ATTACHMENT B

Suggested Changes to Technical Specifications of CoC 1004 Amendment No. *4*

(Changes proposed by CoC Amendment 5 have been included as current configuration.)

Technical Specifications Included:

- Section 1.2.1
- Section 1.2.3
- Section 1.2.3a
- Section 1.2.4
- Section 1.2.4a
- Section 1.2.7
- Section 1.2.7a
- Section 1.2.11
- Section 1.2.15
- Section 1.2.15a
- Section 1.2.15b
- Section 1.2.17
- Section 1.2.17a
- Section 1.3.1

1.2.17a 24PHB DSC Vacuum Drying Duration Limit

Limit/Specifications:

The limit for duration of Vacuum Drying is 20 hrs after completion of 24PHB DSC draining.

Applicability: *This specification is applicable to a 24PHB DSC with design basis heat load.*

Objective: *To ensure the fuel cladding temperature in the 24PHB DSC does not exceed 752°F.*

Action:

1. *If the DSC vacuum drying pressure limit of Technical Specification 1.2.2 cannot be achieved at 20 hours after initiation of vacuum drying, the DSC must be backfilled with 0.1 atm or greater helium pressure within 2 hours.*

2. *Determine the cause of failure to achieve the vacuum drying pressure limit as defined in Technical Specification 1.2.2.*

3. *Initiate vacuum drying after actions in Step 2 are completed or unload the DSC within 30 days.*

Surveillance: *No maintenance or tests are required during the normal storage. Monitoring of the time duration during the vacuum drying operation is required.*

Bases: *The time limit of 20 hours for the 24PHB DSC was selected to ensure that the cladding temperature is within acceptable limits during vacuum drying.*

TABLE OF CONTENTS

Page

N.1 General Discussion N.1-1
N.1.1 Introduction N.1-2
N.1.2 General Description of the NUHOMS®-24PHB DSCs N.1-3
N.1.2.1 NUHOMS®-24PHB DSC Characteristics N.1-3
N.1.2.2 Operational Features N.1-3
N.1.2.3 Cask Contents N.1-3
N.1.3 Identification of Agents and Contractors N.1-4
N.1.4 Generic Cask Arrays N.1-5
N.1.5 Supplemental Data N.1-6
N.1.6 References N.1-7

N.2 Principal Design Criteria N.2-1
N.2.1 Spent Fuel to be Stored N.2-2
N.2.1.1 General Operating Functions N.2-2
N.2.2 Design Criteria for Environmental Conditions and Natural Phenomena N.2-3
N.2.2.1 Tornado Wind and Tornado Missiles N.2-3
N.2.2.2 Water Level (Flood) Design N.2-3
N.2.2.3 Seismic Design N.2-3
N.2.2.4 Snow and Ice Loading N.2-3
N.2.2.5 Combined Load Criteria N.2-3
N.2.3 Safety Protection Systems N.2-4
N.2.3.1 General N.2-4
N.2.3.2 Protection By Multiple Confinement Barriers and Systems N.2-4
N.2.3.3 Protection By Equipment and Instrumentation Selection N.2-4
N.2.3.4 Nuclear Criticality Safety N.2-4
N.2.3.5 Radiological Protection N.2-5
N.2.3.6 Fire and Explosion Protection N.2-5
N.2.4 Decommissioning Considerations N.2-6
N.2.5 Summary of NUHOMS®-24PHB DSC Design Criteria N.2-7
N.2.6 References N.2-8

N.3 Structural Evaluation N.3-1
N.3.1 Structural Design N.3-1
N.3.1.1 Discussion N.3-1
N.3.1.2 Design Criteria N.3-1
N.3.2 Weights N.3-2
N.3.3 Mechanical Properties of Materials N.3-3
N.3.4 General Standards for 24PHB DSCs N.3-4
N.3.4.1 Chemical and Galvanic Reactions N.3-4
N.3.4.2 Positive Closure N.3-4
N.3.4.3 Lifting Devices N.3-4
N.3.4.4 Hot Temperature Behavior N.3-4
N.3.4.5 Cold Temperature Behavior N.3-6
N.3.5 Fuel Rods N.3-7

TABLE OF CONTENTS
(Continued)

Page

N.3.6 Structural Analysis (Normal and Off-Normal Operations) N.3-8
N.3.6.1 Normal Operation Structural Analysis N.3-8
N.3.6.2 Off-Normal Load Structural Analysis N.3-12
N.3.7 Structural Analysis (Accidents) N.3-16
N.3.7.1 Reduced HSM Air Inlet and Outlet Shielding N.3-16
N.3.7.2 Tornado Winds/Tornado Missile N.3-16
N.3.7.3 Earthquake N.3-17
N.3.7.4 Flood N.3-19
N.3.7.5 Accidental Cask Drop N.3-19
N.3.7.6 Lightning N.3-21
N.3.7.7 Blockage of Air Inlet and Outlet Openings N.3-22
N.3.7.8 DSC Leakage N.3-22
N.3.7.9 Accident Pressurization of DSC N.3-22
N.3.7.10 Load Combinations N.3-22
N.3.8 References N.3-33

N.4 Thermal Evaluation N.4-1
N.4.1 Discussion N.4-1
N.4.2 Summary of Thermal Properties of Materials N.4-3
N.4.3 Specifications for Components N.4-4
N.4.4 Thermal Evaluation for Normal Conditions of Storage (NCS) and Transfer (NCT) N.4-5
N.4.4.1 NUHOMS®-24PHB DSC Thermal Models N.4-5
N.4.4.2 Maximum Temperatures N.4-7
N.4.4.3 Minimum Temperatures N.4-7
N.4.4.4 Maximum Internal Pressures N.4-8
N.4.4.5 Maximum Thermal Stresses N.4-10
N.4.4.6 Evaluation of Cask Performance for Normal Conditions N.4-10
N.4.5 Thermal Evaluation for Off-Normal Conditions N.4-11
N.4.5.1 NUHOMS®-24PHB DSC Thermal Models N.4-11
N.4.5.2 Off-Normal Maximum/Minimum Temperatures during Storage and Transfer N.4-12
N.4.5.3 Off-Normal Maximum Internal Pressure during Storage/Transfer N.4-12
N.4.5.4 Maximum Thermal Stresses N.4-13
N.4.5.5 Evaluation of Cask Performance for Off-Normal Conditions N.4-13
N.4.6 Thermal Evaluation for Accident Conditions N.4-14
N.4.6.1 Blocked Vent Accident Evaluation N.4-14
N.4.6.2 Transfer Accident Evaluation N.4-15
N.4.6.3 Hypothetical Fire Accident Evaluation N.4-16
N.4.6.4 Maximum Internal Pressures N.4-16
N.4.6.5 Maximum Thermal Stresses N.4-17
N.4.6.6 Evaluation of Performance During Accident Conditions N.4-17

TABLE OF CONTENTS
(Continued)

Page

N.4.7 Thermal Evaluation for Loading/Unloading Conditions N.4-18
N.4.7.1 Vacuum Drying Analysis N.4-18
N.4.8 References N.4-20

N.5 Shielding Evaluation N.5-1
N.5.1 Discussion and Results N.5-3
N.5.2 Source Specification N.5-4
N.5.2.1 Gamma Source N.5-5
N.5.2.2 Neutron Source Term N.5-6
N.5.2.3 Axial Peaking N.5-7
N.5.2.4 Response Functions for Alternate Nuclear Parameters N.5-7
N.5.3 Model Specification N.5-8
N.5.3.1 Material Densities N.5-8
N.5.4 Shielding Evaluation N.5-9
N.5.4.1 Computer Programs N.5-9
N.5.4.2 Spatial Source Distribution N.5-10
N.5.4.3 Cross Section Data N.5-10
N.5.4.4 Flux-to-Dose-Rate Conversion N.5-11
N.5.4.5 Methodology N.5-11
N.5.4.6 Assumptions N.5-13
N.5.4.7 HSM Dose Rates N.5-14
N.5.4.8 Data Reduction and HSM Dose Rate Results N.5-15
N.5.4.9 TC Dose Rates N.5-17
N.5.5 Code Input N.5-18
N.5.5.1 Annotated SAS2H and ORIGEN-S Input Files N.5-18
N.5.5.2 Annotated DORT Input N.5-22
N.5.5.3 Annotated MCNP Input N.5-30
N.5.6 References N.5-38

N.6 Criticality Evaluation N.6-1
N.6.1 Discussion and Results N.6-2
N.6.2 Package Fuel Loading N.6-3
N.6.3 Model Specification N.6-4
N.6.4 Criticality Analysis N.6-6
N.6.5 Critical Benchmark Experiments N.6-7
N.6.5.1 Benchmark Experiments and Applicability N.6-7
N.6.5.2 Results of the Benchmark Calculations N.6-8
N.6.6 Appendix N.6-9
N.6.6.1 References N.6-9
N.6.6.2 Example Keno V.a Input Listing N.6-10

N.7 Confinement N.7-1
N.7.1 Confinement Boundary N.7-2
N.7.1.1 Confinement Vessel N.7-2
N.7.1.2 Confinement Penetrations N.7-2
N.7.1.3 Seals and Welds N.7-3
N.7.1.4 Closure N.7-3

TABLE OF CONTENTS
(Continued)

Page

N.7.2 Requirements for Normal and Off-Normal Conditions of Storage N.7-4
N.7.2.1 Release of Radioactive Material N.7-4
N.7.2.2 Pressurization of Confinement Vessel N.7-4
N.7.3 Confinement Requirements for Hypothetical Accident Conditions N.7-5
N.7.3.1 Fission Gas Products N.7-5
N.7.3.2 Release of Contents N.7-5
N.7.4 References N.7-6

N.8 Operating Systems N.8-1
N.8.1 Procedures for Loading the Cask N.8-2
N.8.1.1 Preparation of the TC and 24PHB DSC N.8-2
N.8.1.2 24PHB DSC Fuel Loading N.8-2
N.8.1.3 24PHB DSC Drying and Backfilling N.8-3
N.8.1.4 24PHB DSC Sealing Operations N.8-3
N.8.1.5 TC Downending and Transport to ISFSI N.8-3a
N.8.1.6 DSC Transfer to the HSM N.8-3a
N.8.1.7 Monitoring Operations N.8-3a
N.8.2 Procedures for Unloading the Cask N.8-7
N.8.2.1 DSC Retrieval from the HSM N.8-7
N.8.2.2 Removal of Fuel from the DSC N.8-7
N.8.3 Identification of Subjects for Safety Analysis N.8-8
N.8.4 Fuel Handling Systems N.8-9
N.8.5 Other Operating Systems N.8-10
N.8.6 Operation Support System N.8-11
N.8.7 Control Room and/or Control Areas N.8-12
N.8.8 Analytical Sampling N.8-13
N.8.9 References N.8-14

N.9 Acceptance Tests and Maintenance Program N.9-1
N.9.1 Acceptance Tests N.9-1
N.9.1.1 Visual Inspection N.9-1
N.9.1.2 Structural N.9-1
N.9.1.3 Leak Tests N.9-1
N.9.1.4 Components N.9-1
N.9.1.5 Shielding Integrity N.9-1
N.9.1.6 Thermal Acceptance N.9-1
N.9.1.7 Poison Acceptance N.9-1
N.9.2 Maintenance Program N.9-2
N.9.3 References N.9-3

N.10 Radiation Protection N.10-1
N.10.1 Occupational Exposure N.10-2
N.10.2 Off-Site Dose Calculations N.10-3
N.10.2.1 Activity Calculations N.10-5
N.10.2.2 Dose Rates N.10-5
N.10.3 References N.10-7

TABLE OF CONTENTS
(Continued)

Page

N.11 Accident Analyses N.11-1
N.11.1 Off-Normal Operations N.11-2
N.11.1.1 Off-Normal Transfer Loads N.11-2
N.11.1.2 Extreme Temperatures N.11-2
N.11.1.3 Off-Normal Releases of Radionuclides N.11-3
N.11.1.4 Radiological Impact from Off-Normal Operations N.11-4
N.11.2 Postulated Accidents N.11-5
N.11.2.1 Reduced HSM Air Inlet and Outlet Shielding N.11-5
N.11.2.2 Earthquake N.11-6
N.11.2.3 Extreme Wind and Tornado Missiles N.11-6
N.11.2.4 Flood N.11-7
N.11.2.5 Accidental TC Drop N.11-7
N.11.2.6 Lightning N.11-8
N.11.2.7 Blockage of Air Inlet and Outlet Openings N.11-8
N.11.2.8 DSC Leakage N.11-9
N.11.2.9 Accident Pressurization of DSC N.11-9
N.11.2.10 Fire and Explosion N.11-10
N.11.3 References N.11-12
N.12 Conditions for Cask Use - Operating Controls and Limits or Technical Specifications N.12-1
N.13 Quality Assurance N.13-1

LIST OF TABLES

		Page
Table N.2-1	PWR Fuel Specifications for Fuel to be Stored in the NUHOMS®-24PHB DSC	N.2-9
Table N.2-2	PWR Fuel Assembly Design Characteristics	N.2-10
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)	N.2-11
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)	N.2-12
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)	N.2-13
Table N.2-6	Summary of 24PHB-DSC Load Combinations	N.2-14
Table N.2-7	Summary of NUHOMS®-24PHB Design Loadings	N.2-18
Table N.3.6-1	Maximum NUHOMS®-24PHB DSC Stresses for Normal and Off-Normal Loads	N.3-14
Table N.3.7-1	Maximum NUHOMS®-24PHB DSC Stresses for Drop Accident Loads	N.3-24
Table N.3.7-2	NUHOMS®-24PHB DSC Enveloping Load Combination Results for Normal and Off-Normal Loads (ASME Service Levels A and B)	N.3-25
Table N.3.7-3	NUHOMS®-24PHB DSC Enveloping Load Combination Results for Accident Loads (ASME Service Level C)	N.3-26
Table N.3.7-4	NUHOMS®-24PHB DSC Enveloping Load Combination Results for Accident Loads (ASME Service Level D)	N.3-27
Table N.3.7-5	DSC Enveloping Load Combination Table Notes	N.3-28
Table N.3.7-6	24PHBL DSC Bottom Cover Plate Analysis Results	N.3-29
Table N.3.7-7	24PHBL DSC Top Shield Plug Analysis Results	N.3-30
Table N.3.7-8	24PHBL DSC Bottom Shield Plug Analysis Results	N.3-31
Table N.4-1	NUHOMS®-24PHB DSC Component Temperatures During Storage for Configuration 1	N.4-21
Table N.4-2	NUHOMS®-24PHB DSC Component Temperatures During Transfer for Configuration 1	N.4-21
Table N.4-3	NUHOMS®-24PHB DSC Component Temperatures During Storage for Configuration 2	N.4-22
Table N.4-4	NUHOMS®-24PHB DSC Component Temperatures During Transfer for Configuration 2	N.4-23
Table N.4-5	NUHOMS®-24PHB DSC Shell Temperature Results For 24 kW Blocked Vent Case	N.4-24
Table N.4-6	Temperature Distribution within the NUHOMS®-24PHB DSC Vacuum Drying Condition	N.4-25

LIST OF TABLES
(Continued)

		Page
Table N.4-7	NUHOMS®-24PHB DSC Normal, Off-Normal and Accident Pressures	N.4-26
Table N.4-8	NUHOMS®-24PHB DSC Shell Temperatures for Storage and Transfer Conditions	N.4-26a
Table N.5-1	PWR Fuel Assembly Design Characteristics	N.5-40
Table N.5-2	B&W 15x15 Mark B2, B4, and B5 Burnable Poison Rod Assembly Weight Data	N.5-41
Table N.5-3	Summary of NUHOMS®-24PHB System Maximum Dose Rates	N.5-42
Table N.5-4	Summary of HSM Dose Rates with 24PHB DSC	N.5-43
Table N.5-5	PWR 15×15 Fuel Assembly Hardware Parts and Materials	N.5-44
Table N.5-6	Elemental Composition of LWR Fuel-Assembly Structural Materials Used for Source Term Evaluation in SAS2H/ORIGEN-S	N.5-45
Table N.5-7	Flux Correct Factors By Assembly Region	N.5-46
Table N.5-8	CASK-81 Energy Group Structure	N.5-47
Table N.5-9	Gamma Source Term in Zones 1 and 2 from Bottom Nozzle, In-core, Plenum and Top Nozzle Regions	N.5-48
Table N.5-10	Gamma Source Term in Zone 3 from Bottom Nozzle, In-core, Plenum and Top Nozzle Regions	N.5-49
Table N.5-11	Design Basis BPRA Source Terms	N.5-50
Table N.5-12	Heat Load Configuration Region Volumes	N.5-51
Table N.5-13	Neutron Source Term in Different Radial Zones from In-Core Region, n/(sec×FA)	N.5-52
Table N.5-14	Normalized Conservative Burn-Up Shape	N.5-53
Table N.5-15	HSM and TC "Response Function" for Evaluating Fuel with Alternate Parameters	N.5-54
Table N.5-16	Elemental Composition of LWR Fuel Assembly and NUHOMS®-24P DSC Structural Material used in Shielding Analysis	N.5-55
Table N.5-17	Material Densities and Elemental Compositions Used for TC Analysis	N.5-56
Table N.5-18	Material Densities and Elemental Compositions Used for HSM Dose Rate Analysis	N.5-57
Table N.5-19	Surfaces Defining HSM Geometry in MCNP Model	N.5-59
Table N.5-20	ANSI/ANS-6.1.1-1977 Neutron and Gamma-Ray Flux-to-Dose Rate Conversion Factors	N.5-60
Table N.6-1	B&W 15x15 Mark B2 through B7 Fuel Assembly	N.6-22
Table N.6-2	B&W 15x15 Mark B8 Fuel Assembly	N.6-23
Table N.6-3	B&W 15x15 Mark B9 Fuel Assembly	N.6-24
Table N.6-4	B&W 15x15 Mark B10 Fuel Assembly	N.6-25
Table N.6-5	NUHOMS®-24PHB DSC Dimensional Data (Worst Case Tolerances)	N.6-26
Table N.6-6	Criticality Results (Fuel Assembly Comparison)	N.6-27
Table N.6-7	Criticality Results (Water in Fuel-Cladding Gap without BPRAs)	N.6-28
Table N.6-8	Criticality Results (Water in Fuel-Cladding Gap with BPRAs)	N.6-29

LIST OF TABLES
(Continued)

		Page
Table N.6-9	Criticality Results (Void in Fuel-Cladding Gap and without BPRA)	N.6-30
Table N.6-10	Criticality Results (Void in Fuel-Cladding Gap and with BPRA)	N.6-31
Table N.6-11	Criticality Results (4 Reconstituted Fuel Assemblies per DSC)[1]	N.6-32
Table N.6-12	Criticality Results (4 Center Fuel Assembly Locations Empty)	N.6-33
Table N.6-13	Criticality Results (Bounding Boron Loading Per Enrichment)	N.6-34
Table N.6-14	Benchmarking Results	N.6-35
Table N.6-15	USL-1 Results	N.6-38
Table N.6-16	USL Determination for Criticality Analysis	N.6-39
Table N.10-1	Occupational Exposure Summary, 24PHB System	N.10-8
Table N.10-2	Total Annual Exposure, 24PHB System	N.10-9
Table N.10-3	HSM Gamma-Ray Spectrum Calculation Results	N.10-10
Table N.10-4	HSM Neutron Spectrum Calculation Results	N.10-11
Table N.10-5	Summary of ISFSI Surface Activities, 24PHB System	N.10-12
Table N.10-6	MCNP Front Detector Dose Rates for 2x10 Array, 24PHB System	N.10-13
Table N.10-7	MCNP Back Detector Dose Rates for the Two 1x10 Arrays, 24PHB System	N.10.14
Table N.10-8	MCNP Side Detector Dose Rates, 24PHB System	N.10.15
Table N.11-1	Comparison of Total Dose Rates for HSM with and without Adjacent HSM Shielding Effects	N.11-13
Table N.11-2	TC Bounding Accident Dose Rate Results	N.11-14

LIST OF FIGURES

		Page
Figure N.2-1	Heat Load Zoning Configuration 1	N.2-19
Figure N.2-2	Heat Load Zoning Configuration 2	N.2-20
Figure N.2-3	Soluble Boron Concentration vs. Fuel Assembly Initial U-235 Enrichment	N.2-21
Figure N.3.1-1	24PHB DSC Pressure and Confinement Boundaries	N.3-1a
Figure N.3.6-1	24PHB DSC Spacer Disc 180° In-Plane Analytical Model for Thermal Stress Analysis	N.3-15
Figure N.3.7-1	NUHOMS®-24PHB DSC Spacer Disc 360° Analytical Model for Stability Analysis	N.3-32
Figure N.4-1	Axial Heat Flux Profile for PWR Fuel	N.4-27
Figure N.4-2	3-D Thermal ANSYS Model of 24PHB DSC	N.4-28
Figure N.4-3	Standardized HSM 2-D Thermal ANSYS Model	N.4-29
Figure N.4-4	TC Thermal ANSYS Model	N.4-30
Figure N.4-5	Heat Load Zoning Configuration 1	N.4-31
Figure N.4-6	Heat Load Zoning Configuration 2	N.4-32
Figure N.4-7	Bounding Heat Load Configuration 1	N.4-33
Figure N.4-8	Bounding Heat Load Configuration 2	N.4-34
Figure N.4-9	24PHB Basket Configuration 1 Temperature Profile: 70°F Ambient Long Term Storage in HSM	N.4-35
Figure N.4-10	24PHB Basket Configuration 2 Temperature Profile: 70°F Ambient Long Term Storage in HSM	N.4-36
Figure N.4-11	24PHB Basket Temperature Profile: 125°F Ambient Off-Normal in HSM	N.4-37
Figure N.4-12	24PHB Basket Temperature Profile: 125°F Ambient Off-Normal in TC	N.4-38
Figure N.4-13	24PHB Maximum Fuel Cladding Temperature: 117 °F ambient Blocked Vent Accident	N.4-39
Figure N.4-14	NUHOMS®-24PHB DSC and TC Temperature Response to 15 Minute Fire Accident Conditions	N.4-40
Figure N.4-15	24PHB Basket Vacuum Drying Peak Cladding Temperature Response	N.4-41
Figure N.4-16	24PHB Basket Temperature Profile: Vacuum Drying at 35 hours	N.4-42
Figure N.4-17	TemperatureDistribution from Bottom to Top of DSC, Blocked Vent Transient at 34 Hours	N.4-43
Figure N.5-1	HSM "Roof" Model	N.5-61
Figure N.5-2	HSM "Floor" Model	N.5-62
Figure N.5-3	HSM "X-Z" Model	N.5-63
Figure N.5-4A	View of the HSM Geometry in MCNP Model, Cut through YZ Plane	N.5-64
Figure N.5-4B	View of the HSM Geometry in MCNP Model, Cut through XZ Plane	N.5-65
Figure N.5-5	DSC Inside of OS-197 TC	N.5-66
Figure N.5-6A	Gamma Dose Rates on Front Surface for the Module	N.5-67
Figure N.5-6B	Neutron Dose Rates on Front Surface for the Module	N.5-68
Figure N.5-7	Gamma Dose Rates above the HSM Roof Bird Screen	N.5-69

LIST OF FIGURES
(Continued)

		Page
Figure N.5-8	Gamma Dose Rates in front of the HSM Front Bird Screen	N.5-70
Figure N.5-9	Gamma Dose Rates on Roof Surface of HSM	N.5-71
Figure N.5-10	Gamma Dose Rates Along Side of TC, Transfer Mode	N.5-72
Figure N.5-11	Gamma Dose Rates Along Side of TC Including BPRAs, Transfer Mode	N.5-73
Figure N.5-12	Neutron Dose Rates Along Side of TC, Transfer Mode	N.5-74
Figure N.5-13	Gamma Dose Rates at Top End of TC, Transfer Mode	N.5-75
Figure N.5-14	Neutron Dose Rates at Top End of TC, Transfer Mode	N.5-76
Figure N.5-15	Gamma Dose Rates at Bottom End of TC, Transfer Mode	N.5-77
Figure N.5-16	Neutron Dose Rates at Bottom End of TC, Transfer Mode	N.5-78
Figure N.5-17	Gamma Dose Rates Including BPRAs Along Top of DSC During Wet Welding	N.5-79
Figure N.5-18	Gamma Dose Rates Including BPRAs Along Top of DSC During Dry Welding	N.5-80
Figure N.6-1	B&W 15x15 Mark B Fuel Assembly Layout	N.6-40
Figure N.6-2	KENO Model of the DSC Basket	N.6-41
Figure N.6-3	Exploded View of the KENO Model	N.6-42
Figure N.6-4	DSC Geometry	N.6-43
Figure N.6-5	Criticality Results, 4.5 wt. % U-235 Enrichment, 2950 ppm Boron Loading	N.6-44
Figure N.6-6	Minimum Boron Loading as a Function of Enrichment	N.6-45
Figure N.8.1-1	NUHOMS® System Loading Operations Flow Chart	N.8-4
Figure N.10-1	Annual Exposure from the ISFSI as a Function of Distance, 24PHB System	N.10.16
Figure N.11-1	TC Bounding Accident Dose Rate Distribution	N.11-15

N.1.3 Identification of Agents and Contractors

Transnuclear, Inc. (TN), 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 TN's quality assurance program. TN'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 TN 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.

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

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 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 criteria used to design and fabricate the NUHOMS®-24PHB DSC (shell and closure) are described in Section 3.2.5.2. The basket (which includes the spacer disc, the support rods, guide sleeves, over sleeves and their associated welds) is also designed and fabricated following the criteria provided in Section 3.2.5.2.*

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 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.

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

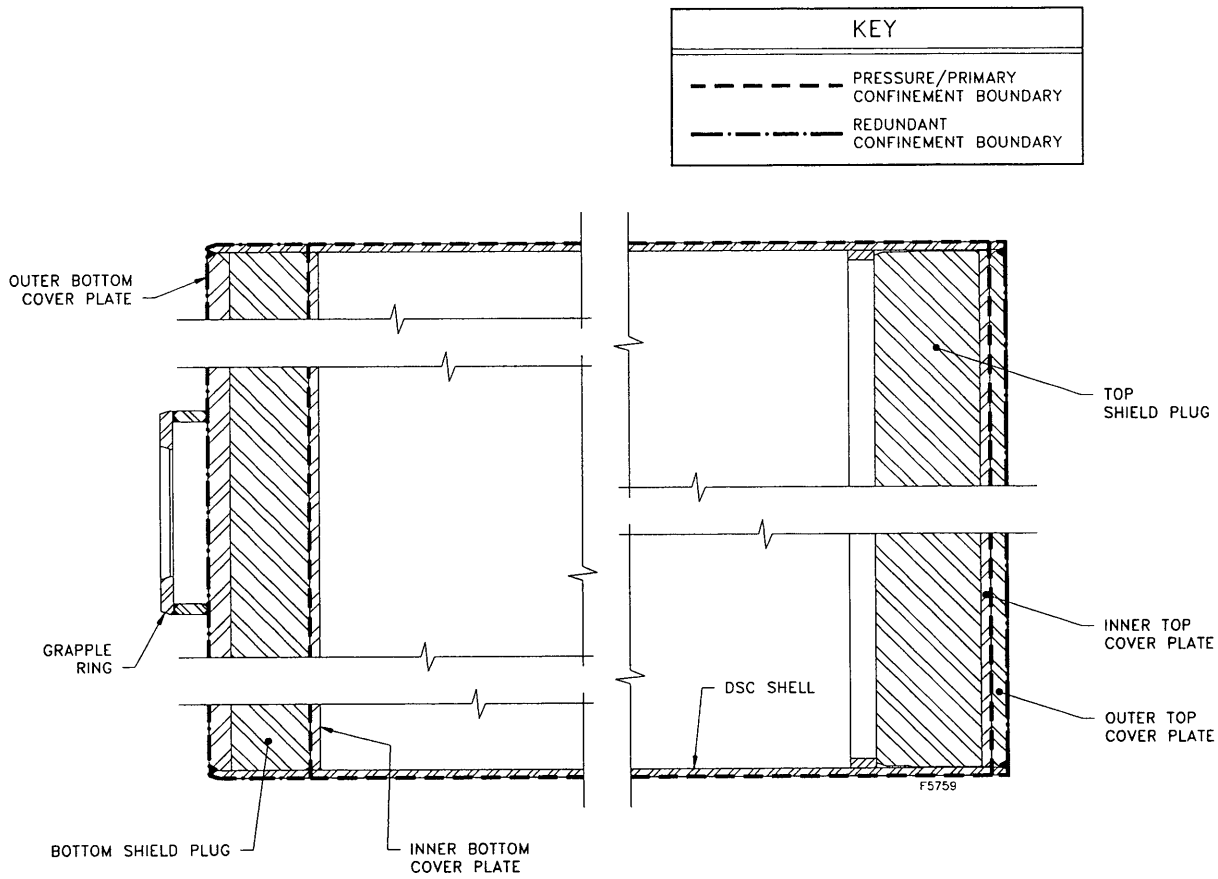
Design criteria for this section are provided in Section N.2.5.

N.3.1.2.1 DSC Confinement Boundary

No change from Section 3.3.2. Figure N.3.1-1 *provides a graphic representation of the 24PHB DSC confinement boundary.*

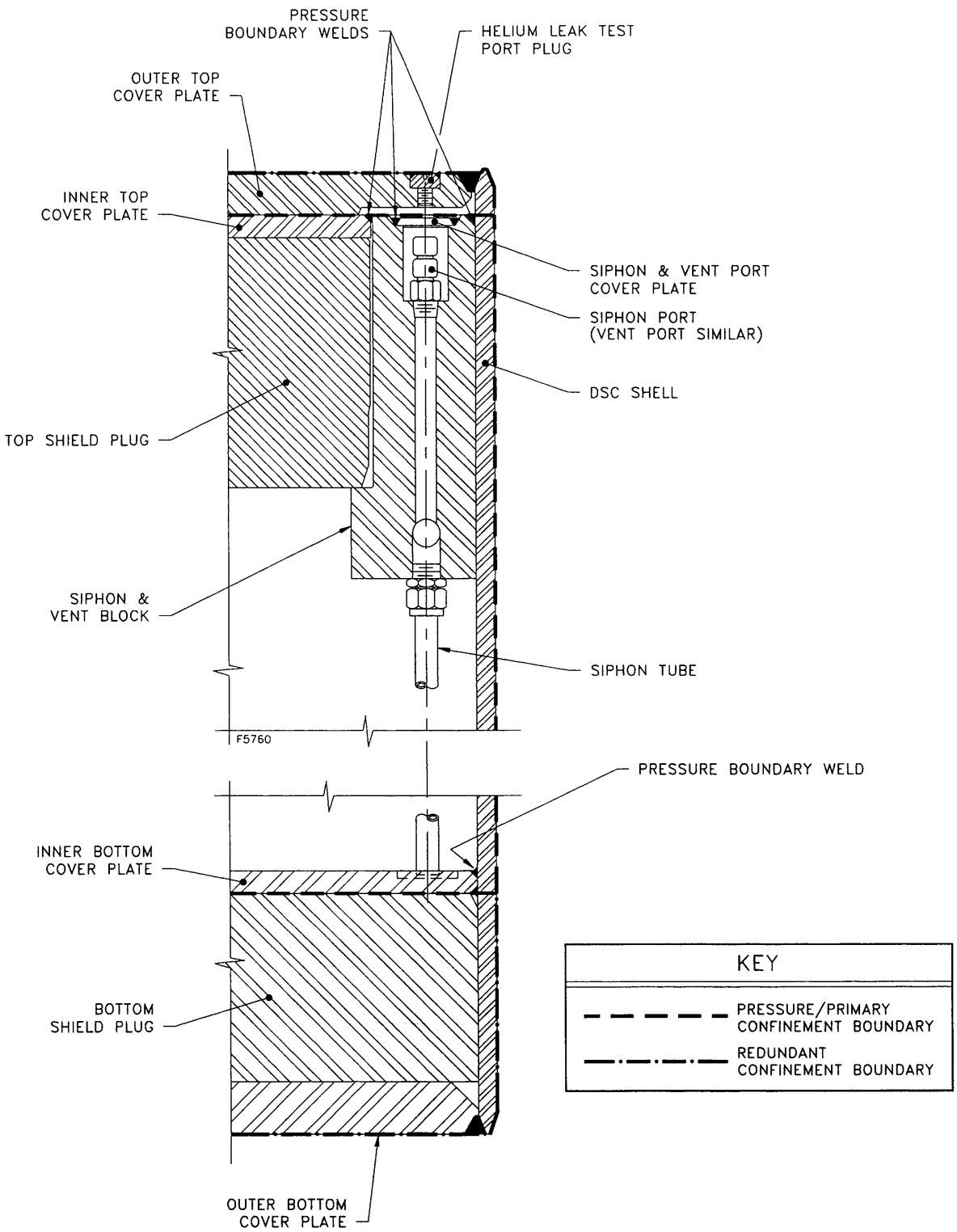
N.3.1.2.2 ASME Code Exceptions for the 24PHB DSCs

No change to the Code exceptions presented in Section 4.8.



Note: *24PHBS DSC configuration is shown.*

Figure N.3.1-1
24PHB DSC Pressure and Confinement Boundaries



Note: *24PHBS DSC configuration is shown.*

Figure N.3.1-1
24PHB DSC Pressure and Confinement Boundaries
(Concluded)

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.3-2. 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 *0.25* inches for the *100*°F ambient DSC in the cask transfer condition. Considering the radial growth of the DSC shell and the tolerances, the 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.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.

Each fuel assembly in the basket is homogenized in its guide sleeve region and effective fuel properties are used for the homogenized fuel assembly region to calculate maximum fuel temperature. This maximum fuel temperature correlates to the maximum fuel cladding temperature based on the validation of fuel effective conductivity values used for the NUHOMS® System design as documented in Appendix B.3 of the FSAR. In addition, alternate confirmatory analysis has been performed to benchmark the maximum fuel cladding temperature calculation methodology [4.13][1].

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. *The temperature of 645 °F is not a limiting temperature. The only temperature limit is the short-term limit of 752 °F [4.2].* It also accounts for short-term loading/unloading,

[1] All references are given in Section N.4.8.

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

The materials used for the NUHOMS®-24PHB system are the same as those for the NUHOMS®-24P system. Therefore, material properties used in the thermal analyses for the NUHOMS®-24PHB system documented in this section are the same as those used for the NUHOMS®-24P system. The material properties are documented in Chapter 8.1.3, Tables 8.1-8, Tables 8.1-9 for the DSC shell and basket materials and Appendix B.2 for the fuel.

The analysis also uses fuel conductivity in the axial direction, which is calculated as follows:

The axial conductivity of the fuel is derived using a parallel resistance method taking no credit for the presence of the fuel pellet and no credit for the presence of guide sleeves or control components.

$$k_{eff} = \frac{(k_{hel} \cdot A_{hel} + k_{zirc} \cdot A_{zirc})}{A_{tot}}$$

where,

A_{tot} *is the total area, conservatively including the area inside the fuel rods,*
A_{hel} *is the total area of helium, and*
A_{zirc} *is the total area of Zircaloy cladding.*

$$A_{zir} = 6.987 in^2$$
$$A_{hel} = 49.00 in^2$$
$$A_{tot} = 79.21 in^2$$

The effective conductivities for fuel region in the axial direction is then given by:

Fuel Region Axial Conductivities with Helium Fill

Temperature, °F	*K_{eff}, Btu/min-in-°F*
400	*1.048e-3*
500	*1.113e-3*
600	*1.194e-3*
700	*1.295e-3*
800	*1.329e-3*

Vacuum drying of the DSC does not reduce the pressure sufficiently to reduce the thermal conductivity of water vapor and air in the DSC cavity [4.3] and [4.12]. Therefore, air is assumed in the DSC cavity during vacuum drying. The procedure for determining the effective conductivities is identical to helium case described above. The helium conductivities are

replaced with air conductivities in determining the axial fuel effective conductivities. The results are given below:

Fuel Region Axial Conductivities With Air Fill

Temperature, °F	*K_{eff}, Btu/min-in-°F*
200	*9.750e-4*
300	*1.004e-3*
400	*1.034e-3*
500	*1.071e-3*
600	*1.112e-3*
700	*1.160e-3*
800	*1.217e-3*

The analyses use interpolated values where appropriate for intermediate temperatures. The interpolation assumes a linear relationship between the reported values. The use of linear interpolation between temperature values in the tables for determining intermediate value of property is justified by the near-linear behavior as a function of temperature for the range of interest.

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. *The maximum heat load for the 24PHB DSC is 24kW for either Configuration 1 or Configuration 2.* 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. *T*he 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. *These shell temperatures are provided in Table N.4-8.* The heat load*s* 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 *FSAR* Section 8.1.*3.3.1.*

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 super elements. 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.

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 *is calculated* in accordance with NUREG 1536 [4.8].

The amount of fission gases released from the fuel are calculated as follows:

The total amount of fission gas products is:

$$n_{fg} = \frac{(24)(14.7)(6894.8\,Pa/psi)(49{,}894\,in^3)(1.6387x10^{-5}\,m^3/in^3)}{(8.314\,J/mol\cdot K)(460°R+32°F)(5/9\,K/°R)}$$

$$n_{fg} = 875\,g-moles$$

Assuming 30% of this fission gas releases in the DSC cavity, the total amount of fission gas products released in the DSC cavity for 100% rod rupture is:

$$n_{fg} = 263\,g-moles$$

Note that the number of gm-moles released calculated above is conservative when compared to the releases predicted by fuel performance code calculations.

Therefore, the moles of fission gas released for normal, off-normal and accident conditions are 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 g-moles of gas could be released to the DSC assuming 100% cladding rupture as given in Appendix J.4.*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:

$$n_{he} = \frac{(18.2\text{psia})(6894.8\text{Pa/psi})(384{,}463\text{in}^3)(1.6387\text{x}10^{-5}\text{m}^3/\text{in}^3)}{(8.314\text{J/mol}\cdot\text{K})(909\,°\text{R})(5/9\text{K}/°\text{R})}$$

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

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:

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

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

The maximum normal operating pressure is then,

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

$$P_{DSC-NOC} = \frac{\left(1.4504\text{x}10^{-4}\frac{\text{psia}}{\text{Pa}}\right)(193\text{g}-\text{moles})(8.314\text{J/mol}\cdot\text{K})(1{,}023\,°\text{R})(5/9\text{K}/°\text{R})}{(384{,}463\text{in}^3)(1.6387\text{x}10^{-5}\text{m}^3/\text{in}^3)}$$

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

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 fuel temperature of 645°F (340°C) and 752°F (400°C), respectively, *used in the calculation of creep strain [4.2]*. 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 *NUHOMS®-24PHB DSC Thermal Models*

The NUHOMS®-24PHB DSC finite element models for the off-normal conditions are the same as those used for normal conditions described in Section N.4.4.1.

N.4.5.1.1 NUHOMS®-24PHB DSC, Basket and Payload Model

The NUHOMS®-24PHB DSC basket and payload models for the off-normal conditions are the same as those used for normal conditions described in Section N.4.4.1.1.

N.4.5.1.2 Decay Heat Load

The decay heat loads applied for the off-normal conditions are the same as those used for normal conditions described in Section N.4.4.1.2.

N.4.5.1.3 HSM Thermal Model

To determine the temperature distributions on the surface of the 24PHB DSC for off-normal conditions, the same model as the normal conditions described in Section N.4.4.1.3. is used.

N.4.5.1.4 TC Thermal Model

The DSC temperature profile for the NUHOMS®-24PHB DSC in the standard TC is taken from Section 8.1.3.3.1. DSC temperature profiles for the NUHOMS®-24PHB DSC in the OS197 TC are calculated for the off-normal conditions using the same models as those used for normal conditions described in Section N.4.4.1.4.

N.4.5.1.5 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.4.5.1.6 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 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 the 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.4.5.2 Off-Normal Maximum/Minimum Temperatures during Storage and Transfer

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.

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 Heat Load Zoning 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.4.5.3 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:

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

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

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

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

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

Short-term events refer to conditions that result in transient fuel cladding temperatures as opposed to long-term storage. These include loading and unloading of fuel in DSC, vacuum drying and backfilling operations, transfer of DSC to the ISFSI, and any postulated accidents.

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 the HSM 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 *H*eat *L*oad *Zoning C*onfigurations 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 *H*eat *L*oad *Z*oning Configuration 1 *is* evaluated, since it envelopes all other configurations for the normal and off-normal conditions of transfer. *T*he temperature*s* of the blocked vent case bound the transfer accident condition *temperatures.*

Fuel Cladding and Basket Materials

The blocked vent results are reported *at 34 hours* for bounding Heat Load Zoning Configuration 1 in Table N.4-1. *The temperatures reported in* Table N.4-2 *are for the transfer cask accident steady state case. These temperatures are bounded by the blocked vent accident case temperature results reported in* Table N.4-1. *The temperature distribution from the bottom to the top of DSC for the blocked vent accident at the end of 34 hours is listed in* Figure N.4-17.

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:

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

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

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 35 hour vacuum drying transient.

N.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

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.

4.12 Roth, A., "Vacuum Technology," 2nd Edition, 1982.

4.13 Calculation, Alternative Thermal Analysis of the NUH-24PHB DSC, Transnuclear Calculation Number NUH-HBU.0403, Revision 0.

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[5] 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.

(5) Maximum temperature used for calculation of creep strain [4.2]. This is not a limiting temperature. The only temperature limit is the short-term limit of 752 °F.

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[5] 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

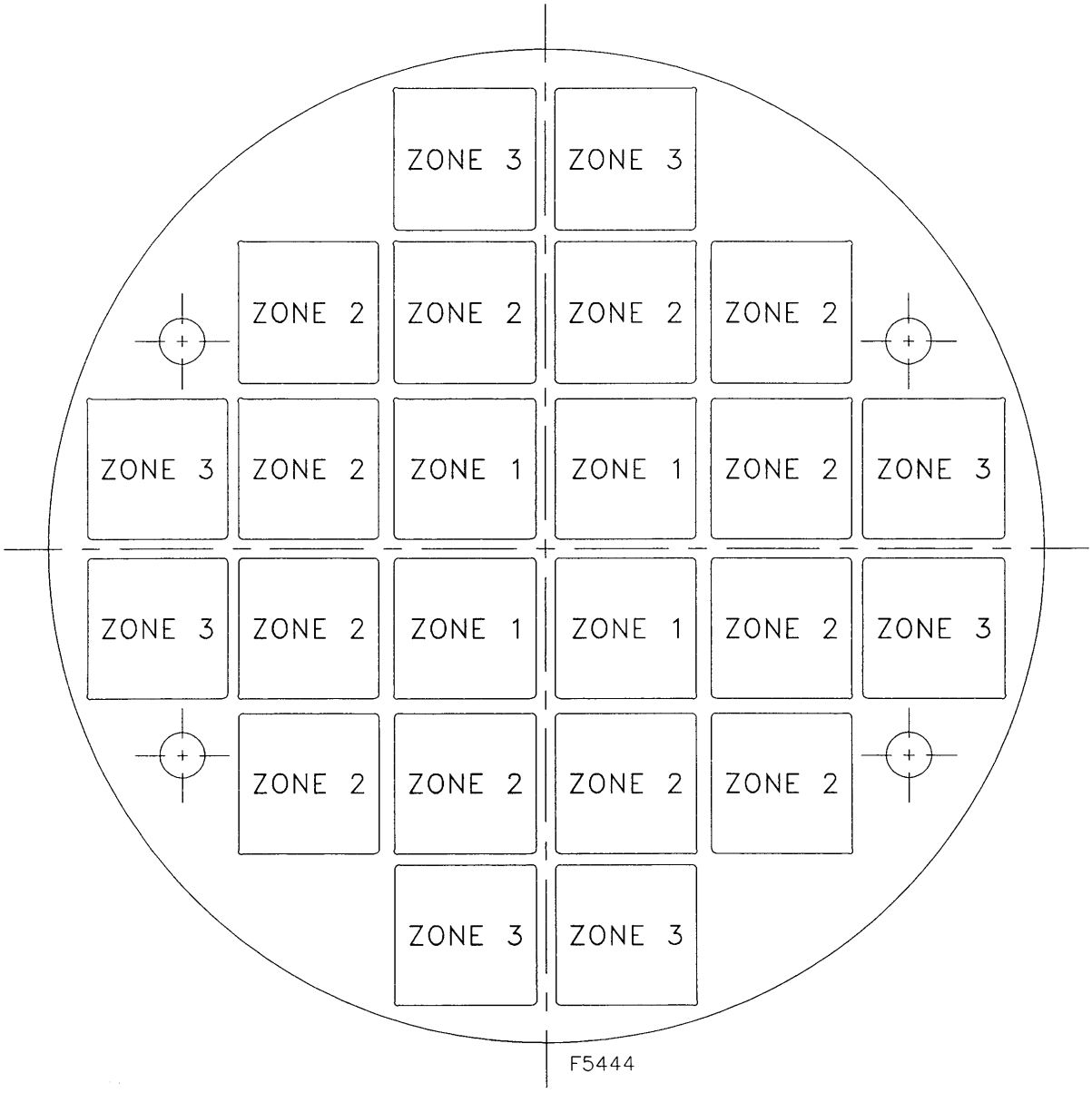
(3) The components perform their intended safety function within the operating range.

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

(5) Maximum temperature used for calculation of creep strain [4.2]. This is not a limiting temperature. The only temperature limit is the short-term limit of 752 °F.

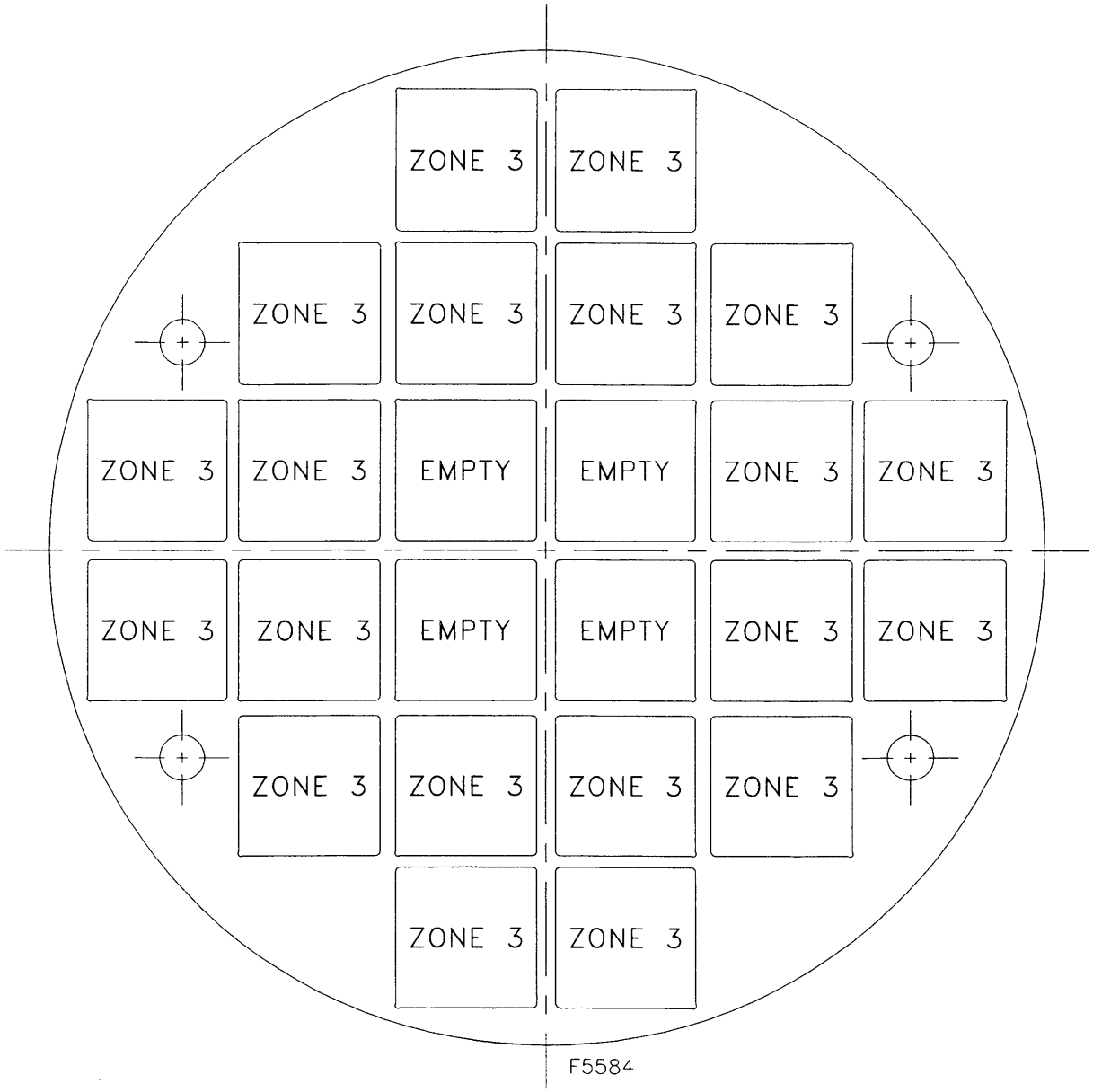
Table N.4-8
NUHOMS®-24PHB DSC Shell Temperatures for Storage and Transfer Conditions

Case	*Ambient Temperature (°F)*	*DSC Shell Temperatures Top/Side/Bottom (°F)*	*Reference FSAR Section*	*Notes*
Storage	*70*	*345/311/248*	*Table 8.1.24*	
	100	*374/339/273*	*Table 8.1.24*	
	117	*399/362/295*	*Table 8.1.24*	*Used 125 °F ambient case results*
Transfer	*100*	*448/361/273*	*Figure 8.1-11*	



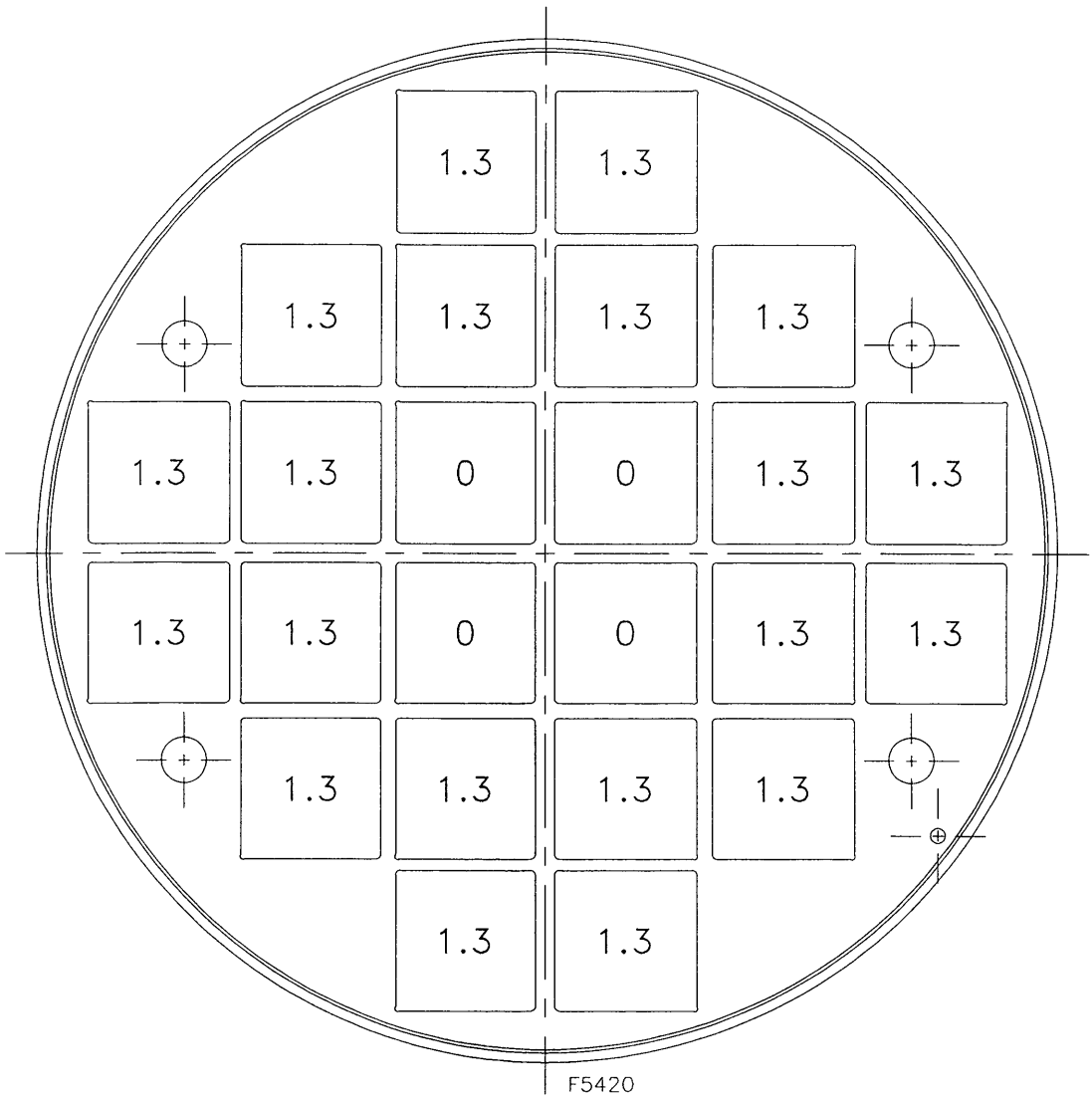
	Zone 1	Zone 2	Zone 3
Maximum Decay Heat (kW/Assembly)	0.7	1.0	1.3
Maximum Decay Heat per Zone (kW)	2.8	10.8	10.4

Figure N.4-5
Heat Load Zoning Configuration 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 2



Note: *The total canister heat load is limited to 24kW.*

Figure N.4-8
Bounding Heat Load Configuration 2

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

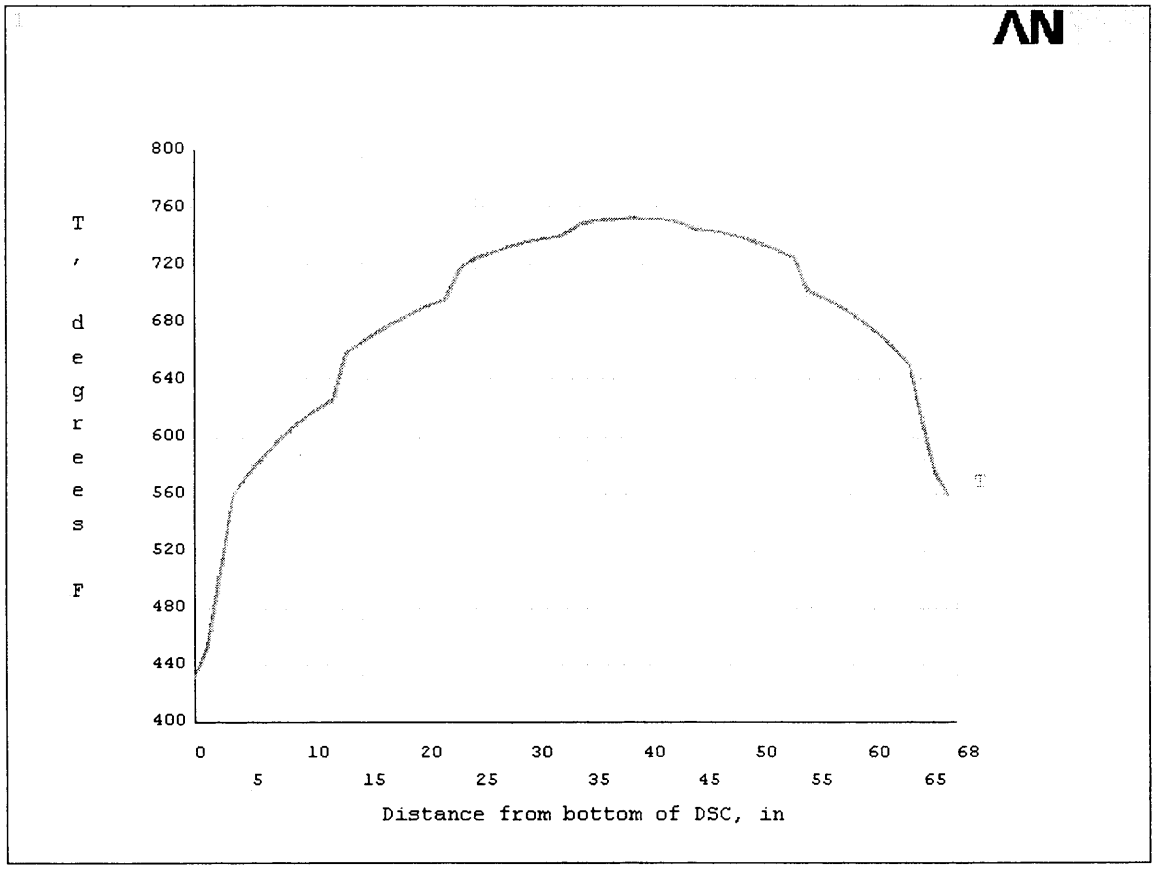


Figure N.4-17
Temperature Distribution from Bottom to Top of DSC, Blocked Vent Transient at 34 Hours

N.5 Shielding Evaluation

The shielding evaluation for the Standardized NUHOMS® System (during loading, transfer and storage) for the 24P and 52B canisters is discussed in Sections 3.3.5, 7.0 and 8.0. The following evaluation specifically addresses the bounding dose rates due to design basis B&W 15x15 PWR fuel and Burnable Poison Rod Assemblies (BPRAs) loaded in a NUHOMS®-24PHB DSC. The fuel assemblies and BPRA characteristics are described in Section N.2-1. The shielding analysis is performed for the two DSC configurations (24PHBS and 24PHBL) of the NUHOMS®-24PHB System described in Section N.2.1. The basket layout for these two DSC configurations is identical except for the shield plug design and length of the DSC components. For shielding purposes, the 24PHBL DSC bounds the 24PHBS DSC because of the additional gamma source due to the BPRAs. Therefore, the dose rates calculated for the 24PHBL DSC with fuel plus BPRAs bound the dose rates for the 24PHBS DSC with fuel.

The design basis PWR fuel source terms are derived from the bounding fuel, B&W 15x15 Mark B 10 assembly design as described in Section N.5.2. The information provided in the Table N.5-1 is based on B&W 15x15 fuel. The types of spent fuel considered in this Appendix 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 or unlimited number of *zircaloy clad* lower enriched UO_2 rods instead of zircaloy clad UO_2 rods. *(Note that lower enriched UO_2 rods are of similar design and behavior as the standard fuel rod aside from the uranium enrichment.)* The reconstituted rods can be at any location in the fuel assemblies. The maximum number of reconstituted fuel assemblies per DSC is four. The reconstituted assemblies can be placed anywhere in the basket.
- Standard BPRA design for the B&W 15x15 class assemblies listed in Appendix J.

Note that while the B&W fuel types are specifically listed, storing reload fuel designed by other manufacturers is also allowed provided an analysis is performed to demonstrate that the limiting features listed in Table N.5-1 bound the specific manufacturers replacement fuel.

The design basis fuel source terms for this evaluation bound the source terms from fuel with the burnup/initial enrichment/cooling time combination given in Table N.2-3 through Table N.2-5 (with or without BPRAs and with or without reconstituted fuel assemblies) and located in the basket as shown in Figure N.2-1 and Figure N.2-2. This evaluation bounds the maximum dose rate on the surface of the HSM (Model 102) and Standard, OS197 or OS197H Transfer Cask (TC). The source terms for the BPRAs are the same as given in Appendix J for the B&W 15x15 BPRAs. The approach used to assure that the neutron and gamma source spectrum and the source terms used, bound the fuel allowed per the fuel qualification tables is consistent with that used for the Standardized NUHOMS®-24P and -52B canister designs.

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 System dose rates are calculated for these two configurations.

To calculate neutron and gamma source terms for Heat Load Zoning Configurations 1 and 2, the following burnup, initial heavy metal loading, minimum initial enrichment and cooling time combinations are used in this analysis:

- Zone 1: 55 GWd/MTU burnup, 3.4 wt. % U-235, 29-year cooling time for neutron and gamma source terms,
- Zone 2: 46 GWd/MTU burnup, 3.2 wt. % U-235 and 8-year cooling time for gamma source terms and 55 GWd/MTU burnup, 3.4 wt. % U-235, and 13.5-year cooling time for neutron source terms, and
- Zone 3: 46 GWd/MTU burnup, 3.2 wt. % U-235, and 5.5-year cooling time for gamma source terms and 55 GWd/MTU burnup, 3.4 wt. % U-235 and 8-years cooling time for neutron source terms.

These neutron and gamma source terms bound the dose rates due to fuel burnup, minimum initial enrichment and minimum cooling times given in the fuel qualification tables with initial heavy metal loadings up to 0.49 MTU.

The Heat Load Zoning Configuration 2 produces the maximum dose rates on the surfaces of the HSM and TCs. The bounding gamma and neutron source terms are used in the shielding models to conservatively calculate dose rates for the NUHOMS®-24PHB System. For Heat Load Zoning Configuration 2, all twenty fuel assemblies in the DSC are modeled with neutron and gamma source terms consistent with 1.3 kW heat load. Therefore, these source terms result in conservative dose rates because the shielding analysis is based on a 26 kW heat load per DSC compared to the 24 kW per DSC design basis limit.

The bounding neutron and gamma source terms are for the various burnups, cooling time and enrichment combinations shown above. Use of these bounding source terms for shielding analysis adds additional conservatism to the dose rates on the 24PHB DSC, HSM and TC. The design basis source terms for the B&W 15x15 BPRAs with up to 2 cycles burnup and 5-year cooling are taken from Appendix J. The properties used to calculate the design basis source terms for the authorized BPRAs are reproduced in Table N.5-2.

The cooling times for the reconstituted fuel assemblies are determined such that the source terms of reconstituted fuel assemblies are bounded by the standard fuel assemblies.

The methodology, assumptions, and criteria used in this evaluation are summarized in the following subsections.

library which includes more accurate evaluation for ^{154}Eu and ^{155}Eu, are used in the ANISN evaluations to calculate the surface dose rates. Heat load Configuration 2 (Figure N.2-2) produced the bounding total surface dose rate for both the HSM and TC.

A sample SAS2H/ORIGEN-S input file for the 55 GWd/MTU, 3.5 wt. % U-235 case is provided in Section N.5.5.1. It is conservatively assumed that a reactor operated at the maximum power from the beginning to the end of each cycle to maximize actinide production rate.

The cobalt concentration used in the various exposure regions and the total for entire fuel assembly was selected to maximize the gamma source terms.

For reconstituted fuel with *zircaloy clad* lower enriched uranium oxide rods, the assembly average enrichment produces the same total assembly decay heat, neutron and gamma source, *where the assembly average enrichment can be calculated by taking the total grams of U-235 in the reconstituted assembly, divided by the total grams of uranium in the assembly, had it been configured in its reconstituted form prior to irradiation.* Therefore, the appropriate fuel qualification table can be used directly to determine the minimum required cooling time by using the calculated average initial enrichment and the assembly average burnup. The resulting cooling time assures that the heat load, clad temperature and dose rate limits are maintained.

For reconstituted fuel with up to 10 stainless steel rods, a series of SAS2H calculations were performed to evaluate the effect of the increased cobalt content from the stainless steel rods. For a given burnup/initial enrichment and cooling time, the total neutron and decay heat are reduced because of the reduced heavy metal in the assembly. Therefore the surface neutron dose rates are reduced and the total decay heat is bounded by fuel that has not been reconstituted. The effect on the gamma source term and resulting gamma dose rate is evaluated using the ANISN models that are used to develop the fuel qualification tables. Based on the results of the ANISN evaluation, reconstituted fuel with up to 10 stainless steel rods can be stored using the same minimum cooling times as those shown in the fuel qualification tables or 9.0 years which ever is greater. Therefore reconstituted fuel with up to 10 stainless steel rods shall not be stored with less than 9.0 years cooling.

Boron concentration, moderator temperature and density values are selected in the depletion model to maximize buildup of isotopic activities such as ^{244}Cm resulting in conservative neutron source terms.

N.5.2.1 Gamma Source

Four SAS2H/ORIGEN-S runs are required to determine gamma source terms for the four exposure regions of interest for each fuel assembly; the bottom, in-core, plenum and top regions. The only difference between the runs is in Block #10 "Light Elements" of the SAS2H input and the 81$$ card in the ORIGEN-S input. Each run includes the appropriate "Light Elements" for the region being evaluated and the 81$$ card is adjusted to have ORIGEN-S output the total gamma source for the in-core region and only the light element source for the plenum, top and bottom nozzle regions.

The design basis source terms for the authorized BPRA designs, taken from Appendix J, are listed in Table N.5-11.

N.5.6 References

5.1 Oak Ridge National Laboratory, RSIC Computer Code Collection, "SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluations for Workstations and Personal Computers," NUREG/CR-0200, Revision 6, ORNL/NUREG/CSD-2/V2/R6.

5.2 "DORT-PC - Two-Dimensional Discrete Ordinates Transport Code System," CCC-532, Oak Ridge National Laboratory, RSIC Computer Code Collection, Version 2.10.1, October 1991.

5.3 CASK-81 - 22 Neutron, 18 Gamma-Ray Group, P3, Cross Sections for Shipping Cask Analysis," DLC-23, Oak Ridge National Laboratory, RSIC Data Library Collection, June 1987.

5.4 Ludwig, S.B., and J.P. Renier, "Standard- and Extended-Burnup PWR and BWR Reactor Models for the ORIGEN2 Computer Code," ORNL/TM-11018, Oak Ridge National Laboratory, December 1989.

5.5 "ANISN-ORNL - One-Dimensional Discrete Ordinates Transport Code System with Anisotropic Scattering", CCC-254, Oak Ridge National Laboratory, RSIC Computer Code Collection, April 1991.

5.6 DeHart, M.D. "Sensitivity and Parametric Evaluations of Significant Aspects of Burnup Credit for PWR Spent Fuel Package, ORNL, May 1996.

5.7 "Topical Report on Actinide-Only Burnup Credit for PWR Spent Nuclear Fuel Packages", Office of Civilian Radioactive Waste Management, DOE/RW-0472 Rev. 0, May 1995.

5.8 "Addition of 61BT DSC to Standardized NUHOMS® System," Amendment No. 3, Revision 3 to NUHOMS® CoC 1004, March 2001, TAC No. L23137 (Amendment under review at NRC).

5.9 Jenal, J. P., P. J. Erickson, W. A. Rhoades, D. B. Simpson, and M. L. Williams, "The Generation of a Computer Library for Discrete Ordinates Quadrature Sets," ORNL/TM-6023, Oak Ridge National Laboratory, October 1977.

5.10 "MCNP4 Monte Carlo Neutron and Photon Transport Code System," CCC-200 A/B, Oak Ridge National Laboratory, RSIC Computer Code Collection, October 1991.

5.11 "American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors," ANSI/ANS-6.1.1-1977, American Nuclear Society, LaGrange Park, Illinois, March 1977.

5.12 Characteristics of Spent Fuel High-Level Waste, and Other Radioactive Wastes which May Require Long-Term Isolation," DOE/RW-0184, December 1987.

Table N.5-12
Heat Load Configuration Region Volumes

Configuration 1

Assembly Region	Zone 1 (cm^3)	Zone 2 (cm^3)	Zone 3 (cm^3)
Bottom	4.35E+4	1.30E+5	1.72E+5
In-Core	7.39E+5	2.22E+6	2.93E+6
Plenum	4.53E+4	1.36E+5	1.80E+5
Top	3.24E+4	9.71E+4	1.28E+5

Configuration 2

Assembly Region	*Zone 1 (cm^3)*	*Zone 2 (cm^3)*	*Zone 3 (cm^3)*
Bottom	*N/A*	*N/A*	*3.02E+5*
In-Core	*N/A*	*N/A*	*5.15E+6*
Plenum	*N/A*	*N/A*	*3.16E+5*
Top	*N/A*	*N/A*	*2.25E+5*

N.8 Operating Systems

The generic operating procedures for the NUHOMS®-24PHB System are essentially the same as those described in Chapter 5 for the NUHOMS®-24P System except for the operational steps which demonstrate that the 24PHB DSC meets requirements of Technical Specifications *1.2.3a,* 1.2.4.a, *1.2.15.b* and 1.2.17*a*. These procedural changes are discussed in the following sections.

N.8.1 Procedures for Loading the Cask

The process flow diagram for operation of the NUHOMS® System is presented in Figure N.8.1-1. The location of the various operations may vary with individual plant requirements. The following steps describe the recommended generic operating procedures for the NUHOMS®-24PHB System.

N.8.1.1 Preparation of the TC and 24PHB DSC

No change *relative to Section 5.1.1.1., except that boron concentration requirements of Technical Specification 1.2.15b apply in step 9.*

N.8.1.2 24PHB DSC Fuel Loading

All operations are the same as described in Section 5.1.1.2 except steps 5, 6, 7 and 8 are revised as described below to eliminate any potential for fuel misloading.

5. *The potential for fuel misloading is essentially eliminated through the implementation of procedural and administrative controls. The controls instituted to ensure that fuel assemblies and BPRAs (if applicable) are placed into a known cell location within a DSC, will typically consist of the following:*

   - *A cask/DSC loading plan is developed to verify that the fuel assemblies and BPRAs, if applicable, meet the burnup, enrichment and cooling time parameters of Technical Specification 1.2.1.*
   - *The loading plan is independently verified and approved before the fuel load.*
   - *A fuel movement schedule is then written, verified and approved based upon the loading plan. All fuel movements from any rack location are performed under strict compliance of the fuel movement schedule.*

6. *Prior to insertion of a spent fuel assembly (and BPRAs, if applicable) into the DSC, the identity of the assembly (and BPRAs, if applicable) is to be verified by two individuals using an underwater video camera or other means. Read and record the identification number from the fuel assembly (and BPRAs, if applicable) and check this identification number against the DSC loading plan which indicates which fuel assemblies (and BPRAs, if applicable) are acceptable for dry storage.*

7. *Position the fuel assembly for insertion into the selected DSC storage cell and load the fuel assembly. Repeat step 6 for each SFA loaded into the DSC. After the DSC has been fully loaded, check and record the identify and location of each fuel assembly and BPRAs, if applicable, in the DSC.*

8. *After all the SFAs (and BPRAs, if applicable) have been placed into the DSC and their identities verified, position the lifting yoke and the top shield plug and lower the shield plug onto the DSC.*

CAUTION: *Verify that all the lifting height restrictions as a function of temperature specified in Technical Specification 1.2.13 can be met in the following steps which involve lifting of the TC.*

N.8.1.3 24PHB DSC Drying and Backfilling

All operations are the same as described in Section 5.1.1.3, except that the vacuum drying time requirements of Technical Specification 1.2.17*a* apply *to steps 21 and 27. Step 28 is revised to state that the DSC helium backfill pressure requirements of Technical Specification 1.2.3.a apply. Step 24 is revised as follows:*

24. Helium leak test the inner top cover plate weld for leakage in accordance with ANSI N.14.5 to a sensitivity of $1x10^{-5}$ atm cm^3/sec.

N.8.1.4 24PHB DSC Sealing Operations

1. Disconnect the VDS from the DSC. Seal weld the prefabricated plugs over the vent and siphon ports, inject helium in blind space and perform a dye penetrant weld examination in accordance with the Technical Specification 1.2.5 requirements.

2. Install the welding machine onto the outer top cover plate and place the outer top cover plate with the welding system onto the DSC. Manual welding is also acceptable. Verify proper fit up of the outer top cover plate with the DSC shell.

3. Tack weld the outer top cover plate to the DSC shell. Place the outer top cover plate weld root pass.

4. Helium leak test the inner top cover plate and vent/siphon port plate welds using the leak test port in the outer top cover plate in accordance with Technical Specification 1.2.4a limits. *Verify that the personnel performing the leak test are qualified in accordance with SNT-TC-1A [8.1].*

5. If a leak is found, remove the outer cover plate root pass, the vent and siphon port plugs and repair the inner cover plate welds. Then install the Strongback and repeat procedure steps from Section *5.1.1.3*, step *20*.

6. Perform dye penetrant examination of the root pass weld. Weld out the outer top cover plate to the DSC shell and perform dye penetrant examination on the weld surface in accordance with the Technical Specification 1.2.5 requirements.

7. Seal weld the prefabricated plug over the outer cover plate test port and perform dye penetrant weld examinations in accordance with Technical Specification 1.2.5 requirement.

8. Rig the cask top cover plate and lower the cover plate onto the TC.

9. Bolt the cask cover plate into place, tightening the bolts to the required torque in a star pattern.

N.8.1.5 TC Downending and Transport to ISFSI

No change.

N.8.1.6 DSC Transfer to the HSM

No change.

N.8.1.7 Monitoring Operations

No change.

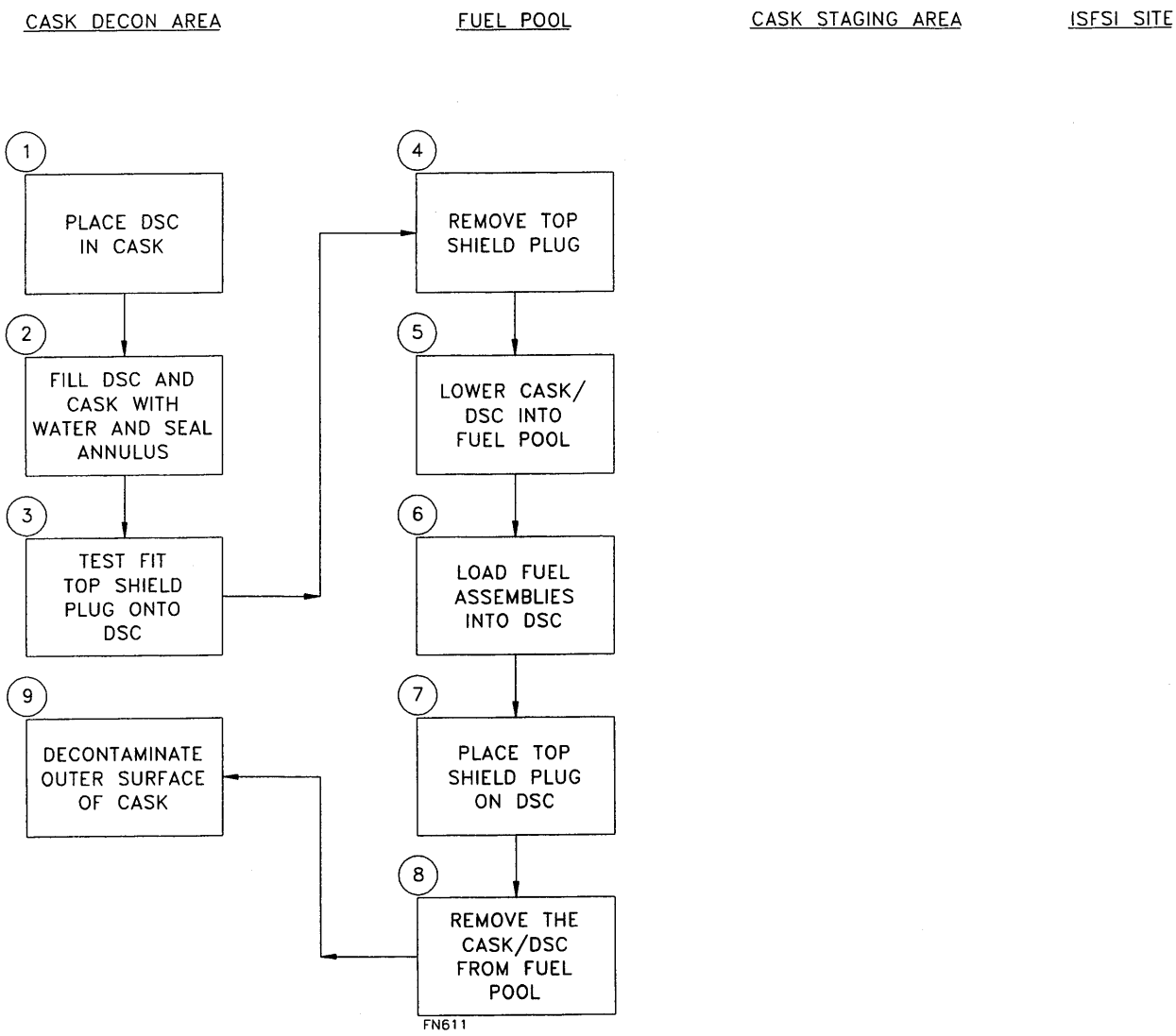


Figure N.8.1-1
NUHOMS® System Loading Operations Flow Chart

N.8.9 References

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

N.9 Acceptance Tests and Maintenance Program

N.9.1 Acceptance Tests

The acceptance requirements for the NUHOMS®-24PHB System are given in the FSAR with the exceptions described in the following sections. The NUHOMS®-24HB DSC has been enhanced to provide leak tight confinement. Additional acceptance testing of the NUHOMS®-24PHB DSC welds is described herein.

N.9.1.1 Visual Inspection

No change.

N.9.1.2 Structural

No change.

N.9.1.3 Leak Tests

The NUHOMS®-24PHB DSC confinement is leak tested to verify it is leaktight in accordance with ANSI N14.5 [9.1]. *The personnel performing the leak test are qualified in accordance with SNT-TC-1A [9.2].*

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

N.9.1.4 Components

No change.

N.9.1.5 Shielding Integrity

No change.

N.9.1.6 Thermal Acceptance

No change.

N.9.1.7 Poison Acceptance

No change.

N.9.3 References

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

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