N.1 General Discussion

This Appendix N to the NUHOMS® Final Safety Analysis Report (FSAR) addresses the Important to Safety aspects of increasing the allowable assembly average burnup of B&W 15x15 spent fuel from 45,000 to 55,000 MWd/MTU and initial enrichment from 4.0 to 4.5 wt.% U-235 for storage in the NUHOMS®-24PHB System. The NUHOMS®-24PHB System consists of a NUHOMS®-24PHB Dry Shielded Canister (DSC) stored in a NUHOMS® Horizontal Storage Module Model 102 (HSM) and transferred in a Standard, OS197 or OS197H Transfer Cask (TC). The NUHOMS®-24P DSC designation covers both the standard cavity 24P DSC and long cavity 24P DSC.

The 24P DSCs containing high burnup fuel (fuel with burnup greater than 45,000 MWd/MTU) are designated as NUHOMS®-24PHBS for standard cavity and NUHOMS®-24PHBL for long cavity DSC designs. The NUHOMS®-24PHBL DSC may also store burnable poison rod assemblies (BPRAs). There is no change to the HSM or the TC as described in the NUHOMS® FSAR. The only change to the DSC design is that the outer top cover plate of the DSC contains a test port and plug to allow for testing 24PHBS or 24PHBL DSCs to a condition of "leak tight" per ANSI N14.5-1997 criteria [1.1].

The format of this Appendix follows the guidance provided in NRC Regulatory Guide 3.61 [1.2] The analysis presented in this Appendix shows that the NUHOMS®-24PHB System meets all the requirements of 10CFR72 [1.3].

The NUHOMS®-24PHB System provides confinement, shielding, criticality control and passive heat removal independent of any other facility structures or components. The NUHOMS®-24PHB DSCs also maintain structural integrity of the fuel during storage and retrievability of the fuel.

NOTE: References to sections or chapters within this Appendix are identified with a prefix N (e.g., Section N.2.3 or Chapter N.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).

N.1.1 Introduction

The NUHOMS® System is a modular canister-based spent fuel storage and transport system. The system includes DSCs, HSMs and the TC. This Appendix N provides the safety analysis for increasing the allowable assembly average burnup for B&W 15x15 spent fuel assemblies to 55,000 MWd/MTU, and initial enrichment to 4.5 wt.% U-235. The only fuel class considered herein is the B&W 15x15 with some reconstituted fuel assemblies and BPRAs. Only those features that are being revised or added to the NUHOMS® System are addressed and evaluated in this Appendix. There are no changes to the HSM or TC as described in the NUHOMS® FSAR.

The NUHOMS®-24PHB DSC design maintains the 24kW decay heat capacity per canister, but increases the maximum decay heat per assembly from 1.0 to 1.3 kW when heat load zoning is considered. The spent fuel which may be stored in the 24PHB DSC is presented in Section N.2.

N.1.2 General Description of the NUHOMS®-24PHB DSCs

N.1.2.1 NUHOMS®-24PHB DSC Characteristics

The only change to the 24P DSC design is that the outer top cover plate of the 24PHB DSC contains a test port and plug to allow for testing the 24PHB DSC to a condition of "leak tight" per ANSI N14.5-1997 criteria [1.1].

N.1.2.2 Operational Features

There are no changes to the operational features of the NUHOMS®-24P DSC except that the DSC is tested to leak tight criteria per ANSI N14.5-1997. This amendment changes the fuel parameters only. The sequence of operations to be performed in loading fuel into the 24PHB system is presented in Chapter N.8.

N.1.2.2.1 Identification of Subjects for Safety and Reliability Analysis

N.1.2.2.1.1 Criticality Prevention

No change.

N.1.2.2.1.2 Chemical Safety

There are no chemical safety hazards associated with operations of the NUHOMS®-24PHB System.

N.1.2.2.1.3 Operation Shutdown Modes

The NUHOMS®-24PHB System is a totally passive system so that consideration of operation shutdown modes is unnecessary.

N.1.2.2.1.4 Instrumentation

No change.

N.1.2.2.1.5 Maintenance Techniques

No change.

N.1.2.3 Cask Contents

The NUHOMS®-24PHB System is designed to store B&W 15x15 fuel with or without BPRAs as described in Section N.2.1. The allowable assembly average burnup limit is increased from 45,000 MWd/MTU to 55,000 MWd/MTU, and initial enrichment is increased from 4.0 wt % U-235 to 4.5 wt % U-235.

Section N.5 provides the shielding analysis. Section N.6 covers the criticality safety of the NUHOMS®-24PHB DSC and its contents.

N.1.3 Identification of Agents and Contractors

Transnuclear West, Inc. (TNW), provides the design, analysis, licensing support and quality assurance for the NUHOMS®-24PHB System. Fabrication of the NUHOMS®-24PHB System cask is done by one or more qualified fabricators under TNW's quality assurance program. TNW's quality assurance program is described in Chapter N.13. This program is written to satisfy the requirements of 10CFR72, Subpart G and covers control of design, procurement, fabrication, inspection, testing, operations and corrective action. Experienced TNW operations personnel provide training to utility personnel prior to first use of the NUHOMS®-24PHB 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®-24PHB System operations and maintenance are performed by utility personnel. Decommissioning activities will be performed by utility personnel in accordance with site procedures.

TNW provides specialized services for the nuclear fuel cycle that support transportation, storage and handling of spent nuclear fuel, radioactive waste and other radioactive materials. TNW is the holder of Certificate of Compliance (CoC) 72-1004.

N.1.4 Generic Cask Arrays

No change.

N.1.5 Supplemental Data

The following Transnuclear West drawing is enclosed:

1. NUH-HBU-1000 Revision 0.

REV	DESCRIPTION:	DRAWN:	ORIGINATED:	VERIFIED:	APPROVED:	LICENSING:
0	INITIAL ISSUE	CML 08/31/01	08/31/01	8/31/01	8/31/01	8/31/01

PROPRIETARY

NOTES:

1. WELD SYMBOLS ARE PER ANSI/AWS 2.4-86. WELD SIZES ARE MINIMUM. ALTERNATE WELDS OF EQUIVALENT STRENGTH MAY BE USED WITH TN WEST APPROVAL.
2. ALL MACHINED SURFACES SHALL BE FINISHED TO 250 √ OR BETTER. ALL STAINLESS STEEL PLATE SURFACES TO BE ASTM A480 #1 FINISH OR BETTER. SAND, GRIT, OR SHOT BLAST CLEANING OF STAINLESS STEEL EXTERIOR SURFACES IS NOT PERMITTED.
3. FOR THE 24PHBS DSC, USE REFERENCE DRAWINGS NUH-03-1020 THRU NUH-03-1023. THE DETAILS SHOWN ON THIS DRAWING FOR THE OUTER TOP COVER PLATE AND THE TEST PORT PLUG ARE IN ADDITION TO THE DETAILS SHOWN ON DRAWING NUH-03-1023 FOR THE OUTER TOP COVER PLATE. FOR THE 24PHBL DSC, USE REFERENCE DRAWINGS NUH-03-1050 THRU NUH-03-1053. THE DETAILS SHOWN ON THIS DRAWING FOR THE OUTER TOP COVER PLATE AND THE TEST PORT PLUG ARE IN ADDITION TO THE DETAILS SHOWN ON DRAWING NUH-03-1053 FOR THE OUTER TOP COVER PLATE.
4. ALL OF THE WELDS OF THE DSC SHELL ASSEMBLY AND CLOSURE PLATES SHALL BE PER REQUIREMENT OF EITHER NUH-03-1023 OR NUH-03-1053.
5. ◇ AREA OF .06 RECESS TO COVER TOP SURFACE OF SIPHON & VENT BLOCK, +1.0 MAX AND ITEM 1 SHALL BE LOCATED WITHIN THIS RECESS AREA.
6. ◇ FABRICATOR MAY PREP OUTER TOP COVER PLATE, ITEM 1, OR BOTH TO ACHIEVE REQUIRED WELD SIZE.
7. SERIAL NUMBERS FOR HIGH BURNUP DSC SHALL BE XXX24PHB-YYY WHERE XXX AND YYY WILL BE ASSIGNED TO EACH DSC BY TN WEST.

REFERENCE DRAWINGS:

NUH-03-1020, "STANDARD PWR FUEL, BASKET ASSEMBLY"
NUH-03-1021, "STANDARD PWR FUEL, SHELL ASSEMBLY"
NUH-03-1022, "STANDARD PWR FUEL, BASKET-SHELL ASSEMBLY"
NUH-03-1023, "STANDARD PWR FUEL, MAIN ASSEMBLY"

NUH-03-1050, "24P LONG CAVITY DSC, BASKET ASSEMBLY"
NUH-03-1051, "24P LONG CAVITY DSC, SHELL ASSEMBLY"
NUH-03-1052, "24P LONG CAVITY DSC, BASKET-SHELL ASSEMBLY"
NUH-03-1053, "24P LONG CAVITY DSC, MAIN ASSEMBLY"

ITEM NO.	QTY REQ'D	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	QUALITY CATEGORY
1	1		TEST PORT PLUG	ASME SA-479 TYPE 304 OR EQUIV	A

PARTS LIST

ALL DIMENSIONS ARE APPLICABLE AT 68°F AND ALL TOLERANCING APPLIES AFTER WELDING AND FINAL MACHINING UNLESS NOTED OTHERWISE.

DIMENSIONS ARE IN INCHES AND DEGREES UNLESS NOTED OTHERWISE. DIMENSIONING AND TOLERANCING IN ACCORDANCE WITH ASME Y14.5M-1994.

3rd ANGLE PROJECTION

DO NOT SCALE DRAWING

TRANSNUCLEAR WEST

TITLE: GENERAL LICENSE NUHOMS® 24PHBS AND 24PHBL DSC

FILE NO.	DWG. NO.	SCALE	SHEET	REV. NO.
NUHHBU.1000	NUH-HBU-1000NP	NONE	1 OF 1	0

DWG NO. NUH-HBU-1000NP SHEET 1 OF 1

N.1.6 References

1.1 ANSI N14.5-1997, “Leakage Tests on Packages for Shipment,” February 1998.

1.2 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.

1.3 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."

N.2 Principal Design Criteria

This section provides the principal design criteria for the NUHOMS®-24PHB System. The NUHOMS®-24PHB DSC is handled, transferred and stored in the same manner as the existing NUHOMS®-24P DSC. There is no change to the NUHOMS® Standard, OS197, or OS197H TC, or the standard NUHOMS® HSM Model 102. Only those principal design criteria that have changed from the existing FSAR, Chapter 3, are described in this chapter. Section N.2.1 presents a general description of the spent fuel to be stored. Section N.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 N.2.3 provides a description of the systems that have been designated as important to safety. Section N.2.4 discusses decommissioning considerations. Section N.2.5 summarizes the NUHOMS®-24PHB DSC design criteria.

N.2.1 Spent Fuel to be Stored

There are two design configurations for the NUHOMS®-24PHB DSC: the 24PHBS and 24PHBL, which are nearly identical to the standard and long cavity 24P DSCs, respectively. Each of the DSC configurations is designed to store 24 intact B&W 15x15 fuel assemblies, including reconstituted assemblies with characteristics described in Table N.2-1. The 24PHBL DSC is designed to store 24 intact B&W 15x15 PWR fuel assemblies with or without BPRAs.

The NUHOMS®-24PHB DSC may store PWR fuel assemblies arranged in one of two alternate Heat Load Zoning Configuration s with a maximum decay heat of 1.3 kW per assembly and a maximum heat load of 24 kW per DSC. The Heat Load Zoning Configuration s are shown in Figure N.2-1 and Figure N.2-2. The NUHOMS®-24PHB DSC is vacuum dried and backfilled with helium at the time of loading. The maximum fuel assembly weight of 1682 lbs with a BPRA is identical to the NUHOMS®-24P DSC design.

The maximum initial fuel cladding temperature limit during long term storage conditions for fuel with burnup less than 30,000 MWd/MTU burnup is determined using the methodology provided by Report-PNL-6189 [2.4]. For burnups greater than 30,000 MWd/MTU, the maximum fuel cladding temperature is evaluated using the methodology described in DPC-NE-2013P [2.5].

The information provided in Table N.2-1 is based on B&W 15x15 fuel. The types of spent fuel considered in Appendix N include the following:

- B&W 15x15 Mark B2, B3, B4, B4Z, B5, B5Z, B6, B7, B8, B9 and B10 fuel assemblies.
- B&W 15x15 reconstituted fuel assemblies with a maximum of 10 stainless steel rods per assembly or unlimited number of lower enrichment UO_2 rods instead of zircaloy clad enriched UO_2 rods. The stainless steel rods are assumed to have two thirds the irradiation time as the zircaloy rods of the assembly. The reconstituted UO_2 rods are assumed to have the same irradiation history as the entire fuel assembly. The reconstituted rods can be at any location in the fuel assemblies. The maximum number of reconstituted fuel assemblies per DSC is four.
- The standard BPRA design for the B&W 15x15 class assemblies is described in Appendix J.

Calculations are performed to determine the fuel assembly type which is most limiting for each of the analyses including shielding, criticality, heat load and confinement.

N.2.1.1 General Operating Functions

No change.

N.2.2 Design Criteria for Environmental Conditions and Natural Phenomena

The NUHOMS®-24PHB DSC is handled and stored in the same manner as the existing NUHOMS®-24P System. The environmental conditions and natural phenomena considered are the same as those described in Table 3.2-1 for the NUHOMS®-24P System with deviations listed in Table N.2-7. These deviations include the maximum off-normal ambient temperature, the normal, off-normal, and accident pressure loads; and the postulated accidental drops. Design criteria for the NUHOMS® HSM and TC remain the same as shown in Table 3.2-1.

The maximum design basis internal pressures for the NUHOMS –24PHB DSC are 15, 20 and 68 psig for normal, off-normal and accident conditions respectively.

N.2.2.1 Tornado Wind and Tornado Missiles

No change.

N.2.2.2 Water Level (Flood) Design

No change.

N.2.2.3 Seismic Design

No change.

N.2.2.4 Snow and Ice Loading

No change.

N.2.2.5 Combined Load Criteria

The NUHOMS®-24PHB 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 Chapter 3. The criteria applicable to the NUHOMS®-24PHB DSC are found in the following subsections.

N.2.2.5.1 NUHOMS®-24PHB DSC Structure Design Criteria

The NUHOMS®-24PHB DSC is designed using the ASME Boiler and Pressure Vessel Code [2.2] criteria given in Chapter 3. A summary of the NUHOMS®-24PHB DSC load combinations is presented in Table N.2-6.

N.2.3 Safety Protection Systems

N.2.3.1 General

The NUHOMS®-24PHB DSC is designed to provide storage of spent fuel for at least 40 years, which is the same as the 24P DSC. The DSC cavity is vacuum dried 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.

N.2.3.2 Protection By Multiple Confinement Barriers and Systems

The NUHOMS®-24PHB DSC provides a leak tight confinement of the spent fuel. Although similar to the existing NUHOMS®-24P DSC, sealing of the NUHOMS®-24PHB DSC involves leak testing in accordance with ANSI N14.5 [2.3] after loading and sealing the canister, as described in Section N.9.

N.2.3.3 Protection By Equipment and Instrumentation Selection

No change.

N.2.3.4 Nuclear Criticality Safety

N.2.3.4.1 Control Methods for Prevention of Criticality

The design criterion for criticality is an upper subcritical limit (USL) of 0.9413 (0.95 minus benchmarking bias and modeling bias) that is 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 soluble boron in the pool and favorable geometry.

The basket is 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 N.6.

N.2.3.4.2 Error Contingency Criteria

Provision for error contingency is built into the criterion used in Section N.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.

N.2.3.4.3 Verification Analysis-Benchmarking

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

N.2.3.5 Radiological Protection

No change.

N.2.3.6 Fire and Explosion Protection

No change.

N.2.4 Decommissioning Considerations

No change.

N.2.5 Summary of NUHOMS®-24PHB DSC Design Criteria

The NUHOMS®-24PHB DSC is designed to store 24 intact B&W 15x15 PWR fuel assemblies with or without BPRAs with assembly average burnup, initial enrichment and cooling time as described in Table N.2-1. The maximum total heat generation rate of the stored fuel is limited to 1.3 kW per fuel assembly and 24 kW per NUHOMS®-24PHB DSC in order to keep the maximum fuel cladding temperature below the limit necessary to ensure cladding integrity for at least 40 years storage [2.5]. The fuel cladding integrity is assured by the NUHOMS®-24PHB DSC and basket design which limits fuel cladding temperature and maintains a nonoxidizing environment in the cask cavity as described in Section N.4.

The NUHOMS®-24PHB DSC design, fabrication and testing are covered by TN West's Quality Assurance Program, which conforms to the criteria in Subpart G of 10CFR72. The NUHOMS®-24PHB DSC (shell and closure) is designed and fabricated to the maximum practicable extent as a Class I component in accordance with the rules of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, Article NB-3200. The basket is designed and fabricated to the maximum practicable extent in accordance with the rules of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NG, Article NG-3200 [2.2].

The NUHOMS®-24PHB DSC is designed to maintain a subcritical configuration during loading, handling, storage and accident conditions. A combination of soluble boron in the pool and favorable geometry are employed to maintain the upper subcritical limit of 0.9413. The required soluble boron concentration in the 24PHB DSC cavity as a function of the initial U-235 enrichment is given in Figure N.2-3.

The NUHOMS®-24PHB DSC is designed to withstand the effects of severe environmental conditions and natural phenomena such as earthquakes, tornadoes, lightning and floods. Section N.11 describes the NUHOMS®-24PHB DSC behavior under these accident conditions.

N.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, 1983 Edition including W85 Addenda.

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

2.4 Levy, et. Al., "Recommended Temperature Limits for Dry Storage of Spent Light Water Reactor Zircaloy–Clad Fuel Rods in Inert Gas," Pacific Northwest Laboratory, PNL-6189, 1987.

2.5 DPC-NE-2013P, "Fuel Rod Analysis for Dry Storage of Spent Nuclear Fuel," Duke Energy, August 2001.

Table N.2-1
PWR Fuel Specifications for Fuel to be Stored in the NUHOMS®-24PHB DSC

Title or Parameter	Specifications
Fuel	Only intact, unconsolidated B&W 15x15 class PWR fuel assemblies (with or without BPRAs) with the following requirements:
Physical Parameters (without BPRAs)	
Maximum Assembly Length (unirradiated)	165.785 in (24PHBS DSC) 171.96 in (24PHBL DSC)
Nominal Cross-Sectional Envelope	8.536 in
Maximum Assembly Weight	1682 lbs
No. of Assemblies per DSC	≤ 24 intact assemblies
Fuel Cladding	Zircalloy-clad fuel with no known or suspected gross cladding breaches
Reconstituted Fuel Assemblies	≤ 4 assemblies with stainless steel rods (up to 10 rods per assembly) or Zircaloy clad lower enrichment uranium rods (any number or rods per assembly).
Physical Parameters (with BPRAs)	
Maximum Assembly + BPRA Length (unirradiated)	171.96 in (24PHBL DSC)
Nominal Cross-Sectional Envelope	8.536 in
Maximum Assembly + BPRA Weight	1682 lbs
No. of Assemblies per DSC	≤ 24 intact assemblies
No. of BPRAs per DSC	≤ 24 BPRAs
Fuel Cladding	Zircalloy-clad fuel with no known or suspected gross cladding breaches
Reconstituted Fuel Assemblies	≤ 4 assemblies with stainless steel rods (up to 10 rods per assembly) or Zircaloy clad lower enrichment uranium rods (any number or rods per assembly).
Nuclear Parameters	
Fuel Initial Enrichment	≤ 4.5 wt. % U-235
Fuel Burnup and Cooling Time	Per Table N.2-3 (Zone 1) or Per Table N.2-4 (Zone 2) or Per Table N.2-5 (Zone 3)
BPRA Cooling Time (Minimum)	5 years
Alternate Nuclear Parameters	
Initial Enrichment	≤ 4.5 wt. % U-235
Decay Heat	Per Figure N.2-1 or Figure N.2-2
Neutron and Gamma Source	Total calculated dose rate shall be less than or equal to 93.7 mrem/hr on the HSM roof surface and 1370.2 mrem/hr on the TC side as determined using the "Response Function" provided in Table N.5-15 and the methodology described in Section N.5.2.4

Table N.2-2
PWR Fuel Assembly Design Characteristics

Assembly Class	B&W 15x15
Assembly Length	See Table N.2-1
Maximum Initial Enrichment	4.5 wt. %
Maximum Quantity of Stainless Steel Replacement Rods per Assembly	10
Maximum Quantity of Replacement Zircaloy clad lower enrichment UO_2 Rods per Assembly	208
Fuel Types	Mark B2, B3, B4, B4Z, B5, B5Z, B6, B7, B8, B9 and B10
Fissile Material	UO_2
Maximum Nominal MTU/Assembly	0.49
Maximum Number of Fuel Rods	208
Maximum Number of Guide/Instrument Tubes	17

Table N.2-3

PWR Fuel Qualification Table for Zone 1 with 0.7 kW per Assembly (Fuel with or without BPRAs) for the NUHOMS®-24PHB DSC (Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Maximum Assembly Average Initial U-235 Enrichment (wt %)																									
	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
10	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
15	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
20	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
25		5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
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	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
30						6.5	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
32							7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
34								8.0	8.0	8.0	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
36									9.0	9.0	9.0	9.0	9.0	9.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
38											10.5	10.5	10.5	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.5	9.5	9.5	9.5
39											11.5	11.0	11.0	11.0	11.0	11.0	11.0	11.0	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
40											12.0	12.0	12.0	12.0	12.0	12.0	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.0	11.0	11.0
41											13.0	13.0	13.0	13.0	13.0	13.0	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.0	12.0	12.0
42											14.5	14.5	14.0	14.0	14.0	14.0	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.0	13.0	13.0
43											15.5	15.5	15.5	15.0	15.0	15.0	15.0	15.0	14.5	14.5	14.5	14.5	14.5	14.5	14.0	14.0
44											17.0	16.5	16.5	16.5	16.5	16.0	16.0	16.0	16.0	16.0	15.5	15.5	15.5	15.5	15.5	15.5
45			Not Analyzed										18.0	17.5	17.5	17.5	17.5	17.0	17.0	17.0	17.0	17.0	16.5	16.5	16.5	16.5
46													18.8	18.7	18.5	18.5	18.3	18.2	18.1	18.0	17.9	17.8	17.7	17.6	17.5	17.4
47													20.1	20.0	19.9	19.6	19.6	19.5	19.4	19.2	19.1	19.0	18.9	18.8	18.7	18.7
48													21.4	21.3	21.1	21.0	20.8	20.8	20.7	20.5	20.4	20.3	20.2	20.1	20.0	19.9
49													22.7	22.6	22.4	22.3	22.1	22.1	21.9	21.8	21.7	21.6	21.5	21.4	21.3	21.2
50															23.7	23.6	23.5	23.4	23.3	23.2	23.0	22.9	22.8	22.7	22.6	22.5
51															25.0	24.9	24.8	24.6	24.5	24.4	24.3	24.2	24.0	23.9	23.8	23.7
52															26.3	26.2	26.0	25.9	25.8	25.7	25.6	25.4	25.3	25.2	25.2	25.0
53															27.5	27.3	27.2	27.1	27.0	26.9	26.8	26.7	26.5	26.4	26.4	26.2
54															28.8	28.6	28.5	28.3	28.2	28.1	28.0	28.0	27.8	27.7	27.6	27.5
55															29.9	29.8	29.7	29.6	29.5	29.3	29.2	29.1	29.0	28.9	28.8	28.7

- BU = maximum assembly average burnup
- Use burnup and enrichment to lookup minimum cooling time in years. The minimum cooling time for fuel assemblies reconstituted with up to 10 stainless steel rods is 9 years. If the cooling time provided by the Fuel Qualification Table is less than 9.0 years then a minimum cooling time of 9.0 years shall be used. 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 greater than 4.5 wt.% U-235 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 46.5 GWd/MTU is acceptable for storage after a 19.5 years cooling time as defined by 3.7 wt. % U-235 (rounding down) and 47 GWd/MTU (rounding up) on the qualification table.
- See Figure N.2-1 for a description of zones.
- For fuel assemblies reconstituted with Zircaloy clad uranium-oxide rods, use the assembly average enrichment to determine the minimum cooling time.

Table N.2-4

PWR Fuel Qualification Table for Zone 2 with 1.0 kW per Assembly (Fuel with or without BPRAs) for the NUHOMS®-24PHB DSC (Minimum required years of cooling time after reactor core discharge)

BU	Maximum Assembly Average Initial U-235 Enrichment (wt %)																									
(GWd/MTU)	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
10	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
15	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
20	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
25		5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
28			5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
30						5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
32							5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
34								5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
36									5.5	5.5	5.5	5.5	5.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
38											6.0	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
39											6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.5	5.5	5.5	5.5	5.5	5.5	5.5
40											6.5	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
41											6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
42											7.0	7.0	7.0	7.0	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
43											7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.5	6.5	6.5	6.5
44											7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
45				Not Analyzed									8.0	8.0	8.0	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.4
46													8.2	8.1	8.0	8.0	7.9	7.8	7.8	7.7	7.7	7.6	7.6	7.5	7.5	7.4
47													8.7	8.6	8.5	8.4	8.4	8.3	8.2	8.2	8.1	8.0	8.0	7.9	7.9	7.8
48													9.2	9.1	9.0	9.0	8.9	8.8	8.7	8.6	8.6	8.5	8.5	8.4	8.3	8.3
49													9.8	9.7	9.6	9.5	9.4	9.3	9.2	9.2	9.1	9.0	9.0	8.9	8.8	8.7
50															10.2	10.1	10.0	9.9	9.8	9.7	9.6	9.6	9.5	9.4	9.3	9.3
51															10.9	10.8	10.7	10.6	10.5	10.3	10.3	10.2	10.1	10.0	9.9	9.9
52															11.6	11.5	11.3	11.2	11.1	11.0	10.9	10.8	10.7	10.6	10.5	10.5
53															12.4	12.2	12.1	12.0	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1
54															13.2	13.1	13.0	12.8	12.7	12.5	12.4	12.3	12.2	12.1	12.0	11.9
55															14.1	13.9	13.8	13.6	13.5	13.4	13.2	13.1	13.0	12.9	12.8	12.6

- BU = maximum assembly average burnup
- Use burnup and enrichment to lookup minimum cooling time in years. The minimum cooling time for fuel assemblies reconstituted with up to 10 stainless steel rods is 9 years. If the cooling time provided by the Fuel Qualification Table is less than 9.0 years then a minimum cooling time of 9.0 years shall be used. 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 greater than 4.5 wt.% U-235 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 46.5 GWd/MTU is acceptable for storage after a 8.3 years cooling time as defined by 3.7 wt. % U-235 (rounding down) and 47 GWd/MTU (rounding up) on the qualification table.
- See Figure N.2-1 for a description of zones.
- For assemblies fuel reconstituted with Zircaloy clad uranium-oxide rods, use the assembly average enrichment to determine the minimum cooling time.

Table N.2-5

PWR Fuel Qualification Table for Zone 3 with 1.3 kW per Assembly (Fuel with or without BPRAs) for the NUHOMS®-24PHB DSC (Minimum required years of cooling time after reactor core discharge)

BU (GWd/MTU)	Maximum Assembly Average Initial U-235 Enrichment (wt %)																									
	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
10	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
15	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
20	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
25		5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
28			5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
30						5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
32							5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
34								5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
36									5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
38											5.5	5.5	5.5.	5.5	5.5	5.5.	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	5.5	5.5	5.5	5.5	5.5	5.5
40											5.5	5.5	5.5.	5.5	5.5	5.5.	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	5.5	5.5	5.5	5.5	5.5	5.5
42											6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
43											6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
44											6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
45			Not Analyzed										6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
46													6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
47													6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
48													6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
49													6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
50															6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
51															6.7	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
52															7.0	6.9	6.9	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
53															7.3	7.2	7.2	7.1	7.1	7.0	6.9	6.9	6.9	6.9	6.9	6.9
54															7.7	7.6	7.5	7.4	7.4	7.3	7.3	7.2	7.1	7.1	7.0	7.0
55															8.0	8.0	7.9	7.8	7.7	7.7	7.6	7.5	7.5	7.4	7.3	7.3

- BU = maximum assembly average burnup
- Use burnup and enrichment to lookup minimum cooling time in years. The minimum cooling time for fuel assemblies reconstituted with up to 10 stainless steel rods is 9 years. If the cooling time provided by the Fuel Qualification Table is less than 9.0 years then a minimum cooling time of 9.0 years shall be used. 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 greater than 4.5 wt.% U-235 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 46.5 GWd/MTU is acceptable for storage after a 6.2 years cooling time as defined by 3.7 wt. % U-235 (rounding down) and 47 GWd/MTU (rounding up) on the qualification table.
- See Figure N.2-1 and Figure N.2-2 for a description of zones.
- For fuel assemblies reconstituted with Zircaloy clad uranium-oxide rods, use the assembly average enrichment to determine the minimum cooling time.

Table N.2-6
Summary of 24PHB-DSC Load Combinations

Load Case	Horizontal DW		Vertical DW		Internal Pressure[9]	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 [13]	--	70° F	--	155 kip axial	Test
NO-3 DSC Uprighting	X	--	--	--	--	--	70°F	X	--	A
NO-4 DSC Vertical Lift	--	--	X	--	--	--	70°F	X	--	A
Fuel Loading Load Cases										
FL-1 DSC/Cask Filling	--	--	Cask	--	--	Hydrostatic	100°F Cask	--	--	A
FL-2 DSC/Cask Filling	--	--	Cask	--	Hydrostatic	Hydrostatic	100°F Cask	--	--	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)	C
Draining/Drying Load Cases										
DD-1 DSC Blowdown	--	--	Cask	X	Hydrostatic + 20 psi	Hydrostatic	100°F Cask	--	--	A
DD-2 Vacuum Drying	--	--	Cask	X	0 psia	Hydrostatic + 14.7 psi	100°F Cask	--	--	A
DD-3 Helium Backfill	--	--	Cask	X	18 psi [13]	Hydrostatic	100°F Cask	--	--	A
DD-4 Final Helium Backfill	--	--	Cask	X	3.5 psi	Hydrostatic	100°F Cask	--	--	A
DD-5 Outer Cover Plate Weld	--	--	Cask	X	3.5 psi	Hydrostatic	100°F Cask	--	--	A
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 N.2-6
Summary of 24PHB-DSC Load Combinations

(continued)

Load Case	Horizontal DW		Vertical DW		Internal Pressure(9)	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 psi	--	0°F Cask	1g Axial	--	A
TR-2 Transverse Load - Cold	Cask	X	--	--	15 psi	--	0°F Cask	1g Transverse	--	A
TR-3 Vertical Load - Cold	Cask	X	--	--	15 psi	--	0°F Cask	1g Vertical	--	A
TR-4 Oblique Load - Cold	Cask	X	--	--	15 psi	--	0°F Cask	½ g Axial + ½ g Trans + ½ g Vert.	--	A
TR-5 Axial Load - Hot	Cask	X	--	--	15 psi	--	100°F Cask	1g Axial	--	A
TR-6 Transverse Load - Hot	Cask	X	--	--	15 psi	--	100°F Cask	1g Trans.	--	A
TR-7 Vertical Load - Hot	Cask	X	--	--	15 psi	--	100°F Cask	1g Vertical	--	A
TR-8 Oblique Load - Hot	Cask	X	--	--	15 psi	--	100°F Cask	½ g Axial + ½ g Trans + ½ g Vert.	--	A
TR-9 25g Corner Drop	Note (1)		--	--	20 psi	--	100°F(2)	--	25g Corner Drop	D
TR-10 75g Side Drop	Note (1)		--	--	20 psi	--	100°F(2)	--	75g Side Drop	D
TR-11 Top or Bottom End Drops	---Not credible, Note 12---									
HSM Loading										
LD-1 Normal Loading - Cold	Cask	X	--	--	15 psi	--	0°F Cask	+80 Kip	--	A
LD-2 Normal Loading - Hot	Cask	X	--	--	15 psi	--	100° F Cask	+80 Kip	--	A
LD-3 Not Used	Cask	X	--	--	15 psi	--	117° F (5)	+80 Kip	--	A
LD-4 Off-Normal Loading - Cold	Cask	X	--	--	20 psi	--	-40° F Cask	+80 Kip	--	B
LD-5 Off-Normal Loading - Hot	Cask	X	--	--	20 psi	--	100° F(5) Cask	+80 Kip	--	B
LD-6 Not Used										
LD-7 Accident Loading	Cask	X	--	--	20 psi	--	117° F	+80 Kip	--	C/D

Table N.2-6
Summary of 24PHB-DSC Load Combinations
(continued)

Load Case	Horizontal DW		Vertical DW		Internal Pressure[9]	External Pressure[9]	Thermal Condition	Handling Loads	Other Loads	Service Level
	DSC	Fuel	DSC	Fuel						
HSM Storage										
HSM-1 Off-Normal	HSM	X	--	--	20 psi	--	-40°F HSM	--	--	B
HSM-2 Normal Storage	HSM	X	--	--	15 psi	--	0°F HSM	--	--	A
HSM-3 Off-Normal Temp	HSM	X	--	--	20 psi	--	117°F HSM	--	--	B
HSM-4 Not Used										
HSM-5 Blocked Vent Storage	HSM	X	--	--	68 psi [8]	--	117°F HSM/BV[4]	--	--	D
HSM-6 Not Used										
HSM-7 Earthquake Loading - Cold	HSM	X	--	--	15 psi	--	0°F HSM	--	EQ	D
HSM-8 Earthquake Loading - Hot	HSM	X	--	--	15 psi	--	100°F HSM	--	EQ	D
HSM-9 Flood Load (50' H_2O) - Cold	HSM	X	--	--	0 psi	22 psi	0°F HSM	--	Flood[3]	D
HSM-10 Flood Load (50' H_2O) - Hot	HSM	X	--	--	0 psi	22 psi	100°F HSM	--	Flood[3]	D
HSM Unloading										
UL-1 Normal Loading - Cold	HSM	X	--	--	15 psi	--	0°F HSM	-60 Kip	--	A
UL-2 Normal Loading - Hot	HSM	X	--	--	15 psi	--	100°F HSM	-60 Kip	--	A
UL-3 Off-Normal Loading - Hot	HSM	X	--	--	20 psi	--	117°F HSM	-60 Kip	--	A
UL-4 Off-Normal Loading - Cold	HSM	X	--	--	20 psi	--	-40°F HSM	-60 Kip	--	B
UL-5 Off-Normal Loading - Hot	HSM	X	--	--	20 psi	--	100°F HSM	-60 Kip	--	B
UL-6 Off-Normal Loading - Hot	HSM	X	--	--	20 psi	--	117°F HSM	-60 Kip	--	B
UL-7 Off-Norm. Unloading - Hot[6, 11]	HSM	X	--	--	20 psi	--	100°F HSM	-80 Kip	--	C
UL-8 Accident Unloading - Hot[7, 11]	HSM	X	--	--	68 psi [7, 8]	--	100°F HSM	-80 Kip	--	D
HSM Unloading / Reflood										
RF-1 DSC Reflood	--	--	Cask	X	68 psi (max)	Hydrostatic	100°F Cask	--	--	D

Table N.2-6
Summary of 24PHB-DSC Load Combinations

(concluded)

Summary of 24PHB-DSC Load Combinations Notes:

(1) The 75g drop acceleration includes gravity effects. Therefore, it is not necessary to add an additional 1.0g load.

(2) For Level D events, only maximum temperature case is considered. (Thermal stresses are not limited for level D events and maximum temperatures give minimum allowables).

(3) Flood load is an external pressure equivalent to 50 feet (164 m) 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) This pressure assumes release of the fuel cover gas and 30% of the fission gas. Since unloading requires the HSM door to be removed, the pressure and temperatures are based on the normal (unblocked vent) condition. Pressure is applied to the inner pressure boundary.

(7) This pressure assumes release of the fuel cover gas and 30% of the fission gas. Although unloading requires the HSM door to be removed, the pressure and temperatures are based on the blocked vent condition. Pressure is applied to the outer pressure boundary.

(8) This pressure is applied to the outer pressure boundary.

(9) Unless noted otherwise, pressure is applied to the inner pressure boundary.

(10) Fuel deck seismic loads are assumed enveloped by handling loads.

(11) Load Cases UL-7 and UL-8 envelop loading cases where the insertion loading of 80 kips (356KN) is considered with an accident pressure (the insertion force is opposed by internal pressure).

(12) The 75g top end drop and bottom end drop are not credible events, therefore these drop analyses are not required. However, to envelop the 25g corner drop case, a 60g end drop is analyzed.

(13) Leak test pressure values used in Load Cases NO-1 and DD-3 are based on the assumption of a calculated Service Level A pressure of 15 psig.

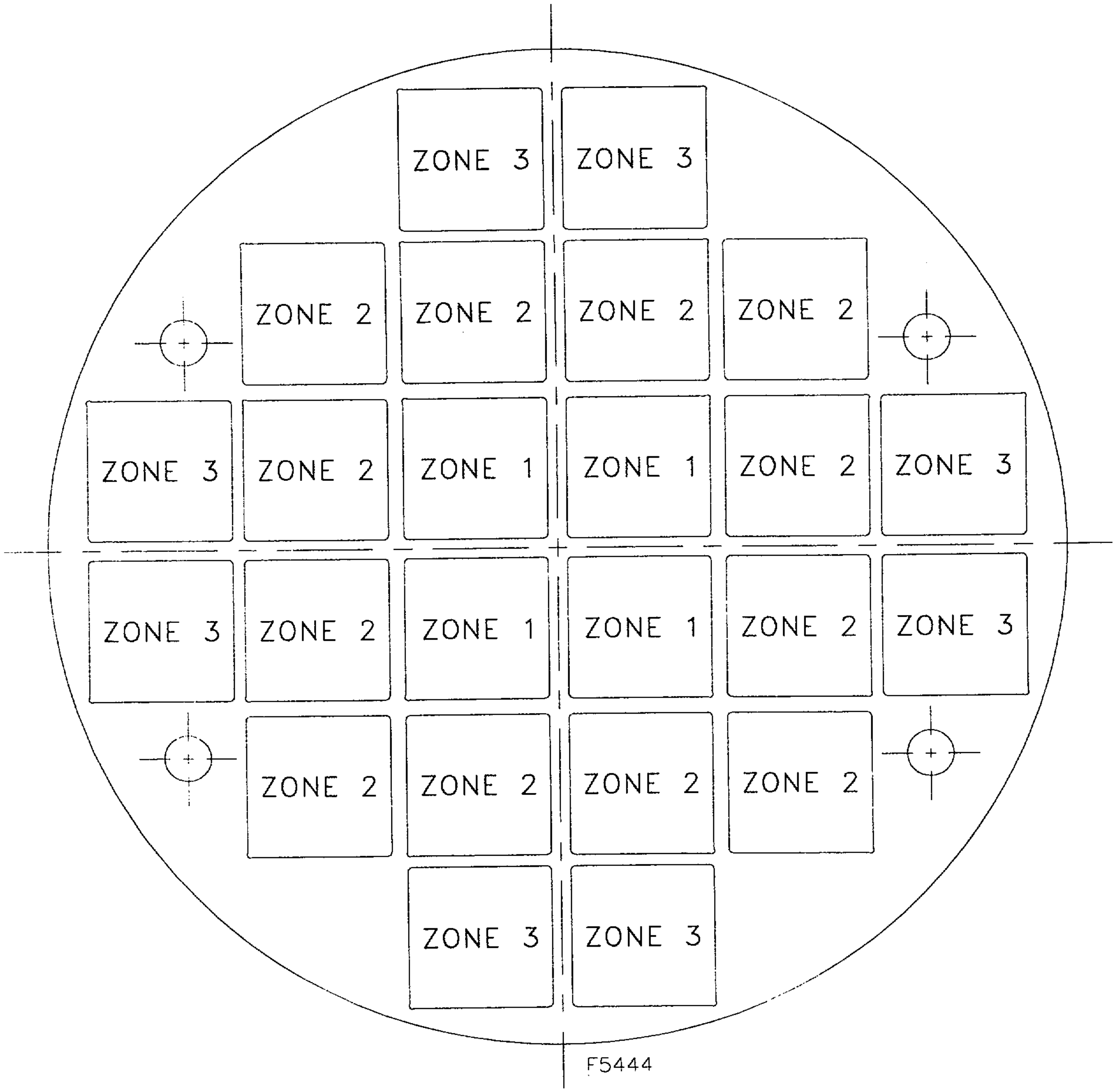
Table N.2-7
Summary of NUHOMS®-24PHB Design Loadings[1]

Design Load Type	FSAR Section Reference	Design Parameters	Applicable Codes
Normal and Off-Normal Pressure	N.3.6.1.2 N.3.6.1.3	Enveloping internal pressure of ≤15 psig (Normal) and < 20 psig (Off-Normal)	10CFR72.122(h)
Test Pressure	N.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 Temperatures	N.4.5	Ambient air temperature –40°F to 117°F	ANSI 57.9-1984
Accidental Cask Drop Loads	N.3.7.5	Equivalent static deceleration of 75g for horizontal side drops, and 25g oblique corner drop (30° from horizontal)[2]	10CFR72.122(b)
Accident Internal Pressure	N.4	Enveloping internal pressure of ≤68 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)

Notes:

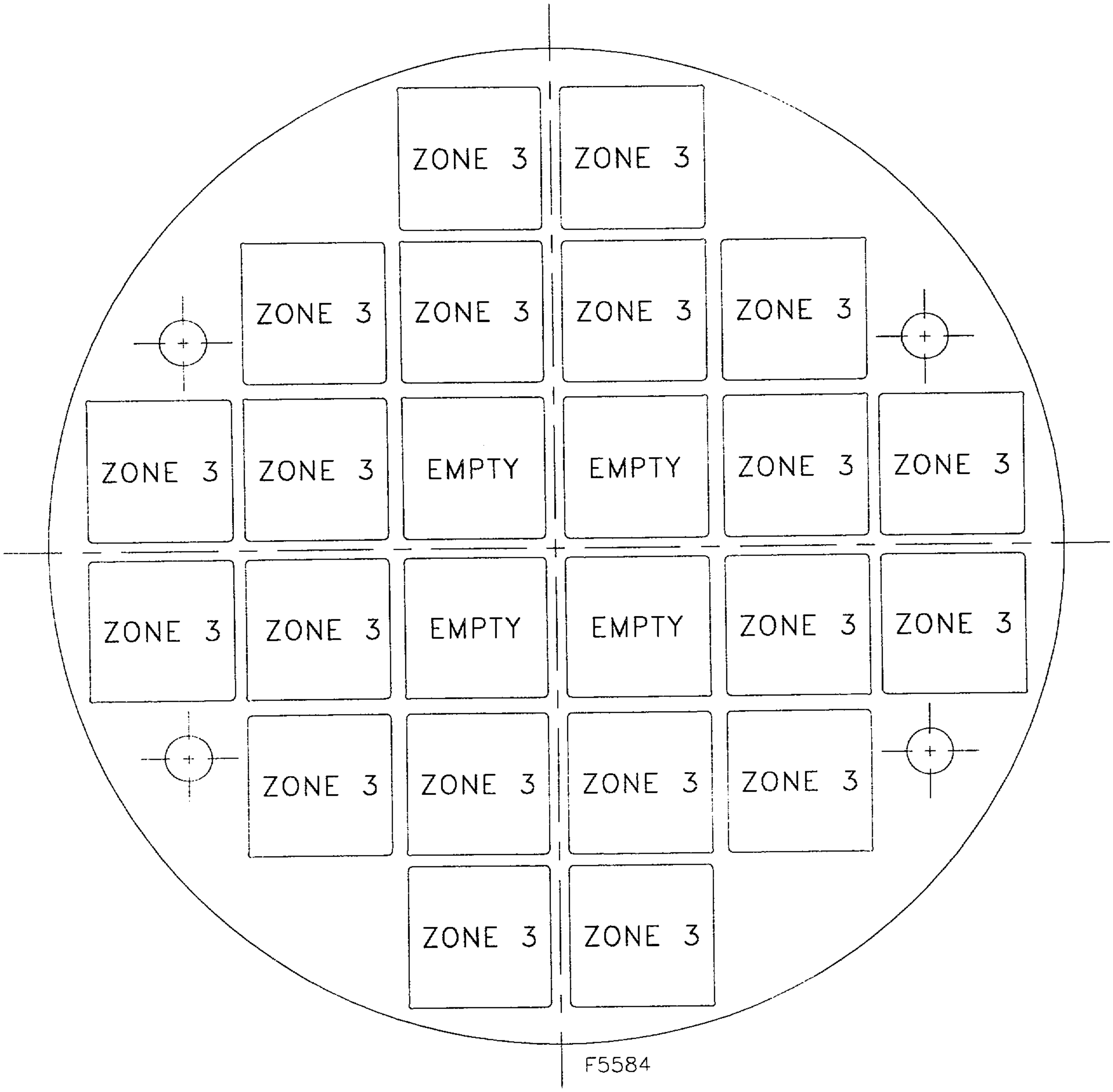
(1) Only the items that are different from the NUHOMS®-24P are listed here. The design criteria for the HSM (including the DSC Steel Support Structure) and the TC remain unchanged from the FSAR (Table 3.2-1).

(2) End drops are not credible for the NUHOMS® System; therefore, they do not need to be evaluated. However, a 60g vertical end drop is evaluated in order to envelop the corner drop loading condition.



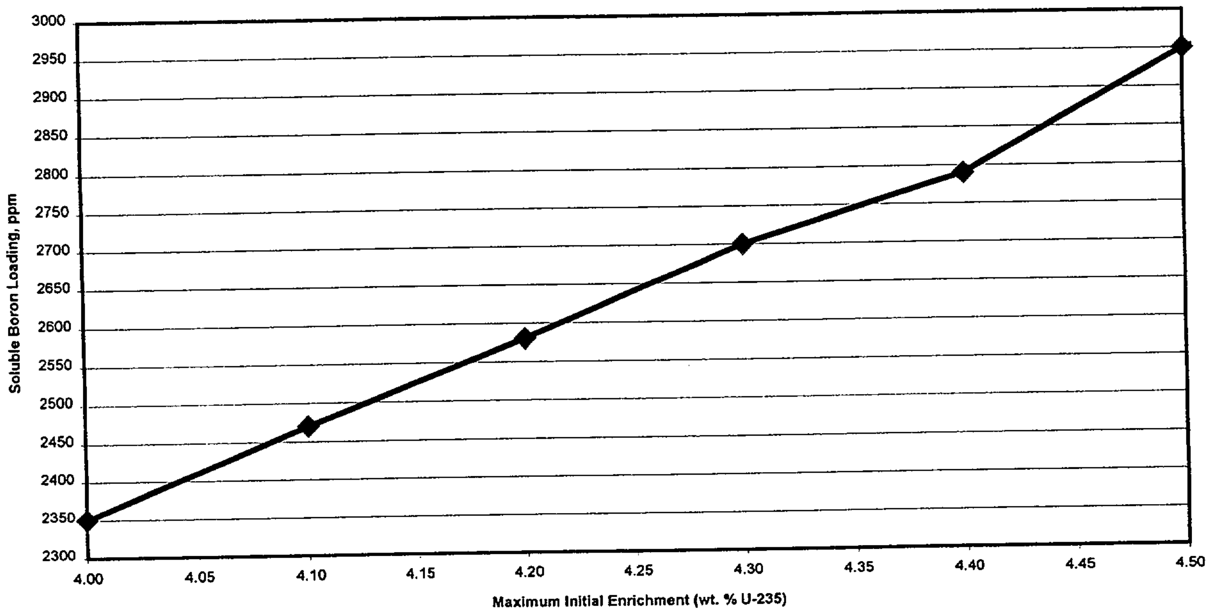
	Zone 1	Zone 2	Zone 3
Maximum Decay Heat (kW / FA)	0.7	1.0	1.3
Maximum Decay Heat per Zone (kW)	2.8	10.8	10.4

Figure N.2-1
Heat Load Zoning Configuration 1



	Zone 1	Zone 2	Zone 3
Maximum Decay Heat (kW / FA)	NA	NA	1.3
Maximum Decay Heat per Zone (kW)	NA	NA	24.0

Figure N.2-2
Heat Load Zoning Configuration 2



Linear Interpalation allowed between points

Enrichment	Boron Loading, ppm
4.0	2350
4.1	2470
4.2	2580
4.3	2700
4.4	2790
4.5	2950

Note: For initial U-235 enrichment of less than 4.0 wt. %, the 24PHB DSC cavity shall be filled with water having a boron concentration of at least 2350 ppm.

Figure N.2-3
Soluble Boron Concentration vs. Fuel Assembly Initial U-235 Enrichment

N.3 Structural Evaluation

N.3.1 Structural Design

N.3.1.1 Discussion

This section describes the structural evaluation of the NUHOMS®-24PHB System for the storage of high burnup fuel. The NUHOMS®-24PHB System consists of the NUHOMS® HSM, the TC and 24PHB DSC. There are two DSC configurations: the 24PHBS and 24PHBL DSC, as described in Section N.2.2. No changes have been made to the TC or to HSM to accommodate the 24PHB DSCs. The 24PHB DSCs will be stored in the HSM Model 102. Where the new components or changes to the loading for high burnup fuel have an effect on the structural evaluations presented in the FSAR, the changes are included in this section. Sections that do not affect the evaluations presented in the FSAR are identified as "No change."

The 24PHBS and 24PHBL DSC shell and basket assembly designs are essentially the same as the 24P standard length and long cavity DSC shell assemblies respectively, which are described in Chapter 4, except the 24PHB DSC outer top cover plate has a test port/plug to allow testing of the canister shell for leak tightness. Materials and component geometric dimensions of the 24PHB DSC shell and basket assemblies are identical to the 24P DSC shell and basket assemblies.

N.3.1.2 Design Criteria

Design criteria for this section are provided in Section N.2.5.

N.3.1.2.1 DSC Confinement Boundary

No change from Section 3.3.2.

N.3.1.2.2 ASME Code Exceptions for the 24PHB DSCs

No change to the Code exceptions presented in Section 4.8.

N.3.2 Weights

No change.

N.3.3 Mechanical Properties of Materials

The mechanical properties of structural materials used in the NUHOMS®-24PHB DSC shell and basket are in accordance with ASME Code Section III, Appendix I [3.1]. The materials used in the fabrication of the 24PHB DSC shell assemblies and basket assemblies are identical to those used in the 24P DSC shell and basket assemblies. Material properties for the 24P shell and basket assemblies are provided in Section 8.1.

N.3.4 General Standards for 24PHB DSCs

N.3.4.1 Chemical and Galvanic Reactions

Bulletin 96-04 [3.2] identified issues related to the potential for chemical, galvanic or other reactions among the materials of a spent fuel storage cask, its contents and the environment the cask may encounter during use. Transnuclear West performed a comprehensive evaluation [3.4] for the 24P System. This evaluation was determined [3.3] to have satisfied the requested actions in Bulletin 96-04 [3.2].

The materials of the NUHOMS®-24PHB DSC shell and basket assemblies are identical to the 24P DSC and thus do not need any additional evaluation.

N.3.4.2 Positive Closure

Positive closure is provided by the redundant closure welds for the 24PHB DSC inner and outer top cover plates and the leak-tested shell assembly.

N.3.4.3 Lifting Devices

No change.

N.3.4.4 Hot Temperature Behavior

N.3.4.4.1 Summary of Pressures and Temperatures

Temperatures and pressures for the 24PHB DSC are described in Section N.4. Section N.4.4, Section N.4.5, and Section N.4.6 describe the thermal evaluations performed for normal, off-normal, and accident conditions, respectively. Section N.4.7 describes the thermal evaluations during fuel loading/unloading operations. Section N.4.4.4 provides the maximum pressures during normal, off-normal and accident conditions which are bounded by the corresponding design pressures used in the evaluations presented in Sections N.3.6 and N.3.7.

N.3.4.4.2 Differential Thermal Expansion

Potential interference due to differential thermal expansion between the 24PHB DSC shell assemblies and the basket assembly components is evaluated in the longitudinal and radial directions.

- In the radial direction, the gaps between the spacer discs and the inside of the 24PHB DSC shell are evaluated for possible interference due to differential thermal expansion of the materials because of the differences in their coefficients of thermal expansion. The analyses show that when including the effect of fabrication tolerances, the radial gap between the spacer disc and the inside of the shell will close, but will not impose significant stresses in the 24PHB DSC shell or the spacer disc.

- For the following interfaces, clearances are established to ensure that potential thermal interferences are accounted for.
  - Guide sleeves to 24PHBS and 24PHBL DSC cavity (lengths)
  - Guide sleeve to spacer disc fuel cutout
  - There is no thermal interference between the support rod assembly and the 24PHBS or the 24PHBL DSC cavity lengths for storage and transfer conditions. A very small (0.0029 inch) interference occurs during vacuum drying conditions. This interference is negligibly small and is of short duration limited to the vacuum drying operations.

- Differential expansion between the carbon steel shield plug(s) and the Type 304 shell is addressed in the thermal stress analyses of the shell using ANSYS models. Since the coefficient of expansion of the shell is significantly higher than the coefficient of expansion for the enclosed plug(s), thermal interferences are minimized. The maximum unirradiated fuel assembly length is slightly increased from 165.75 inches in the NUHOMS®-24P to 165.785 inches in the NUHOMS®-24PHBS. Also, the average temperature for the high power density region is decreased from 662°F in the NUHOMS®-24P to 645°F in the NUHOMS®-24PHBS. Therefore, the clearance between the fuel assembly and the DSC shell cavity is verified to ensure it remains adequate. Using similar thermal expansion calculations as in Section 8.1.1.3(B), the calculated hot length of the spent fuel assembly is 166.112 inches. The minimum hot DSC cavity length from Section 8.1.1.3(B) is 167.043 inches. Thus, the minimum clearance available for irradiation growth at hot conditions is 0.931 inches, which is not significantly different than the 0.960 inches value reported in Section 8.1.1.3(B) for the NUHOMS®-24P.

N.3.4.4.3 Stress Calculations

The stress evaluation is performed using the criteria presented in Section N.2.5. The stress analyses for the 24PHB DSC are summarized in Section N.3.6 for normal and off-normal conditions and in Section N.3.7 for accident conditions. Section N.2.5 provides the detailed load combinations that are applicable to the 24PHB DSC. Finite element models of the shell assembly and the spacer discs have been developed, and detailed computer analyses are performed using the ANSYS [3.5] computer program. The guide sleeves and support rods are analyzed using a combination of computer analysis and hand calculations.

24PHB DSC Shell Assembly

As discussed in Sections N.3.6 and N.3.7, the NUHOMS®-24PHB DSC shell assemblies are evaluated for normal, off-normal and accident pressures using procedures similar to the 24P DSC shell assemblies. Based on the load combination results presented in Section N.3.7, all the stresses in the 24PHBS DSC and 24PHBL DSC confinement boundary assembly are acceptable.

24PHB DSC Basket Assembly

The stress analyses results for the 24PHB DSC basket assembly are summarized in Sections N.3.6 and N.3.7. Based on the comparisons to the 24P guide sleeves and additional evaluation, the guide sleeve stresses are acceptable. The analyses presented in Sections N.3.6 and N.3.7

demonstrate that for the hypothetical accident scenarios, there is sufficient margin to ensure that the basket components perform their intended function.

N.3.4.4.4 Comparison with Allowable Stresses

The stresses for each of the major components of the 24PHBS and 24PHBL DSCs are compared to their allowables in Section N.3.7 and are acceptable.

N.3.4.5 Cold Temperature Behavior

The 24PHB DSCs have been designed for operation at daily average ambient temperatures as low as -40°F when in the HSM during storage. The shielding materials of the DSC and HSM are all solids, thus freezing is not a concern.

The SA 240 Type 304 stainless steel along with the E308/E309 weld metal are not subject to brittle fracture for the range of operating temperatures of the 24PHB DSCs. The spacer disc materials are impact-tested to confirm ductile behavior.

N.3.5 Fuel Rods

No change.

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

In accordance with NRC Regulatory Guide 3.48 [3.6], the design events identified by ANSI/ANS 57.9-1984, [3.7] form the basis for the structural 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®-24PHB System using a format similar to the one used in Section 8.1 for analyzing the NUHOMS®-24P and -52B Systems.

N.3.6.1 Normal Operation Structural Analysis

Table 8.1-1 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 N.3.6.1.1.

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

N.3.6.1.1 Normal Operating Loads

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

1. Dead Weight Loads
2. Design Basis Internal and External Pressure Loads
3. Design Basis Thermal Loads
4. Operational Handling Loads
5. Design Basis Live Loads

These loads are described in detail in the following paragraphs.

A. Dead Weight Loads

No change.

B. Design Basis Internal and External Pressure

The maximum internal pressures of the 24PHB DSCs for the storage and transfer mode are presented in Section N.4.4.4. The design basis maximum internal normal and off normal pressures are 15 psi and 20 psi which bound the maximum DSC pressures calculated in Section N.4. The design basis maximum external pressure is 21.7 psi.

C. Design Basis Thermal Loads

The temperature distribution for the DSC shell assembly for the normal conditions is presented in Section N.4.

D. Operational Handling Loads

Same as Section 8.1.1.1D.

E. Design Basis Live Loads

Same as Section 8.1.1.1E (no effect on the DSC).

N.3.6.1.2 DSC Shell Assembly Analysis

Load conditions applicable to the 24PHB DSCs are the same as those presented in Section 8.1. The internal pressures calculated in Section N.4.4 for the 24PHB DSCs are bounded by the design internal pressures (15 psig for the normal condition and 20 psig for the off-normal condition) used in the evaluation of the shell assemblies. A heat load of 24kW is applicable for the 24PHB DSC designs. This heat load is identical to that used in the 24P design. Since the shell assemblies for the 24PHBS and 24PHBL DSCs are essentially identical to the 24P standard and long cavity designs, the maximum temperatures and temperature distributions for the 24PHB DSC shell assemblies are the same as the 24P. Therefore, the 24P DSC shell assembly thermal stress analyses presented in Section 8.1 and Appendix H are also applicable to the 24PHBS and 24PHBL DSC shell assemblies.

The weights of the 24PHBS and 24PHBL DSC shell assemblies are the same as those of the 24P standard and long cavity DSCs, respectively. The weights of the baskets for the 24PHBS and 24PHBL DSCs are also same as those of the 24P standard and long cavity DSCs, respectively. Of the normal operating load conditions, the basket weight affects the dead weight and the transfer handling loads on the 24PHBS and 24PHBL DSC shell assemblies. The weight of the fuel assemblies in the 24PHBS and 24PHBL DSCs are bounded by those in the 24P DSCs. Therefore, the vertical dead weight and horizontal dead weight stresses in the shell and basket assembly components of the 24PHBS and 24PHBL DSCs are bounded by those of the 24P standard and long cavity DSCs, respectively.

For the transfer handling load, the stress results presented in Section 8.1 for the standard 24P DSC and Appendix H for the 24P long cavity DSC bound the stresses in the 24PHBS and 24PHBL DSCs, respectively.

N.3.6.1.3 DSC Basket Structural Analysis

The arrangement of components of the 24PHBS and 24PHBL basket assemblies is identical to that of the 24P standard cavity and 24P long cavity DSCs, respectively.

N.3.6.1.3.1 Stress Analysis of the Spacer Discs

The stress analysis of the spacer disc is performed using 3-D finite element models developed using the ANSYS program [3.5]. Two basic models are developed for the basket assembly: models for loading in the plane of the spacer discs, and models for loading out of the plane of the spacer discs. The in-plane models are used for horizontal dead weight, thermal, and side drop analyses presented in Section N.3.7. The out-of-plane models are used for vertical dead weight, handling, seismic and end drop analyses.

N.3.6.1.3.1.1 Spacer Disc Dead Weight Analysis

The spacer disc dead weight stresses are calculated for the vertical and horizontal orientation inside the TC and for the horizontal orientation inside the HSM using the procedure described in Section 8.1.1.3A.

N.3.6.1.3.1.2 Spacer Disc Thermal Stress Analysis

The spacer disc thermal model is a 180° half-symmetry model with axial half symmetry that includes the spacer disc only. The model is shown in Figure N.3.6-1. Only the temperature gradients in the plane of the disc are analyzed. The temperature distribution from Section N.4 is imposed onto the spacer disc model at key locations. A coupled field analysis is performed to develop the temperature distribution at all of the nodes in the spacer disc. A static analysis is then performed to determine the thermal stresses.

As described in Section N.4, there are two Heat Load Zoning Configuration options for fuel to be stored in the 24PHB DSCs. Of these two configurations, Configuration 1 stress intensities bound those of Configuration 2. Therefore, thermal stress results of Configuration 1 only are used in the load combinations.

The potential for interference due to differential thermal expansion between the DSC cavity and the support rods is evaluated. The minimum gap between the DSC cavity and the support rods, considering the DSC and support rod tolerances, is 0.38 inches. For the DSC in the cask at 117°F ambient thermal case, the relative growth of the support rod with respect to the growth of the DSC shell is 0.18 inches which yields a gap of 0.2 inches.

The maximum diametrical growth of the spacer disc is 0.24 inches for the 117°F ambient DSC in the cask transfer condition. Considering the radial growth of the DSC shell and the tolerances, the minimum available gap is 0.30 inches.

These evaluations, which include the consideration of fabrication tolerances, show that the gaps between the DSC shell cavity and support rods, and between DSC shell and the spacer discs do not close due to differential thermal expansion, considering all normal and off-normal storage thermal conditions.

N.3.6.1.3.1.3 Spacer Disc Handling Stress Analysis

The spacer disc handling load stresses are calculated using the procedure described in Section 8.1.1.3C.

N.3.6.1.3.1.4 Evaluation of the Results

Linear elastic static analyses are performed for the evaluation of all normal operating loads. Stress results obtained from the analyses are linearized, as appropriate, to allow their categorization into primary membrane and primary or primary-plus-secondary membrane-plus-bending stress intensities. Stress results for the normal load conditions are included in Table N.3.6-1.

The total weight of the Configuration 1 basket assembly with 24 fuel assemblies envelopes Configuration 2 with 20 fuel assemblies. Therefore, the dead weight and handling load stress intensities presented in Table N.3.6-1 are the bounding values for Configuration 1.

N.3.6.1.3.2 Stress Analysis of the Guide sleeves

The guide sleeves for the NUHOMS®-24PHBS DSC and -24PHBL DSC are identical to the NUHOMS®-24P standard and long cavity guide sleeves, respectively. Materials used in the 24PHB guide sleeve designs are also identical to the 24P guide sleeves. Therefore, the maximum stresses in the 24PHB guide sleeves due to normal loads such as dead weight and handling loads are same as those for the 24P guide sleeves. The maximum temperatures of the 24PHB guide sleeves are higher compared to 24P guide sleeves. Therefore, 24PHB guide sleeves have lower a allowable stress. However, the computed maximum stress is still less than the allowable stress.

The 24PHB guide sleeves are free to expand when subjected to thermal loads. Thus, there is no thermal stress in the 24PHB guide sleeves in contrast to the 24P guide sleeves.

N.3.6.1.3.3 Stress Analysis of the Support Rods

The support rods for the NUHOMS®-24PHBS DSC and -24PHBL DSC are identical to the NUHOMS®-24P standard and long cavity support rods, respectively. Materials used in the 24PHB support rod designs are also identical to the 24P support rods. Therefore, the maximum stresses in the 24PHB support rods due to normal loads such as dead weight and handling loads are the same as those for the 24P support rods. The maximum temperatures of the 24PHB support rods are higher compared to 24P support rods. Therefore, 24PHB support rods have a lower stress allowable. However, the computed maximum stress is still less than the allowable stress.

Similar to the 24P support rods, thermal stresses in the 24PHB support rods are not significant since the axial temperature distribution of the DSC shell is relatively constant over the region where the spacer discs are located and there is no appreciable differential thermal expansion between spacer discs.

N.3.6.1.4 DSC Support Structure Analysis

No change.

N.3.6.1.5 HSM Design Analysis

No change.

N.3.6.1.6 HSM Door Analyses

No change.

N.3.6.1.7 HSM Heat Shield Analysis

No change.

N.3.6.1.8 HSM Axial Retainer for DSC

No change.

N.3.6.1.9 On-Site TC Analysis

No change.

N.3.6.2 Off-Normal Load Structural Analysis

Table 8.1-2 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®-24PHB System and presents analyses which demonstrate the adequacy of the design safety features of a NUHOMS®-24PHB System.

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 envelop 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.

N.3.6.2.1 Jammed 24PHB DSC During Transfer

No change.

N.3.6.2.2 Off-Normal Thermal Loads Analysis

The off-normal ambient temperatures of -40°F (extreme winter) and 117°F (extreme summer) are conservatively chosen for the NUHOMS®-24PHB System. Furthermore, these extreme

temperatures, if they occur, would likely last for a short period of time. However, 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 envelops the design basis ambient temperatures for the ISFSI site. The NUHOMS®-24PHB 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 N.4 provides the off-normal thermal analyses for storage and transfer modes for the NUHOMS®-24PHB DSCs. Of the two Heat Load Zoning Configurations in the 24PHB DSCs, Configuration 1 stress intensities for off-normal thermal loads bound those of Configuration 2.

The resulting stress intensities for the NUHOMS®-24PHB DSCs are provided in Table N.3.6-1.

Table N.3.6-1
Maximum NUHOMS®-24PHB DSC Stresses for Normal and Off-Normal Loads

DSC Components	Stress Type	Maximum Stress Intensity (ksi)[1]			
		Dead Weight	Internal Pressure[2]	Thermal[2]	Handling[2]
DSC Shell	Primary Membrane	Note (8)	2.77	N/A	Note (8)
	Membrane + Bending	Note (8)	6.61	N/A	Note (8)
	Primary + Secondary	Note (8)	24.21[6]	Note (8)	Note (8)
Inner Top Cover Plate	Primary Membrane	Note (8)	2.02	N/A	Note (8)
	Membrane + Bending	Note (8)	12.07[6]	N/A	Note (8)
	Primary + Secondary	Note (8)	15.19[6]	Note (8)	Note (8)
Outer Top Cover Plate	Primary Membrane	Note (8)	3.79	N/A	Note (8)
	Membrane + Bending	Note (8)	14.19	N/A	Note (8)
	Primary + Secondary	Note (8)	9.47	Note (8)	Note (8)
Inner Bottom Cover Plate[7]	Primary Membrane	Note (8)	0.49	N/A	Note (8)
	Membrane + Bending	Note (8)	1.49	N/A	Note (8)
	Primary + Secondary	Note (8)	13.2[6]	Note (8)	Note (8)
Outer Bottom Cover Plate[7]	Primary Membrane	Note (8)	0.81	N/A	Note (8)
	Membrane + Bending	Note (8)	1.48	N/A	Note (8)
	Primary + Secondary	Note (8)	5.81[6]	Note (8)	Note (8)
Spacer Disc	Primary Membrane	Note (8)	Note (5)	N/A	Note (8)
	Membrane + Bending	Note (8)	Note (5)	N/A	Note (8)
	Primary + Secondary	Note (8)	Note (5)	87.7[9]	79.80[3, 4]

(1) Values shown are maximum irrespective of location.
(2) Envelope of normal and off-normal conditions.
(3) Includes thermal loads applicable to normal and off-normal handling conditions.
(4) Includes dead weight loads.
(5) The DSC internal structures are not affected by pressure loads.
(6) These stresses are due to Service Level A 20 psig blow down pressure. A strongback is applied to the inner top cover plate
(7) Stress results for the inner and outer bottom cover plates apply only to the 24PHBS design.
(8) The maximum stress intensities are the same or bounded by those reported in Table 8.1-10.
(9) Maximum thermal stress intensity occurs for the vacuum drying load condition.

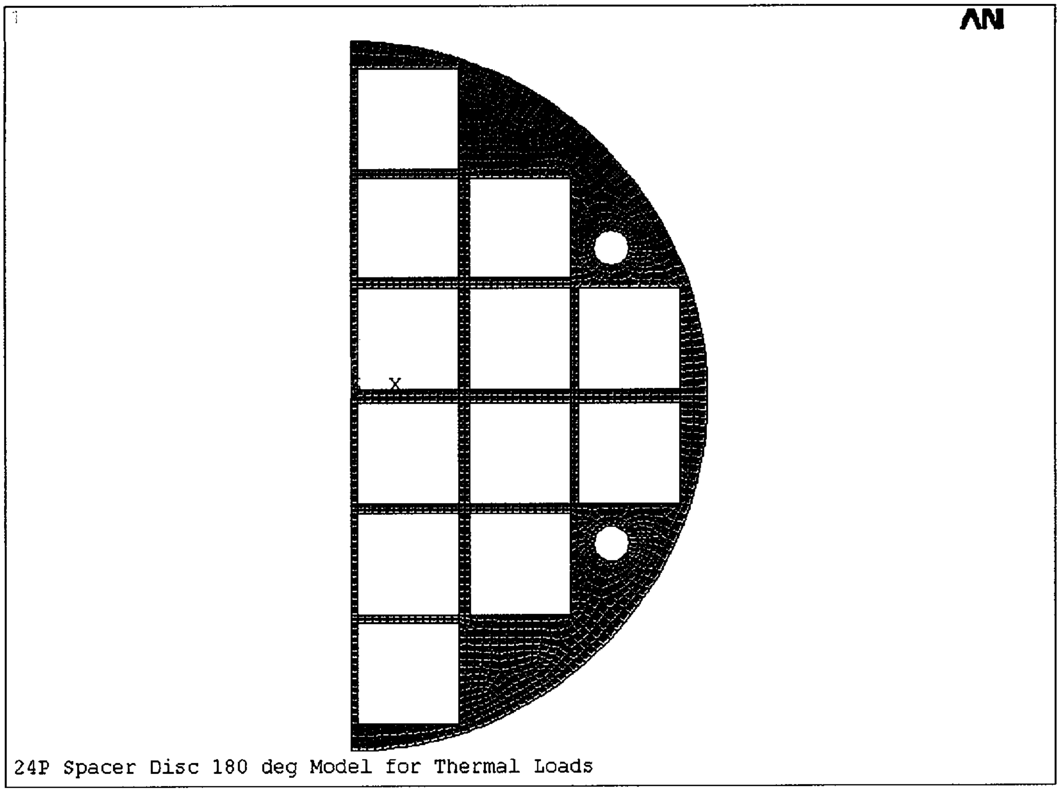


Figure N.3.6-1
NUHOMS®-24PHB DSC Spacer Disc 180° In-Plane Analytical Model for Thermal Stress Analysis

N.3.7 Structural Analysis (Accidents)

The design basis accident events specified by ANSI/ANS 57.9-1984 [3.7], and other credible accidents postulated to affect safe operation of the standardized NUHOMS®-24PHB 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 and the affected NUHOMS® components are 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®-24PHB System design. The resulting accident condition stresses in the NUHOMS®-24PHB 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 Section N.2. Load combination results for the HSM, 24PHB DSCs, and TC and the evaluation for fatigue effects are presented in Section N.3.7.10.

The postulated accident conditions addressed in this section include:

A. Reduced HSM air inlet and outlet shielding (Section N.3.7.1),

B. Tornado winds and tornado generated missiles (Section N.3.7.2),

C. Design basis earthquake (Section N.3.7.3),

D. Design basis flood (Section N.3.7.4),

E. Accidental TC drop with loss of neutron shield (Section N.3.7.5),

F. Lightning effects (Section N.3.7.6),

G. Debris blockage of HSM air inlet and outlet opening (Section N.3.7.7),

H. Postulated DSC leakage (Section N.3.7.8), and

I. Pressurization due to fuel cladding failure within the DSC (Section N.3.7.9).

N.3.7.1 Reduced HSM Air Inlet and Outlet Shielding

No change from Section 8.2.1.

N.3.7.2 Tornado Winds/Tornado Missile

No change from Section 8.2.2 and Appendix C.

N.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®-24PHB System components. Based on NRC Reg. Guide 1.61 [3.8], 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. The dominant structural frequencies computed in the lateral direction are 21.7 Hz and 34.6 Hz for 24PHB DSCs on the support structure and HSM concrete structure. Table 1 of NRC Regulatory Guide 1.60 [3.9] requires amplification factors for these structural frequencies, which result in conservative horizontal accelerations of 0.37g and 0.25g, respectively. The dominant vertical frequencies of the loaded HSM exceed 33Hz, corresponding to the zero period acceleration of 0.17g vertical.

N.3.7.3.1 DSC Shell Assembly Seismic Evaluation

As discussed above, the maximum calculated seismic accelerations for the 24PHB DSCs inside the HSM are 0.37g horizontally and 0.17g vertically. The discussion below addresses the evaluation of stresses in the DSC shell due to vertical and horizontal seismic loads and the evaluation of stability of the DSC against lifting off one of the support rails during a seismic event. The DSC basket and support structure are also subjected to the calculated DSC seismic reaction load.

N.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. The 24PHBS and 24PHBL DSC shells are identical to the 24P standard and long cavity DSC shells. Therefore, the calculation presented in Section 8.2.3.2 is applicable to the 24PHB DSCs. The resulting maximum spectral accelerations in the horizontal and vertical directions correspond to the shell ovalling mode are 1.0g and 0.68g, respectively.

N.3.7.3.1.2 DSC Seismic Stress Analysis

As discussed in Section 8.2.3.2.A, scale factors are used to account for multimode excitation and support by only one rail under horizontal seismic loading. These result in seismic accelerations of 3.0g horizontal and 1.0g vertical. The DSC shell stresses obtained from the analyses of vertical and horizontal seismic loads are summed absolutely. The above seismic accelerations are identical to those presented in Section 8.2.3.2.

As discussed in Section N.3.6.1.2, the 24PHBS and 24PHBL DSC shell assemblies are essentially the same as the 24P standard and long cavity DSC shell assemblies, respectively. In addition, the weights of the 24PHBS and 24PHBL DSC shell assemblies and basket assemblies are the same as those of the 24P standard and long cavity DSCs, respectively. The total weight of the fuel in the 24PHB DSCs is bounded by that in the 24P DSC. Therefore, the stress results presented in Section 8.2 and Appendix H bound the stresses in the 24PHB DSC shell assembly for seismic loading.

Section 8.2.3.2 evaluates the stability of the DSC against lifting off one of the support rails during a seismic event. This evaluation is also applicable to the 24PHB DSCs.

N.3.7.3.2 Basket Seismic Evaluation

The NUHOMS®-24PHB DSC basket is composed of spacer discs, guide sleeves and support rods. The seismic accelerations are bounded by the accelerations evaluated for handling conditions. The stress analysis results for 24P DSC guide sleeves and support rods are the same as those for the 24PHB DSC guide sleeves and support rods.

N.3.7.3.3 HSM Seismic Evaluation

No change.

N.3.7.3.3.1 HSM Frequency Analysis

No change.

N.3.7.3.3.2 HSM Seismic Response Spectrum Analysis

No change.

N.3.7.3.3.3 HSM Overturning Due to Seismic

No change.

N.3.7.3.3.4 HSM Sliding Due to Seismic

No change.

N.3.7.3.4 DSC Support Structure Seismic Evaluation

No change.

N.3.7.3.4.1 DSC Support Structure Natural Frequency

No change.

N.3.7.3.4.2 DSC Support Structure Seismic Response Spectra Analysis

No change.

N.3.7.3.5 DSC Axial Retainer Seismic Evaluation

No change.

N.3.7.3.6 TC Seismic Evaluation

No change.

N.3.7.4 Flood

No change.

N.3.7.4.1 HSM Flooding Analysis

No change.

N.3.7.4.2 DSC Flooding Analyses

No change.

N.3.7.5 Accidental Cask Drop

This section addresses the structural integrity of the standardized NUHOMS® on-site TC, the 24PHB DSC and its internal basket assembly when subjected to postulated cask drop accident conditions.

Cask drop evaluations include the following:

- 24PHB DSC Shell Assembly (Section N.3.7.5.2),
- Basket Assembly (Section N.3.7.5.3),
- On-Site TC (Section N.3.7.5.4), and
- Loss of the TC Neutron Shield (Section N.3.7.5.5).

The 24PHB DSC shell assembly, basket assembly, TC, and loss of neutron shield evaluations are based on the approach presented in the Section 8.2.

A short discussion of the effect of the NUHOMS®-24PHB DSC on the transfer operation, accident scenario and load definition is presented in Section N.3.7.5.1.

N.3.7.5.1 General Discussion

A. Cask Handling and Transfer Operation

No change.

B. 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 or slap down from a height of 80 inches.

2. 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.

C. Cask Drop Accident Load Definitions

The NUHOMS®-24PHBS and 24PHBL DSCs are evaluated for 75g horizontal side drop. The vertical end drop is not a credible event for the NUHOMS® System. However, to envelop the results of the 25g oblique corner drop, analysis is performed for a 60g top and bottom end drop load.

D. Cask Drop Surface Conditions

No change.

N.3.7.5.2 DSC Shell Assembly Drop Evaluation

As discussed in Section N.3.6.1.2 the 24PHBS and 24PHBL DSC shell assemblies are essentially the same as the 24P standard and long cavity DSC shell assemblies, respectively. In addition, the weights of the 24PHBS and 24PHBL DSC shell assemblies and basket assemblies are the same as those of the 24P standard and long cavity DSCs, respectively. The total weight of the fuel in the 24PHB DSCs is bounded by that in the 24P DSC.

The 60g top end drop evaluation does not involve the basket assembly weight except for bearing stress on the top shield plug. However, bearing stress evaluation is not required for Level D conditions. Therefore, bearing stresses on the inner bottom cover plate due to a 60g bottom end drop do not need to be evaluated.

For the 75g side drop, the stress results presented in Section 8.2 and Appendix H bound the stresses in the 24PHBS and 24PHBL DSC shell assembly for cask drop loading.

N.3.7.5.3 Basket Assembly Drop Evaluation

No change to Section 8.2.5.2.A(i).

Stress results obtained from the ANSYS analyses are linearized, as appropriate, to allow their categorization into primary membrane and membrane plus bending stress intensities. The stress results for the side drop conditions are summarized in Table N.3.7-1.

In addition, an ANSYS bifurcation buckling analysis of the entire spacer disc is performed to evaluate the global buckling behavior and stability of the spacer disc similar to that described in Section 8.2.5.2.A(ii). The spacer disc model is shown in Figure N.3.7-1. Elastic shell elements are used to model the disc and the support rod assemblies are included using beam elements. The spacer disc analytical model permits out-of-plane deformations, and is assumed to be supported both in-plane at the perimeter of the spacer disc that is in contact with the DSC shell, and out-of-plane at the four support rod locations. In addition to the 75g side drop loads, the worst case thermal loads are applied to the spacer disc model. Using the stresses from the side drop and thermal loads analyses, a subspace eigenvalue buckling analysis is performed for the drop. A factor of safety of 2.77 against collapse of the spacer disc is calculated for the postulated 75g horizontal side drop.

The 24PHB DSC spacer discs are analyzed for the vertical end drop using the quarter symmetry finite element model described in Section 8.2.5.2. A quarter symmetry model is used since the spacer discs exhibit symmetry along two horizontal axes. Only the spacer disc self weight is considered because the guide sleeves are not attached to the spacer disc. The stress results for the end drop condition are summarized in Table N.3.7-1.

Of the two Heat Load Zoning Configurations for high burnup fuel to be stored in the 24PHB DSC, the total weight of the basket assembly including the fuel weight for the Configuration 1 bound that of the Configuration 2. Therefore, the vertical and horizontal drop stress intensities of Configuration 1 bound those of Configuration 2. The results of spacer disc presented in Table N.3.7-1 are the bounding values.

The stress analysis results presented in Chapter 8 bound the stresses applicable to the 24PHBS and 24PHBL DSC guide sleeves and support rods.

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

Conservatively, the 60g end drop analysis results are used to demonstrate the TC qualification for the 25g corner drop of the 24PHB.

N.3.7.5.5 Loss of the TC Neutron Shield

No change.

N.3.7.6 Lightning

No change.

N.3.7.7 Blockage of Air Inlet and Outlet Openings

The thermal effects of this accident for the 24PHB DSCs are bounded by the storage of 24P DSC which has the same heat load of 24 kW as described in Section N.4. Therefore, the evaluation presented in Section 8.2.7.2 is applicable to storage of the 24PHB DSC also.

N.3.7.8 DSC Leakage

See Section N.11.2.8.

N.3.7.9 Accident Pressurization of DSC

See Section N.11.2.9.

N.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 24PHB System components important to safety are presented in this section. Fatigue effects on the TC and the 24PHB DSC are also addressed in this section.

N.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 are summarized in Section N.2.2. Since the postulated cask drop accidents are by far the most critical, the load combinations for these events envelop all other accident combinations. Table N.3.7-2 through Table N.3.7-4 tabulate the maximum stress intensity for each component of the 24PHBS and 24PHBL DSC shell and basket assemblies calculated for the enveloping normal operating, off-normal, and accident load combinations. Table N.3.7-6 gives the bottom cover plate stresses that apply only to 24PHBL DSCs. For comparison, the appropriate ASME Code allowables are also presented in these tables. Table N.3.7-7 and Table N.3.7-8 present load combination results for 24PHBL DSC shield plug components and their comparison with ASME Code allowables.

Of the two Heat Load Zoning Configurations for high burnup fuel to be stored in the 24PHB DSC, the stress results for the Configuration 1 bound those of the Configuration 2. Therefore, the basket assembly component stress results presented in Table N.3.7-2, Table N.3.7-3 and Table N.3.7-4 are for Configuration 1.

N.3.7.10.2 DSC Fatigue Evaluation

The range of pressure fluctuations due to seasonal temperature changes in the 24PHB DSC are essentially the same as those evaluated for the 24P DSC. Similarly, the normal and off-normal temperature fluctuations for the 24PHB DSCs due to seasonal fluctuations are essentially the

same as those calculated for the 24P DSC. Therefore, the fatigue evaluation presented in Section 8.2.10.2 remains applicable to the 24PHBS and 24PHBL DSCs.

N.3.7.10.3 TC Load Combination Evaluation

No change.

N.3.7.10.4 TC Fatigue Evaluation

No change.

N.3.7.10.5 HSM Load Combination Evaluation

No change.

N.3.7.10.6 Thermal Cycling of the HSM

No change.

N.3.7.10.7 DSC Support Structure Load Combination Evaluation

No change.

Table N.3.7-1
Maximum NUHOMS®-24PHB DSC Stresses for Drop Accident Loads

DSC Components	Stress Type	Calculated Stress (ksi) [1]	
		Vertical[2]	Horizontal
DSC Shell	Primary Membrane	8.46	Note (6)
	Membrane + Bending	20.56	Note (6)
Inner Top Cover Plate	Primary Membrane	0.39	Note (6)
	Membrane + Bending	1.49	Note (6)
Outer Top Cover Plate	Primary Membrane	0.63	Note (6)
	Membrane + Bending	1.75	Note (6)
Inner Bottom Cover Plate	Primary Membrane	6.08	Note (6)
	Membrane + Bending	20.71	Note (6)
Outer Bottom Cover Plate	Primary Membrane	0.86	Note (6)
	Membrane + Bending	1.82	Note (6)
Spacer Discs	Primary Membrane	Note (6)	Note (6)
	Local Membrane	Note (6)	Note (6)
	Membrane + Bending	Note (6)	Note (6)
Support Rods	Compression + Bending Stress Interaction Ratio[3]	Note (6)	Note (6)
	Bending Stress	Note (6)	Note (6)
Guide Sleeves	Axial	Note (6)	Note (6)
	Bending	Note (6)	Note (6)
Top Cover Plate Weld[4, 5]	Primary	0.89	Note (6)
Bottom Cover Plate Weld[4, 5]	Primary	8.56	Note (6)

(1) Values shown are maxima irrespective of location.
(2) Spacer discs, support rods and guide sleeves are evaluated conservatively for 75g vertical drop load. All other components are evaluated for 60g vertical drop load.
(3) For vertical drop case, axial plus bending stress interaction ratio is given for the support rods.
(4) Envelope of inner and outer cover plate weld. Stress values include 20 psig internal pressure.
(5) Top cover plate and bottom cover plate weld stresses are reported only for the 24PHBS DSC.
(6) The calculated stress is same as that reported in Table 8.2-7.

Table N.3.7-2
NUHOMS®-24PHB DSC Enveloping Load Combination Results for Normal and Off-Normal Loads (ASME Service Levels A and B)

DSC Components	Stress Type	Stress (ksi)		
		Controlling Load Combination(1)	Calculated	Allowable(2)
DSC Shell	Primary Membrane	UL-5, UL-6	15.66	18.7
	Membrane + Bending	LD-2	21.65	26.3
	Primary + Secondary	LD-4	43.92	54.3
Inner Bottom Cover Plate(8)	Primary Membrane	LD-5	16.86	19.3
	Membrane + Bending	LD-2	27.44	29.0
	Primary + Secondary	LD-4	35.98	54.3
Outer Bottom Cover Plate(8)	Primary Membrane	UL-5, UL-6	14.18	18.7
	Membrane + Bending	UL-5, UL-6	26.04	28.1
	Primary + Secondary	LD-4	36.07	54.3
Inner Top Cover Plate	Primary Membrane	TR-5	3.98	17.5
	Membrane + Bending	TR-8	11.02	26.3
	Primary + Secondary	TR-4	32.57	54.3
Outer Top Cover Plate	Primary Membrane	TR-7	5.36	17.5
	Membrane + Bending	HSM-3	16.04	27.2
	Primary + Secondary	TR-3	29.46	54.3
Spacer Disc	Primary Membrane	TR-1 through TR-8	8.90	18.1
	Membrane + Bending	TR-1 through TR-8	12.50	27.2
	Primary + Secondary	DD-2	88.40	Note (5)

See Table N.3.7-5 for notes.

Table N.3.7-3
NUHOMS®-24PHB DSC Enveloping Load Combination Results for Accident Loads (ASME Service Level C)

DSC Components	Stress Type	Stress (ksi)		
		Controlling Load Combination(1)	Calculated	Allowable(2)
DSC Shell	Primary Membrane	UL-7	19.69	22.4
	Membrane + Bending	UL-7	27.54	33.7
Inner Bottom Cover Plate(8)	Primary Membrane	UL-7	12.08	22.4
	Membrane + Bending	UL-7	15.07	33.7
Outer Bottom Cover Plate(8)	Primary Membrane	UL-7	18.40	22.4
	Membrane + Bending	UL-7	33.28	33.7
Inner Top Cover Plate	Primary Membrane	Note (6)	Note (6)	Note (6)
	Membrane + Bending	Note (6)	Note (6)	Note (6)
Outer Top Cover Plate	Primary Membrane	Note (6)	Note (6)	Note (6)
	Membrane + Bending	Note (6)	Note (6)	Note (6)
Spacer Disc	Primary Membrane	Note (6)	Note (6)	Note (6)
	Membrane + Bending	Note (6)	Note (6)	Note (6)

See Table N.3.7-5 for notes.

Table N.3.7-4
NUHOMS®-24PHB DSC Enveloping Load Combination Results for Accident Loads (ASME Service Level D)(3)

DSC Components	Stress Type	Stress (ksi)		
		Controlling Load Combination(1)	Calculated	Allowable(2)
DSC Shell	Primary Membrane	TR-11	28.92	44.5
	Membrane + Bending	TR-11	47.26	57.2
Inner Bottom Cover Plate(8)	Primary Membrane	TR-11	39.4	44.5
	Membrane + Bending	TR-11	40.50	57.2
Outer Bottom Cover Plate(8)	Primary Membrane	UL-8	33.42	44.9
	Membrane + Bending	UL-8	65.10	65.3
Inner Top Cover Plate	Primary Membrane	TR-11	33.70	44.5
	Membrane + Bending	TR-11	53.61	57.2
Outer Top Cover Plate	Primary Membrane	TR-11	36.63	44.5
	Membrane + Bending	HSM-5	55.59	57.2
Spacer Disc	Primary Membrane	TR-11	45.60	48.4
	Local Membrane	TR-11	61.10	62.2
	Membrane + Bending	TR-11	61.10	62.2
Support Rods(4, 7)	Axial/Bending Stress Interaction Ratio	TR-9, TR-10	0.97	1.0
Guide Sleeves	Bending Stress	TR-11	16.0	37.9
Top Cover Plate Weld	Primary	TR-11	26.6	26.8
Bottom Cover Plate Weld	Primary	UL-8	14.72	26.9

See Table N.3.7-5 for notes.

Table N.3.7-5
DSC Enveloping Load Combination Table Notes

(1) See Section N.2.2 for load combination nomenclature.

(2) See Table 3.2-9 for allowable stress criteria.

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

(4) Allowable stresses in the support rods are based upon the criteria specified in Subsection NF and Appendix F of the ASME Code.

(5) Qualification of primary and secondary stresses for the spacer disc are based on the simplified elastic-plastic analysis methodology of NB-3228.5.

(6) Per Section N.2.2, there are no Level C loads applicable to the spacer discs and the inner and outer top cover plates.

(7) Spacer discs, support rods and guide sleeves are conservatively evaluated for 75g vertical drop load. All other components are evaluated for 60g vertical drop load.

(8) The inner and outer bottom cover plate stresses reported here are for the 24PHBS DSC only. See Table N.3.7-6 for the stress in the 24PHBL DSC.

Table N.3.7-6
24PHBL DSC Bottom Cover Plate Analysis Results

Component	Controlling Load Combination	Service Level	Stress Type	Stress (ksi)	
				Calculated	Allowable[1]
Inner Bottom Cover Plate	TR-1	A/B	P_m $P_L + P_b$ $P_L + P_b + Q$	0.70 23.90 51.90	16.2 24.3 52.5[3]
	TR-11 TR-11	D	P_m $P_L + P_b$	39.40 40.50	44.5[3] 57.2[3]
Outer Bottom Cover Plate[2]	LD-1	A/B	P_m $P_L + P_b$ $P_L + P_b + Q$	2.93 3.42 21.22	16.2 24.3 48.6
	TR-11	D	P_m $P_L + P_b$	39.40 40.50	44.5[3] 57.2[3]

(1) All allowable stresses are taken at 650°F, unless noted otherwise.
(2) The outer bottom cover plate is integral with the bottom shield plug.
(3) Allowable stresses are taken at 500°F.

Table N.3.7-7
24PHBL DSC Top Shield Plug Analysis Results

Component	Controlling Load Combination	Service Level	Stress Type	Stress (ksi)	
				Calculated	Allowable[2]
Casing Plates	DD-2[3]	A/B	P_m $P_L + P_b$ $P_L + P_b + Q$	3.19 3.44 27.4	17.4 26.1 52.2
	TR-11 TR-10[1]	D	P_m $P_L + P_b$	39.4 55.3	40.6 58.0
Stiffeners	DD-2[3]	A/B	$P_L + P_b$ $P_L + P_b + Q$	7.3 25.2	26.1 52.2
	TR-10[1]	D	$P_L + P_b$	56.9	58.0
Stiffener Welds	DD-2[3]	A/B	Weld Metal	2.1	21.0
			Base Metal	1.6	10.5
	TR-10[1]	D	Weld Metal	16.3	42.0
			Base Metal	12.5	20.7

(1) Conservatively, a vertical drop load (top and bottom end) of 75g is used.
(2) All allowable stresses are taken at 650°F.
(3) Uses an external pressure that is the maximum of the DD-2, HSM-9 and HSM-10 load combinations.

Table N.3.7-8
24PHBL DSC Bottom Shield Plug Analysis Results

Component	Controlling Load Combination	Service Level	Stress Type	Stress (ksi)	
				Calculated	Allowable[1]
Casing Plates	UL-4	A/B	P_m $P_L + P_b$ $P_L + P_b + Q$	2.53 2.96 20.80	16.2 24.3 48.6
	UL-7	C	P_m $P_L + P_b$	2.93 3.42	19.4 29.2
	TR-11 TR-9[4]	D	P_m $P_L + P_b$	39.40 55.40[2]	44.5[3] 57.2[3]
Stiffeners	UL-4	A/B	$P_L + P_b$ $P_L + P_b + Q$	7.41 25.21	24.3 48.6
	UL-7	C	$P_L + P_b$	8.58	29.2
	TR-9[4]	D	$P_L + P_b$	37.80	57.2[3]
Stiffener Welds	UL-4	A/B	Weld Metal Base Metal	3.18 3.18	20.3 7.1
	UL-7	C	Weld Metal Base Metal	3.69 3.69	30.5 10.7
	TR-9[4]	D	Weld Metal Base Metal	13.40 13.40	40.6[3] 14.3[3]

(1) All allowable stresses are taken at 650°F, unless noted otherwise.
(2) Sum of global stress of 15.1 ksi plus local plate stress of 40.3 ksi.
(3) Allowable stresses are taken at 500°F.
(4) Conservatively, a vertical drop load of 75g (top and bottom end drop) is used.

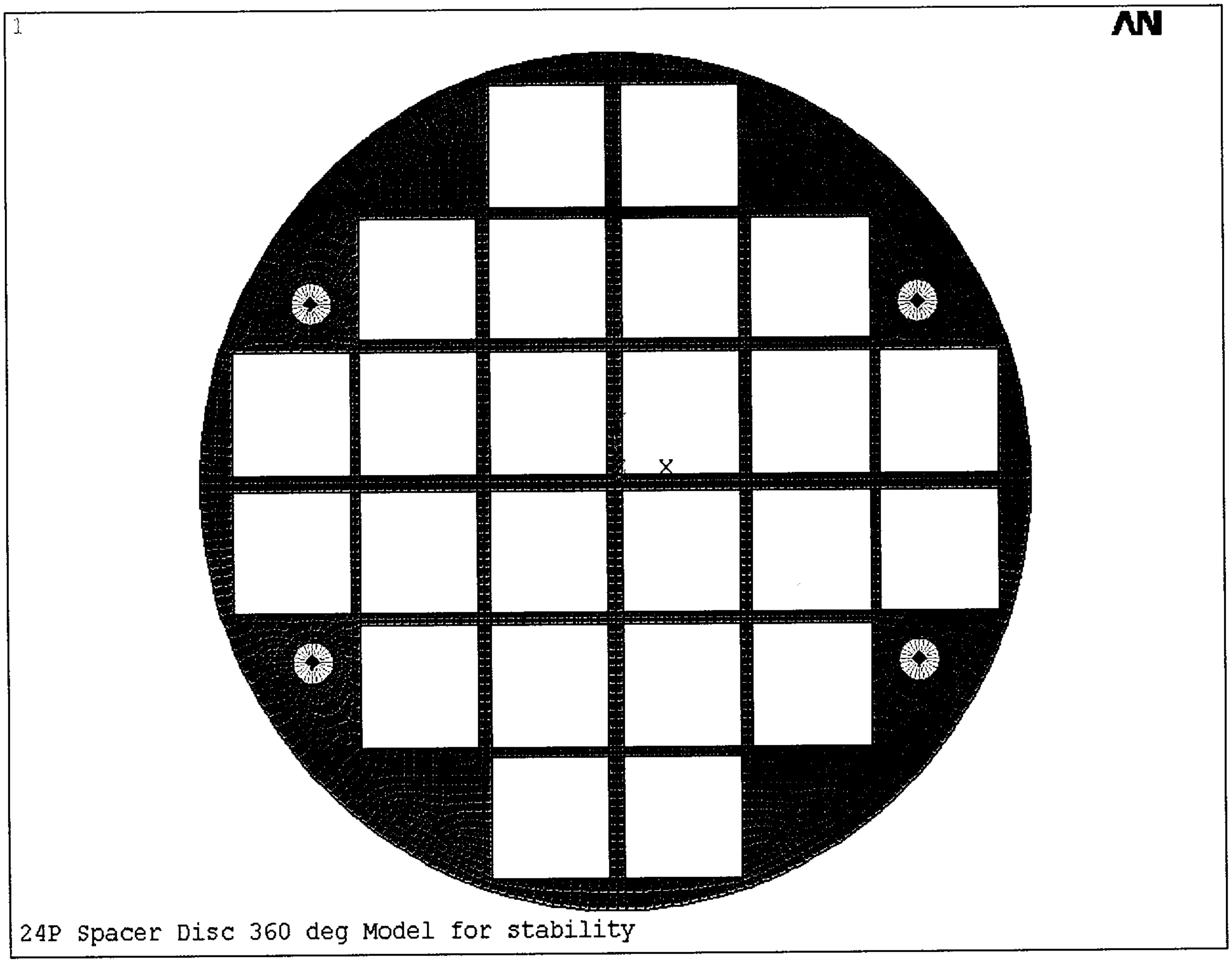


Figure N.3.7-1
NUHOMS®-24PHB DSC Spacer Disc 360° Analytical Model for Stability Analysis

N.3.8 References

3.1 American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, Subsections NB, NC, NF, NG, and Appendices, 1983 Edition with Winter 1985 Addenda.

3.2 U.S. NRC Bulletin 96-04, "Chemical, Galvanic or Other Reactions in Spent Fuel Storage and Transportation Casks."

3.3 U.S. Nuclear Regulatory Commission, "Safety Evaluation of VECTRA Technologies Response to NRC Bulletin 96-04 for the NUHOMS®-24P and NUHOMS®-7P Dry Spent Fuel Storage Systems, November 1997 (Docket 72-1004, 72-3, 72-4, 72-8 and 72-14).

3.4 Transnuclear West Report, "An Assessment of Chemical, Galvanic, or Other Reactions in NUHOMS® Spent Fuel Storage and Transportation Casks, Part I," Document 31-B9604-102, Revision 2.7.

3.5 ANSYS Engineering Analysis System, Users Manual for ANSYS Revisions 5.3, 5.4 and 5.6.2, Swanson Analysis Systems, Inc., Houston, PA.

3.6 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).

3.7 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).

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

3.9 U.S. Atomic Energy Commission, "Design Response Spectra for Seismic Design of Nuclear Power Plants," Regulatory Guide 1.60, Revision 1, December 1973

N.4 Thermal Evaluation

N.4.1 Discussion

The NUHOMS®-24PHB System is designed to passively reject decay heat from a high burnup payload during storage and transfer for normal, off-normal and accident conditions while maintaining temperatures and pressures within specified design limits. Objectives of the thermal analyses performed for this evaluation include:

- Determination of maximum and minimum temperatures with respect to materials limits to ensure components perform their intended safety functions,
- Determination of temperature distributions for the NUHOMS®-24PHB DSC components to support the calculation of thermal stresses for the structural components,
- Determination of maximum internal NUHOMS®-24PHB DSC pressures for the normal, off-normal and accident conditions, and
- Determination of the maximum fuel cladding temperature.

Several thermal design criteria are established for the heat removal capability of the 24PHB DSC basket. These are:

- Maximum temperatures of the confinement structural components must not adversely affect the confinement function,
- The maximum initial fuel cladding temperature limit during long term storage conditions for fuel with burnup less than 30,000 MWd/MTU is determined using the methodology provided by Report PNL-6189 [4.1]. The maximum fuel cladding temperature during long term storage conditions for burnups greater than 30,000 MWd/MTU is evaluated using the methodology described in DPC-NE-2013P [4.2]. This methodology accounts for the maximum cladding temperature of 340°C (645°F), decay time, burnup and internal rod pressure for fuel assembly average burnup of 55 GWD/MTU. It also accounts for short-term loading/unloading, transfer and accident conditions during which the fuel cladding temperature is limited to 400°C (752°F) [4.2],
- The maximum DSC cavity internal pressures during normal, off-normal and accident conditions must be below the design pressures of 15 psig, 20 psig and 68 psig, respectively, and
- The maximum total heat load per DSC is 24 kW with a maximum per assembly heat load of 1.3 kW when heat load zoning is used. Figure N.4-5 and Figure N.4-6 show the 2 alternate Heat Load Zoning Configurations analyzed in the NUHOMS®-24PHB DSC design. Configuration 1 allows for a payload of 24 fuel assemblies with or without BPRAs while Configuration 2 is limited to a payload of 20 fuel assemblies with or

without BPRAs. The two limiting heat zone configurations are presented in Figure N.4-7 and Figure N.4-8.

The analyses consider the effect of the decay heat flux varying axially along active fuel length of a fuel assembly. The axial heat flux profile for a PWR fuel assembly is shown in Figure N.4-1. The thermal analysis is based on total heat load from a fuel assembly with or without control components. The three dimensional model described in N.4.4.1.1 is applicable to both the 24PHBL and 24PHBS DSC designs.

A description of the detailed analyses performed for normal storage and transfer conditions is provided in Section N.4.4, off-normal conditions in Section N.4.5, accident conditions in Section N.4.6, and loading/unloading conditions in Section N.4.7. The evaluation concludes that with a design basis heat load of 24 kW per DSC, all thermal design criteria are satisfied.

N.4.2 Summary of Thermal Properties of Materials

No change.

N.4.3 Specifications for Components

The only change to the NUHOMS®-24P DSC design configuration is the addition of a test port and plug to the outer top cover plate to allow for testing the DSC as "leak tight" per ANSI N14.5-1997.

N.4.4 Thermal Evaluation for Normal Conditions of Storage (NCS) and Transfer (NCT)

The normal conditions of storage and transfer are used for the determination of the maximum fuel cladding temperature, component temperatures, 24PHB DSC internal pressure and thermal stresses. The maximum normal ambient temperature of 100°F and the 10CFR Part 71.71(c) insolation averaged over a 24 hour period are used. The minimum NCS temperature is 0°F without any insolation. For the purposes of determining the long term maximum fuel cladding temperature in storage, an ambient temperature of 70°F and half of the maximum off-normal insolation value are used.

N.4.4.1 NUHOMS®-24PHB DSC Thermal Models

The NUHOMS®-24PHB DSC finite element models are developed using the ANSYS computer code [4.7]. ANSYS is a comprehensive thermal, structural and fluid flow analysis package. It is a finite element analysis code capable of solving steady state and transient thermal analysis problems in one, two or three dimensions. Heat transfer via a combination of conduction, radiation and convection can be modeled by ANSYS. The three-dimensional geometry of the DSC was modeled. Solid entities were modeled by SOLID70 three-dimensional thermal elements or by PLANE55 two-dimensional thermal elements. Heat transfer across small gaps was modeled using LINK32 one-dimensional conduction elements and LINK31 one-dimensional radiation elements. Radiation within the basket and HSM was modeled by MATRIX50 super elements.

N.4.4.1.1 NUHOMS®-24PHB DSC, Basket and Payload Model

Two three-dimensional models were used to represent the NUHOMS®-24HB DSC, basket and payload. The first represents a 21.1 inch axial section between the axial centers of two spacer disks, as shown in Figure N.4-2. Adiabatic boundary conditions are applied to the axial surfaces of the model, conservatively neglecting axial heat conduction to the ends of the canister. The second model used is identical to the first except it represents a 180° section of the DSC and basket, which is used to assess the vacuum drying and blocked vent transient cases. Both models simulate the effective thermal properties of the fuel with a homogenized material occupying the volume within the basket. For the storage cases, the DSC surface temperature distribution calculated by the HSM model are applied to the exterior surfaces of the DSC/basket model. For transfer cases, the maximum calculated temperature of the DSC shell is conservatively used for all DSC shell surfaces in the DSC/basket model.

Within the models, heat is transferred via conduction through fuel regions, the guide sleeves, spacer discs and DSC shell. Heat transfer through the helium cover gas is assumed to be via conduction and radiation. Convective effects in the open spaces of basket surrounding the guide sleeves are conservatively ignored. To bound the heat conductance uncertainty between adjacent components, gaps between the adjacent components have been included in the model. All heat transfer across the gaps is by gaseous conduction and radiation.

N.4.4.1.2 Decay Heat Load

The decay heat load is applied as volumetric heat generation in the elements that represent the homogenized fuel. Two Heat Load Zoning Configurations are analyzed. Configuration 1, Figure N.4-7, represents the maximum allowable decay heat configuration for the 24PHB DSC loaded with 24 fuel assemblies. This configuration shows the worst case decay heat loading for fuel assemblies placed in Zone 2. There is no restriction on where the assemblies with decay heat load of ≤ 1 kW are placed within Zone 2 provided that the maximum heat load for Zone 2 of 10.8 kW is maintained. Configuration 2, Figure N.4-8, represents the worst case decay heat load configuration for the 24PHB DSC loaded with a maximum of 20 fuel assemblies. While a heat load of 26 kW/DSC is analyzed, the payload is limited to a maximum decay heat load of 24 kW/DSC as shown in Figure N.4-6. Therefore, the DSC shell temperatures calculated with the 24 kW HSM and TC models are used as boundary conditions for the Configuration 2 DSC/basket model. The heat load of both configurations were adjusted to account for axial peaking. Approximately 3% of the decay heat is assumed to be conducted axially, therefore a uniform peaking factor of 1.08 was used for the basket model.

N.4.4.1.3 HSM Thermal Model

To determine the temperature distribution on the surface of the 24PHB DSC, a two-dimensional ANSYS model of the cross section of the HSM with a loaded DSC was used to represent the NUHOMS®-24PHB System during storage (Figure N.4-3). Solid entities were modeled by PLANE55 two-dimensional thermal elements. Radiation within the basket was modeled by MATRIX50 super elements.

The methodology given in Section 8.1.3 is used to calculate bulk air temperatures within the HSM cavity surrounding the 24PHB DSC. The decay heat from the payload is modeled as a uniform heat flux on the inner surface of the DSC shell. Heat from the 24PHB DSC surface dissipates via natural convection to the air within the HSM and via radiation to the HSM heat shield and walls. Heat is dissipated from the HSM heat shield and walls via conduction through the walls of the HSM, via convection to the HSM air and via convection and radiation from the HSM outer surfaces to the ambient environment.

N.4.4.1.4 TC Thermal Model

The DSC temperature profile for the NUHOMS®-24PHB DSC in the standard TC was taken from Section 8.1.

DSC temperature profiles for the NUHOMS®-24PHB DSC in the OS197 TC were calculated through a two-dimensional model of the DSC and cask (Figure N.4-4). Solid entities were modeled by PLANE55 two-dimensional elements. Radiation from the DSC to the inner surface of the cask was modeled by MATRIX50 radiation superelements. The payload decay heat was modeled as a uniform heat flux on the inner diameter of the DSC. Heat is dissipated through the cask via conduction, except for the loss of neutron shielding accident case where heat is transferred via radiation and conduction across the empty neutron shielding cavity. Heat is dissipated to the environment from the surface of the model via natural convection and radiation.

N.4.4.1.5 Boundary Conditions, Storage

Normal Conditions of Storage analyses of the NUHOMS®-24PHB DSC within the HSM are carried out for the following ambient conditions:

- Maximum normal ambient temperature of 100°F, with insolation,
- Minimum normal ambient temperature of 0°F, without insolation, and
- Long term average maximum temperatures of 70°F, with insolation.

The HSM thermal model described above provides the surface temperatures of the DSC shell that are applied as boundary conditions to the DSC shell in the DSC, basket and payload finite element model.

N.4.4.1.6 Boundary Conditions, Transfer

In accordance with Section 8.1, analyses of the NUHOMS®-24P DSC within the TC were performed for the following ambient conditions:

- Maximum normal ambient temperature of 100°F, with insolation, and
- Minimum off-normal extreme ambient temperature of 0°F, without insolation.

The maximum calculated 24P DSC temperatures are conservatively applied to the entire exterior surface of the 24PHB DSC in the DSC/Basket/Payload finite element model.

N.4.4.2 Maximum Temperatures

The 24PHB DSC maximum surface temperature distribution for normal conditions of storage and transfer are calculated by steady-state analyses of the HSM and TC models, respectively, with a maximum DSC heat load of 24 kW. For the storage cases, the temperature distributions are applied to the 360° ANSYS model of 24PHB DSC, providing a maximum top to bottom temperature gradient. For the transfer cases, the maximum 24P DSC temperature is conservatively applied to the entire surface of the 360° 24PHB DSC model. Heat load configurations 1 and 2 are used to determine the basket and payload temperature distributions for normal conditions of storage and transfer. The temperature distribution for Configuration 1 and Configuration 2 for long term storage in the HSM at 70°F are shown in Figure N.4-9 and Figure N.4-10, respectively. Configuration 1 provides bounding temperatures for the basket and payload, and therefore represents the controlling thermal case. Summaries of the maximum calculated fuel cladding and 24PHB DSC component temperatures from the bounding Configuration 1 for storage and transfer cases are listed in Table N.4-1 and Table N.4-2, respectively. Summaries of temperatures for Configuration 2 are listed in Table N.4-3 and Table N.4-4.

N.4.4.3 Minimum Temperatures

Under the minimum temperature condition of 0°F ambient, the resulting 24PHB DSC component temperatures will approach 0°F if no credit is taken for the decay heat load. Since the DSC materials, including confinement structures, continue to function at this temperature, the

minimum temperature condition has no adverse effect on the performance of the NUHOMS®-24PHB DSC.

N.4.4.4 Maximum Internal Pressures

During normal conditions, the internal pressure of the NUHOMS®-24PHB DSC is calculated assuming that one percent (1%) of the fuel rods are failed. For determination of internal pressure within the 24PHB DSC, it is assumed that 100 percent of the rod fill gas, and 30 percent of the fission gases within the failed fuel rods are available for release into the DSC cavity [4.8].

N.4.4.4.1 Fission Gas within Fuel Assemblies

The determination of fission gases within the fuel rods is based on high burn-up fuel operational data for a B&W 15x15 PWR assembly with a maximum assembly average burnup of 55,000 MWd/MTU [4.9]. Tritium, Kr^{85}, and Xe^{131m} gases with the assemblies are considered as tabulated below:

Isotope	Volume (in^3/assy)
Tritium (H^3)	19.3
Kr^{85}	4,656.1
Xe^{131m}	45,218.8
Total	49,894.2

The amount of fission gas released into the 24PHB DSC cavity for normal, off-normal and accident condition cases assuming a 30% gas release fraction in accordance with NUREG 1536 [4.8] is tabulated below.

Case	Percentage of Rods Ruptured	Moles of Fission Gas Released
Normal	1	2.63
Off-Normal	10	26.3
Accident	100	263

N.4.4.4.2 Quantity of Gas in BPRAs

The NUHOMS®-24PHBL DSC may include Burnable Poison Rod Assemblies (BPRAs). These BPRAs have an initial helium fill of 14.7 psia, and if 100% of the boron is consumed, and 30% released into the DSC, a total of 53.8 gmoles of gas could be released to the DSC assuming 100% cladding rupture as given in Appendix J.4.

The percentage of BPRA rods ruptured during normal, off-normal and accident conditions is assumed to be 1%, 10% and 100%, respectively, similar to the assumptions for the fuel rod rupturing. The maximum amount of gas released to the 24PHB DSC cavity from the BPRAs for normal, off-normal and accident conditions is tabulated below.

Case	Percentage of BPRA Rods Ruptured	Moles of Control Component Gas Released per DSC, 30% Pellet Release
Normal	1	0.538
Off-Normal	10	5.38
Accident	100	53.8

N.4.4.4.3 Helium Fill Gas within Fuel Rods

The volume of the helium fill gas in a B&W 15x15 fuel pin at cold, unirradiated conditions is 1.6 in^3, and there are 208 fueled pins in an assembly. The maximum fill pressure is 465.3 psig (480 psia) and the fill temperature is assumed to be room temperature (70°F or 530°R). The quantity of fuel rod fill gas in 24 assemblies is:

$$n_{plenum} = \frac{(480\,psia)(6894.8\,Pa/psi)(24 \cdot 208 \cdot 1.6\,in^3)(1.6387x10^{-5}\,m^3/in^3)}{(8.314\,J/mol \cdot K)(530\,°R)(5/9\,K/°R)}$$

$$n_{plenum} = 176.9\,g-moles$$

The maximum fraction of the fuel pins that are assumed to rupture and release their charge gas for normal, off-normal and accident events is 1, 10 and 100%, respectively [4.8]. The amount of helium fill gas released for each of these conditions is summarized below.

Case	Percentage of Rods Ruptured	Moles of Helium Charge Gas Released
Normal	1	1.77
Off-Normal	10	17.7
Accident	100	176.9

N.4.4.4.4 Initial Helium Fill Gas in the DSC

The amount of helium present within the DSC is calculated using the ideal gas law and a maximum initial helium fill pressure of 3.5 psig. The long term average helium fill temperature of 449°F (909°R) is used as the basis for the initial fill. Using the ideal gas law, the quantity of helium in the 24PHB DSC is then equal to:

$$n_{he} = \frac{(18.2\,psia)(6894.8\,Pa/psi)(384{,}463\,in^3)(1.6387x10^{-5}\,m^3/in^3)}{(8.314\,J/mol \cdot K)(909\,°R)(5/9\,K/°R)}$$

$$n_{he} = 188.3\,g-moles$$

N.4.4.4.5 Maximum Internal Pressures During Storage and Transfer

The maximum average cavity gas temperature during normal conditions of storage and transfer is bounded by the normal transfer condition. The maximum average helium temperature for that

case is 563°F (1,023°R). With rupture of one percent of the fuel rods, the pressures within the 24PHB DSC are calculated via the ideal gas law:

$$n_{DSC-NOC} = n_{DSC-He} + 0.01 \cdot n_{pin-He} + 0.01 \cdot n_{fg} + 0.01 \cdot n_{BPRA}$$

$$n_{DSC-NOC} = 188 + 1.77 + 2.63 + 0.583 = 193\,g - moles$$

The maximum normal operating pressure is then,

$$P_{DSC-NOC} = nRT/V$$

$$P_{DSC-NOC} = \frac{\left(1.4504x10^{-4}\,\frac{psia}{Pa}\right)(193\,g - moles)(8.314\,J/mol \cdot K)(1{,}023\,°R)(5/9K/°R)}{(384{,}463\,in^3)(1.6387x10^{-5}\,m^3/in^3)}$$

$$P_{DSC-NOC} = 21\,psia\,(6.3\,psig)$$

This pressure is presented with the controlling pressures for the off-normal and accident cases in Table N.4-7.

N.4.4.5 Maximum Thermal Stresses

The maximum thermal stresses during normal conditions of storage and transfer are calculated in Section N.3.

N.4.4.6 Evaluation of Cask Performance for Normal Conditions

The maximum decay heat load for the NUHOMS® HSM and TC is identical to the values used in Section 8.1.3. The NUHOMS®-24PHB DSC shell and basket are evaluated for these calculated temperatures and pressures in Section N.3. The maximum calculated fuel cladding temperatures for long term storage and short term operating conditions meet the allowable fuel temperature limits of 645°F (341°C) and 752°F (400°C), respectively. The maximum 24PHB DSC internal cavity pressure remains below 15.0 psig during normal conditions of storage and transfer. Based on the thermal analysis, it is concluded that the NUHOMS®-24PHB DSC design meets all applicable thermal requirements.

N.4.5 Thermal Evaluation for Off-Normal Conditions

The NUHOMS®-24PHB System components are evaluated for the extreme ambient temperatures of –40°F (winter) and 117°F (summer). Should these extreme temperatures ever occur, they would be expected to last for a very short duration of time. Nevertheless, these ambient temperatures are conservatively assumed to occur for a significant duration to cause a steady-state temperature distribution in the NUHOMS®-24PHB System components. Section 8.1.3 uses a maximum ambient temperature of 125°F for off-normal conditions for thermal analysis of NUHOMS®-24P DSC in HSM or in TC. The use of the calculated 24P DSC shell temperatures is conservative for the NUHOMS®-24PHB DSC with maximum 117°F off-normal ambient temperatures.

N.4.5.1 Off-Normal Maximum/Minimum Temperatures during Storage

The 24PHB DSC maximum surface temperature distribution for off-normal conditions of storage is calculated by steady-state analyses of the HSM with a maximum DSC heat load of 24 kW. This temperature distribution is applied to the 360° 24PHB DSC model with decay heat configurations 1 and 2 to determine the basket and payload temperature distributions for off-normal conditions of storage. The temperature distribution within a cross section of the basket is shown in Figure N.4-11. A summary of the calculated 24PHB DSC component temperatures is listed in Table N.4-1 for Configuration 1 and Table N.4-3 for Configuration 2.

N.4.5.1.1 Boundary Conditions, Storage

Off-Normal Conditions of storage analyses of the NUHOMS®-24PHB DSC within the HSM are carried out for the following ambient conditions:

- Maximum off-normal ambient temperature of 117°F with insolation, and
- Minimum off-normal ambient temperature of -40°F with insolation.

The HSM and TC thermal models described above provide the surface temperatures of the 24PHB DSC shell that are applied to the DSC shell in the DSC, basket and payload model.

N.4.5.2 Off-Normal Maximum/Minimum Temperatures during Transfer

The DSC maximum surface temperature distribution for off-normal conditions of transfer is calculated by steady-state analyses of the TC with a maximum 24PHB DSC heat load of 24 kW. The 24PHB DSC surface temperature distribution is applied to the 360° DSC model with decay heat configurations 1 and 2 to determine the basket and payload temperature distribution. The temperature distribution within a cross-section of the basket is shown in Figure N.4-12. The component temperatures are listed in Table N.4-2 for Configuration 1 and in Table N.4-4 for Configuration 2.

N.4.5.2.1 Boundary Conditions, Transfer

In accordance with Section 8.1, analyses of the NUHOMS®-24P DSC within the TC were performed for the following ambient conditions:

- Maximum normal ambient temperature of 125°F with solar shield in place, and
- Minimum off-normal extreme ambient temperature of -40°F without insolation

These analyses, which use a total decay heat load of 24.0 kW per DSC, determine maximum 24P DSC surface temperatures. The maximum calculated 24P DSC temperatures are conservatively applied to the entire exterior surface of the 24PHB DSC in the DSC/Basket/Payload finite element model. In the case of the maximum off-normal ambient temperature, the presence of the solar shield makes the maximum normal case bound the off-normal case.

N.4.5.3 Off-Normal Maximum Internal Pressure during Storage/Transfer

N.4.5.3.1 Maximum Internal Pressures

During off-normal conditions, the internal pressure of the NUHOMS®-24PHB DSC is calculated assuming 10% of the fuel rods are failed. For determination of internal pressure within the 24PHB DSC, it is assumed that 100% of the rod fill gas and 30% of the fission gases within the failed fuel rods are available for release into the DSC cavity [4.8]. Using the fuel rod data from Section N.4.4.4, the maximum pressures are calculated.

The average cavity gas temperature during off-normal conditions of storage and transfer is bounded by the normal condition transfer case, where the average helium temperature is 563°F (1,023°R). With rupture of 10% of the fuel rods, the pressures within the 24PHB DSC are calculated via the ideal gas law:

$$n_{DSC-ON} = n_{DSC-He} + 0.1 \cdot n_{pin-He} + 0.1 \cdot n_{fg} + 0.1 \cdot n_{BPRA}$$

$$n_{DSC-ON} = 188 + 17.7 + 26.3 + 5.83 = 237.8\,g-moles$$

$$P_{DSC-ON} = \frac{\left(1.4504x10^{-4}\dfrac{psia}{Pa}\right)(237.8\,g-moles)(8.314\,J/mol \cdot K)(1{,}023\,°R)(5/9\,K/°R)}{(384{,}463\,in^3)(1.6387x10^{-5}\,m^3/in^3)}$$

$$P_{DSC-ON} = 25.9\,psia\,(11.2\,psig)$$

This pressure is reported in Table N.4-7.

N.4.5.4 Maximum Thermal Stresses

The maximum thermal stresses during off-normal conditions of storage and transfer are calculated in Section N.3.

N.4.5.5 Evaluation of Cask Performance for Off-Normal Conditions

The temperatures in the NUHOMS® HSM and TC with the NUHOMS®-24PHB DSC are identical to or bounded by the analyses in Section 8.1.3 with NUHOMS®-24P DSC. The NUHOMS®-24PHB DSC shell and basket are evaluated for calculated temperatures and pressures in Section N.3. The maximum fuel cladding temperatures are below the allowable fuel temperature limit of 752°F (400°C). The 24PHB DSC internal cavity pressures remain below 20.0 psig during off-normal conditions of storage and transfer. Therefore, the NUHOMS®-24PHB DSC design meets all applicable off-normal conditions thermal requirements.

N.4.6 Thermal Evaluation for Accident Conditions

Since the NUHOMS® HSMs are located outdoors, there is a remote possibility that the ventilation air inlet and outlet openings could become blocked by debris from such unlikely events as floods and tornadoes. The NUHOMS® HSM system design features such as the perimeter security fence and redundant protected location of the air inlet and outlet 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.

During transfer under maximum ambient temperature and insolation, the loss of the sun shield concurrent with the loss of the liquid neutron shield for the TC that has a liquid neutron shield represents the controlling transfer case. The temperatures for this case are bounded by the blocked vent case.

It is determined in Section 3.3.6, that the HSM and DSC contain no flammable material and the concrete and steel used for their fabrication can withstand any credible fire accident condition. Fire parameters are dependent on the amount and type of fuel within the transporter and the fire accident condition shall be addressed within site-specific applications. Licensees are required to verify that loadings resulting from potential fires and explosions are acceptable in accordance with 10CFR72.212(b)(2). The hypothetical fire evaluation for the NUHOMS®-24PHB System is included in Section N.4.6.3.

N.4.6.1 Blocked Vent Accident Evaluation

For the postulated blocked vent accident condition, the HSM ventilation inlet and outlet openings are assumed to be completely blocked for a 34-hour period concurrent with the extreme off-normal ambient condition of 117°F with insolation.

For conservatism, a transient thermal analysis is performed using the 2-D model developed in Section N.4.4.1, for heat load zoning Configuration 1, which envelopes the temperature results for heat load zoning Configuration 2. When the inlet and outlet vents are blocked, the air surrounding the 24PHB DSC in the HSM cavity is contained (trapped) in the HSM cavity. The temperature difference between the hot 24PHB DSC surface and the surrounding cooler heat shield and concrete surfaces in the HSM cavity will result in closed cavity convection. This closed cavity convection in the HSM cavity is accounted for by calculating an effective conductivity of air. The HSM cavity is modeled as a combination of separate enclosures as described below.

Enclosure 1 includes the HSM cavity within 0° to 90° sector limited by 24PHB DSC shell surface, vertical and top horizontal heat shield surfaces. Enclosure 2 includes the HSM cavity within -90° to 0° sector limited by 24PHB DSC shell, vertical heat shield and space under the bottom line of DSC shell surfaces. Enclosure 3 includes the bottom of Enclosure 2 and inside surfaces of HSM side wall and floor. Enclosure 4 includes the horizontal space limited by the concrete roof surface and the top horizontal heat shield surface. Enclosure 5 is the vertical space limited by the inside surface of the concrete side wall and the vertical heat shield. To be conservative, the closed cavity convection in Enclosure 3 is neglected and the closed cavity

convection coefficient for Enclosure 2 is assumed to be the average of Enclosures 1 and 3 (9.09 + 1)/2 = 5.045.

For enclosures in theHSM cavity, a thermal conductivity of air k_{air} is adjusted to account for closed cavity convection using an empirical generalized formula [4.10]:

$$\frac{k_{eff\ air}}{k_{air}} = C \cdot Ra^n \cdot \left(\frac{L}{\delta}\right)^m$$

where Ra - Raleigh number, L, δ- length and width of an enclosure, C, n, m - constants, to be defined by flow conditions (Ra) and geometry (L/δ).

An iterative process is used to determine the mean temperatures used in air property calculations. The results are given below.

Enclosure in HSM Cavity	δ, in	L, in	$\overline{T}_{hot}$, °F	$\overline{T}_{cold}$, °F	Gr_δ	Pr	C	n	m	$k_{eff\ air}/k_{air}$
1	9.95	63	561	428	8.91e+6	0.68	0.4	0.2	0	9.09
4	2	40	432	319	1.55e+5	0.683	0.11	0.29	0	3.149
5	3	72	393	271	7.15e+5	0.685	0.197	0.25	-0.111	3.662

These effective conductivities are used in the ANSYS model to determine the transient 24PHB DSC shell temperatures during blocked vent accident. The results are summarized in Table N.4-5. These DSC shell temperatures are then used as boundary conditions to calculate the basket and fuel cladding temperatures during blocked vent transient.

The calculated temperature distribution within the hottest cross section of the basket as a function of time is shown in Figure N.4-13. Summaries of the calculated NUHOMS®-24PHB DSC cladding and component temperatures for heat load configurations 1 and 2 are listed in Table N.4-1 and Table N.4-3, respectively.

N.4.6.2 Transfer Accident Evaluation

The postulated transfer accident event consists of transfer of NUHOMS®-24PHB DSC in the TC in a 117°F ambient environment with loss of the solar shield and the liquid neutron shielding which also bounds the solid neutron shield TC configuration. Only heat load zoning Configuration 1 was evaluated, since it envelopes all other configurations for the normal and off-normal conditions of transfer. Since the temperature of the blocked vent case bounds the transfer accident condition, this case is enveloped by the blocked vent accident case.

Fuel Cladding and Basket Materials

The short term events are defined in Section N.4.1 for the storage and transfer conditions. The blocked vent results are reported for 34 hours. The results are reported for bounding heat load

zoning Configuration 1 in Table N.4-2. The maximum temperatures of the basket assembly after 34 hours are listed in Table N.4-2.

N.4.6.3 Hypothetical Fire Accident Evaluation

For the postulated worst case fire accident, a 300-gallon diesel fire is simulated for a NUHOMS®-24PHB DSC with a decay heat load of 24 kW during transfer in the TC. This bounds fire scenarios associated with loading operations and storage within the HSM due to the large thermal mass of the HSM and the HSM vent configuration which provides protection for the DSC and payload.

Steady-state, off-normal conditions are assumed prior to the fire, which consist of a 117°F ambient condition with solar shield in place on the TC. The fire has a temperature of 1,475°F, and an emittance of 0.9 and a duration of 15 minutes based on the 300-gallon diesel fuel source and complete engulfment of the TC for the duration of the fire. Subsequent to the fire, the TC is subjected to 117°F ambient conditions with maximum solar load. Note that these hypothetical fire parameters are very conservative.

The calculated temperature responses of selected components in the TC and 24PHB DSC during the first 2,000 minutes of the fire accident are shown in Figure N.4-14. The calculated maximum fire transient DSC surface temperature is 499°F, which is less than the blocked vent case maximum DSC temperature of 560°F. Therefore, the NUHOMS®-2PHB DSC temperatures and pressures calculated for the blocked vent case bound the hypothetical fire accident case.

N.4.6.4 Maximum Internal Pressures

The average cavity gas temperature during the blocked vent accident condition is 613 °F (1,073°R). With rupture of one hundred percent of the fuel rods, the pressures within the DSC are calculated via the ideal gas law:

$$n_{DSC-ACC} = n_{DSC-He} + n_{pin-He} + n_{fg} + n_{BPRA}$$
$$n_{DSC-ACC} = 188 + 177 + 263 + 53.8 = 682\,g-moles$$

$$P_{DSC-ACC} = \frac{\left(1.4504x10^{-4}\,\frac{psia}{Pa}\right)(682g-moles)(8.314\,J/mol\cdot K)(1{,}073\,^{\circ}R)(5/9\,K/^{\circ}R)}{(384{,}463\,in^{3})(1.6387x10^{-5}\,m^{3}/in^{3})}$$
$$P_{DSC-ACC} = 77.8\,psia\,(63.1\,psig)$$

This pressure is presented with the controlling pressures for the normal and off-normal cases in Table N.4-7.

N.4.6.5 Maximum Thermal Stresses

The maximum thermal stresses during accident conditions are calculated in Section N.3.

N.4.6.6 Evaluation of Performance During Accident Conditions

The temperatures in the NUHOMS® HSM and TC are the same as those given in Section 8.2 because the maximum heat load per DSC is 24 kW. The NUHOMS®-24PHB DSC shell and basket are evaluated for calculated pressures and temperatures in Section N.3.

The maximum fuel cladding temperature of 752°F is the same as the short-term limit (Section N.4.1) of 752°F (400°C). The accident pressure in the NUHOMS®-24PHB DSC cavity remains below the accident design criteria of 68.0 psig. It is concluded that the NUHOMS®-24PHB System maintains confinement during the postulated accident condition.

N.4.7 Thermal Evaluation for Loading/Unloading Conditions

All fuel transfer operations occur when the NUHOMS®-24PHB DSC/TC is in the spent fuel pool. The fuel is always submerged in free-flowing pool water permitting heat dissipation. After fuel loading is complete, the DSC/TC is removed from the pool, drained, dried, backfilled with helium and sealed.

The loading condition evaluated for the NUHOMS®-24PHB DSC is the heatup of the DSC before its cavity can be backfilled with helium. This typically occurs during the performance of the vacuum drying operation of the DSC cavity. A transient thermal analysis is performed to predict the heatup time history for the NUHOMS®-24PHB DSC components assuming air is in the DSC cavity.

N.4.7.1 Vacuum Drying Analysis

Heatup of the 24PHB DSC prior to being backfilled with helium typically occurs as DSC operations are being performed to drain and dry the DSC. The vacuum drying of the 24PHB DSC generally does not reduce the pressure sufficiently to reduce the thermal conductivity of the air in the DSC cavity. Analyses are performed to determine both steady state temperatures and the transient heat-up during the vacuum drying condition. For both analyses, all gaseous heat conduction within the NUHOMS®-24PHB DSC is through air instead of helium.

N.4.7.1.1 Vacuum Drying Evaluation

Steady-state and transient thermal analyses are performed using the 360° and 180° symmetric models, respectively, developed in Section N.4.4.1, decay heat loads for configurations 1 and 2, and a maximum 24PHB DSC temperature of 215 °F. The initial temperature of the DSC, basket and fuel is assumed to be 215°F, based on the boiling temperature of the fill water. The temperature response of the peak cladding during the transient for Configuration 1, which is the controlling case, is plotted in Figure N.4-15. The maximum allowable cladding temperature limit of 752°F is reached after approximately 36 hours. Table N.4-6 provides the maximum component temperatures for the steady-state analysis and the maximum cladding temperature for a 36 hour limiting transient case. Figure N.4-16 provides the temperature distribution within the basket at the end of the 36 hour vacuum drying transient.

K.4.7.1.2 Reflooding Evaluation

For unloading operations, the 24PHB DSC is filled with the spent fuel pool water through the siphon port. During this filling operation, the 24PHB DSC vent port is maintained open with effluents routed to the plant's off-gas monitoring system. The NUHOMS®-24PHB DSC operating procedures recommend that the DSC cavity atmosphere be sampled first before introducing any reflood water in the DSC cavity.

When the pool water is added to a 24PHB DSC cavity containing hot fuel and basket components, some of the water will flash to steam causing internal cavity pressure to rise. This steam pressure is released through the vent port. The procedures also specify that the flow rate

of the reflood water be controlled such that the internal pressure in the 24PHB DSC cavity does not exceed 20 psig. This is assured by monitoring the maximum internal pressure in the DSC cavity during the reflood event. The reflood for the 24PHB DSC is considered as a service level D event and the design pressure of the DSC is 68 psig. Therefore, there is sufficient margin in the 24PHB DSC internal pressure during the reflooding event to assure that the DSC will not be over pressurized.

The maximum fuel cladding temperature during reflooding event will be significantly less than the vacuum drying condition due to the presence of water/steam in the 24PHB DSC cavity. The analysis presented in Section N.4.7.1.1 shows that the maximum cladding temperature at 36 hours is 752°F. Since the reflooding procedure requires less than 36 hours and water/steam will be present in the DSC cavity, the peak cladding temperature during the reflooding operation will be less than 752°F. Therefore, no cladding damage is expected due to the reflood event. This is also substantiated by the operating experience gained with the loading and unloading of transportation packages like IF-300 [4.11] which show that fuel cladding integrity is maintained during these operations and fuel handling and retrieval is not impacted.

N.4.8 References

4.1 Levy, et. al., *Recommended Temperature Limits for Dry Storage of Spent Light Water Reactor Zircaloy - Clad Fuel Rods in Inert Gas*, Pacific Northwest Laboratory, PNL-6189, 1987.

4.2 *Fuel Rod Analysis for Dry Storage of Spent Nuclear Fuel,* DPC-NE-2013P, Duke Energy, August 2001.

4.3 Rohsenow, W. M., et. al., *Handbook of Heat Transfer Fundamentals*, McGraw-Hill Publishing, New York 1985.

4.4 *American Society for Mechanical Engineers (ASME) Boiler and Pressure Vessel Code*, Section II, Part D, 1998 Edition Including 1999 Addenda.

4.5 Baumeister, T., et al. *Marks' Standard Handbook for Mechanical Engineers*, 8th Edition, McGraw Hill, 1978.

4.6 NUREG-0497, *MATPRO-Version 11: A Handbook of Materials Properties for Use in the Analysis of Light Water Reactor Fuel Rod Behavior*, EG&G Idaho, Idaho Falls, February 1979, NUREG-CR/0497.

4.7 ANSYS, Inc., ANSYS Engineering Analysis System User's Manual for ANSYS Revision 5.6, Houston, PA.

4.8 *Standard Review Plan for Dry Cask Storage Systems*, NUREG-1536, Nuclear Regulatory Commission.

4.9 *Extended Fuel Burnup Demonstration Program,* DOE/ET/34014-10 NAC C-8327, Nuclear Assurance Corporation, September 1983.

4.10 Holman, J. P., Heat Transfer, McGraw Hill, 1989.

4.11 Consolidated Safety Analysis Report for IF-300 Shipping Cask, CoC 9001.

Table N.4-1
NUHOMS®-24PHB DSC Component Temperatures During Storage for Configuration 1

Component	Normal Conditions			Off-Normal Conditions			Accident Conditions	
	Maximum Temperature (°F)	Minimum Temperature(1) (°F)	Allowable Temperature (°F)	Maximum Temperature (°F)	Minimum Temperature(2) (°F)	Allowable Temperature (°F)	Blocked Vent Condition(4) (°F)	Allowable Temperature (°F)
DSC Shell	374	0	(3)	399	-40	(3)	560	(3)
Spacer Disc	647	0	(3)	659	-40	(3)	741	(3)
Guide Sleeve	658	0	(3)	670	-40	(3)	752	(3)
Support Rod	473	0	(3)	490	-40	(3)	605	(3)
Fuel Cladding	645	0	645 (max)	671	-40	752 max	752	752 max

Notes:

(1) Assuming no credit for decay heat and a daily average ambient temperature of 0°F.

(2) Assuming no credit for decay heat and a daily average ambient temperature of -40°F

(3) The components perform their intended safety function within the operating range.

(4) Temperatures after 34 hours of blocked vent conditions.

Table N.4-2
NUHOMS®-24PHB DSC Component Temperatures During Transfer for Configuration 1

Component	Normal Conditions			Off-Normal Conditions			Accident Conditions	
	Maximum Temperature (°F)	Minimum Temperature(1) (°F)	Allowable Temperature (°F)	Maximum Temperature (°F)	Minimum Temperature(2) (°F)	Allowable Temperature (°F)	Maximum Temperature (°F)	Allowable Temperature (°F)
DSC Shell	448	0	(3)	448	-40	(3)	536	(3)
Spacer Disc	713	0	(3)	713	-40	(3)	729	(3)
Guide Sleeve	721	0	(3)	722	-40	(3)	738	(3)
Support Rod	549	0	(3)	559	-40	(3)	582	(3)
Fuel Cladding	722	0	752 max	722	-40	752 max	738	752 max

Notes:

(1) Assuming no credit for decay heat and a daily average ambient temperature of 0°F.

(2) Assuming no credit for decay heat and a daily average ambient temperature of -40°F

(3) The components perform their intended safety function within the operating range.

(4) The Off-Normal 117°F ambient temperature case w/solar shield is bounded by the normal, full solar case.

Table N.4-3
NUHOMS®-24PHB DSC Component Temperatures During Storage for Configuration 2

Component	Normal Conditions			Off-Normal Conditions			Accident Conditions	
	Maximum Temperature (°F)	Minimum Temperature[(1)] (°F)	Allowable Temperature (°F)	Maximum Temperature (°F)	Minimum Temperature[(2)] (°F)	Allowable Temperature (°F)	Blocked Vent Condition[(4)] (°F)	Allowable Temperature (°F)
DSC Shell	374	0	(3)	399	-40	(3)	<560	(3)
Spacer Disc	616	0	(3)	644	-40	(3)	<741	(3)
Guide Sleeve	644	0	(3)	657	-40	(3)	<752	(3)
Support Rod	480	0	(3)	497	-40	(3)	<605	(3)
Fuel Cladding	631	0	645 (max)	658	-40	752 max	<752	752 max

Notes:

(1) Assuming no credit for decay heat and a daily average ambient temperature of 0°F.

(2) Assuming no credit for decay heat and a daily average ambient temperature of -40°F

(3) The components perform their intended safety function within the operating range.

(4) Temperatures after 34 hours of blocked vent conditions are bounded by Configuration 1.

Table N.4-4
NUHOMS®-24PHB DSC Component Temperatures During Transfer for Configuration 2

Component	Normal Conditions			Off-Normal Conditions[4]			Accident Conditions	
	Maximum Temperature (°F)	Minimum Temperature[1] (°F)	Allowable Temperature (°F)	Maximum Temperature (°F)	Minimum Temperature[2] (°F)	Allowable Temperature (°F)	Maximum Temperature (°F)	Allowable Temperature (°F)
DSC Shell	448	0	(3)	448	-40	(3)	<536	(3)
Spacer Disc	693	0	(3)	697	-40	(3)	<729	(3)
Guide Sleeve	702	0	(3)	707	-40	(3)	<738	(3)
Support Rod	556	0	(3)	565	-40	(3)	<582	(3)
Fuel Cladding	703	0	752 max	708	-40	752 max	<738	752 max

Notes:

(1) Assuming no credit for decay heat and a daily average ambient temperature of 0°F.

(2) Assuming no credit for decay heat and a daily average ambient temperature of -40°F

(3) The components perform their intended safety function within the operating range.

(4) The Off-Normal 117°F ambient temperature case w/solar shield is bounded by the normal, full solar case.

Table N.4-5
NUHOMS®-24PHB DSC Shell Temperature Results For 24 kW Blocked Vent Case

Time	Top (°F)	Side (°F)	Bottom (°F)
0 hours	387	345	307
4 hours	439	407	351
8 hours	467	435	369
12 hours	488	455	382
16 hours	506	471	393
20 hours	521	485	402
24 hours	534	497	411
28 hours	545	507	419
32 hours	556	517	426
36 hours	565	526	433
40 hours	574	534	440

Table N.4-6
Temperature Distribution within the NUHOMS®-24PHB DSC Vacuum Drying Condition

Component	Maximum Temperature for Configuration 1 (°F)	Maximum Temperature for Configuration 2 (°F)	Allowable Temperature (°F)
DSC Shell	215	215	(2)
Spacer Disc	789	743	(2)
Guide Sleeve	811	776	(2)
Support Rod	451	465	(2)
Fuel Cladding	812/752(1)	776/<752(1)	752°F

(1) Steady-state vacuum/36 hour transient. The steady-state results are shown for information only.

(2) The components perform their intended safety function within the operating range.

Table N.4-7
NUHOMS®-24PHB DSC Normal, Off-Normal and Accident Pressures

Operation Condition	Limiting Case Description	Average Cavity Gas Temp. (°F)	Maximum DSC Pressure (psig)	Design Basis Pressure (psig)
Normal	DSC in Cask, 100°F, Full Solar	563	6.3	15.0
Off-Normal	DSC in Cask 100°F, Full Solar	563	11.2	20.0
Accident	Blocked Vent Case	613	63.1	68.0

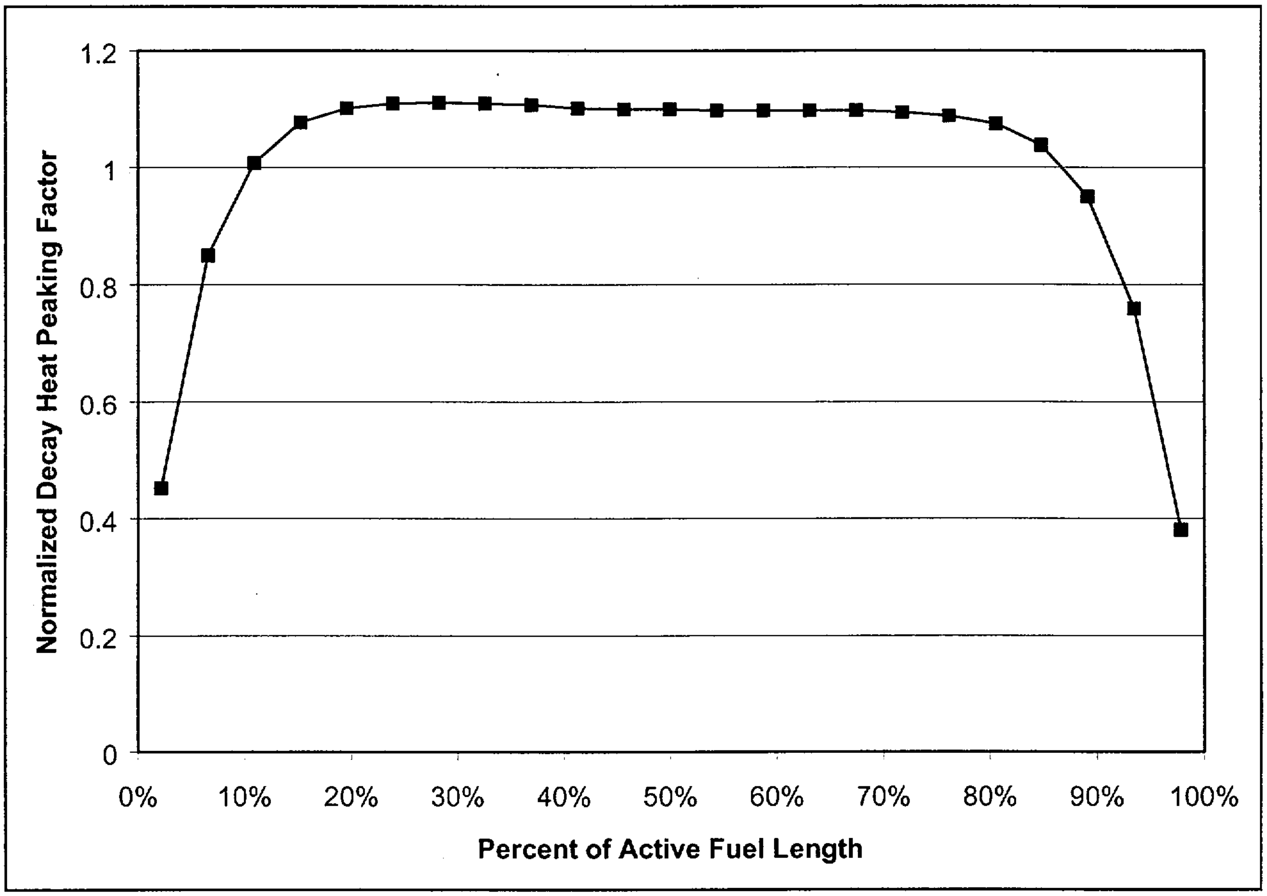
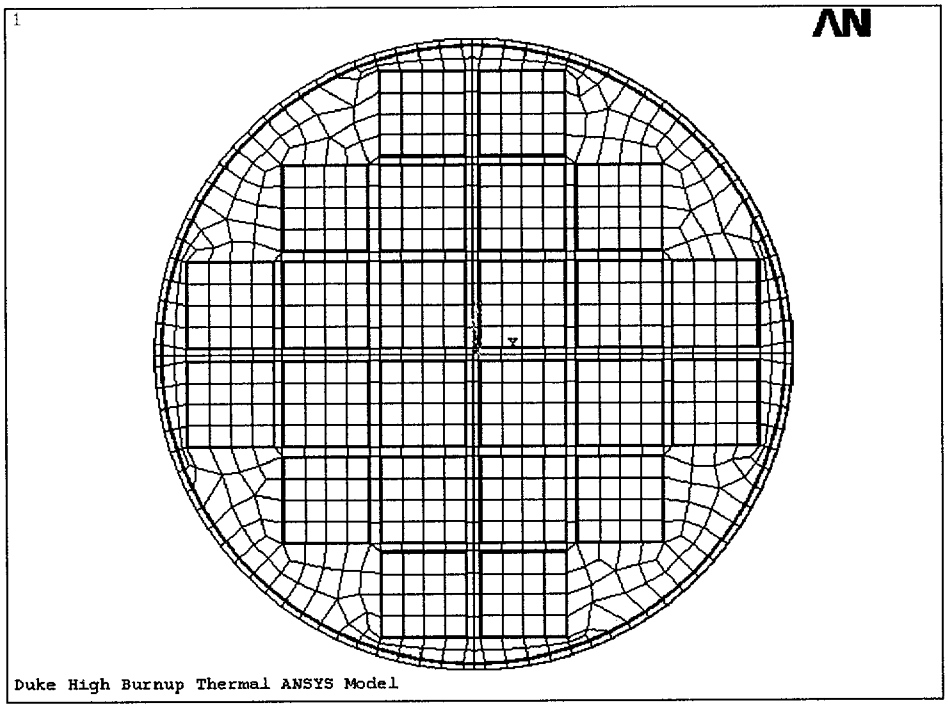
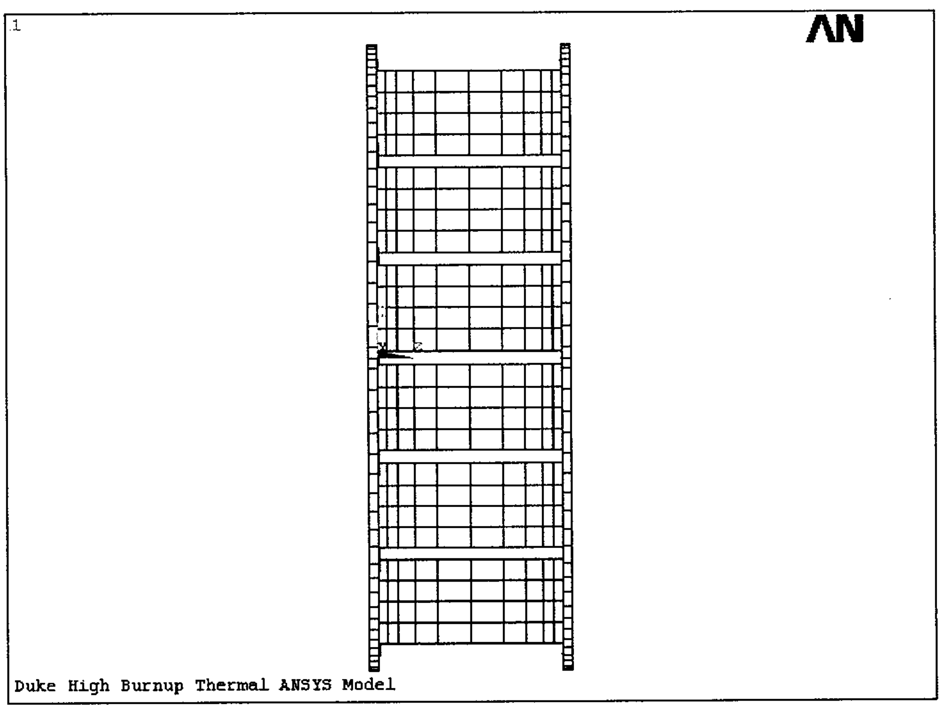


Figure N.4-1
Axial Heat Flux Profile for PWR Fuel



Front View



Side View (Shown without DSC Shell)

Figure N.4-2
3-D Thermal ANSYS Model of 24PHB DSC

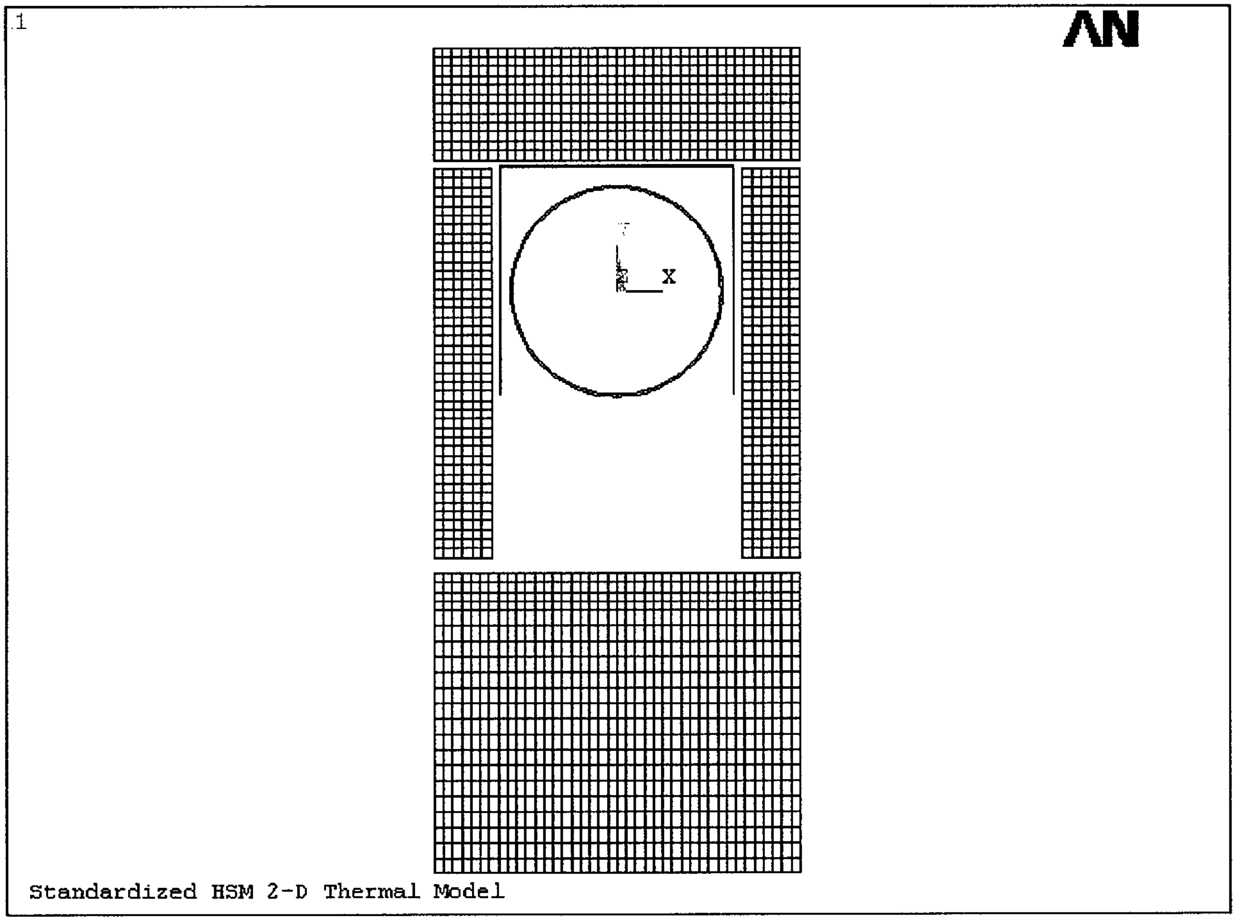


Figure N.4-3
Standardized HSM 2-D Thermal ANSYS Model

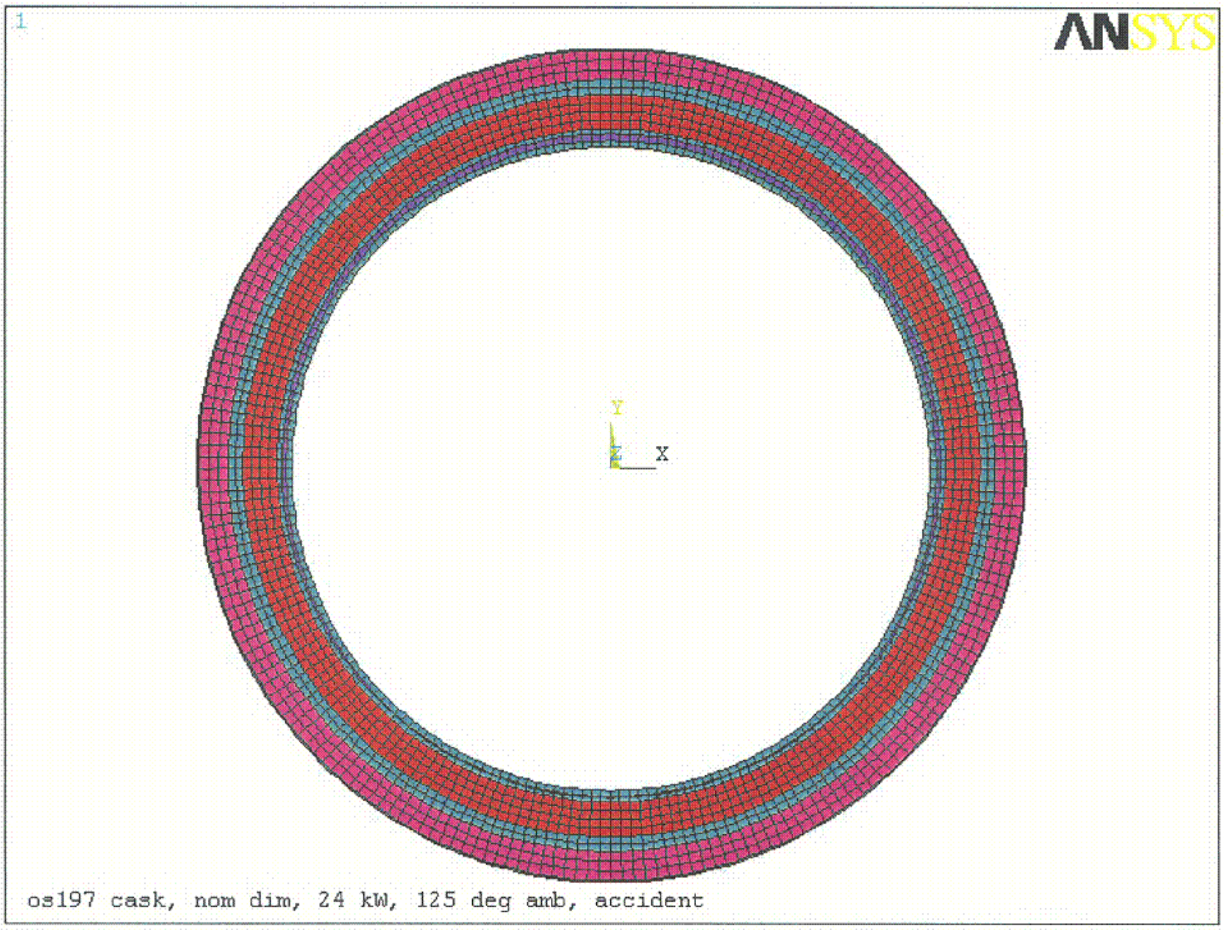
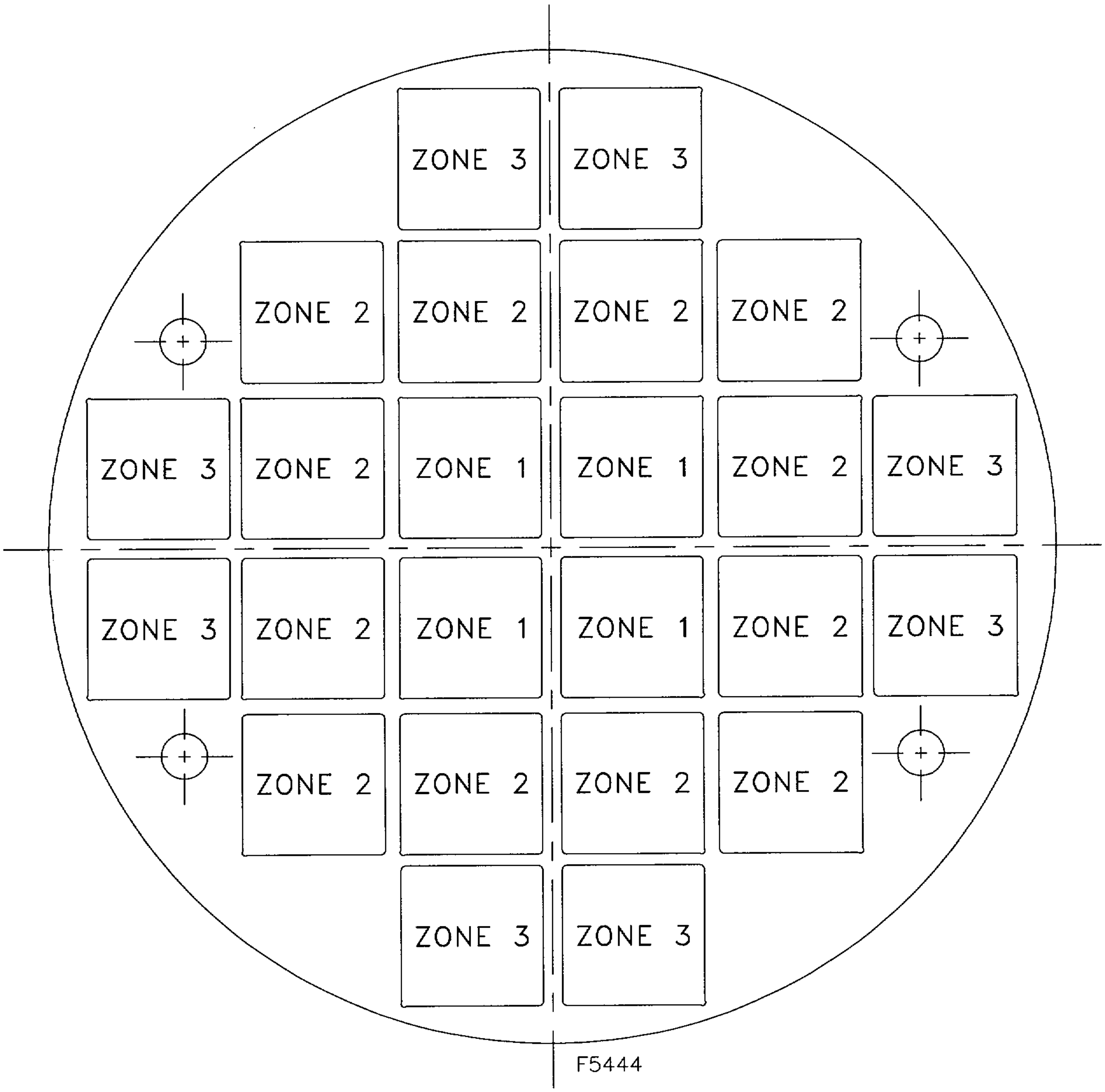


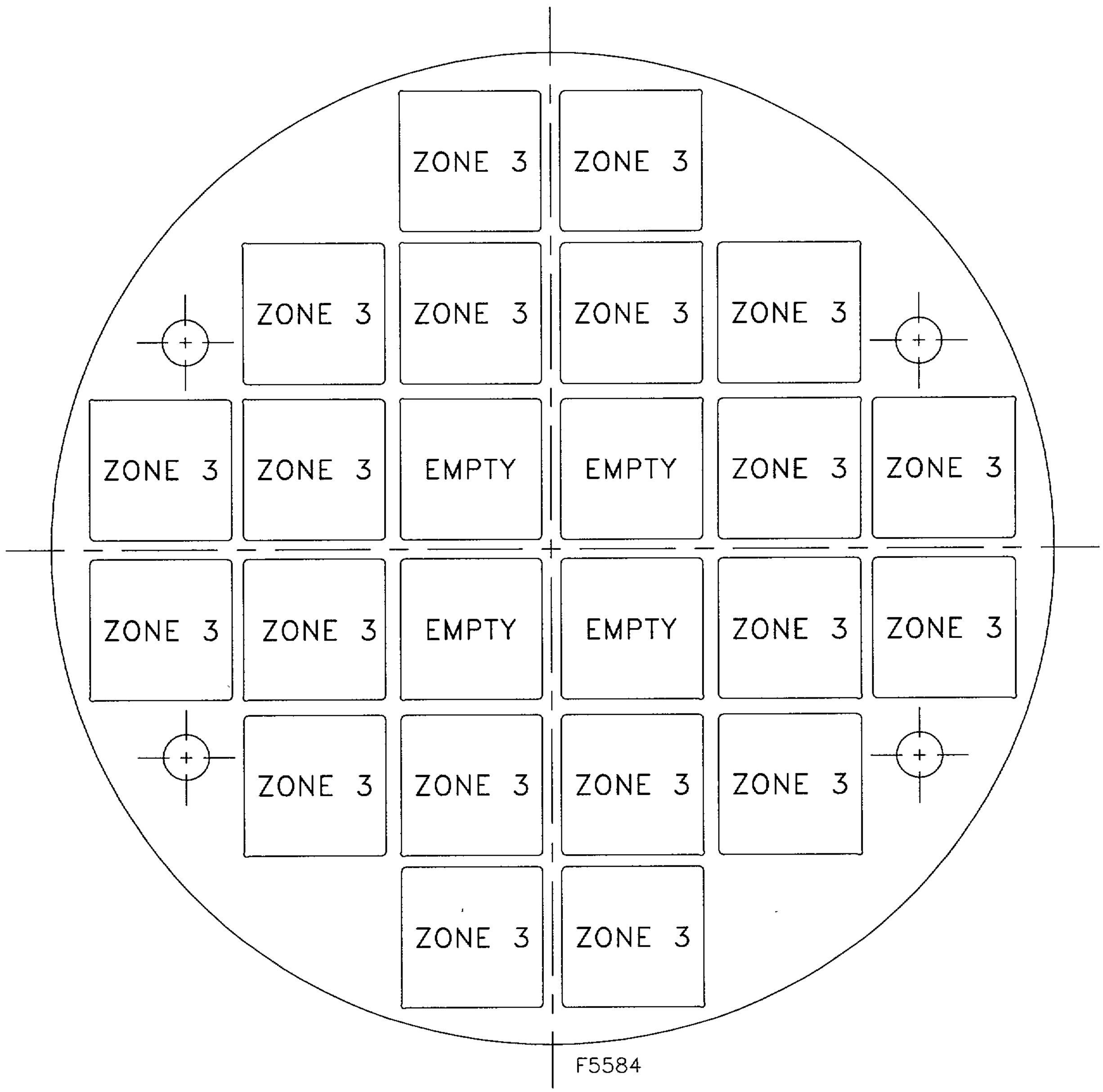
Figure N.4-4
TC Thermal ANSYS Model

C01



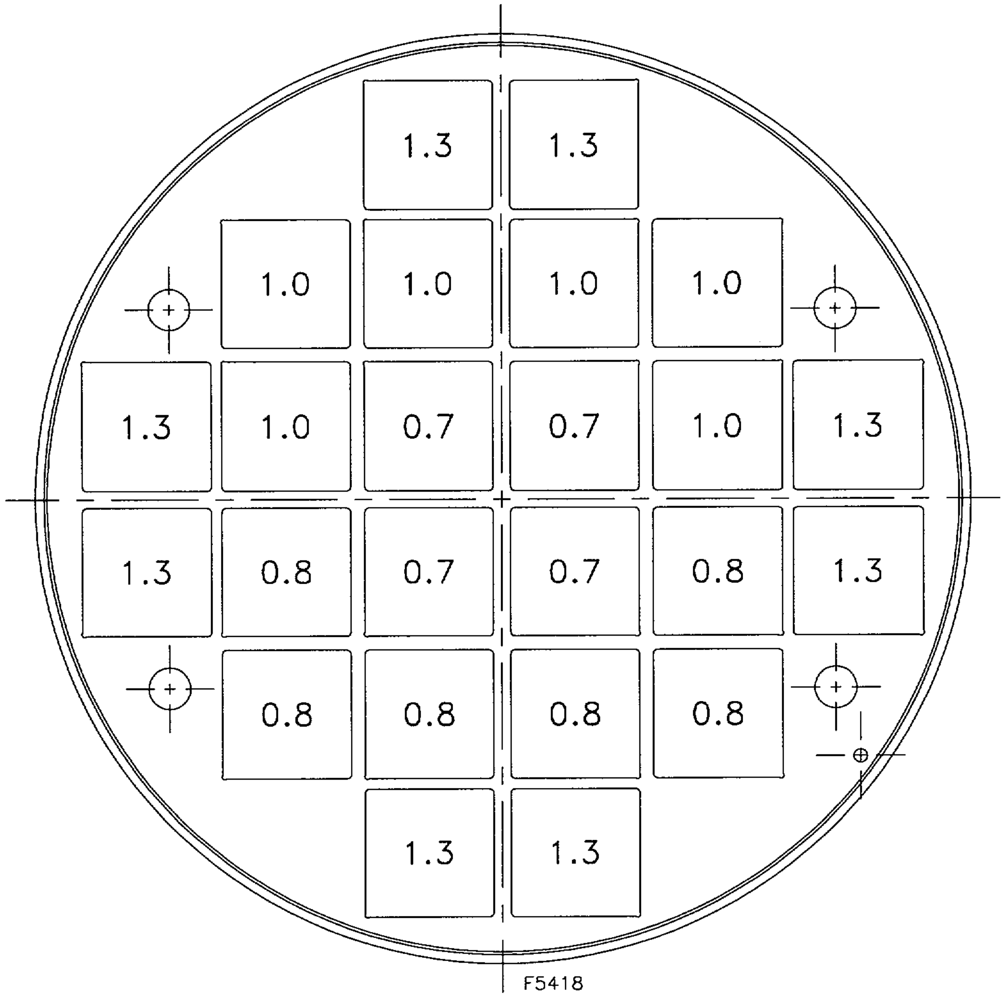
	Zone 1	Zone 2	Zone 3
Maximum Decay Heat (kW/Assembly)	0.7	1.0	1.3
Maximum Decay Heat per Zone (kW)	2.8	10.8	10.4

Figure N.4-5
Heat Load Zoning Configuration – Configuration 1



	Zone 1	Zone 2	Zone 3
Maximum Decay Heat (kW / FA)	NA	NA	1.3
Maximum Decay Heat per Zone (kW)	NA	NA	24.0

Figure N.4-6
Heat Load Zoning Configuration - Configuration 2



Note: The 1.0 kW and 0.8 kW assemblies shown for Zone 2 produced bounding temperatures. Fuel assemblies with heat load ≤ 1 kW can be placed in any locations in Zone 2 as long as the total heat load for Zone 2 is ≤ 10.8 kW

Figure N.4-7
Bounding Heat Load Configuration 1

(Numbers shown are maximum heat load in kW/Assembly.)

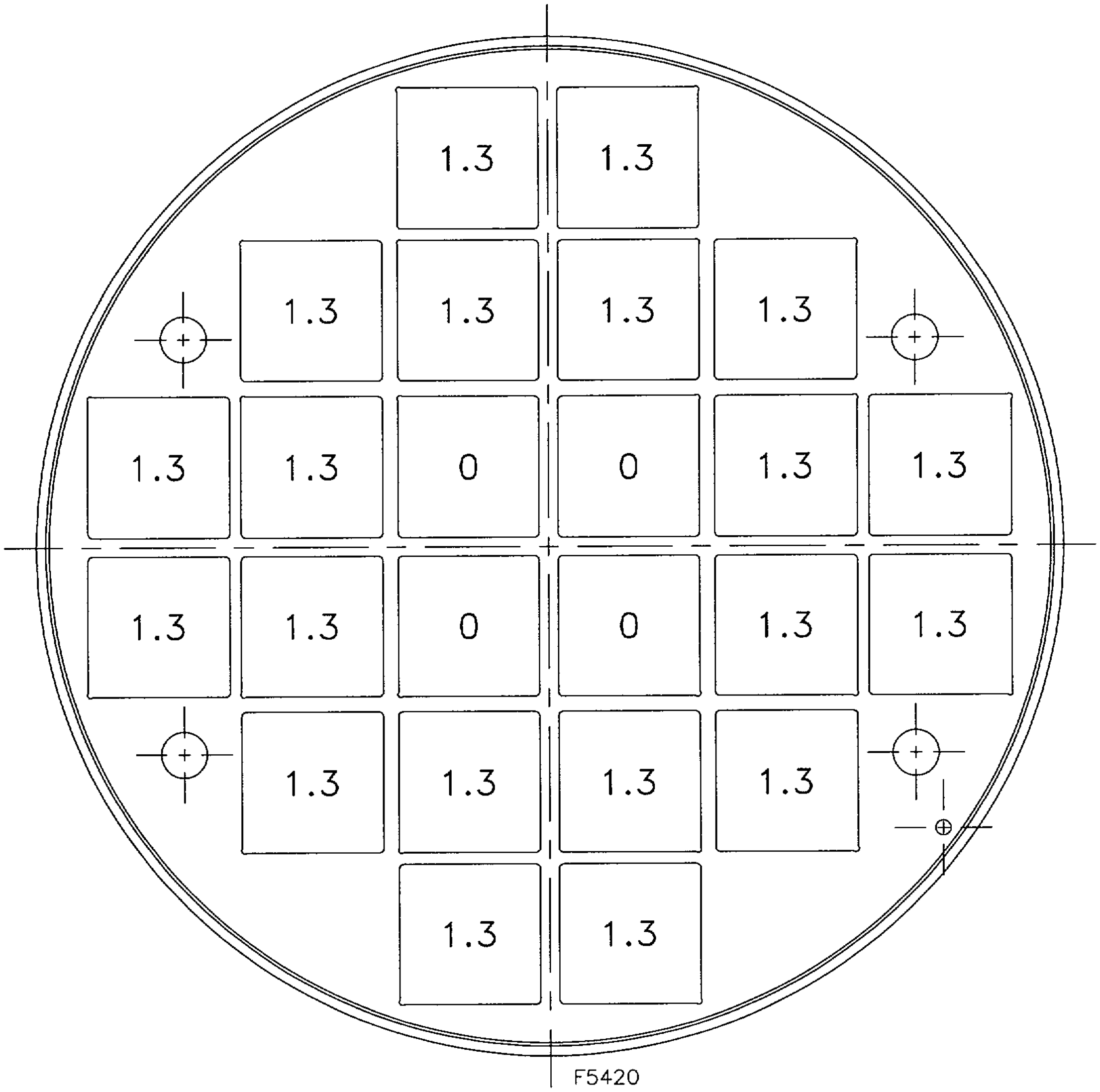


Figure N.4-8
Bounding Heat Load Configuration 2

(Numbers shown are maximum heat load in kW/Assembly.)

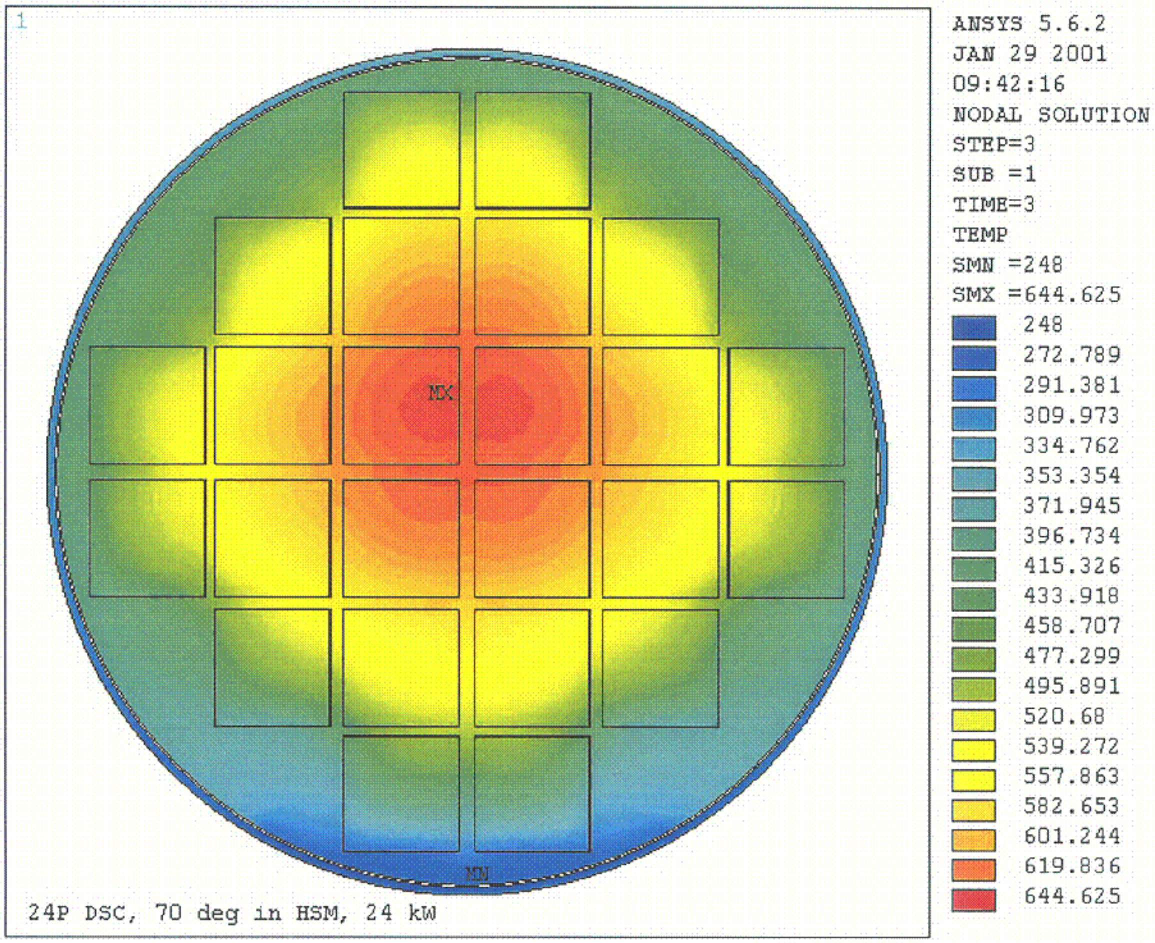


Figure N.4-9
24PHB Basket Configuration 1 Temperature Profile: 70°F Ambient Long Term Storage in HSM

C02

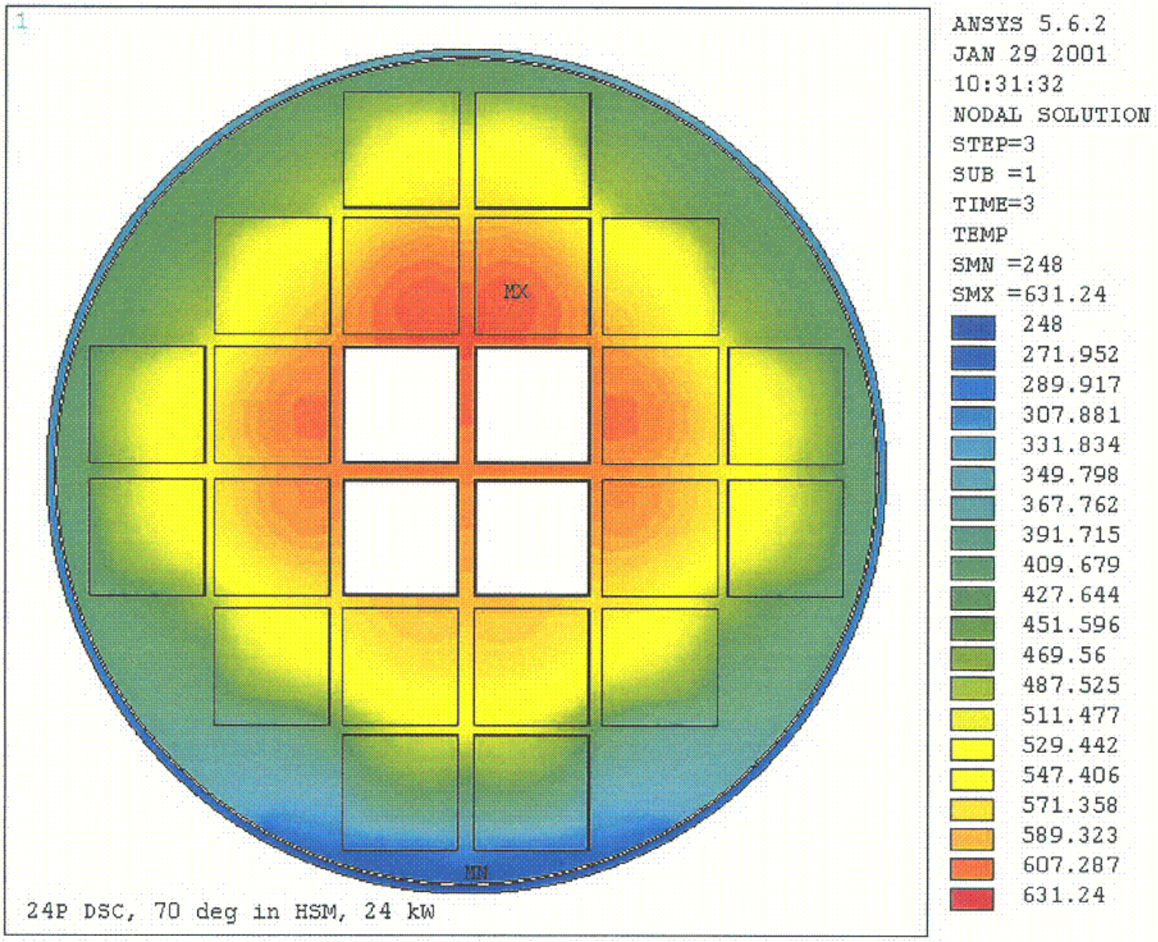


Figure N.4-10
24PHB Basket Configuration 2 Temperature Profile: 70°F Ambient Long Term Storage in HSM

C03

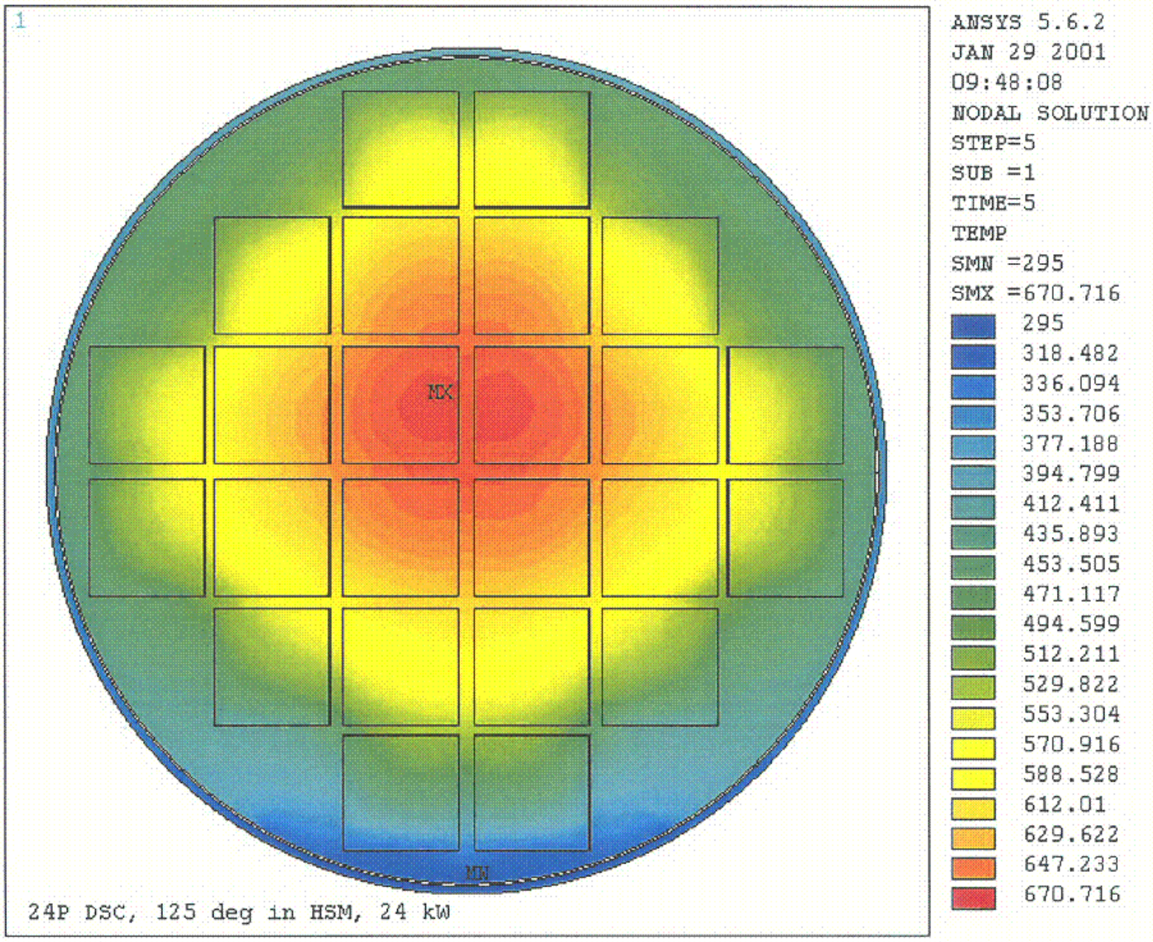


Figure N.4-11
24PHB Basket Temperature Profile: 125°F Ambient Off-Normal in HSM

C04

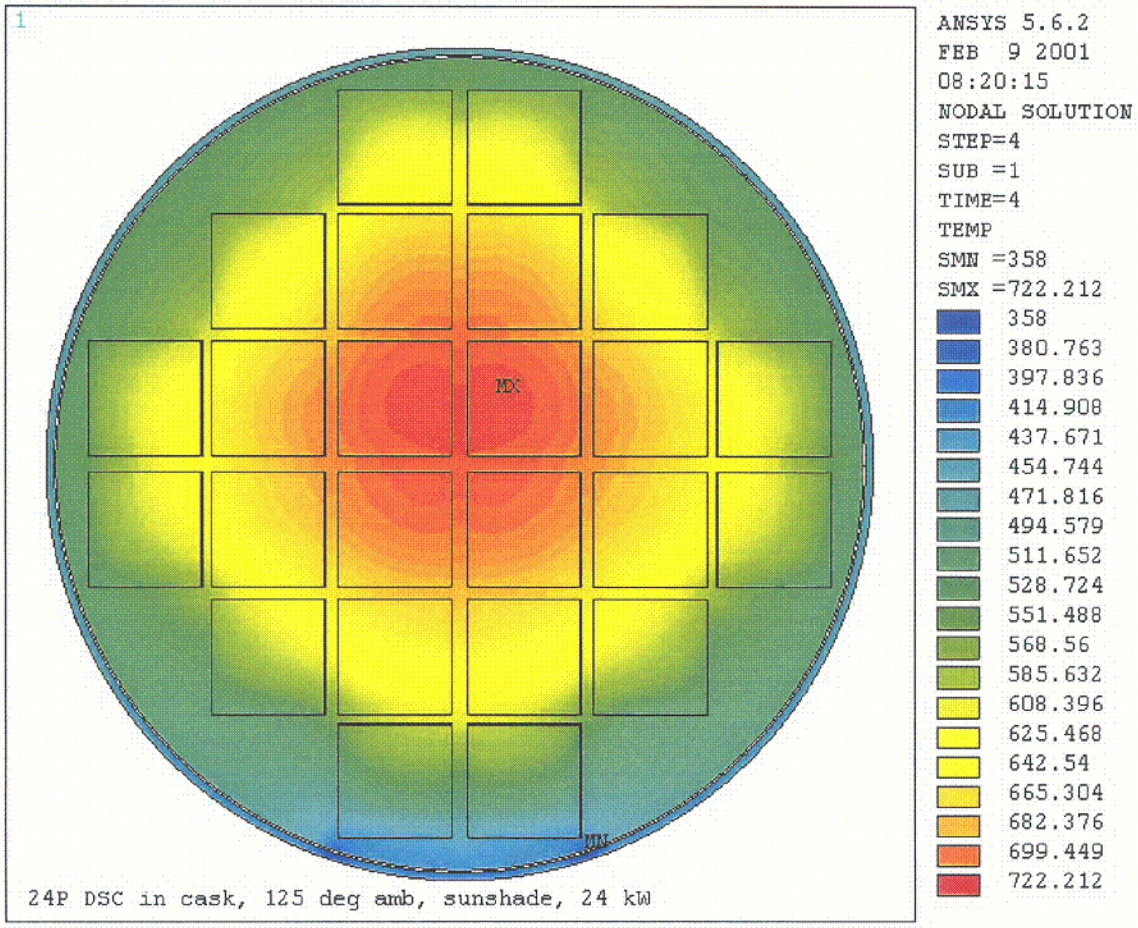


Figure N.4-12
24PHB Basket Temperature Profile: 125°F Ambient Off-Normal in TC

C05

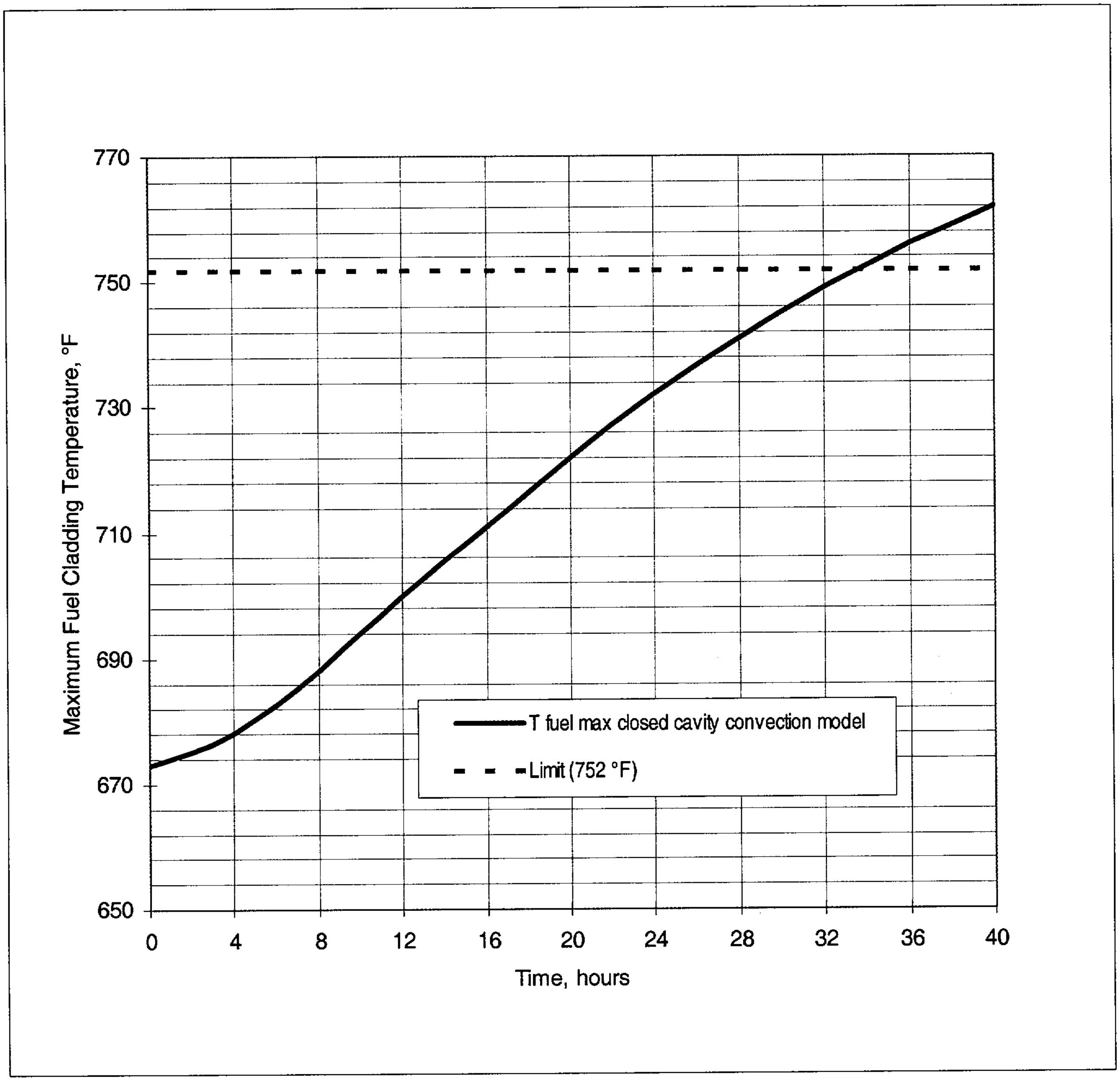


Figure N.4-13
24PHB Maximum Fuel Cladding Temperature: 117 °F ambient Blocked Vent Accident

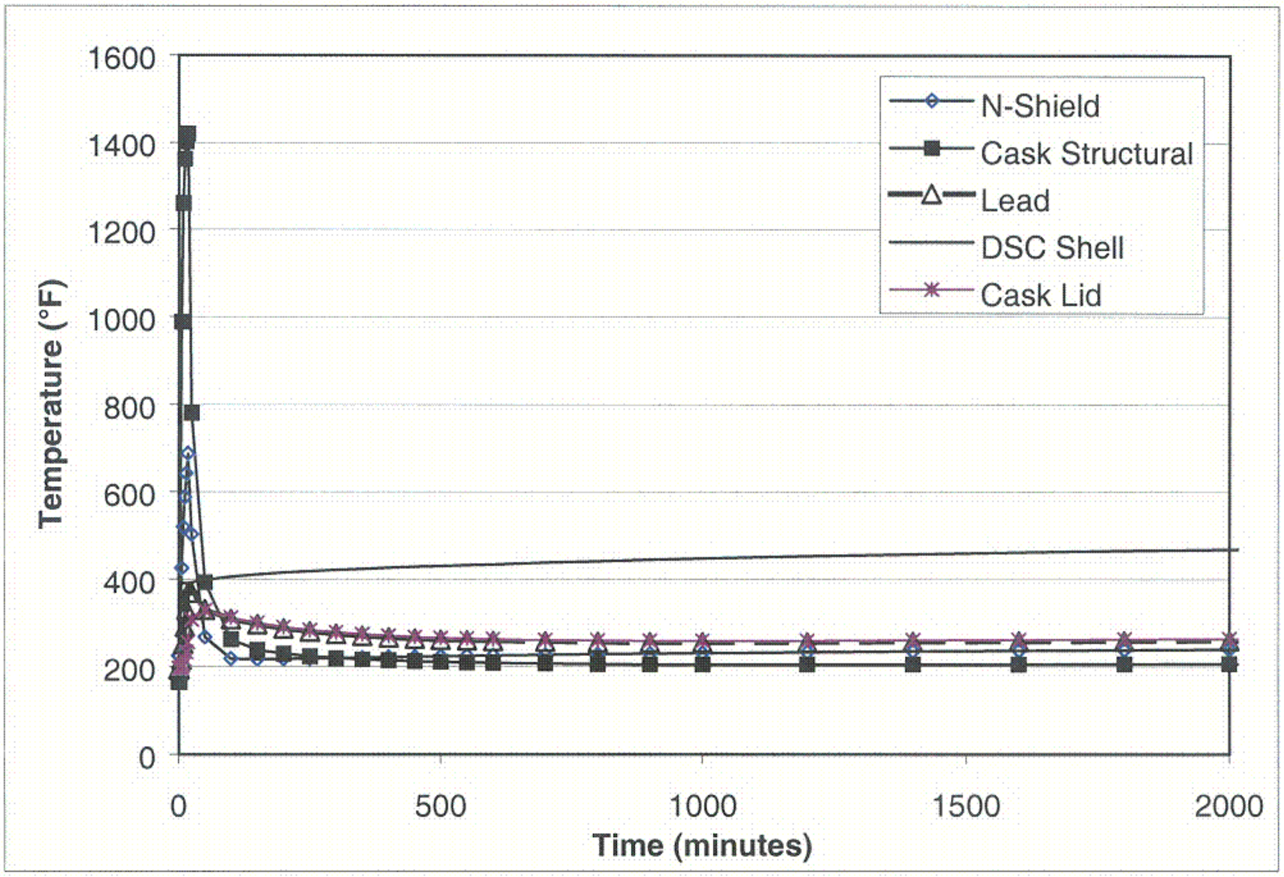


Figure N.4-14
NUHOMS®-24PHB DSC and TC Temperature Response to 15 Minute Fire Accident Conditions

C06

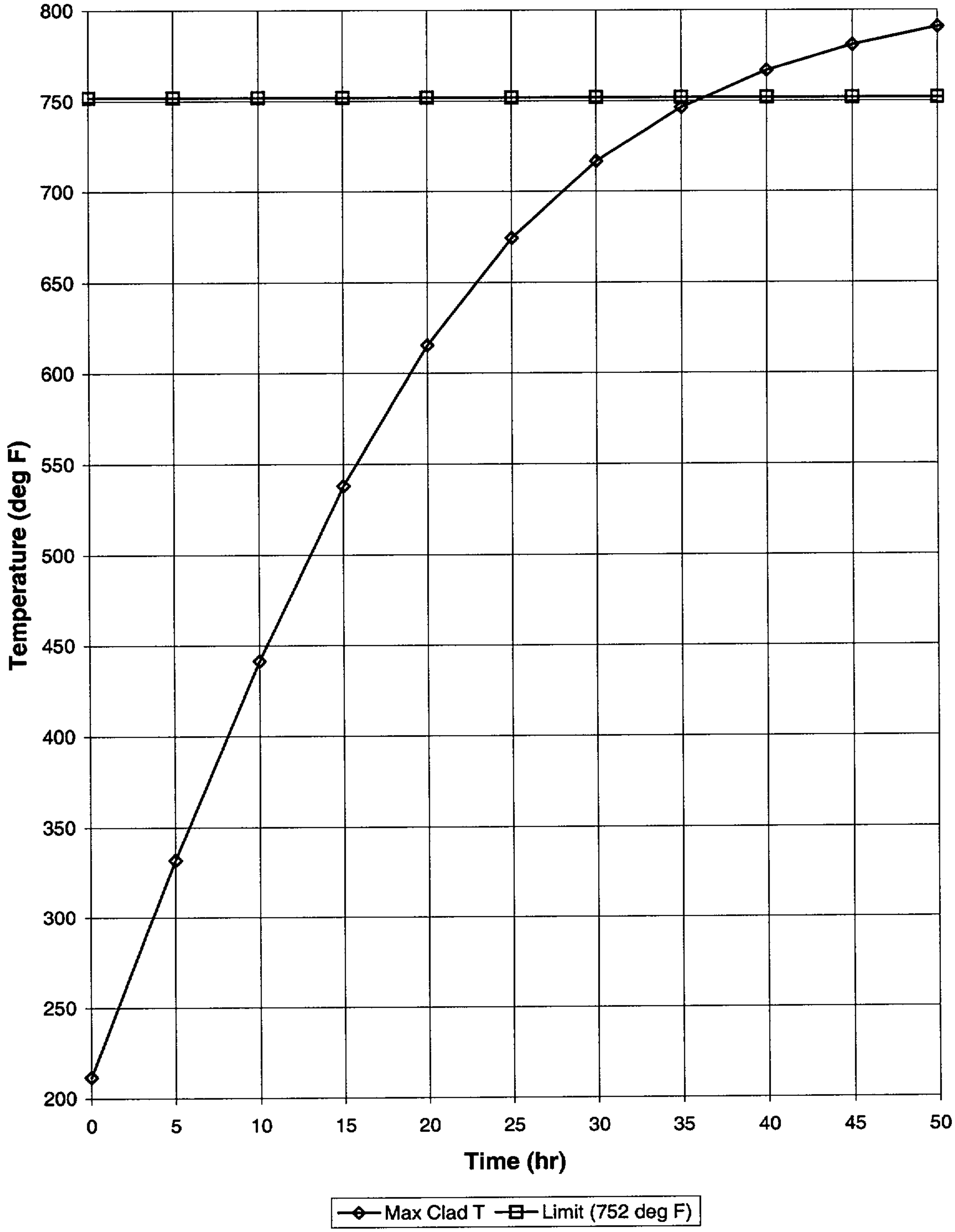


Figure N.4-15
24PHB Basket Vacuum Drying Peak Cladding Temperature Response

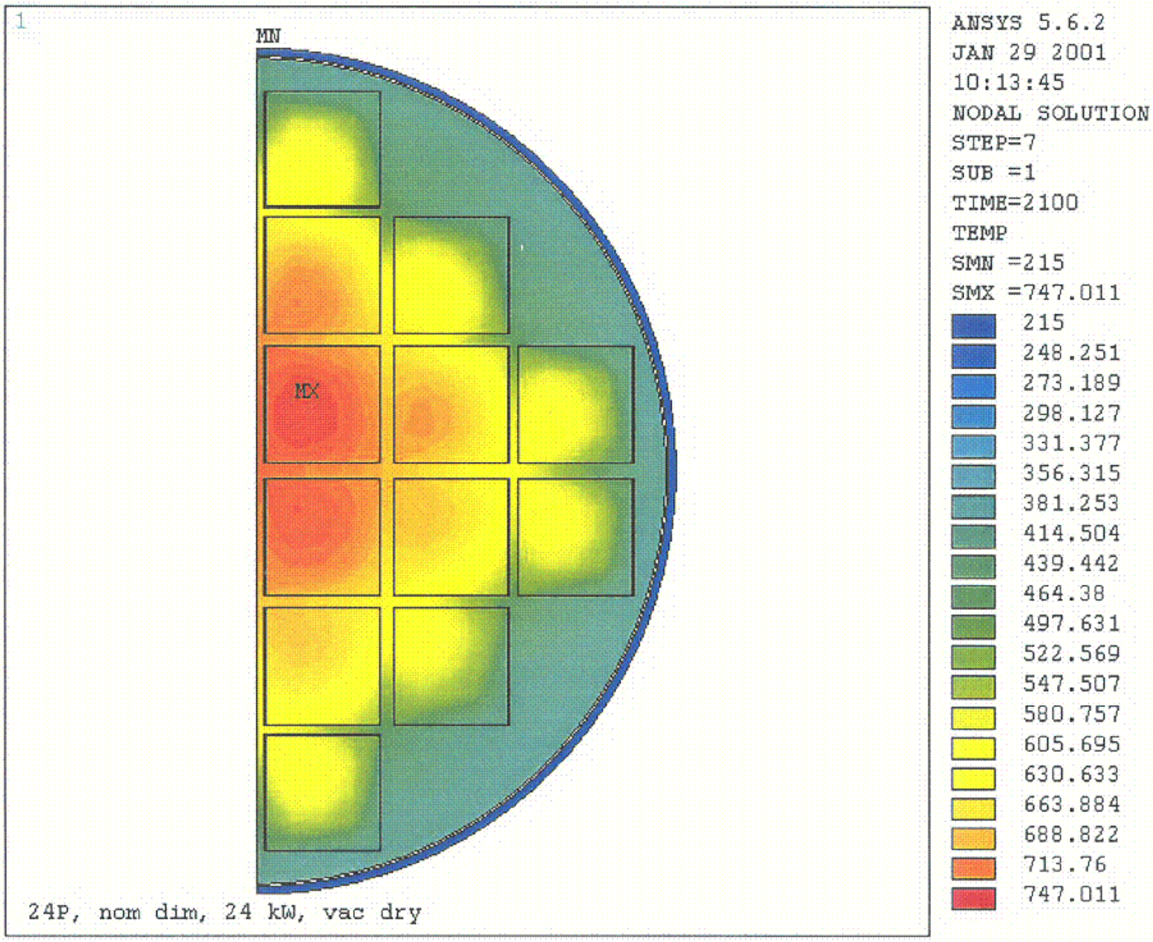


Figure N.4-16
24PHB Basket Temperature Profile: Vacuum Drying at 35 hours

C07