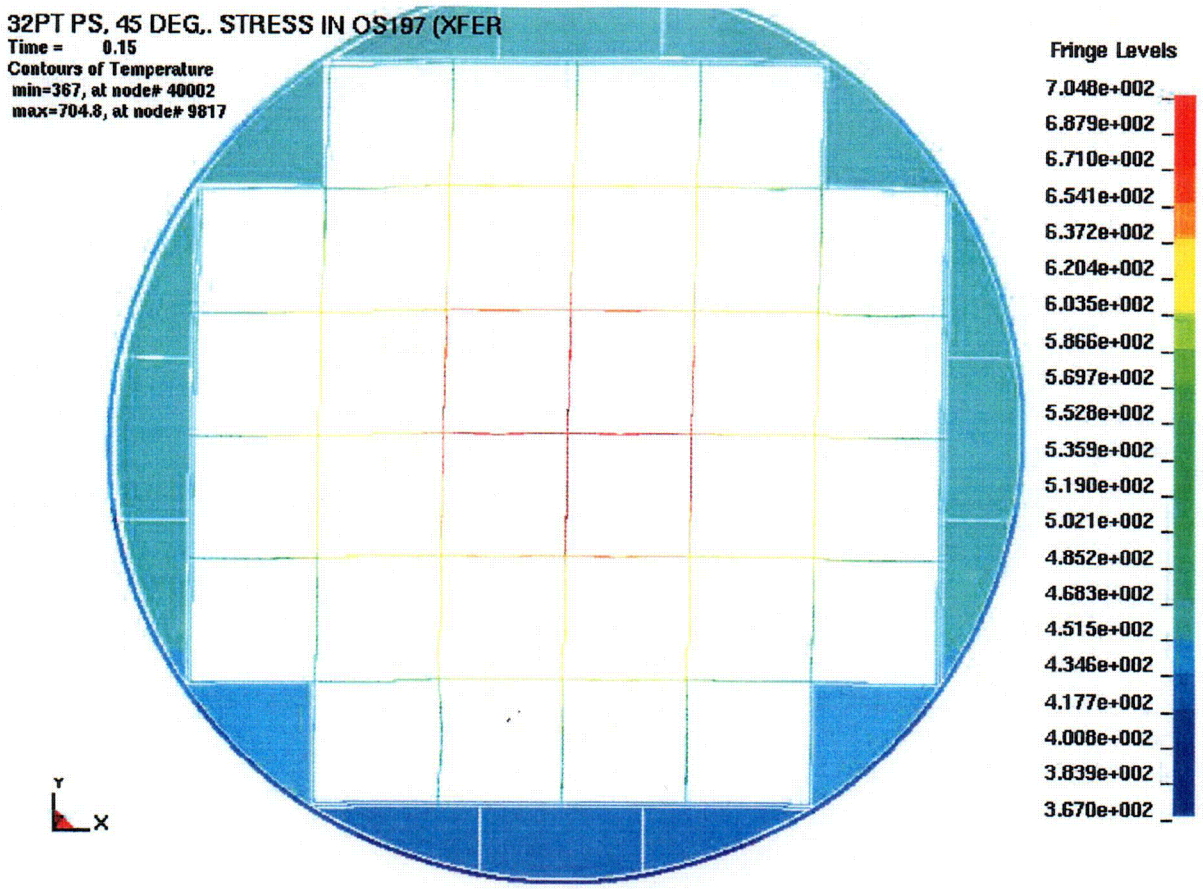


Figure M.3.7-12
32PT Basket with Aluminum Transition Rails Temperature Distribution, 100°F in Cask

M.3.8 References

3.1 American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, Subsections NB, NF, NG, and Appendices 1998, with 2000 Addenda including Code Case N-595-2.

3.2 American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section II, Part D, 1998 with 2000 Addenda.

3.3 Kaufman, J.G., ed., "Properties of Aluminum Alloys: Tensile, Creep, and Fatigue Data and High and Low Temperatures", The Aluminum Association (Washington, D.C.) and ASM International (Metals Park, Ohio), 1999.

3.4 Pacific Northwest Laboratory Annual Report – FY 1979, "Spent Fuel and Fuel Pool Component Integrity," May 1980.

3.5 G. Wranglen, "An Introduction to Corrosion and Protection of Metals," Chapman and Hall, 1985, pp. 109-112.

3.6 A.J. McEvily, Jr., ed., "Atlas of Stress Corrosion and Corrosion Fatigue Curves," ASM Int'l, 1995, p. 185.

3.7 TN West Document No. 31-B9604.97-003, dated December 19, 1997; Addendum to TN West Document No. 31-B9604.0102, Rev. 2, "An Assessment of Chemical, Galvanic and Other Reactions in NUHOMS® Spent Fuel Storage and Transportation Casks."

3.8 Baratta, et al. "Evaluation of Dimensional Stability and Corrosion Resistance of Borated Aluminum," Final Report submitted to Eagle-Pitcher Industries, Inc. by the Nuclear Engineering Department, Pennsylvania State University.

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

3.10 W.C. Young, "Roark's Formulas for Stress and Strain," Sixth Edition, McGraw-Hill, New York, N.Y., 1989.

3.11 ANSYS Engineering Analysis System, Users Manual for ANSYS Rev. 5.6, Swanson Analysis Systems, Inc., Houston, PA, 1998.

3.12 U.S. Nuclear Regulatory Commission (U.S. NRC), "Standard Format and Content for the Safety Analysis Report for an Independent Spent Fuel Storage Installation (Dry Storage)," Regulatory Guide 3.48 (Task FP-029-4), (October 1981).

3.13 ANSI N14.5-1997, "Leakage Tests on Packages for Shipment," February 1998.

3.14 American National Standard, "Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type)," ANSI/ANS 57.9-1984, American Nuclear Society, La Grange Park, Illinois (1984).

3.15 U.S. Atomic Energy Commission, "Damping Values for Seismic Design of Nuclear Power Plants," Regulatory Guide 1.61, (October 1973).

3.16 R. D. Blevins, "Formulas for Natural Frequency and Mode Shape," Van Nostrand Reinhold Co., New York, N.Y., (1979).