HOLTEC INTERNATIONAL

HI-STORM 100 CERTIFICATE OF COMPLIANCE 72-1014

LICENSE AMENDMENT REQUEST 1014-1

HOLTEC
INTERNATIONAL

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BY OVERNIGHT MAIL

April 25, 2000

Ms. Marissa Bailey
Project Manager, SFPO, NMSS
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville MD, 20852

References: 1. Holtec Project No. 5014
2. Holtec License Amendment Request No. 1014-1, dated April 14, 2000

Subject: Holtec Proprietary Information

Dear Ms. Bailey:

In response to your verbal request of April 21, 2000, this letter is provided to clarify the classification of information submitted for NRC review in the above-referenced License Amendment Request (LAR). The Holtec-proprietary drawings listed below are included in LAR 1014-1 but are not stamped "Proprietary." Please replace the below-listed drawings in the LAR with the enclosed copies of these drawings, which are stamped "Proprietary", and destroy the unstamped versions. No other information in the LAR 1014-1 submittal is considered Holtec-proprietary. The footer of proposed Revision 11, Appendix 3.T that refers to non-existent proprietary information will be removed in the final version of this TSAR revision.

Holtec-Proprietary Drawings

2889 through 2892
2898 and 2899
3065 through 3075

These drawings contain information which is commercially sensitive to Holtec International and is treated by us with strict confidentiality. This information is of the type described in 10 CFR 2.790(b)(4). The drawings are considered proprietary to Holtec. The attached affidavit sets forth the bases for which the information is required to be withheld from public disclosure, consistent with these considerations and pursuant to the provisions of 10 CFR 2.790(b)(1). It is therefore requested that the proprietary information enclosed be withheld from public disclosure in accordance with applicable NRC regulations.

We apologize for any inconvenience this has caused you or your staff. If you have comments or require additional information please feel free to contact me at 856-797-0900, ext. 668.

Sincerely,

Brian Gutherman, P.E.
Licensing Manager

Document ID: 5014386

Attachment: Affidavit Pursuant to 10 CFR 7.290

Enclosures: Holtec Proprietary Drawings 2889 – 2892, 2898, 2899, and 3065 – 3077 (11 copies)

HOLTEC
INTERNATIONAL

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April 14, 2000

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Subject: NRC 10 CFR 72 Certificate of Compliance No. 1014, TAC L22221
License Amendment Request 1014-1

References:
1. Holtec Project No. 5014
2. Holtec Topical Safety Analysis Report No. HI-951312, Revision 10.
3. Holtec letter to NRC dated March 3, 2000

Dear Sir:

Holtec International hereby submits License Amendment Request (LAR) 1014-1, Revision 0, proposing certain amendments to 10 CFR 72 Certificate of Compliance (CoC) No. 1014 and its supporting Topical Safety Analysis Report for the HI-STORM 100 System. Information describing and justifying the changes requested by this LAR is contained in the attachments listed below. In preparing this amendment request package, we have intentionally included non-mandatory material, such as marked-up and final versions of the CoC, and proposed Topical Safety Analysis Report (TSAR) changes. This non-mandatory information adds to the overall bulk of the submittal, but should greatly facilitate the NRC staff's review effort.

Attachment 1: Summary of Proposed Changes, including the descriptions, reasons, and justifications for the proposed changes.

Attachment 2: Mark-ups of Proposed Changes to CoC Appendices A and B (strikeout/italic format).

Attachment 3: Proposed Revised CoC Appendices A and B (final form).

Attachment 4: New and Revised Holtec Design Drawings.

Attachment 5: Proposed Revision 11 Changes to the HI-STORM Topical Safety Analysis Report.

This LAR proposes changes to the Appendices to the CoC, the design drawings, and the TSAR which include 1) editorial corrections and clarifications, 2) revisions to limits for existing fuel array/classes 3) four new fuel array/classes, 4) four new fuel canisters, 5) four types of non-fuel

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PWR hardware, 6) antimony-beryllium neutron sources, 7) enhanced MPC-24 and MPC-68 baskets (called MPC-24E and MPC-68FF, respectively), 8) the reintroduction of MPC-32, and 9) an alternative, slightly shorter HI-STORM 100 overpack design (labeled HI-STORM 100S).

Two of the new fuel canisters added are those in which Dresden Unit 1 fuel assemblies previously stored at West Valley are now stored in Dresden Units 2 and 3 spent fuel pools. These canisters have previously been reviewed by the NRC under HI-STAR 100 License Amendment Request 1008-1 submitted in November, 1999 (Docket 72-1008). The remaining two new fuel canisters are Holtec's new generic designs for storing a wide range of PWR and BWR damaged fuel. The MPC-24E and MPC-68FF are designed to accommodate the generic PWR and BWR damaged fuel canisters, respectively. Design drawings, as appropriate, are provided for the MPC-24E, MPC-32, and HI-STORM 100S. Revised MPC-68 drawings are provided for the MPC-68FF.

Drawing changes for the HI-STORM 100 overpack, MPC-32, MPC-24, MPC-68, HI-TRAC 100, and HI-TRAC 125 include changes (indicated by "Rev triangles" in the body of the design drawings and Bills-of-Material) that correct minor errors, internal consistencies, and ambiguities in the previous revisions which have been detected during the manufacturing process of first production unit (Serial No. 001) for Plant Hatch and an in-depth operational and fabricability review. The changes to the drawings accordingly seek to clarify inspection criteria, remove ambiguity in verbiage, provide explicit design direction to the manufacturer, eliminate internal inconsistencies, and replace unfabricable details with those that can be fabricated with reduced welding-induced distortion. In some cases, where experience has shown that a higher quality level can be achieved through well-calibrated fixturing, the recourse to inherently inferior palliatives (such as shims) has been removed to assure improved hardware quality. In all cases, the safety margins reported in the TSAR and in the NRC's Safety Evaluation Report continue to remain robust. A vast majority of these changes for the MPCs have already been reviewed by the NRC as part of HI-STAR License Amendment Request 1008-1.

All changes in the drawings and TSAR text material have been subjected to our rigorous multi-disciplinary engineering change acceptance review process and appropriately documented in our quality files.

You will note that the proposed TSAR changes included in Attachment 5 indicate Revision 11. This is because the latest approved TSAR for HI-STORM is Revision 10. We understand that a *Final* Safety Analysis Report, Revision 0, is to be submitted by us within 90 days of the final approval (expected later this month) of the HI-STORM 100 System design by the NRC in accordance with 10 CFR 72.248. At the time this amendment request is approved, we will conform these proposed TSAR Revision 11 changes into Revision 1 of the FSAR, to be submitted in accordance with the applicable regulations.

We appreciate the SFPO's consideration of this amendment request which is tailored to fulfill the immediate needs of our existing customers. MPC-32, whose review was nearly completed before its deletion from the MPC lineup, is now a high priority item to serve TVA's Sequoyah plant. To ensure that TVA and other PWR clients of Holtec have no concern with respect to the transportability of MPC-32 (that they will load in the near future), we intend to submit an amendment request to include MPC-32 into the dual purpose HI-STAR 100 System shortly. We respectfully request a high priority review of this LAR to assist us in being responsive to our clients' needs.

Sincerely,	Approved:
Brian Gutherman, P.E. Licensing Manager	K. P. Singh, Ph.D., P.E. President and CEO

Document I.D.: 5014372

Attachments: 1 – 5: As Stated Above

Cc: Ms. Virginia Tharpe, USNRC, (10 hard copies, w/attach and encl.; and floppy disk of cover letter and Attachments 1 through 3)
Dr. Stan Turner, Holtec Florida Operations Center (cover letter only)
Mr. E. W. Brach, USNRC (cover letter only)
Ms. S. Frant-Shankman, USNRC (cover letter only)
Mr. W. Hodges, USNRC (cover letter only)
Mr. R. Hall, USNRC (cover letter only)
Mr. M. McNamara, Holtec (cover letter only)
Mr. R. Kellar, Holtec (cover letter only)
Holtec Dry Storage Project Managers (cover letter only)
Mr. R. Moscardini, UST&D (cover letter only)
Mr. J. Singh, Omni Fabricators (cover letter only)

Technical Concurrence:

Mr. Bernard Gilligan (Configuration Control)	
Dr. Alan Soler (Structural Evaluation)	Alan Soler
Dr. Indresh Rampall (Thermal/Accident Evaluations)	Indresh Rampall
Dr. Everett Redmond II (Shielding Evaluation)	
Dr. Stefan Anton (Criticality Evaluation)	Stefan Anton
Mr. Kris Cummings (Confinement Evaluation)	Kris W. Cummings
Mr. Steve Agace (Operations)	S. Agace
Mr. Mark Soler (Quality Assurance)	Mark Soler

Distribution (w/ attach. 1):

Recipient	Utility
Mr. David Bland	Southern Nuclear Operating Company
Mr. Ken Phy	New York Power Authority
Mr. J. Nathan Leech	Commonwealth Edison
Dr. Max DeLong	Private Fuel Storage
Mr. Stan Miller	Vermont Yankee Nuclear Power Corporation
Mr. Bruce Patton	Pacific Gas & Electric – Diablo Canyon
Mr. Mark Smith	Pacific Gas & Electric – Humboldt Bay
Mr. Rodney Pickard	American Electric Power
Mr. David Larkin	Energy Northwest
Mr. Eric Meils	Wisconsin Electric Power Company
Mr. Paul Plante	Maine Yankee Atomic Power Company
Mr. Jeff Ellis	Southern California Edison
Mr. Darrell Williams	Entergy Operations – Arkansas Nuclear One
Mr. Joe Andrescavage	GPUN – Oyster Creek Nuclear Power Station

<u>Distribution (w/ attach. 1) (continued):</u>

Mr. Ron Bowker	IES Utilities
Mr. William Swantz	Nebraska Public Power District
Mr. Chris Kudla	Entergy Operations – Millstone Unit 1 Decommissioning
Mr. Keith Waldrop	Duke Power
Mr. Matt Eyre	PECO Energy
Mr. Al Gould	Florida Power & Light
Dr. Seymour Raffety	Dairyland Power
Mr. John Sanchez	Consolidated Edison
Ms. Kathy Picciott	Niagara Mohawk
Mr. Charles Davis	Tennessee Valley Authority – Sequoyah Nuclear Plant
Mr. John Donnell	Private Fuel Storage, LLC (SWEC)

SUMMARY OF PROPOSED HI-STORM 100 CHANGES[1]

SECTION I – PROPOSED CHANGES TO CERTIFICATE OF COMPLIANCE 1014

Proposed Change No. 1*

Certificate of Compliance, Appendix A, LCO 3.1.1, SR 3.1.1.2, and Table 3-1:

The MPC helium backfill *density* limit is revised to be a maximum helium backfill *pressure* with acceptance criteria as shown in the attached marked-up LCO and table.

NOTE: The MPC helium backfill pressure cited here for the MPC-24/24E is lower than that proposed under HI-STAR LAR 1008-1 and LAR 9261-1. This is due to the higher heat capacity of the HI-STORM 100 System compared to HI-STAR under normal conditions, which creates a more severe transient under postulated accident conditions. To ensure fungibility of the MPCs for both HI-STAR and HI-STORM, the MPC helium backfill pressure will be reduced in the HI-STAR CoC in a future amendment request.

Reason for Proposed Change

The existing TS limits on helium backfill density are overly restrictive and not necessary without credit being taken for convection heat transfer within the MPC. Therefore, a change in favor of a simpler requirement is warranted. The change is designed to relieve the users of an unnecessary burden of confirming helium backfill within a narrow range of acceptance.

Justification for Proposed Change

The proposed change to the MPC helium backfill TS requires the users to backfill the MPC within a range of helium pressures. This ensures the presence of helium in the MPC free space. Any positive helium pressure in the MPC (i.e., > 1 atm) is consistent with the governing thermal analyses. The positive helium pressure in the MPC provides reasonable assurance of no air inleakage into the MPC cavity during storage operations. The upper pressure limit protects the MPC from potential overpressure during the hypothetical accident scenario where 100% of the fuel rods are assumed to rupture.

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[1] Proposed changes marked with a "*" have previously been submitted under License Amendment Request (LAR) 1008-1 for HI-STAR 100 (Docket 1008, 11/24/99). These changes have nearly completed NRC review as of the date of this LAR and are provided again here for completeness.

Proposed Change No. 1A

Certificate of Compliance, Appendix A, Surveillance Requirement SR 3.1.2.1:

Revise the Surveillance Requirement to add delta T limits for the MPC-32 and the MPC-24E and to increase the limits for the MPC-24 and MPC-68 (including MPC-68F and MPC-68FF).

Reason and Justification for Proposed Changes

The delta T limits are based on the proposed heat loads for the cask system as discussed elsewhere in this section (see Proposed Change No. 7).

Proposed Change No. 1B

Certificate of Compliance, Appendix A, LCO 3.2.1:

Revise HI-TRAC dose rate acceptance criteria as shown on the attached mark-ups of the LCO.

Reason for Proposed Change

The addition of the MPC-32 basket and non-fuel hardware have increased the dose rates for the loaded HI-TRAC 100 and HI-TRAC 125 transfer casks.

Justification for Proposed Change

The HI-TRAC dose rates are based on conservative, design basis source terms, using relatively low cooling times and high burnups. Users, simply through the nature of core operating cycles, will likely not have any one MPC loaded with design basis fuel. Users will determine the actual (lower) expected dose rates based on their particular fuel characteristics prior to fuel loading. The purpose of this LCO is simply to provide a limit above which users should suspect that a fuel assembly (or multiple fuel assemblies) not meeting the CoC has been loaded into the MPC, and they must the action required by the Technical Specifications. Users' radiation protection/ALARA programs and operating procedures will control the use of temporary shielding and specific operating activities, as appropriate to ensure doses are ALARA. Note that the TSAR currently recommends that users choose the 125-ton HI-TRAC transfer cask because it provides better shielding. However, users with lower capacity cranes will need to perform an ALARA evaluation to either upgrade their crane capacity or implement temporary shielding to ensure occupational exposures are ALARA.

Proposed Change No. 2

Certificate of Compliance, Appendix A, LCO 3.2.3:

a. The LCO acceptance criteria for the side of the overpack and the inlet and outlet vents are increased to 50 and 40 mrem/hr, respectively.

b. The LCO Applicability is revised to delete "TRANSPORT OPERATIONS."

c. Required Action A.2 is revised to substitute a written evaluation in lieu of an analysis.

Reason for Proposed Changes

a. The side dose rate limit is increased due to the addition of the MPC-32 basket and non-fuel hardware. The inlet and outlet vent duct dose rate limit is increased due to the addition of the MPC-32 basket, non-fuel hardware, and design changes associated with the HI-STORM 100S overpack design.

b. The dose rate acceptance criteria are not required to be met until the overpack is in its final storage configuration and in its designated storage location at the ISFSI. Therefore, having this LCO applicable during TRANSPORT OPERATIONS.

c. This change is proposed to broaden the options for the user in this area while accomplishing the same objective

Justification for Proposed Change

a. In both cases, the higher dose rate acceptance criteria are a result of increasing the number of PWR fuel assemblies in the MPC with the addition of MPC-32, as well as adding non-fuel hardware to the contents of the PWR MPCs. The duct dose rate also is affected by the design changes made to create the HI-STORM 100S, which include shortening the overall length of the HI-STORM overpack. This involved changes to the lid design, which incorporates the outlet ducts directly into the lid, and shortening the pedestal upon which the MPC rests. These changes moved the MPC closer to the top of the inlet ducts and closer to the bottom of the outlet ducts.

   While these changes increase dose rates somewhat, they remain low. Further, use of the 32-assembly MPC will reduce the total number of MPCs to be loaded by a given PWR user, thereby reducing the total occupational dose over an entire loading campaign. The duct dose rates are higher only at a very short distance from the duct openings. At approximately one meter from the ducts, the calculated dose rate is approximately 13 mrem/hr, which is comparable to the dose rates prior to these changes. Increasing the dose rate limits will not jeopardize the ability of the system to meet the 10CFR72.104 requirements for off-site dose. In addition, each site will perform an evaluation considering their specific fuel to demonstrate compliance with 10CFR72.104 prior to utilizing the HI-STORM 100 system.

b. In its final storage configuration, the overpack has its gamma shield cross plate installed in the inlet and outlet ducts. If the overpack is transported while supported from the bottom (e.g., with air pads) these shielding devices cannot be installed until the overpack is at its final storage location. This change is also consistent with the current Surveillance Requirement Frequency, which does not require measuring dose rates until within the first 24 hours after the beginning of STORAGE OPERATIONS. By definition, STORAGE OPERATIONS begin when the overpack is at the ISFSI.

c. A written evaluation may include an analysis but does not necessarily need to. Depending upon the circumstances and magnitude of the high dose rates, an evaluation may include something less than an analysis and the user should have the option of performing the appropriate type of evaluation for the situation. This proposed change makes HI-STORM consistent with the dose rate LCO for HI-STAR (LCO 2.2.1).

Proposed Change No. 3

Certificate of Compliance, Appendix A, LCO 3.3.1:

This new LCO is added to provide limits for the minimum soluble boron concentration during wet loading and unloading operations with the MPC-32 and for storage of relatively higher enriched fuel in the MPC-24 and MPC-24E.

Reason for Proposed Change

Many PWR users need to load fuel up to 5% enrichment. In order to authorize storage of any reasonably enriched PWR fuel in the MPC-32 and relatively higher enriched PWR fuel in the MPC-24 and MPC-24E (discussed later in Section I), credit for soluble boron in the MPC water during wet loading and unloading operations was taken in the criticality analyses. Since this is a licensee-controlled operational activity of significant reactivity concern, a new technical specification LCO is being created to establish appropriate limits, actions, and surveillance requirements for boron concentration during these operations.

Justification for Proposed Change[2]

Criticality calculations have been performed demonstrating that for the listed conditions (maximum enrichment and minimum soluble boron concentration) for each MPC, the cask system is in compliance with the regulatory requirement of $k_{eff} < 0.95$ for all PWR fuel array/classes. The maximum k_{eff} calculated for the HI-TRAC is 0.9468 for the MPC-24, 0.9467 for the MPC-24E and 0.9464 for the MPC-32. In the HI-STORM, where no water is present inside the MPC, the maximum k_{eff} is below 0.52 for all PWR fuel array/classes and MPC models. Additional results, including results from the HI-STAR TSAR, which are directly applicable to the HI-TRAC, can be found in Tables 6.1.2 through 6.1.6 in Section 6.1 of the Proposed Rev. 11 of the TSAR (see Attachment 5).

Proposed Change No. 4

Certificate of Compliance, Appendix A, Section 5.5:

New specification item 5.5.c is added to address the transport of the loaded TRANSFER CASK or OVERPACK from the FUEL BUILDING to the ISFSI. Note 2 is revised accordingly. The new section allows lifting of the loaded TRANSFER CASK or OVERPACK above the established lift height limits provided the lift device (e.g., crawler) is designed in accordance with ANSI N14.6 and includes redundant drop protection features.

Reason for Proposed Change

This change is proposed based on user feedback which indicated there were no requirements established for onsite transport of the TRANSFER CASK or OVERPACK that address lifting the TRANSFER CASK or OVERPACK above the lift height limits. This may be required at some sites based on the transport path between the FUEL BUILDING and the ISFSI.

Justification for Proposed Change

A lift device designed in accordance with ANSI N14.6 and having redundant drop protection features ensures that a drop of the TRANSFER CASK or OVERPACK is not a credible event. This change provides necessary flexibility for users with non-compliant transport path conditions (e.g., a portion of the path that is harder than the reference pad). This change is consistent with HI-STAR 100 LCO 2.1.3.b.

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[2] This justification is focused on the criticality aspects of soluble boron. Refer to the new Bases for LCO 3.3.1 proposed to be added to TSAR Chapter 12, Appendix 12.A (Proposed Change No. 35.d) for discussion of the Required Actions and Surveillance Requirements, Frequencies, etc.

Proposed Change No. 5

Certificate of Compliance, Appendix B, Section 1.0:

The definition of DAMAGED FUEL CONTAINER (DFC)[3] in Appendix B is revised to include three additional DFCs in addition to the previously approved Holtec DFC designed exclusively for Dresden Unit 1 and Humboldt Bay fuel. The new DFC designs are: 1) a Transnuclear (TN) DFC currently containing Dresden Unit 1 (D-1) fuel*, 2) a Holtec generic PWR DFC, and 3) a Holtec generic BWR DFC. Detailed drawings for the TN/D-1 DFC are contained in Holtec LAR 1008-1 for HI-STAR 100 submitted to the NRC on November 24, 1999. Sketches of the TN/D-1 DFC and the two new Holtec-designed DFCs are included as proposed new TSAR Figures 2.1.2, 2.1.2B and 2.1.2C (see Attachment 5). In all cases, only outline sketches showing key DFC dimensions and general fabrication details are included in proposed TSAR Revision 11. Detailed design drawings of the Holtec DFC are being removed from the TSAR with this amendment request.

Reason for Proposed Changes

TN/D-1 DFC

There are a significant number of Dresden Unit 1 fuel assemblies meeting the HI-STORM fuel specifications which are currently stored in TN DFCs. Authorizing this fuel for storage in the HI-STORM 100 system without having to remove it from the TN/D-1 DFCs and load it into the Holtec DFCs will avoid imposing undue burden on the general licensee with no additional safety benefit. Implementation of this change will allow Dresden Unit 1 to complete decommissioning of the plant in a timely manner. Further, the fuel in the TN/D-1 DFCs is currently located in the Dresden Unit 2/3 spent fuel pool. Removal of this fuel is necessary to maintain full core offload capability and allow D-2/3 to continue operation.

Holtec Generic PWR and BWR DFCs

The current HI-STORM CoC authorizes only damaged fuel and fuel debris from the Dresden Unit 1 and Humboldt Bay plants for storage in HI-STORM 100. Many other customers have informed Holtec that some of their fuel would be classified as damaged fuel or fuel debris. These new generic DFC designs allow

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[3] The terms Damaged Fuel Container and Damaged Fuel Canister are used interchangeably throughout this document and "DFC" is applicable to both.

for storage of a much broader scope of damaged fuel (both PWR and BWR) and fuel debris (BWR only).

Justification for Proposed Changes

TN/D-1 DFC

The justification for this proposed change is provided below, arranged by technical discipline, as applicable. Conforming changes to the TSAR are summarized in Section II of this attachment and included in Attachment 5.

Structural Evaluation

The TN/D-1 DFC was previously approved for use in the TN-9 transportation package. In addition, the TN/D-1 DFC has been structurally evaluated by Holtec International and found to meet all design requirements for storage in the HI-STORM 100 system. The details of this evaluation are contained in proposed new TSAR Appendix 3.AR, included in Attachment 5 to this letter. All required safety margins are greater than zero or, in other words, the factors of safety are greater than 1.0.

The TSAR Chapter 3 NUREG-1536 compliance matrix has been revised to address the new DFCs and the supporting appendix. Since all required text changes are confined to the new appendix, no new chapter text is required.

Thermal Evaluation

Storage of D-1 damaged fuel and fuel debris meeting the specifications of the CoC is permitted in the HI-STORM MPC-68, MPC-68F, and MPC–68FF when encased in a DFC. The thermal characteristics of the TN/D-1 DFC and the Holtec DFC were compared in support of this amendment request. The TN/D-1 DFC is a square shaped canister box fabricated from 12 gage stainless steel plates. A bounding thermal calculation has been prepared in support of this amendment to determine the most heat resistive fuel from the Low Heat Emitting (LHE) group of assemblies encased in a DFC. It is noted that in this configuration, interruption of radiation heat exchange between the fuel assembly and the fuel basket by the DFC boundary renders the DFC configuration as the bounding case when compared with the absence of a DFC. Both canister designs were evaluated and the one exhibiting lower heat dissipation characteristics was adopted for analysis.

For the LHE group of assemblies, the low decay heat load of D-1 fuel (approximately 8 kW) guarantees large thermal margins to permit safe storage of D-1 fuel in the TN/D-1 DFC. The HI-STORM temperature field for this case was calculated and is reported in proposed revisions to HI-STORM TSAR Chapter 4 at Subsection 4.4.1.1.13 (see Attachment 5). Substantial cladding thermal margins are demonstrated by the analysis.

Shielding Evaluation

Storage of D-1 damaged fuel and fuel debris meeting the specifications of the CoC is permitted in the HI-STORM MPC-68, MPC-68F, and MPC-68FF when encased in a DFC. Sections 5.4.2 and 5.4.5 of the HI-STORM TSAR, Revision 10 discuss the post-accident shielding evaluation for D-1 and Humboldt Bay damaged fuel. These sections assume that the damaged fuel assemblies and fuel debris collapse to a height of 80 inches. This dimension was calculated based on the inside dimension of the DFC and the dimensions of the fuel assemblies. Since the TN/D-1 DFC has a smaller inside dimension than the Holtec DFC, the analysis in Sections 5.4.2 and 5.4.5 of the HI-STORM TSAR is applicable and conservative. In addition, the shielding analysis does not take credit for the DFC container in determining the acceptability of storing the approved damaged fuel and fuel debris. Therefore, the use of the TN/D-1 DFC does not affect the shielding analysis and no changes to the Chapter 5 of the TSAR are necessary as a result of this proposed change.

Criticality Evaluation

The TN/D-1 DFC was analyzed with the same set of contents used for the analysis of the Holtec DFC documented in Rev. 10 of the HI-STORM 100 TSAR. This set includes 6x6 and 7x7 fuel assemblies with various numbers of rods missing, a collapsed assembly and dispersed fuel powder. The maximum k_{eff} values for both DFCs are listed in proposed Revision 11 TSAR Table 6.4.5 (Attachment 5). There is no significant difference in reactivity between the two DFCs. For only one case (collapsed assembly), the reactivity for the TN/D-1 DFC is increased marginally ($\Delta k = 0.0012$) compared to the Holtec DFC. In all other cases, the reactivity for the TN/D-1 DFC is below the reactivity of the Holtec DFC with the same contents. Therefore, with the TN/D-1 DFC used instead of the Holtec DFC, the cask system is still in compliance with the regulatory requirement of $k_{eff} < 0.95$ for all authorized contents.

HOLTEC GENERIC PWR DFC

Structural Evaluation

The proposed Holtec generic PWR DFC design (see new TSAR Figure 2.1.2B) is a square shaped tube fabricated from 0.075-inch stainless steel. An appropriate cover is included that permits lifting of the unit. The structural evaluation of the generic DFC design for PWR fuel is based on the same design criteria used for the approved Holtec DFC for Dresden/Humboldt Bay fuel. Structural analyses have been performed for the lifting condition (where NUREG-0612 stress limits are applicable) and for a handling accident leading to an end impact (ASME Code Level D limits are applicable). Positive safety margins are achieved. The results are presented in Appendix 3.AS (see Attachment 5).

Thermal Evaluation

The proposed PWR DFC design (see proposed TSAR Figure 2.1.2B in Attachment 5) is a square shaped tube fabricated from 0.075-inch stainless steel. Bounding thermal calculations have been prepared in support of this amendment to determine the most heat resistive Zircaloy and stainless steel clad fuels encased in DFCs. In this configuration, interruption of thermal radiation heat exchange between the fuel assembly and the fuel basket by the DFC renders the DFC configuration as bounding when compared with non-canistered assemblies. Storage of damaged PWR fuel assemblies in generic DFCs is evaluated in TSAR Subsection 4.4.1.1.4 (see Attachment 5). The MPC-24E is designed with four enlarged fuel storage cells to accommodate the DFC. The CoC requires damaged fuel to be stored only in these particular fuel storage locations to preserve the assumptions of the analysis. At least 20 of the 24 fuel storage locations will be occupied by intact fuel assemblies. Therefore, the overall effect of DFC storage on the basket heat dissipation rate is quite small. Conservatively, a 5% reduction MPC heat rating is specified for accommodating damaged, Zircaloy clad fuel. Stainless steel clad fuel storage is evaluated in TSAR Subsection 4.3.2 for a bounding storage configuration (within a DFC).

Shielding Evaluation

The Holtec generic PWR DFC is designed to accommodate any PWR fuel assembly that can physically fit inside the DFC. Damaged fuel assemblies under normal conditions, for the most part, resemble intact fuel assemblies from a shielding perspective. Under accident conditions, it cannot be guaranteed that the damaged fuel assembly will remain intact. As a result, the damaged fuel assembly may begin to resemble fuel debris in its possible configuration after an accident.

Since damaged fuel is identical to intact fuel from a shielding perspective, no specific analysis is required for damaged fuel under normal conditions. However, a generic shielding evaluation was performed to demonstrate that fuel debris under normal or accident conditions, or damaged fuel in a post-accident configuration, will not result in a significant increase in the dose rates around the 100-ton HI-TRAC. Only the 100-ton HI-TRAC was analyzed because it can be concluded that if the dose rate change is not significant for the 100-ton HI-TRAC, then the change will not be significant for the 125-ton HI-TRAC or the HI-STORM overpacks.

Fuel debris or a damaged fuel assembly which has collapsed can have an average fuel density that is higher than the fuel density for an intact fuel assembly. If the damaged fuel assembly were to fully or partially collapse, the fuel density in one portion of the assembly would increase and the density in the other portion of the assembly would decrease. This scenario was analyzed with MCNP-4A in a conservative, bounding fashion to determine the potential change in dose rate as a result of fuel debris or a damaged fuel assembly collapse. The analysis consisted of modeling the fuel assemblies in the four peripheral damaged fuel locations in the MPC-24E and the 16 peripheral locations in the MPC-68 (including the MPC-68FF) with a fuel density that was twice the normal fuel density and correspondingly increasing the source rate for these locations by a factor of two. A flat axial power distribution was used which is approximately representative of the source distribution if the top half of an assembly collapsed into the bottom half of the assembly. Increasing the fuel density over the entire fuel length, rather than in the top half or bottom half of the fuel assembly, is conservative and provides the dose rate change in both the top and bottom portion of the cask.

The results of this analysis indicate that the dose rates in the top and bottom portion of the 100-ton HI-TRAC increase by less than 15% while the dose rate in the center of the HI-TRAC actually decreases a little bit. The increase in the top and bottom is due to the assumed flat power distribution. These results indicate that the potential effect on the dose rate is not very significant for the storage of damaged fuel and/or fuel debris. This conclusion is further reinforced by the fact that the majority of the significantly damaged fuel assemblies in the spent fuel inventories are older assemblies from the earlier days of nuclear plant operations. Therefore, these assemblies will have a considerably lower burnup and longer cooling times than the assemblies analyzed in this amendment request. Section 5.4.2 of proposed TSAR Revision 11 (see Attachment 5) provides the discussion and a presentation of the results of the damaged fuel analysis.

Criticality Evaluation

Criticality calculations have been performed for an MPC-24E loaded with intact and damaged fuel (up to 4 damaged fuel assemblies placed in DFCs) with a maximum enrichment of 4.0 wt% ^{235}U. The calculations use a bounding approach to account for the possible wide variation of fuel distribution inside the DFC. The bounding parameters such as fuel amount per unit length and fuel distribution within a cross section of the DFC are determined through parametric studies. Additionally, typical damaged fuel conditions such as missing rods or collapsed assemblies are analyzed for selected array/classes. The analyses are presented in Section 6.4.4.2 of the Proposed Rev. 11 of the TSAR (see Attachment 5). The maximum calculated k_{eff} for the HI-TRAC is 0.9403, which demonstrates that the cask system is in compliance with the regulatory requirement of $k_{eff} < 0.95$ for all PWR fuel array/classes.

HOLTEC GENERIC BWR DFC

Structural Evaluation

The proposed Holtec generic BWR DFC design (see new TSAR Figure 2.1.2C) is a square shaped tube fabricated from 0.035-inch stainless steel. An evaluation of structural integrity under lifting and handling accident conditions has been performed, similar to that performed for the generic PWR DFC. Positive safety margins are achieved. Structural integrity results are reported in Appendix 3.AS (see Attachment 5).

Thermal Evaluation

The proposed Holtec generic BWR DFC design is a square shaped tube fabricated from 0.035-inch stainless steel. Bounding thermal calculations have been prepared in support of this amendment to determine the most heat resistive Zircaloy and stainless steel clad fuels encased in DFCs. In this configuration, interruption of thermal radiation heat exchange between the fuel assembly and the fuel basket by the DFC renders the DFC configuration as bounding when compared with non-canistered assemblies. Storage of damaged BWR fuel assemblies in generic DFCs is evaluated in TSAR Subsection 4.4.1.1.4 (see Attachment 5). The MPC-68 and MPC-68FF are analyzed assuming damaged fuel is stored in up to 16 peripheral fuel storage cells in DFCs. The CoC requires damaged fuel to be stored only in these particular fuel storage locations to preserve the assumptions of the analysis. At least 52 of the 68 fuel storage locations will be occupied by intact fuel assemblies. Therefore, the overall effect of DFC storage on the basket heat dissipation rate is quite small. Conservatively, a 5% reduction MPC heat rating is specified for accommodating damaged, Zircaloy clad fuel. Stainless steel clad fuel storage is evaluated in TSAR Subsection 4.3.2 for a bounding storage configuration (within a DFC).

Shielding Evaluation

See justification for Holtec Generic PWR DFC.

Criticality Evaluation

Criticality calculations have been performed for an MPC-68 loaded with intact and damaged fuel/fuel debris (up to 16 damaged fuel assemblies placed in DFCs) and maximum enrichments of up to 4.0 wt% ^{235}U for the damaged fuel/fuel debris and up to 3.7 wt% ^{235}U for the intact fuel. The calculations use a bounding approach to account for the possible wide variation of fuel distribution inside the DFC. The bounding parameters such as fuel amount per unit length and fuel distribution within a cross section of the DFC are determined through parametric studies. Also, typical damaged fuel conditions such as missing rods or collapsed assemblies are analyzed for selected array/classes. Additionally, arrays of fuel pellets without cladding are analyzed, which approximate possible configurations of fuel debris in the DFC. The analyses are presented in Section 6.4.4.2 of the Proposed Rev. 11 of the TSAR. The maximum calculated k_{eff} is 0.9316, which demonstrates that the cask system is in compliance with the regulatory requirement of $k_{eff} < 0.95$ for all PWR fuel array/classes.

Proposed Change No. 6

Certificate of Compliance, Appendix B, Subsection 2.1.1:

a. The wording of Item 2.1.1.a is revised to add the words "and certain non-fuel hardware" and "and other referenced tables."

b. Item 2.1.1.c is revised to add a clarification that this requirement applies only to uniform loading.

c. New Item 2.1.1.e is added; the notes in Table 2.1-1, Items II.C and II.C are revised; and the word "Zircaloy" is removed from Table 2.1-1, Items II.A.1 through 4 and III.A.1 through 6 to reflect the authorization for loading of BWR fuel assemblies in stainless steel channels.

Reason for Proposed Changes

a. This change is provided to clarify that PWR fuel may be stored with non-fuel hardware as discussed in Proposed Change Number 9, and to clarify that Table 2.1-1 incorporates other tables by reference.

b. Without this clarification, regionalized fuel loading would not be possible with damaged fuel assemblies and fuel debris due to this limitation on decay heat.

c. LaCrosse plant has stainless steel channels and is a Private Fuel Storage, LLC (PFS) member. HI-STORM 100 is one of the storage cask designs referenced in the PFS Part 72 license application.

Justification for Proposed Changes

a. Clarification to recognize that non-fuel hardware (as defined in Table 2.1-1) is authorized for loading with PWR fuel. The second change is editorial.

b. For the regionalized fuel storage configuration described in proposed TSAR subsection 4.4.1.1.9, low heat emitting fuel is arrayed away from the central region occupied by hotter fuel. The note is added so that the regionalized loading strategy is not unduly restricted by a stipulation designed for uniform loading.

c. The justification for this change is presented by technical discipline below.

Structural Evaluation

As the CoC does not permit the total weight of the fuel assembly plus the non-fuel hardware to exceed the design basis weights (BWR -700 lb., PWR –1680 lb.), there are no new structural evaluations nor changes to existing evaluations required.

Thermal Evaluation

Zircaloy and stainless steel have comparable thermal conductivities, the latter being approximately 10% greater than the former. The thermal analysis presented in Revision 10 of the TSAR and proposed Revision 11 utilize the thermal properties of Zircaloy. Even though the thermal conductivity of the stainless steel channels is greater than that of a Zircaloy channel, the aggregate impact of the thermal properties of the fuel channel on the overall basket conductivity is quite modest. As a result, small differences in the thermal properties (e.g., conductivity, emissivity, etc.) of stainless steel and Zircaloy channels produce a second order effect on the thermal performance of the storage system. Therefore, the analyses using Zircaloy channel properties are also considered to be applicable to stainless steel channels.

Shielding Evaluation

The LaCrosse nuclear plant used two types of channels for their BWR assemblies: stainless steel and Zircaloy. Since the irradiation of Zircaloy does not produce significant activation, there are no restrictions on the storage of these channels and they are not explicitly analyzed in the shielding evaluation. The stainless steel channels, however, can produce a significant amount of activation, predominantly from Co-60. LaCrosse has thirty-two stainless steel channels, a few of which have been in the reactor core for approximately the lifetime of the plant. Therefore, the activation of the stainless steel channels was conservatively calculated to demonstrate that they are acceptable for storage in the HI-STORM 100 system. For conservatism, the number of stainless steel channels in an MPC-68 or MPC-68FF is being limited to sixteen and Appendix B to the CoC requires that these channels be stored in the inner sixteen locations.

The activation of a single stainless steel channel was calculated by simulating the irradiation of the channels with ORIGEN-S using the flux calculated from the LaCrosse fuel assembly. The mass of the steel channel in the active fuel zone (83 inches) was used in the analysis. For burnups beyond 22,500 MWD/MTU, it was assumed, for the purpose of the calculation, that the burned fuel assembly was replaced with a fresh fuel assembly every 22,500 MWD/MTU. This was achieved in ORIGEN-S by resetting the flux levels and cross sections to the 0 MWD/MTU condition after every 22,500 MWD/MTU.

LaCrosse was commercially operated from November 1969 until it was shut down in April 1987. Therefore, the shortest cooling time for the assemblies and the channels is 13 years. Assuming the plant operated continually from 11/69 until 4/87 (approximately 17.5 years or 6388 days), the accumulated burnup for the channels would be 186,000 MWD/MTU (6388 days times 29.17 MW/MTU from Table 5.2.3 of Revision 10 of the HI-STORM TSAR). Therefore, the cobalt activity calculated for a single stainless steel channel irradiated for 180,000 MWD/MTU was calculated to be 667 curies of Co-60 for 13 years cooling. This is equivalent to a source of 4.94E+13 photons/sec in the energy range of 1.0-1.5 MeV.

In order to demonstrate that sixteen stainless steel channels are acceptable for storage in an MPC-68 or MPC-68FF, a comparison of source terms is performed. Table 5.2.8 of Revision 10 of the HI-STORM TSAR indicates that the source term for the LaCrosse design basis fuel assembly in the 1.0-1.5 MeV range is 6.34E+13 photons/sec for 10 years cooling, assuming a 144-inch active fuel length. This is equivalent to 4.31E+15 photons/sec/cask. At 13 years cooling, the fuel source term in that energy range decreases to 4.31E+13 photons/sec, which is equivalent to 2.93E+15 photons/sec/cask. If the source term from the stainless steel channels is scaled to 144 inches and added to the 13 year fuel source term the result is 4.30E+15 photons/sec/cask (2.93E+15 photons/sec/cask + 4.94E+13 photons/sec/channel x 144 inch/83 inch x 16 channels/cask). This number is equivalent to the 10 year 4.31E+15 photons/sec/cask source used in the shielding analysis. Therefore, it is concluded that the storage of 16 stainless steel channels in an MPC-68 is acceptable.

This discussion is provided in Section 5.2.8 of proposed TSAR Revision 11 provided in Attachment 5.

Criticality Evaluation

The criticality calculations presented in Chapter 6 of the HI-STORM TSAR for BWR fuel array/classes 10x10D and 10x10E have been performed using Zircaloy as the material for the flow channels. Stainless steel, which is used for some of the these assemblies, has a higher neutron absorption than Zircaloy, which would lead to a slight reduction in reactivity. The calculations using Zircaloy are therefore bounding for assemblies with stainless steel channels and no further calculations are required.

Proposed Change No. 7

Certificate of Compliance, Appendix B, Sections 2.1.2 and 2.1.3:

a. Subsection 2.1.2 is revised to state that preferential loading is applicable during uniform loading (which is also defined) and to state that regionalized loading meets the intent of preferential loading.

b. New Subsection 2.1.3 and Figures 2.1-1 through 2.1-4 are added to introduce regionalized fuel loading as an option. Specific cooling time, burnup, and decay heat limits for regionalized fuel loading are specified in Tables 2.1-6 and 2.1-7 in the Approved Contents section of Appendix B to the CoC.

Reason for Proposed Change

a. Clarification to distinguish between uniform fuel loading and regionalized fuel loading and to clarify that regionalized loading meets the intent of preferential fuel loading.

b. Regionalized fuel loading, in accordance with Figures 2.1-1 through 2.1-4 and Tables 2.1-6 and 2.1-7, as applicable, allows users to load relatively higher heat emitting fuel assemblies than would otherwise be allowed using uniform fuel loading.

Justification for Proposed Change

a. Clarification

b. This change is proposed to allow users a method to store fuel assemblies with higher heat emission rates with those having lower heat emission rates, while remaining within the total heat dissipation capabilities of the storage cask design. The specific technical justification is arranged by affected technical discipline below.

Thermal Evaluation

In the regionalized fuel loading scenario, a two-region fuel configuration is analyzed. The two regions are defined as an inner region (Region 1) for storing relatively hot fuel, and an outer region (Region 2) physically enveloping the inner region and storing relatively cooler fuel. These regions are specifically defined by fuel storage cell number in Appendix B to the CoC. To permit hot fuel storage in the inner region, a low decay heat rate is specified for fuel in the outer region. The maximum allowable heat load for the inner region fuel is then a function of fuel age-dependent permissible cladding temperatures. The regionalized fuel loading thermal modeling is discussed in detail in proposed TSAR Subsection 4.4.1.1.9 and the results of the analysis are provided in proposed TSAR Subsection 4.4.2 (see Attachment 5).

Shielding Evaluation

Regionalized loading in the HI-STORM cask system is used to place fuel with higher heat emission rates (higher burnups and shorter cooling times) in the center of an MPC surrounded by fuel with lower heat emission rates (lower burnup and longer cooling time). From a shielding perspective, the older fuel on the outside of the MPC is serving as shielding for the fuel on the center of the MPC for the dose rates on the side of the casks. The dose rates on the ends of the casks, however, increase as a result of putting hotter fuel on the inside of the MPC. However, this is a localized effect. Proposed revised TSAR Section 5.4 in Attachment 5 presents the dose rates around the 100-ton HI-TRAC for a single regionalized loading burnup and cooling time combination in the MPC-24, MPC-32, and MPC-68. Comparing these dose rate to the design basis uniform loading dose rates also provided in TSAR Section 5.1 and 5.4, it is evident that the uniform loading patterns bound the regionalized loading patterns for the radial dose rates. The axial dose rates from the regionalized loading patterns may be higher than the axial dose rates from the uniform loading patterns. However, because of the location of these higher dose rates (the ends of the cask), the occupational exposure during loading and transfer operations is not significantly affected by a regionalized loading pattern. In fact, the occupational exposure may, in practice, be less as a result of a regionalized loading pattern that reduces the radial dose rates. Therefore, this is an acceptable loading pattern to be used in the HI-STORM 100 System.

Confinement Evaluation

Regionalized loading allows higher heat emitting fuel (higher burnup fuel at shorter decay times) to be loaded into the HI-STORM cask. From a confinement perspective the newer, high burnup fuel in the center of the cask has an increased radionuclide inventory due to increased fission products. The radionuclide inventories for each of the MPC designs that allow regionalized loading was revised to ensure that bounding source terms are maintained. The resultant doses are presented in Table 7.3.2 through Table 7.3.4 in proposed Revision 11 of the TSAR (see Attachment 5). Additionally, Table 7.3.8 of proposed Revision 11 of the TSAR presents bounding doses for casks containing PWR and BWR fuel and compares them directly to the limits of 10CFR72.

Proposed Change No. 8

Certificate of Compliance, Appendix B, Table 2.1-1 (throughout):

a. Cooling time, burnup, and decay heat limits are presented by array/class designation instead of by cladding material.

b. The wording in the right side of the table for cooling time, burnup, and decay heat is made consistent.

c. Fuel assembly weights are clarified to include non-fuel hardware (PWR), channels (BWR), and damaged fuel canisters, as applicable.

Reason and Justification for Proposed Change

a. With the addition of more fuel types and unique limits for certain Zircaloy clad fuel assemblies, the presentation format became too complex for users to follow. This change simplifies the presentation.

b. Editorial clarification.

c. The MPC has been analyzed with a maximum bounding weight assumed and divided among the total number of fuel storage cells. The user must ensure that all components loaded into a storage location, in total, do not exceed that limit. There is no need to distinguish among the components.

Proposed Change No. 9

Certificate of Compliance, Appendix B, Table 2.1-1, and new Table 2.1-8:

MPC-24, Items I.A and C, are revised; new Note 1 is added to Item I, and new Table 2.1-8 is added as shown in the attached marked-up CoC pages to allow storage of non-fuel hardware, including Burnable Poison Rod Assemblies (BPRAs)*, Thimble Plug Devices (TPDs)*, Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs) and similarly designed devices with different names. Non-fuel hardware is also proposed to be authorized for loading into MPC-24E and MPC-32 and the same limits are specified for those MPC models later in Table 2.1-1.

Reason for Proposed Change

A large number of PWR plant fuel assemblies are currently stored in spent fuel pools with either BPRAs or TPDs as integral hardware to the assemblies. A smaller number of PWR assemblies are stored with CRAs or APSRs. This irradiated hardware must be authorized for dry storage with the assemblies to accommodate user needs (particularly for plants who wish to decommission their spent fuel pools) and is therefore proposed to be added to the authorized contents.

Justification for Proposed Change

Structural Evaluation

There is no effect on the structural evaluation because these changes do not change the fuel assembly geometry or weight used in the structural analyses. The limits on these parameters as stated elsewhere in the CoC fuel tables remain the same and fuel assemblies containing these components must meet these limits.

Thermal Evaluation

The non-fuel bearing hardware (i.e. BPRAs TPDs, CRAs, and APSRs) becomes activated as a result of in-core irradiation. In the dry cask storage scenario, this hardware represents a Low Heat Emitting (LHE) source distributed over the length of the fuel assembly. The non-fuel hardware contribution to the total decay heat load burden of a cask is quite small.

The BPRAs, CRAs, and APSRs, when inserted in the fuel assemblies, displace the gas in the guide tubes and replace them with solid materials (neutron absorbers and metals) which conduct heat much more readily. As a result, dissipation of heat by the fuel assemblies is enhanced by the presence of these components. In the thermal evaluation supporting this amendment request, no credit was taken for this enhanced decay heat dissipation. Thus, the design basis heat load of the HI-STORM cask is conservatively unaltered by this proposed change. To conservatively compute a lower bound value for the permissible burnup and cooling time limits for storage in the HI-STORM cask, the limiting fuel type for the class of PWR fuel (i.e., the one with the highest uranium mass) is utilized. In the CoC, a requirement is specified to comply with these burnup and cooling time limits. In addition, each assembly proposed for storage must be confirmed to have a total heat emission rate less than the design maximum, including the fuel and any non-fuel hardware, as applicable.

The addition of this non-fuel hardware has two effects on the MPC cavity pressures. As discussed in the last paragraph, non-fuel hardware enhances heat dissipation, thus lowering fuel and MPC cavity fill gas temperatures. The gas volume displaced by the mass of the non-fuel hardware lowers the cavity free volume. These two effects, namely, temperature lowering and free volume reduction, have opposing influences on the MPC cavity pressure. The first effect lowers the gas pressure while the second effect raises it. In the HI-STORM thermal analysis, the computed temperature field (with non-fuel hardware *excluded*) provides a conservatively bounding thermal response of the HI-STORM cask. The MPC cavity free space was computed based on displacement by the heaviest fuel (bounding weight) with non-fuel hardware *included*. Thus, the previously computed MPC cavity pressure results remain conservative with respect to gas temperature and free space as affected by the changes proposed in this amendment.

PWR fuel assemblies with BPRAs containing helium gas have been evaluated under the hypothetical accident condition where 100% of the BPRAs rupture, releasing all of the contained helium into the MPC cavity. The maximum helium backfill pressure TS limit for the PWR MPCs is adjusted appropriately so that the resultant post-accident MPC cavity pressure, including BPRA gas release, is limited to an acceptable value, within the design pressure of the MPC. Appropriate discussion has been added to proposed Revision 11 TSAR Chapters 4 and 11 (see Attachment 5).

Shielding Evaluation –BPRAs and TPDs

Burnable Poison Rod Assemblies (including Wet Annular Burnable Absorbers and other similarly designed devices with different names) and Thimble Plug Devices (including orifice rod assemblies, guide tube plugs, and other similarly designed devices with different names) are an integral, yet removable, part of a large portion of PWR fuel. The TPDs are not used in all assemblies in a reactor core, but are re-used from cycle to cycle. Therefore, these devices can achieve very high burnups. In contrast, BPRAs are burned with a fuel assembly in core and are not reused. In fact, many BPRAs are removed after one or two cycles before the fuel assembly is discharged. Therefore, the achieved burnup for BPRAs is not significantly different than fuel assemblies.

TPDs are made of stainless steel and contain a small amount of Inconel. These devices extend down into the plenum region of the fuel assembly but do not extend into the active fuel region with the exception of the Westinghouse 14x14 water displacement guide tube plugs. Since these devices are made of stainless steel, there is a significant amount of Co-60 produced during irradiation. This is the only significant radiation source from the activation of steel and Inconel.

BPRAs are made of stainless steel in the region above the active fuel zone and may contain a small amount of Inconel in this region. Within the active fuel zone, the BPRAs may contain two to 24 rodlets which are burnable absorbers clad in either Zircaloy or stainless steel. The stainless steel clad BPRAs create a significant radiation source (Co-60) while the Zircaloy clad BPRAs create a negligible radiation source. Therefore the stainless steel clad BPRAs are bounding.

SAS2H and ORIGEN-S were used to calculate a radiation source term for the TPDs and BPRAs. These calculations were performed by irradiating the appropriate mass of steel and Inconel using the flux calculated for the design basis B&W 15x15 fuel assembly. The mass of material in the regions above the active fuel zone was scaled by the appropriate scaling factors listed in Table 5.2.10 of the HI-STORM TSAR, Rev. 10 in order to account for the reduced flux levels above the fuel assembly. The total curies of cobalt and the decay heat load were calculated for the TPDs and BPRAs as a function of burnup and cooling time. For burnups beyond 45,000 MWD/MTU, it was assumed, for the purpose of the calculation, that the burned fuel assembly was replaced with a fresh fuel assembly every 45,000 MWD/MTU. This was achieved in ORIGEN-S by resetting the flux levels and cross sections to the 0 MWD/MTU condition after every 45,000 MWD/MTU.

Since the HI-STORM 100 cask system is designed to store many varieties of PWR fuel, a bounding TPD and BPRA had to be determined for the purposes of the analysis. This was accomplished by analyzing all of the fuel containing BPRAs and TPDs (Westinghouse and B&W 14x14 through 17x17) found in TSAR references [5.2.5] and [5.2.7] listed in Section 5.6 of the TSAR to determine the TPD and BPRA which produced the highest Co-60 source term and decay heat for a specific burnup and cooling time. The bounding TPD was determined to be the Westinghouse 17x17 guide tube plug and the bounding BPRA was actually determined by combining the higher masses of the Westinghouse 17x17 and 15x15 BPRAs into a single hypothetical BPRA. The masses of this TPD and BPRA are listed in Table 5.2.30 of the proposed Revision 11 of the HI-STORM TSAR (see Attachment 5). As mentioned above, TSAR reference [5.2.5] describes the Westinghouse 14x14 water displacement guide tube plug as having a steel portion that extends into the active fuel zone. This particular water displacement guide tube plug was analyzed and determined to be bounded by the design basis TPD and BPRA.

Once the bounding BPRA and TPD were determined, the Co-60 source from the BPRA and TPD were specified: 50 Curies for each TPD, and 831 Curies for each BPRA. Table 5.2.31 of the proposed Revision 11 of the HI-STORM TSAR shows the Curies of Co-60 that were calculated for BPRAs and TPDs in each region of the fuel assembly (e.g., incore, plenum, top). An allowable burnup and cooling time, separate from the fuel assemblies, is used for the BPRAs and TPDs themselves. These burnup and cooling times assure that the Co-60 activity remains below the allowable levels specified above. It should be noted that at very high burnups (greater than 200,000 MWD/MTU) the Co-60 source for a given cooling time actually decreases as the burnup continues to increase. This is due to a decrease in the Co-60 production rate as the initial Co-59 impurity is depleted. Conservatively, a constant cooling time has been specified for burnups from 180,000 to 630,000 MWD/MTU for the TPDs.

Shielding Evaluation – CRAs and APSRs

Control Rod Assemblies (CRAs) and Axial Power Shaping Rods (APSRs) are an integral portion of many PWR fuel assemblies going into dry storage. These devices are utilized for many years (upwards of 20 years) prior to discharge into the spent fuel pool. The manner in which the CRAs are utilized varies from plant to plant. Some utilities maintain the CRAs fully withdrawn during normal operation while others may operate with a bank of rods partially inserted (approximately 10%) during normal operation. Even when fully withdrawn, the ends of the CRAs are present in the upper portion of the fuel assembly since they are never fully removed from the fuel assembly during operation. The result of the different operating styles is a variation in the source term for the CRAs. In all cases, however, only the lower portion of the CRAs will be significantly activated. Therefore, when the CRAs are stored with the PWR fuel assembly, the activated portion of the CRAs will be in the lower portion of the cask. CRAs are fabricated of various materials. The cladding is typically stainless steel, although Inconel has been used. The absorber can be a single material or a combination of materials. Silver-Indium-Cadmium (Ag-In-Cd) is possibly the most common absorber, although B_4C in aluminum is used, and hafnium has also been used. Ag-In-Cd produces a noticeable source term in the 0.3-1.0 MeV range due to the activation of Ag. The source term from the other absorbers is negligible, therefore the Ag-In-Cd CRAs are the bounding CRAs.

APSRs are used to flatten the axial power distribution during normal operation and, as a result, these devices achieve a considerably higher activation than CRAs. There are two types of B&W stainless steel clad APSRs: gray and black. According to TSAR reference [5.2.5], the black APSRs have 36 inches of Ag-In-Cd as the absorber while the gray ones use 63 inches of Inconel as the absorber. Because of the Cobalt-60 source from the activation of Inconel, the gray APSRs produce a higher source term than the black APSRs and therefore are the bounding APSR.

Since the level of activation of CRAs and APSRs can vary, the quantity that can be stored in an MPC is being limited to four CRAs and/or APSRs. These four devices are required to be stored in the inner four locations in the MPC-24, MPC-24E, and MPC-32 as specified in Appendix B to the CoC.

In order to determine the impact on the dose rates around the HI-STORM 100 System, source terms for the CRAs and APSRs were calculated using SAS2H and ORIGEN-S. In the ORIGEN-S calculations the cobalt-59 impurity level was conservatively assumed to be 0.8 gm/kg for stainless steel and 4.7 gm/kg for Inconel. These calculations were performed by irradiating 1 kg of steel, Inconel, and Ag-In-Cd using the flux calculated for the design basis B&W 15x15 fuel assembly. The total curies of cobalt for the steel and Inconel and the 0.3-1.0 MeV source for the Ag-In-Cd were calculated as a function of burnup and cooling time to a maximum burnup of 630,000 MWD/MTU. For burnups beyond 45,000 MWD/MTU it was assumed, for the purpose of the calculation, that the burned fuel assembly was replaced with a fresh fuel assembly every 45,000 MWD/MTU. This was achieved in ORIGEN-S by resetting the flux levels and cross sections to the 0 MWD/MTU condition after every 45,000 MWD/MTU.

The sources were then scaled by the appropriate mass using the flux weighting factors for the different regions of the assembly to determine the final source term. Two different configurations were analyzed for both the CRAs and APSRs with an additional third configuration analyzed for the APSRs. The configurations, which are summarized below, are described in Tables 5.2.32, of the proposed Revision 11 of the TSAR, for the CRAs and Table 5.2.33, of the proposed Revision 11 of the TSAR, for the APSR. The masses of the materials listed in these tables were determined from a review of TSAR reference [5.2.5] with bounding values chosen. The masses listed in Tables 5.2.32 and 5.2.33 do not match exact values from TSAR reference [5.2.5] because the values in the reference were adjusted to the lengths shown in the tables.

Configuration 1: CRA and APSR

This configuration had the lower 15 inches of the CRA and APSR activated at full flux with two regions above the 15 inches activated at a reduced power level. This simulates a CRA or APSR which was operated at 10% insertion. The regions above the 15 inches reflect the upper portion of the fuel assembly.

Configuration 2: CRA and APSR

This configuration represents a fully removed CRA or APSR during normal core operations. The activated portion corresponds to the upper portion of a fuel assembly above the active fuel length with the appropriate flux weighting factors used.

Configuration 3: APSR

This configuration represents a fully inserted gray APSR during normal core operations. The region in full flux was assumed to be the 63 inches of the absorber.

Tables 5.2.34 and 5.2.35 of proposed Revision 11 of the TSAR present the source terms that were calculated for the CRAs and APSRs, respectively. The only significant source from the activation of Inconel or steel is Co-60 and the only significant source from the activation of Ag-In-Cd is in the range of 0.3-1.0 MeV. The source terms for CRAs, Table 5.2.34, were calculated for a maximum burnup of 630,000 MWD/MTU and a minimum cooling time of 5 years. Because of the significant source term in APSRs that have seen extensive in-core operations, the source term in Table 5.2.35 was calculated to be a bounding source term for a variable burnup and cooling time as outlined in Appendix B to the CoC. The very large Cobalt-60 activity in Configuration 3 in Table 5.2.35 is due to the assumed Cobalt-59 impurity level of 4.7 gm/kg. If this impurity level was similar to the assumed value for steel, 0.8 gm/kg, this source would decrease by approximately a factor of 5.8.

Summary

Section 5.4.6 of proposed Revision 11 of the HI-STORM TSAR provides the dose rate increase due to the inclusion of BPRAs, TPDs, CRAs, and APSRs. The data in this section indicate that BPRAs result in the highest dose rate increase on the radial surfaces of the cask while the APSRs result in the largest dose rate increase in the bottom of the cask. The increase in the dose rates at the bottom of the cask will not significantly affect occupational exposure. Therefore, the additional dose rate from the BPRAs was included in the design basis analysis presented in Section 5.1 and in the dose rates calculated in Section 5.4 of the proposed Revision 11 of the HI-STORM TSAR found in Attachment 5. The occupational exposure estimates provided in Chapter 10 of the TSAR were also revised to include the dose rate contribution from BPRAs. These new values can be found in proposed Revision 11 of Chapter 10 in Attachment 5. The controlled area boundary dose rate analysis provided in Chapter 5 of Revision 10 of the TSAR was not revised to include the effect of BPRAs because this analysis had been performed with a bounding burnup and cooling time of 45 GWD/MTU and 5 year cooling which results in dose rates that bound the dose rates from allowed burnup and cooling times, including BPRAs.

In conclusion, the shielding analysis has been revised to include the additional dose rate from non-fuel hardware. While the dose rates around the HI-TRAC have increased as a result of including this non-fuel hardware, the safety of the system has not been compromised.

Criticality Evaluation

Inserts into PWR fuel assemblies such as BPRAs, TPDs, CRAs, and APSRs have no effect on the criticality analyses. The reactivity of any PWR assembly with inserts is bounded by (i.e. lower than) the reactivity of the same assembly without the insert. This is due to the fact that the insert reduces the amount of moderator in the assembly, while the amount of fissile material remains unchanged. Therefore, from a criticality safety perspective, inserts into PWR assemblies are acceptable for all allowable PWR types, and increase the safety margin.

Proposed Change No. 10

Certificate of Compliance, Appendix B, Table 2.1-1:

Item II.A.2 is revised to authorize a broader range of BWR damaged fuel, beyond the currently authorized Dresden Unit 1 and Humboldt Bay damaged fuel. The additional damaged fuel must be loaded into the new generic BWR DFC for loading into the MPC-68. Further, the damaged fuel is only authorized for loading into the 16 peripheral fuel storage locations, called out numerically in revised Item II.B.3. Damaged fuel assemblies meeting the same specifications are also proposed to be authorized for loading into the MPC-68FF as discussed later in this section.

Reason for Proposed Change

Most users have at least some fuel assemblies destined for dry storage that would be classified as damaged fuel assemblies in accordance with the CoC. The current CoC only authorizes damaged fuel from Dresden Unit 1 and Humboldt Bay for storage. The CoC needs to be expanded to accommodate customer needs.

Justification for Proposed Change

Structural Evaluation

The only structural requirements on the contents of a BWR or PWR fuel basket are that the total weight per cell does not exceed the design basis weight (700 lbs for BWR assemblies and 1,680 lbs for PWR assemblies), and that loading of these assemblies does not alter the temperature limits used in the design basis analyses. The damaged fuel assemblies covered by this change, together with the appropriate DFC, satisfy these restrictions, so that no additional structural evaluation is necessary.

Thermal Evaluation

The thermal performance characteristics of the most heat resistive Zircaloy and stainless steel clad BWR fuel assemblies, encased in the proposed DFC design, have been evaluated in support of this amendment. The interruption of thermal radiation heat exchange between the fuel assembly and the fuel basket by the DFC renders the DFC configuration more restrictive than the non-DFC configuration. The thermal performance characteristics of MPC-68s loaded entirely with fuel assemblies in BWR DFCs were evaluated, using the same methods employed to evaluate the previously approved MPC-68 with Dresden Unit 1 and Humboldt Bay damaged fuel, and appropriate decay heat loads determined. It is noted that this amendment only requests loading of 16 BWR DFCs, so the thermal evaluations of MPCs completely loaded with fuel in DFCs is highly conservative.

Shielding Evaluation

See the shielding evaluation for Proposed Change Number 5.

Criticality Evaluation

Criticality calculations have been performed for an MPC-68 loaded with intact and damaged fuel/fuel debris (up to 16 damaged fuel assemblies placed in DFCs) and maximum enrichments of up to 4.0 wt% ^{235}U for the damaged fuel/fuel debris and up to 3.7 wt% ^{235}U for the intact fuel. The calculations use a bounding approach to account for the possible wide variation of fuel distribution inside the DFC. The bounding parameters such as fuel amount per unit length and fuel distribution within a cross section of the DFC are determined through parametric studies. Also, typical damaged fuel conditions such as missing rods or collapsed assemblies are analyzed for selected array/classes. Additionally, arrays of fuel pellets without cladding are analyzed, which approximate possible configurations of fuel debris in the DFC. The analyses are presented in Section 6.4.4.2 of proposed Revision 11 of the TSAR (see Attachment 5). The maximum calculated k_{eff} is 0.9316, which demonstrates that the cask system is in compliance with the regulatory requirement of $k_{eff} < 0.95$ for all PWR fuel array/classes.

Proposed Change No. 11*

Certificate of Compliance, Appendix B, Table 2.1-1:

New Items II.A.5 and III.A.7 are added to Table 2.1-1 for MPC-68 and MPC–68F as shown in the attached marked-up pages of the CoC table to allow storage of one Dresden Unit 1 (D-1) Thoria Rod Canister in these MPC models. Drawings of the D-1 Thoria Rod Canister were provided in LAR 1008-1 submitted to the NRC in November, 1999 for the HI-STAR 100 System (Docket 72-1008). Figure 2.1.2A is added to the TSAR showing key dimensions and major fabrication details for the Thoria Rod Canister (see Attachment 5). Conforming revisions are also made to Appendix B, Items II.B and III.B.

Reason for Proposed Change

Dresden Unit 1 needs to place one Thoria Rod Canister into dry storage to support plant decommissioning.

Justification for Proposed Change

Structural Evaluation

The Dresden Unit 1 Thoria Rod Canister has been structurally evaluated by Holtec International and found to meet all required design requirements for storage in the HI-STORM 100 system. The details of this evaluation are contained in proposed Revision 11 TSAR Appendix 3.AR, included in Attachment 5 to this letter. All required safety margins are greater than zero or, in other words, the factors of safety are greater than 1.0.

Thermal Evaluation

The Thoria Rod Canister is designed to hold a maximum of 20 fuel rods arrayed in a 5x4 configuration. Eighteen rods are actually in the canister. The fuel rods contain a mixture of enriched UO_2 and thorium oxide in the fuel pellets. The fuel rods were originally constituted as part of an 8x8 fuel assembly and used in the second and third cycle of Dresden-1 operation. The maximum fuel burnup of these rods is quite low (< 16,000 MWD/MTIHM). The Thoria Rod Canister internal design is a honeycomb structure formed from 12 gage stainless steel plates. The rods are loaded in individual square cells and thus are isolated from each other by the cell walls. The few number of rods (18 per assembly) and very low burnup of fuel stored in these Dresden-1 canisters render them as miniscule sources of decay heat. The canister all-metal internal honeycomb construction serves as an additional means of heat dissipation in the fuel cell space. In accordance with preferential fuel loading requirements imposed in the Approved Contents section of Appendix B to the CoC, low burnup fuel is required to be loaded toward the basket periphery (i.e., away from the hot central core of the fuel basket). All these considerations provide ample assurance that these fuel rods will be stored in a benign thermal environment and therefore remain protected during long-term storage.

Shielding Evaluation

The Dresden Unit 1 Thoria Rod Canister contains 18 thoria rods that have obtained a relatively low burnup, 16,000 MWD/MTIHM. These rods were removed from two 8x8 fuel assemblies that contained 9 rods each. The irradiation of thorium produces an isotope that is not commonly found in depleted uranium fuel. Th-232, when irradiated, produces U-233. The U-233 can undergo an (n,2n) reaction that produces U-232. The U-232 decays to produce Tl-208 that produces a 2.6 MeV gamma during beta decay. This results in a significant source in the 2.5-3.0 MeV range that is not commonly present in depleted uranium fuel. Therefore, this single DFC container was analyzed to determine if it was bounded by the current shielding analysis.

A radiation source term was calculated for the 18 thoria rods using SAS2H and ORIGEN-S for a burnup of 16,000 MWD/MTIHM and a cooling time of 18 years. Table 5.2.36 of proposed Revision 11 of the HI-STORM TSAR (Attachment 5) describes the 8x8 fuel assembly that contains the thoria rods. Table 5.2.37 and 5.2.38 of proposed Revision 11 of the HI-STORM TSAR shows the gamma and neutron source terms, respectively, that were calculated for the 18 thoria rods in the Thoria Rod Canister. Comparing these source terms to the design basis 6x6 source terms for Dresden Unit 1 fuel in TSAR Tables 5.2.7 and 5.2.18 clearly indicates that the design basis source terms bound the thoria rod source terms in all neutron groups and in all gamma groups except the 2.5-3.0 MeV group. As mentioned above, the thoria rods have a significant source in this energy range due to the decay of Tl-208.

It is obvious that the neutron spectrum from the 6x6 fuel assembly bounds the thoria rod neutron spectra with a significant margin. In order to demonstrate that the gamma spectrum from the single Thoria Rod Canister is bounded by the gamma spectrum from the design basis 6x6 fuel assembly, the gamma dose rate on the outer radial surface of the 100-ton HI-TRAC transfer cask and the HI-STORM overpack was estimated conservatively assuming an MPC-68 filled with Thoria Rod Canisters. This gamma dose rate was compared to an estimate of the dose rate from an MPC full of design basis 6x6 fuel assemblies. The gamma dose rate from the 6x6 fuel was higher for the 100-ton HI-TRAC and only 17% lower for the HI-STORM overpack than the dose rate from an MPC full of Thoria Rod Canisters. This, in conjunction with the significant margin in neutron spectrum and the fact that only one thoria rod canister is proposed to be authorized for storage in the HI-STORM 100 System clearly demonstrates that the Thoria Rod Canister is acceptable for storage in the MPC-68 or the MPC-68F.

Criticality Evaluation

The Thoria Rod Canister is similar to a DFC with an internal separator assembly containing 18 fuel rods. The configuration is illustrated in proposed Revision 11 TSAR Figure 6.4.19 (see Attachment 5). The k_{eff} value for an MPC-68/68F filled with Thoria Rod Canisters is calculated to be 0.18. This low reactivity is attributed to the relatively low content in ^{235}U (equivalent to UO_2 fuel with an enrichment of approximately 1.7 wt% ^{235}U), the large spacing between the rods (the pitch is approximately 1", the cladding outside diameter is 0.412"), and the absorption in the separator assembly. Together with the maximum k_{eff} values listed in TSAR Tables 6.1.7 and 6.1.8 this result demonstrates that the k_{eff} for a Thoria Rod Canister loaded into the MPC-68 or the MPC-68F together with other approved fuel assemblies or DFCs will remain well below the regulatory requirement of $k_{eff} < 0.95$.

Confinement Evaluation

The HI-STORM confinement analyses have been revised to account for several new isotopes associated with the Thoria Rod Canister. These isotopes (Bi-212, Pb-212, Po-216, Ra-224, Rn-220, Th-228 and U-232) had a negligible effect on the resulting doses because only one Thoria Rod Canister is authorized for loading in an MPC-68 or –68F with 67 other design basis BWR assemblies. Therefore, the Thoria Rod isotopes are not included in the presentation of the confinement analysis inputs or results in the TSAR.

Proposed Change No. 12*

Certificate of Compliance, Appendix B, Table 2.1-1

New Items II.D and III.D are added as shown in the attached marked-up CoC pages to authorize Dresden Unit 1 fuel assemblies containing up to one antimony-beryllium neutron source in the assembly lattice for storage.

Reason for Proposed Change

Dresden Unit 1 needs to place fuel assemblies containing antimony-beryllium neutron sources into dry storage to support plant decommissioning.

Justification for Proposed Change

Structural Evaluation

The structural evaluation is not affected because the fuel assembly parameters used in the design basis structural evaluations are not affected by this change. The neutron sources have no impact on component temperatures or fuel assembly size and weight.

Thermal Evaluation

The substitution of antimony-beryllium sources in a fuel assembly in lieu of heat emitting fuel rods is bounded by the existing thermal analyses, which assume decay heat production from the replaced fuel rods.

Shielding Evaluation

Dresden Unit 1 has antimony-beryllium neutron sources that are placed in the water rod location of their fuel assemblies. These sources are steel rods that contain a cylindrical antimony-beryllium source that is 77.25 inches in length. The steel rod is approximately 95 inches in length. Information obtained from Dresden Unit 1 characterizes these sources in the following manner: "About one-quarter pound of beryllium will be employed as a special neutron source material. The beryllium produces neutrons upon gamma irradiation. The gamma rays for the source at initial start-up will be provided by neutron-activated antimony (about 865 curies). The source strength is approximately 1E+8 neutrons/second."

As stated above, beryllium produces neutrons through gamma irradiation and, in this particular case, antimony is used as the gamma source. The threshold gamma energy for producing neutrons from beryllium is 1.666 MeV. The outgoing neutron energy increases as the incident gamma energy increases. Sb-124, that decays by beta decay with a half-life of 60.2 days, produces a gamma of energy 1.69 MeV that is just energetic enough to produce a neutron from beryllium. Approximately 54% of the beta decays for Sb-124 produce gammas with energies greater than or equal to 1.69 MeV. Therefore, the neutron production rate in the neutron source can be specified as 5.8E-6 neutrons per gamma (1E+8/865/3.7e+10/0.54) with energy greater than 1.666 MeV or 1.16E+5 neutrons/curie (1E+8/865) of Sb-124.

With the short half life of 60.2 days, all of the initial Sb-124 is decayed and any Sb-124 that was produced while the neutron source was in the reactor is also decayed since these neutron sources are required to have the same minimum cooling time as the Dresden 1 fuel assemblies (array classes 6x6A, 6x6B, 6x6C, and 8x8A) of 18 years. Therefore, there are only two possible gamma sources that can produce neutrons from this antimony-beryllium source. The first is the gammas from the decay of fission products in the fuel assemblies in the MPC. The second gamma source is from Sb-124 that is produced in the MPC from neutron activation by neutrons from the decay of fission products.

MCNP calculations were performed to determine the gamma source as a result of decay gammas from fuel assemblies and Sb-124 activation. The calculations explicitly modeled the 6x6 fuel assembly described in Table 5.2.2 of Revision 10 of the HI-STORM TSAR. A single fuel rod was removed and replaced by a guide tube. In order to determine the amount of Sb-124 that is activated from neutrons in the MPC it was necessary to estimate the amount of antimony in the neutron source. The O.D. of the source was assumed to be the I.D. of the steel rod encasing the source (0.345 in.). The length of the source is 77.25 inches. The beryllium is assumed to be annular in shape encompassing the antimony. Using the assumed O.D. of the beryllium and the mass and length, the I.D. of the beryllium was calculated to be 0.24 inches. The antimony is assumed to be a solid cylinder with an O.D. equal to the I.D. of the beryllium. These assumptions are conservative since the antimony and beryllium are likely encased in another material that would reduce the mass of antimony. A larger mass of antimony is conservative since the calculated activity of Sb-124 is directly proportional to the initial mass of antimony.

The number of gammas from fuel assemblies with energies greater than 1.666 MeV entering the 77.25 inch long neutron source was calculated to be 1.04E+8 gammas/sec that would produce a neutron source of 603.2 neutrons/sec (1.04E+8 * 5.8E-6). The steady state amount of Sb-124 activated in the antimony was calculated to be 39.9 curies. This activity level would produce a neutron source of 4.63E+6 neutrons/sec (39.9 * 1.16E+5) or 6.0E+4 neutrons/sec/inch (4.63E+6/77.25). These calculations conservatively neglect the reduction in antimony and beryllium that would have occurred while the neutron sources were in the core and being irradiated at full reactor power.

Since this is a localized source (77.25 inches in length) it is appropriate to compare the neutron source per inch from the design basis Dresden Unit 1 fuel assembly, 6x6, containing an Sb-Be neutron source to the design basis fuel neutron source per inch. This comparison, presented in Table 12.1 below, demonstrates that a Dresden Unit 1 fuel assembly containing an Sb-Be neutron source is bounded by the design basis fuel.

As stated above, the Sb-Be source is encased in a steel rod. Therefore, the gamma source from the activation of the steel was considered assuming a burnup of 120,000 MWD/MTU which is the minimum burnup assuming the Sb-Be source was in the reactor for the entire 18-year life of Dresden Unit 1. The cooling time was assumed to be 18 years that is the minimum cooling time for Dresden Unit 1 fuel. The source from the steel is bounded by the design basis fuel assembly. In conclusion, storage of a Dresden Unit 1 Sb-Be neutron source in a Dresden Unit 1 fuel assembly is acceptable and bounded by the current analysis.

Table 12.1
Comparison of Neutron Source per Inch per Second for Design Basis 7x7 Fuel and Design Basis Dresden Unit 1 Fuel

Assembly	Active fuel length (inches)	Neutrons per sec per inch	Neutrons per sec per inch with Sb-Be source	Reference for neutrons per sec per inch
7x7 design basis	144	5.94E+5	N/A	Table 5.2.17 Rev. 11 HI-STORM TSAR 35.5 GWD/MTU and 5 year cooling
6x6 design basis	110	2.0E+5	2.6E+5	Table 5.2.18 Rev. 10 HI-STORM TSAR
6x6 design basis MOX	110	3.06E+5	3.66E+5	Table 5.2.23 Rev. 10 HI-STORM TSAR

Criticality Evaluation

The reactivity of a fuel assembly is not affected by the presence of a neutron source (other than by the presence of the material of the source, which is discussed later). This is true because in a system with a k_{eff} less than 1.0, any given neutron population at any time, regardless of its origin or size, will decrease over time. Therefore, a neutron source of any strength will not increase reactivity, but only the neutron flux in a system, and no additional criticality analyses are required. Sources are inserted as rods into fuel assemblies, i.e., they replace either a fuel rod or water rod (moderator). Therefore, the insertion of the material of the source into a fuel assembly will also not lead to an increase of reactivity.

Proposed Change No. 13

Certificate of Compliance, Appendix B, Table 2.1-1

Items III.A.1.f, g, and h are revised as shown in the attached CoC markups to correct these dimensional limits to match the dimensions for Zircaloy fuel assembly array/classes 6x6A, 6x6C, 7x7A, and 8x8A (Dresden Unit 1 and

Humboldt Bay). Only these array/classes (and 6x6B MOX fuel) are authorized for loading into the MPC-68F. This is simply an editorial change because fuel assemblies exceeding the correct dimensional limits would not be able to be inadvertently loaded as they would not fall into the above-mentioned array/classes.

Reason and Justification for Proposed Change

Editorial correction.

Proposed Change No. 14

Certificate of Compliance, Appendix B, Table 2.1-1

New Item IV is added to the table for MPC-24E. See also, proposed Change Number 22.

Reason for Proposed Change

The MPC-24E provides for storage of higher enriched fuel than the MPC-24 through the optimization of the storage cell layout. In addition, storage of damaged PWR fuel assemblies in generic PWR DFC is authorized. This change is required to meet customers' needs for storage of higher enriched fuel and damaged fuel. The MPC-24E has been analyzed for storage of two ranges of enrichment for PWR fuel. The lower of the two ranges has been analyzed with unborated water in the MPC during wet loading and unloading operations and the higher range has been analyzed with credit taken for soluble boron in the MPC water (see associated changes to Table 2.1-2 and Proposed Change Number 3).

Justification for Proposed Change

The MPC-24E is a very close variant of the previously approved MPC-24. Holtec's engineers and analysts have taken advantage of optimizing the fuel storage cell configuration, flux trap sizes, and ^{10}B loading in the Boral, while still meeting subcriticality requirements. The basic honeycomb basket structure remains unchanged. The structural and thermal characteristics of the basket are virtually the same as the MPC-24. There is an effect on the confinement analysis due to the addition of damaged fuel. A detailed discussion of this change is provided below, arranged by technical discipline.

Structural Evaluation

A finite element model of the MPC-24E fuel basket was prepared in the same manner that was used for the previously approved MPC-24 and MPC-68 fuel baskets. The analyses of the MPC-24E fuel basket under applied inertia loads, simulating a handling accident, have been carried out to obtain primary stresses in the fuel basket structure and in the MPC shell. The safety factors, after applying the appropriate dynamic amplifier, exceed 1.0 and are reported in the proposed TSAR revision in appropriate tables in Chapter 3, Subsection 3.4. Text in Chapter 3 of the TSAR has been appropriately modified to reflect the addition of this new fuel basket. All other structural analyses currently approved have been reviewed to ensure that the bounding loads used as input for the specific structural analyses remained bounding. The bounding weights used as input for the TSAR analyses were not changed by the addition of this new basket; therefore, previously reported safety factors in the TSAR are not altered by this new fuel basket. See Attachment 5 for proposed TSAR changes.

Thermal Evaluation

With respect to thermal performance, the MPC-24E configuration is slightly different (symmetric basket layout) from the previously approved MPC-24, but employs the same general construction (integral honeycomb basket) and the same heat rejection mechanisms. The thermal performance of the MPC-24E design has been evaluated, in support of this amendment request, using the analysis methods employed to determine the performance of the previously approved MPC-24 and MPC-68. The substantial conservative assumptions embedded in the evaluations of the MPC-24 and MPC-68 designs have also been incorporated in the evaluations of the MPC-24E. Allowable decay heat loads have been determined for design-basis (DB) intact Zircaloy clad, damaged Zircaloy clad, and stainless steel clad fuel that ensure safe long-term storage of SNF in the MPC-24E. The HI-STORM temperature field for the MPC-24E loaded with design-basis heat emitting fuel was calculated and is reported in proposed revisions to HI-STORM TSAR Chapter 4 (see Attachment 5).

Shielding Evaluation

From a shielding perspective, the new MPC-24E is identical to the MPC-24 and therefore was not explicitly analyzed. The different fuel cell pitch in the MPC-24E, compared to the MPC-24, will have little impact on the dose rates outside the overpack. In addition, all of the steel fuel cell walls in the MPC-24E are 5/16 inch thickness and provide somewhat more shielding compared to the MPC-24 (which utilizes both 9/32 and 5/16 inch walls). The analysis of the MPC-24 in Chapter 5 of the proposed Revision 11 of the HI-STORM TSAR conservatively bounds the allowable contents for both the MPC-24 and the MPC-24E.

Criticality Evaluation

In order to increase the maximum permissible fuel enrichment for the MPC-24E compared to the MPC-24, the following changes were introduced into the MPC-24E:

- The fuel storage cells and flux traps are arranged in a fully symmetric manner, which allows moving some cells further away from the center of the basket. This results in increased flux traps in some areas of the basket.
- The ^{10}B loading of the Boral is increased from 0.0267 (minimum) to 0.0372 g/cm2 (minimum). This requires a change in the Boral thickness from 0.082 inches to 0.101 inches.
- The cell pitch is slightly increased.

Additionally, four of the peripheral cells have an increased cell ID to accommodate PWR Damaged Fuel Containers. This results in decreased flux traps for these cells.

Overall, this design allows an increase in the maximum permissible fuel enrichment of 0.4 wt% ^{235}U for most fuel classes, while maintaining the same level of margin toward the regulatory requirement of $k_{eff} < 0.95$. The maximum k_{eff} for the bounding assembly in each class is listed in Table 6.1.3 in Section 6.1 of the proposed Revision 11 of the TSAR (see Attachment 5).

Additionally, the MPC-24E is analyzed with credit taken for soluble boron present in the water during wet loading and unloading operations. With a minimum soluble boron concentration in the water of 300 ppmb, a maximum enrichment of 5.0 wt% ^{235}U for all assembly classes is permissible. To ensure that the actual k_{eff} is always below the maximum calculated k_{eff}, the following additional conservative assumptions are applied in the calculations with soluble boron.

- The pellet to clad gap is assumed to be flooded with pure, unborated water.
- The water above and below the active regions is assumed to be pure, unborated water.

The maximum k_{eff} for the bounding assembly in each class for this condition is listed in Table 6.1.4 in Section 6.1 of the Proposed Rev. 11 of the TSAR.

Confinement Evaluation

From a confinement perspective, the evaluation for the MPC-24 and MPC-24E are identical with the exception of the minimum free volume in the MPC cavity. The MPC-24E minimum free volume is slightly less than the MPC-24 due to increased thickness of the basket cell walls and the presence of more basket cell walls. This increases the concentration of radionuclides slightly due to the smaller dilution volume. The resultant doses from the MPC-24E are presented in TSAR Table 7.3.2 in proposed Revision 11 of the TSAR and bound the doses from the MPC-24 (see Attachment 5).

Proposed Change No. 15

Certificate of Compliance, Appendix A, Table 3-1 and Appendix B, Table 2.1-1

New Item V is added to the table for MPC-32.

Reason for Proposed Change

The MPC-32 allows users to place PWR fuel into dry storage using one third fewer casks due to its increased storage capacity over the MPC-24 and MPC-24E. Fewer casks to load decreases the probability of cask handling mishaps, reduces the overall occupational exposure for the fuel loading campaign, and reduces customer cost.

Justification for Proposed Change

The MPC-32 basket design is very similar to the previously approved BWR MPC-68. However, unlike the MPC-24 series PWR basket, no flux traps are used. As such, credit for soluble boron is taken in the MPC-32 criticality analyses for all authorized fuel enrichments. Two ranges of enrichment, with two separate minimum boron concentration requirements have been analyzed (see associated changes to Table 2.1-2 and Proposed Change Number 3). A detailed discussion of this change is provided below, arranged by technical discipline.

Structural Evaluation

The structural analysis of the MPC-32 was considered in the initial versions of the HI-STAR TSAR (Docket 72-1008). The review of the structural analysis of the MPC-32 fuel basket was performed by the NRC staff and all structural questions from the NRC staff resolved. Prior to final approval of the HI-STAR TSAR, however, the MPC-32 basket was removed from the submittal to permit final resolution of some outstanding non-structural issues without a delay in the CoC approval process. The MPC-32 was also removed from the HI-STORM TSAR submittal at the same time.

The re-introduction of the MPC, from a structural point of view, required only the addition back into the text and appendices previously reviewed calculations and results. To that end, all TSAR text, tables, and appendices have been reviewed and updated to include the MPC-32 input data and structural results. The finite element model of the MPC-32 fuel basket was originally prepared at the same time and in the same manner as the currently reviewed and approved MPC-24 and MPC-68 fuel baskets. The analyses of the MPC-32 fuel basket under applied inertia loads, simulating a handling accident was carried out to obtain stresses in the fuel basket structure and in the MPC shell. The safety factors, previously reviewed, after applying the appropriate dynamic amplifier, exceed 1.0 and are re-introduced into the TSAR document in the appropriate tabular form. Since the MPC-32 was (and still is) the heaviest MPC when fully loaded, there has been no change in the bounding loads used as input for other calculations. Appropriate text and tables in Section 3 of the TSAR have been updated to reflect the presence of this new fuel basket (see Attachment 5). The changes to the MPC-32 drawings as described in Section III of this attachment, were reviewed and found to be insignificant with respect to the structural evaluation. No new structural evaluations have been introduced into the TSAR as a result of restoring the MPC-32.

Thermal Evaluation

With respect to thermal performance, the MPC-32 design for PWR fuel is akin to the previously approved MPC-68 for BWR fuel in that the same general construction and the same heat rejection mechanisms are present. The thermal performance of the MPC-32 design has been evaluated, in support of this amendment, using the analysis methods employed to determine the performance of the previously approved MPC-24 and MPC-68. The substantial conservative assumptions embedded in the evaluations of the MPC-24 and MPC-68 designs have also been incorporated in the evaluations of the MPC-32. Allowable decay heat loads have been determined for design-basis (DB) intact Zircaloy and stainless steel clad fuel that ensure safe long-term storage of SNF in the MPC-32. The HI-STORM temperature field for the MPC-32 loaded with design-basis heat emitting fuel was calculated and is reported in proposed revisions to HI-STORM TSAR Chapter 4 (see Attachment 5). This analysis demonstrates substantial cladding thermal margins.

Shielding Evaluation

The MPC-32 was explicitly analyzed in Chapter 5 of the proposed Revision 11 to the HI-STORM TSAR (see Attachment 5). Consistent with Revision 10 of the HI-

STORM TSAR, the dose rates around the HI-STORM overpack were analyzed at a burnup of 45,000 MWD/MTU and 5 year cooling for the MPC-32. Only the 100-ton HI-TRAC was analyzed with the MPC-32 since those dose rates bound the dose rates from the 125-ton HI-TRAC. The burnup and cooling times used for the HI-TRAC analysis are consistent with the burnup and cooling times specified in the proposed changes to the Approved Contents section of Appendix B to the CoC. Since the specified burnups and cooling times for the MPC-32 are considerably lower than the MPC-24, the MPC-24 was still used for the site-boundary evaluation to demonstrate compliance with 10CFR72.104. In addition, because of the differences in burnup and cooling times between the MPC-32 and the MPC-24, the radial dose rates from the MPC-24 are typically higher than for the MPC-32. Therefore, the MPC-24 was still used for the dose rate evaluations in Chapter 10.

Sections 5.1 and 5.4 of proposed Revision 11 of the HI-STORM TSAR report the calculated dose rates for the MPC-32 and Section 5.2 reports the source terms used for the MPC-32 evaluations.

Criticality Evaluation

The MPC-32 is analyzed with credit for soluble boron present in the water during wet loading and unloading operations. Two soluble boron concentrations are used in the analysis, 1800 ppmb and 2600 ppmb. With a minimum soluble boron concentration in the water of 1800 ppmb, a maximum enrichment of 4.0 wt% ^{235}U for all authorized fuel assembly array/classes is permissible. At 2600 ppmb, a maximum enrichment of 5.0 wt% ^{235}U for all authorized fuel assembly array/classes is permissible. As for the MPC-24E, the following additional conservative assumptions are applied to ensure that the actual k_{eff} is always below the maximum calculated k_{eff}.

- The pellet to clad gap is assumed to be flooded with pure, unborated water.

- The water above and below the active regions is assumed to be pure, unborated water.

The maximum k_{eff} for the bounding assembly in each class for the two soluble boron levels is listed in Tables 6.1.5 and 6.16 in Section 6.1 of the Proposed Rev. 11 of the TSAR (see Attachment 5).

Confinement Evaluation

The MPC-32 is explicitly analyzed in Chapter 7 of proposed Revision 11 of the HI-STORM TSAR. The radionuclide inventories were conservatively calculated assuming the design basis assembly at a burnup of 45,000MWD/MTU at a 5 year cooling time. The fuel specifications in the Approved Contents section of Appendix B to the CoC limit the fuel assembly burnup to below 45,000MWD/MTU for this cooling time, ensuring that this inventory exceeds that of the actual fuel acceptable for loading into the MPC-32. The resultant doses are summarized in Table 7.3.3 of proposed Revision 11 of the TSAR (see Attachment 5).

Proposed Change No. 16

Certificate of Compliance, Appendix B, Table 2.1-1

New Item VI is added to the table for MPC-68FF.

Reason for Proposed Change

The MPC-68FF allows users to place BWR fuel debris into dry storage where this was previously not authorized beyond Dresden Unit 1 and Humboldt Bay Fuel. User feedback on fuel condition indicates that some fuel assemblies destined for dry storage would be classified as fuel debris in accordance with the CoC.

Justification for Proposed Change

The MPC-68FF combines the thickened top portion of the previously approved MPC-68F shell with the maximized ^{10}B loading in the Boral neutron absorbers of the standard MPC-68, to allow storage of a wide range of damaged BWR fuel or fuel debris, loaded into DFCs. A detailed discussion of this change is provided below, arranged by technical discipline.

Structural Evaluation

With the exception of the thickened top portion of the MPC shell, the MPC-68FF is identical to the previously approved MPC-68F. The thickening of the MPC shell is limited to the closure lid region, and has already been evaluated for structural integrity and approved as part of the HI-STAR 100 Part 71 SAR.

Thermal Evaluation

With the notable exception of the thickened top portion of the MPC shell, the MPC-68FF is identical to the previously approved MPC-68. The thickening of the MPC shell is limited to the closure lid region, and has no impact on the thermal performance of the MPC. The thermal performance of the MPC-68FF is, therefore, identical to that of the previously approved MPC-68.

Shielding Evaluation

The MPC-68FF is identical to the MPC-68 from a shielding perspective. Therefore the analysis of the MPC-68, including damaged fuel, in Chapter 5 of proposed Revision 11 of the HI-STORM TSAR is applicable for the MPC-68FF and no explicit analysis of the MPC-68FF is required.

Criticality Evaluation

The basket structure in the MPC-68FF is identical to the basket structure inside the MPC-68. More specifically, all dimensions relevant for the criticality analysis such as pitch, basket wall thickness and ^{10}B loading in the Boral are identical between MPC-68 and MPC-68FF. Therefore, all criticality results obtained for the MPC-68 are valid for the MPC-68FF and no further analyses are necessary. With regard to the analyses of damaged fuel and fuel debris, see Proposed Change No. 5, Holtec Generic BWR DFC.

Confinement Evaluation

The MPC-68FF confinement analysis is bounded by the evaluation of the MPC-68. The MPC-68FF has a larger MPC lid-to-shell weld, which is necessary for storage and transportation of fuel debris. The smaller MPC lid-to-shell weld in the MPC-68 conservatively overestimates the leakage rate from the MPC-68FF. Therefore, no separate explicit analysis of the MPC-68FF is required.

Proposed Change No. 17

Certificate of Compliance, Appendix B, Table 2.1-2:

Table 2.1-2 is revised to indicate two ranges of enrichment for PWR fuel to be stored in the MPC-24 and MPC-24E, with and without soluble boron in the MPC water (see also Proposed Change Numbers 3 and 14).

Reason for Proposed Change

This change is proposed to allow higher enriched PWR fuel to be stored in the MPC-24 and MPC-24E with credit taken for soluble boron in the MPC water during wet loading and unloading operations.

Justification for Proposed Change

Criticality Evaluation

Both the MPC-24 and MPC-24E are analyzed with credit taken for the soluble boron present in the water during wet loading and unloading operations. With a minimum soluble boron concentration in the water of 400 ppmb in the MPC-24 or 300 ppmb in the MPC-24E, a maximum enrichment of 5.0 wt% ^{235}U for all authorized fuel assembly array/classes is permissible. To ensure that the actual k_{eff} is always below the maximum calculated k_{eff}, the following additional conservative assumptions are applied in the calculations with soluble boron.

- The pellet to clad gap is assumed to be flooded with pure, unborated water.

- The water above and below the active regions is assumed to be pure, unborated water.

The maximum k_{eff} for the bounding assembly in each class for this condition is listed in Tables 6.1.2 (MPC-24) and 6.1.4 (MPC-24E) in Section 6.1 of proposed Revision 11 of the TSAR (see Attachment 5).

Proposed Change No. 18

Certificate of Compliance, Appendix B, Tables 2.1-2 and 2.1-3

Notes at the end of Tables 2.1-2 and 2.1-3 are revised/added as shown in the attached marked-up pages of the CoC. Pointers to these notes in the tables are also revised accordingly.

a. Note 3 in both tables is revised to clarify the intent.*

b. New Note 5 is added to Table 2.1-2.

c. New Note 6 is added to Table 2.1-2.

d. New Note 7 is added to Table 2.1-2

e. Note 4 in Table 2.1-3 is revised to increase the allowable weight percent of U-235 in the MOX rods of fuel assembly array/class 6x6B from 0.612 to 0.635. This note is also clarified to state that the weight percentages are to be calculated based on the total fuel weight (i.e., uranium oxide plus plutonium oxide).*

f. Notes 6 and 7 in Table 2.1-3 are swapped.

g. New Note 11 is added to Table 2.1-3.*

h. New Note 12 is added to Table 2.1-3.*

i. New Note 13 is added to Table 2.1-3.*

j. New Note 14 is added to Table 2.1-3.

Reason for Proposed Changes

a. As currently worded, it is unclear whether implementation of the tolerance offered by Note 3 allows adjusting the documented value of the as-delivered uranium mass for a fuel assembly, or adjusting the uranium mass limit specified in the table for comparison against users' fuel records. The intent is to adjust the uranium mass limit up (within the prescribed tolerance), as necessary, for comparison against users fuel records. This eliminates a potential poor practice of users adjusting uranium mass values found on fuel records.

b. This note is required to connect the enrichment level for PWR fuel to be loaded with the LCO for the required boron concentration in the MPC water.

c. This note is necessary to recognize that this array/class (representing only the Indian Point Unit 1 fuel assembly) includes two different fuel rod pitches.

d. This note is required due to the addition of damaged PWR fuel to the authorized contents.

e. User feedback indicates that there are fuel assemblies with MOX rods containing less than 1.578 weight percent fissile plutonium in natural uranium. To bound this situation, the uranium content in the MOX rods is increased slightly. The second change to Note 4 is proposed to improve clarity regarding the intent of the note.

f. These notes are swapped for consistency between the HI-STAR and HI-STORM for these same notes.

g. New Note 11 is proposed in response to user feedback that some assemblies may include non-fuel rods which are filled with zirconium or an alloy of zirconium material in lieu of water.

h. New Note 12 is proposed to be added for information on this new array/class.

i. New Note 13 is proposed to address a situation for the 9x9E fuel assembly array/class where one assembly type in the class (SPC 9x9-5) contains rods of different dimensions within the array.

j. New Note 14 addresses an issue related to the criticality analyses for stainless steel clad fuel from the LaCrosse plant.

Justification for Proposed Changes

a. None. The tolerance in the mass limit allowed by this note is in the current, approved CoC.

b. This note provides required logic for proper implementation of the CoC requirements.

c. The Indian Point Unit 1 (IP-1) fuel assembly is unique and has been analyzed separately to account for the two different pitches. Only the IP-1 assembly fits into this array/class. The criticality analysis for the IP-1 fuel assembly is performed based on the actual configuration with different pitches in different sectors of the assembly. However, as this assembly class does not bound any assemblies other than the IP-1, the pitches are not listed in Table 2.1-2.

d. The addition of damaged fuel in the PWR MPC-24E requires that the maximum enrichment of all fuel assemblies in the MPC be no greater than the maximum enrichment for the damaged fuel to preserve the assumptions of the criticality analyses. In the criticality analysis for damaged fuel in the generic PWR damaged fuel container, both intact and damaged fuel loaded into the same MPC are modeled at an enrichment of 4.0 wt% ^{235}U. The results of the analysis demonstrates that this ensures compliance with the regulatory requirement of k_{eff} <0.95. Therefore, limiting the maximum initial enrichment to 4.0 wt% for this loading situation is a requirement to ensure regulatory compliance.

e. All criticality calculations for the 6x6B (MOX) fuel assembly array/class were re-performed (see proposed revised TSAR Table 6.2.38 in Attachment 5). The change in reactivity for this change is small (less than 2Φ). This demonstrates that the maximum k_{eff} remains below 0.95 with the increased uranium concentration. The second change is proposed for clarity.

f. Editorial.

g. Replacing water with a non-fissile zirconium material will reduce the amount of moderator without increasing the amount of fissile material. This results in a decreased reactivity. This situation is comparable to the overall reduction of water density analyzed in Section 6.4.2.1 of the TSAR, which shows a decrease of reactivity with decreasing water density (i.e. decreasing the amount of water in the cask). The existing calculations assuming water in the water rods are therefore bounding for rods with non-fissile material in lieu of water.

h. New fuel assembly array/class 8x8F represents a unique fuel assembly type known as the QUAD+. New Note 12 is proposed to describe the unique water rod features of this assembly.

i. The SPC 9x9-5 fuel assembly is configured with two types of fuel rods having differing dimensions. Accordingly, the criticality analyses have been performed considering the varying fuel rod dimensions in the SPC 9x9-5 fuel type. Bounding all fuel rods in the assembly with one set of rod dimensions is not feasible because of excessive dimensional overlap. The SPC 9x9-5 fuel type is configured with two types of fuel rods having differing dimensions. Accordingly, the criticality analyses have been performed considering the varying fuel rod dimensions in the SPC 9x9-5 fuel type.

j. In the criticality analysis for damaged fuel in the generic BWR damaged fuel container, intact and damaged fuel/fuel debris loaded into the same MPC are modeled at enrichments of 3.7 wt% ^{235}U (intact) and 4.0 wt% ^{235}U (damaged/debris). The results of the analysis demonstrate that this ensures compliance with the regulatory requirement of k_{eff} <0.95. Therefore, limiting the maximum initial enrichment of the intact fuel to 3.7 wt% for this loading situation is a requirement to ensure the assumptions of the criticality analyses are preserved.

Proposed Change No. 19*

Certificate of Compliance, Appendix B, Tables 2.1-2 and 2.1-3 :

The maximum allowed design initial uranium masses for selected fuel assemblies are increased as shown in the marked-up CoC tables. This affects PWR fuel assembly array/classes 14x14A, 14x14B, 14x14C, 15x15A, 16x16A, 17x17A, 17x17B, and 17x17C in Table 2.1-2 and BWR fuel assembly array/classes 6x6A, 6x6B, 6x6C, 8x8B, 8x8C, 8x8D, 8x8E, 9x9A, 9x9B, 9x9C, 9x9D, 9x9E, 9x9F, 10x10A, 10x10B, and 10x10C in Table 2.1-3.

Reason for Proposed Changes

To respond to user feedback describing certain fuel assemblies which have uranium masses slightly above the specified limit (including the tolerance allowed by Note 3 included with Tables 2.1-2 and 2.1-3) for the applicable fuel assembly array/class. These changes are required to ensure users can load all of the fuel they plan to place into dry storage.

Justification for Proposed Changes

Structural Evaluation

There is no effect on the existing structural evaluation. The increased uranium masses do not cause an increase in the overall assembly weight limits in the CoC. These weights (or greater) were used in the structural evaluation. Since the allowed assembly weights are not being changed, the structural evaluation is unaffected.

Thermal Evaluation

There is no effect on the existing thermal evaluation. This is because the allowed heat load for the cask is computed based on the heat transfer characteristics of the cask system and permissible peak cladding temperatures. The increase in uranium mass does not impact any assumption made in determining the heat transfer characteristics of the cask system.

Shielding Evaluation

The uranium mass limit is a value that is determined from the shielding analysis. An increase in the mass of uranium will result in an increase in the neutron and gamma source term and decay heat load for a specified burnup and cooling time. The current CoC developed from the analyses in Revision 10 of the HI-STORM TSAR provides some margin between the analyzed mass of uranium and the approved mass of uranium as listed in the CoC. The allowable burnup and cooling times in the CoC were developed by comparing the calculated decay heat for the design basis assemblies to the allowable decay heat load as determined in the thermal analysis. The decay heat values that are compared against the limits were calculated using the mass of uranium listed in Chapter 5 of the HI-STORM TSAR for the design basis fuel assemblies. Since a lower mass of uranium will result in a lower decay heat, it is conservative, and provides margin, to specify the allowable mass of uranium in the current CoC for the design basis fuel assemblies (B&W 15x15 and 7x7) lower than the values analyzed in TSAR Chapter 5.

As discussed in Section 5.2.5 of the HI-STORM TSAR Revision 10, the design basis assembly was chosen by comparing the source terms for many different types of assemblies. All of the assemblies were shown to have a lower source term than the design basis fuel assemblies. For additional conservatism, the mass of uranium specified in the current CoC for these non-design basis fuel assemblies is also specified lower than the mass used in the comparison in Chapter 5 of TSAR Revision 10. This level of conservatism is unnecessary since the decay heat load used to determine the allowable burnup and cooling times for all assemblies was the decay heat load from the design basis fuel assemblies. Therefore, there was already a significant amount of conservatism for the non-design basis fuel assemblies included by using the design basis decay heat to determine the allowable burnup and cooling times. Section 5.2.5.3 of Revision 10 of the HI-STORM TSAR provides an indication of the level of conservatism associated with using the design basis decay heat for the non-design basis fuel assemblies.

The proposed change in the CoC is to increase the mass of uranium for the non-design basis fuel assemblies up to the value that was used in the analysis in Chapter 5 of the HI-STORM TSAR to determine the design basis fuel assembly. In order to permit a slightly larger increase in the uranium mass loadings relative to Revision 10 of the HI-STORM TSAR, the analysis in Sections 5.2.5.2 and 5.2.5.3, specifically Tables 5.2.26 and 5.2.28, has been modified to use a slightly larger uranium mass loading for the 8x8, 9x9, and 10x10 assemblies. As mentioned above, this change eliminates unnecessary over-conservatism while still maintaining a significant degree of conservatism and margin for the non-design basis fuel assemblies. The design basis fuel assemblies and the allowable mass loading for the design basis fuel assemblies remains unchanged. Therefore, the proposed change does not affect the shielding analysis presented in Revision 10 of the HI-STORM TSAR. Additional clarification has been added to the proposed Revision 11 of the HI-STORM TSAR to discuss this issue (see Attachment 5).

Criticality Evaluation

The criticality analyses are not affected by the proposed changes to the maximum allowed design uranium masses shown in the Certificate of Compliance (CoC). The uranium mass limits in the CoC are determined from the shielding analysis, and are specified as bounding values for groups of fuel classes (e.g. all B&W 15x15). The criticality analyses are based on an independent bounding assumption of a fuel stack density of 96.0% of the theoretical fuel density of 10.96 g/cm^3. The fuel stack density is approximately equal to 98% of the pellet density. Therefore, while the pellet density of some fuels might be slightly greater than 96% of theoretical, the actual stack density will be less. For some fuel classes, this density assumption results in a uranium mass for the criticality analyses that is below the value shown in the CoC. However, this only indicates the conservatism of the shielding analysis for these classes. The criticality analyses are still valid and bounding for all classes, due to the density assumption stated above, which is valid for current and future fuel assemblies.

Confinement Evaluation

As described in the shielding evaluation, the values of uranium mass used in the shielding analyses have not changed. These proposed changes simply increase the allowed uranium masses for non-design basis fuel assemblies to those used in the analysis for the design basis fuel assembly. The source terms used in the confinement analyses were taken from the design basis source terms used in the shielding analyses. Therefore, the existing confinement evaluation is still bounding for the proposed new uranium mass limits.

Proposed Change No. 20*

Certificate of Compliance, Appendix B, Tables 2.1-2 and 2.1-3:

Certain fuel assembly parameter limits are revised as shown in the attached marked-up CoC tables. This affects PWR fuel assembly array/class 14x14C in Table 2.1-2 and BWR fuel assembly array/classes 6x6A, 6x6B, 7x7A, 7x7B, 8x8A, 8x8B, 8x8D, 9x9B, 9x9D, 9x9E, 9x9F, and 10x10C in Table 2.1-3.

Reason for Proposed Changes

To respond to user feedback describing certain fuel assemblies that have parameters outside of the limits in the existing CoC Tables. These changes are required to ensure users can load all of the fuel they plan to place into dry storage.

Justification for Proposed Changes

Structural Evaluation

The proposed changes to fuel parameter limits for some of the existing fuel assembly array/classes have no impact on the structural evaluation because the design basis weights used in the analyses (and provided as limits elsewhere in the CoC) are not changed, the design basis temperatures are not changed, and the geometry of the fuel assemblies (also limited by the CoC) are not changed.

Thermal Evaluation

The active fuel length for array/classes 6x6A and 6x6B is proposed to be increased to 120 inches to bound an earlier variant of Dresden-1 fuel. Among the fuel assemblies included in the 6x6A array/class, one particular fuel type was determined to be fabricated with a thinner cladding (0.026 in.) relative to other fuel in this class (minimum 0.030 in. cladding). In the 7x7A array/class of fuel assemblies, minor adjustments to the fuel parameters[4] was necessary to bound Humboldt Bay fuel. Changes to the 7x7B and 8x8B array/classes were necessary to bound the fuel types at Oyster Creek plant. Accordingly, the thermal analyses for these fuel types were evaluated in support of this amendment and additional analyses performed, as required.

A review of the Oyster Creek fuel parameters against the fuel parameters of other fuel types in the same array/classes has revealed no significant differences. The Oyster Creek 7x7 fuel rod mechanical parameters are identical to an existing member of the 7x7B class. The relatively larger pellet diameter (from 0.491 vs. 0.488 in) necessitates an adjustment to the uranium weight limit for this array/class. The Oyster Creek 8x8 fuel rod diameter is slightly larger than other members in the 8x8B class and has a thicker cladding.

An 8x8 fuel assembly used at Browns Ferry and a 9x9 fuel assembly from Grand Gulf, have been evaluated in support of this amendment request to modify the BWR fuel parameters. Likewise, a Millstone Unit 2 14x14 fuel assembly has been evaluated to support modification of the PWR fuel tables. As explained below, these PWR and other BWR fuel have been evaluated in accordance with the NRC-approved HI-STORM thermal analysis methodologies to confirm that the HI-STORM 100 temperature field is bounded by the design basis analyses.

The overall HI-STORM thermal analysis methodology is partitioned into two evaluations. The first evaluation pertains to determining the appropriate peak cladding temperature limits for long term dry storage for each proposed fuel type. For this purpose, theoretical bounding rod gas pressures for the PWR and BWR classes of fuel are employed. In the second evaluation, the temperature field in the HI-STORM 100 cask is computed and the resulting cladding temperatures demonstrated to be below the respective temperature limits. The analytical evaluations for BWR fuel are further sub-divided in two groups of fuel assemblies classified as Low Heat Emitting (LHE) fuel assemblies and Design Basis (DB) fuel assemblies. The LHE fuel assemblies are characterized by low burnup, long cooling time and short active fuel lengths. Consequently, their heat loads are dwarfed by the full active length DB fuel assemblies. The additional Dresden-1 and Humboldt Bay fuel assemblies in the 6x6A and 7x7A array/classes belong to

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[4] Cladding thickness change from 0.033 inch to 0.0328 inch and active fuel length from 79 in to 80 in.

the LHE group of fuel, while the additional Oyster Creek, Browns Ferry, and Grand Gulf fuel assemblies are included in the DB group.

In accordance with the PNL-6189 methodology, peak fuel cladding temperature limits are specified as a function of cladding stress and age of fuel. The cladding stress calculations for the additional fuel are documented in proposed revised TSAR Tables 4.3.2, 4.3.3, 4.3.5 and 4.3.6 in Attachment 5 to this letter. The cladding stress in the additional DB fuel types is bounded by the limiting cladding stress computed previously. An adjustment to the 10x10 SVEA-96 fuel parameters (an O.D. change by 0.001 inch) is insignificant for the cladding stress evaluation as it is bounded by the design basis cladding stress. Consequently, the age-dependent peak fuel cladding temperature limits do not require changes to accommodate the additional fuel. For the LHE fuel group, the thin-clad Dresden-1 fuel type is determined to be the limiting fuel resulting in a downward shift in the applicable fuel cladding temperature limit. The revised temperature limits for LHE and DB fuel are summarized in proposed revised TSAR Tables 4.3.7 and 4.3.8.

The second evaluation pertaining to computation of the HI-STORM 100 cask temperature field is functionally dependent upon the effective conductivity of fuel assemblies loaded in the MPC-68 fuel cells. The LHE fuel assemblies are further analyzed under the assumption that they are loaded while encased in stainless steel DFCs. Due to interruption of radiation heat exchange between the fuel assembly and the fuel basket by the DFC boundary, this configuration is bounding for the thermal evaluation. Two DFC designs are evaluated - a previously approved Holtec design (TSAR Figure 2.1.1) and an existing TN/D-1 DFC in which some of the Dresden-1 fuel is currently stored (TSAR Figure 2.1.2) (see Proposed Change Number 5). The most resistive fuel assembly determined by analytical evaluation is considered for the HI-STORM 100 cask thermal evaluation. The results of the evaluation of additional fuel types performed in support of this amendment request are summarized in proposed revised Table 4.4.6 for LHE and DB fuel (see Attachment 5).

In both groups investigated, the thermal conductivity of the additional fuels is bounded by the limiting fuel types in each group. For the DB group of fuel assemblies, it is shown that the peak cladding temperature limits for the limiting fuel type adequately cover the additional fuel. The most resistive fuel characteristics also bound the additional fuel in the list of DB fuel types authorized for storage in the HI-STORM 100 System. Thus, the design basis thermal analysis envelopes the HI-STORM 100 System thermal response when loaded with the additional BWR and PWR fuel. For the LHE group of assemblies, the low decay heat load burden on the HI-STORM 100 cask (~ 8kW) guarantees large thermal margins to permit safe storage of Dresden-1 and Humboldt Bay fuel. Nevertheless, a conservative analysis was performed and is described in the proposed Revision 11 TSAR and the temperature field determined and reported Subsection 4.4.1.1.13 (see Attachment 5).

Shielding Evaluation

The accuracy of the shielding analysis is dependent upon the calculation of the radiation source term. The source term is dependent on the mass of uranium in the fuel assembly. For a specified burnup and cooling time, the radiation source term will increase as the mass of uranium increases (this is addressed in Proposed Change Number 19). The minor changes proposed for the dimensions of the fuel assembly array/classes will have a negligible impact on the radiation source term. Since the allowable uranium mass loadings are not being changed as a result of these changes in dimensions, it is concluded that these changes will have a negligible effect of the shielding analysis and therefore are not explicitly considered in Revision 11 of Chapter 5 of the HI-STORM TSAR.

Criticality Evaluation

For the criticality evaluation, the fuel assemblies are grouped into assembly array/classes. The proposed CoC modifications to fuel assemblies already included are reflected in proposed revised TSAR Table 6.2.1 (see Attachment 5). For each assembly array/class, a theoretical bounding assembly is defined. The characteristics of the bounding assembly for each affected array/class was amended to reflect the additional fuel types within an array/class.

Criticality calculations were performed for the changed fuel types and the bounding assembly in each array/class to account for the modified dimensions. Table 20.1 below shows the comparison between the maximum k_{eff} for each of the affected array/classes and the corresponding current values (i.e. TSAR Rev. 10). The TSAR table number containing the detailed results is also listed. The comparison demonstrates that, apart from the 10x10C assembly class, the maximum k_{eff} of each affected class only changes slightly as a result of the changes in the fuel assembly characteristics.

For the 10x10C assembly class, the changes are larger due to a change in the material of the internal structures (water tubes) inside the assembly. The initial calculation assumed stainless steel for these structures, whereas the actual material is a zirconium alloy. This results in an increase in reactivity, as the zirconium alloy shows a lower neutron absorption compared to stainless steel. Overall, the highest reactivity calculated for any BWR or PWR class (0.9457 for the bounding assembly in the BWR 10x10A class and 0.9478 for PWR assembly class 15x15F) remains unaltered (see proposed revised TSAR Tables 6.2.30 and 6.2.13, respectively). Therefore, with the proposed changes, the cask system is still in compliance with the regulatory requirement of $k_{eff} < 0.95$ for all authorized fuel assembly array/classes.

Table 20.1
Comparison of Maximum k_{eff} for TSAR Rev. 10 and Proposed Rev. 11

Assembly Array/Class	Maximum k_{eff} TSAR Rev. 10	Table Number in TSAR Rev. 10	Maximum k_{eff} TSAR Proposed Rev. 11	Table Number in Proposed Rev. 11 of the TSAR
6x6A	0.7602	6.2.35	0.7888	6.2.41
6x6B	0.7611	6.2.36	0.7824	6.2.42
7x7A	0.7973	6.2.38	0.7974	6.2.44
7x7B	0.9375	6.2.19	0.9386	6.2.23
8x8A	0.7685	6.2.39	0.7697	6.2.45
8x8B	0.9368	6.2.20	0.9416	6.2.24
8x8D	0.9366	6.2.22	0.9403	6.2.26
9x9B	0.9388	6.2.25	0.9422	6.2.30
9x9D	0.9392	6.2.27	0.9394	6.2.32
9x9E	0.9406	6.2.28	0.9401	6.2.33
9x9F	0.9377	6.2.29	0.9401	6.2.34
10x10C	0.8990	6.2.32	0.9424	6.2.38
14x14C	0.9361	6.2.6	0.9400	6.2.8

Confinement Evaluation

There is no effect of these proposed changes on the confinement evaluation because the source terms used in the confinement analysis are not changed.

Proposed Change No. 21

Certificate of Compliance, Appendix B, Tables 2.1-2 and 2.1-3:

Four new fuel assembly array/classes, 14x14E and 15x15H* (PWR); and 8x8F* and 9x9G (BWR) are added to Appendix B, Tables 2.1-2 and 2.1-3, respectively, as shown in Tables 21.1 and 21.2 below and in the attached marked-up CoC tables. Items II.A.1.d and e and Items VI.a.1.d and e in Table 2.1-1 are also revised to add separate decay heat, cooling time, and burnup limits for the 8x8F array/class (QUAD+ assembly).

Table 21.1
New PWR Fuel Assembly Array/Classes 14x14E and 15x15H

Fuel Assembly Array/Class	**14x14E**	**15x15H**
Clad Material	SS	Zr
Design Initial U (kg/assy.)	≤ 206	≤ 475
Initial Enrichment (wt % ^{235}U)		
MPC-24 without soluble boron credit	≤ 5.0	≤ 3.8
MPC-24E without soluble boron credit	≤ 5.0	≤ 4.2
Any PWR MPC with soluble boron credit	≤ 5.0	≤ 5.0
No, of Fuel Rods	173	208
Clad O.D. (in.)	≥ 0.3145	≥ 0.414
Clad I.D. (in.)	≤ 0.3175	≤ 0.3700
Pellet Dia. (in.)	≤ 0.3130	≤ 0.3622
Fuel Rod Pitch (in.)	0.441 and 0.453	≤ 0.568
Active Fuel Length (in.)	≤ 102	≤ 150
No. of Guide Tubes	0	17
Guide Tube Thickness (in.)	N/A	≥ 0.0140

Table 21.2
New BWR Fuel Assembly Array/Classes 8x8F and 9x9G

Fuel Assembly Array/Class	**8x8F**	**9x9G**
Clad Material	Zr	Zr
Design Initial U (kg/assy.)	≤ 191	≤ 179
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U)	≤ 3.6	≤ 4.2
Initial Maximum Rod Enrichment(wt.% ^{235}U)	≤ 5.0	≤ 5.0
No. of Fuel Rods	64	72
Clad O.D. (in.)	≥ 0.4576	≥ 0.4240
Clad I.D. (in.)	≤ 0.3996	≤ 0.3640
Pellet Dia. (in.)	≤ 0.3913	≤ 0.3565
Fuel Rod Pitch (in.)	≤ 0.609	≤ 0.572
Design Active Fuel Length (in.)	≤ 150	≤ 150
No. of Water Rods	N/A	1
Water Rod Thickness (in.)	≥ 0.0315	≥ 0.320
Channel Thickness (in.)	≤ 0.055	≤ 0.120

Reason for Proposed Changes

Based on user feedback, additional fuel assemblies were identified that did not fit into any of the existing fuel assembly array/classes. Four new assembly array/classes are required to assure all user fuel types can be loaded. The 14x14E array/class represents only Indian Point Unit 1 fuel. The 15x15H includes the B&W Mark B11 fuel design. The 8x8F represents only the "QUAD+" assembly. The 9x9G array/class represents the ANF-9X fuel assembly.

Justification for Proposed Changes

Structural Evaluation

The addition of new fuel types permitted to be stored in the HI-STORM 100 System can have an effect on the structural analyses performed in Chapter 3 if, and only if, one or more of the following occurs because of the new fuel types:

1. The design basis weights of 700 lbs (BWR) or 1680 lbs. (PWR), including non-fuel hardware, channels, and DFCs, as applicable, are exceeded.

2. The design basis temperatures are exceeded because of the presence of the new fuel types.

3. The lengths of the new fuel assemblies cause an increase in the length of the Holtec fuel spacers.

Section 3.0 of the HI-STORM TSAR contains a compliance matrix showing how the structural review requirements of NUREG 1536 have been satisfied by the totality of analyses currently reviewed and reported in Chapter 3. To ascertain whether any of the proposed amendment items require a re-visiting of any or all of the currently approved analyses reported in Chapter 3, the Compliance Matrix was reviewed and the following conclusions reached.

1. The weights of the proposed new fuel types do not exceed the limiting (i.e., design basis) weights specified in Table 2.1-1 of Appendix B to the CoC. Therefore, no structural analysis currently approved needs to be re-visited.

2. The design basis temperatures of all components have not exceeded the values currently licensed. Therefore, no structural analyses or free thermal expansion analyses currently approved needs to be revisited.

3. The lengths of the proposed new fuel types are longer than the minimum length of the fuel assemblies currently approved for the HI-STORM 100. Therefore, the fuel spacer stability analysis in the TSAR remains bounding. The lengths of the proposed new fuel types are also less than the maximum lengths specified in Table 2.1-1 of Appendix B to the CoC.

Thermal Evaluation

The Indian Point Unit 1, B&W Mark B11, QUAD+, and ANF-9X fuel types have been evaluated along with the changes to the existing 8x8 and 15x15 fuel assembly array/classes as described in Proposed Change No. 20 above.

The B&W Mark B11 and ANF-9X fuel assemblies are bounded by the existing design basis thermal analyses. The QUAD+ fuel assembly is included in the LHE group of BWR fuel assemblies and has been found acceptable for safe storage in proposed Revision 11 of the HI-STORM TSAR Subsection 4.4.1.1.13. The Indian Point Unit 1 fuel assembly is included in the stainless steel group of PWR fuel assemblies and has been found acceptable for safe storage in proposed Revision 11 of the HI-STORM TSAR Subsection 4.4.1.1.13.

Shielding Evaluation

The accuracy of the shielding analysis is dependent upon the calculation of the radiation source term. The source term is dependent on the mass of uranium in the fuel assembly. For a specified burnup and cooling time, the radiation source term will increase as the mass of uranium increases. Minor variations in the dimensions of a fuel assembly will have a negligible impact on the radiation source term if the mass or uranium remains constant. The additional fuel assemblies proposed for the CoC are not significantly different than the currently licensed fuel assemblies to require an assembly-specific source term calculation. These new fuel assemblies are bounded by the current design basis fuel assemblies. In addition, the allowable uranium mass loadings for these new fuel assemblies is specified consistent with similar fuel assemblies in the CoC thereby assuring that these assemblies are bounded by the current design basis fuel assemblies. Therefore, these additions will have a negligible effect of the shielding analysis and therefore are not explicitly considered in proposed Revision 11 of Chapter 5 of the HI-STORM TSAR.

Criticality Evaluation

Criticality calculations were performed for all four new fuel array/classes. The results for these classes in the MPC-24 and MPC-68 are summarized in Table 21.3 below. The two PWR assemblies (14x14E and 15x15H) are also permitted in the MPC-24E, MPC-32 and the MPC-24 with credit for soluble boron. Maximum k_{eff} values for these baskets are similar to the values listed in Table 21.3 below, and can be found in Tables 6.1.2 through 6.1.6 in Section 6.1 of the Proposed Rev. 11 of the TSAR (see Attachment 5). Overall, the highest reactivity calculated for any BWR or PWR class (0.9457 for the bounding assembly in the BWR 10x10A class and 0.9478 for PWR assembly class 15x15F remains unaltered (see proposed revised TSAR Tables 6.2.30 and 6.2.13, respectively). Therefore, with the proposed changes, the cask system is still in compliance with the regulatory requirement of $k_{eff} < 0.95$ for all authorized fuel assembly array/classes.

Table 21.3
Maximum k_{eff} for new PWR and BWR Fuel Assembly Array/Classes

Fuel Assembly Array/Class	Basket Type	Maximum k_{eff}	Table Number in Proposed Rev. 11 of the TSAR
14x14E	MPC-24	0.7715	6.2.10
15x15H	MPC-24	0.9411	6.2.18
8x8F	MPC-68/68FF	0.9153	6.2.28
9x9G	MPC-68/68FF	0.9309	6.2.35

Confinement Evaluation

The source terms used for the existing confinement analysis bound those of the new fuel assembly array/classes. Therefore, there is no impact on confinement.

Proposed Change No. 22

Design Features Section 3.2:

New design features important for criticality control are added for the MPC-24E, MPC-68FF and the MPC-32.

Reason and Justification for Proposed Changes

These changes are conforming changes in support of the addition of these MPC models to the CoC. The values for Boron-10 loading and flux trap size are consistent with their respective design drawings, including tolerances.

Proposed Change No. 23*

Certificate of Compliance, Appendix B, Table 3-1:

The entry in the "Exception, Justification & Compensatory Measures" column for the exception to Code Section NB-5230 for the closure ring, vent, and drain cover plate welds is clarified as shown in the attached marked-up CoC table to recognize welds which may be single pass welds.

Reason for Proposed Change

To provide clarification and as a conforming change to a proposed drawing change (see Attachment 4).

Justification for Proposed Change

Small welds, such as 1/8 inch will likely be completed in one pass, with no root.

SECTION II – PROPOSED CHANGES TO THE TSAR

Proposed Change No. 24

TSAR Chapter 1

a. The last paragraph of Section 1.0 is revised to annotate that this is Revision 11 and it has been made on a page basis. Clarification is added regarding the control of drawings and Bills-of-Material.

b. The definitions of Damaged Fuel Assembly, Damaged Fuel Container, Fuel Debris, and HI-STORM 100 overpack in Table 1.0.1 are revised.

c. New definitions of Preferential Fuel Loading, Regionalized Fuel Loading, and Uniform Fuel Loading are added to Table 1.0.1.

d. The definition of Holtite-A in Table 1.0.1 is revised to specify the B_4C loading as nominal in lieu of minimum.

e. Section 1.1 is revised to add discussion of the additional MPC-24E, MPC-32, and MPC-68FF fuel baskets and the optional HI-STORM 100S overpack design.

f. New Figures 1.1.1A and 1.1.3A are added to depict the HI-STORM 100S overpack.

g. Subsection 1.2.1 is revised to add a footnote that clarifies that the dimensions cited in the text of this section are nominal.

h. Subsection 1.2.1.1 is revised to clarify that the MPC basket and shell may be fabricated using different alloys in the Alloy X family.

i. Subsection 1.2.1.1 is revised to add descriptions for the MPC-24E, MPC-32, and MPC-68FF baskets, to clarify the description of the heat conduction elements, to refer to the fuel spacer lengths in Tables 2.1.9 and 2.1.10 as suggested values, and to replace “mass” with “pressure” in discussion of MPC helium backfill.

j. Subsection 1.2.1.2.1 is revised to add discussion of the HI-STORM 100S overpack option.

k. Subsection 1.2.1.3.2 is revised to specify the 1% boron carbide as a nominal value rather than a minimum value.

l. Subsections 1.2.2.1 and 1.2.2.2 and Table 1.2.2 are revised to specify that the MPC is backfilled with a helium pressure in lieu of a helium mass and to delete the free volume measurement.

m. Subsection 1.2.2.2 is revised to note that this section provides a summary of the "general actions needed for loading" to ensure that it is understood that these operations are described generically.

n. Subsection 1.2.2.2 is revised throughout to add clarifying text to address: soluble boron credit for certain MPC models, optional welding processes, multi-layer liquid penetrant examination for the MPV lid-to-shell weld, backfilling the MPC with helium to a specified pressure instead of a mass, and using the temporary overpack lid with HI-STORM 100S.

o. Subsection 1.2.2.3.1 is revised to address soluble boron credit for certain MPC models.

p. Subsection 1.2.2.3.4 is revised to replace "thermocouple" with "temperature elements."

q. Subsection 1.2.3 and Tables 1.2.1 are 1.2.2 are revised to reflect the addition of MPC-24E, MPC-32, and MPC-68FF. See Proposed Change Numbers 14, 15, and 16.

r. Figures 1.2.1A, 1.2.3, 1.2.4A and 1.2.8A are added.

s. Subsection 1.5 is revised as follows:

    1) New and revised Holtec Design Drawings are added to Section 1.5 to reflect the addition of three MPC models, the addition of the optional HI-STORM 100S overpack; and fabricability enhancements for the previous MPC models, the standard HI-STORM 100 overpack and the HI-TRAC transfer casks and lids.

    2) The detailed fabrication drawings and Bills-of-Material for the Holtec damaged fuel container for Dresden Unit 1 and Humboldt Bay are removed from the TSAR.

    3) Drawings 1495, Sheet 6 and 1561, Sheet 5 showing details such as nameplates and temperature monitoring instrumentation, are removed from the TSAR

t. Appendix 1.B is revised to change the Holtite-A density value from a maximum value to a nominal value.

u. Table 1.D.1 is revised to clarify the terminology used for the local concrete temperature limits.

Reason for Proposed Changes

a. The first change is required to maintain consistency and specify that this revision is made on a section-by-section or page-by-page basis, as appropriate. The second change is a clarification distinguishing between control of Bills-of-Material and design drawings.

b. These are clarifying change to match the revised definitions for these terms in other Holtec documents and to address HI-STORM 100S.

c. These new definitions are needed to recognize regionalized fuel loading as an optional fuel loading strategy. See Proposed Change Number 7.

d. The weight percent boron carbide used in the procedure for mixing each batch of Holtite-A remains greater than 1%. However, the as-mixed boron carbide weight percent can vary from slightly above to slightly below the 1% value. This change provides necessary flexibility for field mixing of the Holtite-A.

e. This text is required to introduce the additional MPC models and the alternative HI-STORM 100S overpack design.

f. The new figures are needed to show the alternative HI-STORM 100S overpack design concept.

g. This change is made to clarify that the cited dimensions are nominal. The dimensional requirements governing fabrication are specified in the design drawings in Section 1.5.

h. This change is made to clarify the intent of the "single alloy" statement.

i. The text regarding the additional MPC models provides necessary descriptive information for these MPCs. The text describing the heat conduction elements is clarified to note that the design ensures a snug fit in the periphery of the basket in lieu of just the shape. The text regarding fuel spacers is clarified as a conforming change to match proposed change 25.h below. The text regarding helium pressure is a conforming change to match a CoC change from mass to pressure as the helium backfill acceptance criterion.

j. This text provides necessary descriptive text for the alternative HI-STORM 100S overpack design. The HI-STORM 100S was designed to accommodate users who wish to perform the MPC inter-cask transfer in the Part 50 facility, where existing door heights may not be compatible with the standard HI-STORM 100 overpack.

k. Changing the boron carbide to a nominal value allows for minor variations that may occur during fabrication.

l. Conforming change. See Proposed Change Number 1.

m. The loading operations described in TSAR Subsection 1.2.2.2 do not include a statement allowing users to depart from the specific wording in this TSAR section provided the intent of the TSAR is met. This flexibility is already included in TSAR Section 8.0, making this a conforming change to match a previously approved provision in another TSAR section.

n. These text changes provide necessary clarifying information on the subjects addressed.

o. This text provides discussion of the credit taken for soluble boron in the criticality analyses for certain MPC models. This is a conforming change in support of Proposed Change Number 3 and associated changes.

p. This is a correction to match existing flexibility in this area on the design drawings and elsewhere in the TSAR

q. This is a conforming change to reflect the addition of MPC-24E, MPC-32, and MPC-68FF. See Proposed Change Numbers 14, 15, and 16.

r. Figures 1.2.1A and 1.2.8A are required to show the HI-STORM 100S overpack design. Figure 1.2.3 shows the MPC-32 basket layout and Figure 1.2.4A shows the MPC-24E basket layout.

s. Subsection 1.5

    1) The new and revised drawings are necessary to show fabrication details for the additional MPCs and HI-STORM 100S as well as changes to previously authorized cask components.

    2) The DFC fabrication drawings were removed because they include an unnecessary level of detail. Figure 2.1.1 has been revised to add an appropriate amount detail for this DFC for control under 10 CFR 72.48.

3) These drawings are not part of the storage system. They show ancillary equipment and are not appropriate for control as part of the TSAR.

t. The as-poured Holtite-A density can vary slightly above or below the nominal value of 1.68 g/cc.

u. Clarification.

Justification for Proposed Changes

a. Administrative clarification.

b. This is a conforming change to make the definitions consistent with the HI-STORM and HI-STAR CoCs, and to address the alternate HI-STORM 100S overpack. See Proposed Change Number 24.i.

c. These definitions are conforming changes to match the introduction of the regionalized fuel loading strategy proposed in the CoC. See Proposed Change Number 7.

d. Sensitivity analyses have been performed by reducing the boron carbide concentration from 1% to 0.5% and 0.75%. The sensitivity analyses demonstrate that at a boron carbide loading of 0.75% (a 25% reduction) the total dose rate (gamma and neutron) increases by only 3%. It should be noted that this increase is not much greater than the accuracy of the calculation and occurs at the higher burnups. The effect is lessened as the burnup decreases. Therefore, if a value can vary by as much as 25% without significantly affecting the dose rates, it is clearly a nominal value.

e. These changes add descriptive text. See Proposed Change Numbers 14, 15, 16, and 24.i.

f. The figures are necessary to give the reader a visual perspective of the HI-STORM 100S overpack alternative.

g. The intent of the dimensions presented is to provide the reader with a general idea of the size of the MPC and overpack. They were not intended to be design dimensions. By adding "nominal", it is clarified that these are not design requirements as the design dimensions are specified in the Design Drawings in Section 1.5.

h. The intent of the "single alloy" statement is that any welded components be fabricated of the same alloy in the Alloy X family. That is, the basket and its welded components are required to be fabricated from the same alloy, while the shell and its welded components are required to be fabricated from the same alloy. However, the alloys used for the basket and the shell may be different from one another.

i. The text regarding the additional MPC's and HI-STORM 100S is needed to address these components. The minor revision to the heat conduction element description is editorial. The change to the spacer lengths in Tables 2.1.9 and 2.1.10 being suggested values is in recognition of the fact that fuel assemblies with and without non-fuel hardware may need plant-specific fuel spacers fabricated to ensure the active fuel remains in the required location. The "mass" to "pressure" change is a conforming change to support Proposed Change Number 1.

j. The HI-STORM 100S is discussed by affected technical discipline below:

Structural Evaluation

The HI-STORM 100S overpack is a slightly shortened version of HI-STORM 100 overpack that is approximately 12,000 lb. lighter. The weight reduction has been achieved by reduction in the height of the concrete pedestal supporting the MPC and by the shortening of the overpack inner, outer, and shield shell, and the contained concrete. The weight of the HI-STORM 100S lid, however, is increased. Section 3.2 provides the specifics of the weights and center of gravity locations for the HI-STORM 100S loaded with the different MPCs. Detailed evaluations are performed in Chapter 3 to justify that nearly all analysis results previously performed and approved for the HI-STORM 100 bound results for the HI-STORM 100S and need not be repeated. Where justifications could not be provided, the detailed evaluations specific to the HI-STORM 100S are performed. All new safety factors specific to the HI-STORM 100S are greater than 1.0. Where required to perform specific evaluations for the short HI-STORM, new appendices have been added to Chapter 3. Attachment 5 details all changed text and calculations specific to the introduction of the HI-STORM 100S into the TSAR.

Thermal Evaluation

From the standpoint of thermal performance, the HI-STORM 100S overpack is nearly identical to HI-STORM 100. HI-STORM 100S features a slightly smaller inlet duct-to-outlet duct separation and a slightly enhanced gamma shield cross plate (which acts as a flow straightener) than its older counterpart. As would be expected, the close geometric correspondence between "100S" and "100" translates into virtually identical thermal performance between the two designs. FLUENT code simulations show that the difference in the computed peak cladding temperature in an MPC containing design basis fuel loaded into the two overpacks is less than 1° C. Therefore, HI-STORM 100S and HI-STORM 100 are considered to be interchangeable from the thermal-hydraulic standpoint.

Shielding Evaluation

The HI-STORM 100S overpack is quite similar to the current HI-STORM overpack. The only significant difference from a shielding perspective is that the MPC has been moved closer to the upper and lower air ducts. This results in an increase in the local dose rate at the opening of the ducts. In addition, the lid design has been changed by moving the concrete shielding from below the 4 inch thick steel to above the 4 inch steel plate in the top lid. The radial shielding is identical between the HI-STORM 100 and the HI-STORM 100S overpacks.

Chapter 5 of proposed Revision 11 of the HI-STORM TSAR specifically analyzes the HI-STORM 100S with the MPC-32 and the MPC-68. The MPC-24 analysis in the HI-STORM 100 overpack was unchanged. A comparison of the dose rates between the MPC-32 and MPC-24 indicates that the dose rate at the duct openings has increased in the HI-STORM 100S. This increase in the dose rate does not pose an ALARA concern and does not alter the HI-STORM 100 System's capability of meeting 10CFR72.104 requirements. Since the only significant change in the dose rate between the HI-STORM 100 and the HI-STORM 100S is at the duct opening, the previous analysis of the controlled area boundary dose rates using the HI-STORM 100 overpack was maintained.

For those users that are especially concerned with the dose rate at the duct openings, the HI-STORM 100S offers optional gamma shield cross plates which have more metal than the standard gamma shield cross plates and would therefore further reduce the dose rates at the duct openings.

k. This is a conforming change. See Proposed Change Number 24.d.

l. This is a conforming change. See Proposed Change Number 1.

m. The intent of the operating procedures in Chapter 8 and the short description of loading operations in Chapter 1 is to describe the general sequence of operations and desired objective of the steps. The TSAR information is not detailed enough to use for implementation at a user's site, nor should it be, for a generically certified cask system. Chapter 8 at Section 8.0 currently allows users to perform steps in different sequence than shown, to delete or add steps as necessary, and to use different equipment than specified provided the intent of the steps is met. These changes to Chapter 1 are being made to be consistent with Chapter 8.

n. These are clarifying changes to correctly reflect the CoC and other sections of the TSAR.

o. This is a conforming change. See Proposed Change Number 3 and associated changes.

p. This is a correction to match other TSAR sections and Design Drawing 1495, Sheet 6.

q. These are conforming changes to support the addition of three MPC models. See Proposed Change Numbers 14, 15, and 16.

r. These are conforming changes in support of the additional of the MPC-24E (Proposed Change Number 14), MPC-32 (Proposed Change Number 15) and the HI-STORM 100S (Proposed Change Number 24.i).

s. Subsection 1.5

   1) Drawings reflect new and revised component designs justified elsewhere in this document.

   2) The detailed DFC fabrication drawings are removed from the TSAR based on conversations with the NRC SFPO project manager. The appropriate level of detail to be controlled under 10 CFR 72.48 is now located in revised Figure 2.1.1.

   3) The drawings for the nameplates and temperature monitoring instrumentation will be controlled under Holtec's QA program. Changes to these drawings have no potential to significantly impact the certified storage system and are, therefore, not subject to control under 10 CFR 72.48.

t. The current version of the TSAR specifies the Holtite density as 1.68 g/cc maximum. The shielding analysis conservatively assumes a Holtite density of 1.61 g/cc. This density accounts for any potential weight loss or inability to reach the required density. Increasing the Holtite density only acts to increase the effectiveness of the shielding. By deleting the maximum, the density is allowed to be increased. The small variations in Holtite density will have a negligible effect on the total weight of the cask. The total weight of the

Holtite in the overpack is less than 13,000 lbs. An increase in the Holtite density from 1.68 g/cc to 1.70 g/cc equates to only a 150 pound increase.

u. This is an editorial change to bring the table terminology in line with the application of these limits in the HI-STORM thermal analysis. The new terminology reflects the fact that off-normal conditions may, in fact, be long-term conditions.

Proposed Change No. 25

TSAR Chapter 2

a. Section 2.0.1 is revised in several places to address the following:

   1) Recognize multi-layer PT in lieu of volumetric examination for the MPC lid-to-shell weld.

   2) Correct the reference for the content and location of the Technical Specifications, Approved Contents, and Design Features as appendices to the CoC.

   3) Change MPC helium backfill mass to pressure.

   4) Regionalized fuel loading.

   5) Provide clarification regarding how a single certified cask design is demonstrated to comply with 72.104 and 72.106 versus a site-specific ISFSI.

   6) Credit for soluble boron in the criticality analyses for certain MPC models.

   7) Address changes to 72.104 and 72.106 made in October, 1998.

   8) Referring to the CoC instead of Chapter 12 for the ambient temperature limit applicable to cask loading.

b. Table 2.0.1 is revised to:

   1) Remove the term "& Fabrication" under the listing of Structural design codes for the MPC.

2) Revise weight values to reflect new MPC models and modifications to the overpack.

3) Replace “mass” with “pressure” under “Canister Backfill” and correct the TSAR reference.

4) Provide clarification on NDE for the closure ring and port cover welds.

5) Add “atm” to the MPC leak rate acceptance criterion and clarify the TSAR reference.

6) Revise the boron loading criteria to include the additional MPC models.

7) Add a row for minimum soluble boron and provide the correct TSAR reference.

8) Revise the number of assemblies per canister to include the additional MPC models.

9) Clarify cladding types and fuel condition.

10) Remove the note prohibiting storage of control components under “Type/Configuration.”

11) Revise the maximum burnup value.

12) Revise the maximum per assembly decay heat values for PWR and BWR fuel and add clarifying notes explaining that these are maximum values for regionalized loading and that the CoC provides the decay heat limits per assembly. Revise the TSAR reference to refer to the correct Table in Chapter 4.

13) Clarify that the maximum fuel assembly weights include non-fuel hardware, channels, and damaged fuel canister.

14) Revise the minimum cooling time to indicate only 5 years and not distinguish among fuel types.

15) Delete “horizontal” under the “transfer orientation” heading.

16) Clarify “Fuel Rod Rupture Releases” to indicate that it includes gas releases from non-fuel hardware.

17) Move "Partial Blockage of MPC Basket Vent Holes" from the Natural Phenomenon section to the Accident section.

c. Table 2.0.2 is revised to:

   1) Revise the calculated weight values to reflect minor revisions in the weight calculation and the additional MPC models.

   2) Correctly represent the revised 72.104 and 72.106 regulations.

   3) Add "Explosive Overpressure External Pressure" to the table.

   4) Delete "& Fabrication" from the HI-TRAC table.

   5) Delete "or horizontal" from the "Transfer Orientation" row.

d. Subsection 2.1.1 is revised to delete one of the two exceptions to fuel assembly types suitable for loading in the HI-STORM system.

e. Subsection 2.1.2 is revised in various places to correct the location reference for the Technical Specifications and Approved Contents.

f. Subsection 2.1.3 is revised to make the definitions of damaged fuel and fuel debris the same as the glossary and the CoC.

g. Subsection 2.1.3 is revised to add discussion of the TN Dresden Unit 1 damaged fuel container and Thoria Rod Canister, and to discuss the addition of other BWR PWR and BWR damaged fuel now authorized for loading.

h. Subsection 2.1.5 and Tables 2.1.9 and 2.1.10 are revised to clarify the intent of the lengths provided for the fuel spacers.

i. Subsection 2.1.6 is revised to add discussion of regionalized fuel loading burnup and cooling time.

j. Subsection 2.1.6 is revised to add discussion of the Thoria Rod Canister, the antimony-beryllium neutron sources, and non-fuel hardware being added to the CoC for storage.

k. Subsection 2.1.7 is revised to address regionalized fuel loading.

l. Subsection 2.1.7 is revised to address the Dresden Unit 1 Thoria Rod Canister, SB-Be neutron sources, and non-fuel hardware.

m. Subsection 2.1.8 is revised to provide text that discusses the ^{10}B density in Boral.

n. Subsection 2.1.9 is revised to re-format the presentation of the summary of SNF design criteria.

o. Table 2.1.1 is revised to add an exception for System 80^{TM} fuel assemblies and to add Indian Point Unit 1 fuel.

p. Table 2.1.2 is revised to delete the exception for 8x8 WE QUAD+ assemblies.

q. Tables 2.1.3 and 2.1.4 are revised to modify the fuel parameters and notes as proposed in the CoC changes in Section I of this attachment.

r. Table 2.1.5 is revised to add MPC-24E and MPC-32.

s. Tables 2.1.6, 2.1.7, and 2.1.8 is revised to reflect changes in the CoC and to re-format the information.

t. Table 2.1.9 is revised to add Indian Point Unit 1 fuel assemblies.

u. New Table 2.1.12 is added for the Thoria Rod Canister.

v. New Table 2.1.13 is added to define the fuel loading regions.

w. New Table 2.1.14 is added to define soluble boron requirements.

x. Figure 2.1.1 is revised to show more detail.

y. New Figures 2.1.2, 2.1.2A, 2.1.2B, and 2.1.2C are added to show the TN/D-1 DFC, the TN Thoria Rod Canister, the Holtec PWR generic DFC, and the Holtec BWR generic DFC, respectively.

z. Figures 2.1.3 and 2.1.4 are revised to delete the proprietary note in the footer.

aa. Figure 2.1.6 is deleted.

bb. Subsection 2.2.1.2 is revised to reflect a change to the CoC to clarify that the minimum ambient temperature for loading operations applies to the local working area.

cc. Subsection 2.2.1.3 is revised to make the discussion of damaged fuel more broad than Dresden Unit 1 and Humboldt Bay fuel and to state that gas release from non-fuel hardware is considered.

dd. Subsection 2.2.2.5 is revised to clarify the wording on the partial blockage or air inlets.

ee. Subsection 2.2.2.6 is revised to clarify the expected reaction of the HI-TRAC transfer cask if the lift cables go momentarily slack.

ff. Subsection 2.2.3.1 is revised to add clarification that handling requirements apply to loaded overpacks and to clarify the location of certain conditions for use related to MPC transfer.

gg. Subsection 2.2.3.5 is revised to clarify the missile protection requirements.

hh. Subsection 2.2.3.8 is revised to address gas contained in non-fuel hardware.

ii. The Note under Table 2.2.2 is revised to clarify the ambient temperature requirement and to correct the location reference for the ambient temperature limit in the CoC.

jj. Table 2.2.6 is revised to:

1) Replace the term “helium retention” with “confinement” in the MPC section.

2) Clarify the material requirements for the lower fuel spacer column.

3) Correct the material requirements for the lid stud and nut to match the BOM.

4) Correct the material requirements for the pool lid outer ring to match the BOM.

5) Correct the material requirements for the top lid nut to match the BOM.

kk. Table 2.2.8 is revised to clarify a footnote to match the CoC requirements for friction factor.

ll. Table 2.2.15 is revised to clarify that there may not be a root pass for the MPC closure ring and vent and drain port cover plate welds.

mm. Subsection 2.3.1 is revised to correct the location reference for surveillance requirements.

nn. Subsection 2.3.2.1 is revised to delete an inappropriate reference to the Technical Specifications.

oo. Subsection 2.3.3.1 is revised to add the HI-STORM 100S to a footnote.

pp. Subsection 2.3.4.1 is revised to discuss soluble boron and to correct a location reference to the CoC.

qq. Subsection 2.3.5.2 is revised to increase the design objective dose rate for the radial surface of the overpack from 40 mrem/hr to 50 mrem/hr.

rr. Table 2.3.1 is revised to reflect the current language in 10 CFR 72.104 and 72.106.

Reason and Justification for Proposed Changes

a. Section 2.0.1:

1) This is a correction to match the existing CoC requirements.

2) Clarification.

3) Conforming change in support of the change from MPC helium backfill density (mass) to pressure in the CoC (see Proposed Change Number 1).

4) Conforming change in support of regionalized fuel loading (see proposed Change Number 7)

5) Clarification.

6) Conforming change in support of credit being taken for soluble boron in the MPC water for certain MPC models (see Proposed Change Numbers 3, 14 and 15).

7) Conforming change to match a change in the Part 72 regulations.

8) Conforming change to match the CoC.

b. Table 2.0.1:

1) Clarification.

2) Conforming change in support of new MPC models and HI-STORM 100S overpack.

3) Conforming change in support of MPC helium backfill density changing to pressure (see Proposed Change Number 1).

4) Conforming change in support of a drawing change which reduces the size of these welds.

5) Editorial.

6) Conforming change in support of the additional MPC models (see Proposed Change Numbers 14, 15, and 16).

7) Conforming change in support of soluble boron in the MPC water for certain MPC models (see Proposed Change Numbers 3, 14, and 15).

8) Conforming change in support of the addition of MPC-24E, MPC-32, and MPC-68F (see Proposed Change Numbers 14, 15, and 16).

9) Clarifying change to reflect other changes related to additional damaged fuel made in the CoC.

10) Conforming change in support of adding non-fuel hardware to the authorized contents (see Proposed Change Number 9).

11) Conforming change in support of increased allowed burnups due to regionalized fuel loading (see Proposed Change Number 7).

12) Clarifications and conforming changes in support of increased allowed decay heats due to regionalized fuel loading (see Proposed Change Number 7).

13) Clarification.

14) Clarification.

15) Correction. The transfer of the MPC between the HI-TRAC transfer cask and the HI-STORM overpack is always performed vertically.

16) Conforming change in support of the addition of non-fuel hardware to the authorized contents (see Proposed Change Number 9).

17) Correction. This line item describes a postulated accident event, not a natural phenomenon event.

c. Table 2.0.2:

1) Conforming change in support of the addition of MPC-32 and minor corrections.

2) Conforming change in support of changes to the 72.104 and 72.106 regulations which went into effect in October, 1998.

3) Correction.

4) Clarification.

5) Correction. The transfer of the MPC between the HI-TRAC transfer cask and the HI-STORM overpack is always performed vertically.

d. This is a conforming change in support of the revised and new fuel assembly array/classes. See Section I of this attachment.

e. Correction.

f. Clarification.

g. Conforming change in support of the addition of the TN/D-1 DFC and the D-1 Thoria Rod Canister and a broader range of damaged fuel (see Proposed Change Numbers 5 and 11).

h. The lengths of fuel spacers provided for the various fuel types in TSAR Tables 2.1.9 and 2.1.10 do not account for the assemblies having non-fuel hardware such as BPRAs, TPDs, CRAs, and APSRs installed. Authorization for loading these types of non-fuel hardware is being proposed in this amendment request. Therefore, the presentation of fuel spacer lengths in these tables needs to be qualified to provide the necessary flexibility for users to size the spacers for their specific fuel storage needs (see Proposed Change Number 9). The purpose of the fuel spacers is to ensure the active fuel region remains adjacent to the Boral neutron absorber affixed to fuel cell walls. Allowing fuel assemblies to be stored with their integral non-fuel hardware may alter the overall height of the assembly. It is not possible to predict, under a general certification, the exact length of fuel spacers each user will need. The specific length of a given fuel spacer is to be determined by the user. The user is obligated under 10 CFR 72.212 to ensure that the active fuel region of all assemblies is located correctly with regard to the Boral neutron absorber in accordance with the TSAR.

i. Conforming change in support of regionalized fuel loading (see Proposed Change Number 7).

j. Conforming change in support of the addition of the Thoria Rod Canister, Sb-Be neutron sources, and non-fuel hardware being added to the CoC for storage in HI-STORM 100 (see Proposed Change Numbers 9, 11, and 12).

k. Conforming change in support of regionalized fuel loading (see Proposed Change Number 7).

l. Conforming change in support of the addition of the Thoria Rod Canister, Sb-Be neutron sources, and non-fuel hardware being added to the CoC for storage in HI-STORM 100 (see Proposed Change Numbers 9, 11, and 12).

m. Clarification and conforming change in support of the additional MPC models (see Proposed Change Numbers 14, 15, 16, and 22).

n. Due to the addition of more damaged fuel types and the evolution of the CoC since this TSAR text was first developed, it became necessary to provide more general information in the TSAR with a reference to the CoC for specific limits on the fuel assemblies.

o. Clarification.

p. Conforming change in support of one of the new assembly array/classes being added (see Proposed Change Number 21).

q. Conforming changes in support of similar changes made in the CoC (see Proposed Change Numbers 19 and 20).

r. Conforming change (see proposed Change Numbers 14, 15, and 16).

s. Clarification. With the addition of a wider range of damaged fuel and the evolution of the CoC, it became obvious that continuing to include all of the various fuel limits in these tables would be confusing to the reader. The tables have been re-formatted to display strictly the limiting values for the various parameters and a note was added to refer to the CoC for the specific limits for each fuel assembly array/class.

t. Conforming change in support of the addition of Indian Point 1 fuel to the authorized contents (see Proposed Change Number 21).

u. This is a conforming change in support of the addition of the Thoria Rod Canister to the CoC for storage in HI-STORM 100 (see Proposed Change Number 11).

v. Conforming change in support of regionalized fuel loading (see Proposed Change Number 7).

w. Conforming change in support of the use of soluble boron in the MPC water (see Proposed Change Numbers 1, 14, and 15).

x. The detailed fabrication drawings of the damaged fuel container is being deleted from the TSAR as agreed to by the NRC. As part of that agreement, some additional detail needed to be added to the TSAR Figure for clarity and future change control under 10 CFR 72.48.

y. Conforming change in support of a wider range of damaged fuel, the TN/D-1 DFC, and the D-1 Thoria Rod Canister (see Proposed Change Numbers 5, 10, and 11).

z. Editorial.

aa. To have revised this figure to include all of the additional fuel and MPC baskets would have rendered the figure incomprehensible. The CoC has evolved into the authoritative source for burn up and cooling time limits for all fuel assemblies authorized for Loading into the HI-STORM 100 System.

bb. Correction to make the TSAR agree with the CoC.

cc. Conforming change in support of the authorization of a wider range of damaged fuel and the inclusion of non-fuel hardware (see Proposed Change Numbers 5 and 9).

dd. Editorial.

ee. Clarification.

ff. Clarification.

gg. Clarification. Missile protection may be provided by missile shields or other engineered design feature(s). This changes allows that flexibility.

hh. Conforming change in support of the addition of non-fuel hardware to the authorized contents of the Hi-STORM 100 System (see Proposed Change Number 9).

ii. Clarification.

jj. Table 2.2.6:

  1) Clarification

  2) The lower fuel spacer column is designed as a square stainless steel tube. There is no ASME material specification for square stainless steel tubing. This change maintains that the fuel spacer column must be made from one of the Alloy X materials and must meet the required tensile, yield and chemical properties, consistent with the structural analysis.

  3) Correction.

  4) Correction.

  5) Correction.

kk. The NRC required a test to confirm the validity of the 0.53 friction factor during the resolution of public comments during rulemaking. This correction is consistent with the existing requirement for users to confirm whatever friction factor is used by test (not just those higher than 0.53).

ll. Conforming change in support of the reduction in the closure ring and vent and drain port cover plate weld sizes.

mm. Editorial.

nn. Editorial.

oo. Editorial.

pp. Editorial and a conforming change in support of the use of soluble boron in the MPC water (see Proposed Change Numbers 3, 14, and 15).

qq. Conforming change in support of the addition of MPC-32 and non-fuel hardware to the authorized contents of HI-STORM 100. The additional PWR fuel assemblies and non-fuel hardware increases the source term for shielding. With no commensurate changes in the overpack, the dose rates increase. A 10 mrem/hr increase is considered moderate and easily accommodated by users.

rr. Conforming change to reflect the changes to 10 CFR 72.104 and 72.106 from rulemaking approved in October, 1998.

Proposed Change No. 26

TSAR Chapter 3

a. Table 3.0.1, is updated to incorporate all new appendices that are added to reflect the addition of the HI-STORM 100S, the MPC 32 and 24E, and the DFC's to the CoC.

b. Subsection 3.1.1 text is modified as necessary to reflect the fact that there are more than two MPC's. The currently approved TSAR specifically calls out "two" MPCs.

c. Table 3.2.1 is updated to reflect revised weight calculations and to include the weights for the HI-STORM 100S, the MPC32 and the MPC24E.

d. Table 3.2.2 is revised to update weight data for the HI-TRAC transfer casks and to include the addition of the MPC32 and MPC24E to the table.

e. Table 3.2.3 is revised to reflect center-of-gravity locations of all new and revised components.

f. Table 3.2.4 is revised to change the weight of the lift yoke for the HI-TRAC 100 to 3200 lb.

g. Subsection 3.4 is modified to reflect changes in text and tables that occurred because of the following items:

   1) Addition of MPC 32 and MPC24E.

   2) Addition of HI-STORM 100S and increase in diameter of the lift studs for the HI-STORM 100.

   3) Enhancements to HI-TRAC 125 and HI-TRAC 100.

   4) Textual changes are made as necessary to eliminate references to two MPC's and to add-in the necessary text to include the MPC32 and 24E. Textual changes are made to include reference to the HI-STORM 100S whenever HI-STORM 100 is considered. These text changes state and justify why the HI-STORM 100S need not be analyzed or

refer to a new or modified appendix where a calculation specific to the HI-STORM 100S is contained.

5) All safety factor tables throughout the subsection have been updated to reflect revised calculations in affected appendices and to reflect the addition of the new structural components.

h. Subsection 3.6.3 is revised to add new Appendices 3.AO – 3.AS to the list of Appendices and to add back the previously deleted appendices specific to the MPC-32.

i. The following items detail the modifications to specific appendices to reflect the addition of new components and the enhancement to existing components. No new calculational procedures are introduced; current approved calculations are either updated to reflect revised geometry or added in to reflect application to new components.

1) Appendix 3.A has a note added to Table 3.A.1 to permit measurements other than a plate test to be used to confirm the soil modulus.

2) Appendix 3.D is updated to reflect increase in diameter of lift stud.

3) Appendix 3.I is updated to reflect current thermal analysis results.

4) Appendix 3.K is updated to reflect increase in diameter of lift stud.

5) Appendix 3.L is updated to reflect increase in diameter of lift stud.

6) Appendix 3.M updated to include calculation for the heavier HI-STORM 100S lid.

7) Appendices 3.P and 3.R have been added back into the TSAR to reflect the addition of the MPC32.

8) Appendix 3.T is updated to reflect the addition of the MPC-32.

9) Appendix 3.U is updated to reflect current thermal analysis.

10) Appendix 3.V is added back to the TSAR to reflect the addition of the MPC-32.

11) Appendix 3.W is updated to reflect the current thermal analysis.

12) Appendix 3.Y is updated to incorporate MPC-32 and MPC-24E.

13) Appendix 3.AC is updated to use bounding weight of HI-STORM 100S lid in the calculation.

14) Appendix 3.AD updated to reflect current component weights and updated analysis of lid separation.

15) Appendix 3.AE updated to reflect revised finite element analysis that incorporates trunnion block geometry change to increase size and structural capacity.

16) Appendix 3.AF updated to reflect current thermal analysis.

17) Appendix 3.AH updated to reflect current geometry.

18) Appendix 3.AJ updated to reflect revised lid weights.

19) Appendix 3.AO added as a new appendix to evaluate HI-STORM 100S top lid retention in the event of a tipover.

20) Appendix 3.AP added as a new appendix to evaluate HI-STORM 100S top lid bolting.

21) Appendix 3.AQ added as a new appendix to evaluate free thermal expansion of the MPC-24E inside the HI-STORM 100.

22) Appendix 3.AR added as a new appendix supporting the use of the Transnuclear DFC and Thoria Rod Canister in the HI-STORM system.

23) Appendix 3.AS added as a new appendix supporting the analysis of generic DFC's for BWR and PWR fuel types.

Reason for Proposed Changes

a. Editorial.

b. Clarification.

c. To provide clarifying information regarding the weights used in the structural analyses. The weight calculations for all components have been updated as necessary to reflect component enhancements and "lessons learned." New weight data needed to be added to cover the new structural items (HI-STORM 100S, MPC-32, and MPC-24E) that are added to the proposed TSAR revision.

d. To provide updated information regarding the weights of the components. The weight of the transfer casks (mainly the transfer lid) has been updated as necessary to reflect enhancements and "lessons learned."

e. To provide updated information on center-of-gravity locations.

f. To correct the value based on actual lift yoke design.

g. Subsection 3.4 is revised throughout to provide updated information reflecting calculation changes caused by changed weights in the existing structural components and the inclusion of new and enhanced components in the system. Since many structural appendices are updated or added to make them current with enhancements or changes in configuration based on "lessons learned", the safety factor summary tables throughout the subsection required updating and/or additions.

h. Editorial.

i. Appendices

   1) To allow site flexibility in determination of soil properties prior to pouring concrete.

   2) The lift stud diameter where it is threaded into lifting block in HI-STORM 100 overpack has been increased from 3" to 3.25" diameter.

   3) Clarification for consistency with thermal analysis results summarized in tabular form in Chapter 4.

   4) The lift stud diameter where it is threaded into lifting block in HI-STORM 100 overpack has been increased from 3" to 3.25" diameter.

   5) The lift stud diameter where it is threaded into lifting block in HI-STORM 100 overpack has been increased from 3" to 3.25" diameter.

   6) Calculation update to reflect heavier component.

   7) Conforming change in support of adding MPC-32 back into the CoC.

   8) Conforming change in support of adding MPC-32 back into the CoC.

   9) Conforming change to reflect current thermal analysis.

10) Conforming change in support of adding MPC-32 back into the CoC.

11) Conforming change to reflect current thermal analysis.

12) Conforming change in support of adding MPC-32 and MPC-24E back into the CoC.

13) HI-STORM 100S lid is heavier than lid of HI-STORM 100.

14) For consistency with current transfer lid weight and tipover results from Appendix 3.AN.

15) Consistent with revised analysis that reflects new trunnion block geometry. The trunnion block geometry has been changed on both HI-TRAC overpacks to make the trunnion identical to HI-STAR.

16) Conforming change to reflect current thermal analysis.

17) For consistency with new lid geometry.

18) HI-TRAC 100 transfer lid weight has been decreased and lid separation loads are made consistent with results from Appendix 3.AN rather than assumed as an unreasonably large bounding value.

19) New appendix in support of HI-STORM 100S overpack.

20) New appendix in support of HI-STORM 100S overpack.

21) New appendix to evaluate free thermal expansion of MPC-24E.

22) New appendix for Dresden TN DFC and Thoria Rod Canister.

23) New appendix for new Holtec generic DFCs.

Justification for Proposed Changes

a. Editorial

b. Editorial.

c. Conforming change in support of HI-STORM 100S, MPC-24E, and MPC-32.

d. Conforming changes in support of design enhancement for the HI-TRAC transfer cask and transfer lid.

e. Conforming change in support of new designs and design changes.

f. The lift yoke weight is an estimated value provided for information to the users to determine total load on the plant crane hook based on their actual lift yoke weight. In designing lift yokes since HI-STORM was first licensed, the weight was found to be lower.

g. Subsection 3.4

1) MPC-24E and MPC-32:

The addition of the MPC-24E and MPC-32 to the CoC requires that new text and tabular information be added to Subsection 3.4. Since the MPC-24E does not alter the weight of the "bounding" MPC, this change has minimal effect on the specific calculation appendices. The addition of the MPC-32 to the TSAR requires that text, tables, and calculations that were removed prior to initial approval of the TSAR be added back to the proposed Revision 11 of the TSAR. Appendix 3.Y specifically addresses each MPC in turn, so this appendix does include the extension of previous calculations and results to include the MPC-24E

2) HI-STORM 100S and Increased Lift Stud Diameter

Generally, the HI-STORM 100S results are bounded by those using the already approved HI-STORM since the weight and length of the overpack is decreased. However, since the lid weight of the HI-STORM 100S is increased, calculations that use a bounding lid weight have been re-visited using the larger value for the bounding lid weight. To accommodate the revised lid configuration and prevent lid separation during a hypothetical tipover event, a segmented shear ring has been added so that the lid lifting bolts are free of shear load during the event. The structural evaluation of the tipover event for the HI-STORM 100S lid has been included in the Appendix 3.AO to address the HI-STORM 100S.

The currently approved lift stud for the HI-STORM 100 calls for a 3.25" diameter at the top and a 3" diameter at the bottom (where the stud threaded into the lifting block). In the proposed revision, the stud is called out with a single 3.25" diameter for ease of procurement and fabrication. The new stud meets all loading requirements.

3) Enhancements to HI-TRAC 125 and HI-TRAC 100

Numerous enhancements have been made to the HI-TRAC transfer casks. The trunnions on both casks have been made identical (tip-to-tip diameter across cask) to those used on the HI-STAR 100. This required an increase in size of the trunnion block so calculations have been updated to reflect this modification. No "new" calculation methodology is employed to address the change in configuration.

The addition of larger studs to hold the top lid to the body of the HI-TRAC overpack enhances the ability of the studs to retain the lid in-place in the event of a tipover. The tipover calculation is revisited and we demonstrate that the tongue and groove construction is not needed.

Tongue and groove construction has also been removed from the pool lid and the transfer lid in both transfer casks. This fabrication enhancement is allowed because the driving calculation for the tipover event was re-visited and the input loads taken directly from the DYNA3D analysis in Appendix 3.AN (rather than using very conservative overestimates of the shear load in the currently approved TSAR). While Appendix 3.AN is unchanged in the proposed revision, the appendices addressing lid separation have been revised with the correct input loads that are consistent with the tipover analysis in Appendix 3.AN.

4) Text Changes are clarifying in nature to discuss the design changes and new designs, as appropriate.

5) Conforming changes resulting from re-analysis of new designs and design changes.

h. Editorial.

i. Appendices (Refer to the referenced Appendix text in Attachment 5, Chapter 3 for detailed justifications and analytical results)

1) Based on user feedback, flexibility has been added to allow users to perform appropriate testing to qualify the soil beneath the ISFSI pad. This may or may not include a plate test.

2) Larger diameter stud is a fabrication enhancement and increases structural safety margin.

3) Conforming change.

4) Larger diameter stud is a fabrication enhancement and increases structural safety margin.

5) Larger diameter stud is a fabrication enhancement and increases structural safety margin.

6) See Appendix 3.M. The heavier Hi-STORM 100S lid is now the bounding weight.

7) See Appendices 3.P and 3.R for discussion of MPC-32.

8) See Appendix 3.T for discussion of MPC-32.

9) Reflects updated thermal analysis.

10) See Appendix 3.V for discussion of MPC-32.

11) Reflects updated thermal analysis.

12) See Appendix 3.Y for discussion of MPC-32 and MPC-24E.

13) See Appendix 3.AC. The heavier Hi-STORM 100S lid is now the bounding weight.

14) See Appendix 3.AD. The heavier Hi-STORM 100S lid is now the bounding weight.

15) Finite element analysis has been revised for the updated trunnion block geometry.

16) Reflects updated thermal analysis.

17) See Appendix 3.AH. Calculations updated to reflect new top lid geometry.

18) See Appendix 3.AJ for analysis of revised lid weights.

19) See Appendix 3.AO for discussion of tipover considering HI-STORM 100S lid.

20) See Appendix 3. AP for analysis of HI-STORM 100S top lid bolting.

21) See Appendix 3.AQ for calculation of thermal expansion of MPC-24E.

22) See Appendix 3.AR and Proposed Change Numbers 5 and 11.

23) See Appendix 3.AS and Proposed Change Number 5.

Proposed Change No. 27

TSAR Chapter 4

a. Section 4.3 text and Tables 4.3.2, 4.3.3, 4.3.5, 4.3.6, and 4.3.7 are revised and Table 4.3.8 added as conforming changes in support of changes proposed in Section I of this attachment to modify/add fuel assembly array/classes. These revisions address fuel cladding stress and temperature limits for the following fuel:

   B&W 15x15 Mark B-11 (Entergy-ANO)
   CE-14x14 (Millstone Unit 2)
   GE 6x6 Dresden-1 Fuel (with TN Damaged Fuel Container)
   GE 7x7 (GPUN-Oyster Creek)
   GE 8x8 (GPUN-Oyster Creek)
   GE 8x8 QUAD+ (NYPA-Fitzpatrick)
   GE 8x8 (TVA-Browns Ferry)
   Seimens 9x9 SPC-5 (Entergy-Grand Gulf)
   ANF 8x8
   ANF-9X (9x9)

b. Subsection 4.4.1.1.2 text and Tables 4.4.1 through 4.4.2 are revised, and new Table 4.4.23 is added as a conforming changes in support of changes proposed in Section I of this attachment to modify/add fuel assembly array/classes (see list in Item ‘a’ above).

c. Rod rupture assumptions for basket conductivities deleted in Subsection 4.4.1.1.11.

d. Subsection 4.5.1.1.6 is revised to change the units of “t” from “°F” to “hrs.” and revise helium flow rates.

e. New Subsection 4.4.1.1.13 is added as a conforming change in support of changes proposed in Section I of this attachment to provide a discussion of Low Heat Emitting (LHE) fuel, including the TN/D-1 damaged fuel canister and the D-1 Thoria Rod Canister.

f. Subsection 4.4.4 and Table 4.4.14 are revised as conforming changes in support of changes proposed in Section I of this attachment to address the addition of non-fuel PWR hardware (BPRAs and TPDs).

g. Section 4.1 revised to include discussion on MPC-32 and MPC-24E and Rayleigh effect.

h. Subsection 4.4.1.1.4 revised to include discussion on axial conductivity of MPC and damaged fuel storage in MPC-24E and MPC-68.

i. Role of Rayleigh effect and Table 4.4.4 revised in Subsection 4.4.1.1.5.

j. Subsection 4.4.1.1.9 revised to include discussion on HI-STORM 100S and regionalized loading.

k. Subsection 4.4.2 revised to include results for MPC-32, MPC-24E and regionalized loading and revise results (MPC-68 & MPC-24). Tables 4.4.3, 4.4.9, 4.4.10, 4.4.15, 4.4.19, 4.4.20, 4.4.21 revised, Tables 4.4.17 and 4.4.18 deleted and 4.4.26 through 4.4.31 added.

l. Subsection 4.5.1.1.5 and Tables 4.5.5 and 4.5.6 revised.

m. Subsection 4.5.1.1.4 revised, Table 4.5.7 deleted and Table 4.5.9 added.

n. Subsections 4.5.1.1.7 and 4.5.2 and Tables 4.5.2 through 4.5.4 revised.

Reason for Proposed Changes

a. This is a conforming change in support of changes to the CoC. See Section I of this attachment.

b. This is a conforming change in support of changes to the CoC. See Section I of this attachment.

c. Eliminate overly conservative rod rupture assumptions.

d. Editorial. To align results with revised heat loads.

e. This is a conforming change in support of changes to the CoC. See Section I of this attachment.

f. This is a conforming change in support of changes to the CoC. See Section I of this attachment.

g. This is a conforming change in support of changes to CoC for inclusion of MPC-32 and MPC-24E for PWR fuel storage. Rayleigh effect ignored in the thermal analysis.

h. To alleviate excessive conservatism in the axial heat dissipation assumption. Conforming change in support of changes to CoC for permitting fuel storage in damaged fuel containers.

i. Rayleigh effect ignored in thermal analysis.

j. This is a conforming change in support of changes to the CoC. See Section I of this attachment.

k. This is a conforming change in support of changes to the CoC. See Section I of this attachment.

l. To align results with revised heat loads.

m. To align results with revised heat loads.

n. To align HI-TRAC analyses with revised heat loads.

Justification for Proposed Change

a. See thermal evaluation of this change in Section I of this attachment.

b. See thermal evaluation of this change in Section I of this attachment.

c. Relatively minor impact of rod rupture on MPC heat dissipation characteristics.

d. Editorial. Helium flow rates computed at bounding heat load and reported.

e. See thermal evaluation of this change in Section I of this attachment.

f. See thermal evaluation of this change in Section I of this attachment.

g. Thermal evaluation of MPC-32 and MPC-24E is reported in Section 4.4. Conservative to neglect heat dissipation by Rayleigh effect.

h. See thermal evaluation of this change in Section I of this attachment and the TSAR changes in Subsection 4.4.1.1.4.

i. Conservative to neglect heat dissipation by Rayleigh effect.

j. See thermal evaluation of this change in Section I of this attachment.

k. See thermal evaluation of this change in Section I of this attachment.

l. Time to boil calculated on bounding heat load and reported in Table 4.5.6.

m. Vacuum temperatures computed and reported in an added Table 4.5.9.

n. Temperatures and pressures computed at bounding heat load and reported.

Proposed Change No. 28

TSAR Chapter 5 Changes

a. References to Technical Specifications have been changed to Appendix B of the CoC.

b. Section 5.0 is revised to include a discussion of MPC-24E, MPC-32, MPC-68FF, HI-STORM 100S, antimony-beryllium sources, BPRAs, TPDs, CRAs, APSRs, and regionalized loading.

c. Section 5.0 is revised to change the wording of acceptance criterion 4.

d. Section 5.1 is revised to add Dresden Unit 1 antimony-beryllium neutron sources to the list of neutron sources.

e. References to intact fuel assemblies and design basis damaged fuel assemblies (which was previously Dresden Unit 1 and Humboldt Bay fuel) have been change in Chapter 5 to support the addition of generic damaged PWR and BWR fuel.

f. Discussion of and references to the MPC-32 and regionalized loading in all baskets have been added to Section 5.1.

g. Discussion of burnup and cooling times analyzed have been changed in Section 5.1 to support the increase in heat load capability for the MPCs.

h. Subsection 5.1.1 is revised to add the word "critical" before the word organ in the item 1 discussion about 10CFR72.104 regulations.

i. Subsection 5.1.1 is revised to discuss MPC-32, HI-STORM 100S, Thoria rod canister, non-fuel hardware, and antimony-beryllium neutron sources.

j. Subsection 5.1.2 is revised to change the wording in the discussion of 10CFR72.106.

k. The HI-TRAC accident condition dose rate in Subsection 5.1.2 was increased to accommodate an increase in the burnup and cooling time in the CoC.

l. Tables 5.1.1 and 5.1.4 were added to support the addition of the MPC-32.

m. Tables 5.1.2 and 5.1.5 were changed to add BPRA dose rates.

n. Tables 5.1.3 and 5.1.6 were changed to represent dose rates from the HI-STORM 100S.

o. Tables 5.1.7, 5.1.8, and 5.1.10 were changed to add BPRA dose rates.

p. Figure 5.1.1 was changed to refer to HI-STORM 100 overpack rather than HI-STORM overpack. Figure 5.1.12 was added to show dose locations around the HI-STORM 100S.

q. Minor editorial changes to Section 5.2, Subsection 5.2.1, and Subsection 5.2.2 to discuss damaged fuel and uniform versus regionalized loading.

r. Section 5.2.4 was modified and Subsections 5.2.4.1 and 5.2.4.2 were added to support the addition of non-fuel hardware in the CoC.

s. Subsection 5.2.5.1 was modified to mention Indian Point 1 fuel to support that addition of this array class in the CoC.

t. Subsection 5.2.5.3 was modified to add discussion about heavy metal mass.

u. Subsection 5.2.6 was added to discuss the Thoria rod canister.

v. Subsection 5.2.7 was added to discuss fuel assembly neutron sources.

w. Subsection 5.2.8 was added to discuss stainless steel BWR channels.

x. Minor editorial changes on a significant number of tables in Section 5.2.

y. Tables 5.2.3, 5.2.9, and 5.2.20 were modified and Tables 5.2.4, 5.2.11, and 5.2.15 were added.

z. Tables 5.2.6, 5.2.13, and 5.2.17 were modified.

aa. Tables 5.2.26 and 5.2.28 were modified.

bb. Tables 5.2.30 through 5.2.38 were added.

cc. Subsection 5.3.1 was modified to add discussion about the HI-STORM 100S and modeling discrepancies for the HI-TRACs.

dd. Subsection 5.3.1.2 was modified to add a brief discussion on the port covers.

ee. Figures 5.3.1, 5.3.4, and 5.3.18 were added.

ff. Section 5.4 was modified to add discussion of the MPC-32, regionalized loading and make editorial changes.

gg. Dose rates in Subsection 5.4.1 were changed.

hh. Subsection 5.4.2 was renamed 5.4.2.1 and Subsection 5.4.2.2 was added.

ii. Subsections 5.4.6, 5.4.7, and 5.4.8 were added.

jj. Tables 5.4.2 through 5.4.5 and 5.4.8 through 5.4.10 were modified and Tables 5.4.11 through 5.4.21 were added.

Reason for Proposed Changes

a. This is a conforming change to support the revised format for acceptable fuel storage criteria.

b. This is a conforming change to support the addition of these items to the CoC for storage.

c. The wording of 10CFR72.104 and 10CFR72.106 has changed since Revision 10 of the HI-STORM TSAR.

d. This is a conforming change to support the addition of this item in the CoC.

e. This is a conforming change to support the addition of generic damaged fuel in the CoC.

f. This is a conforming change to support the addition of these items in the CoC.

g. This is a conforming change to support the increase in the burnup and cooling times in the CoC.

h. The wording of 10CFR72.104 has changed since Revision 10 of the HI-STORM TSAR.

i. This is a conforming change to support the addition of these items in the CoC.

j. The wording of 10CFR72.106 has changed since Revision 10 of the HI-STORM TSAR.

k. This is a conforming change to support the increase in the burnup and cooling times in the CoC.

l. This is a conforming change to support the addition of this item in the CoC.

m. This is a conforming change to support the addition of non-fuel hardware.

n. This is a conforming change to support the addition of the HI-STORM 100S.

o. This is a conforming change to support the addition of non-fuel hardware.

p. This is a conforming change to support the addition of the HI-STORM 100S.

q. This is a conforming change to support the addition of generic damaged fuel and regionalized loading.

r. This is a conforming change to support the addition of non-fuel hardware.

s. This is a conforming change to support the addition of this fuel in the CoC.

t. This is a conforming change to support the increase of the uranium mass loadings in the CoC.
u. This is a conforming change to support the addition of this item in the CoC.

v. This is a conforming change to support the addition of antimony-beryllium neutron sources in the CoC.

w. This is a conforming change to support the addition of stainless steel BWR channels in the CoC.

x. This is a conforming change to support generic damaged fuel and the relocation of the approved contents to the CoC from Chapter 12.

y. This is a conforming change to support the addition of the MPC-32 in the CoC.

z. This is a conforming change to support the increase in the heat load for the MPC-68 in the CoC.

aa. This is a conforming change to support the increase in the uranium mass for some array classes in the CoC.

bb. This is a conforming change to support the addition of non-fuel hardware and thoria rod canisters in the CoC.

cc. This is a conforming change to support the addition of the HI-STORM 100S and minor design enhancements to the HI-TRACs.

dd. This is a conforming change to support minor design enhancements to the MPCs.

ee. This is a conforming change to support the addition of the MPC-32 and HI-STORM 100S.

ff. This is a conforming change to support the addition of the MPC-32 and regionalized loading in all baskets and increased heat loads in the MPC-68.

gg. This is a conforming change to support the increase heat loads of the baskets in the CoC.

hh. This is a conforming change to support the addition of generic damaged fuel.

ii. This is a conforming change to support the addition of non-fuel hardware, antimony-beryllium neutron sources, and thoria rod canister.

jj. This is a conforming change to support the addition of the MPC-32, antimony-beryllium sources, and non-fuel hardware in the CoC and to support the increase in the heat loads for the MPC-68 in the CoC.

Justification for Proposed Changes

a. Editorial.

b. See shielding evaluation in Section I of this attachment.

c. This is a conforming change to bring the wording in the TSAR into agreement with the current regulations.

d. See shielding evaluation in Section I of this attachment.

e. See shielding evaluation in Section I of this attachment.

f. See shielding evaluation in Section I of this attachment.

g. See revised Chapter 5 in Attachment 5.

h. This is a conforming change to bring the wording in the TSAR into agreement with the current regulations.

i. See shielding evaluation in Section I of this attachment.

j. This is a conforming change to bring the wording in the TSAR into agreement with the current regulations.

k. See revised Chapter 5 in Attachment 5.

l. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

m. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

n. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

o. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

p. See shielding evaluation in Section I of this attachment.

q. Editorial.

r. See shielding evaluation in Section I of this attachment.

s. See shielding evaluation in Section I of this attachment.
t. See shielding evaluation in Section I of this attachment.

u. See shielding evaluation in Section I of this attachment.

v. See shielding evaluation in Section I of this attachment.

w. See shielding evaluation in Section I of this attachment.

x. Editorial.

y. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

z. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

aa. See shielding evaluation in Section I of this attachment.

bb. See shielding evaluation in Section I of this attachment.

cc. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

dd. See revised Chapter 5 in Attachment 5.

ee. See shielding evaluation in Section I of this attachment.

ff. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

gg. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

hh. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

ii. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

jj. See revised Chapter 5 in Attachment 5 and shielding evaluation in Section I of this attachment.

Proposed Change No. 29

TSAR Chapter 6

a. Throughout Chapter 6, all references to the Technical Specifications are replaced by references to the Certificate of Compliance.

b. In Section 6.1, fourth paragraph, the second sentence is revised to change "NUREG-1536" to "10CFR72.124(b)", and delete "... as required by 10CFR72.124(b)".

c. "$k_{eff} < 0.40$" is changed to "$k_{eff} < 0.52$"

d. Table numbers in Section 6.1 are revised as follows:

Tables 6.1.2 and 6.1.3 become Tables 6.1.7 and 6.1.8

Table references throughout TSAR Chapter 6 are updated accordingly.

e. Table numbers in section 6.2 are revised as follows:

Tables 6.2.4 through 6.2.7 become Tables 6.2.6 through 6.2.9
Tables 6.2.8 through 6.2.14 become Tables 6.2.11 through 6.2.17
Tables 6.2.15 through 6.2.23 become Tables 6.2.19 through 6.2.27
Tables 6.2.24 through 6.2.29 become Tables 6.2.29 through 6.2.34
Tables 6.2.30 through 6.2.39 become Tables 6.2.36 through 6.2.45

Table references throughout TSAR Chapter 6 are updated accordingly.

f. Changes are made throughout Chapter 6 to introduce the two new PWR basket designs, MPC-24E and MPC-32. This includes the following text additions and new tables and figures:

1. In Section 6.1, second paragraph, the MPC-24E is listed together with the MPC-24 in the first design parameter.

2. In Section 6.1, sixth paragraph, the two new basket designs are listed.

3. In Section 6.1, when presenting the results of the analysis, the additional basket designs are addressed.

4. Tables 6.1.3 through 6.1.6 are added to Section 6.1 to show results for the additional basket versions.

5. Changes are made to subsection 6.2.1 and 6.2.2, and Tables 6.2.4 and 6.2.5 are added to address the additional PWR MPC designs.

6. Subsection 6.3.1 and Tables 6.3.2 through 6.3.4 are revised to address the additional MPC basket designs. Figures 6.3.1a, 6.3.2, 6.3.4a and 6.3.5 are added, and Figure 6.3.7 is revised.

g. Changes are made throughout Chapter 6 to introduce soluble boron credit for all PWR basket designs. This includes the following text additions and new tables:

1. In Section 6.1, second paragraph, the number of principal design parameter is increased from three to four and design parameter four is added, introducing the administrative limit on the minimum soluble boron concentration, i.e. the soluble boron credit.

2. In Section 6.1, sixth paragraph, soluble boron credit is applied for all PWR baskets (MPC-24, MPC-24E and MPC-32). For the MPC-24 and MPC24E, this is only required for higher fuel enrichments.

3. In Section 6.1, eighth paragraph, the last sentence "Soluble boron credit ..." is deleted

4. In Section 6.1, 11th paragraph, the soluble boron concentration is added to the list of design parameters.

5. In Section 6.1, in the list of conservative design criteria and assumptions, changes are made and criteria and assumptions are added relating to the soluble boron credit.

6. In Section 6.1, when presenting the results of the analysis, changes are made to address the soluble boron credit.

7. Tables 6.1.2, 6.1.4 and 6.1.6 are added to Section 6.1 to show results for the PWR basket design with credit for soluble boron.

8. Changes are made to subsection 6.2.1 and 6.2.2, and Tables 6.2.4 and 6.2.5 are added to address the additional PWR MPC designs and the soluble boron credit.

9. Subsections 6.2.2.2, 6.2.2.3 and 6.2.2.4 are added to specify enrichment limits and minimum soluble boron concentrations for the MPC-24, MPC-24E and MPC-32, respectively.

10. Subsection 6.3.1 and Tables 6.3.2 through 6.3.4 are revised to address the additional MPC basket designs with soluble boron credit.

11. Subsection 6.4.2.1.2 and Table 6.4.6 are added to address the determination of the moderator density for optimum moderation.

12. Table 6.4.2 is extended to show the impact of partial flooding with borated water.

h. Changes are made throughout Chapter 6 to introduce the new BWR basket designs MPC-68FF. This includes the following:

   1. In Section 6.1, sixth paragraph, The new MPC-68FF is listed as a variation of the MPC-68.

   2. In Section 6.1, when presenting the results of the analysis, the MPC-68FF is addressed.

   3. Changes were made to Subsection 6.2.3 to address the additional MPC-68FF design.

i. Changes are made throughout Chapter 6 to extend the scope of fuel array classes. This includes the following:

   1. In Section 6.1, Tables 6.1.1, 6.1.7, and 6.1.8 are revised.

   2. Tables 6.2.1, 2, 8, 23, 24, 26, 30, 32, 33, 34, 38, 41, 42, 44 and 45 and Appendix 6.C are revised to reflect changes to the authorized fuel contents for HI-STORM 100.

   3. Tables 6.2.10, 18, 28 and 35, and Figure 6.2.1 are added to reflect additions to the authorized fuel contents for HI-STORM 100.

j. Changes are made throughout Chapter 6 to introduce the new generic PWR and BWR DFCs. This includes the following:

   1. In Section 6.1, when discussing results, changes were made to address the new generic DFCs

   2. Tables 6.1.9 and 6.1.11 are added to reflect the changes due to the new PWR and BWR Generic Damaged Fuel Container.

   3. Table 6.1.10 is added to Section 6.1 for consistency of presentation, together with new Tables 6.1.9 and 6.1.11.

   4. Changes were made to Subsection 6.2.4 to address the extended range of damaged fuel and fuel debris authorized for loading into the generic BWR and PWR DFC. These changes also clarify the applicability of the existing text sections.

5. Subsections 6.2.4.2 and 6.2.4.3 are added to specify enrichment limits for damaged fuel / fuel debris loaded into generic DFCs for BWR and PWR fuel, respectively.

6. Section 6.4.4 is revised and significantly expanded to explain the methodology used to qualify the new generic BWR and PWR DFCs. This includes changes to Table 6.4.5, additional Tables 6.4.7 to 6.4.9 and additional Figures 6.4.11 through 6.1.18

k. The following changes were made in support of adding the Thoria Rod Canister to the list of approved contents:

   1. Subsection 6.2.5 is added, together with Table 6.2.46. This subsection and table provide information about the Thoria Rod Canister (see Section I of this attachment).

   2. In Table 6.3.4, Specification for fuel in Thoria Rods is added.

   3. Subsection 6.4.6 is added, discussing results of the criticality analyses for the thoria rod canister.

l. In Table 6.3.4, the MOX fuel specification is revised as follows

92235, Atom-Density from 1.659E-04 to 1.719E-04
92235, Wgt.-Fraction from 6.150E-03 to 6.380E-03
92238, Wgt.-Fraction from 8.586E-01 to 8.584E-01

m. Subsection 6.4.7 is added, discussing the impact of sealed water rods in BWR fuel assemblies on the reactivity of the cask.

n. Subsection 6.4.8 is added, discussing the impact of including non-fuel hardware with PWR fuel assemblies on the reactivity of the cask.

o. Subsection 6.4.9 is added, discussing the impact of neutron sources in BWR fuel assemblies on the reactivity of the cask.

Reason for Proposed Changes

a. Editorial clarification.

b. To bring text in line with a recent change to 10CFR72.124(b) (FR publication date 6/22/99)

c. This is a conforming change to support the new MPC-32 basket design with higher fuel enrichment (see Section I of this attachment, Proposed Change No. 3 and 15)

d. This is a conforming change to support the new PWR basket designs and the soluble boron credit for PWR fuel (see Section I of this attachment, Proposed Change No. 3, 14, 15 and 17)

e. These are conforming changes to support the new PWR basket designs, the soluble boron credit for PWR fuel and the extended scope of fuel array classes (see Section I of this attachment, Proposed Change No. 3, 14, 15, 17, 18, 20 and 21)

f. These are conforming changes to support the new PWR fuel basket designs (see Section I of this attachment, Proposed Change No. 14 and 15)

g. These are conforming changes to support the soluble boron credit for existing and new PWR fuel basket designs (see Section I of this attachment, Proposed Change No. 3, 14, 15 and 17)

h. These are conforming changes to support the new MPC-68FF basket design (see Section I of this attachment, Proposed Change No. 16)

i. These are conforming changes to support the extended scope of fuel array classes (see Section I of this attachment, Proposed Change No. 18, 20 and 21)

j. These are conforming changes to support the extended scope of damaged fuel and fuel debris, and the new Generic PWR and BWR damaged fuel containers (see Section I of this attachment, Proposed Change No. 5 and 10)

k. These are conforming changes in support of adding the Thoria Rod Canister to the approved contents (see Section I of this attachment, Proposed Change No. 11)

l. This is a conforming change to support the increase in the U-235 enrichment in the MOX fuel rods for fuel assembly array/class 6x6B (see Section I of this attachment, Proposed Change No. 20)

m. This is a conforming change in support of adding BWR fuel assemblies with sealed water rods to the approved contents (see Section I of this attachment, Proposed Change No. 18)

n. This is a conforming change to support the addition of PWR non-fuel hardware to the approved contents (see Section I of this attachment, Proposed Change No. 9)

o. This is a conforming change support of adding BWR assemblies with neutron sources to the approved contents (see Section I of this attachment, Proposed Change No. 12).

Justification for Proposed Changes

a. Clarification

b. 10 CFR 72.124(b) was amended in June, 1999 to no longer require continued verification of the efficacy of neutron absorbers in dry storage systems. This proposed TSAR text change us a conforming change in support of this change to the regulations.

c. See Criticality evaluations for these changes in Section I of this attachment

d. and e. Editorial

f. through o. See Criticality evaluations for these changes in Section I of this attachment

Proposed Change No. 30

TSAR Chapter 7

a. Subsection 7.1.1 and 7.1.3 is revised to clarify that root and final pass PT is applicable only for multi-pass welds.

b. Subsection 7.1.5 is revised to include storage of damaged fuel in the MPC-68FF and MPC-24E and fuel debris in the MPC-68FF; and to remove the description of the number of DFCs containing fuel debris that may be loaded into an MPC.

c. Table 7.1.2 is revised to change “full” to “partial” in describing the MPC closure ring segment to closure ring segment radial welds.

d. Table 7.1.3 is revised to clarify that root pass PT examination is required only for multi-pass welds.

e. Subsection 7.2.1 is revised to clarify that the specified leakage rate of $5x10^{-6}$ atm-cm/sec is the reference condition leakage rate.

f. Subsection 7.2.3 is revised to address the annual dose equivalent to the whole body, thyroid and other critical organs; and to clarify that root and final pass PT is applicable only for multi-pass welds.

g. Subsection 7.2.7.1 is revised to change the title to Confinement Boundary Leakage Rate.

h. Subsection 7.2.7.2 is revised to refer to Chapter 4 tables for the minimum free volume; and to add that the minimum free volume of the MPC-24E conservatively bound the MPC-24.

i. Subsection 7.2.7.3 is revised to clarify that the release fraction is that portion of the radionuclide inventory that is released from the inside of the fuel rod to the MPC cavity.

j. Subsection 7.2.8 is revised to address the annual dose equivalent to the whole body, thyroid and other critical organs; and to revise the location of normal and off-normal doses.

k. Subsection 7.2.8.1 is revised to address annual dose equivalents to the whole body; and that the annual dose equivalent to the whole body is the sum of the committed effective dose equivalent and the deep dose equivalent; revised title to remove Total Effective Dose Equivalent.

l. Subsection 7.2.8.2 is revised to address annual dose equivalents to the critical organs; clarified that the annual dose equivalent to a critical organ is the sum of the committed dose equivalent and the deep dose equivalent; and removed the description of dose to the lens of the eye.

m. Subsection 7.2.8.3 is added to address and summarize annual dose equivalent under normal and off-normal conditions to the whole body, thyroid and other critical organs at the minimum site boundary.

n. Subsection 7.2.9 is revised to combine assumption 2 and assumption 3; add assumption that the leak hole diameter calculated for reference test conditions conservatively estimates the leak hole diameter from actual test conditions; and clarify last assumption to specify that leakage rate is at reference test conditions.

o. Section 7.3 is revised to discuss committed dose equivalent (CDE), deep dose equivalent (DDE), lens dose equivalent (LDE), shallow dose equivalent (SDE), total effective dose equivalent (TEDE) and total organ dose equivalent (TODE).

p. Subsection 7.3.1 is revised to update source terms

q. Subsection 7.3.2 is revised to include the MPC-24E, MPC-32 and MPC-68FF to the confinement evaluation.

r. Subsection 7.3.3.1 is revised to change the title to Confinement Boundary Leakage Rate; and to clarify that use of reference test conditions for determining the leak hole diameter conservatively bounds the leak hole diameter under actual test conditions.

s. Subsection 7.3.3.2 is revised to clarify that the release fraction is that portion of the radionuclide inventory that is released from the inside of the fuel rod to the MPC cavity.

t. Subsection 7.3.4 is revised to discuss the committed dose equivalent (CDE), deep dose equivalent (DDE), lens dose equivalent (LDE), shallow dose equivalent (SDE), total effective dose equivalent (TEDE) and total organ dose equivalent (TODE); revised location of doses.

u. Subsection 7.3.4.1 is revised to clarify that the total effective dose equivalent is the sum of the committed dose equivalent and the deep dose equivalent.

v. Subsection 7.3.4.2 is revised to discuss the lens dose equivalent for BWR and PWR MPCs.

w. Subsection 7.3.5 is revised to discuss bounding accident doses at the site boundary for BWR fuel and PWR fuel separately; removed annual doses and relocated in Subsection 7.2.8.3.

x. Subsection 7.3.6 is revised to add assumption that the leak hole diameter calculated for reference test conditions conservatively estimates the leak hole diameter from actual test conditions; clarified last assumption to specify that leakage rate is at reference test conditions.

y. Table 7.3.1 is revised to add inventories for the following isotopes: ^{237}Np, ^{242}Pu, ^{242}Am, ^{242m}Am.

z. Table 7.3.2 is revised to reflect the updated confinement analysis for normal, off-normal and hypothetical accident conditions for the MPC-24 and MPC-24E.

aa. Tables 7.3.3 and 7.3.4 are renumbered 7.3.4 and 7.3.5. Renumbered Tables 7.3.4 and 7.3.5 are revised to reflect to updated confinement analysis for normal, off-normal and hypothetical accident conditions for the MPC68, MPC68FF and MPC-68F.

bb. Table 7.3.3 is added to include the updated confinement analysis for normal, off-normal and hypothetical accident conditions for the MPC-32.

cc. Tables 7.3.5 and 7.3.6 are renumbered as 7.3.6 and 7.3.7 respectively.

dd. Table 7.3.7 is revised to include the parameters for the actual test conditions of 85 psig (min) and 373K max.

ee. Table 7.3.8 is added to summarize bounding doses for BWR and PWR fuel and compare them to the regulatory limits of 10CFR72.104(a) and 10CFR72.106(b).

ff. Appendix A is revised to add detailed calculations of estimated doses from MPC-32 for normal, off-normal and hypothetical accident conditions of storage.

Reason and Justification for Proposed Changes

a. This is a conforming change to reflect the reduction of closure ring weld sizes on the design drawings (see Attachment 4).

b. Editorial change

c. This is a conforming change to reflect the reduction of closure ring weld sizes on the design drawings (see Attachment 4).

d. This is a conforming change to reflect the reduction of closure ring weld sizes on the design drawings (see Attachment 4).

e. through ff. The proposed changes to the discussion of the confinement analysis for HI-STORM 100 reflect the updated analyses performed to demonstrate compliance with 10CFR72.104 and 72.106. The results of the updated confinement analysis show continued compliance with the dose limits 10CFR72.104 and 72.106.

The confinement analyses supporting TSAR Chapter 7 were also revised to account for new MPC designs (MPC-24E and MPC-32) add new isotope inventories for higher burnup fuel at shorter cooling times (45,000MWD/MTU at 5 years cooling time).

Proposed Change No. 31

TSAR Chapter 8

a. General Changes

1) Add water boron concentration requirements.

2) Incorporate the HI-STORM 100S.

3) Add the MPC-32.

4) Remove the lid-mounted MPC downloader option.

5) Replace alignment pins with alignment device.

6) Replace volumetric examination of field welds with ultrasonic or multi-layer PT examination.

7) Editorial changes to improve readability and enhance clarity.

j. 8.1.2 Step 12.d: Revise the inflation pressure to Inflate the seal to between 30 and 35 psig or as directed by the manufacturer.

k. 8.1.2 Step 3.a. Allow the HI-TRAC to be downended with the pool lid as long as it is fitted with auxiliary shielding.

l. 8.1.5 Reformat the numbering.

m. 8.1.5 Step 1. Remove the step that flushes the upper surface of HI-TRAC and MPC with plant demineralized water to remove any activated or highly radioactive particles from HI-TRAC or MPC. Inserted step to remove any activated or highly radioactive particles from HI-TRAC or MPC.

n. 8.1.5 Step 1.s. Add step to verify lid dose rates are within Technical Specifications limits.

o. 8.1.5 Step 2. Move the removal of the annulus seal to after the water removal for welding.

p. 8.1.5 Step 2.b. Change the amount of water to be removed prior to welding to between 50 and 120 gallons.

q. 8.1.5 Step 4.d. Change the helium test pressure to 90+5-0 and allowed the correlation of the test pressure to the acceptance criteria.

r. 8.1.5 Step 5. Change the backfill procedure to be consistent with the revised Technical Specifications. Includes all references to water volume measurement.

s. 8.1.5 Step 5.h. Allow users to continue blowing the MPC with gas to remove excess MPC water.

t. 8.1.5 Steps 8 and 9. Change the vent and drain cover plate weld leakage testing procedure.

u. 8.1.6. Add a note that allows the HI-STORM to be moved out from under the empty HI-TRAC to install the HI-STORM lid. The note directs users to evaluate the effects of the move on their Part 50 license.

v. 8.1.6 Step 3. Change the warning such that it applies to only non-single-failure proof type lifts.

w. 8.1.6. Add: Installation of the lid, vent screen, and other components may vary according to the cask movement methods and location of MPC transfer.

x. 8.1.7 Step 11. No longer close the doors prior to removal of the empty HI-TRAC from on top of HI-STORM.

y. Table 8.1.1. Revise weights.

z. Table 8.1.5: Add HI-STORM 100S Lid Nuts Added MPC Lift Studs.

aa. Table 8.1.6: Revise Table to add temporary lid and clarify descriptions.

bb. 8.3.2 Step 5. Revise steps to remove the transfer lid door locking pins and open the doors prior to placement of the HI-TRAC on the HI-STORM 100 Overpack.

cc. 8.3.3 Step 2. Add flushing of the annulus as an integral portion of the cool-down process.

dd. 8.3.3 Step 4. Add the allowance for users to select alternate methods of obtaining a gas sample.

ee. Figures General. Provide improved isometric graphics.

ff. Figure 8.1.1: Modify order of steps.

gg. Figure 8.3.1: Modify order of steps.

Reason and Justification for Proposed Changes

a. General

1) Appropriate guidance for the MPC-32 whenever water may be added to or recirculated through the MPC is necessary with the addition of soluble boron requirements for certain MPC models..

2) Operating weights may be different between the HI-STORM 100 and the HI-STORM 100S.

3) Additional or different steps are required for MPC=-32 where the operations and weights may differ from the existing information provided.

4) Weight limitations preclude use of this option.

5) General design change to support HI-STORM 100S and plant-specific configurations.

6) Correction to be consistent with the CoC and other portions of the TSAR.

7) Clarifications and editorial improvements.

b. Different seal manufacturers have different inflation requirements.

c. Site conditions may require the cask to be moved to another location to perform bottom lid replacement.

d. Better grouping of steps. Steps placed into discrete categories.

e. Boron concentration in the spent fuel pool and MPC-32 may be reduced (i.e., positive reactivity added) by using demineralized water.

f. Correction to add missing information.

g. To prevent contaminated water that may spill from the pump to enter the annulus.

h. Lesson learned based on results of Plant Hatch dry run activities. By reducing the amount of water that must be removed prior to welding, the dose rates are lowered.

i. Actual testing proved that the acceptance criterion is very close to the limits of the MSLD for sniff mode testing at plant conditions. Changing the pressure and correlating the results in accordance with ANSI N14.5 allows comparison against the technical specification leakage rate limit with greater accuracy.

j. Conforming change in support of changing MPC helium backfill from density to pressure (see Proposed Change Number 1).

k. ALARA improvement. Actual field testing showed this reduces time spent in a radiation field to perform vacuum drying.

l. New method provides superior assurance of long-term confinement for the vent and drain port cover plates and welds.

m. It may be necessary (due to travel limitations of the overhead crane through the equipment hatch, potential for load drop on the MPC, time and dose required to reconfigure the crane with the HI-STORM lid, or overhead clearances) to move HI-STORM from under the empty HI-TRAC to install the HI-STORM lid.

n. Some sites do not have sufficient crane access or room to meet the requirement without additional cask handling, which increases occupation exposure.

o. Sites using air pads will have to install lower vent screens after jacking to remove the air pad. The vertical cask crawler allows the screens to be installed before movement (ALARA dose reduction).

p. Slings and cleats may interfere with closure of the door following MPC transfer into HI-STORM 100S.

q. Revised to add HI-STORM 100S and MPC-32 and design changes to the HI-TRAC transfer casks.

r. Specifics regarding HI-STORM 100S and the MPC lift cleats were missing.

s. Clarification. Optional temporary lid for interim movement of casks may be used if the site conditions prevent immediate installation of the permanent HI-STORM 100 lid.

t. Slings and cleats may interfere with closure of the door following MPC transfer into HI-STORM 100S.

u. Analysis shows that MPC bulk temperatures can be reduced significantly using the annulus flush.

v. Plant chemistry systems vary by site and may not be compatible with the current method.

w. Clarification

x. To match text changes.

y. To match text changes.

Proposed Change No. 32

TSAR Chapter 9

a. Subsection 9.1.5.1 is revised regarding Holtite-A testing as shown in the attached proposed revised TSAR pages to re-define the frequency of testing to be every manufactured lot instead of every mixed batch.

b. Subsection 9.1.5.1 is revised regarding lead shielding installation as shown in the attached proposed revised TSAR pages to allow cast sections to be installed as an option to pouring molten lead.

c. Subsection 9.1.5.3 is revised to indicate that travelers and/or quality control procedures shall be in place to assure each required cell wall contains a Boral panel.

d. Table 9.1.1 is revised in two places to add reference to the NF subsection of the ASME Section III Code.

e. Table 9.1.4 is revised to 1) delete the liquid penetrant (PT) examination requirement for the root pass of the closure ring welds (3 places) and 2) delete the PT examination requirement for the fuel spacers.

Reason for Proposed Changes

a. To provide an appropriate level of testing for the Holtite material while reducing unnecessary burden on the fabricator.

b. This change is proposed to allow the HI-TRAC fabricator an option other than of pouring molten lead into the transfer cask.

c. This change is required to reflect the actual QA control in the fabrication shop for this activity.

d. This is an editorial clarification. The NF Code is used for inspection of the fuel spacers, which are designed in accordance with Subsection NG (per TSAR Table 2.2.6).

e. 1) This is a conforming change based on a proposed drawing change to reduce the size of three closure ring welds to 1/8 inch. The proposed welds will not have a separate root and final pass. See Attachment 4. 2) A PT examination of the fuel spacer welds is not required by the NF Code.

Justification for Proposed Changes

a. Testing each mixed batch of Holtite is overly conservative and costly considering the controls used to mix and pour each batch. Sufficient confidence that each batch of as-poured Holtite-A is in compliance with the design requirements is provided by testing the total amount of material, (regardless of the number of mixed batches it produces) which contains the same constituent lots. Testing will be performed any time a new lot of constituent material is used in a mixed batch. Refer to the enclosed Holtec Standard Procedure HSP-107 for procedural controls imposed on Holtite-A mixing and pouring.

b. The necessary thickness of lead and the avoidance of streaming paths can be controlled through administrative procedures on the lead casting design and installation process to preserve the assumptions of the shielding analysis. Without this option, either lead pouring equipment and personnel has to be set up in the cask fabrication shop or the cask must be trucked to a lead pouring facility. Given concerns with potential airborne lead, the casting option is desirable from an occupational safety standpoint since the cask will not have to be handled and trucked to a lead pour shop and all molten lead pouring can be conducted at a dedicated shop designed to handle lead with appropriately trained personnel.

c. This is an editorial clarification. Either travelers or QC procedures, or both are adequate to ensure Boral panels are installed appropriately.

d. The stress analyses for the fuel spacers were performed in accordance with Subsection NG per current TSAR Table 2.2.6. This was done because they interface with the fuel basket, which is also designed to NG. The intent of the note in TSAR Table 2.2.6 is to clarify that Subsection NG applies *only* to the stress analyses. Functionally, the fuel spacers are more akin to piping and component supports than to core support structures. Therefore, Subsection NF was always intended to be the Code governing inspection of the fuel spacers. This, therefore, is a clarifying change to more clearly describe the scope of Code sections governing inspection of MPC components.

e. 1) This is a conforming change based on a drawing change proposed in Attachment 4 which reduces the size of three closure ring welds to 1/8 inch. One-eighth inch welds will not have separate root and final passes. Therefore, a PT of the final pass is the appropriate inspection in addition to visual inspection. 2) Article NF-5231 only requires PT examination of primary member welds greater than 1 inch. Other welds require visual examination. The fuel spacer welds do not meet either criterion requiring PT examination.

Proposed Change No. 33

TSAR Chapter 10

Tables 10.3.1a through 10.3.3.b are revised to incorporate modified step sequences from Chapter 8 and to reflect new dose rates calculated in the shielding evaluation. Note that due to the complete revision of all three tables, revision bars are not shown to the right of the tables in the proposed TSAR pages in Attachment 5.

Reason and Justification for Proposed Changes

The revisions to the Radiation Protection chapter are conforming changes in support of new dose rates created by the addition of MPC-32 and non-fuel hardware to the approved contents of the Hi-STORM 100 System.

Proposed Change No. 34

TSAR Chapter 11

a. Subsection 11.1.1.3 text and calculations are updated as conforming changes to support the proposed addition of non-fuel hardware to the contents of the HI-STORM 100 and the proposed refinements to the MPC thermal modeling.

b. Subsection 11.1.2.3 text is revised as a conforming change to support the proposed addition of the MPC-24E and MPC-32 to the HI-STORM System.

c. Subsection 11.1.3 text is revised to clarify that root pass PT examination is only performed on multi-pass welds.

d. Subsection 11.1.4.1 text is revised to correct the reference for the location of the Technical Specifications as an appendix to the CoC.

e. Subsection 11.1.4.3 text and calculations updated: (1) to specify that only the MPC-68 is evaluated under the off-normal condition, and (2) as conforming changes to support the proposed addition of non-fuel hardware to the contents of the HI-STORM 100 and the proposed refinements to the MPC thermal modeling.

f. Subsection 11.1.4.1 text is revised to correct the reference for the location of the Technical Specifications as an appendix to the CoC.

g. Table 11.1.1 is updated as a conforming change to support the proposed refinements to the MPC thermal modeling.

h. Table 11.1.2 is updated as a conforming change to support the proposed refinements to the MPC thermal modeling and to reflect that only the MPC-68 is evaluated under the off-normal condition.

i. Subsection 11.2.1.1 text is revised to correct the reference for the location of the Technical Specifications as an appendix to the CoC.

j. Subsection 11.2.1.2 text is revised to remove redundant information that is already contained elsewhere in the TSAR and to correctly reflect updated shielding calculations for the accident condition.

k. Subsection 11.2.1.3 text is revised to remove redundant information that is already contained elsewhere in the TSAR and to correctly reflect updated shielding calculations for the accident condition.

l. Subsection 11.2.2.1 text is revised to correct the reference for the location of the Technical Specifications as an appendix to the CoC.

m. Subsection 11.2.4.2.1 text and calculations are revised (1) to correct the reference for the location of the Technical Specifications as an appendix to the CoC, (2) to support the proposed addition of non-fuel hardware to the contents of the HI-STORM 100 and the proposed refinements to the MPC thermal modeling, and (3) to correctly reflect the MPC thermal inertia.

n. Subsection 11.2.4.2.2 text and calculations are revised (1) to correct the reference for the location of the Technical Specifications as an appendix to the CoC, (2) to support the proposed refinements to the MPC thermal modeling, and (3) to correctly reflect the thermal calculations for this accident condition.

o. Subsection 11.2.5.1 text is revised as a conforming change to support the proposed addition of the MPC-24E and MPC-32 to the HI-STORM System.

p. Subsection 11.2.10.2 text is revised as editorial changes to correctly reflect the updated confinement calculations for the accident condition and to correct the reference for the location of the Technical Specifications as an appendix to the CoC, and a conforming change to support the proposed addition of the MPC-24E, MPC-32 and MPC-68FF for the HI-STORM System.

q. Subsection 11.2.10.3 text is revised to remove redundant information that is already contained elsewhere in the TSAR and to correctly reflect updated confinement calculations for the accident condition.

r. Subsection 11.2.13.2 text and calculations are revised as (1) conforming changes to support the proposed addition of non-fuel hardware to the contents of the HI-STORM 100, the proposed refinements to the MPC thermal modeling, and the proposed addition of the MPC-24E and MPC-32 to the HI-STORM System, and (2) editorial changes to correctly reflect the thermal calculations for this accident condition and to correct the reference for the location of the Technical Specifications as an appendix to the CoC.

s. Subsection 11.2.13.2 text is revised to correct the reference for the location of the Technical Specifications as an appendix to the CoC.

t. Subsection 11.2.13.4 is revised to correctly reflect updated thermal evaluations for this accident condition and to correct the reference for the location of the Technical Specifications as an appendix to the CoC.

u. Subsection 11.2.14.2 text and calculations are revised as (1) conforming changes to support the proposed addition of non-fuel hardware to the contents of the HI-STORM 100, the proposed refinements to the MPC thermal modeling, and the proposed addition of the MPC-24E and MPC-32 to the HI-STORM System, and (2) editorial changes to correctly reflect the thermal calculations for this accident condition and to correct the reference for the location of the Technical Specifications as an appendix to the CoC.

v. Subsection 11.2.14.4 is revised to correctly reflect updated thermal evaluations for this accident condition.

w. Subsection 11.2.15.2 text is revised as a conforming change to support the proposed addition of the MPC-24E and MPC-32 to the HI-STORM System.

x. Table 11.2.2 is revised as conforming change to support the proposed addition of the MPC-24E and MPC-32 to the HI-STORM System and the proposed refinements to the MPC thermal modeling.

y. Table 11.2.3 is revised as conforming change to support the proposed modifications to the HI-TRAC transfer cask designs and the proposed refinements to the MPC thermal modeling.

z. Table 11.2.4 is revised as conforming changes to support the proposed addition of non-fuel hardware to the contents of the HI-STORM 100 and the proposed refinements to the MPC thermal modeling.

aa. Table 11.2.5 is revised as conforming changes to support the proposed refinements to the MPC thermal modeling and the thermal analysis of this accident condition.

bb. Table 11.2.6 is revised as a conforming change to support the proposed refinements to the MPC thermal modeling.

cc. Table 11.2.7 is revised as a conforming change to support the proposed refinements to the MPC thermal modeling.

dd. Table 11.2.8 is revised as a conforming change to support the proposed refinements to the MPC thermal modeling.

ee. Table 11.2.9 is revised as conforming changes to support the proposed refinements to the MPC thermal modeling and the thermal analysis of this accident condition.

ff. Figure 11.2.6 is revised as a conforming change to reflect the updated thermal analysis of this accident condition.

gg. Figure 11.2.7 is revised as a conforming change to reflect the updated thermal analysis of this accident condition.

hh. Figure 11.2.8 is deleted as an editorial change.

Reason for Proposed Changes

a. These are conforming changes to support the addition of non-fuel hardware to the authorized contents of the cask (see Section I of this attachment) and computational refinements made to the MPC thermal modeling. Some non-fuel hardware, such as BPRAs, contain helium gas that must be accounted for in the evaluation of off-normal conditions. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

b. This is an editorial clarification to correctly reflect the increase in the number of MPC designs included in the TSAR.

c. This is an editorial clarification to correctly reflect the MPC confinement boundary welding procedures.

d. This is an editorial clarification to correctly reflect the location of the Technical Specifications.

e. These are an editorial change to correctly reflect the calculations performed for the off-normal condition and conforming changes to support the addition of non-fuel hardware to the authorized contents of the cask (see Section I of this attachment) and computational refinements made to the MPC thermal modeling. The MPC-68 now bounds all other MPC designs with respect to this off-normal condition. Some non-fuel hardware, such as BPRAs, contain helium gas that must be accounted for in the evaluation of off-normal conditions. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

f. This is an editorial clarification to correctly reflect the location of the Technical Specifications.

g. This is a conforming change to support computational refinements made to the MPC thermal modeling. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

h. These are conforming changes to support computational refinements made to the MPC thermal modeling. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

i. This is an editorial clarification to correctly reflect the location of the Technical Specifications.

j. These are editorial clarifications to reduce unnecessary redundancy in the TSAR and to correctly reflect the shielding calculations for this accident condition.

k. These are editorial clarifications to reduce unnecessary redundancy in the TSAR and to correctly reflect the shielding calculations for this accident condition.

l. This is an editorial clarification to correctly reflect the location of the Technical Specifications.

m. These are an editorial change to correctly reflect the location of the Technical Specifications and conforming changes to support the addition of non-fuel hardware to the authorized contents of the cask (see Section I of this attachment) and computational refinements made to the MPC thermal modeling. Some non-fuel hardware, such as BPRAs, contain helium gas that must be accounted for in the evaluation of off-normal conditions. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

n. These are an editorial change to correctly reflect the location of the Technical Specifications and conforming changes to support computational refinements made to the MPC thermal modeling and improvements to the thermal modeling of this accident condition. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions. The fire convection heat transfer coefficient is updated to match that used in the evaluation of the HI-STORM 100.

o. This is an editorial clarification to correctly reflect the increase in the number of MPC designs included in the TSAR.

p. These are editorial changes to correctly reflect the confinement calculations for this accident condition, to correct the reference for the location of the Technical Specifications as an appendix to the CoC, and to correctly reflect the increase in the number of MPC designs included in the TSAR.

q. These are editorial clarifications to reduce unnecessary redundancy in the TSAR and to correctly reflect the confinement calculations for this accident condition.

r. These are conforming changes to support the addition of non-fuel hardware to the authorized contents of the cask (see Section I of this attachment) and computational refinements made to the MPC thermal modeling and editorial changes to correctly reflect the thermal calculations for this accident condition and to correct the reference for the location of the Technical Specifications as an appendix to the CoC. Some non-fuel hardware, such as BPRAs, contain helium gas that must be accounted for in the evaluation of off-normal conditions. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

s. This is an editorial clarification to correctly reflect the location of the Technical Specifications.

t. These are editorial clarifications to correctly reflect the thermal calculations for this accident condition and to correctly reflect the location of the Technical Specifications.

u. These are conforming changes to support the addition of non-fuel hardware to the authorized contents of the cask (see Section I of this attachment) and computational refinements made to the MPC thermal modeling and editorial changes to correctly reflect the thermal calculations for this accident condition and to correct the reference for the location of the Technical Specifications as an appendix to the CoC. Some non-fuel hardware, such as BPRAs, contain helium gas that must be accounted for in the evaluation of off-normal conditions. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

v. This is an editorial clarification to correctly reflect the thermal calculations for this accident condition.

w. This is an editorial clarification to correctly reflect the increase in the number of MPC designs included in the TSAR.

x. These are an editorial clarification to correctly reflect the increase in the number of MPC designs included in the TSAR and a conforming change to support computational refinements made to the MPC thermal modeling. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

y. These are conforming changes to correctly reflect the new HI-TRAC weights and to support computational refinements made to the MPC thermal modeling. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

z. These are conforming changes to support the addition of non-fuel hardware to the authorized contents of the cask (see Section I of this attachment) and computational refinements made to the MPC thermal modeling and to correctly reflect the thermal calculations for this accident condition. Some non-fuel hardware, such as BPRAs, contain helium gas that must be accounted for in the evaluation of off-normal conditions. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

aa. These are conforming changes to support computational refinements made to the MPC thermal modeling and to correctly reflect the thermal calculations for this accident condition. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

bb. This is a conforming change to support computational refinements made to the MPC thermal modeling. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

cc. This is a conforming change to support computational refinements made to the MPC thermal modeling. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

dd. This is a conforming change to support computational refinements made to the MPC thermal modeling. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

ee. These are conforming changes to support computational refinements made to the MPC thermal modeling and to correctly reflect the thermal calculations for this accident condition. The MPC thermal modeling refinements result in slightly different allowable decay heat loads and MPC temperature distributions.

ff. This is a conforming change to correctly reflect the thermal calculations for this accident condition.

gg. This is a conforming change to correctly reflect the thermal calculations for this accident condition.

hh. This is an editorial change to remove unnecessary information.

Justification for Proposed Changes

a. Conforming changes to reflect helium backfill pressure adjustments made in TSAR Subsection 4.4.1.1.16 and heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

b. Editorial clarification only.

c. Editorial clarification only.

d. Editorial clarification and conforming change.

e. Conforming changes to reflect helium backfill pressure adjustments made in TSAR Subsection 4.4.1.1.16 and heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

f. Editorial clarification and conforming change.

g. Conforming change to reflect heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

h. Conforming changes to reflect heat load and temperature results changes stemming from improvements in the MPC thermal modeling. The MPC-68 now bounds all other MPC designs with respect to this off-normal condition.

i. Editorial clarification and conforming change.

j. Editorial clarification only.

k. Editorial clarification only.

l. Editorial clarification and conforming change.

m. Editorial clarification and conforming changes to reflect helium backfill pressure adjustments made in TSAR Subsection 4.4.1.1.16 and heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

n. Editorial clarification and conforming changes to reflect heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

o. Editorial clarification only.

p. Editorial clarifications and conforming changes.

q. Editorial clarification only.

r. Editorial clarifications and conforming changes to reflect helium backfill pressure adjustments made in TSAR Subsection 4.4.1.1.16 and heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

s. Editorial clarification and conforming change.

t. Editorial clarification and conforming change.

u. Editorial clarifications and conforming changes to reflect helium backfill pressure adjustments made in TSAR Subsection 4.4.1.1.16 and heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

v. Editorial clarification only.

w. Editorial clarification only.

x. Editorial change and a conforming change to reflect heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

y. Conforming change to reflect slightly reduced HI-TRAC and HI-TRAC component weights and heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

z. Conforming changes to reflect helium backfill pressure adjustments made in TSAR Subsection 4.4.1.1.16 and heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

aa. Conforming changes to reflect heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

bb. Conforming change to reflect heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

cc. Conforming change to reflect heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

dd. Conforming change to reflect heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

ee. Conforming changes to reflect heat load and temperature results changes stemming from improvements in the MPC thermal modeling.

ff. Conforming change only.

gg. Conforming change only.

hh. This figure is not longer used or referenced.

Proposed Change No. 35

TSAR Chapter 12

a. Section 12.1.1.2 is revised to add a “C” to “Co” in the third line.

b. Tables 12.1.1 and 12.1.2 are revised to add “Boron Concentration” as a new LCO.

c. Appendix 12.A, Bases B 3.1.1, "Multi-Purpose Canister" is revised as a conforming change to reflect the change from helium density to pressure for the acceptance criterion for MPC backfilling. See Section I of this attachment.

d. In Appendix 12.A, new Bases section B 3.3.1 "Boron Concentration" is added As a conforming change in support of new LCO 3.3.1. See Proposed Change Number 3.

Reason for Proposed Changes

a. Editorial.

b. Editorial.

c. This change provides clarification as requested through user feedback.

d. Conforming change in support of new LCO 3.3.1.

Justification for Proposed Changes

a. Editorial.

b. Editorial

c. The current acceptance criteria for MPC helium backfill *density* are based upon credit being taken in the thermal analysis for convection heat transfer, where the density of the helium in the MPC is an important input parameter. HI-STORM 100 was licensed assuming helium in the MPC, but without credit for convection heat transfer. Therefore, only the *presence* of helium in the MPC must be confirmed. A more appropriate acceptance criterion is helium backfill pressure. Accordingly, Table 3-1 in Appendix A to the CoC is proposed to be revised to provide an acceptable pressure range (see Section I of this attachment). This proposed change to TSAR Appendix 12.A (the TS Bases) is a conforming revision providing the technical basis for the new acceptance criterion in CoC Appendix A, Table 3-1. See Proposed Change Number 1.

d. Conforming change. See Proposed Change Number 3.

Section III – PROPOSED CHANGES TO DESIGN DRAWINGS

Proposed Change No. 36

Based on lessons learned during the fabrication of the HI-STORM 100 prototype and the first production unit for Plant Hatch, a number of MPC drawing changes are proposed. Attachment 4 provides the revised drawings. The text provided in Section III of Attachment 1 to License Amendment Request (LAR) 1008-1 submitted on November 24, 1999 for the HI-STAR 100 System gives the rationale behind the changes. Since the same MPCs are used in both the HI-STAR and HI-STORM systems, those drawings are included here as well. Drawings in LAR 1008-1 for the HI-STAR overpack are, of course, not applicable to this HI-STORM LAR. Please note that a minor number of additional changes to the MPC drawings have been added which do not appear on the versions of the MPC drawings included in LAR 1008-1 and its supplements. This is due to changes that arose on subsequent HI-STAR units in the Plant Hatch fabrication effort after LAR 1008-1 was submitted. These changes will be included in future LAR 1008-2 to make all MPC drawings consistent between the HI-STAR and HI-STORM systems.

Proposed Change No. 37

Drawings for MPC-24E, MPC-32, MPC-68FF, and HI-STORM 100S

a. The MPC-24E required the generation of four (4) new design drawings: 2889, 2890, 2891, 2892 and BOMs 2898 and 2899. Where appropriate, the existing (standard) MPC-24 drawings (1395 and 1396 series) have been revised as required to indicate certain dimensions and details which differ between the MPC-24 and the MPC-24E.

b. The MPC-32 required the return of the ten (10) drawings previously included in the HI-STORM TSAR in the early phases of the license review (1392 and 1393 series, and BM-1477, Sheets 1 and 2). These drawings have been revised to incorporate the lessons learned from Plant Hatch and the HI-STAR prototype fabrication activities similar to the MPC-24 and MPC-68 drawings (See Proposed Change 36).

c. The MPC-68FF required the revision of four (4) existing (standard) MPC-68 drawings (1402 series) to show the enhanced MPC upper shell and deeper MPC lid weld, similar to the MPC-68F.

d. The HI-STORM 100S required the creation of eleven (11) new drawings (3067 through 3077) and a new Bill-of-Materials (3065 and 3066). Only nine of the eleven drawings are included in the TSAR. Drawings 3076 and 3077 depict the cask nameplate and inlet and outlet vent screens, respectively. This equipment is considered ancillary to the cask system. Therefore, the drawings are not considered necessary to be included in the TSAR.

All new and revised drawings are included in Attachment 4 of this submittal.

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3.1 SFSC INTEGRITY

3.1.1 Multi-Purpose Canister (MPC)

LCO 3.1.1 The MPC shall be dry and helium filled.

APPLICABILITY: During TRANSPORT OPERATIONS and STORAGE OPERATIONS.

ACTIONS

--NOTE--

Separate Condition entry is allowed for each MPC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. MPC cavity vacuum drying pressure limit not met.	A.1 Perform an engineering evaluation to determine the quantity of moisture left in the MPC.	7 days
	<u>AND</u>	
	A.2 Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	30 days
B. MPC helium backfill ~~density~~ *pressure* limit not met.	B.1 Perform an engineering evaluation to determine the impact of helium differential.	72 hours
	<u>AND</u>	
	B.2 Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	14 days

ACTIONS
(continued)

CONDITION	REQUIRED ACTION	COMPLETION TIME
C. MPC helium leak rate limit not met.	C.1 Perform an engineering evaluation to determine the impact of increased helium leak rate on heat removal capability and offsite dose.	24 hours
	<u>AND</u>	
	C.2 Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	7 days
D. Required Actions and associated Completion Times not met.	D.1 Remove all fuel assemblies from the SFSC.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.1.1	Verify MPC cavity vacuum drying pressure is within the limit specified in Table 3-1 for the applicable MPC model.	Once, prior to TRANSPORT OPERATIONS
SR 3.1.1.2	Verify MPC helium backfill ~~density~~ *pressure* is within the limit specified in Table 3-1 for the applicable MPC model.	Once, prior to TRANSPORT OPERATIONS
SR 3.1.1.3	Verify that the total helium leak rate through the MPC lid confinement weld and the drain and vent port confinement welds is within the limit specified in Table 3-1 for the applicable MPC model.	Once, prior to TRANSPORT OPERATIONS

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.2.1	Verify all OVERPACK inlet and outlet air ducts are free of blockage.	24 hours
	<u>OR</u>	
	For OVERPACKS with installed temperature monitoring equipment, verify *that* the difference between the average OVERPACK air outlet temperature and ISFSI ambient temperature ~~is ≤ 99° F (for the MPC-24) and ≤ 105° F (for the MPC-68 and MPC-68F)~~ *meets the following limits, as applicable:* *a. MPC-24: ≤ 102°F* *b. MPC-24E: ≤ 107°F* *c. MPC-32: ≤ 100°F* *d. MPC-68/68F/68FF: ≤ 118°F*	24 hours

3.2 SFSC RADIATION PROTECTION

3.2.1 TRANSFER CASK Average Surface Dose Rates

LCO 3.2.1 The average surface dose rates of each TRANSFER CASK shall not exceed:

a. 125 Ton TRANSFER CASK

   i. ~~130~~ *145* mrem/hour (neutron + gamma) on the side;

   ii. ~~40~~ *55* mrem/hour (neutron + gamma) on the top

b. 100 Ton TRANSFER CASK

   i. ~~890~~ *1120* mrem/hour (neutron + gamma) on the side;

   ii. ~~170~~ *200* mrem/hour (neutron + gamma) on the top

APPLICABILITY: During TRANSPORT OPERATIONS.

ACTIONS

---NOTE---

Separate Condition entry is allowed for each TRANSFER CASK.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. TRANSFER CASK average surface dose rate limits not met.	A.1 Administratively verify correct fuel loading.	24 hours
	AND	
	A.2 Perform evaluation to verify compliance with the ISFSI offsite radiation protection requirements of 10 CFR Part 20 and 10 CFR Part 72.	24 hours

3.2 SFSC RADIATION PROTECTION

3.2.3 OVERPACK Average Surface Dose Rates

LCO 3.2.3 The average surface dose rates of each OVERPACK shall not exceed:

a. ~~40~~ *50* mrem/hour (neutron + gamma) on the side |

b. 10 mrem/hour (neutron + gamma) on the top

c. ~~16~~ *40* mrem/hour (neutron + gamma) at the inlet and outlet vent ducts |

APPLICABILITY: During ~~TRANSPORT OPERATIONS AND~~ STORAGE OPERATIONS. |

ACTIONS

-----NOTE-----
Separate Condition entry is allowed for each SFSC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. OVERPACK average surface dose rate limits not met.	A.1 Administratively verify correct fuel loading.	24 hours
	<u>AND</u>	
	A.2 Perform ~~analysis~~ *a written evaluation* to verify compliance with the ISFSI offsite radiation protection requirements of 10 CFR Part 20 and 10 CFR Part 72.	~~24~~ *48* hours
B. Required Action and associated Completion Time not met.	B.1 Remove all fuel assemblies from the SFSC.	30 days

3.3 SFSC CRITICALITY CONTROL

3.3.1 Boron Concentration

LCO 3.3.1 As required by CoC Appendix B, Table 2.1-2, the concentration of boron in the water in the MPC shall meet the following limits for the applicable MPC model:

a. MPC-24 with one or more fuel assemblies having an initial enrichment greater than the value in Table 2.1-2 for no soluble boron credit and $\leq$ 5.0 wt% ^{235}U: $\geq$ 400 ppmb

b. MPC-24E with one or more fuel assemblies having an initial enrichment greater than the value in Table 2.1-2 for no soluble boron credit and $\leq$ 5.0 wt% ^{235}U: $\geq$ 300 ppmb

c. MPC-32 with all fuel assemblies having an initial enrichment $\leq$ 4.0 wt% ^{235}U: $\geq$ 1800 ppmb

d. MPC-32 with one or more fuel assemblies having an initial enrichment > 4.0 and $\leq$ 5.0 wt% ^{235}U: $\geq$ 2600 ppmb

APPLICABILITY: During PWR fuel LOADING OPERATIONS with fuel and water in the MPC

AND

During PWR fuel UNLOADING OPERATIONS with fuel and water in the MPC.

ACTIONS

--------------------NOTE--------------------
Separate Condition entry is allowed for each MPC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Boron concentration not within limit.	A.1 Suspend LOADING OPERATIONS or UNLOADING OPERATIONS.	Immediately
	AND	
	A.2 Suspend positive reactivity additions.	Immediately
	AND	
	A.3 Initiate action to restore boron concentration to within limit.	Immediately

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
--------------------NOTE-------------------- This surveillance is only required to be performed if the MPC is submerged in water or if water is to be added to, or recirculated through the MPC. --		Within 4 hours of entering the Applicability of this LCO. AND Every 48 hours thereafter.
SR 3.3.1.1	Verify boron concentration is within the applicable limit using two independent measurements.	

Table 3-1
MPC Model-Dependent Limits

MPC MODEL	LIMITS
1. MPC-24/*24E*	
a. MPC Cavity Vacuum Drying Pressure	≤ 3 torr for ≥ 30 min
b. MPC Helium Backfill ~~Density~~ *Pressure*[1]	~~0.1212 +0/-10% g-moles/l~~ *≤ 22.2 psig*
c. MPC Helium Leak Rate	≤ 5.0E-6 atm cc/sec (He)
2. MPC-68/*68F/68FF*	
a. MPC Cavity Vacuum Drying Pressure	≤ 3 torr for ≥ 30 min
b. MPC Helium Backfill ~~Density~~ *Pressure*[1]	~~0.1218 +0/-10% g-moles/l~~ *≤ 28.5 psig*
c. MPC Helium Leak Rate	≤ 5.0E-6 atm cc/sec (He)
3. MPC-32	
a. MPC Cavity Vacuum Drying Pressure	*≤ 3 torr for ≥ 30 min*
b. MPC Helium Backfill Pressure	*≤ 20.3 psig*
c. MPC Helium Leak Rate	*≤ 5.0E-6 atm cc/sec (He)*

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[1] Helium used for backfill of MPC shall have a purity of ≥ 99.995%.

5.5 Cask Transport Evaluation Program (continued)

b. For site-specific transport conditions which are not bounded by the surface characteristics in Section 3.4.6 of Appendix B to Certificate of Compliance No. 1014, the program may evaluate the site-specific conditions to ensure that the impact loading due to design basis drop events does not exceed 45 g. This alternative analysis shall be commensurate with the drop analyses described in the Topical Safety Analysis Report for the HI-STORM 100 Cask System. The program shall ensure that these alternative analyses are documented and controlled.

c. The TRANSFER CASK or OVERPACK, when loaded with spent fuel, may be lifted above its lifting height limit during transportation from the FUEL BUILDING to the ISFSI pad provided the lifting device (e.g., crawler) is designed in accordance with ANSI N14.6 and has redundant drop protection features.

~~c~~ *d.* The TRANSFER CASK and MPC, when loaded with spent fuel, may be lifted to those heights necessary to perform cask handling operations, including MPC transfer, provided the lifts are made with structures and components designed in accordance with the criteria specified in Section 3.5 of Appendix B to Certificate of Compliance No. 1014, as applicable.

Table 5-1

TRANSFER CASK and OVERPACK Lifting Requirements

ITEM	ORIENTATION	LIFTING HEIGHT LIMIT (in.)
TRANSFER CASK	Horizontal	42 (Note 1)
TRANSFER CASK	Vertical	None Established (Note 2)
OVERPACK	Horizontal	Not Permitted
OVERPACK	Vertical	11 (Note 2)

Notes:
1. To be measured from the lowest point on the TRANSFER CASK (i.e., the bottom edge of the transfer lid)
2. See Technical Specification 5.5c *and d.*

1.0 Definitions

NOTE

The defined terms of this section appear in capitalized type and are applicable throughout these Technical Specifications and Bases.

Term	Definition
CASK TRANSFER FACILITY (CTF)	The CASK TRANSFER FACILITY includes the following components and equipment: (1) a Cask Transfer Structure used to stabilize the TRANSFER CASK and MPC during lifts involving spent fuel not bounded by the regulations of 10 CFR Part 50, and (2) Either a stationary lifting device or a mobile lifting device used in concert with the stationary structure to lift the OVERPACK, TRANSFER CASK, and MPC
DAMAGED FUEL ASSEMBLY	DAMAGED FUEL ASSEMBLIES are fuel assemblies with known or suspected cladding defects, as determined by a review of records, greater than pinhole leaks or hairline cracks, missing fuel rods that are not replaced with dummy rods, or those that cannot be handled by normal means. Fuel assemblies which cannot be handled by normal means due to fuel cladding damage are considered FUEL DEBRIS.
DAMAGED FUEL CONTAINER (DFC)	DFCs are specially designed enclosures for DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS which permit gaseous and liquid media to escape while minimizing dispersal of gross particulates. *DFCs authorized for use in the HI-STORM 100 System are as follows:* *1. Holtec Dresden Unit 1/Humboldt Bay design* *2. Transnuclear Dresden Unit 1 design* *3. Holtec Generic BWR design* *4. Holtec Generic PWR design*
FUEL DEBRIS	FUEL DEBRIS is ruptured fuel rods, severed rods, loose fuel pellets or fuel assemblies with known or suspected defects which cannot be handled by normal means due to fuel cladding damage.

(continued)

2.0 APPROVED CONTENTS

2.1 Fuel Specifications and Loading Conditions

2.1.1 Fuel To Be Stored In The HI-STORM 100 SFSC System

a. INTACT FUEL ASSEMBLIES, DAMAGED FUEL ASSEMBLIES, ~~and~~ FUEL DEBRIS, *and certain non-fuel hardware* meeting the limits specified in Table 2.1-1 *and other referenced tables* may be stored in the HI-STORM 100 SFSC System.

b. For MPCs partially loaded with stainless steel clad fuel assemblies, all remaining fuel assemblies in the MPC shall meet the decay heat generation limit for the stainless steel clad fuel assemblies.

c. For MPCs partially loaded with DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS, all remaining Zircaloy clad INTACT FUEL ASSEMBLIES in the MPC shall meet the decay heat generation limits for the DAMAGED FUEL ASSEMBLIES. *This requirement applies only to uniform fuel loading.*

d. For MPC-68's partially loaded with array/class 6x6A, 6x6B, 6x6C, or 8x8A fuel assemblies, all remaining Zircaloy clad INTACT FUEL ASSEMBLIES in the MPC shall meet the decay heat generation limits for the 6x6A, 6x6B, 6x6C, *7x7A* and 8x8A fuel assemblies.

e. *All BWR fuel assemblies may be stored with or without Zircaloy channels with the exception of array/class 10x10D and 10x10E fuel assemblies, which may be stored with or without Zircaloy or stainless steel channels.*

(continued)

2.0 Approved Contents ~~(continued)~~

2.1 Fuel Specifications and Loading Conditions (cont'd)

2.1.2 Preferential Fuel Loading

Preferential fuel loading shall be used *during uniform loading (i.e., any authorized fuel assembly in any fuel storage location)* whenever fuel assemblies with significantly different post-irradiation cooling times (≥ 1 year) are to be loaded in the same MPC. Fuel assemblies with the longest post-irradiation cooling times shall be loaded into fuel storage locations at the periphery of the basket. Fuel assemblies with shorter post-irradiation cooling times shall be placed toward the center of the basket. *Regionalized fuel loading as described in Technical Specification 2.1.3 below meets the intent of preferential fuel loading.*

2.1.3 Regionalized Fuel Loading

Users may choose to store fuel using regionalized loading in lieu of uniform loading to allow higher heat emitting fuel assemblies to be stored than would otherwise be able to be stored using uniform loading. Regionalized loading is limited to those fuel assemblies with Zircaloy (or other alloy of zirconium) cladding. Figures 2.1-1 through 2.1-4 define the regions for the MPC-24, MPC-24E, MPC-32, and MPC-68 (including MPC-68F and MPC-68FF) models, respectively. Fuel assembly burnup, decay heat, and cooling time limits for regionalized loading are specified in Tables 2.1-6 and 2.1-7. Fuel assemblies used in regionalized loading shall meet all other applicable limits specified in Tables 2.1-1 through 2.1-3.

2.2 Violations

If any Fuel Specifications or Loading Conditions of 2.1 are violated, the following actions shall be completed:

2.2.1 The affected fuel assemblies shall be placed in a safe condition.

2.2.2 Within 24 hours, notify the NRC Operations Center.

2.2.3 Within 30 days, submit a special report which describes the cause of the violation, and actions taken to restore compliance and prevent recurrence.

LEGEND:

REGION 1: ▨

REGION 2: □

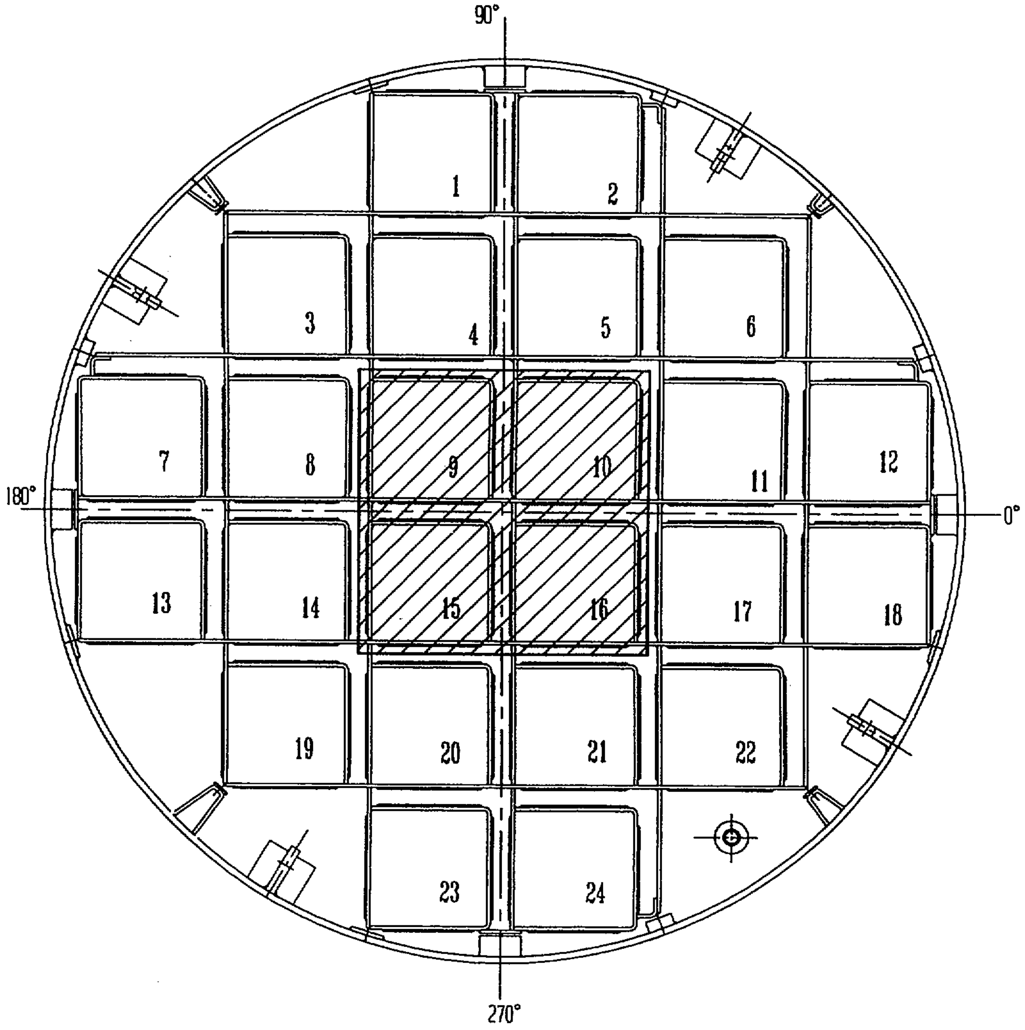

FIGURE 2.1-1
FUEL LOADING REGIONS - MPC-24

LEGEND:

REGION 1: ▨

REGION 2: ☐

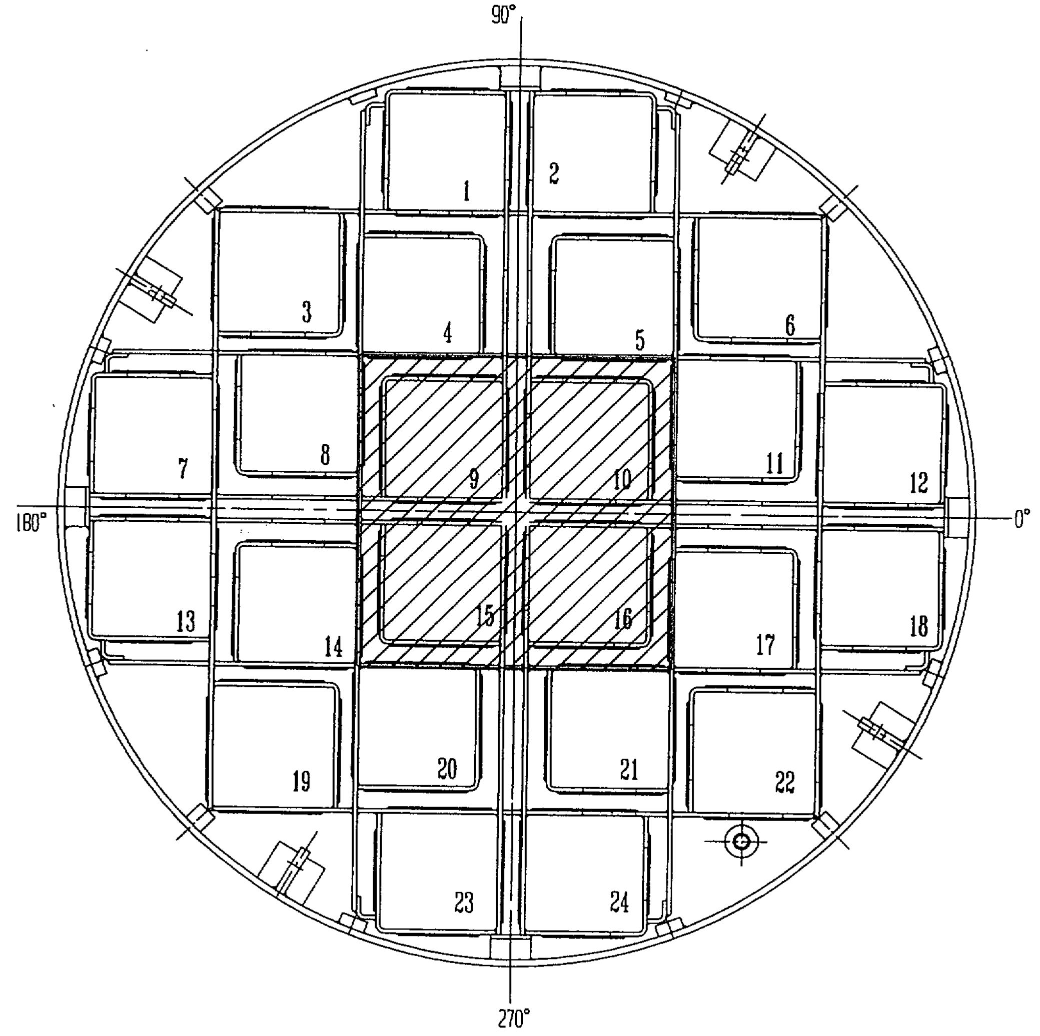

FIGURE 2.1-2

FUEL LOADING REGIONS - MPC-24E

LEGEND:

REGION 1: ▨

REGION 2: ☐

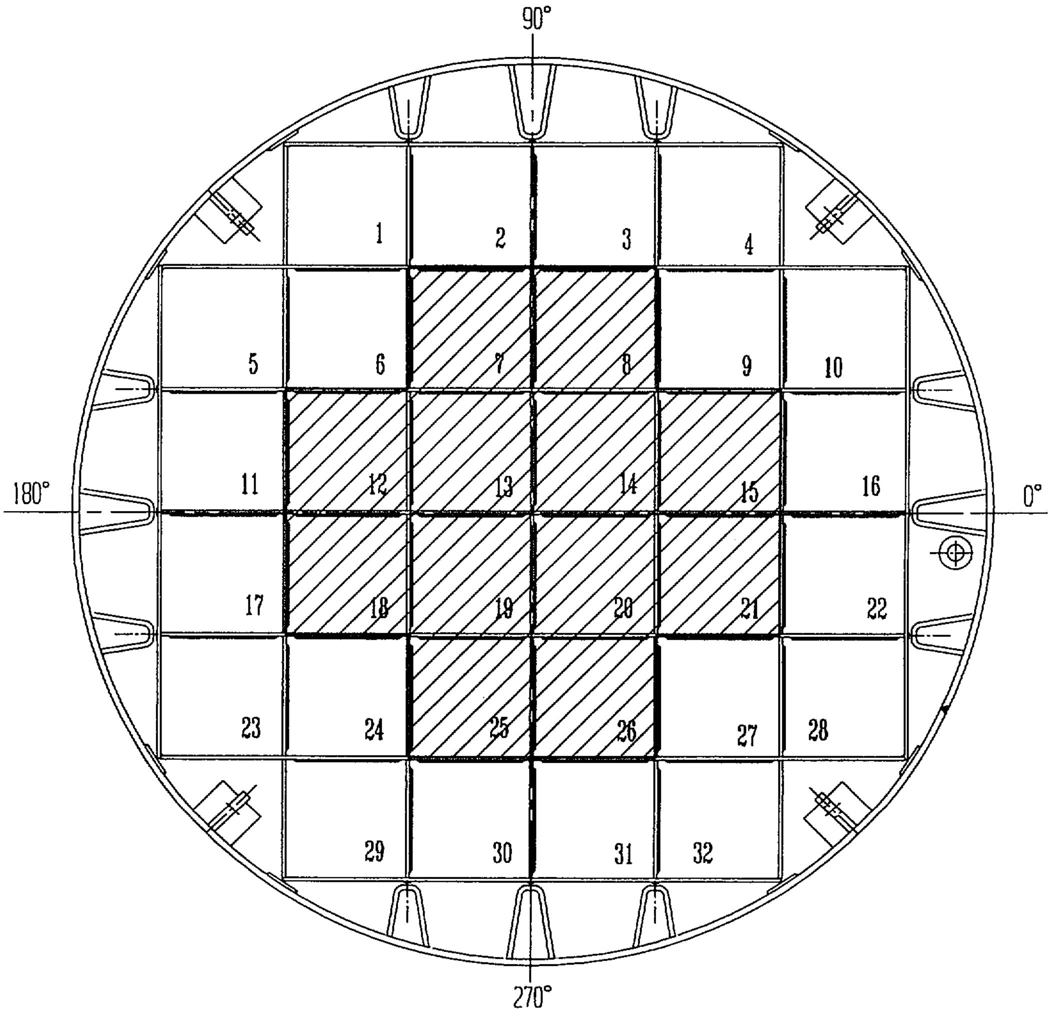

FIGURE 2.1-3

FUEL LOADING REGIONS - MPC-32

LEGEND:

REGION 1: ▨

REGION 2: ☐

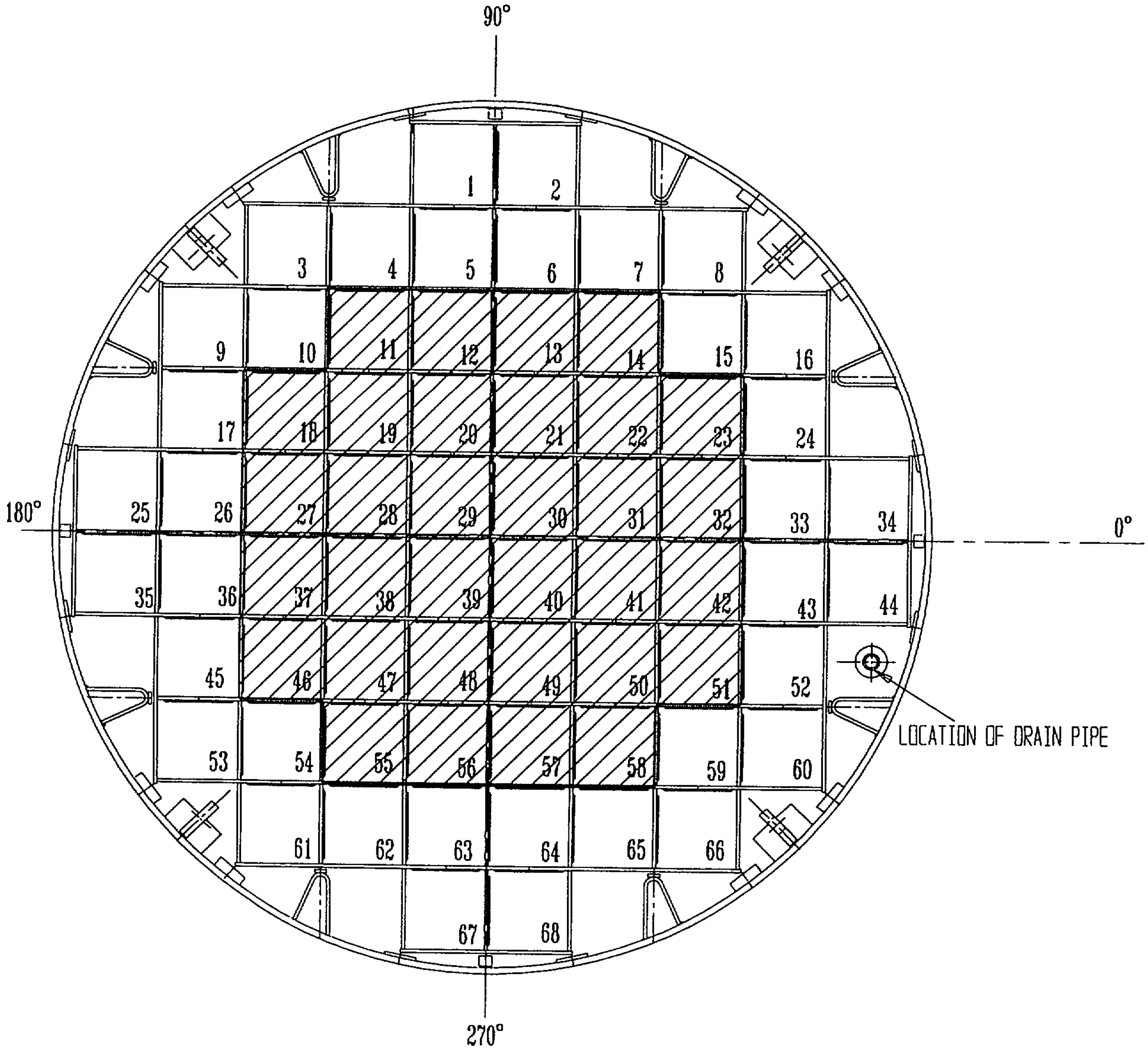

FIGURE 2.1-4

FUEL LOADING REGIONS - MPC-68/68FF

Table 2.1-1 (page 1 of ~~14~~ *29*)
Fuel Assembly Limits

I. MPC MODEL: MPC-24

A. Allowable Contents

1. Uranium oxide, PWR INTACT FUEL ASSEMBLIES listed in Table 2.1-2, *with or without non-fuel hardware* and meeting the following specifications *(Note 1)*:

a. Cladding Type:	Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class.
b. Initial Enrichment:	As specified in Table 2.1-2 for the applicable fuel assembly array/class.
c. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. ~~Zr Clad:~~ *Array/Classes 14x14D, 14x14E, and 15x15G*	~~An assembly post-irradiation~~ Cooling time ≥ 8 years and an average burnup ≤ 40,000 MWD/MTU.
ii. ~~SS Clad:~~ *All Other Array/Classes*	~~An assembly post-irradiation~~ Cooling time and average burnup as specified in Table*s* 2.1-4 *and 2.1-6*.
iii. *Non-Fuel Hardware*	*As specified in Table 2.1-8.*

Table 2.1-1 (page 2 of ~~14~~ *29*)
Fuel Assembly Limits

I. MPC MODEL: MPC-24 (continued)

d. Decay Heat Per Assembly:

i. ~~Zr Clad~~ *Array/Classes 14x14D, 14x14E, and 15x15G*	≤ 710 Watts
ii ~~SS Clad~~ All Other Array/Classes	~~An assembly decay heat~~ As specified in Table*s* 2.1-5 *and/or 2.1-7* ~~for the applicable post-irradiation cooling time~~.

e. Fuel Assembly Length:	≤ 176.8 inches (nominal design)
f. Fuel Assembly Width:	≤ 8.54 inches (nominal design)
g. Fuel Assembly Weight:	≤ 1,680 lbs *(including non-fuel hardware)*

B. Quantity per MPC: Up to 24 fuel assemblies.

C. ~~Fuel assemblies shall not contain control components.~~ *Deleted.*

D. DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS are not authorized for loading into the MPC-24.

Note 1: *Non-fuel hardware is defined as Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Devices (TPDs), Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs) and other similarly designed devices with different names. Fuel assemblies containing BPRAs or TPDs may be stored in any fuel cell location. Fuel assemblies containing CRAs or APSRs may only be loaded in fuel storage locations 9, 10, 15, and/or 16. These requirements are in addition to any other requirements specified for preferential or regionalized fuel loading.*

Table 2.1-1 (page 3 of ~~14~~ *29*)
Fuel Assembly Limits

II. MPC MODEL: MPC-68

A. Allowable Contents

1. Uranium oxide, BWR INTACT FUEL ASSEMBLIES listed in Table 2.1-3, with or without ~~Zircaloy~~ channels, and meeting the following specifications:

a. Cladding Type:	Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-3 for the applicable fuel assembly array/class.
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Zr Clad: *Array/Classes 6x6A, 6x6C, 7x7A, and 8x8A*:	~~An assembly post-irradiation~~ Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU
ii. ~~SS Clad:~~ *Array/Class 8x8F*	*Cooling time ≥ 10 years and an average burnup ≤ 27,500 MWD/MTU.*
iii. Array/Classes 10x10D and 10x10E	~~An assembly post-irradiation~~ Cooling time ≥ 10 years and an average burnup ≤ 22,500 MWD/MTU.
iv. All Other Array/Classes	~~An assembly post-irradiation cooling time and average burnup~~ As specified in Tables 2.1-4 *and 2.1-6*.

Table 2.1-1 (page 4 of ~~14~~ *29*)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

e. Decay Heat Per Assembly:

i. ~~Zr Clad:~~ *Array/Classes 6x6A, 6x6C, 7x7A, and 8x8A*	≤ 115 Watts
ii. ~~SS Clad:~~ *Array/Class 8x8F*	*≤ 183.5 Watts.*
iii. *Array/Classes 10x10D and 10x10E*	≤ 95 Watts
iv. All Other Array/Classes	~~An assembly maximum decay heat~~ As specified in Tables 2.1-5 *and 2.1-7.*
f. Fuel Assembly Length:	≤ 176.2 inches (nominal design)
g. Fuel Assembly Width:	≤ 5.85 inches (nominal design)
h. Fuel Assembly Weight:	≤ 700 lbs, including channels

Table 2.1-1 (page 5 of ~~14~~ *29*)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

2. Uranium oxide, BWR DAMAGED FUEL ASSEMBLIES, with or without ~~Zircaloy~~ channels, placed in DAMAGED FUEL CONTAINERS. Uranium oxide BWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 ~~for fuel assembly array/class 6x6A, 6x6C, 7x7A, or 8x8A,~~ and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr) *or Stainless Steel (SS) as specified in Table 2.1-3 for the applicable fuel assembly array/class.*
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	
i. Array/Classes 6x6A, 6x6C, 7x7A, and 8x8A	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
ii. All Other Array/Classes specified in Table 2.1-3	*4.0 wt%* ^{235}U
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 6x6A, 6x6C, 7x7A,and 8x8A	*Cooling time* $\geq$ *18 years and an average burnup* $\leq$ *30,000 MWD/MTU.*
ii. Array/Class 8x8F	*Cooling time* $\geq$ *10 years and an average burnup* $\leq$ *27,500 MWD/MTU.*
iii. Array/Classes 10x10D and 10x10E	*Cooling time* $\geq$ *10 years and an average burnup* $\leq$ *22,500 MWD/MTU.*
iv. All Other Array Classes	*As specified in Tables 2.1-4 and 2.1-6.*

Table 2.1-1 (page 6 of 29)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

e. Decay Heat Per Assembly:

i.	*Array/Class 6x6A, 6x6C, 7x7A, and 8x8A*	*≤ 115 Watts*
ii.	*Array/Class 8x8F*	*≤ 183.5 Watts*
iii.	*Array/Classes 10x10D and 10x10E*	*≤ 95 Watts*
iv.	*All Other Array/Classes*	*As specified in Tables 2.1-5 and 2.1-7*

f. Fuel Assembly Length:

i.	*Array/Class 6x6A, 6x6C, 7x7A, or 8x8A*	*≤ 135.0 inches (nominal design)*
ii.	*All Other Array/Classes*	*≤ 176.2 inches (nominal design)*

g. Fuel Assembly Width:

i.	*Array/Class 6x6A, 6x6C, 7x7A, or 8x8A*	*≤ 4.70 inches (nominal design)*
ii.	*All Other Array/Classes*	*≤ 5.85 inches (nominal design)*

h. Fuel Assembly Weight:

i.	*Array/Class 6x6A, 6x6C, 7x7A, or 8x8A*	*≤ 550 lbs, including channels and DFC*
ii.	*All Other Array/Classes*	*≤ 700 lbs, including channels and DFC*

Table 2.1-1 (page 7 of ~~14~~ *29*)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

3. Mixed oxide (MOX), BWR INTACT FUEL ASSEMBLIES, with or without ~~Zircaloy~~ channels. MOX BWR INTACT FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	~~An assembly post-irradiation~~ Cooling time $\geq$ 18 years and an average burnup $\leq$ 30,000 MWD/MTIHM.
e. Decay Heat Per Assembly:	$\leq$ 115 Watts
f. Fuel Assembly Length:	$\leq$ 135.0 inches (nominal design)
g. Fuel Assembly Width:	$\leq$ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	$\leq$ 400 lbs, including channels

Table 2.1-1 (page 8 of ~~14~~ *29*)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

4. Mixed oxide (MOX), BWR DAMAGED FUEL ASSEMBLIES, with or without ~~Zircaloy~~ channels, placed in DAMAGED FUEL CONTAINERS. MOX BWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	~~An assembly post-irradiation~~ Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTIHM.
e. Decay Heat Per Assembly:	≤ 115 Watts
f. Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	≤ ~~400~~ *550* lbs, including channels *and DFC*

Table 2.1-1 (page 9 of 29)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

5. Thoria rods (ThO_2 and UO_2) placed in Dresden Unit 1 Thoria Rod Canisters and meeting the following specifications:

a. Cladding Type:	*Zircaloy (Zr)*
b. Composition:	*98.2 wt.% ThO_2, 1.8 wt. % UO_2 with an enrichment of 93.5 wt. % ^{235}U.*
c. Number of Rods Per Thoria Rod Canister:	*$\leq$ 18*
d. Decay Heat Per Thoria Rod Canister:	*$\leq$ 115 Watts*
e. Post-irradiation Fuel Cooling Time and Average Burnup Per Thoria Rod Canister:	*A fuel post-irradiation cooling time $\geq$ 18 years and an average burnup $\leq$ 16,000 MWD/MTIHM.*
f. Initial Heavy Metal Weight:	*$\leq$ 27 kg/canister*
g. Fuel Cladding O.D.:	*$\geq$ 0.412 inches*
h. Fuel Cladding I.D.:	*$\leq$ 0.362 inches*
i. Fuel Pellet O.D.:	*$\leq$ 0.358 inches*
j. Active Fuel Length:	*$\leq$ 111 inches*
k. Canister Weight:	*$\leq$ 550 lbs, including fuel*

Table 2.1-1 (page 10 of 29)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

B. Quantity per MPC:

1. *Up to one (1) Dresden Unit 1 Thoria Rod Canister;*

2. *Up to 68 array/class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A DAMAGED FUEL ASSEMBLIES in DAMAGE FUEL CONTAINERS;*

3. *Up to sixteen (16) other BWR DAMAGED FUEL ASSEMBLIES in DAMAGED FUEL CONTAINERS in fuel storage locations 1, 2, 3, 8, 9, 16, 25, 34, 35, 44, 53, 60, 61, 66, 67, and/or 68; and/or*

4. *Any number of BWR INTACT FUEL ASSEMBLIES up to a total of 68.*

C. ~~Fuel assemblies with stainless steel channels are not authorized for loading in the MPC-68.~~ *Array/Class 10x10D and 10x10E fuel assemblies in stainless steel channels must be stored in fuel storage locations 19 - 22, 28 - 31, 38 -41, and/or 47 - 50.*

D. Dresden Unit 1 fuel assemblies with one Antimony-Beryllium neutron source are authorized for loading in the MPC-68. The Antimony-Beryllium source material shall be in a water rod location.

Table 2.1-1 (page ~~8~~ *11* of ~~14~~ *29*)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F

A. Allowable Contents

1. Uranium oxide, BWR INTACT FUEL ASSEMBLIES, with or without ~~Zircaloy~~ channels. Uranium oxide BWR INTACT FUEL ASSEMBLIES shall meet the criteria *specified* in Table 2.1-3 for fuel assembly array class 6x6A, 6x6C, 7x7A or 8x8A, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	~~An assembly post-irradiation~~ Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU.
e. Decay Heat Per Assembly	≤ 115 Watts
f. Fuel Assembly Length:	≤ ~~176.2~~ *135.0* inches (nominal design)
g. Fuel Assembly Width:	≤ ~~5.85~~ *4.70* inches (nominal design)
h. Fuel Assembly Weight:	≤ ~~700~~ *400* lbs, including channels

Table 2.1-1 (page ~~9~~ *12* of ~~14~~ *29*)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

2. Uranium oxide, BWR DAMAGED FUEL ASSEMBLIES, with or without ~~Zircaloy~~ channels, placed in DAMAGED FUEL CONTAINERS. Uranium oxide BWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6A, 6x6C, 7x7A, or 8x8A, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	*Cooling time* ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU.
e. Decay Heat Per Assembly:	≤ 115 Watts
f. Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	≤ ~~400~~ *550* lbs, including channels *and DFC*

Table 2.1-1 (page ~~10~~ *13* of ~~14~~ *29*)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

3. Uranium oxide, BWR FUEL DEBRIS, with or without ~~Zircaloy~~ channels, placed in DAMAGED FUEL CONTAINERS. The original fuel assemblies for the uranium oxide BWR FUEL DEBRIS shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6A, 6x6C, 7x7A, or 8x8A, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable original fuel assembly array/class.
c Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable original fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly	~~A post-irradiation~~ Cooling time ~~after discharge~~ ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU for the original fuel assembly.
e. Decay Heat Per Assembly	≤ 115 Watts
f. Original Fuel Assembly Length	≤ 135.0 inches (nominal design)
g. Original Fuel Assembly Width	≤ 4.70 inches (nominal design)
h. Fuel Debris Weight	≤ ~~400~~ *550* lbs, including channels *and DFC*

Table 2.1-1 (page ~~11~~ *14* of ~~14~~ *29*)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

4. Mixed oxide (MOX), BWR INTACT FUEL ASSEMBLIES, with or without ~~Zircaloy~~ channels. MOX BWR INTACT FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	~~An assembly post-irradiation~~ Cooling time ~~after discharge~~ ≥ 18 years and an average burnup ≤ 30,000 MWD/MTIHM.
e. Decay Heat Per Assembly	≤ 115 Watts
f. Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	≤ 400 lbs, including channels

Table 2.1-1 (page ~~12~~ *15* of ~~14~~ *29*)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

5. Mixed oxide (MOX), BWR DAMAGED FUEL ASSEMBLIES, with or without ~~Zircaloy~~ channels, placed in DAMAGED FUEL CONTAINERS. MOX BWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	~~A post-irradiation~~ Cooling time ~~after discharge~~ ≥ 18 years and an average burnup ≤ 30,000 MWD/MTIHM.
e. Decay Heat Per Assembly	≤ 115 Watts
f. Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	≤ ~~400~~ *550* lbs, including channels *and DFC*

Table 2.1-1 (page ~~13~~ *16* of ~~14~~ *29*)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

6. Mixed Oxide (MOX), BWR FUEL DEBRIS, with or without ~~Zircaloy~~ channels, placed in DAMAGED FUEL CONTAINERS. The original fuel assemblies for the MOX BWR FUEL DEBRIS shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for original fuel assembly array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for original fuel assembly array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	~~A post-irradiation~~ Cooling time ~~after discharge~~ ≥ 18 years and an average burnup ≤ 30,000 MWD/MTIHM for the original fuel assembly.
e. Decay Heat Per Assembly	≤ 115 Watts
f. Original Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Original Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Debris Weight:	≤ ~~400~~ *550* lbs, including channels *and DFC*

Table 2.1-1 (page 17 of 29)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

7. Thoria rods (ThO_2 and UO_2) placed in Dresden Unit 1 Thoria Rod Canisters and meeting the following specifications:

a. Cladding Type:	*Zircaloy (Zr)*
b. Composition:	*98.2 wt.% ThO_2, 1.8 wt. % UO_2 with an enrichment of 93.5 wt. % ^{235}U.*
c. Number of Rods Per Thoria Rod Canister:	*$\leq$ 18*
d. Decay Heat Per Thoria Rod Canister:	*$\leq$ 115 Watts*
e. Post-irradiation Fuel Cooling Time and Average Burnup Per Thoria Rod Canister:	*A fuel post-irradiation cooling time $\geq$ 18 years and an average burnup $\leq$ 16,000 MWD/MTIHM.*
f. Initial Heavy Metal Weight:	*$\leq$ 27 kg/canister*
g. Fuel Cladding O.D.:	*$\geq$ 0.412 inches*
h. Fuel Cladding I.D.:	*$\leq$ 0.362 inches*
i. Fuel Pellet O.D.:	*$\leq$ 0.358 inches*
j. Active Fuel Length:	*$\leq$ 111 inches*
k. Canister Weight:	*$\leq$ 550 lbs, including fuel*

Table 2.1-1 (page ~~14~~ *18* of ~~14~~ *29*)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

B. Quantity per MPC (up to a total of 68 assemblies):
(All fuel assemblies must be array/class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A):

Up to four (4) DFCs containing uranium oxide BWR FUEL DEBRIS or MOX BWR FUEL DEBRIS. The remaining MPC-68F fuel storage locations may be filled with ~~array/class 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A~~ fuel assemblies of the following type, as applicable:

1. Uranium oxide BWR INTACT FUEL ASSEMBLIES;
2. MOX BWR INTACT FUEL ASSEMBLIES;
3. Uranium oxide BWR DAMAGED FUEL ASSEMBLIES placed in DFCs; ~~or~~
4. MOX BWR DAMAGED FUEL ASSEMBLIES placed in DFCs; *or*
5. *Up to one (1) Dresden Unit 1 Thoria Rod Canister.*

C. Fuel assemblies with stainless steel channels are not authorized for loading in the MPC-68F.

D. Dresden Unit 1 fuel assemblies with one Antimony-Beryllium neutron source are authorized for loading in the MPC-68F. The Antimony-Beryllium source material shall be in a water rod location.

Table 2.1-1 (page 19 of 29)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E

A. Allowable Contents

1. Uranium oxide, PWR INTACT FUEL ASSEMBLIES listed in Table 2.1-2, with or without non-fuel hardware and meeting the following specifications (Note 1):

a. Cladding Type:	*Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class*
b. Initial Enrichment:	*As specified in Table 2.1-2 for the applicable fuel assembly array/class.*
c. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	*Cooling time ≥ 8 years and an average burnup ≤ 40,000 MWD/MTU.*
ii. All Other Array/Classes	*As specified in Tables 2.1-4 and 2.1-6.*
iii. Non-fuel Hardware	*As specified in Table 2.1-8.*

Table 2.1-1 (page 20 of 29)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E (continued)

d. Decay Heat Per Assembly:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	*≤ 710 Watts.*
ii. All other Array/Classes	*As specified in Tables 2.1-5 and 2.1-7.*
e. Fuel Assembly Length:	*≤ 176.8 inches (nominal design)*
f. Fuel Assembly Width:	*≤ 8.54 inches (nominal design)*
g. Fuel Assembly Weight:	*≤ 1,680 lbs (including non-fuel hardware)*

Table 2.1-1 (page 21 of 29)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E (continued)

2. *Uranium oxide, PWR DAMAGED FUEL ASSEMBLIES, with or without non-fuel hardware, placed in DAMAGED FUEL CONTAINERS. Uranium oxide PWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-2 and meet the following specifications (Note 1):*

a. Cladding Type:	*Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class*
b. Initial Enrichment:	*$\leq$ 4.0 wt% ^{235}U.*
c. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	*Cooling time $\geq$ 8 years and an average burnup $\leq$ 40,000 MWD/MTU.*
ii. All Other Array/Classes	*As specified in Tables 2.1-4 and 2.1-6.*
iii. Non-Fuel Hardware	*As specified in Table 2.1-8.*

Table 2.1-1 (page 22 of 29)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E (continued)

d. Decay Heat Per Assembly	
i. Array/Classes 14x14D, 14x14E, and 15x15G	*≤ 710 Watts.*
ii. All Other Array/Classes	*As specified in Tables 2.1-5 and 2.1-7.*
e. Fuel Assembly Length	*≤ 176.8 inches (nominal design)*
f. Fuel Assembly Width	*≤ 8.54 inches (nominal design)*
g. Fuel Assembly Weight	*≤ 1,680 lbs (including non-fuel hardware and DFC)*

B. Quantity per MPC: Up to four (4) DAMAGED FUEL ASSEMBLIES in DAMAGED FUEL CONTAINERS, stored in fuel storage locations 3, 6, 19 and/or 22. The remaining MPC-24E fuel storage locations may be filled with PWR INTACT FUEL ASSEMBLIES meeting the applicable specifications.

C. FUEL DEBRIS is not authorized for loading in the MPC-24E.

Note 1: Non-fuel hardware is defined as Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Devices (TPDs), Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs) and other similarly designed devices with different names. Fuel assemblies containing BPRAs or TPDs may be stored in any fuel storage location. Fuel assemblies containing CRAs or APSRs must be loaded in fuel storage locations 9,10,15 and/or 16. These requirements are in addition to any other requirements specified for preferential or regionalized fuel loading.

Table 2.1-1 (page 23 of 29)
Fuel Assembly Limits

V. MPC MODEL: MPC-32

A. Allowable Contents

1. Uranium oxide, PWR INTACT FUEL ASSEMBLIES listed in Table 2.1-2, with or without non-fuel hardware and meeting the following specifications (Note 1):

a. Cladding Type:	*Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class*
b. Initial Enrichment:	*As specified in Table 2.1-2 for the applicable fuel assembly array/class.*
c. Post-irradiation Cooling Time and Average Burnup Per Assembly	
i. Array/Classes 14x14D, 14x14E, and 15x15G	*Cooling time ≥ 9 years and an average burnup ≤ 30,000 MWD/MTU or cooling time ≥ 20 years and an average burnup ≤ 40,000 MWD/MTU.*
ii. All Other Array/Classes	*As specified in Tables 2.1-4 and 2.1-6.*
iii. Non-fuel Hardware	*As specified in Table 2.1-8.*

Table 2.1-1 (page 24 of 29)
Fuel Assembly Limits

V. MPC MODEL: MPC-32 (continued)

d. Decay Heat Per Assembly	
i. Array/Classes 14x14D, 14x14E, and 15x15G	*≤ 500 Watts*
ii. All Other Array/Classes	*As specified in Tables 2.1-5 and 2.1-7.*
e. Fuel Assembly Length	*≤ 176.8 inches (nominal design)*
f. Fuel Assembly Width	*≤ 8.54 inches (nominal design)*
g. Fuel Assembly Weight	*≤ 1,680 lbs (including non-fuel hardware)*

B. Quantity per MPC: Up to 32 PWR INTACT FUEL ASSEMBLIES.

C. DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS are not authorized for loading in the MPC-32.

Note 1: Non-fuel hardware is defined as Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Devices (TPDs), Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs) and other similarly designed devices with different names. Fuel assemblies containing BPRAs or TPDs may be stored in any fuel storage location. Fuel assemblies containing CRAs or APSRs must be loaded in fuel storage locations 13, 14, 19, and/or 20. These requirements are in addition to any other requirements specified for preferential or regionalized fuel loading.

Table 2.1-1 (page 25 of 29)
Fuel Assembly Limits

VI. MPC MODEL: MPC-68FF

A. Allowable Contents

1. Uranium oxide or MOX BWR INTACT FUEL ASSEMBLIES listed in Table 2.1-2, with or without channels and meeting the following specifications:

a. Cladding Type:	*Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-3 for the applicable fuel assembly array/class*
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	*As specified in Table 2.1-3 for the applicable fuel assembly array/class.*
c. Initial Maximum Rod Enrichment	*As specified in Table 2.1-3 for the applicable fuel assembly array/class.*
d. Post-irradiation Cooling Time and Average Burnup Per Assembly	
i. Array/Classes 6x6A, 6x6C, 7x7A, and 8x8A	*Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU.*
ii. Array/Class 8x8F	*Cooling time ≥ 10 years and an average burnup ≤ 27,500 MWD/MTU.*
iii. Array/Classes 10x10D and 10x10E	*Cooling time ≥ 10 years and an average burnup ≤ 22,500 MWD/MTU.*
iv. All Other Array/Classes	*As specified in Tables 2.1-4 and 2.1-6.*

Table 2.1-1 (page 26 of 29)
Fuel Assembly Limits

VI. MPC MODEL: MPC-68FF (continued)

e. Decay Heat Per Assembly	
i. Array/Classes 6x6A, 6x6C, 7x7A, and 8x8A	*≤ 115 Watts*
ii. Array/Class 8x8F	*≤ 183.5 Watts*
iii. Array/Classes 10x10D and 10x10E	*≤ 95 Watts*
iv. All Other Array/Classes	*As specified in Tables 2.1-5 and 2.1-7.*
f. Fuel Assembly Length	*≤ 176.2 inches (nominal design)*
g. Fuel Assembly Width	*≤ 5.85 inches (nominal design)*
h. Fuel Assembly Weight	*≤ 700 lbs, including channels*

Table 2.1-1 (page 27 of 29)
Fuel Assembly Limits

VI. MPC MODEL: MPC-68FF (continued)

2. Uranium oxide or MOX BWR DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS, with or without channels, placed in DAMAGED FUEL CONTAINERS. Uranium oxide and MOX BWR DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS shall meet the criteria specified in Table 2.1-3, and meet the following specifications:

a. Cladding Type:	*Zircaloy (Zr) or Stainless Steel (SS) in accordance with Table 2.1-3 for the applicable fuel assembly array/class.*
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	
i. Array/Classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A.	*As specified in Table 2.1-3 for the applicable fuel assembly array/class.*
ii. All Other Array Classes	*$\leq$ 4.0 wt.% ^{235}U.*
c. Initial Maximum Rod Enrichment	*As specified in Table 2.1-3 for the applicable fuel assembly array/class.*
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	*Cooling time $\geq$ 18 years and an average burnup $\leq$ 30,000 MWD/MTU (or MWD/MTIHM).*
ii. Array/Class 8x8F	*Cooling time $\geq$ 10 years and an average burnup $\leq$ 27,500 MWD/MTU.*
iii. Array/Class 10x10D and 10x10E	*Cooling time $\geq$ 10 years and an average burnup $\leq$ 22,500 MWD/MTU.*
iv. All Other Array/Classes	*As specified in Tables 2.1-4 and 2.1-6.*

Table 2.1-1 (page 28 of 29)
Fuel Assembly Limits

VI. MPC MODEL: MPC-68FF (continued)

e. Decay Heat Per Assembly

i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 115 Watts
ii.	Array/Class 8x8F	≤ 183.5 Watts
iii.	Array/Classes 10x10D and 10x10E	≤ 95 Watts
iv.	All Other Array/Classes	As specified in Tables 2.1-5 and 2.1-7

f. Fuel Assembly Length

i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 135.0 inches (nominal design)
ii.	All Other Array/Classes	≤ 176.2 inches (nominal design)

g. Fuel Assembly Width

i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 4.70 inches (nominal design)
ii.	All Other Array/Classes	≤ 5.85 inches (nominal design)

h. Fuel Assembly Weight

i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 550 lbs, including channels and DFC
ii.	All Other Array/Classes	≤ 700 lbs, including channels and DFC

Table 2.1-1 (page 29 of 29)
Fuel Assembly limits

VI. MPC MODEL: MPC-68FF (continued)

B. Quantity per MPC (up to a total of 68 assemblies)

Up to sixteen (16) DFCs containing BWR DAMAGED FUEL ASSEMBLIES and/or up to eight (8) DFCs containing FUEL DEBRIS. DFCs shall be located only in fuel storage locations 1, 2, 3, 8, 9, 16, 25, 34, 35, 44, 53, 60, 61, 66, 67, and/or 68. The remaining MPC-68FF fuel storage locations may be filled with fuel assemblies of the following type:

3. Uranium Oxide BWR INTACT FUEL ASSEMBLIES; or

4. MOX BWR INTACT FUEL ASSEMBLIES;

C. Dresden Unit 1 fuel assemblies with one Antimony-Beryllium neutron source are authorized for loading in the MPC-68FF. The Antimony-Beryllium source material shall be in a water rod location.

D. Array/Class 10x10D and 10x10E fuel assemblies in stainless steel channels must be stored in fuel storage locations 19 - 22, 28 - 31, 38 -41, and/or 47 - 50.

Table 2.1-2 (page 1 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**14x14A**	**14x14B**	**14x14C**	**14x14D**	***14x14E***
Clad Material (Note 2)	Zr	Zr	Zr	SS	*SS*
Design Initial U (kg/assy.) (Note 3)	~~≤ 402~~ *≤ 407*	~~≤ 402~~ *≤ 407*	~~≤ 410~~ *≤ 425*	≤ 400	*≤ 206*
Initial Enrichment *(MPC-24 and 24E without soluble boron credit)* (wt % ^{235}U) *(Note 7)*	≤ 4.6 *(24)* *≤ 5.0 (24E)*	≤ 4.6 *(24)* *≤ 5.0 (24E)*	≤ 4.6 *(24)* *≤ 5.0 (24E)*	≤ 4.0 *(24)* *≤ 5.0 (24E)*	*≤ 5.0 (24)* *≤ 5.0 (24E)*
Initial Enrichment (MPC-24, 24E, or 32 with soluble boron credit - see Notes 5 and 7) (wt % ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rods	179	179	176	180	*173*
Clad O.D. (in.)	≥ 0.400	≥ 0.417	≥ 0.440	≥ 0.422	*≥ 0.3415*
Clad I.D. (in.)	≤ 0.3514	≤ 0.3734	~~≤ 0.3840~~ *≤ 0.3880*	≤ 0.3890	*≤ 0.3175*
Pellet Dia. (in.)	≤ 0.3444	≤ 0.3659	~~≤ 0.3770~~ *≤ 0.3805*	≤ 0.3835	*≤ 0.3130*
Fuel Rod Pitch (in.)	≤ 0.556	≤ 0.556	≤ 0.580	≤ 0.556	*Note 6*
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 144	*≤ 102*
No. of Guide Tubes	17	17	5 (Note 4)	16	*0*
Guide Tube Thickness (in.)	≥ 0.017	≥ 0.017	~~≥ 0.040~~ *≥ 0.038*	≥ 0.0145	*N/A*

Table 2.1-2 (page 2 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**15x15A**	**15x15B**	**15x15C**	**15x15D**	**15x15E**	**15x15F**
Clad Material (Note 2)	Zr	Zr	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note 3)	~~≤ 420~~ *≤ 464*	≤ 464	≤ 464	≤ 475	≤ 475	≤ 475
Initial Enrichment *(MPC-24 and 24E without soluble boron credit)* (wt % ^{235}U) *(Note 7)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*
Initial Enrichment (MPC-24, 24E, or 32 with soluble boron credit - see Notes 5 and 7) (wt % ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rods	204	204	204	208	208	208
Clad O.D. (in.)	≥ 0.418	≥ 0.420	≥ 0.417	≥ 0.430	≥ 0.428	≥ 0.428
Clad I.D. (in.)	≤ 0.3660	≤ 0.3736	≤ 0.3640	≤ 0.3800	≤ 0.3790	≤ 0.3820
Pellet Dia. (in.)	≤ 0.3580	≤ 0.3671	≤ 0.3570	≤ 0.3735	≤ 0.3707	≤ 0.3742
Fuel Rod Pitch (in.)	≤ 0.550	≤ 0.563	≤ 0.563	≤ 0.568	≤ 0.568	≤ 0.568
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide Tubes	21	21	21	17	17	17
Guide Tube Thickness (in.)	≥ 0.0165	≥ 0.015	≥ 0.0165	≥ 0.0150	≥ 0.0140	≥ 0.0140

Table 2.1-2 (page 3 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/ Class	**15x15G**	***15x15H***	**16x16A**	**17x17A**	**17x17B**	**17x17C**
Clad Material (Note 2)	SS	*Zr*	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note 3)	≤ 420	*≤ 475*	~~≤ 430~~ *≤ 443*	~~≤ 450~~ *≤ 467*	~~≤ 464~~ *≤ 467*	~~≤ 460~~ *≤ 474*
Initial Enrichment *(MPC-24 and 24E without soluble boron credit)* (wt % ^{235}U) *(Note 7)*	≤ 4.0 *(24)* *≤ 4.5 (24E)*	*≤ 3.8 (24)* *≤ 4.2 (24E)*	≤ 4.6 *(24)* *≤ 5.0 (24E)*	≤ 4.0 *(24)* *≤ 4.4 (24E)*	≤ 4.0 *(24)* *≤ 4.4 (24E)*	≤ 4.0 *(24)* *≤ 4.4 (24E)*
Initial Enrichment (MPC-24, 24E, or 32 with soluble boron credit - see Notes 5 and 7) (wt % ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rods	204	*208*	236	264	264	264
Clad O.D. (in.)	≥ 0.422	*≥ 0.414*	≥ 0.382	≥ 0.360	≥ 0.372	≥ 0.377
Clad I.D. (in.)	≤ 0.3890	*≤ 0.3700*	≤ 0.3320	≤ 0.3150	≤ 0.3310	≤ 0.3330
Pellet Dia. (in.)	≤ 0.3825	*≤ 0.3622*	≤ 0.3255	≤ 0.3088	≤ 0.3232	≤ 0.3252
Fuel Rod Pitch (in.)	≤ 0.563	*≤ 0.568*	≤ 0.506	≤ 0.496	≤ 0.496	≤ 0.502
Active Fuel Length (in.)	≤ 144	*≤ 150*	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide Tubes	21	*17*	5 (Note 4)	25	25	25
Guide Tube Thickness (in.)	≥ 0.0145	*≥ 0.0140*	≥ 0.0400	≥ 0.016	≥ 0.014	≥ 0.020

Table 2.1-2 (page 4 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.

2. Zr designates cladding material made of zirconium or zirconium alloys.

3. Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or reactor user. For each PWR fuel assembly, the total ~~initial~~ uranium weight *limit specified in this table* may be *increased* up to 2.0 percent ~~higher than the design initial uranium weight due~~ *for comparison with users' fuel records* to *account for* manufacturer's tolerances.

4. Each guide tube replaces four fuel rods.

5. *Soluble boron concentration per LCO 3.3.1.*

6. *This fuel assembly array/class includes only the Indian Point Unit 1 fuel assembly. This fuel assembly has two pitches in different sectors of the assembly.*

7. *For those MPCs loaded with both INTACT FUEL ASSEMBLIES and DAMAGED FUEL ASSEMBLIES, the maximum initial enrichment of the INTACT FUEL ASSEMBLIES is limited to the maximum initial enrichment of the DAMAGED FUEL ASSEMBLIES (i.e., 4.0 wt.% ^{235}U).*

Table 2.1-3 (page 1 of 5)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**6x6A**	**6x6B**	**6x6C**	**7x7A**	**7x7B**	**8x8A**
Clad Material (Note 2)	Zr	Zr	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note 3)	≤ ~~108~~ *110*	≤ ~~108~~ *110*	≤ ~~108~~ *110*	≤ 100	≤ 195	≤ 120
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) *(Note 14)*	≤ 2.7	≤ 2.7 for the UO_2 rods. See Note 4 for MOX rods	≤ 2.7	≤ 2.7	≤ 4.2	≤ 2.7
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 4.0	≤ 4.0	≤ 4.0	~~≤ 4.0~~ *≤ 5.5*	≤ 5.0	≤ 4.0
No. of Fuel Rods	*35 or* 36	*35 or* 36 (up to 9 MOX rods)	36	49	49	*63 or* 64
Clad O.D. (in.)	≥ 0.5550	≥ 0.5625	≥ 0.5630	≥ 0.4860	≥ 0.5630	≥ 0.4120
Clad I.D. (in.)	~~≤ 0.4945~~ *≤ 0.5105*	≤ 0.4945	≤ 0.4990	~~≤ 0.4200~~ *≤ 0.4204*	≤ 0.4990	≤ 0.3620
Pellet Dia. (in.)	~~≤ 0.4940~~ *≤ 0.4980*	≤ 0.4820	≤ 0.4880	≤ 0.4110	~~≤ 0.4880~~ *≤ 0.4910*	≤ 0.3580
Fuel Rod Pitch (in.)	~~≤ 0.694~~ *≤ 0.710*	~~≤ 0.694~~ *≤ 0.710*	≤ 0.740	≤ 0.631	≤ 0.738	≤ 0.523
Active Fuel Length (in.)	~~≤ 110~~ *≤ 120*	~~≤ 110~~ *≤ 120*	≤ 77.5	~~≤ 79~~ *≤ 80*	≤ 150	~~≤ 110~~ *≤ 120*
No. of Water Rods *(Note 11)*	*1 or* 0	*1 or* 0	0	0	0	*1 or* 0
Water Rod Thickness (in.)	~~N/A~~ *> 0*	~~N/A~~ *> 0*	N/A	N/A	N/A	~~N/A~~ *≥ 0*
Channel Thickness (in.)	≤ 0.060	≤ 0.060	≤ 0.060	≤ 0.060	≤ 0.120	≤ 0.100

Table 2.1-3 (2 of 5)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**8x8B**	**8x8C**	**8x8D**	**8x8E**	***8x8F***	**9x9A**
Clad Material (Note 2)	Zr	Zr	Zr	Zr	*Zr*	Zr
Design Initial U (kg/assy.) (Note 3)	~~≤ 185~~ ≤ *191*	~~≤ 185~~ ≤ *191*	~~≤ 185~~ ≤ *191*	~~≤ 180~~ ≤ *191*	≤ *191*	~~≤ 173~~ ≤ *179*
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) *(Note 14)*	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.2	≤ *3.6*	≤ 4.2
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ *5.0*	≤ 5.0
No. of Fuel Rods	63 *or 64*	62	60 *or 61*	59	*64*	74/66 (Note 5)
Clad O.D. (in.)	≥ 0.4840	≥ 0.4830	≥ 0.4830	≥ 0.4930	≥ *0.4576*	≥ 0.4400
Clad I.D. (in.)	~~≤ 0.4250~~ ≤ *0.4295*	≤ 0.4250	~~≤ 0.4190~~ ≤ *0.4230*	≤ 0.4250	≤ *0.3996*	≤ 0.3840
Pellet Dia. (in.)	~~≤ 0.4160~~ ≤ *0.4195*	≤ 0.4160	~~≤ 0.4110~~ ≤ *0.4140*	≤ 0.4160	≤ *0.3913*	≤ 0.3760
Fuel Rod Pitch (in.)	~~≤ 0.641~~ ≤ *0.642*	≤ 0.641	≤ 0.640	≤ 0.640	≤ *0.609*	≤ 0.566
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ *150*	≤ 150
No. of Water Rods *(Note 11)*	1 *or 0*	2	1 - 4 (Note ~~6~~ *7*)	5	*N/A* *(Note 12)*	2
Water Rod Thickness (in.)	≥ 0.034	> 0.00	> 0.00	≥ 0.034	≥ *0.0315*	> 0.00
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.100	≤ *0.055*	≤ 0.120

Table 2.1-3 (page 3 of 5)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**9x9B**	**9x9C**	**9x9D**	**9x9E** ***(Note 13)***	**9x9F** ***(Note 13)***	***9x9G***
Clad Material (Note 2)	Zr	Zr	Zr	Zr	Zr	*Zr*
Design Initial U (kg/assy.) (Note 3)	~~≤ 173~~ *≤ 179*	~~≤ 173~~ *≤ 179*	~~≤ 170~~ *≤ 179*	~~≤ 170~~ *≤ 179*	~~≤ 170~~ *≤ 179*	*≤ 179*
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) *(Note 14)*	≤ 4.2	≤ 4.2	≤ 4.2	~~≤ 4.2~~ *≤ 4.0*	~~≤ 4.2~~ *≤ 4.0*	*≤ 4.2*
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	*≤ 5.0*
No. of Fuel Rods	72	80	79	76	76	*72*
Clad O.D. (in.)	≥ 0.4330	≥ 0.4230	≥ 0.4240	≥ 0.4170	≥ 0.4430	*≥ 0.4240*
Clad I.D. (in.)	≤ 0.3810	≤ 0.3640	≤ 0.3640	~~≤ 0.3590~~ *≤ 0.3640*	~~≤ 0.3810~~ *≤ 0.3860*	*≤ 0.3640*
Pellet Dia. (in.)	≤ 0.3740	≤ 0.3565	≤ 0.3565	~~≤ 0.3525~~ *≤ 0.3530*	≤ 0.3745	*≤ 0.3565*
Fuel Rod Pitch (in.)	~~≤ 0.569~~ *≤ 0.572*	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572	*≤ 0.572*
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	*≤ 150*
No. of Water Rods *(Note 11)*	1 (Note ~~7~~ *6*)	1	2	5	5	*1* *(Note 6)*
Water Rod Thickness (in.)	> 0.00	≥ 0.020	~~≥ 0.0305~~ *≥ 0.0300*	~~≥ 0.0305~~ *≥ 0.0120*	~~≥ 0.0305~~ *≥ 0.0120*	*≥ 0.320*
Channel Thickness (in.)	≤ 0.120	≤ 0.100	≤ 0.100	~~≤ 0.100~~ *≤ 0.120*	~~≤ 0.100~~ *≤ 0.120*	*≤ 0.120*

Table 2.1-3 (page 4 of 5)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**10x10A**	**10x10B**	**10x10C**	**10x10D**	**10x10E**
Clad Material (Note 2)	Zr	Zr	Zr	SS	SS
Design Initial U (kg/assy.) (Note 3)	~~≤ 182~~ *≤ 188*	~~≤ 182~~ *≤ 188*	~~≤ 180~~ *≤ 188*	≤ 125	≤ 125
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) *(Note 14)*	≤ 4.2	≤ 4.2	~~≤ 4.2~~ *≤ 4.0*	≤ 4.0	≤ 4.0
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rods	92/78 (Note 8)	91/83 (Note 9)	96	100	96
Clad O.D. (in.)	≥ 0.4040	≥ 0.3957	~~≥ 0.3790~~ *≥ 0.3780*	≥ 0.3960	≥ 0.3940
Clad I.D. (in.)	≤ 0.3520	≤ 0.3480	≤ 0.3294	≤ 0.3560	≤ 0.3500
Pellet Dia. (in.)	≤ 0.3455	≤ 0.3420	≤ 0.3224	≤ 0.3500	≤ 0.3430
Fuel Rod Pitch (in.)	≤ 0.510	≤ 0.510	≤ 0.488	≤ 0.565	≤ 0.557
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 83	≤ 83
No. of Water Rods *(Note 11)*	2	1 (Note ~~7~~ *6*)	5 (Note 10)	0	4
Water Rod Thickness (in.)	≥ 0.0300	> 0.00	~~≥ 0.034~~ *≥ 0.031*	N/A	≥ 0.022
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.055	≤ 0.080	≤ 0.080

Table 2.1-3 (page 5 of 5)

BWR FUEL ASSEMBLY CHARACTERISTICS

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.

2. Zr designates cladding material made of zirconium or zirconium alloys.

3. Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or reactor user. For each BWR fuel assembly, the total ~~initial~~ uranium weight *limit specified in this table* may be *increased* up to 1.5 percent ~~higher than the design initial uranium weight due~~ *for comparison with users' fuel records* to *account for* manufacturer tolerances.

4. $\leq$ ~~0.612~~ *0.635* wt. % ^{235}U and $\leq$ 1.578 wt. % total fissile plutonium (^{239}Pu and ^{241}Pu), *(wt. % of total fuel weight, i.e., UO_2 plus PuO_2).*

5. This assembly class contains 74 total rods; 66 full length rods and 8 partial length rods.

6. *Square, replacing nine fuel rods.*

7. *Variable.*

8. This assembly contains 92 total fuel rods; 78 full length rods and 14 partial length rods.

9. This assembly class contains 91 total fuel rods; 83 full length rods and 8 partial length rods.

10. One diamond-shaped water rod replacing the four center fuel rods and four rectangular water rods dividing the assembly into four quadrants.

11. *These rods may also be sealed at both ends and contain Zr material in lieu of water.*

12. *This assembly is known as "QUAD+." It has four rectangular water cross segments dividing the assembly into four quadrants.*

13. *For the SPC 9x9-5 fuel assembly, each fuel rod must meet either the 9x9E or the 9x9F set of limits for clad O.D., clad I.D., and pellet diameter.*

14. *For those MPCs loaded with both INTACT FUEL ASSEMBLIES and DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS, the maximum PLANAR AVERAGE INITIAL ENRICHMENT for the INTACT FUEL ASSEMBLIES is limited to 3.7 wt.% ^{235}U, as applicable.*

Table 2.1-4

FUEL ASSEMBLY COOLING AND *MAXIMUM* AVERAGE BURNUP ~~(Note 1)~~
(UNIFORM FUEL LOADING)

Post-irradiation Cooling Time (years)	**MPC-24 PWR Assembly Burnup *(INTACT FUEL ASSEMBLIES)* (MWD/MTU)**	***MPC-24E PWR Assembly Burnup (INTACT FUEL ASSEMBLIES) (MWD/MTU)***	***MPC-24E PWR Assembly Burnup (DAMAGED FUEL ASSEMBLIES) (MWD/MTU)***	***MPC-32 PWR Assembly Burnup (INTACT FUEL ASSEMBLIES (MWD/MTU)***	**MPC-68/*68FF* BWR Assembly Burnup *(INTACT FUEL ASSEMBLIES) (MWD/MTU)***	***MPC-68/68FF BWR Assembly Burnup (DAMAGED FUEL ASSEMBLIES AND FUEL DEBRIS) (MWD/MTU)***
≥ 5	*33,100*	*34,900*	*33,200*	*24,500*	*35,200*	*33,400*
≥ 6	*37,200*	*39,100*	*37,300*	*28,000*	*38,200*	*36,600*
≥ 7	*37,700*	*39,700*	*37,900*	*28,700*	*38,600*	*37,000*
≥ 8	*40,100*	*41,900*	*40,300*	*30,500*	*40,800*	*39,100*
≥ 9	*41,700*	*43,700*	*41,900*	*31,900*	*42,400*	*40,700*
≥ 10	*43,000*	*45,000*	*43,300*	*32,900*	*43,700*	*41,900*
≥ 11	*44,200*	*NC*	*44,400*	*33,900*	*45,000*	*43,000*
≥ 12	*45,000*	*NC*	*45,000*	*34,700*	*NC*	*44,100*
≥ 13	*NC*	*NC*	*NC*	*35,400*	*NC*	*45,000*
≥ 14	*NC*	*NC*	*NC*	*35,900*	*NC*	*NC*
≥ 15	*NC*	*NC*	*NC*	*36,500*	*NC*	*NC*

Notes: 1. Linear interpolation between points is permitted.

2. NC means not calculated.

Table 2.1-5

FUEL ASSEMBLY COOLING AND *MAXIMUM* DECAY HEAT ~~(Note 1)~~
(UNIFORM FUEL LOADING)

Post-irradiation Cooling Time (years)	**MPC-24 PWR Assembly Decay Heat *(INTACT FUEL ASSEMBLIES)* (Watts)**	***MPC-24E PWR Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts)***	***MPC-24E PWR Assembly Decay Heat (DAMAGED FUEL ASSEMBLIES) (Watts)***	***MPC-32 PWR Assembly Decay Heat (INTACT FUEL ASSEMBLIES (Watts)***	**MPC-68/*68FF* BWR Assembly Decay Heat *(INTACT FUEL ASSEMBLIES) (Watts)***	***MPC-68/68FF BWR Assembly Decay Heat (DAMAGED FUEL ASSEMBLIES AND FUEL DEBRIS) (Watts)***
≥ 5	925	976	927	668	375	356
≥ 6	895	945	898	647	355	337
≥ 7	812	860	817	590	324	308
≥ 8	805	854	811	585	321	305
≥ 9	799	847	804	581	319	303
≥ 10	792	840	798	576	316	300
≥ 11	788	NC	794	573	315	299
≥ 12	784	NC	789	570	NC	297
≥ 13	NC	NC	NC	567	NC	296
≥ 14	NC	NC	NC	564	NC	NC
≥ 15	NC	NC	NC	561	NC	NC

Notes:

1. Linear interpolation between points is permitted.
2. *Includes all sources of heat (i.e., fuel and non-fuel hardware).*
3. *NC means not calculated.*

Table 2.1-6 (page 1 of 2)

FUEL ASSEMBLY COOLING AND MAXIMUM AVERAGE BURNUP (REGIONALIZED FUEL LOADING)

Post-irradiation Cooling Time (years)	**MPC-24 PWR Assembly Burnup for Region 1 (MWD/MTU)**	**MPC-24 PWR Assembly Burnup for Region 2 (MWD/MTU)**	**MPC-24E PWR Assembly Burnup for Region 1 (MWD/MTU)**	**MPC-24E PWR Assembly Burnup for Region 2 (MWD/MTU)**
≥ 5	40,400	23,900	44,700	23,900
≥ 6	42,600	28,100	45,000	28,100
≥ 7	42,600	31,100	NC	31,100
≥ 8	44,700	33,400	NC	33,400
≥ 9	45,000	35,200	NC	35,200
≥ 10	NC	36,500	NC	36,500
≥ 11	NC	37,700	NC	37,700
≥ 12	NC	38,700	NC	38,700
≥ 13	NC	39,700	NC	39,700
≥ 14	NC	40,500	NC	40,500
≥ 15	NC	41,300	NC	41,300
≥ 16	NC	42,100	NC	42,100
≥ 17	NC	42,800	NC	42,800
≥ 18	NC	43,600	NC	43,600
≥ 19	NC	44,400	NC	44,400
≥ 20	NC	45,000	NC	45,000

Notes: 1. Linear interpolation between points is permitted.
2. *NC means not calculated.*

Table 2.1-6 (page 2 of 2)

FUEL ASSEMBLY COOLING AND MAXIMUM AVERAGE BURNUP
(REGIONALIZED FUEL LOADING)

Post-irradiation Cooling Time (years)	**MPC-32 PWR Assembly Burnup for Region 1 (MWD/MTU)**	**MPC-32 PWR Assembly Burnup for Region 2 (MWD/MTU)**	**MPC-68/68FF BWR Assembly Burnup for Region 1 (MWD/MTU)**	**MPC-68/68FF BWR Assembly Burnup for Region 2 (MWD/MTU)**
≥ 5	30,500	NC	41,300	NC
≥ 6	34,200	NC	44,200	20,100
≥ 7	34,200	NC	44,200	22,300
≥ 8	36,200	20,500	45,000	24,100
≥ 9	37,700	21,600	NC	25,300
≥ 10	38,900	22,500	NC	26,300
≥ 11	39,900	23,200	NC	27,200
≥ 12	40,800	23,900	NC	28,000
≥ 13	41,400	24,500	NC	28,600
≥ 14	42,100	25,000	NC	29,300
≥ 15	42,600	25,500	NC	29,900
≥ 16	NC	26,000	NC	30,500
≥ 17	NC	26,500	NC	31,100
≥ 18	NC	26,900	NC	31,700
≥ 19	NC	27,400	NC	32,200
≥ 20	NC	27,900	NC	32,800

Notes 1. Linear interpolation between points is permitted.
2. *NC means not calculated.*

Table 2.1-7 (page 1 of 2)

FUEL ASSEMBLY COOLING AND MAXIMUM DECAY HEAT
(REGIONALIZED FUEL LOADING)

Post-irradiation Cooling Time (years)	***MPC-24 PWR Assembly Decay Heat for Region 1 (Watts)***	***MPC-24 PWR Assembly Decay Heat for Region 2 (Watts)***	***MPC-24E PWR Assembly Decay Heat for Region 1 (Watts)***	***MPC-24E PWR Assembly Decay Heat for Region 2 (Watts)***
≥ 5	1,152	650	1,295	650
≥ 6	1,152	650	1,295	650
≥ 7	942	650	NC	650
≥ 8	924	650	NC	650
≥ 9	905	650	NC	650
≥ 10	NC	650	NC	650
≥ 11	NC	650	NC	650
≥ 12	NC	650	NC	650
≥ 13	NC	650	NC	650
≥ 14	NC	650	NC	650
≥ 15	NC	650	NC	650
≥ 16	NC	650	NC	650
≥ 17	NC	650	NC	650
≥ 18	NC	650	NC	650
≥ 19	NC	650	NC	650
≥ 20	NC	650	NC	650

Notes: 1. Linear interpolation between points is permitted.

2. *Includes all sources of decay heat (i.e., fuel and non-fuel hardware).*

3. *NC means not calculated.*

Table 2.1-7 (page 2 of 2)

FUEL ASSEMBLY COOLING AND MAXIMUM DECAY HEAT
(REGIONALIZED FUEL LOADING)

Post-irradiation Cooling Time (years)	**MPC-32 PWR Assembly Decay Heat for Region 1 (Watts)**	**MPC-32 PWR Assembly Decay Heat for Region 2 (Watts)**	**MPC-68/68FF BWR Assembly Decay Heat for Region 1 (Watts)**	**MPC-68/68FF BWR Assembly Decay Heat for Region 2 (Watts)**
≥ 5	846	375	452	175
≥ 6	813	375	425	175
≥ 7	722	375	382	175
≥ 8	715	375	379	175
≥ 9	707	375	NC	175
≥ 10	700	375	NC	175
≥ 11	695	375	NC	175
≥ 12	690	375	NC	175
≥ 13	685	375	NC	175
≥ 14	680	375	NC	175
≥ 15	675	375	NC	175
≥ 16	NC	375	NC	175
≥ 17	NC	375	NC	175
≥ 18	NC	375	NC	175
≥ 19	NC	375	NC	175
≥ 20	NC	375	NC	175

Notes: 1. Linear interpolation between points is permitted.

2. *Includes all sources of decay heat (i.e., fuel and non-fuel hardware).*

3. *NC means not calculated.*

Table 2.1-8
NON-FUEL HARDWARE COOLING AND AVERAGE BURNUP

Post-irradiation Cooling Time (years)	**BPRA BURNUP (MWD/MTU)**	**TPD BURNUP (MWD/MTU)**	**CRA BURNUP (MWD/MTU)**	**APSR BURNUP (MWD/MTU)**
≥ 3	≤ 20,000	NC	NC	NC
≥ 4	NC	≤ 20,000	NC	NC
≥ 5	≤ 30,000	NC	≤ 630,000	≤ 45,000
≥ 6	≤ 40,000	≤ 30,000	NC	≤ 54,500
≥ 7	NC	≤ 40,000	NC	≤ 68,000
≥ 8	≤ 50,000	NC	NC	≤ 83,000
≥ 9	≤ 60,000	≤ 50,000	NC	≤ 111,000
≥ 10	NC	≤ 60,000	NC	≤ 180,000
≥ 11	NC	NC	NC	≤ 630,000
≥ 12	NC	≤ 90,000	NC	NC
≥ 13	NC	≤ 180,000	NC	NC
≥ 14	NC	≤ 630,000	NC	NC

Notes:
1. Linear interpolation between points is permitted, except that TPD and APSR burnups > 180,000 MWD/MTU and ≤ 630,000 MWD/MTU must be cooled ≥ 14 years and ≥ 11 years, respectively.
2. Applicable to uniform loading and regionalized loading.
3. NC means not calculated

3.0 DESIGN FEATURES

3.1 Site

3.1.1 Site Location

The HI-STORM 100 Cask System is authorized for general use by 10 CFR Part 50 license holders at various site locations under the provisions of 10 CFR 72, Subpart K.

3.2 Design Features Important for Criticality Control

3.2.1 MPC-24

1. Flux trap size: ≥ 1.09 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0267 g/cm^2

3.2.2 MPC-68 *and MPC-68FF*

1. Fuel cell pitch: ≥ 6.43 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0372 g/cm^2

3.2.3 MPC-68F

1. Fuel cell pitch: ≥ 6.43 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.01 g/cm^2

3.2.4 MPC-24E

1. *Flux trap size:*
    - *i. Cells 3, 6, 19, and 22: ≥ 0.776 inch*
    - *ii. All Other Cells: ≥ 1.076 inches*
2. *^{10}B loading in the Boral neutron absorbers: ≥ 0.0372 g/cm^2*

3.2.5 MPC-32

1. *Fuel cell pitch: ≥ 9.158 inches*
2. *^{10}B loading in the Boral neutron absorbers: ≥ 0.0372 g/cm^2*

DESIGN FEATURES

Table 3-1 (page 1 of 5)

LIST OF ASME CODE EXCEPTIONS FOR HI-STORM 100 CASK SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Exception, Justification & Compensatory Measures
MPC	NB-1100	Statement of requirements for Code stamping of components.	MPC enclosure vessel is designed and will be fabricated in accordance with ASME Code, Section III, Subsection NB to the maximum practical extent, but Code stamping is not required.
MPC	NB-2000	Requires materials to be supplied by ASME-approved material supplier.	Materials will be supplied by Holtec-approved suppliers with Certified Material Test Reports (CMTRs) in accordance with NB-2000 requirements.
MPC Lid and Closure Ring Welds	NB-4243	Full penetration welds required for Category C Joints (flat head to main shell per NB-3352.3).	MPC lid and closure ring are not full penetration welds. They are welded independently to provide a redundant seal. Additionally, a weld efficiency factor of 0.45 has been applied to the analyses of these welds.
MPC Lid to Shell Weld	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required	Only UT or multi-layer liquid penetrant (PT) examination is permitted. If PT alone is used, at a minimum, it will include the root and final weld layers and each approximately 3/8 inch of weld depth.
MPC Closure Ring, Vent and Drain Cover Plate Welds	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required	Root *(if more than one weld pass is required)* and final liquid penetrant examination to be performed in accordance with NB-5245. The MPC vent and drain cover plate welds are leak tested. The closure ring provides independent redundant closure for vent and drain cover plates.

(continued)

Table 3-1
MPC Model-Dependent Limits

MPC MODEL	LIMITS
1. MPC-*24/24E*	
a. MPC Cavity Vacuum Drying Pressure	≤ 3 torr for ≥ 30 min
b. MPC Helium Backfill ~~Density~~ *Pressure*[1]	~~0.1212 +0/-10% g-moles/l~~ *≥ 0 psig and ≤ 15.3 psig*
c. MPC Helium Leak Rate	≤ 5.0E-6 atm cc/sec (He)
2. MPC-68*/68F/68FF*	
a. MPC Cavity Vacuum Drying Pressure	≤ 3 torr for ≥ 30 min
b. MPC Helium Backfill ~~Density~~ *Pressure*[1]	~~0.1218 +0/-10% g-moles/l~~ *≥ 0 psig and ≤ 28.5 psig*
c. MPC Helium Leak Rate	≤ 5.0E-6 atm cc/sec (He)
3. MPC-32	
a. MPC Cavity Vacuum Drying Pressure	*≤ 3 torr for ≥ 30 min*
b. MPC Helium Backfill Pressure	*≥ 0 psig and ≤ 7.3 psig*
c. MPC Helium Leak Rate	*≤ 5.0E-6 atm cc/sec (He)*

---

[1] Helium used for backfill of MPC shall have a purity of ≥ 99.995%.

TABLE OF CONTENTS

3.1 SFSC INTEGRITY

3.1.1 Multi-Purpose Canister (MPC)

LCO 3.1.1 The MPC shall be dry and helium filled.

APPLICABILITY: During TRANSPORT OPERATIONS and STORAGE OPERATIONS.

ACTIONS

-----NOTE-----

Separate Condition entry is allowed for each MPC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. MPC cavity vacuum drying pressure limit not met.	A.1 Perform an engineering evaluation to determine the quantity of moisture left in the MPC.	7 days
	AND	
	A.2 Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	30 days
B. MPC helium backfill pressure limit not met.	B.1 Perform an engineering evaluation to determine the impact of helium differential.	72 hours
	AND	
	B.2 Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	14 days

ACTIONS
(continued)

CONDITION	REQUIRED ACTION	COMPLETION TIME
C. MPC helium leak rate limit not met.	C.1 Perform an engineering evaluation to determine the impact of increased helium leak rate on heat removal capability and offsite dose.	24 hours
	<u>AND</u>	
	C.2 Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	7 days
D. Required Actions and associated Completion Times not met.	D.1 Remove all fuel assemblies from the SFSC.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.1.1	Verify MPC cavity vacuum drying pressure is within the limit specified in Table 3-1 for the applicable MPC model.	Once, prior to TRANSPORT OPERATIONS
SR 3.1.1.2	Verify MPC helium backfill pressure is within the limit specified in Table 3-1 for the applicable MPC model.	Once, prior to TRANSPORT OPERATIONS
SR 3.1.1.3	Verify that the total helium leak rate through the MPC lid confinement weld and the drain and vent port confinement welds is within the limit specified in Table 3-1 for the applicable MPC model.	Once, prior to TRANSPORT OPERATIONS

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.2.1	Verify all OVERPACK inlet and outlet air ducts are free of blockage.	24 hours
	<u>OR</u>	
	For OVERPACKS with installed temperature monitoring equipment, verify that the difference between the average OVERPACK air outlet temperature and ISFSI ambient temperature meets the following limits, as applicable: a. MPC-24: ≤ 102°F b. MPC-24E: ≤ 107°F c. MPC-32: ≤ 100°F d. MPC-68/68F/68FF: ≤ 118°F	24 hours

3.2 SFSC RADIATION PROTECTION

3.2.1 TRANSFER CASK Average Surface Dose Rates

LCO 3.2.1 The average surface dose rates of each TRANSFER CASK shall not exceed:

a. 125 Ton TRANSFER CASK

- i. 145 mrem/hour (neutron + gamma) on the side; |
- ii. 55 mrem/hour (neutron + gamma) on the top |

b. 100 Ton TRANSFER CASK

- i. 1120 mrem/hour (neutron + gamma) on the side; |
- ii. 200 mrem/hour (neutron + gamma) on the top |

APPLICABILITY: During TRANSPORT OPERATIONS.

ACTIONS

---NOTE---
-

Separate Condition entry is allowed for each TRANSFER CASK.

--

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. TRANSFER CASK average surface dose rate limits not met.	A.1 Administratively verify correct fuel loading.	24 hours
	<u>AND</u>	
	A.2 Perform evaluation to verify compliance with the ISFSI offsite radiation protection requirements of 10 CFR Part 20 and 10 CFR Part 72.	24 hours

3.2 SFSC RADIATION PROTECTION

3.2.3 OVERPACK Average Surface Dose Rates

LCO 3.2.3 The average surface dose rates of each OVERPACK shall not exceed:

a. 50 mrem/hour (neutron + gamma) on the side

b. 10 mrem/hour (neutron + gamma) on the top

c. 40 mrem/hour (neutron + gamma) at the inlet and outlet vent ducts

APPLICABILITY: During STORAGE OPERATIONS.

ACTIONS

-----NOTE-----
Separate Condition entry is allowed for each SFSC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. OVERPACK average surface dose rate limits not met.	A.1 Administratively verify correct fuel loading.	24 hours
	<u>AND</u>	
	A.2 Perform a written evaluation to verify compliance with the ISFSI offsite radiation protection requirements of 10 CFR Part 20 and 10 CFR Part 72.	48 hours
B. Required Action and associated Completion Time not met.	B.1 Remove all fuel assemblies from the SFSC.	30 days

3.3 SFSC CRITICALITY CONTROL

3.3.1 Boron Concentration

LCO 3.3.1

As required by CoC Appendix B, Table 2.1-2, the concentration of boron in the water in the MPC shall meet the following limits for the applicable MPC model:

a. MPC-24 with one or more fuel assemblies having an initial enrichment greater than the value in Table 2.1-2 for no soluble boron credit and $\leq$ 5.0 wt% ^{235}U: $\geq$ 400 ppmb

b. MPC-24E with one or more fuel assemblies having an initial enrichment greater than the value in Table 2.1-2 for no soluble boron credit and $\leq$ 5.0 wt% ^{235}U: $\geq$ 300 ppmb

c. MPC-32 with all fuel assemblies having an initial enrichment $\leq$ 4.0 wt% ^{235}U: $\geq$ 1800 ppmb

d. MPC-32 with one or more fuel assemblies having an initial enrichment > 4.0 and $\leq$ 5.0 wt% ^{235}U: $\geq$ 2600 ppmb

APPLICABILITY:

During PWR fuel LOADING OPERATIONS with fuel and water in the MPC

AND

During PWR fuel UNLOADING OPERATIONS with fuel and water in the MPC.

ACTIONS

--NOTE--
Separate Condition entry is allowed for each MPC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Boron concentration not within limit.	A.1 Suspend LOADING OPERATIONS or UNLOADING OPERATIONS.	Immediately
	<u>AND</u>	
	A.2 Suspend positive reactivity additions.	Immediately
	<u>AND</u>	
	A.3 Initiate action to restore boron concentration to within limit.	Immediately

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
------------------------NOTE------------------------ This surveillance is only required to be performed if the MPC is submerged in water or if water is to be added to, or recirculated through the MPC. --	Within 4 hours of entering the Applicability of this LCO.
SR 3.3.1.1 Verify boron concentration is within the applicable limit using two independent measurements.	AND Every 48 hours thereafter.

5.5 Cask Transport Evaluation Program (continued)

b. For site-specific transport conditions which are not bounded by the surface characteristics in Section 3.4.6 of Appendix B to Certificate of Compliance No. 1014, the program may evaluate the site-specific conditions to ensure that the impact loading due to design basis drop events does not exceed 45 g. This alternative analysis shall be commensurate with the drop analyses described in the Topical Safety Analysis Report for the HI-STORM 100 Cask System. The program shall ensure that these alternative analyses are documented and controlled.

c. The TRANSFER CASK or OVERPACK, when loaded with spent fuel, may be lifted above its lifting height limit during transportation from the FUEL BUILDING to the ISFSI pad provided the lifting device (e.g., crawler) is designed in accordance with ANSI N14.6 and has redundant drop protection features.

e d. The TRANSFER CASK and MPC, when loaded with spent fuel, may be lifted to those heights necessary to perform cask handling operations, including MPC transfer, provided the lifts are made with structures and components designed in accordance with the criteria specified in Section 3.5 of Appendix B to Certificate of Compliance No. 1014, as applicable.

Table 5-1

TRANSFER CASK and OVERPACK Lifting Requirements

ITEM	ORIENTATION	LIFTING HEIGHT LIMIT (in.)
TRANSFER CASK	Horizontal	42 (Note 1)
TRANSFER CASK	Vertical	None Established (Note 2)
OVERPACK	Horizontal	Not Permitted
OVERPACK	Vertical	11 (Note 2)

Notes:
1. To be measured from the lowest point on the TRANSFER CASK (i.e., the bottom edge of the transfer lid)
2. See Technical Specification 5.5c and d.

1.0 Definitions

----------NOTE----------
The defined terms of this section appear in capitalized type and are applicable throughout these Technical Specifications and Bases.

Term	Definition
CASK TRANSFER FACILITY (CTF)	The CASK TRANSFER FACILITY includes the following components and equipment: (1) a Cask Transfer Structure used to stabilize the TRANSFER CASK and MPC during lifts involving spent fuel not bounded by the regulations of 10 CFR Part 50, and (2) Either a stationary lifting device or a mobile lifting device used in concert with the stationary structure to lift the OVERPACK, TRANSFER CASK, and MPC
DAMAGED FUEL ASSEMBLY	DAMAGED FUEL ASSEMBLIES are fuel assemblies with known or suspected cladding defects, as determined by a review of records, greater than pinhole leaks or hairline cracks, missing fuel rods that are not replaced with dummy rods, or those that cannot be handled by normal means. Fuel assemblies which cannot be handled by normal means due to fuel cladding damage are considered FUEL DEBRIS.
DAMAGED FUEL CONTAINER (DFC)	DFCs are specially designed enclosures for DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS which permit gaseous and liquid media to escape while minimizing dispersal of gross particulates. DFCs authorized for use in the HI-STORM 100 System are as follows: 1. Holtec Dresden Unit 1/Humboldt Bay design 2. Transnuclear Dresden Unit 1 design 3. Holtec Generic BWR design 4. Holtec Generic PWR design
FUEL DEBRIS	FUEL DEBRIS is ruptured fuel rods, severed rods, loose fuel pellets or fuel assemblies with known or suspected defects which cannot be handled by normal means due to fuel cladding damage.

(continued)

2.0 APPROVED CONTENTS

2.1 Fuel Specifications and Loading Conditions

2.1.1 Fuel To Be Stored In The HI-STORM 100 SFSC System

a. INTACT FUEL ASSEMBLIES, DAMAGED FUEL ASSEMBLIES, FUEL DEBRIS, and certain non-fuel hardware meeting the limits specified in Table 2.1-1 and other referenced tables may be stored in the HI-STORM 100 SFSC System.

b. For MPCs partially loaded with stainless steel clad fuel assemblies, all remaining fuel assemblies in the MPC shall meet the decay heat generation limit for the stainless steel clad fuel assemblies.

c. For MPCs partially loaded with DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS, all remaining Zircaloy clad INTACT FUEL ASSEMBLIES in the MPC shall meet the decay heat generation limits for the DAMAGED FUEL ASSEMBLIES. This requirement applies only to uniform fuel loading.

d. For MPC-68's partially loaded with array/class 6x6A, 6x6B, 6x6C, or 8x8A fuel assemblies, all remaining Zircaloy clad INTACT FUEL ASSEMBLIES in the MPC shall meet the decay heat generation limits for the 6x6A, 6x6B, 6x6C, 7x7A and 8x8A fuel assemblies.

e. All BWR fuel assemblies may be stored with or without Zircaloy channels with the exception of array/class 10x10D and 10x10E fuel assemblies, which may be stored with or without Zircaloy or stainless steel channels.

(continued)

2.0 Approved Contents

2.1 Fuel Specifications and Loading Conditions (cont'd)

2.1.2 Preferential Fuel Loading

Preferential fuel loading shall be used during uniform loading (i.e., any authorized fuel assembly in any fuel storage location) whenever fuel assemblies with significantly different post-irradiation cooling times (≥ 1 year) are to be loaded in the same MPC. Fuel assemblies with the longest post-irradiation cooling times shall be loaded into fuel storage locations at the periphery of the basket. Fuel assemblies with shorter post-irradiation cooling times shall be placed toward the center of the basket. Regionalized fuel loading as described in Technical Specification 2.1.3 below meets the intent of preferential fuel loading.

2.1.3 Regionalized Fuel Loading

Users may choose to store fuel using regionalized loading in lieu of uniform loading to allow higher heat emitting fuel assemblies to be stored than would otherwise be able to be stored using uniform loading. Regionalized loading is limited to those fuel assemblies with Zircaloy (or other alloy of zirconium) cladding. Figures 2.1-1 through 2.1-4 define the regions for the MPC-24, MPC-24E, MPC-32, and MPC-68 (including MPC-68F and MPC-68FF) models, respectively. Fuel assembly burnup, decay heat, and cooling time limits for regionalized loading are specified in Tables 2.1-6 and 2.1-7. Fuel assemblies used in regionalized loading shall meet all other applicable limits specified in Tables 2.1-1 through 2.1-3.

2.2 Violations

If any Fuel Specifications or Loading Conditions of 2.1 are violated, the following actions shall be completed:

2.2.1 The affected fuel assemblies shall be placed in a safe condition.

2.2.2 Within 24 hours, notify the NRC Operations Center.

2.2.3 Within 30 days, submit a special report which describes the cause of the violation, and actions taken to restore compliance and prevent recurrence.

LEGEND:

REGION 1: ▨

REGION 2: ☐

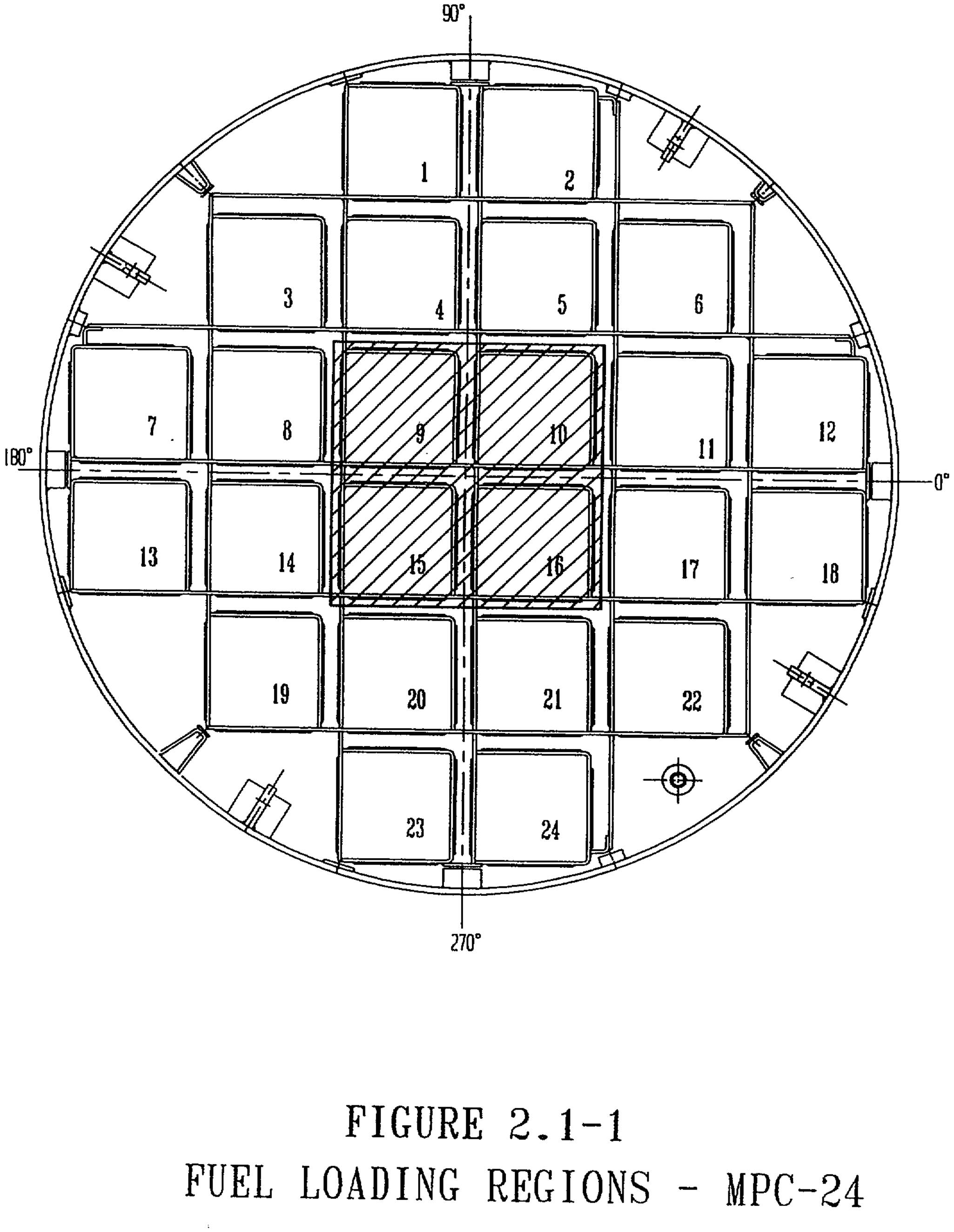

FIGURE 2.1-1
FUEL LOADING REGIONS - MPC-24

LEGEND:

REGION 1: ▨

REGION 2: ☐

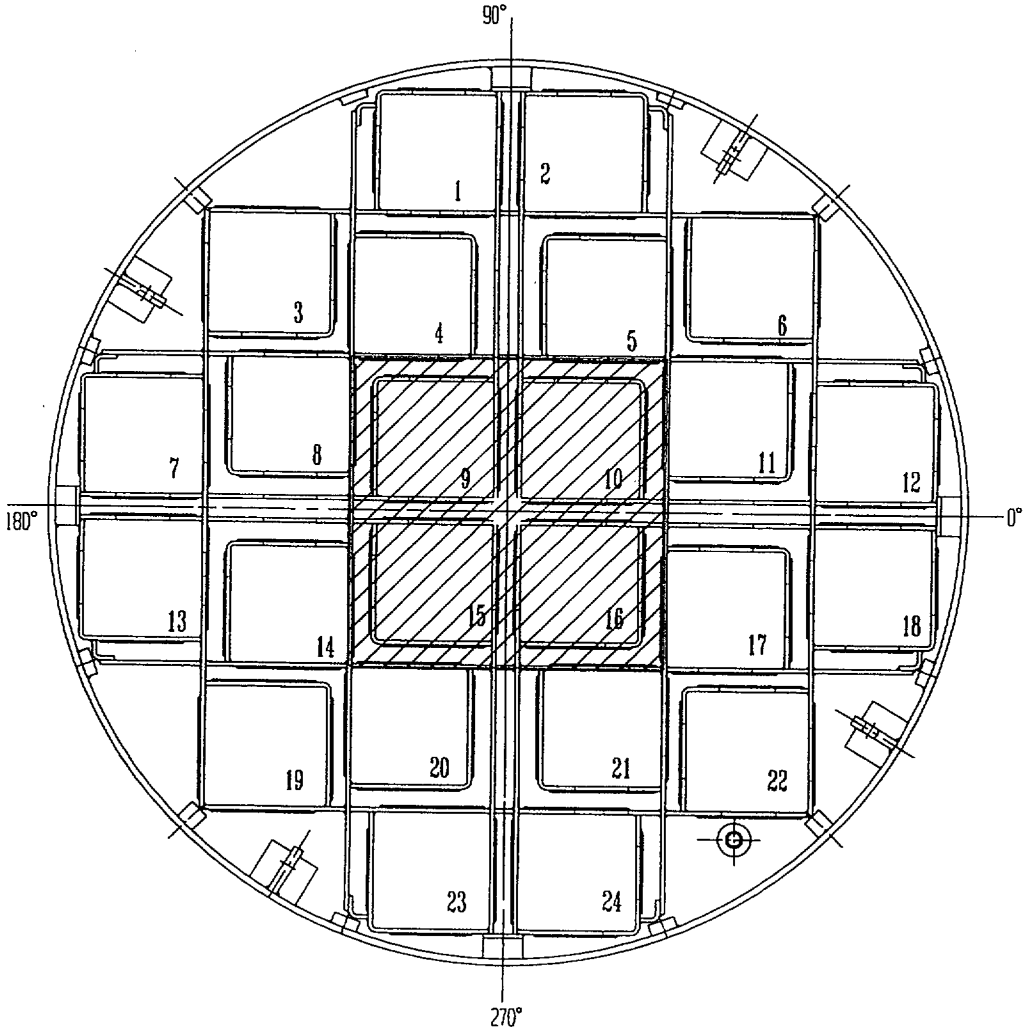

FIGURE 2.1-2

FUEL LOADING REGIONS - MPC-24E

LEGEND:

REGION 1: ▨

REGION 2: ☐

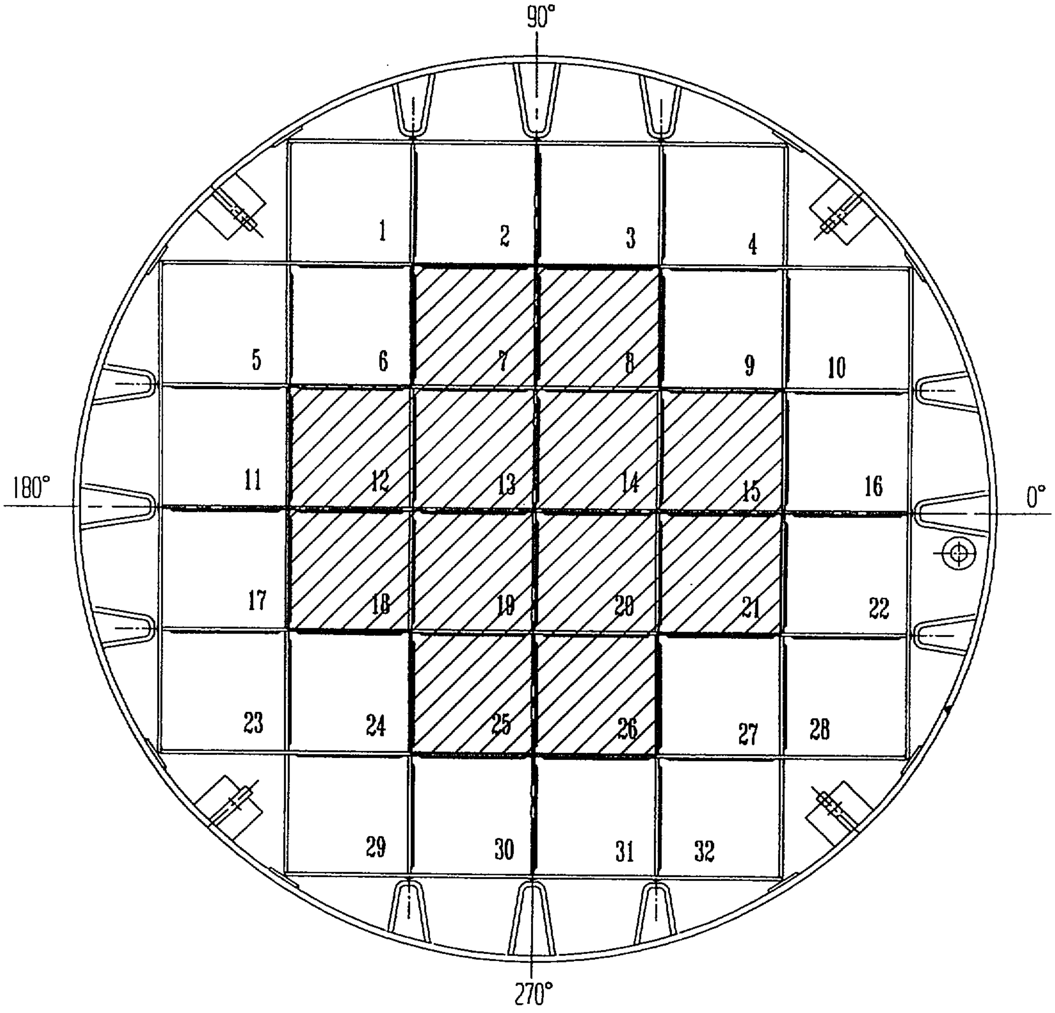

FIGURE 2.1-3

FUEL LOADING REGIONS - MPC-32

LEGEND:

REGION 1: ▨

REGION 2: ☐

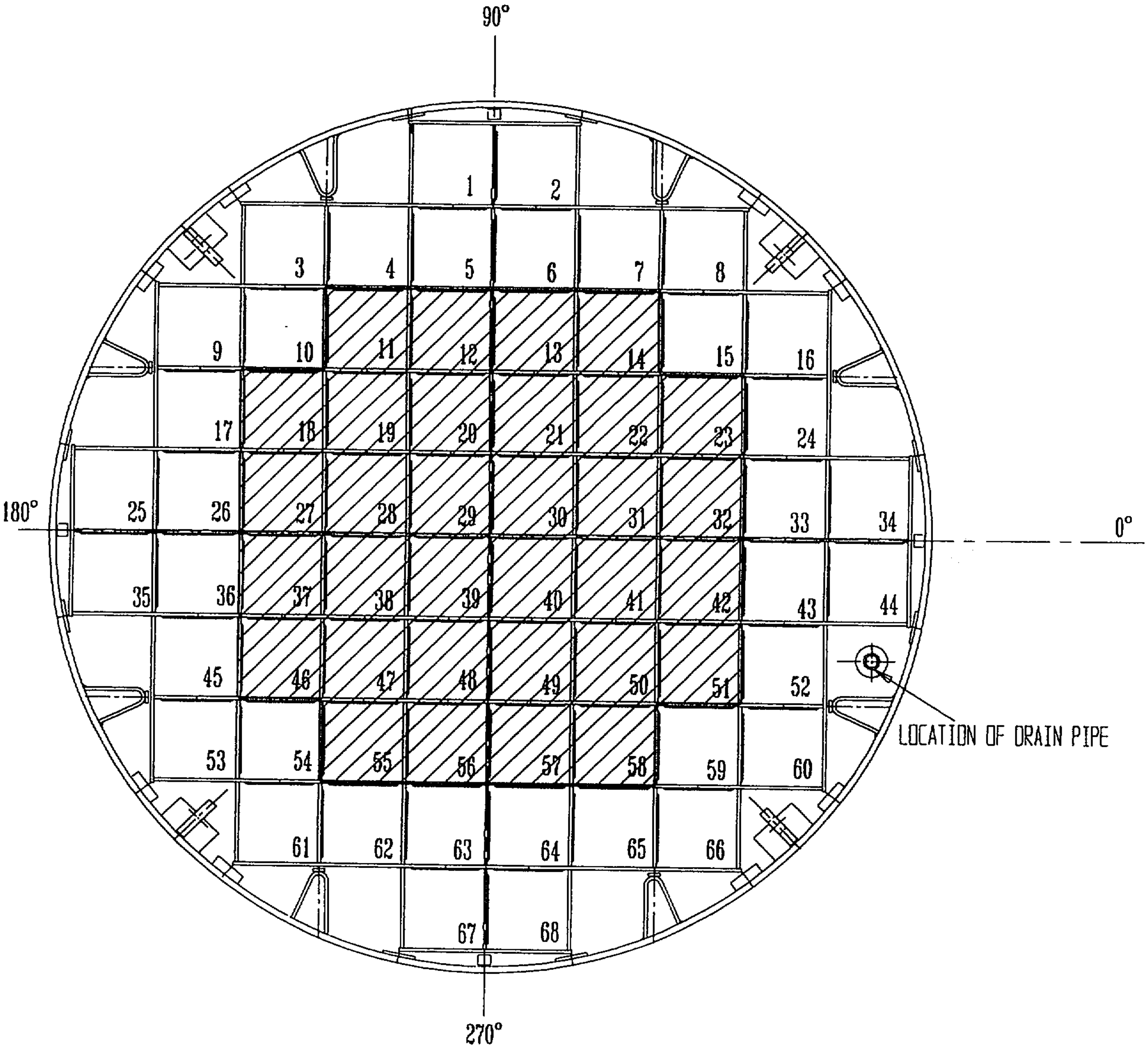

FIGURE 2.1-4

FUEL LOADING REGIONS - MPC-68/68FF

Table 2.1-1 (page 1 of 29)
Fuel Assembly Limits

I. MPC MODEL: MPC-24

A. Allowable Contents

1. Uranium oxide, PWR INTACT FUEL ASSEMBLIES listed in Table 2.1-2, with or without non-fuel hardware and meeting the following specifications (Note 1):

a. Cladding Type:	Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class.
b. Initial Enrichment:	As specified in Table 2.1-2 for the applicable fuel assembly array/class.
c. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 14x14D,14x14E, and 15x15G	Cooling time ≥ 8 years and an average burnup ≤ 40,000 MWD/MTU.
ii. All Other Array/Classes	Cooling time and average burnup as specified in Tables 2.1-4 and 2.1-6.
iii. Non-Fuel Hardware	As specified in Table 2.1-8.

Table 2.1-1 (page 2 of 29)
Fuel Assembly Limits

I. MPC MODEL: MPC-24 (continued)

d. Decay Heat Per Assembly:

i. Array/Classes 14x14D, 14x14E, and 15x15G	≤ 710 Watts
ii All Other Array/Classes	As specified in Tables 2.1-5 and 2.1-7.
e. Fuel Assembly Length:	≤ 176.8 inches (nominal design)
f. Fuel Assembly Width:	≤ 8.54 inches (nominal design)
g. Fuel Assembly Weight:	≤ 1,680 lbs (including non-fuel hardware)

B. Quantity per MPC: Up to 24 fuel assemblies.

C. ~~Fuel assemblies shall not contain control components.~~ Deleted.

D. DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS are not authorized for loading into the MPC-24.

Note 1: Non-fuel hardware is defined as Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Devices (TPDs), Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs) and other similarly designed devices with different names. Fuel assemblies containing BPRAs or TPDs may be stored in any fuel cell location. Fuel assemblies containing CRAs or APSRs may only be loaded in fuel storage locations 9, 10, 15, and/or 16. These requirements are in addition to any other requirements specified for preferential or regionalized fuel loading.

Table 2.1-1 (page 3 of 29)
Fuel Assembly Limits

II. MPC MODEL: MPC-68

A. Allowable Contents

1. Uranium oxide, BWR INTACT FUEL ASSEMBLIES listed in Table 2.1-3, with or without channels, and meeting the following specifications:

a. Cladding Type:	Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-3 for the applicable fuel assembly array/class.
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 6x6A, 6x6C, 7x7A, and 8x8A:	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU
ii. Array/Class 8x8F	Cooling time ≥ 10 years and an average burnup ≤ 27,500 MWD/MTU.
iii. Array/Classes 10x10D and 10x10E	Cooling time ≥ 10 years and an average burnup ≤ 22,500 MWD/MTU.
iv. All Other Array/Classes	As specified in Tables 2.1-4 and 2.1-6.

Table 2.1-1 (page 4 of 29)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

e. Decay Heat Per Assembly:

i. Array/Classes 6x6A, 6x6C, 7x7A, and 8x8A	≤ 115 Watts
ii. Array/Class 8x8F	≤ 183.5 Watts.
iii. *Array/Classes 10x10D and 10x10E*	≤ 95 Watts
iv. All Other Array/Classes	As specified in Tables 2.1-5 and 2.1-7.
f. Fuel Assembly Length:	≤ 176.2 inches (nominal design)
g. Fuel Assembly Width:	≤ 5.85 inches (nominal design)
h. Fuel Assembly Weight:	≤ 700 lbs, including channels

Table 2.1-1 (page 5 of 29)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

2. Uranium oxide, BWR DAMAGED FUEL ASSEMBLIES, with or without channels, placed in DAMAGED FUEL CONTAINERS. Uranium oxide BWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-3 for the applicable fuel assembly array/class.
c. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	
i. Array/Classes 6x6A, 6x6C, 7x7A, and 8x8A	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
ii. All Other Array/Classes specified in Table 2.1-3	4.0 wt% ^{235}U
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
v. Array/Classes 6x6A, 6x6C, 7x7A,and 8x8A	Cooling time $\geq$ 18 years and an average burnup $\leq$ 30,000 MWD/MTU.
vi. Array/Class 8x8F	Cooling time $\geq$ 10 years and an average burnup $\leq$ 27,500 MWD/MTU.
vii. Array/Classes 10x10D and 10x10E	Cooling time $\geq$ 10 years and an average burnup $\leq$ 22,500 MWD/MTU.
viii. All Other Array Classes	As specified in Tables 2.1-4 and 2.1-6.

Table 2.1-1 (page 6 of 29)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

e. Decay Heat Per Assembly:

i.	Array/Class 6x6A, 6x6C, 7x7A, and 8x8A	≤ 115 Watts
ii.	Array/Class 8x8F	≤ 183.5 Watts
iii.	Array/Classes 10x10D and 10x10E	≤ 95 Watts
iv.	All Other Array/Classes	As specified in Tables 2.1-5 and 2.1-7

f. Fuel Assembly Length:

i.	Array/Class 6x6A, 6x6C, 7x7A, or 8x8A	≤ 135.0 inches (nominal design)
ii.	All Other Array/Classes	≤ 176.2 inches (nominal design)

g. Fuel Assembly Width:

i.	Array/Class 6x6A, 6x6C, 7x7A, or 8x8A	≤ 4.70 inches (nominal design)
ii.	All Other Array/Classes	≤ 5.85 inches (nominal design)

h. Fuel Assembly Weight:

i.	Array/Class 6x6A, 6x6C, 7x7A, or 8x8A	≤ 550 lbs, including channels and DFC
ii.	All Other Array/Classes	≤ 700 lbs, including channels and DFC

Table 2.1-1 (page 7 of 29)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

3. Mixed oxide (MOX), BWR INTACT FUEL ASSEMBLIES, with or without channels. MOX BWR INTACT FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTIHM.
e. Decay Heat Per Assembly:	≤ 115 Watts
f. Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	≤ 400 lbs, including channels

Table 2.1-1 (page 8 of 29)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

4. Mixed oxide (MOX), BWR DAMAGED FUEL ASSEMBLIES, with or without channels, placed in DAMAGED FUEL CONTAINERS. MOX BWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTIHM.
e. Decay Heat Per Assembly:	≤ 115 Watts
f. Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	≤ 550 lbs, including channels and DFC

Table 2.1-1 (page 9 of 29)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

5. Thoria rods (ThO_2 and UO_2) placed in Dresden Unit 1 Thoria Rod Canisters and meeting the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Composition:	98.2 wt.% ThO_2, 1.8 wt. % UO_2 with an enrichment of 93.5 wt. % ^{235}U.
c. Number of Rods Per Thoria Rod Canister:	$\leq$ 18
d. Decay Heat Per Thoria Rod Canister:	$\leq$ 115 Watts
e. Post-irradiation Fuel Cooling Time and Average Burnup Per Thoria Rod Canister:	A fuel post-irradiation cooling time $\geq$ 18 years and an average burnup $\leq$ 16,000 MWD/MTIHM.
f. Initial Heavy Metal Weight:	$\leq$ 27 kg/canister
g. Fuel Cladding O.D.:	$\geq$ 0.412 inches
h. Fuel Cladding I.D.:	$\leq$ 0.362 inches
i. Fuel Pellet O.D.:	$\leq$ 0.358 inches
j. Active Fuel Length:	$\leq$ 111 inches
k. Canister Weight:	$\leq$ 550 lbs, including fuel

Table 2.1-1 (page 10 of 29)
Fuel Assembly Limits

II. MPC MODEL: MPC-68 (continued)

B. Quantity per MPC:

1. Up to one (1) Dresden Unit 1 Thoria Rod Canister;

2. Up to 68 array/class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A DAMAGED FUEL ASSEMBLIES in DAMAGE FUEL CONTAINERS;

3. Up to sixteen (16) other BWR DAMAGED FUEL ASSEMBLIES in DAMAGED FUEL CONTAINERS in fuel storage locations 1, 2, 3, 8, 9, 16, 25, 34, 35, 44, 53, 60, 61, 66, 67, and/or 68; and/or

4. Any number of BWR INTACT FUEL ASSEMBLIES up to a total of 68.

C. Array/Class 10x10D and 10x10E fuel assemblies in stainless steel channels must be stored in fuel storage locations 19 - 22, 28 - 31, 38 -41, and/or 47 - 50.

D. Dresden Unit 1 fuel assemblies with one Antimony-Beryllium neutron source are authorized for loading in the MPC-68. The Antimony-Beryllium source material shall be in a water rod location.

Table 2.1-1 (page 11 of 29)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F

A. Allowable Contents

1. Uranium oxide, BWR INTACT FUEL ASSEMBLIES, with or without channels. Uranium oxide BWR INTACT FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array class 6x6A, 6x6C, 7x7A or 8x8A, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU.
e. Decay Heat Per Assembly	≤ 115 Watts
f. Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	≤ 400 lbs, including channels

Table 2.1-1 (page 12 of 29)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

2. Uranium oxide, BWR DAMAGED FUEL ASSEMBLIES, with or without channels, placed in DAMAGED FUEL CONTAINERS. Uranium oxide BWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6A, 6x6C, 7x7A, or 8x8A, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU.
e. Decay Heat Per Assembly:	≤ 115 Watts
f. Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	≤ 550 lbs, including channels and DFC

Table 2.1-1 (page 13 of 29)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

3. Uranium oxide, BWR FUEL DEBRIS, with or without channels, placed in DAMAGED FUEL CONTAINERS. The original fuel assemblies for the uranium oxide BWR FUEL DEBRIS shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6A, 6x6C, 7x7A, or 8x8A, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable original fuel assembly array/class.
c Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable original fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU for the original fuel assembly.
e. Decay Heat Per Assembly	≤ 115 Watts
f. Original Fuel Assembly Length	≤ 135.0 inches (nominal design)
g. Original Fuel Assembly Width	≤ 4.70 inches (nominal design)
h. Fuel Debris Weight	≤ 550 lbs, including channels and DFC

Table 2.1-1 (page 14 of 29)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

4. Mixed oxide (MOX), BWR INTACT FUEL ASSEMBLIES, with or without channels. MOX BWR INTACT FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTIHM.
e. Decay Heat Per Assembly	≤ 115 Watts
f. Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	≤ 400 lbs, including channels

Table 2.1-1 (page 15 of 29)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

5. Mixed oxide (MOX), BWR DAMAGED FUEL ASSEMBLIES, with or without channels, placed in DAMAGED FUEL CONTAINERS. MOX BWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTIHM.
e. Decay Heat Per Assembly	≤ 115 Watts
f. Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	≤ 550 lbs, including channels and DFC

Table 2.1-1 (page16 of 29)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

6. Mixed Oxide (MOX), BWR FUEL DEBRIS, with or without channels, placed in DAMAGED FUEL CONTAINERS. The original fuel assemblies for the MOX BWR FUEL DEBRIS shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for original fuel assembly array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for original fuel assembly array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTIHM for the original fuel assembly.
e. Decay Heat Per Assembly	≤ 115 Watts
f. Original Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Original Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Debris Weight:	≤ 550 lbs, including channels and DFC

Table 2.1-1 (page 17 of 29)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

7. Thoria rods (ThO_2 and UO_2) placed in Dresden Unit 1 Thoria Rod Canisters and meeting the following specifications:

a. Cladding Type:	Zircaloy (Zr)
b. Composition:	98.2 wt.% ThO_2, 1.8 wt. % UO_2 with an enrichment of 93.5 wt. % ^{235}U.
c. Number of Rods Per Thoria Rod Canister:	≤ 18
d. Decay Heat Per Thoria Rod Canister:	$\leq$ 115 Watts
e. Post-irradiation Fuel Cooling Time and Average Burnup Per Thoria Rod Canister:	A fuel post-irradiation cooling time $\geq$ 18 years and an average burnup $\leq$ 16,000 MWD/MTIHM.
f. Initial Heavy Metal Weight:	$\leq$ 27 kg/canister
g. Fuel Cladding O.D.:	$\geq$ 0.412 inches
h. Fuel Cladding I.D.:	$\leq$ 0.362 inches
i. Fuel Pellet O.D.:	$\leq$ 0.358 inches
j. Active Fuel Length:	$\leq$ 111 inches
k. Canister Weight:	$\leq$ 550 lbs, including fuel

Table 2.1-1 (page 18 of 29)
Fuel Assembly Limits

III. MPC MODEL: MPC-68F (continued)

B. Quantity per MPC (up to a total of 68 assemblies):
(All fuel assemblies must be array/class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A):

Up to four (4) DFCs containing uranium oxide BWR FUEL DEBRIS or MOX BWR FUEL DEBRIS. The remaining MPC-68F fuel storage locations may be filled with fuel assemblies of the following type, as applicable:

1. Uranium oxide BWR INTACT FUEL ASSEMBLIES;
2. MOX BWR INTACT FUEL ASSEMBLIES;
3. Uranium oxide BWR DAMAGED FUEL ASSEMBLIES placed in DFCs; ~~or~~
4. MOX BWR DAMAGED FUEL ASSEMBLIES placed in DFCs; *or*
5. Up to one (1) Dresden Unit 1 Thoria Rod Canister.

C. Fuel assemblies with stainless steel channels are not authorized for loading in the MPC-68F.

D. Dresden Unit 1 fuel assemblies with one Antimony-Beryllium neutron source are authorized for loading in the MPC-68F. The Antimony-Beryllium source material shall be in a water rod location.

Table 2.1-1 (page 19 of 29)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E

A. Allowable Contents

1. Uranium oxide, PWR INTACT FUEL ASSEMBLIES listed in Table 2.1-2, with or without non-fuel hardware and meeting the following specifications (Note 1):

a. Cladding Type:	Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class
b. Initial Enrichment:	As specified in Table 2.1-2 for the applicable fuel assembly array/class.
c. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	Cooling time ≥ 8 years and an average burnup ≤ 40,000 MWD/MTU.
ii. All Other Array/Classes	As specified in Tables 2.1-4 and 2.1-6.
iii. Non-fuel Hardware	As specified in Table 2.1-8.

Table 2.1-1 (page 20 of 29)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E (continued)

d. Decay Heat Per Assembly:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	*≤ 710 Watts.*
ii. All other Array/Classes	*As specified in Tables 2.1-5 and 2.1-7.*
e. Fuel Assembly Length:	*≤ 176.8 inches (nominal design)*
f. Fuel Assembly Width:	*≤ 8.54 inches (nominal design)*
g. Fuel Assembly Weight:	*≤ 1,680 lbs (including non-fuel hardware)*

Table 2.1-1 (page 21 of 29)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E (continued)

- Uranium oxide, PWR DAMAGED FUEL ASSEMBLIES, with or without non-fuel hardware, placed in DAMAGED FUEL CONTAINERS. Uranium oxide PWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-2 and meet the following specifications (Note 1):

a. Cladding Type:	Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class
b. Initial Enrichment:	$\leq$ 4.0 wt% ^{235}U.
c. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	Cooling time $\geq$ 8 years and an average burnup $\leq$ 40,000 MWD/MTU.
ii. All Other Array/Classes	As specified in Tables 2.1-4 and 2.1-6.
iii. Non-Fuel Hardware	As specified in Table 2.1-8.

Table 2.1-1 (page 22 of 29)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E (continued)

d. Decay Heat Per Assembly	
i. Array/Classes 14x14D, 14x14E, and 15x15G	≤ 710 Watts.
ii. All Other Array/Classes	As specified in Tables 2.1-5 and 2.1-7.
e. Fuel Assembly Length	≤ 176.8 inches (nominal design)
f. Fuel Assembly Width	≤ 8.54 inches (nominal design)
g. Fuel Assembly Weight	≤ 1,680 lbs (including non-fuel hardware and DFC)

B. Quantity per MPC: Up to four (4) DAMAGED FUEL ASSEMBLIES in DAMAGED FUEL CONTAINERS, stored in fuel storage locations 3, 6, 19 and/or 22. The remaining MPC-24E fuel storage locations may be filled with PWR INTACT FUEL ASSEMBLIES meeting the applicable specifications.

C. FUEL DEBRIS is not authorized for loading in the MPC-24E.

Note 1: Non-fuel hardware is defined as Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Devices (TPDs), Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs) and other similarly designed devices with different names. Fuel assemblies containing BPRAs or TPDs may be stored in any fuel storage location. Fuel assemblies containing CRAs or APSRs must be loaded in fuel storage locations 9,10,15 and/or 16. These requirements are in addition to any other requirements specified for preferential or regionalized fuel loading.

Table 2.1-1 (page 23 of 29)
Fuel Assembly Limits

V. MPC MODEL: MPC-32

A. Allowable Contents

1. Uranium oxide, PWR INTACT FUEL ASSEMBLIES listed in Table 2.1-2, with or without non-fuel hardware and meeting the following specifications (Note 1):

a. Cladding Type:	Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class
b. Initial Enrichment:	As specified in Table 2.1-2 for the applicable fuel assembly array/class.
c. Post-irradiaton Cooling Time and Average Burnup Per Assembly	
i. Array/Classes 14x14D, 14x14E, and 15x15G	Cooling time $\geq$ 9 years and an average burnup $\leq$ 30,000 MWD/MTU or cooling time $\geq$ 20 years and an average burnup $\leq$ 40,000 MWD/MTU.
ii. All Other Array/Classes	As specified in Tables 2.1-4 and 2.1-6.
iii. Non-fuel Hardware	As specified in Table 2.1-8.

Table 2.1-1 (page 24 of 29)
Fuel Assembly Limits

V. MPC MODEL: MPC-32 (continued)

d. Decay Heat Per Assembly	
i. Array/Classes 14x14D, 14x14E, and 15x15G	≤ 500 Watts
ii. All Other Array/Classes	As specified in Tables 2.1-5 and 2.1-7.
e. Fuel Assembly Length	≤ 176.8 inches (nominal design)
f. Fuel Assembly Width	≤ 8.54 inches (nominal design)
g. Fuel Assembly Weight	≤ 1,680 lbs (including non-fuel hardware)

B. Quantity per MPC: Up to 32 PWR INTACT FUEL ASSEMBLIES.

C. DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS are not authorized for loading in the MPC-32.

Note 1: Non-fuel hardware is defined as Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Devices (TPDs), Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs) and other similarly designed devices with different names. Fuel assemblies containing BPRAs or TPDs may be stored in any fuel storage location. Fuel assemblies containing CRAs or APSRs must be loaded in fuel storage locations 13, 14, 19, and/or 20. These requirements are in addition to any other requirements specified for preferential or regionalized fuel loading.

Table 2.1-1 (page 25 of 29)
Fuel Assembly Limits

VI. MPC MODEL: MPC-68FF

A. Allowable Contents

1. Uranium oxide or MOX BWR INTACT FUEL ASSEMBLIES listed in Table 2.1-2, with or without channels and meeting the following specifications:

a. Cladding Type:	Zircaloy (Zr) or Stainless Steel (SS) as specified in Table 2.1-3 for the applicable fuel assembly array/class
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
c. Initial Maximum Rod Enrichment	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly	
i. Array/Classes 6x6A, 6x6C, 7x7A, and 8x8A	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU.
ii. Array/Class 8x8F	Cooling time ≥ 10 years and an average burnup ≤ 27,500 MWD/MTU.
iii. Array/Classes 10x10D and 10x10E	Cooling time ≥ 10 years and an average burnup ≤ 22,500 MWD/MTU.
iv. All Other Array/Classes	As specified in Tables 2.1-4 and 2.1-6.

Table 2.1-1 (page 26 of 29)
Fuel Assembly Limits

VI. MPC MODEL: MPC-68FF (continued)

e. Decay Heat Per Assembly

i. Array/Classes 6x6A, 6x6C, 7x7A, and 8x8A	≤ 115 Watts
ii. Array/Class 8x8F	≤ 183.5 Watts
iii. Array/Classes 10x10D and 10x10E	≤ 95 Watts
iv. All Other Array/Classes	As specified in Tables 2.1-5 and 2.1-7.
f. Fuel Assembly Length	≤ 176.2 inches (nominal design)
g. Fuel Assembly Width	≤ 5.85 inches (nominal design)
h. Fuel Assembly Weight	≤ 700 lbs, including channels

Table 2.1-1 (page 27 of 29)
Fuel Assembly Limits

VI. MPC MODEL: MPC-68FF (continued)

2. Uranium oxide or MOX BWR DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS, with or without channels, placed in DAMAGED FUEL CONTAINERS. Uranium oxide and MOX BWR DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS shall meet the criteria specified in Table 2.1-3, and meet the following specifications:

a. Cladding Type:	Zircaloy (Zr) or Stainless Steel (SS) in accordance with Table 2.1-3 for the applicable fuel assembly array/class.
. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	
. Array/Classes 6x6A, 6x6B, 6x6C, 7x7A, 8x8A.	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
ii. All Other Array Classes	$\leq$ 4.0 wt.% ^{235}U.
. Initial Maximum Rod Enrichment	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	Cooling time $\geq$ 18 years and an average burnup $\leq$ 30,000 MWD/MTU (or MWD/MTIHM).
ii. Array/Class 8x8F	Cooling time $\geq$ 10 years and an average burnup $\leq$ 27,500 MWD/MTU.
iii. Array/Class 10x10D and 10x10E	Cooling time $\geq$ 10 years and an average burnup $\leq$ 22,500 MWD/MTU.
iv. All Other Array/Classes	As specified in Tables 2.1-4 and 2.1-6.

Table 2.1-1 (page 28 of 29)
Fuel Assembly Limits

VI. MPC MODEL: MPC-68FF (continued)

e.	Decay Heat Per Assembly	
i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 115 Watts
ii.	Array/Class 8x8F	≤ 183.5 Watts
iii.	Array/Classes 10x10D and 10x10E	≤ 95 Watts
iv.	All Other Array/Classes	As specified in Tables 2.1-5 and 2.1-7
f.	Fuel Assembly Length	
i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 135.0 inches (nominal design)
ii.	All Other Array/Classes	≤ 176.2 inches (nominal design)
g.	Fuel Assembly Width	
i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 4.70 inches (nominal design)
ii.	All Other Array/Classes	≤ 5.85 inches (nominal design)
h.	Fuel Assembly Weight	
i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 550 lbs, including channels and DFC
ii.	All Other Array/Classes	≤ 700 lbs, including channels and DFC

Table 2.1-1 (page 29 of 29)
Fuel Assembly limits

VI. MPC MODEL: MPC-68FF (continued)

B. Quantity per MPC (up to a total of 68 assemblies)

Up to sixteen (16) DFCs containing BWR DAMAGED FUEL ASSEMBLIES and/or up to eight (8) DFCs containing FUEL DEBRIS. DFCs shall be located only in fuel storage locations 1, 2, 3, 8, 9, 16, 25, 34, 35, 44, 53, 60, 61, 66, 67, and/or 68. The remaining MPC-68FF fuel storage locations may be filled with fuel assemblies of the following type:

1. Uranium Oxide BWR INTACT FUEL ASSEMBLIES; or

2. MOX BWR INTACT FUEL ASSEMBLIES;

C. Dresden Unit 1 fuel assemblies with one Antimony-Beryllium neutron source are authorized for loading in the MPC-68FF. The Antimony-Beryllium source material shall be in a water rod location.

D. Array/Class 10x10D and 10x10E fuel assemblies in stainless steel channels must be stored in fuel storage locations 19 - 22, 28 - 31, 38 -41, and/or 47 - 50.

Table 2.1-2 (page 1 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**14x14A**	**14x14B**	**14x14C**	**14x14D**	**14x14E**
Clad Material (Note 2)	Zr	Zr	Zr	SS	SS
Design Initial U (kg/assy.) (Note 3)	≤ 407	≤ 407	≤ 407	≤ 400	≤ 206
Initial Enrichment (MPC-24 and 24E without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.6 (24) ≤ 5.0 (24E)	≤ 4.6 (24) ≤ 5.0 (24E)	≤ 4.6 (24) ≤ 5.0 (24E)	≤ 4.0 (24) ≤ 5.0 (24E)	≤ 5.0 (24) ≤ 5.0 (24E)
Initial Enrichment (MPC-24, 24E, or 32 with soluble boron credit - see Notes 5 and 7) (wt % ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rods	179	179	176	180	173
Clad O.D. (in.)	≥ 0.400	≥ 0.417	≥ 0.440	≥ 0.422	≥ 0.3415
Clad I.D. (in.)	≤ 0.3514	≤ 0.3734	≤ 0.3880	≤ 0.3890	≤ 0.3175
Pellet Dia. (in.)	≤ 0.3444	≤ 0.3659	≤ 0.3805	≤ 0.3835	≤ 0.3130
Fuel Rod Pitch (in.)	≤ 0.556	≤ 0.556	≤ 0.580	≤ 0.556	Note 6
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 144	≤ 102
No. of Guide Tubes	17	17	5 (Note 4)	16	0
Guide Tube Thickness (in.)	≥ 0.017	≥ 0.017	≥ 0.038	≥ 0.0145	N/A

Table 2.1-2 (page 2 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**15x15A**	**15x15B**	**15x15C**	**15x15D**	**15x15E**	**15x15F**
Clad Material (Note 2)	Zr	Zr	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note 3)	≤ 464	≤ 464	≤ 464	≤ 475	≤ 475	≤ 475
Initial Enrichment (MPC-24 and 24E without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.1 (24) ≤ 4.5 (24E)	≤ 4.1 (24) ≤ 4.5 (24E)	≤ 4.1 (24) ≤ 4.5 (24E)	≤ 4.1 (24) ≤ 4.5 (24E)	≤ 4.1 (24) ≤ 4.5 (24E)	≤ 4.1 (24) ≤ 4.5 (24E)
Initial Enrichment (MPC-24, 24E, or 32 with soluble boron credit - see Notes 5 and 7) (wt % ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rods	204	204	204	208	208	208
Clad O.D. (in.)	≥ 0.418	≥ 0.420	≥ 0.417	≥ 0.430	≥ 0.428	≥ 0.428
Clad I.D. (in.)	≤ 0.3660	≤ 0.3736	≤ 0.3640	≤ 0.3800	≤ 0.3790	≤ 0.3820
Pellet Dia. (in.)	≤ 0.3580	≤ 0.3671	≤ 0.3570	≤ 0.3735	≤ 0.3707	≤ 0.3742
Fuel Rod Pitch (in.)	≤ 0.550	≤ 0.563	≤ 0.563	≤ 0.568	≤ 0.568	≤ 0.568
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide Tubes	21	21	21	17	17	17
Guide Tube Thickness (in.)	≥ 0.0165	≥ 0.015	≥ 0.0165	≥ 0.0150	≥ 0.0140	≥ 0.0140

Table 2.1-2 (page 3 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/ Class	**15x15G**	**15x15H**	**16x16A**	**17x17A**	**17x17B**	**17x17C**
Clad Material (Note 2)	SS	Zr	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note 3)	≤ 420	≤ 475	≤ 443	≤ 467	≤ 467	≤ 474
Initial Enrichment (MPC-24 and 24E without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.0 (24) ≤ 4.5 (24E)	≤ 3.8 (24) ≤ 4.2 (24E)	≤ 4.6 (24) ≤ 5.0 (24E)	≤ 4.0 (24) *≤ 4.4 (24E)*	≤ 4.0 (24) ≤ 4.4 (24E)	≤ 4.0 (24) ≤ 4.4 (24E)
Initial Enrichment (MPC-24, 24E, or 32 with soluble boron credit - see Note 5) (wt % ^{235}U*)*	*≤ 5.0*	≤ 5.0	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rods	204	208	236	264	264	264
Clad O.D. (in.)	≥ 0.422	≥ 0.414	≥ 0.382	≥ 0.360	≥ 0.372	≥ 0.377
Clad I.D. (in.)	≤ 0.3890	≤ 0.3700	≤ 0.3320	≤ 0.3150	≤ 0.3310	≤ 0.3330
Pellet Dia. (in.)	≤ 0.3825	≤ 0.3622	≤ 0.3255	≤ 0.3088	≤ 0.3232	≤ 0.3252
Fuel Rod Pitch (in.)	≤ 0.563	≤ 0.568	≤ 0.506	≤ 0.496	≤ 0.496	≤ 0.502
Active Fuel Length (in.)	≤ 144	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide Tubes	21	17	5 (Note 4)	25	25	25
Guide Tube Thickness (in.)	≥ 0.0145	≥ 0.0140	≥ 0.0400	≥ 0.016	≥ 0.014	≥ 0.020

Table 2.1-2 (page 4 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.

2. Zr designates cladding material made of zirconium or zirconium alloys.

3. Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or reactor user. For each PWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 2.0 percent for comparison with users' fuel records to account for manufacturer's tolerances.

4. Each guide tube replaces four fuel rods.

5. Soluble boron concentration per LCO 3.3.1.

6. This fuel assembly array/class includes only the Indian Point Unit 1 fuel assembly. This fuel assembly has two pitches in different sectors of the assembly.

7. For those MPCs containing both INTACT FUEL ASSEMBLIES and DAMAGED FUEL ASSEMBLIES, the maximum initial enrichment of the INTACT FUEL ASSEMBLIES is limited to the maximum initial enrichment of the DAMAGED FUEL ASSEMBLIES (4.0 wt.% ^{235}U).

Table 2.1-3 (page 1 of 5)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**6x6A**	**6x6B**	**6x6C**	**7x7A**	**7x7B**	**8x8A**
Clad Material (Note 2)	Zr	Zr	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note 3)	110	110	110	≤ 100	≤ 195	≤ 120
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) (Note 14)	≤ 2.7	≤ 2.7 for the UO_2 rods. See Note 4 for MOX rods	≤ 2.7	≤ 2.7	≤ 4.2	≤ 2.7
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 4.0	≤ 4.0	≤ 4.0	≤ 5.5	≤ 5.0	≤ 4.0
No. of Fuel Rods	35 or 36	35 or 36 (up to 9 MOX rods)	36	49	49	63 or 64
Clad O.D. (in.)	≥ 0.5550	≥ 0.5625	≥ 0.5630	≥ 0.4860	≥ 0.5630	≥ 0.4120
Clad I.D. (in.)	≤ 0.5105	≤ 0.4945	≤ 0.4990	≤ 0.4204	≤ 0.4990	≤ 0.3620
Pellet Dia. (in.)	≤ 0.4980	≤ 0.4820	≤ 0.4880	≤ 0.4110	≤ 0.4910	≤ 0.3580
Fuel Rod Pitch (in.)	≤ 0.710	≤ 0.710	≤ 0.740	≤ 0.631	≤ 0.738	≤ 0.523
Active Fuel Length (in.)	≤ 120	≤ 120	≤ 77.5	≤ 80	≤ 150	≤ 120
No. of Water Rods (Note 11)	1 or 0	1 or 0	0	0	0	1 or 0
Water Rod Thickness (in.)	> 0	> 0	N/A	N/A	N/A	≥ 0
Channel Thickness (in.)	≤ 0.060	≤ 0.060	≤ 0.060	≤ 0.060	≤ 0.120	≤ 0.100

Table 2.1-3 (2 of 5)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**8x8B**	**8x8C**	**8x8D**	**8x8E**	**8x8F**	**9x9A**
Clad Material (Note 2)	Zr	Zr	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note 3)	≤ 191	≤ 191	≤ 191	≤ 191	≤ 191	≤ 179
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) (Note 14)	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.2	≤ 3.6	≤ 4.2
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rods	63 or 64	62	60 or 61	59	64	74/66 (Note 5)
Clad O.D. (in.)	≥ 0.4840	≥ 0.4830	≥ 0.4830	≥ 0.4930	≥ 0.4576	≥ 0.4400
Clad I.D. (in.)	≤ 0.4295	≤ 0.4250	≤ 0.4230	≤ 0.4250	≤ 0.3996	≤ 0.3840
Pellet Dia. (in.)	≤ 0.4195	≤ 0.4160	≤ 0.4140	≤ 0.4160	≤ 0.3913	≤ 0.3760
Fuel Rod Pitch (in.)	≤ 0.642	≤ 0.641	≤ 0.640	≤ 0.640	≤ 0.609	≤ 0.566
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 11)	1 *or 0*	2	1 - 4 (Note 7)	5	N/A (Note 12)	2
Water Rod Thickness (in.)	≥ 0.034	> 0.00	> 0.00	≥ 0.034	≥ 0.0315	> 0.00
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.100	≤ 0.055	≤ 0.120

Table 2.1-3 (page 3 of 5)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**9x9B**	**9x9C**	**9x9D**	**9x9E (Note 13)**	**9x9F (Note 13)**	**9x9G**
Clad Material (Note 2)	Zr	Zr	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note 3)	≤ 179	≤ 179	≤ 179	≤ 179	≤ 179	≤ 179
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) (Note 14)	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.0	≤ 4.0	≤ 4.2
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rods	72	80	79	76	76	72
Clad O.D. (in.)	≥ 0.4330	≥ 0.4230	≥ 0.4240	≥ 0.4170	≥ 0.4430	≥ 0.4240
Clad I.D. (in.)	≤ 0.3810	≤ 0.3640	≤ 0.3640	≤ 0.3640	≤ 0.3860	≤ 0.3640
Pellet Dia. (in.)	≤ 0.3740	≤ 0.3565	≤ 0.3565	≤ 0.3530	≤ 0.3745	≤ 0.3565
Fuel Rod Pitch (in.)	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 11)	1 (Note 6)	1	2	5	5	1 (Note 6)
Water Rod Thickness (in.)	> 0.00	≥ 0.020	≥ 0.0300	≥ 0.0120	≥ 0.0120	≥ 0.320
Channel Thickness (in.)	≤ 0.120	≤ 0.100	≤ 0.100	≤ 0.120	≤ 0.120	≤ 0.120

Table 2.1-3 (page 4 of 5)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**10x10A**	**10x10B**	**10x10C**	**10x10D**	**10x10E**
Clad Material (Note 2)	Zr	Zr	Zr	SS	SS
Design Initial U (kg/assy.) (Note 3)	≤ 188	≤ 188	≤ 188	≤ 125	≤ 125
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) (Note 14)	≤ 4.2	≤ 4.2	≤ 4.0	≤ 4.0	≤ 4.0
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rods	92/78 (Note 8)	91/83 (Note 9)	96	100	96
Clad O.D. (in.)	≥ 0.4040	≥ 0.3957	≥ 0.3780	≥ 0.3960	≥ 0.3940
Clad I.D. (in.)	≤ 0.3520	≤ 0.3480	≤ 0.3294	≤ 0.3560	≤ 0.3500
Pellet Dia. (in.)	≤ 0.3455	≤ 0.3420	≤ 0.3224	≤ 0.3500	≤ 0.3430
Fuel Rod Pitch (in.)	≤ 0.510	≤ 0.510	≤ 0.488	≤ 0.565	≤ 0.557
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 83	≤ 83
No. of Water Rods (Note 11)	2	1 (Note 6)	5 (Note 10)	0	4
Water Rod Thickness (in.)	≥ 0.0300	> 0.00	≥ 0.031	N/A	≥ 0.022
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.055	≤ 0.080	≤ 0.080

Table 2.1-3 (page 5 of 5)

BWR FUEL ASSEMBLY CHARACTERISTICS

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.

2. Zr designates cladding material made of zirconium or zirconium alloys.

3. Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or reactor user. For each BWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 1.5 percent for comparison with users' fuel records to account for manufacturer tolerances.

4. $\leq$ 0.635 wt. % ^{235}U and $\leq$ 1.578 wt. % total fissile plutonium (^{239}Pu and ^{241}Pu), (wt. % of total fuel weight, i.e., UO_2 plus PuO_2).

5. This assembly class contains 74 total rods; 66 full length rods and 8 partial length rods.

6. Square, replacing nine fuel rods.

7. Variable.

8. This assembly contains 92 total fuel rods; 78 full length rods and 14 partial length rods.

9. This assembly class contains 91 total fuel rods; 83 full length rods and 8 partial length rods.

10. One diamond-shaped water rod replacing the four center fuel rods and four rectangular water rods dividing the assembly into four quadrants.

11. These rods may also be sealed at both ends and contain Zr material in lieu of water.

12. This assembly is known as "QUAD+." It has four rectangular water cross segments dividing the assembly into four quadrants.

13. For the SPC 9x9-5 fuel assembly, each fuel rod must meet either the 9x9E or the 9x9F set of limits for clad O.D., clad I.D., and pellet diameter.

14. For those MPCs loaded with both INTACT FUEL ASSEMBLIES and DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS, the maximum PLANAR AVERAGE INITIAL ENRICHMENT for the INTACT FUEL ASSEMBLIES is limited to 3.7 wt.% ^{235}U, as applicable.

Table 2.1-4

FUEL ASSEMBLY COOLING AND MAXIMUM AVERAGE BURNUP
(UNIFORM FUEL LOADING)

Post-irradiation Cooling Time (years)	**MPC-24 PWR Assembly Burnup (INTACT FUEL ASSEMBLIES) (MWD/MTU)**	**MPC-24E PWR Assembly Burnup (INTACT FUEL ASSEMBLIES) (MWD/MTU)**	**MPC-24E PWR Assembly Burnup (DAMAGED FUEL ASSEMBLIES) (MWD/MTU)**	**MPC-32 PWR Assembly Burnup (INTACT FUEL ASSEMBLIES (MWD/MTU)**	**MPC-68/68FF BWR Assembly Burnup (INTACT FUEL ASSEMBLIES) (MWD/MTU)**	**MPC-68/68FF BWR Assembly Burnup (DAMAGED FUEL ASSEMBLIES AND FUEL DEBRIS) (MWD/MTU)**
≥ 5	33,100	34,900	33,200	24,500	35,200	33,400
≥ 6	37,200	39,100	37,300	28,000	38,200	36,600
≥ 7	37,700	39,700	37,900	28,700	38,600	37,000
≥ 8	40,100	41,900	40,300	30,500	40,800	39,100
≥ 9	41,700	43,700	41,900	31,900	42,400	40,700
≥ 10	43,000	45,000	43,300	32,900	43,700	41,900
≥ 11	44,200	NC	44,400	33,900	45,000	43,000
≥ 12	45,000	NC	45,000	34,700	NC	44,100
≥ 13	NC	NC	NC	35,400	NC	45,000
≥ 14	NC	NC	NC	35,900	NC	NC
≥ 15	NC	NC	NC	36,500	NC	NC

Notes:
1. Linear interpolation between points is permitted.
2. NC means not calculated.

Table 2.1-5

FUEL ASSEMBLY COOLING AND MAXIMUM DECAY HEAT
(UNIFORM FUEL LOADING)

Post-irradiation Cooling Time (years)	MPC-24 PWR Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts)	MPC-24E PWR Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts)	MPC-24E PWR Assembly Decay Heat (DAMAGED FUEL ASSEMBLIES) (Watts)	MPC-32 PWR Assembly Decay Heat (INTACT FUEL ASSEMBLIES (Watts)	MPC-68/68FF BWR Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts)	MPC-68/68FF BWR Assembly Decay Heat (DAMAGED FUEL ASSEMBLIES AND FUEL DEBRIS) (Watts)
≥ 5	925	976	927	668	375	356
≥ 6	895	945	898	647	355	337
≥ 7	812	860	817	590	324	308
≥ 8	805	854	811	585	321	305
≥ 9	799	847	804	581	319	303
≥ 10	792	840	798	576	316	300
≥ 11	788	NC	794	573	315	299
≥ 12	784	NC	789	570	NC	297
≥ 13	NC	NC	NC	567	NC	296
≥ 14	NC	NC	NC	564	NC	NC
≥ 15	NC	NC	NC	561	NC	NC

Notes:
1. Linear interpolation between points is permitted.
2. Includes all sources of heat (i.e., fuel and non-fuel hardware).
3. NC means not calculated.

Table 2.1-6 (page 1 of 2)

FUEL ASSEMBLY COOLING AND MAXIMUM AVERAGE BURNUP (REGIONALIZED FUEL LOADING)

Post-irradiation Cooling Time (years)	**MPC-24 PWR Assembly Burnup for Region 1 (MWD/MTU)**	**MPC-24 PWR Assembly Burnup for Region 2 (MWD/MTU)**	**MPC-24E PWR Assembly Burnup for Region 1 (MWD/MTU)**	**MPC-24E PWR Assembly Burnup for Region 2 (MWD/MTU)**
≥ 5	40,400	23,900	44,700	23,900
≥ 6	42,600	28,100	45,000	28,100
≥ 7	42,600	31,100	NC	31,100
≥ 8	44,700	33,400	NC	33,400
≥ 9	45,000	35,200	NC	35,200
≥ 10	NC	36,500	NC	36,500
≥ 11	NC	37,700	NC	37,700
≥ 12	*NC*	*38,700*	*NC*	*38,700*
≥ *13*	NC	39,700	NC	39,700
≥ *14*	NC	40,500	NC	40,500
≥ *15*	NC	41,300	NC	41,300
≥ 16	*NC*	42,100	*NC*	42,100
≥ 17	*NC*	42,800	*NC*	42,800
≥ 18	*NC*	43,600	*NC*	43,600
≥ 19	*NC*	44,400	*NC*	44,400
≥ 20	*NC*	45,000	*NC*	45,000

Notes: 1. Linear interpolation between points is permitted.
2. NC means not calculated.

Table 2.1-6 (page 2 of 2)

FUEL ASSEMBLY COOLING AND MAXIMUM AVERAGE BURNUP
(REGIONALIZED FUEL LOADING)

Post-irradiation Cooling Time (years)	MPC-32 PWR Assembly Burnup for Region 1 (MWD/MTU)	MPC-32 PWR Assembly Burnup for Region 2 (MWD/MTU)	MPC-68/68FF BWR Assembly Burnup for Region 1 (MWD/MTU)	MPC-68/68FF BWR Assembly Burnup for Region 2 (MWD/MTU)
≥ 5	30,500	NC	41,300	NC
≥ 6	34,200	NC	44,200	20,100
≥ 7	34,200	NC	44,200	22,300
≥ 8	36,200	20,500	45,000	24,100
≥ 9	37,700	21,600	NC	25,300
≥ 10	38,900	22,500	NC	26,300
≥ 11	39,900	23,200	NC	27,200
≥ 12	40,800	23,900	NC	28,000
≥ 13	41,400	24,500	NC	28,600
≥ 14	42,100	25,000	NC	29,300
≥ 15	42,600	25,500	NC	29,900
≥ 16	NC	26,000	NC	30,500
≥ 17	NC	26,500	NC	31,100
≥ 18	NC	26,900	NC	31,700
≥ 19	NC	27,400	NC	32,200
≥ 20	NC	27,900	NC	32,800

Notes
1. Linear interpolation between points is permitted.
2. NC means not calculated.

Table 2.1-7 (page 1 of 2)

FUEL ASSEMBLY COOLING AND MAXIMUM DECAY HEAT
(REGIONALIZED FUEL LOADING)

Post-irradiation Cooling Time (years)	MPC-24 PWR Assembly Decay Heat for Region 1 (Watts)	MPC-24 PWR Assembly Decay Heat for Region 2 (Watts)	MPC-24E PWR Assembly Decay Heat for Region 1 (Watts)	MPC-24E PWR Assembly Decay Heat for Region 2 (Watts)
≥ 5	1,152	650	1,295	650
≥ 6	1,152	650	1,295	650
≥ 7	942	650	NC	650
≥ 8	924	650	NC	650
≥ 9	905	650	NC	650
≥ 10	NC	650	NC	650
≥ 11	NC	650	NC	650
≥ 12	NC	650	NC	650
≥ 13	NC	650	NC	650
≥ 14	NC	650	NC	650
≥ 15	NC	650	NC	650
≥ 16	NC	650	NC	650
≥ 17	NC	650	NC	650
≥ 18	NC	650	NC	650
≥ 19	NC	650	NC	650
≥ 20	NC	650	NC	650

Notes:
1. Linear interpolation between points is permitted.
2. Includes all sources of decay heat (i.e., fuel and non-fuel hardware).
3. NC means not calculated.

Table 2.1-7 (page 2 of 2)

FUEL ASSEMBLY COOLING AND MAXIMUM DECAY HEAT
(REGIONALIZED FUEL LOADING)

Post-irradiation Cooling Time (years)	**MPC-32 PWR Assembly Decay Heat for Region 1 (Watts)**	**MPC-32 PWR Assembly Decay Heat for Region 2 (Watts)**	**MPC-68/68FF BWR Assembly Decay Heat for Region 1 (Watts)**	**MPC-68/68FF BWR Assembly Decay Heat for Region 2 (Watts)**
≥ 5	846	375	452	175
≥ 6	813	375	425	175
≥ 7	722	375	382	175
≥ 8	715	375	379	175
≥ 9	707	375	NC	175
≥ 10	700	375	NC	175
≥ 11	695	375	NC	175
≥ 12	690	375	NC	175
≥ 13	685	375	NC	175
≥ 14	680	375	NC	175
≥ 15	675	375	NC	175
≥ 16	NC	375	NC	175
≥ 17	NC	375	NC	175
≥ 18	NC	375	NC	175
≥ 19	NC	375	NC	175
≥ 20	NC	375	NC	175

Notes:
1. Linear interpolation between points is permitted.
2. Includes all sources of decay heat (i.e., fuel and non-fuel hardware).
3. NC means not calculated.

Table 2.1-8
NON-FUEL HARDWARE COOLING AND AVERAGE BURNUP

Post-irradiation Cooling Time (years)	BPRA BURNUP (MWD/MTU)	TPD BURNUP (MWD/MTU)	CRA BURNUP (MWD/MTU)	APSR BURNUP (MWD/MTU)
≥ 3	≤ 20,000	NC	NC	NC
≥ 4	NC	≤ 20,000	NC	NC
≥ 5	≤ 30,000	NC	≤ 630,000	≤ 45,000
≥ 6	≤ 40,000	≤ 30,000	NC	≤ 54,500
≥ 7	NC	≤ 40,000	NC	≤ 68,000
≥ 8	≤ 50,000	NC	NC	≤ 83,000
≥ 9	≤ 60,000	≤ 50,000	NC	≤ 111,000
≥ 10	NC	≤ 60,000	NC	≤ 180,000
≥ 11	NC	NC	NC	≤ 630,000
≥ 12	NC	≤ 90,000	NC	NC
≥ 13	NC	≤ 180,000	NC	NC
≥ 14	NC	≤ 630,000	NC	NC

Notes:
1. Linear interpolation between points is permitted, except that TPD and APSR burnups > 180,000 MWD/MTU and ≤ 630,000 MWD/MTU must be cooled ≥ 14 years and ≥ 11 years, respectively.
2. Applicable to uniform loading and regionalized loading.
3. NC means not calculated.

3.0 DESIGN FEATURES

3.1 Site

3.1.1 Site Location

The HI-STORM 100 Cask System is authorized for general use by 10 CFR Part 50 license holders at various site locations under the provisions of 10 CFR 72, Subpart K.

3.2 Design Features Important for Criticality Control

3.2.1 MPC-24

1. Flux trap size: ≥ 1.09 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0267 g/cm^2

3.2.2 MPC-68 and MPC-68FF

1. Fuel cell pitch: ≥ 6.43 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0372 g/cm^2

3.2.3 MPC-68F

1. Fuel cell pitch: ≥ 6.43 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.01 g/cm^2

3.2.4 MPC-24E

1. Flux trap size:
   i. Cells 3, 6, 19, and 22: ≥ 0.776 inch
   ii. All Other Cells: ≥ 1.076 inches
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0372 g/cm^2

3.2.5 MPC-32

1. Fuel cell pitch: ≥ 9.158 inches
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0372 g/cm^2

DESIGN FEATURES

Table 3-1 (page 1 of 5)

LIST OF ASME CODE EXCEPTIONS FOR HI-STORM 100 CASK SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Exception, Justification & Compensatory Measures
MPC	NB-1100	Statement of requirements for Code stamping of components.	MPC enclosure vessel is designed and will be fabricated in accordance with ASME Code, Section III, Subsection NB to the maximum practical extent, but Code stamping is not required.
MPC	NB-2000	Requires materials to be supplied by ASME-approved material supplier.	Materials will be supplied by Holtec-approved suppliers with Certified Material Test Reports (CMTRs) in accordance with NB-2000 requirements.
MPC Lid and Closure Ring Welds	NB-4243	Full penetration welds required for Category C Joints (flat head to main shell per NB-3352.3).	MPC lid and closure ring are not full penetration welds. They are welded independently to provide a redundant seal. Additionally, a weld efficiency factor of 0.45 has been applied to the analyses of these welds.
MPC Lid to Shell Weld	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required	Only UT or multi-layer liquid penetrant (PT) examination is permitted. If PT alone is used, at a minimum, it will include the root and final weld layers and each approximately 3/8 inch of weld depth.
MPC Closure Ring, Vent and Drain Cover Plate Welds	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required	Root (if more than one weld pass is required) and final liquid penetrant examination to be performed in accordance with NB-5245. The MPC vent and drain cover plate welds are leak tested. The closure ring provides independent redundant closure for vent and drain cover plates.

(continued)

Table 3-1
MPC Model-Dependent Limits

MPC MODEL	LIMITS
1. MPC-24/24E	
a. MPC Cavity Vacuum Drying Pressure	≤ 3 torr for ≥ 30 min
b. MPC Helium Backfill Pressure[1]	≥ 0 psig and ≤ 15.3 psig
c. MPC Helium Leak Rate	≤ 5.0E-6 atm cc/sec (He)
2. MPC-68/68F/68FF	
a. MPC Cavity Vacuum Drying Pressure	≤ 3 torr for ≥ 30 min
b. MPC Helium Backfill Pressure[1]	≥ 0 psig and ≤ 28.5 psig
c. MPC Helium Leak Rate	≤ 5.0E-6 atm cc/sec (He)
3. MPC-32	
a. MPC Cavity Vacuum Drying Pressure	≤ 3 torr for ≥ 30 min
b. MPC Helium Backfill Pressure	≥ 0 psig and ≤ 7.3 psig
c. MPC Helium Leak Rate	≤ 5.0E-6 atm cc/sec (He)

---

[1] Helium used for backfill of MPC shall have a purity of ≥ 99.995%.

BILL OF MATERIALS FOR 32-ASSEMBLY HI-STAR 100 PWR MPC.(BM-1477)
(E.I.D. 2849)

REF. DWG. 1392 & 1393.

SHEET 1 OF 2

REV. NO.	PREP. BY & DATE	CHECKED BY & DATE	PROJ. MANAGER & DATE	QA. MANAGER & DATE
9	J.A. 4-11-00 ECO 1023-1, ECO 5014-6	B.G. 4/13/00	4/14/00	4/14/00.

	ITEM NO.	QTY.	MATERIAL	DESCRIPTION	NOMENCLATURE
	1A	5	ALLOY "X" SEE NOTE 1.	PLATE 9/32" THK.X 55.59" W. X 176 1/2" LG	BASKET CELL PLATE
	1B	2	ALLOY "X" SEE NOTE 1.	PLATE 9/32" THK X 37.15"W. X 176 1/2"LG.	BASKET CELL PLATE
	1C	38	ALLOY "X" SEE NOTE 1.	PLATE 9/32" THK X 8.937" (REF) W. X 176 1/2"LG.	BASKET CELL PLATE
9	3A	52	BORAL	.101"THK. X 7.5"W. X 156" LG.PER DET.DWG.1392. SEE NOTE 2.	NEUTRON ABSORBER
9	4A	52	ALLOY "X" SEE NOTE 1.	.075" THK. SHEATHING PER DET. DWG. 1392.	SHEATHING
	5A	32		PLATE 3/8"THK X 8.5" SQ.	LOWER FUEL SPACER END PLATE
	5B	32		PLATE 3/8"THK X 8.5" SQ.	LOWER FUEL SPACER END PLATE
	6	1		1/2" THK X 68 3/8" O.D. X 187 5/8" LG. CYLINDER.	SHELL
	7	1		BASEPLATE 2 1/2" THK X 68 3/8" O.D.	BASEPLATE
	8A	4		PLATE 5/16"THK.X 14" APPROX. W X 168" LG. PER DET. DWG.1392.	BASKET SUPPORT
	8B	8		PLATE 5/16"THK. X 14" APPROX.W X 168" LG. PER DET.DWG. 1392.	BASKET SUPPORT
	8C	--		DELETED	----
9	9A	12		1" WIDE X 168" LG. THICKESS AS REQD.	BASKET SUPPORT SHIM
9	9B	---	---	DELETED	----
	9C	---	---	DELETED	----
9	9D	AS REQD.	ALLOY "X" SEE NOTE 1.	AS REQD.	BASKET SUPPORT
9	9E	---	---	DELETED	----
	10	4	ALLOY "X" SEE NOTE 1.	PLATE 3/4" THK. X 3 1/2" WIDE X 8 3/4" LG.	LIFT LUG
	11	4		PLATE 3/4" THK. X 3" WIDE X 4" LG.	LIFT LUG BASEPLATE
	12	1		BAR 3 3/4" OD. x 5 7/8" LG.	DRAIN SHIELD BLOCK
9	13A	2	304 S/S	BAR Ø 2 11/16 X 6 3/4" LG, DIMENSION SHOWN ON DWG 1393 SHT4	VENT AND DRAIN TUBE
9	13B	2	304 S/S	BAR Ø 2 1/4 X 2 1/4" LG, DIMENSION SHOWN ON DWG 1393 SHT4	VENT AND DRAIN TUBE CAP
	14	1	ALLOY "X" SEE NOTE 1.	PLATE 9 1/2" THK. X 67 1/4" O.D.	MPC LID
9	15	1	ALLOY "X" SEE NOTE 1.	RING 3/8" THK.X 53 1/4" ID. X 67 5/8" O.D.	MPC CLOSURE RING
	16	1	S/S	2-1/2 SCH 10 PIPE 150" LG W/FUNNEL	DRAIN GUIDE TUBE

BILL OF MATERIALS FOR 32-ASSEMBLY HI-STAR 100 PWR MPC.(BM-1477)

(E.I.D. 2850)

REF. DWG. 1392 & 1393.

SHEET 2 OF 2

REV. NO.	PREP. BY & DATE	CHECKED BY & DATE	PROJ. MANAGER & DATE	QA. MANAGER & DATE
10	J.A. 4-11-2000 INCORPORATED ECO 5014-6, ECO-1021-7 & 8	B.G. 3/13/00	4/14/00	4/14/00

	ITEM NO.	QTY.	MATERIAL	DESCRIPTION	NOMENCLATURE
	17	---	---	DELETED	---
△10	18	AS REQD	ALLOY "X" SEE NOTE 1.	AS REQUIRED	BASKET SUPPORT
	19	2	ALLOY "X" SEE NOTE 1.	PLATE 3/8" THK. X 3 7/8"OD.	PORT COVER PLATE
	20	32	A-193-B8 OR SIMILAR	3/4"-10UNC X 1 3/8"LG. HEX. BOLT FULL THRD.	UPPER FUEL SPACER BOLT
△10	21	AS REQD	ALLOY "X" SEE NOTE 1.	3/4" X 2" X THICKNESS AS REQURED.	LIFT LUG SHIM
	22	---	---	DELETED	---
	23	4	A-193-B8 OR SIMILAR	1 3/4"-5UNC X 2 3/4" LG SOCKET SET SCREW	LID LIFT HOLE PLUG
	24	32	ALLOY "X" SEE NOTE 1.	3"-SCH 80 PIPE LGTH AS REQD.	UPPER FUEL SPACER PIPE
	25	1 SET	ALLOY "X" SEE NOTE1.	LENGTH, WIDTH AND THICKNESS AS REQ'D.	LID SHIM
△10	26	1	S/S	COUPLING	COUPLING
△10	27	AS REQD	ALLOY "X" SEE NOTE 1.	3/4" X 5" DIAMETER	UPPER FUEL SPACER END PLATE
	28	1	ALLOY "X" SEE NOTE1.	BAR 3 3/4" OD. X 5.5" LG.	VENT SHIELD BLOCK
	29	4	ALLOY "X" SEE NOTE1.	BAR 3/4" OD. X 1/2" LG.	VENT SHIELD BLOCK SPACER
	30	1	ALLOY "X" SEE NOTE1.	2"-SCH 10 PIPE X 173 1/2"APPROX. LG	DRAIN LINE
△10	31	4	S/S	SOCKET SET SCREW 1/4-20 1/4" LG	COVER PLATE PLUG
△10	32	32	ALLOY "X" SEE NOTE1.	PLATE 3/8" THK X 4" OD.	UPPER FUEL SPACER END PLATE
	33	32	S/S SEE NOTE 5	6" SQ. X 1/4" WALL TUBE LGTH AS REQD.	LOWER FUEL SPACER CLUMN
△10	34	AS REQD.	ALUM. 1100	1/8" THK. ALUM. SHEET AS REQD X 176 1/2" LG (153" LG APP. AT DRAIN PIPE LOCATION) WITH S/S SPRINGS.	HEAT CONDUCTION ELEMENTS
	35	2	ALUMINUM	0.065" THK X 1.484 OD, .250 HOLE	SEAL WASHER
	36	2	S/S	1/4" DIA X 3/8" LG	SEAL WASHER BOLT
	37	2	ALLOY "X" SEE NOTE1.	1/8" THK	DRAIN LINE
△10	38	---	--------	DELETED	---------

NOTES: (FOR SHEET 1 & 2)

1. ALLOY X IS ANY OF THE FOLLOWING ACCEPTABLE STAINLESS STEEL ALLOYS: ASME TYPE 316, 316LN, 304, 304LN. THE ALLOY TO BE USED SHALL BE SPECIFIED BY THE LICENSEE.
2. MINIMUM BORAL B-10 LOADING IS 0.0372 g/cm^2 . BORAL TO BE PASSIVATED PRIOR TO INSTALLATION.
3. ALL DIMENSIONS ARE APPROXIMATE DIMENSIONS.
4. ITEMS 8A,8B,9A,9D,18 AND 34 MAY BE MADE FROM MORE THAN ONE PIECE. THE ENDS OF THE PIECES DO NOT NEED TO BE WELDED TOGETHER BUT THEY MUST BE FLUSH WITH EACH OTHER WHEN INSTALLED.
5. △10 MUST BE TYPE 304, 304LN, 316, OR 316LN TENSILE STRENGTH>75 ksi, YIELD STRENGTH>30ksi, AND CHEMICALS PER ASTM A554 .

BILL OF MATERIALS FOR 24-ASSEMBLY HI-STAR 100 PWR MPC.(BM-1478)

REF. DWG. 1395 & 1396.

SHEET 1 OF 2

REV.NO.	PREP. BY & DATE	CHECKED BY & DATE	PROJ. MANAGER & DATE	QA. MANAGER & DATE
10	S.GEE 11-3-99 REVISED AS INDICATED	11/22/99	B.G. 11/23/99	MC 11/22/99

	ITEM NO.	QTY.	MATERIAL	DESCRIPTION	NOMENCLATURE
	1A	2	ALLOY "X" SEE NOTE 1.	PLATE 5/16" THK.X 63.20" REF W. X 176 1/2" LG	BASKET CELL PLATE
	1B	1	│	PLATE 5/16" THK X 60.57" REF W. X 176 1/2"LG.	BASKET CELL PLATE
	1C	2	│	PLATE 5/16" THK X 43.42" REF W. X 176 1/2"LG.	BASKET CELL PLATE
	1D	1	│	PLATE 5/16" THK X 20.402 " REF W. X 176 1/2"LG.	BASKET CELL PLATE
	1E	1	│	PLATE 5/16" THK X 7.7175" REF W. X 176 1/2"LG.	BASKET CELL PLATE
	1F	22	│	PLATE 5/16" THK X10.4625 " REF W. X 176 1/2"LG.	BASKET CELL PLATE
	1G	1	│	PLATE 5/16" THK X 9.7445 " REF W. X 176 1/2"LG.	BASKET CELL PLATE
	1H	2	│	PLATE 5/16" THK X 9.03 " REF W. X 176 1/2"LG.	BASKET CELL PLATE
	2	24	▽	PIPE 3"-SCH 80 LGTH AS REQD.	UPPER FUEL SPACER PIPE
	3A (3B)	84(12)	BORAL	.075"THK. X 7.5"W.(6 1/4") X 156" LG.PER DET.DWG.1395. SEE NOTE 2.	NEUTRON ABSORBER
	4A (4B)	84(12)	ALLOY "X" SEE NOTE 1.	.06" THK. SHEATHING PER DET. DWG. 1395.	SHEATHING
	5A	4	│	PLATE 5/16"THK X 3" W. X 176 1/2"LG.	BASKET CELL PLATE
	5B	4	│	PLATE 5/16"THK X 3 3/4" APPROX. W. X 176 1/2"LG.	BASKET CELL PLATE
	5C	4	│	PLATE 1.5" APP THK. X 3" W. X 168"LG.	BASKET SUPPORT
△10	5D	4	│	2 1/2" W X 168" LG	BASKET SUPPORT
	5E	4	│	2 "WIDE X 168"LG. THICKNESS AS REQD.	BASKET SUPPORT
△10	5F	-	│	DELETED	---
△10	5G	4	│	1 1/4" W X 1" THK X 168" LG.	BASKET SUPPORT SHIM
	5H	---	│	DELETED	-----
	6	1	│	1/2" THK X 68 3/8" O.D. X 187 5/8" LG. CYLINDER.	SHELL
	7	1	│	BASEPLATE 2 1/2" THK X 68 3/8" O.D.	BASEPLATE
	8A	22	│	9/32"THK. ANGLE X 176 1/2" LG. FROM PLATE PER DET. DWG.1395.	BASKET CELL ANGLE
	8B	2	│	9/32"THK. CHANNEL X 176 1/2" LG. FROM PLATE PER DET.DWG. 1395.	BASKET CELL CHANNEL
	9A	1	│	5/16" THK.X 10" W. APP. X 168" LG. PER DET.	BASKET SUPPORT
	9B	2	│	5/16"THK. X 7 1/2" APP. W. X 168" LG. PER DET.	BASKET SUPPORT
	9C	1	│	5/16"THK. X 5" APP. W. X 168" LG. PER DET	BASKET SUPPORT
△10	9D	AS REQD	│	AS REQUIRED	BASKET SUPPORT
	9E	----	│	DELETED	---
	9F	---	│	DELETED	---
	9G	---	│	DELETED	---
	9H	---	│	DELETED	---
	10	4	▽	PLATE 3/4" THK. X 3 1/2" WIDE X 8 3/4" LG.	LIFT LUG

\DRAWINGS\5014\5014\MPC\BM1478-1.R10

BILL OF MATERIALS FOR 24-ASSEMBLY HI-STAR 100 PWR MPC.(BM-1478)

EID #3098

REF. DWG. 1395 & 1396.

SHEET 2 OF 2

REV.NO.	PREP. BY & DATE	CHECKED BY & DATE	PROJ. MANAGER & DATE	QA. MANAGER & DATE
13	J.A. 4-11-00 ECO 1021-7 & 8 ECO 1022-3	B.G. 4/14/00	4/14/00	4/14/00

	ITEM NO.	QTY.	MATERIAL	DESCRIPTION	NOMENCLATURE
	11	4	ALLOY "X" SEE NOTE 1.	PLATE 3/4" THK. X 4" WIDE X 3" LG.	LIFT LUG BASEPLATE
	12	1	ALLOY "X" SEE NOTE 1.	BAR 3.75" OD. X 5 7/8" LG.	DRAIN SHIELD BLOCK
	13A	2	304 S/S	BAR 2 11/16" OD X 6.75" LG, DIMENSIONS AS SHOWN ON DWG 1396 SH 4	VENT AND DRAIN TUBE
	13B	2	304 S/S	BAR 2 1/4 OD X 2 1/4 LG, DIMENSIONS AS SHOWN ON DWG 1396 SH 4	VENT AND DRAIN TUBE CAP
	14	1	ALLOY "X" SEE NOTE 1.	9 1/2" THK. X 67 1/4" O.D.	MPC LID
	15	1	↓	RING 3/8" THK.X 53 1/4" ID. X 67 5/8" O.D.	MPC CLOSURE RING
△13	16	1	S/S	2-1/2" SCH. 10 PIPE, 158" LG WITH FUNNEL	DRAIN GUIDE TUBE
	17	—	----	DELETED	—
	18	AS REQD	ALLOY "X" SEE NOTE 1.	AS REQUIRED	BASKET SUPPORT
	19	2	ALLOY "X" SEE NOTE 1.	PLATE 3/8" THK. X 3 7/8"OD.	PORT COVER PLATE
	20	24	A-193-B8 OR SIMILAR	3/4"-10UNC X 1 1/4"LG. HEX BOLT WITH FULL THRD.	UPPER FUEL SPACER BOLT
	21	AS REQD	ALLOY "X" SEE NOTE 1.	3/4" X 2" X THICKNESS AS REQUIRED	LIFT LUG SHIM
	22	---	---	DELETED	---
	23	4	A-193-B8 OR SIMILAR	1 3/4"-5UNC X 2 3/4"LG SOCKET SET SCREW	LID LIFT HOLE PLUG
	24	24	ALLOY "X" SEE NOTE 1.	PLATE 3/8" THK X 4" OD.	UPPER FUEL SPACER END PLATE
	25	1 SET	ALLOY "X" SEE NOTE 1.	LENGTH, WIDTH AND THICKNESS OF SHIMS AS REQUIRED.	LID SHIM
	26	1	S/S	COUPLING	COUPLING
	27	AS REQD	ALLOY "X" SEE NOTE 1.	3/4" X 5" DIAM.	UPPER FUEL SPACER END PLATE
	28	1	ALLOY "X" SEE NOTE 1.	BAR 3.75" OD. X 5.5"LG.	VENT QUICK DISCONN. CPLG.
	29	4	ALLOY "X" SEE NOTE 1.	BAR 3/4" OD. X 1/2" LG.	VENT SHIELD BLOCK SPACER
	30	1	ALLOY "X" SEE NOTE 1.	2"-SCH 10 PIPE X 173 1/2"APPROX. LG.	DRAIN LINE
△13	31	4	S/S	SOCKET SET SCREW 1/4-20 1/4" LG	COVER PLATE PLUG
△13	32	24	S/S SEE NOTE 5	6" SQ. TUBING X 1/4" WALL LENGTH AS REQ'D.	LOWER FUEL SPACER CLUMN
△13	33A	24	ALLOY "X" SEE NOTE 1.	PLATE 3/8" THK X 8.5" SQ.	LOWER FUEL SPACER END PLATE
△13	33B	24	———	PLATE 3/8" THK X 8.5" SQ.	LOWER FUEL SPACER END PLATE
	34	---	———	DELETED	———
	35	AS REQ'D.	ALUM. ALLOY 1100 & S/S	1/8" THICK X 176 1/2" LG. ALUM. SHEET (153" LG (APP.) AT DRAIN PIPE LOCATION) WITH S/S SPRINGS	HEAT CONDUCTION ELEMENTS
	36	2	ALUMINUM	0.065" THK 1.494 OD, 0.250" HOLE	SEAL WASHER
	37	2	S/S	1/4" DIA X 3/8" LG	SEAL WASHER BOLT
	38	2	ALLOY "X" SEE NOTE 1.	1/8" X 10 1/2" X 9 1/2" SHEET	DRAINLINE
	39	—	---	DELETED	—

NOTES: (FOR SHEET 1 & 2)

1. ALLOY X IS ANY OF THE FOLLOWING ACCEPTABLE STAINLESS STEEL ALLOYS: ASME TYPE 316, 316LN, 304, 304LN. THE ALLOY TO BE USED SHALL BE SPECIFIED BY THE LICENSEE.
2. MINIMUM BORAL B-10 LOADING IS 0.0267 g/cm^2. BORAL TO BE PASSIVATED PRIOR TO INSTALLATION.
3. ALL DIMENSIONS ARE APPROXIMATE DIMENSIONS.
4. △13 ITEMS 5C,5D,5E,5G 9A,9B,9C,9D,16,18, AND 35 MAY BE MADE FROM MORE THAN ONE PIECE. THE ENDS OF PIECES DO NOT NEED TO BE WELDED TOGETHER BUT THEY MUST NE FLUSH WITH EACH OTHER WHEN INSTALLED.
5. MUST BE TYPE 304, 304LN, 316, OR 316LN WITH TENSILE STRENGTH>75ksi, YIELD STRENGTH>30ksi, AND CHEMICALS PER ASTM A554.

BILL OF MATERIALS FOR 68-ASSEMBLY HI-STAR 100 BWR MPC. (BM-1479)

E.I.D. #3099

SHEET 1 OF 2

REF. DWGS. 1401 & 1402.

REV. NO.	PREP. BY & DATE	CHECKED BY DATE	PROJ. MANAGER & DATE	QA. MANAGER & DATE
12	J.A. 4-11-00 ECO 1021-4	B.G. 4/14/00	4/14/00	4/14/00

ITEM NO.	QTY.	MATERIAL	DESCRIPTION	NOMENCLATURE
1A	3	ALLOY "X" SEE NOTE 1.	PLATE 1/4" THK. X 65.65"W. X 176" LG PER DET. DWG.1401.	BASKET CELL PLATE
1B	4	↓	PLATE 1/4" THK. X 52.67"W. X 176" LG PER DET. DWG.1401.	BASKET CELL PLATE
1C	2	↓	PLATE 1/4" THK. X 39.69W. X 176" LG PER DET. DWG.1401.	BASKET CELL PLATE
1D	2	↓	PLATE 1/4" THK. X 13.73"W. X 176" LG PER DET. DWG.1401.	BASKET CELL PLATE
1E	78	↓	PLATE 1/4" THK. X 6.24"W. X 176" LG PER DET. DWG.1401.	BASKET CELL PLATE
2	68	↓	3"- SCH 80 PIPE LGTH AS REQD.	UPPER FUEL SPCER CLUMN
3A	116	BORAL	.101"THK. X 4 3/4"W. X 156" LG.PER DET.DWG.1401. SEE NOTE 2.	NEUTRON ABSORBER
4A	116	ALLOY "X" SEE NOTE 1.	.075" THK. SHEATHING PER DET. DWG.1401.	SHEATHING
5	8	↓	BAR 1" WIDE X 168" LG X THICKNESS AS REQUIRED	BASKET SUPPORT SHIM
6	1	↓	1/2" THK X 68 3/8" O.D. X 187 5/8" LG. CYLINDER.	SHELL
7	1	↓	BASEPLATE 2 1/2" THK X 68 3/8" O.D.	BASEPLATE
8	8	↓	PLATE 5/16"THK. X 10" APPROX.W.X 168 1/2" LG. PER DET. DWG.1401.	BASKET SUPPORT
9A	4	↓	BAR 1" W. X .8" APPROX.THK. X 168 1/2" LG.	BASKET SUPPORT
9B	---	↓	DELETED	---
9C	8	↓	2 1/2" WIDE X 168 1/2" LG. THICKNESS AS REQD. ROLL TO SHELL I.D.	BASKET SUPPORT
9D	AS REQD	↓	AS REQUIRED	BASKET SUPPORT
10	4	↓	PLATE 3/4" THK. X 3 1/2" WIDE X 8 3/4" LG.	LIFT LUG
11	4	↓	PLATE 3/4" THK. X 2 1/2" WIDE X 4" LG.	LIFT LUG BASEPLATE
12	1	↓	BAR 3.75"OD. X 5 7/8" LG.	DRAIN SHIELD BLOCK
13A	2	304 S/S	BAR 2 11/16" OD X 6 3/4" REF LG, DIMENSION ON DWG 1402 SHT 4	VENT AND DRAIN TUBE
13B	2	304 S/S	BAR 2 1/4" OD X 2 1/4" REF LG, DIMENSION ON DWG 1402 SHT 4	VENT AND DRAIN TUBE CAP
14	1	ALLOY "X" SEE NOTE 1.	10" THK. X 67 1/4" O.D. [MPC-68] 10" THK. X 66 1/4" O.D. [MPC-68F]	MPC LID
15	1	ALLOY "X" SEE NOTE 1.	RING 3/8" THK. X 53 1/4" ID. X 67 5/8" O.D. [MPC-68] RING 3/8" THK. X 53 1/4" ID. X 67 1/8" O.D. [MPC-68F]	MPC CLOSURE RING
16	1	S/S	2-1/2"-SCH 10 PIPE 158" LG WITH FUNNEL	DRAIN GUIDE TUBE

BILL OF MATERIALS FOR 68-ASSEMBLY HI-STAR 100 BWR MPC. (BM-1479)
(E.I.D. 3083)

REF. DWGS. 1401 & 1402.

SHEET 2 OF 2

REV. NO.	PREP. BY & DATE	CHECKED BY DATE	PROJ. MANAGER & DATE	QA. MANAGER & DATE
15	J.A. 4-11-00 INCORPORATED ECO-1021-3, 7, & 8	B.G. 4/13/00	4/14/00	4/14/00

	ITEM NO.	QTY.	MATERIAL	DESCRIPTION	NOMENCLATURE
	17	1	ALLOY "X" SEE NOTE 1.	1" THK X 68 3/8" OD X 11 5/8" LG. CYLINDER [MPC-68F]	SHELL
	18	8	ALLOY "X" SEE NOTE 1.	3/8" THK FEMALE SUPPORT SHIM PER DETAIL, DWG. 1401, SHT 4.	BASKET SUPPORT SHIM
	19	2	ALLOY "X" SEE NOTE 1.	PLATE 3/8" THK X 3 7/8" OD.	PORT COVER PLATE
	20	68	A-193-B8 OR SIMILAR	3/4"-10UNC X 1.375"LG. FULL THRD. HEX. BOLT	UPPER FUEL SPACER BOLT
	21	AS REQD	ALLOY "X" SEE NOTE 1.	3/4" W X 2' LG X THICKNESS AS REQUIRED	LIFT LEG SHIM
	22	---	---	DELETED	---
	23	4	A-193-B8 OR SIMILAR	1 3/4"-5UNC X 2 3/4" LG. SOCKET SET SCREW.	LIFT HOLE PLUG
	24	68	ALLOY "X" SEE NOTE 1.	PLATE 3/8" THK X 4" OD.	UPPER FUEL SPACER END PLATE
	25	1 SET	ALLOY "X" SEE NOTE 1	LENGTH, WIDTH , THICKNESS AND QUANTITY AS REQD.	LID SHIM
	26	1	S/S	2" FEMALE X 1 1/4" MALE SCH. 40, S/S COUPLING	COUPLING
	27			DELETED	
	28	1	ALLOY "X" SEE NOTE 1.	BAR 3.75" OD. X 5.5" LG.	VENT SHIELD BLOCK
	29	4	ALLOY "X" SEE NOTE 1.	BAR .75"OD X .5"LG.	VENT SHIELD BLOCK SPACER
	30	1	ALLOY "X" SEE NOTE 1.	2"-SCH 10 PIPE X 173" APPROX.LG.	DRAIN LINE
△15	31	4	S/S	SOCKET SET SCREW 1/4-20 1/4" LG	COVER PLATE PLUG
	32	--		DELETD	---
△15	33	68	S/S SEE NOTE 5	4" SQ. TUBE X 1/4" WALL LENGTH AS REQD. (FOR SHORT FUEL ONLY)	LOWER FUEL SPACER COLUMN
	34A	68	ALLOY "X" SEE NOTE 1.	3/8" THK. X 5 3/4" SQ. PLATE (FOR SHORT FUEL ONLY)	LOWER FUEL SPACER END PLATE
	34B	68	ALLOY "X" SEE NOTE 1.	3/8" THK. X 5 3/4" SQ. PLATE (FOR SHORT FUEL ONLY)	LOWER FUEL SPACER END PLATE
	35			DELETED	
	36	----	------	DELETED	
	37	AS REQD	ALUM. ALLOY 1100	1/8" THK. X 176" LG. ALUM. SHEET. (153" LG APP. AT DRAIN PIPE LOCATION.) W/S/S SPRINGS.	HEAT CONDUCTION ELEMENTS
	38	2	ALUMINUM	.065" THK X 1.494 OD, .250 HOLE	SEAL WASHER
	39	2	S/S	1/4" DIA X 3/8 LG	SEAL WASHER BOLT
	40	2	ALLOY "X" SEE NOTE 1	1/8" THK. 6" X 6" APPROX. SHEET	DRAIN LINE
	41	----	------------	DELETED	------------

NOTES: (FOR SHEET 1 & 2)

1. ALLOY X IS ANY OF THE FOLLOWING ACCEPTABLE STAINLESS STEEL ALLOYS: ASME TYPE 316, 316LN, 304, 304LN. THE ALLOY TO BE USED SHALL BE SPECIFIED BY THE LICENSEE.
2. FOR MPC-68 AND MPC-68FF, MINIMUM BORAL B-10 LOADING IS 0.0372 g/cm$_2$. FOR MPC-68F, MINIMUM BORAL B-10 LOADING IS 0.01 g/cm$_2$. BORAL TO BE PASSIVATED PRIOR TO INSTALLATION. △15
3. ALL DIMENSIONS ARE APPROXIMATE DIMENSIONS.
4. ITEMS 5,8,9A,9B,9C,16,18,36 AND 37 MAY BE MADE FROM MORE THAN ONE PIECE. THE ENDS OF PIECES DO NOT NEED TO BE WELDED TOGETHER BUT THEY MUST BE FLUSH WITH EACH OTHER WHEN INSTALLED.
5. △15 MUST BE TYPE 304, 304LN, 316, OR 316LN WITH TENSILE STRENGTH>75ksi, YIELD STRENGTH>30ksi, AND CHEMICALS PER ASTM A554.

\DRAWINGS\5014\5014\MPC\BM1479-2.R15

BM-1575 (E.I.D. 2839) BILL OF MATERIAL FOR HI-STORM (DWG. 1495, 1561) SHT 1 OF 2

REV. NO.	PREP. BY	CHECKED BY	PROJ. MANAGER	QA. MANAGER
10	S.GEE 3-22-2000 INCORPORATED ECO 1024-2	4/5/00	4/5/00	S.S. 4/5/00

	ITEM	QTY.	SPECIFICATION	NOMENCLATURE	DESCRIPTION
	1	1	SA 516 GR. 70	BASEPLATE	2 THK. X 133 7/8Ø BASEPLATE
	2	1	SA 516 GR. 70	OUTER SHELL	3/4 THK. X 224 1/2 LG. X 132 1/2 O.D. CYLINDER (MAY BE MADE IN SECTIONS, SEE DWG 1495 SHT 5)
	3	1	SA 516 GR. 70	INNER SHELL	1 1/4 THK. X 224 1/2 LG. X 76 O.D. CYLINDER
	4	1	CONCRETE	RADIAL SHIELD	26 3/4 THK. RADIAL SHIELD
	5	1	SA 516 GR. 70	PEDESTAL SHELL	1/4 THK. X 68 3/8 O.D. X 21 5/8 LG. CYLINDER
9	6	1	SA 516 GR. 70	LID BOTTOM PLATE	1 1/4 THK. X 67" Ø PLATE.
9	7	1	SA 516 GR. 70	LID SHELL	1 THK. X 11 3/4 WIDE X 69 O.D.
9	8	4	SA 516 GR. 70	EXIT VENT HORIZONTAL PLATE	1 1/4 THK. X 26 WIDE X 29 1/2 LG. PLATE (SEE DET. DWG. 1561 SHT. 4)
9	9	1	SA 516 GR. 70	TOP PLATE	3/4 THK. X 131 1/2 O.D. X 73 1/2 I.D RING (CUT IN 4 PIECES)
9	10A	1	SA-516-70	LID TOP PLATE	2 THK. X 124 Ø PLATE (SEE NOTE 4)
9	10B	1	SA-516-70	LID TOP PLATE	2 THK. X 126 Ø PLATE (SEE NOTE 4)
9	11	4	SA-516-70	INLET VENT HORIZONTAL PLATE	2 THK. X 16 1/2 WIDE X 29 1/2 LG. PLATE (SEE DET. DWG. 1561 SHT. 3)
9	12	8	SA 516 GR. 70	EXIT VENT VERTICAL PLATE	1/2 THK. X 5 1/4 WIDE X 29 1/2 APPROX. LG. PLATE
9	13	8	SA 516 GR. 70	INLET VENT VERTICAL PLATE	3/4 THK. X 10 WIDE X 29 1/2 APPROX. LG. PLATE
	14	4	SA 516 GR. 70	RADIAL PLATE	3/4 THK. X 27 1/2 WIDE X 224 1/2 LG. PLATE
10	15	4	SA 194 2H	TOP LID NUT	3 1/4 - 4 UNC HEAVY HEX NUT
10	16	4	SA 564-630 AGE HARDENED AT 1075°F	LID STUD	3 1/4- 4 UNC X 16 LG. (SEE DWG. 1561, SHT 2)
9	17	4	SA 350 LF3 OR SA 203 E	BOLT ANCHOR BLOCK	5 X 5 X 6 ANCHOR BLOCK W/ 3 1/4 - 4 UNC X 5 LG HOLE IN CENTER
	18	--	--	DELETED	---
	19	16	SA 516 GR. 70	CHANNEL	3/16 THK. X 6 WIDE X 170 7/8 LG. CHANNEL (SEE DETAIL 1495 SH. 5)
9	20	1	SA 516 GR. 70	SHIELD BLOCK RING	1/4 THK. X 63 1/2 I.D. X 85 1/2 O.D. (MAY BE MADE FROM MORE THAN 1 PIECE.)
	21	1	CONCRETE	PEDESTAL SHIELD	17" THK. PLATFORM
	22	1	CONCRETE	LID SHIELD	10 1/2 THK. TOP SHIELD
9	23	1	SA 516 GR. 70	PEDESTAL PLATE	1/2 THK X 67 7/8 Ø
9	24	1	SA 516 GR. 70	PEDESTAL PLATFORM	5 THK. X 67 7/8 Ø PLATE (MAY USE MULTIPLE PLATES OF LESSER THICKNESS - NUMBER OF PLATES AND THICKNESS OF PLATES OPTIONAL)
	25	1	CONCRETE	SHIELD BLOCK	8" THK.
	26	1	SA 516 GR. 70	SHIELD BLOCK SHELL	1/2 THK X 86 O.D. CYLINDER X 8" HIGH (MAY MAKE OUT OF MORE THAN 1 PIECE)
	27	1	SA 516 GR. 70	SHIELD BLOCK SHELL	1/2 THK X 64 O.D. CYLINDER X 8" HIGH (MAY MAKE OUT OF MORE THAN 1 PIECE)
*	28	4	SA 516 GR. 70	SHIELD SHELL	3/4 THK. X 58.5 APPROX. WIDE X 205" LG. PLATE
*	29	1	SA 240 304	STORAGE MARKING NAME PLATE	14 GAGE (0.0751 THK.) X 4 WIDE X 10 LG. SHEET
*	30	4	C/S OR S/S	LID PLUGS	1 1/2"-6UNC X 2 1/2" OP BOLT

NOTE:

1) THE CONCRETE MATERIAL IS TO MEET THE REQUIREMENTS SPECIFIED IN APPENDIX 1.D OF THE HI-STORM 100 TSAR DOCKET NUMBER 72-1014 (LATEST REVISION).
2) ALL DIMENSIONS IDENTIFIED ON BM-1575 ARE APPROXIMATE DIMENSIONS EXCEPT THICKNESSES OF STEEL PLATES WHICH IN THE RAW MATERIAL FORM MUST HAVE TOLERANCES MEETING THE APPLICABLE SPECIFICATION.
3) ITEMS WITH A * CONSIDERED NOT TO BE NF CLASS 3 (NON STRUCTURAL)
4) AS AN OPTION, ITEMS 10A & 10B CAN BE COMBINED AS A SINGLE 4" THICK PLATE AT 126" Ø. (9)

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BM-1575 (E.I.D. 2836) BILL OF MATERIAL FOR HI-STORM (DWG. 1495, 1561) SHT 2 OF 2

REV. NO.	PREP. BY	CHECKED BY	PROJ. MANAGER	QA. MANAGER
9	S. GEE 2-10-2000 INCORPORATED ECO-1024-1	B.G. 3/16/00	3/16/00	9-3- 3/17/00

	ITEM	QTY.	SPECIFICATION	NOMENCLATURE	DESCRIPTION
	31	--	---	DELETED	---
*	32	4	SA 240 304	EXIT VENT SCREEN SHEET	16 GAGE (0.0595 THK.) X 6 1/4 WIDE X 28 LG. SHEET
*	33	4	SA 240 304	EXIT VENT SCREEN FRAME	16 GAGE (0.0595 THK.)
*	34	1	COMMERCIAL	SCREEN	16 WIDE X 212 LG. 6 X 6 MESH 0.020 WIRE Ø 0.147 WIDTH OPEN FROM McMASTER-CARR 101 PAGE# 2521 ITEM# 9220T67 CUT AS NECESSARY OR EQUIVALENT
*	35	4	SA 240 304	INLET VENT SCREEN FRAME	16 GAGE (0.0595 THK.)
*	36	2	COMMERCIAL	THERMOCOUPLE OR RTD	1/8 Ø SHEATH WITH TEMPERATURE ELEMENT (BY USER).
*	37	16	SA240-304	GAMMA SHIELD CROSS PLATE	1/4 THK X 2.75 X 24
*	38	4	SA240-304	GAMMA SHIELD CROSS PLATE	1/4 THK X 24 X 24 5/8
9 *	39	24	SA240-304	CROSS PLATE TABS	.075 THK X 1/4 X 2 1/2
*	40	8	SA240-304	GAMMA SHIELD CROSS PLATE	1/4 THK X 14 5/8 X 24
*	41	16	SA240-304	GAMMA SHIELD CROSS PLATE	1/4 THK X 3.09 X 24
9 *	42	2	C/S OR S/S	DRAIN PIPE	3/4 SCH 160 PIPE X 11 1/2 LG
*	43	8	SA240-304	GAMMA SHIELD CROSS PLATE	1/4 THK X 5.09 X 17 1/4
*	44	2	316 SS	COMPRESSION FITTING	1/8" X 1/4 NPT MALE PASS THRU COMPRESSION FITTING (OPTIONAL)
*	45	2	CAST IRON	PROTECTION HEAD	1/2 NPT X 1/2 NPT (OPTIONAL)
*	46	2	304 SS	BUSHING	1/4 X 1/2 NPT (OPTIONAL)
*	47	2	304 SS	COUPLING	1/2 NPT COUPLING W/ MOUNTING STUD 1/2 DIA X 3" LG. (OPTIONAL)
*	48	2	304 SS	HEX NIPPLE	1/2 X 1/2 NPT HEX NIPPLE (OPTIONAL)
*	49	2	304 SS	CONNECTION	1/2 NPT CONDUIT CONNECTION (OPTIONAL)
9 *	50	4	C/S	SHIMS	1/2" X 1/2" BAR
9	51	---	---	DELETED	---
9	52	---	---	DELETED	---
9	53	8	C/S	SHIMS	2" THK X 3" LONG X 2" HIGH

BM-1880 (E.I.D. 3002) BILL OF MATERIAL FOR 125 TON HI-TRAC (DWG. 1880) SHT. 1 OF 2

REV. NO.	PREP. BY	CHECKED BY	PROJ. MANAGER	QA. MANAGER
8	S. GEE 4-8-2000 INCORPORATED ECO 1025-1 & 1025-2	4/10/00	4/10/0	4/10/00

	ITEM	QTY.	SPECIFICATION	NOMENCLATURE	DESCRIPTION
	1	1	ASTM B 29	RADIAL LEAD SHIELD	113 CU. FT. COMMON LEAD APPROX.
	2	1	SA 516 GR. 70	OUTER SHELL	1 THK. X 81.25 O.D. X 184.75 LG. CYLINDER
	3	1	SA 516 GR. 70	INNER SHELL	0.75 THK. X 68.75 I.D. X 184.75 LG. CYLINDER
	4	12	SA 516 GR. 70	RADIAL CHANNEL	0.5 THK. X 20 (APPROX) X 168.75 LG.
	4A	1	SA 516 GR. 70	RADIAL CHANNEL	0.5 THK. X 20 (APPROX) X 164.625 LG.
	4B	1	SA 516 GR. 70	RADIAL CHANNEL	0.5 THK. X 20 (APPROX) X 152.625 LG.
	5	10	SA 516 GR. 70	ENCLOSURE SHELL PANEL	0.5 THK. X 11.72 WIDE X 168.75 LG.
	5A	4	SA 516 GR. 70	ENCLOSURE SHELL PANELS	0.5 THK. X 11.72 WIDE X 164.625 LG.
△8	6A	2	SA 516 GR. 70	WATER JACKET END PLATE	1 THK. X 94.625 O.D. X 81.25 I.D. X 141° (APP) (MAY BE MADE FROM MORE THAN 1 PIECE)
△8	6B	1	SA 516 GR. 70	WATER JACKET END PLATE	1 THK. X 94.625 O.D. X 81.25 I.D. RING (MAY BE MADE FROM MORE THAN 1 PIECE)
	7	1	SA 350 LF3	TOP FLANGE	4.5 THK. X 81.25 O.D. X 68.75 I.D. RING
	8	1	SA 516 GR. 70	LOWER WATER JACKET SHELL	0.5 THK. X 86.25 O.D. X 6 LG. CYLINDER
	9	1	SA 516 GR. 70 OR SA 350 LF3	BOTTOM FLANGE	2 THK. X 93 O.D. X 68.75 I.D.
△8	10	1	SA 516 GR. 70 OR SA 203-E OR SA 350 LF3	POOL LID OUTER RING	3.5 THK. X 93 O.D. X 75 I.D. RING
△8	11	1	SA 516 GR. 70	POOL LID TOP PLATE	2 THK. X 93 Ø PLATE
	12	1	ASTM B 29	POOL LID LEAD SHIELD	6.39 CU. FT. COMMON LEAD APPROX.
△8	13	1	SA 516 GR. 70	TOP LID OUTER RING	0.5 THK. X 71.875 O.D. X 3.75 LG. CYLINDER
	14	1	SA 516 GR. 70	TOP LID INNER RING	0.5 THK. X 29 O.D. X 3.75 LG. CYLINDER
△8	15	1	SA 516 GR. 70	TOP LID TOP PLATE	0.5 THK. X 70.875 O.D. X 29 I.D. RING
	16	1	SA 516 GR. 70	TOP LID BOTTOM PLATE	1.0 THK. X 81.25 O.D. X 27 I.D. RING
	17	1	HOLTITE	TOP LID SHIELDING	5.41 CU. FT. APPROX.
	18	8	SA 516 GR. 70	FILL PORT CAPS	0.25 THK. X 2.375 Ø PLATE
△8	19	24	SA 193 B7	TOP LID STUD	1-8 UNC X 4 3/8 LG. STUDS (4 3/8 FULL LENGTH THREAD WITH WRENCH FLAT AT ONE END)
△8	20	24	SA 194 2H	TOP LID NUT	1-8 UNC HEAVY HEX WITH WASHER
	21	1	ELASTOMER	POOL LID GASKET	0.25 THK. X 87.25 O.D. X 86.25 I.D. COMMERCIAL
△8	22	36	SA 193 B7	POOL LID BOLT	1 - 8 UNC X 3.125 LG. HEX. BOLTS X 1.25 MIN THREAD LENGTH W/WASHER

NOTE: 1) ALL SA-350-LF3 MATERIAL MAY BE REPLACED BY SA-203-E.

2) ALL DIMENSIONS ARE FOR REFERENCE ONLY.

\DRAWINGS\5014\5014\TRNSFER\BM1880-1.R8

BM-1880 (E.I.D 3003) BILL OF MATERIAL FOR 125 TON HI-TRAC (DWG. 1880) SHT. 2 OF 2

REV. NO.	PREP. BY	CHECKED BY	PROJ. MANAGER	QA. MANAGER
6	S. GEE 4-8-2000 INCORPORATED ECO 1025-1 & 1025-2	4/10/00	4/10/00	4/10/00

	ITEM	QTY.	SPECIFICATION	NOMENCLATURE	DESCRIPTION
	23	--	---	DELETED	---
△6	24	2	SA 350 LF3	LIFTING TRUNNION BLOCK	7.625 (APPROX) X 10 X 10
△6	25	--	---	DELETED	---
△6	26	2	SB 637 N07718	LIFTING TRUNNION	6.25 Ø X 9.25 LG. BAR
△6	27	2	SA 516 GR. 70	LIFTING TRUNNION END CAP	0.5 THK. X 6.25 Ø PLATE
△6	28	4	SA 193 B7	END CAP BOLTS	0.5 - 13 UNC X 1 LG. WITH 5/8 LG THREAD
	29	2	SA 350 LF3	POCKET TRUNNION	12.375 X 13 X 12.5 BLOCK
	30	1	SA 106	DRAIN PIPE	1 SHC. 80 X 7 (APPROX.) LG. PIPE
	31	--	--	DELETED	----
	32	1	SA 193 B7	DRAIN BOLT	1 - 8UNC X 1.75 LG. SOCKET CAP BOLT
△6	33	--	---	DELETED	---
△6	34	2	SA 516 GR. 70	WATER JACKET END PLATE	1 THK. X 94.625 O.D. X 81.25 I.D. X 39° (APP)
△6	35	--	---	DELETED	---
△6	36	1	SA 516 GR. 70	POOL LID BOTTOM PLATE	1 THK. X 77 Ø PLATE
△6	37	1	COMMERCIAL	VENT COUPLING	1 1/2-3000 lb. SCREWED HALF COUPLING (OR SIMILAR)
△6	38	1	COMMERCIAL	VENT PLUG	1 1/2-3000 lb. SCREWED HEXAGON HEAD PLUG (OR SIMILAR)
△6	39	1	COMMERCIAL	PRESSURE RELIEF COUPLING	1-3000 lb. SCREWED HALF COUPLING (OR SIMILAR)
△6	40	1	COMMERCIAL	PRESSURE RELIEF VALVE	MEDIUM PRESSURE BRONZE POP VALVE (OR SIMILAR)
	41	1	SA 106	JACKET DRAIN PIPE	1 1/2 SCH. 40 X 5 LG. PIPE
△6	42	1	COMMERCIAL	JACKET DRAIN VALVE	1 1/2 NONRISING STEM BRONZE GATE VALVE (OR SIMILAR)
	43	4	C/S OR S/S	HOLE PLUGS	N/A
	44	4	SA 516 GR. 70	TOP LID LIFTING BLOCK	1.5 SQ. X 3.25 LG. BLOCK
	45	--	COMMERCIAL	THERMAL EXPANSION FOAM	0.125 THK.
△6	46	--	---	DELETED	---

@\DRAWINGS\5014\5014\TRNSFER\BM1880-2.R6

BM-1928 (E.I.D. 3001) BILL OF MATERIAL FOR 125 TON HI-TRAC TRANSFER LID (DWG. 1928)

REV. NO.	PREP. BY	CHECKED BY	PROJ. MANAGER	QA. MANAGER
9	S.GEE, 4-12-2000 INCORPORATED ECO 1025-3	4/12/00	B.G. 4/12/00	4/13/00

	ITEM	QTY.	SPECIFICATION	NOMENCLATURE	DESCRIPTION
	1	1	SA 516 GR. 70	LID TOP PLATE	1.5 THK. X 93 WIDE X 128 LG. PLATE
	2	1	SA 516 GR. 70	LID BOTTOM PLATE	2 THK. X 93 WIDE X 128 LG. PLATE
	3	2	SA 516 GR. 70	LID INTERMEDIATE PLATE	1.5 THK. X 8.375 WIDE X 132 LG. PLATE
	4	2	SA 516 GR. 70	LEAD COVER PLATE	1 THK. X 8.375 WIDE X 78 LG. PLATE
	5	8	SA 516 GR. 70	LEAD COVER SIDE PLATE	1 THK. X 4.5 WIDE X 8.375 LG. PLATE
	6	1	ASTM B 29	SIDE LEAD SHIELD	2.65 (APPROX.) CU. FT.
	7	2	SA 36	WHEEL TRACK	0.125 THK. X 0.75 X 0.75 X 128 LG. ANGLE
△8	8	2	SA 516 GR. 70	DOOR TOP PLATE	2 1/4 THK. X 47 WIDE X 80 LG. PLATE (CUT AS NECESSARY)
	9	2	ASTM B 29	DOOR LEAD SHIELD	2.9 (APPROX.) CU. FT.
	10	2	SA 516 GR. 70	DOOR MIDDLE PLATE	1/2 THK. X 47 WIDE X 65 LG. PLATE (CUT AS NECESSARY)
	11	2	HOLTITE	DOOR SHIELDING	3.65 (APPROX.) CU. FT.
	12	2	SA 516 GR. 70	DOOR BOTTOM PLATE	3/4 THK. X 47 WIDE X 65 LG. PLATE (CUT AS NECESSARY)
△8	13	4	SA 516-70	DOOR WHEEL HOUSING	1 7/8 THK. X 6 WIDE X 25 LG. PLATE
	14	2	SA 516 GR. 70	DOOR INTERFACE PLATE	1 THK. X 3 7/8 WIDE X 80 LG. PLATE
△8	15	2	SA 516 GR. 70	DOOR SIDE PLATE	1 THK. X 5.75 WIDE X 65 LG. PLATE
△8	15A	4	SA 516 GR. 70	DOOR SIDE PLATE	1 THK. X 5.75 WIDE X 65 LG. PLATE
△8	16	4	SA 516 GR. 70	DOOR SIDE PLATE	1 THK. X 5.75 WIDE X 32.625 APPROX. LG. PLATE
△8	17	2	C/S OR S/S	DOOR HANDLE	3/4-10UNC EYE BOLT
△8	18	12	COMMERCIAL	DOOR WHEEL	6 X 3 V-GROOVE WHEEL.
△8	19	12	SA 193-B7	WHEEL SHAFT	1.25-7UNC (1.25" THREAD LENGTH) X 6.625 LG. BAR WITH SCREWDRIVER SLOT FOR INSTALLATION AT UNTHREADED END.
△8	20	---	---	DELETED	---
	21	2	SA 516 GR. 70	LID HOUSING STIFFENER	1 THK. X 3.5 WIDE X 8.375 LG. PLATE
△9	22	4	SA 193 B7	DOOR LOCK BOLT	3 - 4 UNC X 10.875" LG. HEX. BOLTS W/ 1.5 LG. THREADED AT END
	23	4	SA 516 GR. 70	DOOR STOP BLOCK	2 THK. X 2 WIDE X 8 LG. BLOCK
	24	8	SA 193 B7	DOOR STOP BLOCK BOLT	1 - 8 UNC X 3 LG. BOLT W/ 2.5 LG. THREADED AT END
△8	25	2	SA 516 GR. 70	DOOR END PLATE	1 THK. X 5.75 WIDE X 19 LG. PLATE
	26	4	SA 516 GR. 70	LIFTING LUG	0.75 THK. X 3 WIDE X 3.5 LG. PLATE
	27	4	SA 516 GR. 70	LIFTING LUG PAD	0.5 THK. X 5 SQ. PLATE

NOTE:

1) ALL DIMENSIONS ARE APPROXIMATE.

BM-2145 (E.I.D. 3049) BILL OF MATERIAL FOR 100 TON HI-TRAC (DWG. 2145) SHT. 1 OF 2

REV. NO.	PREP. BY	CHECKED BY	PROJ. MANAGER	QA. MANAGER
5	S. GEE 4-8-2000 INCORPORATED ECO-1026-1 & 1026-2	4/10/00	4/10/00	5-S 4/11/00

ITEM	QTY.	SPECIFICATION	NOMENCLATURE	DESCRIPTION
1	1	ASTM B 29	RADIAL LEAD SHIELD	71.15 CU. FT. COMMON LEAD APPROX.
2	1	SA 516 GR. 70	OUTER SHELL	1 THK. X 78 O.D. X 184.75 LG. CYLINDER
3	1	SA 516 GR. 70	INNER SHELL	0.75 THK. X 68.75 I.D. X 184.75 LG. CYLINDER
4	11	SA 516 GR. 70	RADIAL CHANNEL	.375 THK. X 18.8 (APPROX) X 168.75 LG.
4A	2	SA 516 GR. 70	RADIAL CHANNEL	0.375 THK. X 18.8 (APPROX) X 164.625 LG.
4B	2	SA516 GR.70	RADIAL CHANNEL	0.375 THK X 18.8 (APPROX) X 168.75 LG
5	11	SA 516 GR. 70	ENCLOSURE SHELL PANELS	0.375 THK. X 9.7125 WIDE X 168.75 LG.
5A	4	SA 516 GR. 70	ENCLOSURE SHELL PANELS	0.375 THK. X 9.7125 WIDE X 164.625 LG.
6A	2	SA 516 GR. 70	WATER JACKET END PLATE	1 THK. X 91 O.D. X 78 I.D. RING X 132° REF (MAY BE MADE FROM MORE THAN 1 PIECE)
6B	1	SA 516 GR. 70	WATER JACKET END PLATE	1 THK. X 91 O.D. X 78 I.D. RING (MAY BE MADE FROM MORE THAN 1 PIECE)
7	1	SA 350 LF3	TOP FLANGE	4.5 THK. X 78.00 O.D. X 68.75 I.D. RING
8	1	SA 516 GR. 70	LOWER WATER JACKET SHELL	1.25 THK. X 83.00 O.D. X 6 LG. CYLINDER
9	1	SA 350 LF3, OR SA 516 GR. 70	BOTTOM FLANGE	2 THK. X 89 O.D. X 68.75 I.D.
10	1	SA516 GR 70 OR SA 203-E OR SA350 LF3	POOL LID OUTER RING	2.0 THK X 89 O.D. X 75 I.D.
11	1	SA 516 GR. 70	POOL LID TOP PLATE	2 THK. X 89 Ø
12	1	ASTM B 29	POOL LID LEAD SHIELD	3.84 CU FT APPROX. COMMON LEAD
13	--	---	DELETED	---
14	--	---	DELETED	---
15	--	---	DELETED	---
16	1	SA 516 GR. 70	TOP LID BOTTOM PLATE	1.0 THK. X 78.00 O.D. X 27 I.D. RING
17	1	SA 516 GR 70	POOL LID BOTTOM PLATE	.5 THK X 76.5 Ø
18	8	SA 516 GR. 70	FILL PORT CAPS	0.25 THK. X 2.375 Ø PLATE
19	24	SA 193 B7	TOP LID STUD	1-8 UNC X 4 3/8 LG. STUDS (4 3/8" FULL LENGTH THREAD WITH WRENCH FLAT ONE END)
20	24	SA 194 2H	TOP LID NUT	1-8 UNC HEAVY HEX WITH WASHER
21	1	ELASTOMER	POOL LID GASKET	0.25 THK. X 83.625 O.D. X 82.625 I.D. COMMERCIAL
22	36	SA 193 B7	POOL LID BOLT	1-8UNC X 3.125 LG. HEX BOLTS WITH 1.25" MIN THRD LENGTH W/WASHER
23	--	---	DELETED	---
24	2	SA 350 LF3	LIFTING TRUNNION BLOCK	7.25 (APP) X 10 X 10
25	--	---	DELETED	---

NOTES: 1. ALL SA-350-LF3 MATERIAL MAY BE REPLACED BY SA-203-E.

2. ALL DIMENSIONS ARE FOR REFERENCE ONLY.

BM-2145 (E.I.D. 3050) BILL OF MATERIAL FOR 100 TON HI-TRAC (DWG. 2145) SHT. 2 OF 2

REV. NO.	PREP. BY	CHECKED BY	PROJ. MANAGER	QA. MANAGER
4	S. GEE 4-8-2000 INCORPORATED ECO-1026-1 & 1026-2	4/10/00	4/10/00	4/11/00

	ITEM	QTY.	SPECIFICATION	NOMENCLATURE	DESCRIPTION
△4	26	2	SB 637 N07718	LIFTING TRUNNION	6.25 Ø X 9.25 LG. BAR
△4	27	2	SA 516 GR. 70	LIFTING TRUNNION END CAP	0.5 THK. X 6.25 Ø PLATE
△4	28	4	SA 193 B7	END CAP BOLTS	0.5 - 13 UNC X 1 LG. WITH 5/8 MIN THREAD.
	29	2	SA 350 LF3	REMOVABLE POCKET TRUNNION	3.9375 X 13 X 12.375 BLOCK
	30	6	SA564-630 (H1100)	DOWEL PINS	1 3/8" Ø BAR
	31	1	SA 106	DRAIN PIPE	1 SCH 80 X 6 LG APPROX (CUT TO SUIT)
	32	1	SA 193 B7	DRAIN BOLT	1 - 8UNC X 1.75 LG. SOCKET CAP BOLT
△4	33	--	---	DELETED	---
△4	34	2	SA 516 GR. 70	WATER JACKET END PLATE	1 THK. X 91 O.D. X 78 I.D. X 48° APP
△4	35	--	---	DELETED	---
	36	--	---	DELETED	---
△4	37	1	COMMERCIAL	VENT COUPLING	1 1/2-3000 lb. SCREWED HALF COUPLING (OR SIMILAR)
△4	38	1	COMMERCIAL	VENT PLUG	1 1/2-3000 lb. SCREWED HEXAGON HEAD PLUG (OR SIMILAR)
△4	39	1	COMMERCIAL	PRESSURE RELIEF COUPLING	1-3000 lb. SCREWED HALF COUPLING (OR SIMILAR)
△4	40	1	COMMERCIAL	PRESSURE RELIEF VALVE	MEDIUM PRESSURE BRONZE POP VALVE (OR SIMILAR)
	41	1	SA 106	JACKET DRAIN PIPE	1 1/2 SCH. 40 X 5 LG. PIPE
△4	42	1	COMMERCIAL	JACKET DRAIN VALVE	1 1/2 NONRISING STEM BRONZE GATE VALVE (OR SIMILAR)
	43	4	C/S OR S/S	HOLE PLUGS	N/A
	44	--	---	DELETED	---
	45	--	---	DELETED	---
△4	46	--	---	DELETED	---
	47	2	SA 350 LF3	POCKET TRUNNION BASE	8.03 X 13 X 12.375
	48	4	SA564-630 (H1100)	POCKET TRUNNION BOLTS	1-8 UNC X 6.25 WITH 2.3125" MIN LG THREAD
△4	49	--	---	DELETED	---

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BM-2152 BILL OF MATERIAL FOR 100 TON HI-TRAC TRANSFER LID (DWG. 2152)

REV. NO.	PREP. BY	CHECKED BY	PROJ. MANAGER	QA. MANAGER
7	S. GEE, 4-12-2000. INCORPORATED ECO-1026-3	4/12/00	BG. 4/12/00	4/13/00

	ITEM	QTY.	SPECIFICATION	NOMENCLATURE	DESCRIPTION
	1	1	SA 516 GR. 70	LID TOP PLATE	1.5 THK. X 89 WIDE X 128 LG. PLATE
	2	1	SA 516 GR. 70	LID BOTTOM PLATE	1 1/2 THK. X 89 WIDE X 128 LG. PLATE
△6	3	2	SA 516 GR. 70	LID INTERMEDIATE PLATE	1.5 THK. X 8.375 WIDE X 132 LG. PLATE
	4	2	SA 516 GR. 70	LEAD COVER PLATE	1 THK. X 8.375 WIDE X 78 LG. PLATE
	5	4	SA 516 GR. 70	LEAD COVER SIDE PLATE	1 THK. X 2.5 WIDE X 8.375 LG. PLATE
	6	1	ASTM B 29	SIDE LEAD SHIELD	1.136 APPROX. CU. FT.
	7	2	SA 36	WHEEL TRACK	0.125 THK. X 0.75 X 0.75 X 128 LG. ANGLE
△6	8	2	SA 516 GR. 70	DOOR TOP PLATE	2.25 THK. X 47 WIDE X 80 LG. (CUT AS NECESSARY)
	9	2	ASTM B 29	DOOR LEAD SHIELD	2.04 APPROX CU. FT.
	10		DELETED	- - -	- - -
	11	--	DELETED	---	---
△6	12	2	SA 516 GR. 70	DOOR BOTTOM PLATE	1/2 THK. X 44.5 WIDE X 65 LG. PLATE (CUT AS NECESSARY)
	13	4	SA 516 GR 70,	DOOR WHEEL HOUSING	1 7/8 THK. X 6 WIDE X 25 LG.
	14	2	SA 516 GR. 70	DOOR INTERFACE PLATE	1 THK. X 3 7/8 WIDE X 80 LG. PLATE
△6	15	2	SA 516 GR. 70	DOOR SIDE PLATE	1 THK. X 2 WIDE X 65 LG. PLATE
△6	15A	4	SA 516 GR. 70	DOOR SIDE PLATE	1 THK. X 2 WIDE X 65 LG. PLATE
△6	16	4	SA 516 GR. 70	DOOR SIDE PLATE	1 THK. X 2 WIDE X 29 APPROX. LG. PLATE
△6	17	2	C/SOR S/S	DOOR HANDLE	3/4-10UNC EYE BOLT
△6	18	12	COMMERCIAL	DOOR WHEEL	6 X 3 V-GROOVE WHEEL
△6	19	12	SA 193 B7	WHEEL SHAFT	1.25-7UNC (1.25 THREAD LENGTH) X 6.625 LG. BAR WITH SCREWDRIVER SLOT FOR INSTALLATION AT UNTHREADED END.
△6	20	--	---	DELETED	---
	21	2	SA 516 GR. 70	LID HOUSING STIFFENER	1 THK. X 1.5 WIDE X 8.375 LG. PLATE
△7	22	4	SA 193 B7	DOOR LOCK BOLT	3 - 4 UNC X 10.875 LG. HEX. BOLTS W/ 1.5 LG. THREADED AT END
	23	4	SA 516 GR. 70	DOOR STOP BLOCK	2 THK. X 2 WIDE X 8 LG. BLOCK
	24	8	SA 193 B7	DOOR STOP BLOCK BOLT	1 - 8 UNC X 3 LG. BOLT W/ 2.5 LG. THREADED AT END
△6	25	2	SA 516 GR. 70	DOOR END PLATE	1 THK. X 2 WIDE X 24 LG. PLATE
	26	4	SA 516 GR. 70	LIFTING LUG	0.75 THK. X 3 WIDE X 3.5 LG. PLATE
	27	4	SA 516 GR. 70	LIFTING LUG PAD	0.5 THK. X 5 SQ. PLATE

NOTES:

1) ALL DIMENSIONS ARE APPROXIMATE.

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(BM-2898) BILL OF MATERIALS FOR 24-ASSEMBLY HI-STAR 100 PWR MPC-24E (SHEET 1).

REF. DWG. 2889 TO 2892, 1395 SHT 3 & 1396 SHT 1 TO SHT 5

REV.NO.	PREP. BY & DATE	CHECKED BY & DATE	PROJ. MANAGER & DATE	QA. MANAGER & DATE
0	S.GEE 4-6-2000 ISSUED FOR APPROVAL	C.B. 4/12/00.	4/12/00	4/13/00

ITEM NO.	QTY.	MATERIAL	DESCRIPTION	NOMENCLATURE
1A	2	ALLOY "X" SEE NOTE 1.	PLATE 5/16" THK.X 64.543" REF W. X 176 1/2" LG	BASKET CELL PLATE
1B	4	↓	PLATE 5/16" THK X 23.165" REF W. X 176 1/2"LG.	BASKET CELL PLATE
1C	2	↓	PLATE 5/16" THK X 45.985" REF W. X 176 1/2"LG.	BASKET CELL PLATE
1D	4	↓	5/16 ANGLE X 10.847 X 10.847 X 176 1/2" LG	BASKET CELL ANGLE
1E	4	↓	PLATE 5/16" THK X 9.5" REF W. X 176 1/2"LG.	BASKET CELL PLATE
1F	16	↓	PLATE 5/16" THK X 10.535 " REF W. X 176 1/2"LG.	BASKET CELL PLATE
2	24	↓	PIPE 3"-SCH 80 LGTH AS REQD.	UPPER FUEL SPACER PIPE
3A (3B)	72(24)	BORAL	.101"THK. X 7.5"W.(6 1/4") X 156" LG.PER DET.DWG.1395 SHT 3. SEE NOTE 2.	NEUTRON ABSORBER
4A (4B)	72(24)	ALLOY "X" SEE NOTE 1.	.06" THK. SHEATHING PER DET. DWG. 1395.	SHEATHING
5A	4	↓	PLATE 5/16" THK X 3" W. X 176 1/2" LG.	BASKET CELL PLATE
5B	8	↓	PLATE 2" REF WIDE X 168" LG X THICKNESS AS REQD	BASKET SUPPORT
5C	4	↓	PLATE 3" REF W. X 168"LG. X THICKNESS AS REQD	BASKET SUPPORT
5D	4	↓	PLATE 5/16"THK X 1.472" APPROX W. X 176 1/2"LG.	BASKET CELL PLATE
6	1	↓	1/2" THK X 68 3/8" O.D. X 187 5/8" LG. CYLINDER.	SHELL
7	1	↓	BASEPLATE 2 1/2" THK X 68 3/8" O.D.	BASEPLATE
8A	12	↓	5/16"THK. ANGLE X 176 1/2" LG. FROM PLATE PER DET. DWG.1395 SHT 3	BASKET CELL ANGLE
8B	8	↓	5/16"THK. CHANNEL X 176 1/2" LG. FROM PLATE PER DET.DWG. 1395 SHT 3.	BASKET CELL CHANNEL
8C	4	↓	5/16"THK. ANGLE X 176 1/2" LG. FROM PLATE PER DET.DWG. 1395 SHT 3	BASKET CELL CHANNEL
9	4	↓	PLATE 1.25" APP. THK. X 2" W. X 168"LG.	BASKET SUPPORT
10	4	↓	PLATE 3/4" THK. X 3 1/2" WIDE X 8 3/4" LG.	LIFT LUG

(BM2899) BILL OF MATERIALS FOR 24-ASSEMBLY HI-STAR 100 PWR MPC-24E.(SHEET 2)

REF. DWG. 2889 TO 2892,1395 SHT 3 & 1396 SHT 1 TO SHT 5.

REV.NO.	PREP. BY & DATE	CHECKED BY & DATE	PROJ. MANAGER & DATE	QA. MANAGER & DATE
0	S.GEE 4-6-2000 ISSUED FOR APPROVAL	C.B. 4/12/00.	4/13/00	MS 4/13/00

ITEM NO.	QTY.	MATERIAL	DESCRIPTION	NOMENCLATURE
11	4	ALLOY "X" SEE NOTE 1.	PLATE 3/4" THK. X 4" WIDE X 3" LG.	LIFT LUG BASEPLATE
12	1	ALLOY "X" SEE NOTE 1.	BAR 3.75" OD. X 5 7/8" LG.	DRAIN SHIELD BLOCK
13A	2	304 S/S	BAR 2 11/16" OD X 6.75" LG, DIMENSIONS AS SHOWN ON DWG 1396 SH 4	VENT AND DRAIN TUBE
13B	2	304 S/S	BAR 2 1/4 OD X 2 1/4 LG, DIMENSIONS AS SHOWN ON DWG 1396 SH 4	VENT AND DRAIN TUBE CAP
14	1	ALLOY "X" SEE NOTE 1.	9 1/2" THK. X 67 1/4" O.D.	MPC LID
15	1	↓	RING 3/8" THK.X 53 1/4" ID. X 67 5/8" O.D.	MPC CLOSURE RING
16	1	S/S	2 1/2" SCH 10S PIPE, 158" LG WITH FUNNEL.	DRAIN GUIDE TUBE
17	----	----	DELETED	----
18	AS REQD	ALLOY "X" SEE NOTE 1.	AS REQUIRED	BASKET SUPPORT
19	2	ALLOY "X" SEE NOTE 1.	PLATE 3/8" THK. X 3 7/8"OD.	PORT COVER PLATE
20	AS REQD	A-193-B8 OR SIMILAR	3/4"-10UNC X 1 1/4"LG. HEX BOLT WITH FULL THRD.	UPPER FUEL SPACER BOLT
21	AS REQD	ALLOY "X" SEE NOTE 1.	3/4" X 2" X THICKNESS AS REQUIRED	LIFT LUG SHIM
22	---	---	DELETED	---
23	4	A-193-B8 OR SIMILAR	1 3/4"-5UNC X 2 3/4"LG SOCKET SET SCREW	LID LIFT HOLE PLUG
24	AS REQD	ALLOY "X" SEE NOTE 1.	PLATE 3/4" THK X 5" OD.	UPPER FUEL SPACER END PLATE
25	1 SET	ALLOY "X" SEE NOTE 1.	LENGTH, WIDTH AND THICKNESS OF SHIMS AS REQUIRED.	LID SHIM
26	1	S/S	COUPLING	COUPLING
27	AS REQD	ALLOY "X" SEE NOTE 1.	3/4" X 5" DIAM.	UPPER FUEL SPACER END PLATE
28	1	ALLOY "X" SEE NOTE 1.	BAR 3.75" OD. X 5.5"LG.	VENT QUICK DISCONN. CPLG.
29	4	ALLOY "X" SEE NOTE 1.	BAR 3/4" OD. X 1/2" LG.	VENT SHIELD BLOCK SPACER
30	1	ALLOY "X" SEE NOTE 1.	2"-SCH 10 PIPE X 173 1/2"APPROX. LG.	DRAIN LINE
31	--	-------	DELETED	-----
32	AS REQD	↓	6" SQ. TUBING X 1/4" WALL LENGTH AS REQ'D.	LOWER FUEL SPACER COLUMN
33A	AS REQD	↓	PLATE 3/8" THK X 8.5" SQ.	LOWER FUEL SPCAER END PLATE
33B	AS REQD	↓	PLATE 3/8" THK X 8.5" SQ.	LOWER FUEL SPCAER END PLATE
34	---	--------	DELETED	-------
35	AS REQ'D.	ALUM. ALLOY 1100 & S/S	1/8" THICK X 176 1/2" LG. ALUM. SHEET (153" LG (APP.) AT DRAIN PIPE LOCATION) WITH S/S SPRINGS	HEAT CONDUCTION ELEMENTS
36	2	ALUMINUM	0.065" THK 1.494 OD, 0.250" HOLE	SEAL WASHER
37	2	S/S	1/4" DIA X 3/8" LG	SEAL WASHER BOLT
38	2	ALLOY "X" SEE NOTE 1.	1/8" X 10 1/2" X 9 1/2" SHEET	DRAINLINE
39	8	ALLOY "X" SEE NOTE 1.	1/8" X 4" X 4 1/2" APPROX SHEET	DRAINLINE
40	1	ALLOY "X" SEE NOTE 1.	2.722" SQ APPROX X 176 1/2" LG	CENTER COLUMN

NOTES: (FOR SHEET 1 & 2) THE ALLOY TO BE USED SHALL BE SPECIFIED BY THE LICENSEE.

1. ALLOY X IS ANY OF THE FOLLOWING ACCEPTABLE STAINLESS STEEL ALLOYS: ASME TYPE 316, 316LN, 304, 304LN.
2. MINIMUM BORAL B-10 LOADING IS 0.0267 g/cm^2. BORAL TO BE PASSIVATED PRIOR TO INSTALLATION.
3. ALL DIMENSIONS ARE APPROXIMATE DIMENSIONS.
4. ITEMS 5C,5D, 9,18, AND 35 MAY BE MADE FROM MORE THAN ONE PIECE. THE ENDS OF PIECES DO NOT NEED TO BE WELDED TOGETHER BUT THEY MUST BE FLUSH WITH EACH OTHER WHEN INSTALLED.

-3065 BILL OF MATERIAL FOR HI-STORM 1 (DWGS. 3067-3077)

REV. NO.	PREP. BY	CHECKED BY	PROJ. MANAGER	QA. MANAGER
0	S.GEE 3-9-2000 ISSUED FOR APPROVAL	4/7/00	4/7/00	4/13/00

ITEM	QTY.	SPECIFICATION	NOMENCLATURE	DESCRIPTION
1	1	SA 516 GR. 70	BASEPLATE	2 THK. X 133 7/8Ø BASEPLATE
2	1	SA 516 GR. 70	OUTER SHELL	3/4 THK. X 207 3/4 LG. X 132 1/2 O.D. CYLINDER (MAY BE MADE IN SECTIONS, SEE DWG 3071)
3	1	SA 516 GR. 70	INNER SHELL	1 1/4 THK. X 207 3/4 LG. X 76 O.D. CYLINDER
4	1	CONCRETE	RADIAL SHIELD	26 3/4 THK. RADIAL SHIELD
5	1	SA 516 GR. 70	PEDESTAL SHELL	1/4 THK. X 68 3/8 O.D. X 16.5 LG. CYLINDER
6	4	SA 516 GR. 70	LID SHIELD	1 1/4 THK. X 6" X 32" LG.
7	4	SA 516 GR. 70	LID SHIELD	3/4" THK. X 6" X 74" LG.
8	---	---	DELETED	---
9	1	SA 516 GR. 70	TOP PLATE	3/4 THK. X 132 1/2 O.D. X 73 1/2 I.D RING (MAY BE MADE FROM MORE THAN ONE PIECE)
10A	1	SA-516-70	LID TOP PLATE	2 THK. X 124.75 Ø PLATE (SEE NOTE 4)
10B	1	SA-516-70	LID TOP PLATE	2 THK. X 126.75 Ø PLATE (SEE NOTE 4)
11	4	SA-516-70	INLET VENT HORIZONTAL PLATE	2 THK. X 16.5 WIDE X 31 1/2 LG. PLATE
12	8	SA 516 GR. 70	LID SHIELD VERTICAL PLATE	1/2 THK. X 6" X 26.25.
13	8	SA 516 GR. 70	INLET VENT VERTICAL PLATE	3/4 THK. X 10 WIDE X 29 1/2 APPROX. LG. PLATE
14	4	SA 516 GR. 70	RADIAL PLATE	3/4 THK. X 27 1/2 WIDE X 207 3/4 LG. PLATE
15	4	SA 194 2H	TOP LID NUT	3 1/4 - 4 UNC HEAVY HEX NUT
16	4	SA 564-630 AGE HARDENED AT 1075°F	LID STUD	3 1/4 - 4 UNC X 22 1/2 LG. (SEE DWG. 3074)
17	4	SA 350 LF3 OR SA 203 E	BOLT ANCHOR BLOCK	5 X 5 X 6 ANCHOR BLOCK W/ 3 1/4 - 4 UNC X 5 LG HOLE IN CENTER
18	--	--	DELETED	---
19	16	SA 516 GR. 70	CHANNEL	3/16 THK. X 6 WIDE X 171 1/2 LG. CHANNEL (SEE DWG 3071)
20	1	SA 516 GR. 70	SHIELD BLOCK COVER	1/4 THK. X 85 1/2 O.D.
21	1	CONCRETE	PEDESTAL SHIELD	11.5" THK. PLATFORM
22	1	CONCRETE	LID SHIELD	6" THK. SHIELD
23	1	SA516 GR 70	PEDESTAL BASEPLATE	1/2" X 67 7/8" Ø
24	1	SA 516 GR. 70	PEDESTAL PLATFORM	5 THK. X 67 7/8 Ø PLATE (MAY USE MULTIPLE PLATES OF LESSER THICKNESS - NUMBER OF PLATES AND THICKNESS OPTIONAL)
25	1	CONCRETE	SHIELD BLOCK	10" THK. SHIELD
26	1	SA 516 GR. 70	SHIELD BLOCK SHELL	1/2 THK X 86 O.D. CYLINDER X 10" HIGH (MAY MAKE OUT OF MORE THAN 1 PIECE)
27	1	SA 516 GR. 70	LID SHIELD RING	1/2 THK X 73 1/2 I.D. X 126.75" O.D.
* 28	4	SA 516 GR. 70	SHIELD SHELL	3/4 THK. X 58.5 APPROX. WIDE X 195 1/4" LG. PLATE
* 29	1	SA 240 304	STORAGE MARKING NAME PLATE	14 GAGE (0.0751 THK.) X 4 WIDE X 10 LG. SHEET
* 30	4	C/S OR S/S	LID PLUGS	1 1/2"-6UNC X 2 1/2" OP BOLT

NOTE:

1) THE CONCRETE MATERIAL IS TO MEET THE REQUIREMENTS SPECIFIED IN APPENDIX 1.D OF THE HI-STORM 100 TSAR DOCKET NUMBER 72-1014 (LATEST REVISION).
2) ALL DIMENSIONS IDENTIFIED ON DWGS BM-3065, BM-3066 ARE APPROXIMATE DIMENSIONS EXCEPT THICKNESSES OF STEEL PLATES WHICH IN THE RAW MATERIAL FORM MUST HAVE TOLERANCES MEETING THE APPLICABLE SPECIFICATION.
3) ITEMS WITH A * CONSIDERED NOT TO BE NF CLASS 3 (NON STRUCTURAL)
4) AS AN OPTION, ITEMS 10A & 10B CAN BE COMBINED AS A SINGLE 4" THICK PLATE AT 126.75" Ø.

BM-3066 BILL OF MATERIAL FOR HI-STORM 100S (DWGS.3067-3077)

REV. NO.	PREP. BY	CHECKED BY	PROJ. MANAGER	QA. MANAGER
0	S. GEE 3-9-2000 ISSUED FOR APPROVAL	4/7/00	4/7/00	MS 4/13/00

	ITEM	QTY.	SPECIFICATION	NOMENCLATURE	DESCRIPTION
	31	--	---	DELETED	---
	32	--	---	DELETED	---
*	33	4	SA 240 304	EXIT VENT SCREEN FRAME	16 GAGE (0.0595 THK.)
*	34	1	COMMERCIAL	SCREEN	16 WIDE X 212 LG. 6 X 6 MESH 0.020 WIRE Ø 0.147 WIDTH OPEN FROM McMASTER-CARR 101 PAGE# 2521 ITEM# 9220T67 CUT AS NECESSARY OR EQUIVALENT
*	35	4	SA 240 304	INLET VENT SCREEN FRAME	16 GAGE (0.0595 THK.)
*	36	2	COMMERCIAL	THERMOCOUPLE OR RTD	1/8 Ø SHEATH WITH TEMPERATURE ELEMENT (BY USER).
*	37	16	SA240-304	GAMMA SHIELD CROSS PLATE	1/4 THK X 2.75 X 24
*	38	4	SA240-304	GAMMA SHIELD CROSS PLATE	1/4 THK X 24 X 24 5/8
*	39	24	SA240-304	CROSS PLATE TABS	.075 THK X 1/4 X 2 1/2
*	40	8	SA240-304	GAMMA SHIELD CROSS PLATE	1/4 THK X 14 5/8 X 24
*	41	16	SA240-304	GAMMA SHIELD CROSS PLATE	1/4 THK X 3.09 X 24
*	42	--	---	DELETED	---
*	43	8	SA240-304	GAMMA SHIELD CROSS PLATE	1/4 THK X 5.09 X 17 1/4
*	44	2	316 SS	COMPRESSION FITTING	1/8" X 1/4 NPT MALE PASS THRU COMPRESSION FITTING (OPTIONAL)
*	45	2	CAST IRON	PROTECTION HEAD	1/2 NPT X 1/2 NPT (OPTIONAL)
*	46	2	304 SS	BUSHING	1/4 X 1/2 NPT (OPTIONAL)
*	47	2	304 SS	COUPLING	1/2 NPT COUPLING W/ MOUNTING STUD 1/2 DIA X 3" LG. (OPTIONAL)
*	48	2	304 SS	HEX NIPPLE	1/2 X 1/2 NPT HEX NIPPLE (OPTIONAL)
*	49	2	304 SS	CONNECTION	1/2 NPT CONDUIT CONNECTION (OPTIONAL)
*	50	8	C/S	SHIMS	1/2" X 1/2" BAR
	51	4	C/S	ROUND TUBING	1/8" WALL X 4" OD TUBING X 6" LG.
	52	4	SA516-70	SHEAR BAR	5/8" THK. x 2" x 57" LONG (APPROX)

@\DRAWINGS\5014\5014\HI-STORM\BM3066R0

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

BY: BY:

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-32 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1393

REV.
10

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1392 SHT 1 OF 4
(E.I.D. 2840)

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-32 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1393

REV.
10

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1392 SHT 2 OF 4
(E.I.D. 2841)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-32 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1393

REV.
10

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1392 SHT 3 OF 4
(E.I.D. 2842)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-32 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1393

REV.
9

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1392 SHT 4 OF 4
(E.I.D. 2843)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-32 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1392

REV.
11

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1393 SHT 1 OF 6
(E.I.D. 2844)

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-32 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1392

REV.
10

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1393 SHT 2 OF 6
(E.I.D. 2845)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION		
HOLTEC INTERNATIONAL	EQUIPMENT DESIGN ANALYSIS CONSULTING	
DESCRIPTION HI-STAR 100 MPC-32 CONSTRUCTION		
CLIENT N/A		
COMPANION DRAWINGS 1392		REV. 10
PROJECT No. 5014	DRAWING No. 1393 SHT 3 OF 6 (E.I.D. 2846)	
P.O. No. N/A		

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-32 CONSTRUCTION

CLIENT N/A

A

COMPANION DRAWINGS
1392

REV.
9

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1393 SHT 4 OF 6
(E.I.D. 2847)

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-32 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1392

REV.
8

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1393 SHT 5 OF 6
EID #3095

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-32 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1392

REV.
8

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1393 SHT 6 OF 6
(E.I.D. 2848)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1396

REV.
12

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1395 SHT 1 OF 4
(E.I.D. 2853)

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1396

REV.
10

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1395 SHT 2 OF 4

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1396, 2889 TO 2892

REV.
11

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1395 SHT 3 OF 4
(E.I.D. 2893)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

4

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1396

REV.
9

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1395 SHT 4 OF 4

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24 CONSTRUCTION

CLIENT N/A

A

COMPANION DRAWINGS
1395,2889 TO 2892

REV.
14

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1396 SHT 1 OF 6
(E.I.D. 2894)

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1395, 2889 TO 2892

REV.
12

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1396 SHT 2 OF 6
(E.I.D. 2881)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

BY: BY:

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1395, 2889 TO 2892

REV.
11

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1396 SHT 3 OF 6
(E.I.D. 2895)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1395, 2889 TO 2892

REV.
10

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1396 SHT 4 OF 6
(E.I.D. 2896)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

BY: BY:

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1395, 2889 TO 2892

REV.
9

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1396 SHT 5 OF 6
(E.I.D. 2897)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1395

REV.
8

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1396 SHT 6 OF 6

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-68 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1402

REV.
13

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1401 SHT 1 OF 4
(E.I.D. 2859)

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-68 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1402

REV.
9

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1401 SHT 2 OF 4

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

DESCRIPTION	BY:	BY:	ENG.	Q. A.

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-68 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1402

REV.
10

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1401 SHT 3 OF 4

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-68 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1402

REV.
9

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1401 SHT 4 OF 4

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-68 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1401

REV.
15

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1402 SHT 1 OF 6
(E.I.D. 3084)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-68 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1401

REV.
14

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1402 SHT 2 OF 6
(E.I.D. 2882)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

BY: BY:

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-68 CONSTRUCTION

CLIENT N/A

COMPANION CLIENT DRAWINGS
1401

REV.
13

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1402 SHT 3 OF 6
(E.I.D. 3085)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-68 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1401

REV.
11

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1402 SHT 4 OF 6
EID #3096

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

BY: BY:

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-68 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1401

REV.
10

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
1402 SHT 5 OF 6
EID #3097

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-68 CONSTRUCTION

CLIENT N/A

COMPANION DRAWINGS
1401

REV.
10

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
1402 SHT 6 OF 6
(E.I.D. 2860)

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

DESCRIPTION:
HI-STORM ASSEMBLY

CLIENT:
N/A

COMPANION DRAWINGS:

PROJECT No.: 5014	SCALE: .06 = 1	DRAWING No.: 1495 (B.I.B. 3079)	REV.: 9
P.O. No.: N/A			SHEET: 1 of 6

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
CROSS SECTION "Z" - "Z"
VIEW OF HI-STORM

CLIENT:
N/A

COMPANION DRAWINGS:
1561, B/M 1575

PROJECT No.: 5014
SCALE: .0625 = 1
DRAWING No.: 1495 (E.I.D. 2901)
REV.: 10
P.O. No.: N/A
SHEET: 2 of 6

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
SECTION "Y" - "Y"
OF HI-STORM

CLIENT:
N/A

COMPANION DRAWINGS:
1561, B/M 1575

PROJECT No.: 5014	SCALE: .09375 = 1	DRAWING No.: 1495 (E.I.D. 2902)	REV.: 8
P.O. No.:	N/A		SHEET: 3 of 6

A

1

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
SECTION "X" - "X"
OF HI-STORM

CLIENT:
N/A

COMPANION DRAWINGS:
1561, B/M 1575

PROJECT No.: 5014
SCALE: .09375 = 1
DRAWING No.: 1495 (E.I.D.2834)
REV.: 9
P.O. No.: N/A
SHEET: 4 of 6

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION: SECTION "W" - "W" OF HI-STORM			
CLIENT: N/A			
COMPANION DRAWINGS: 1561, B/M 1575			
PROJECT No.: 5014	SCALE: .0625 = 1	DRAWING No.: 1495 (E.I.D. 2907)	REV.: 10
P.O. No.: N/A			SHEET: 5 of 6

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
VIEW "A" - "A"
OF HI-STORM

CLIENT:
N/A

COMPANION DRAWINGS:
1495, B/M 1575

PROJECT No.: 5014
SCALE: .0625 = 1
DRAWING No.: 1561 (E.I.D. 2904)
REV.: 8
P.O. No.: N/A
SHEET: 1 of 5

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
DETAIL "B"
OF HI-STORM

CLIENT:
N/A

COMPANION DRAWINGS:
1495, B/M 1575

PROJECT No.: 5014
SCALE: .25 = 1
DRAWING No.: 1561 (E.I.D. 2905)
REV.: 8
P.O. No.: N/A
SHEET: 2 of 5

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
DETAIL OF AIR INLET
OF HI-STORM

CLIENT:
N/A

COMPANION DRAWINGS:
1495, B/M 1575

PROJECT No.: 5014	SCALE: NONE	DRAWING No.: 1561 (E.I.D. 3028)	REV.: 8
P.O. No.: N/A			SHEET: 3 of 5

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
DETAIL OF AIR OUTLET
OF HI-STORM

CLIENT:
N/A

COMPANION DRAWINGS:
1495, B/M 1575

PROJECT No.: 5014	SCALE: NONE	DRAWING No.: 1561 (E.I.D. 2906)	REV.: 8
P.O. No.: N/A			SHEET: 4 of 5

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION: 125TON HI-TRAC OUTLINE WITH POOL LID			
CLIENT: N/A			
COMPANION DRAWINGS: B/M 1880			
PROJECT No.: 5014	SCALE: .04 = 1	DRAWING No.: 1880 (E.I.D. 3004)	REV.: 8
P.O. No.: N/A			SHEET: 1 of 10

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
125TON HI-TRAC BODY
SECTIONED ELEVATION

CLIENT: N/A

COMPANION DRAWINGS: B/M 1880

PROJECT No.: 5014
SCALE: .10 = 1
P.O. No.: N/A
DRAWING No.: 1880 (E.I.D. 3005)
REV.: 9
SHEET: 2 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
125TON HI-TRAC BODY
SECTIONED ELEVATION "B"-"B"

CLIENT:

COMPANION DRAWINGS:
B/M 1880

PROJECT No.: 5014
SCALE: .08 = 1
DRAWING No.: 1880 (E.I.D. 3006)
REV.: 8
P.O. No.:
SHEET: 3 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
125TON TRANSFER CASK
DETAIL OF BOTTOM FLANGE

CLIENT:

COMPANION DRAWINGS:
B/M 1880

PROJECT No.: 5014	SCALE: .08 = 1	DRAWING No.: 1880 (E.I.D. 3007)	REV.: 9
P.O. No.:			SHEET: 4 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
125TON TRANSFER CASK
DETAIL OF POOL LID

CLIENT:

COMPANION DRAWINGS:
B/M 1880

PROJECT No.: 5014
SCALE: .08 = 1
DRAWING No.: 1880
(E.I.D. 3008)
REV.: 9
P.O. No.:
SHEET: 5 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
125TON TRANSFER CASK
DETAIL OF TOP FLANGE

CLIENT:

COMPANION DRAWINGS:
B/M 1880

PROJECT No.: 5014	SCALE: .10 = 1	DRAWING No.: 1880 (E.I.B. 3009)	REV.: 9
P.O. No.:			SHEET: 6 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
125TON TRANSFER CASK
DETAIL OF TOP LID

CLIENT:

COMPANION DRAWINGS:
B/M 1880

PROJECT No.: 5014
SCALE: .125 = 1
DRAWING No.: 1880
(E.I.D 3010)
REV.: 8
P.O. No.:
SHEET: 7 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL
EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
125TONTRANSFER CASK
VIEW "Y"-"Y"

CLIENT:
COMPANION DRAWINGS:

B/M 1880

PROJECT No.: 5014
SCALE: .1875 = 1
DRAWING No.: 1880 (E.I.B. 3091)
REV.: 8
P.O. No.:
SHEET: 8 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
125TON TRANSFER CASK LIFTING
TRUNNION AND LOCKING PAD

CLIENT:

COMPANION DRAWINGS:
B/M 1880

PROJECT No.: 5014
SCALE: NONE
P.O. No.:
DRAWING No.: 1880
(E.I.D. 3011)
REV.: 6
SHEET: 9 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
125TON TRANSFER CASK
VIEW "Z"-"Z"

CLIENT:

COMPANION DRAWINGS:
B/M 1880

PROJECT No.: 5014	SCALE: .20 = 1	DRAWING No.: 1880 (E.I.D.3012)	REV.: 8
P.O. No.:			SHEET: 10 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
125TON HI-TRAC TRANSFER LID
HOUSING DETAIL

CLIENT:
N/A

COMPANION DRAWINGS:
B/M 1884

PROJECT No.: 5014
SCALE: .0625 = 1
DRAWING No.: 1928 (E.I.D. 2999)
REV.: 10
P.O. No.: N/A
SHEET: 1 of 2

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
125TON HI-TRAC TRANSFER LID
DOOR DETAIL

CLIENT:
N/A

COMPANION DRAWINGS:
B/M 1884

PROJECT No.: 5014	SCALE: .0625 = 1	DRAWING No.: 1928 (E.I.D. 3000)	REV.: 9
P.O. No.: N/A			SHEET: 2 of 2

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
100 TON HI-TRAC OUTLINE
WITH POOL LID

CLIENT:
N/A

COMPANION DRAWINGS:
BM 2145

PROJECT No.: 5014
SCALE: .04 = 1
DRAWING No.: 2145 (E.I.B. 3051)
REV.: 7
P.O. No.: N/A
SHEET: 1 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
100 TON HI-TRAC BODY
SECTIONED ELEVATION

CLIENT:
N/A

COMPANION DRAWINGS:
BM 2145

PROJECT No.: 5014
SCALE: 10 = 1
DRAWING No.: 2145 (E.I.D. 3052)
REV.: 7
P.O. No.: N/A
SHEET: 2 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
100 TON HI-TRAC BODY
SECTIONED ELEVATION 'B-B'

CLIENT:
N/A

COMPANION DRAWINGS:
BM 2145

PROJECT No.: 5014	SCALE: .08 = 1	DRAWING No.: 2145 (E.I.D.3053)	REV.: 7
P.O. No.: N/A			SHEET: 3 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
100 TON HI-TRAC
DETAIL OF BOTTOM FLANGE

CLIENT:
N/A

COMPANION DRAWINGS:
BM 2145

PROJECT No.: 5014
SCALE: .08 = 1
DRAWING No.: 2145 (E.I.B. 3054)
REV.: 6
P.O. No.: N/A
SHEET: 4 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
100 TON HI-TRAC
DETAIL OF POOL LID

CLIENT:
N/A

COMPANION DRAWINGS:
BM 2145

PROJECT No.: 5014
SCALE: .08 = 1
DRAWING No.: 2145 (E.I.D.3055)
REV.: 5
P.O. No.: N/A
SHEET: 5 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
100 TON HI-TRAC
DETAIL OF TOP FLANGE

CLIENT: N/A

COMPANION DRAWINGS: BM 2145

PROJECT No.: 5014
SCALE: .10 = 1
DRAWING No.: 2145 (E.I.D. 3056)
REV.: 7
P.O. No.: N/A
SHEET: 6 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
100 TON HI-TRAC
DETAIL OF TOP LID

CLIENT: N/A

COMPANION DRAWINGS: BM 2145

PROJECT No.: 5014
SCALE: .125 = 1
DRAWING No.: 2145 (E.I.D. 3092)
REV.: 7
P.O. No.: N/A
SHEET: 7 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
100 TON HI-TRAC
VIEW Y-Y

CLIENT:
COMPANION DRAWINGS: N/A

COMPANION DRAWINGS:
BM 2145

PROJECT No.: 5014
SCALE: .1875 = 1
DRAWING No.: 2145
E.I.B. 3093
REV.: 7
P.O. No.: N/A
SHEET: 8 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
100 TON HI-TRAC LIFTING
TRUNNION AND LOCKING PAD

CLIENT:
N/A

COMPANION DRAWINGS:
BM 2145

PROJECT No.: 5014	SCALE: NONE	DRAWING No.: 2145 (E.I.D. 3057)	REV.: 4
P.O. No.: N/A			SHEET: 9 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC INTERNATIONAL

EQUIPMENT DESIGN

ANALYSIS

CONSULTING

DESCRIPTION:

100 TON HI-TRAC
VIEW Z-Z

CLIENT:
N/A

COMPANION DRAWINGS:
BM 2145

PROJECT No.: 5014
SCALE: .20 = 1
DRAWING No.: 2145 (E.I.D. 3058))
REV.: 6
P.O. No.: N/A
SHEET: 10 of 10

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
100 TON HI-TRAC TRANSFER
LID HOUSING DETAIL

CLIENT:
N/A

COMPANION DRAWINGS:
BM 2152

PROJECT No.: 5014
SCALE: .0625 = 1
DRAWING No.: 2152 (E.I.D. 3059)
REV.: 8
P.O. No.: N/A
SHEET: 1 of 2

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
100 TON HI-TRAC TRANSFER
LID DOOR DETAIL

CLIENT:
N/A

COMPANION DRAWINGS:
BM 2152

PROJECT No.: 5014	SCALE: .0625 = 1	DRAWING No.: 2152 (E.I.B. 3060)	REV.: 7
P.O. No.:	N/A		SHEET: 2 of 2

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

MAR. 27-2000	0	FOR APPROVAL	S.GEE 3-27-2000	CB 4/12/00	4/13/00	4/13/00
DATE	REV.	DESCRIPTION	PREP. BY:	CHECKED BY:	P. M.	Q. A.

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24E CONSTRUCTION (1)

CLIENT N/A

COMPANION DRAWINGS
2890 TO 2892, 1395 SHT 3, 1396 SHT 1 TO SHT 5

REV.
0

PROJECT No. 5014
P.O. No. N/A

DRAWING No.
2889

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

MAR. 27-2000	0	ISSUED FOR APPROVAL	S.GEE 3-27-00	4/12/00	4/12/00	4/13/00
DATE	REV.	DESCRIPTION	PREP. BY:	CHECKED BY:	P. M.	Q. A.

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION

HI-STAR 100 MPC-24E CONSTRUCTION (2)

CLIENT N/A

COMPANION DRAWINGS
2889, 2891, 2892, 1395 SHT 3, 1396 SHT 1 TO SHT 5

REV.
0

PROJECT No. 5014

P.O. No. N/A

DRAWING No.
2890

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24E CONSTRUCTION (3)

CLIENT N/A

COMPANION DRAWINGS
2889, 2890, 2892, 1395 SHT 3, 1396 SHT 1 TO SHT 5

REV. 0

PROJECT No. 5014

P.O. No. N/A

DRAWING No. 2891

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

MAR. 27-2000	0	ISSUED FOR APPROVAL	S.GEE 3-27-2000	C.S. 4/12/00	[illegible]	4/13/00
DATE	REV.	DESCRIPTION	PREP. BY:	CHECKED BY:	P.M.	Q. A.

REVISION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION
HI-STAR 100 MPC-24E CONSTRUCTION (4)

CLIENT N/A

COMPANION DRAWINGS
2889 TO 2891, 1395 SHT 3, 1396 SHT 1 TO SHT 5

REV. 0

PROJECT No. 5014

P.O. No. N/A

DRAWING No. 2892

FIGURE WITHHELD AS SENSITIVE
UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION: HI-STORM 100S ASSEMBLY
CLIENT: N/A
COMPANION DRAWINGS: BM-3065, BM-3066, 3068-3077
PROJECT No.: 5014
SCALE: NTS
P.O. No.: N/A
DRAWING No.: 3067
REV.: 0
SHEET: 1

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
CROSS SECTION "Z" - "Z"
VIEW OF HI-STORM 100S

CLIENT:
N/A

COMPANION DRAWINGS:
BM3065,BM-3066, 3067, 3069-3077

PROJECT No.: 5014	SCALE: .0625 = 1	DRAWING No.: 3068	REV.: 0
P.O. No.: N/A			SHEET: 1

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
SECTION "Y" - "Y"
OF HI-STORM 100S

CLIENT:
N/A

COMPANION DRAWINGS:
BM-3065, BM-3066, 3067, 3068, 3070-3077

PROJECT No.:	SCALE:	DRAWING No.:	REV.:
5014	.09375 = 1	3069	0
P.O. No.: N/A			SHEET: 1

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
SECTION "X" - "X"
OF HI-STORM 100S

CLIENT:
N/A

COMPANION DRAWINGS:
BM3065, BM3066, 3067-3069, 3071-3077

PROJECT No.: 5014
SCALE: .09375 = 1
DRAWING No.: 3070
REV.: 0
P.O. No.: N/A
SHEET: 1

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
SECTION "W" - "W"
OF HI-STORM 100S

CLIENT:
N/A

COMPANION DRAWINGS:
BM-3065, BM3066, 3067-3970, 3072-3077

PROJECT No.: 5014	SCALE: .0625 = 1	DRAWING No.: 3071	REV.: 0
P.O. No.: N/A			SHEET: 1

A

1

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
VIEW "A" - "A"
OF HI-STORM 100S

CLIENT:
N/A

COMPANION DRAWINGS:
BM3065, BM3066, 3067-3071, 3073-3077

PROJECT No.: 5014
SCALE: .0625 = 1
DRAWING No.: 3072
REV.: 0
P.O. No.: N/A
SHEET: 1

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
SECTION B- B OF LID SHIELD
OF HI-STORM 100S

CLIENT: N/A

COMPANION DRAWINGS: 3065 - 3077

PROJECT No.: 5014
SCALE: .0625=1
DRAWING No.: 3073
REV.: 0
P.O. No.: N/A
SHEET: 1

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL
EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
DETAIL "B"
OF HI-STORM 100S

CLIENT:
N/A

COMPANION DRAWINGS:
BM-3065, BM-3066, 3067-3073, 3075-3077

PROJECT No.: 5014	SCALE: .1875	DRAWING No.: 3074	REV.: 0
P.O. No.: N/A			SHEET: 1

A

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

HOLTEC
INTERNATIONAL

EQUIPMENT DESIGN
ANALYSIS
CONSULTING

DESCRIPTION:
DETAIL OF AIR INLET
OF HI-STORM 100S

CLIENT:
N/A

COMPANION DRAWINGS:
BM3065, BM3066, 3067-3074, 3076-3077

PROJECT No.: 5014	SCALE: NONE	DRAWING No.: 3075	REV.: 0
P.O. No.: N/A			SHEET: 1

A

The generic safety analyses contained in the HI-STORM 100 TSAR may be used as input and for guidance by the licensee in performing a 10CFR72.212 evaluation.

Within this report, all figures, tables and references cited are identified by the double decimal system m.n.i, where m is the chapter number, n is the section number, and i is the sequential number. Thus, for example, Figure 1.2.3 is the third figure in Section 1.2 of Chapter 1.

Revision of this document to Revision ~~8~~ *11* was made on a *page or* section level basis *depending upon the extensiveness of the changes.* Therefore, *from chapter to chapter,* if any change occurred in a section, *anywhere from a single page to* the whole section was updated to Revision ~~8~~ *11*. The sole exception is the figures ~~and drawings~~, which were updated to Revision ~~8~~ *11 on a figure-specific basis* only if a change was made specifically to that figure. ~~or drawing~~. *Drawings are controlled separately within the Holtec QA program and have individual revision numbers. Bills-of-Material (BOMs) are considered separate drawings and are not necessarily at the same revision level as the drawing(s) to which they apply. If a drawing was revised in support of the current TSAR revision, that drawing is included in Section 1.5 at its latest revision level.*

Table 1.0.1

TERMINOLOGY AND NOTATION

ALARA is an acronym for As Low As Reasonably Achievable.

Boral is a generic term to denote an aluminum-boron carbide cermet manufactured in accordance with U.S. Patent No. 4027377. The individual material supplier may use another trade name to refer to the same product.

Boral™ means Boral manufactured by AAR Advanced Structures.

BWR is an acronym for boiling water reactor.

C.G. is an acronym for center of gravity.

Confinement Boundary means the outline formed by the sealed, cylindrical enclosure of the Multi-Purpose Canister (MPC) shell welded to a solid baseplate, a lid welded around the top circumference of the shell wall, the port cover plates welded to the lid, and the closure ring welded to the lid and MPC shell providing the redundant sealing.

Confinement System means the Multi-Purpose Canister (MPC) which encloses and confines the spent nuclear fuel during storage.

Controlled Area means that area immediately surrounding an ISFSI for which the owner/user exercises authority over its use and within which operations are performed.

DBE means Design Basis Earthquake.

DCSS is an acronym for Dry Cask Storage System.

Damaged Fuel Assembly is a fuel assembly with known or suspected cladding defects, as determined by review of records, greater than pinhole leaks or hairline cracks, missing fuel rods that are not replaced with dummy fuel rods, or those that cannot be handled by normal means. ~~A damaged fuel assembly's inability to be handled by normal means may be due to mechanical damage and must not be due to fuel cladding damage.~~ *Fuel assemblies which cannot be handled by normal means due to fuel cladding damage are considered fuel debris.*

Table 1.0.1 (continued)

TERMINOLOGY AND NOTATION

Damaged Fuel Container ***(or Canister)*** means a specially designed enclosure for damaged fuel or fuel debris which permits gaseous and liquid media to escape while minimizing dispersal of gross particulates. The Damaged Fuel Container/*Canister* (DFC) features a lifting location which is suitable for remote handling of a loaded or unloaded DFC.

Design Life is the minimum duration for which the component is engineered to perform its intended function set forth in this TSAR, if operated and maintained in accordance with this TSAR.

Design Report is a document prepared, reviewed and QA validated in accordance with the provisions of 10CFR72 Subpart G. The Design Report shall demonstrate compliance with the requirements set forth in the Design Specification. A Design Report is mandatory for systems, structures, and components designated as Important to Safety.

Design Specification is a document prepared in accordance with the quality assurance requirements of 10CFR72 Subpart G to provide a complete set of design criteria and functional requirements for a system, structure, or component, designated as Important to Safety, intended to be used in the operation, implementation, or decommissioning of the HI-STORM 100 System.

Enclosure Vessel means the pressure vessel defined by the cylindrical shell, baseplate, port cover plates, lid, and closure ring which provides confinement for the helium gas contained within the MPC. The Enclosure Vessel (EV) and the fuel basket together constitute the multi-purpose canister.

Fracture Toughness is a property which is a measure of the ability of a material to limit crack propagation under a suddenly applied load.

Fuel Basket means a honeycombed structural weldment with square openings which can accept a fuel assembly of the type for which it is designed.

Fuel Debris refers to ruptured fuel rods, severed rods, ~~and~~ loose fuel pellets, *or fuel assemblies* with known or suspected defects which cannot be handled by normal means due to fuel cladding damage.

Table 1.0.1 (continued)

TERMINOLOGY AND NOTATION

HI-TRAC transfer cask or HI-TRAC means the transfer cask used to house the MPC during MPC fuel loading, unloading, drying, sealing, and on-site transfer operations to a HI-STORM storage overpack or HI-STAR storage/transportation overpack. The HI-TRAC shields the loaded MPC allowing loading operations to be performed while limiting radiation exposure to personnel. The HI-TRAC is equipped with a pair of lifting trunnions and pocket trunnions to lift and downend/upend the HI-TRAC with a loaded MPC. HI-TRAC is an acronym for **H**oltec **I**nternational **Tra**nsfer **C**ask. In this submittal there are two HI-TRAC transfer casks, the 125 ton HI-TRAC (HI-TRAC-125) and the 100 ton HI-TRAC (HI-TRAC-100). The 100 ton HI-TRAC is provided for use at sites with a maximum crane capacity of 100 tons. The term HI-TRAC is used as a generic term to refer to both the 125 ton and 100 ton HI-TRAC.

HI-STORM 100 overpack or storage overpack means the cask which receives and contains the sealed multi-purpose canisters containing spent nuclear fuel. It provides the gamma and neutron shielding, ventilation passages, missile protection, and protection against natural phenomena and accidents for the MPC. *The term "overpack" as used in this TSAR refers to both the standard and short design HI-STORM overpack (HI-STORM 100S), unless otherwise clarified.*

HI-STORM 100 System consists of a loaded MPC placed within the HI-STORM 100 overpack.

Holtite™ is a trade name denoting an approved neutron shield material for use in the HI-STORM 100 System. In this application, Holtite-A is the only approved neutron shield material.

Holtite™-A is a commercially available neutron shield material developed by Bisco, Inc., and currently sold under the trade name NS-4-FR. The neutron shield material is specified with a ~~minimum~~ *nominal* B_4C loading of 1 weight percent. An equivalent neutron shield material with equivalent neutron shielding properties and composition, but not sold under the trade name NS-4-FR, may be used.

Important to Safety (ITS) means a function or condition required to store spent nuclear fuel safely; to prevent damage to spent nuclear fuel during handling and storage, and to provide reasonable assurance that spent nuclear fuel can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public.

Independent Spent Fuel Storage Installation (ISFSI) means a facility designed, constructed, and licensed for the interim storage of spent nuclear fuel and other radioactive materials associated with spent fuel storage in accordance with 10CFR72.

Table 1.0.1 (continued)

TERMINOLOGY AND NOTATION

Planar-Average Initial Enrichment is the average of the distributed fuel rod initial enrichments within a given axial plane of the assembly lattice.

Preferential Fuel Loading *is a requirement in the CoC to be used during uniform fuel loading whenever fuel assemblies with significantly different post-irradiation cooling times (≥ 1 year) are to be loaded in the same MPC. Fuel assemblies with the longest post-irradiation cooling time are loaded into fuel storage locations at the periphery of the basket. Fuel assemblies with shorter post-irradiation cooling times are placed toward the center of the basket. Regionalized fuel loading meets the intent of preferential fuel loading. Preferential fuel loading is a requirement in addition to other restrictions in the CoC such as those for non-fuel hardware and damaged fuel containers.*

PWR is an acronym for pressurized water reactor.

Reactivity is used synonymously with effective neutron multiplication factor or k-effective.

Regionalized Fuel Loading *is a term used to describe an optional fuel loading strategy which limits higher heat emitting fuel assemblies to fuel storage locations in the center of the fuel basket and lower decay heat fuel assemblies in the peripheral fuel storage locations. Users choosing regionalized fuel loading must also consider other restrictions in the CoC such as those for non-fuel hardware and damaged fuel containers. Regionalized fuel loading meets the intent of preferential fuel loading.*

SAR is an acronym for Safety Analysis Report (10CFR71).

Service Life means the duration for which the component is reasonably expected to perform its intended function, if operated and maintained in accordance with the provisions of this TSAR. Service Life may be much longer than the Design Life because of the conservatism inherent in the codes, standards, and procedures used to design, fabricate, operate, and maintain the component.

Single Failure Proof means that the handling system is designed so that all directly loaded tension and compression members are engineered to satisfy the enhanced safety criteria of Paragraphs 5.1.6(1)(a) and (b) of NUREG-0612.

SNF is an acronym for spent nuclear fuel.

Table 1.0.1 (continued)

TERMINOLOGY AND NOTATION

SSC is an acronym for Structures, Systems and Components.

STP is Standard Temperature and Pressure conditions.

TSAR is an acronym for Topical Safety Analysis Report (10CFR72).

Uniform Fuel Loading *is a fuel loading strategy where any authorized fuel assembly may be stored in any fuel storage location, subject to other applicable restrictions in the CoC, such as preferential fuel loading, non-fuel hardware, and damaged fuel containers.*

ZPA is an acronym for zero period acceleration.

1.1 INTRODUCTION

HI-STORM 100 (acronym for Holtec International Storage and Transfer Operation Reinforced Module) is a spent nuclear fuel storage system designed to be in full compliance with the requirements of 10CFR72. The annex "100" is a model number designation which denotes a system weighing over 100 tons. The HI-STORM 100 System consists of a sealed metallic canister, herein abbreviated as the "MPC", contained within an overpack. Its design features are intended to simplify and reduce on-site SNF loading, handling, and monitoring operations, and to provide for radiological protection and maintenance of structural and thermal safety margins.

The HI-STORM 100S overpack is a variant of the HI-STORM 100 overpack and has its own set of design drawings in Section 1.5. The "S" suffix indicates a shorter overpack with a re-designed top lid. The HI-STORM 100S accepts the same MPCs and fuel types as the HI-STORM 100 and the basic structural, shielding, and thermal-hydraulic characteristics remain unchanged. Hereafter in this TSAR reference to HI-STORM 100 System or the HI-STORM 100 overpack is construed to apply to both the HI-STORM 100 and the HI-STORM 100S. Where appropriate, the text distinguishes between the two overpack designs.

The HI-STORM 100 System is designed to accommodate a wide variety of spent nuclear fuel assemblies in a single overpack design by utilizing different MPCs. The external dimensions of all MPCs are identical to allow the use of a single overpack. Each of the MPCs has different internals (baskets) to accommodate distinct fuel characteristics. Each MPC is identified by the maximum quantity of fuel assemblies it is capable of receiving. The MPC-24 *and MPC-24E* contains a maximum of 24 PWR fuel assemblies*; the MPC-32 contains a maximum of 32 PWR fuel assemblies;* and the MPC-68, *MPC-68F, and MPC-68FF* contains a maximum of 68 BWR fuel assemblies.

The HI-STORM 100 overpack is constructed from a combination of steel and concrete, both of which are materials with long, proven histories of usage in nuclear applications. HI-STORM 100 incorporates and combines many desirable features of previously-approved concrete and metal module designs. In essence, the HI-STORM 100 overpack is a hybrid of metal and concrete systems, with the design objective of emulating the best features and dispensing with the drawbacks of both. The HI-STORM overpack is best referred to as a METCON (metal/concrete composite) system.

Figure 1.1.1 shows the HI-STORM 100 with two of its major constituents, the MPC and the storage overpack, in a cut-away view. The MPC, shown partially withdrawn from the storage overpack, is an integrally welded pressure vessel designed to meet the stress limits of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB [1.1.1]. The MPC defines the confinement boundary for the stored spent nuclear fuel assemblies with respect to 10CFR72 requirements and attendant review considerations. The HI-STORM 100 storage overpack

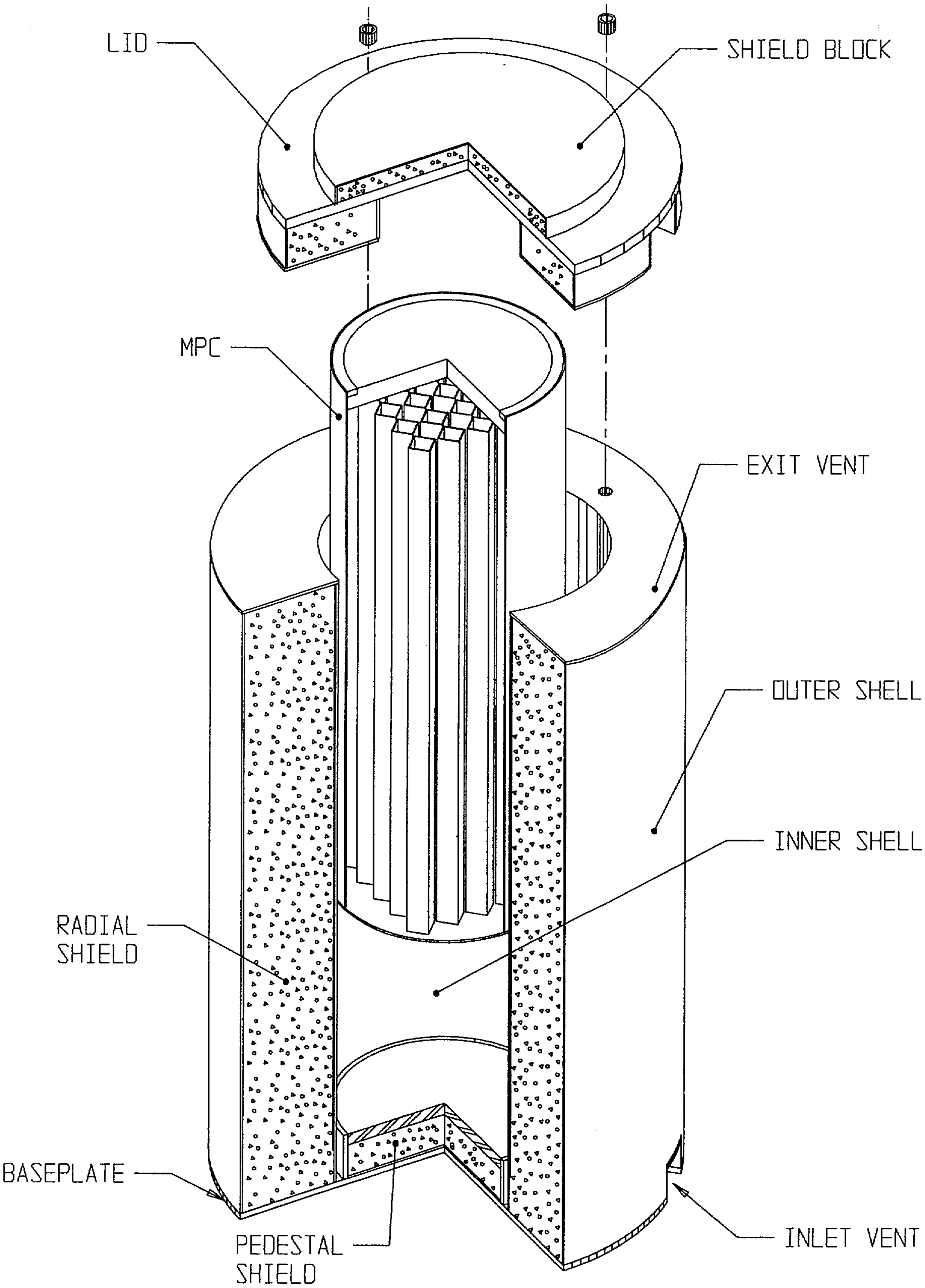

FIGURE 1.1.1A; HI-STORM 100S OVERPACK WITH MPC PARTIALLY INSERTED

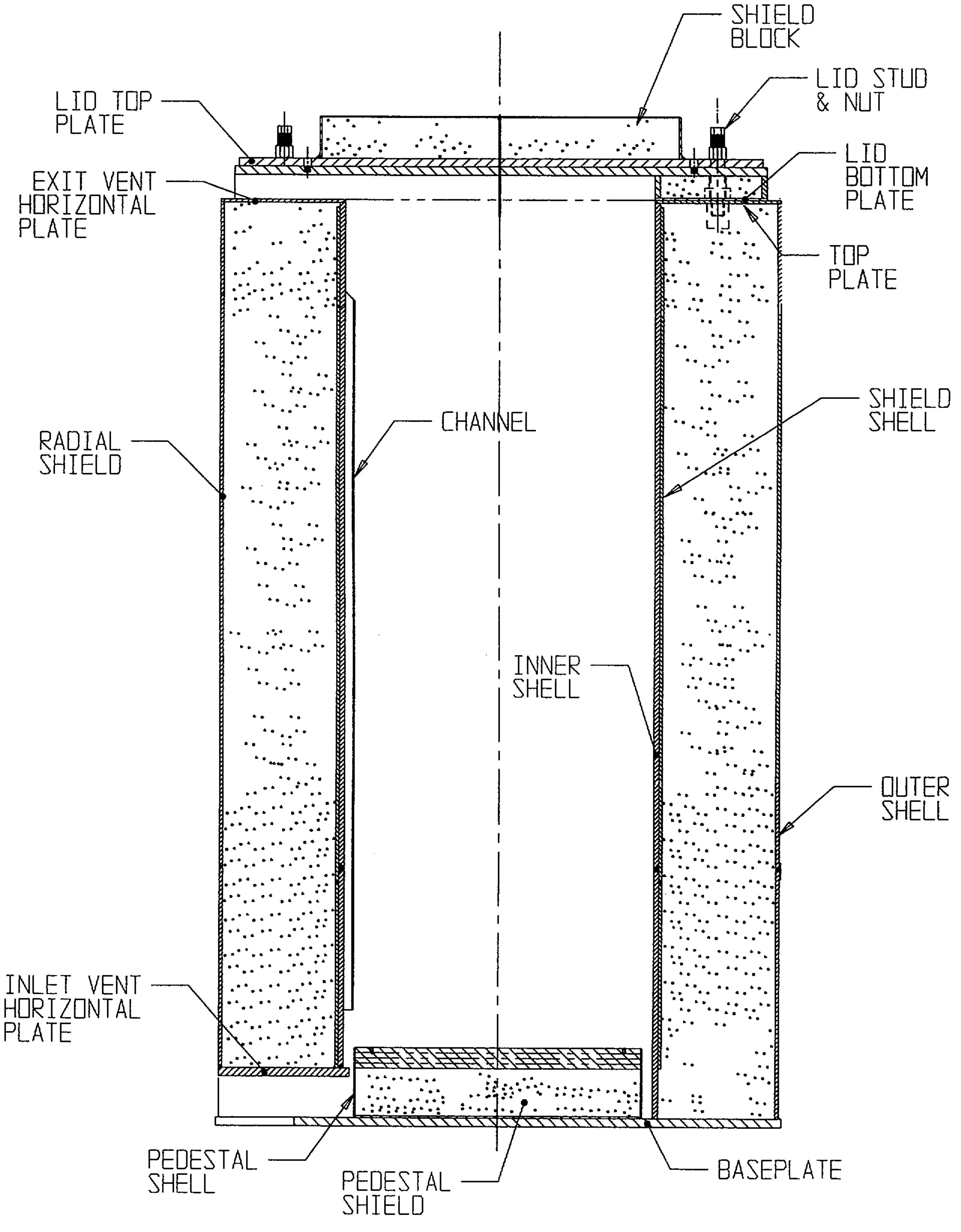

FIGURE 1.1.3A; HI-STORM 100S OVERPACK CROSS SECTIONAL ELEVATION VIEW

1.2 GENERAL DESCRIPTION OF HI-STORM 100 System

1.2.1 System Characteristics

The basic HI-STORM 100 System consists of interchangeable MPCs providing a confinement boundary for BWR or PWR spent nuclear fuel, a storage overpack providing a structural and radiological boundary for long-term storage of the MPC placed inside it, and a transfer cask providing a structural and radiological boundary for transfer of a loaded MPC from a nuclear plant spent fuel storage pool to the storage overpack. Figure 1.2.1 provides a cross sectional view of the HI-STORM 100 System with an MPC inserted into a storage overpack. Each of these components is described below, including information with respect to component fabrication techniques and designed safety features. All structures, systems, and components of the HI-STORM 100 System which are identified as Important to Safety are specified in Table 2.2.6. This discussion is supplemented with a full set of detailed design drawings in Section 1.5.

The HI-STORM 100 System is comprised of three discrete components:

i. multi-purpose canister (MPC)
ii. storage overpack (HI-STORM)
iii. transfer cask (HI-TRAC)

Necessary auxiliaries required to deploy the HI-STORM 100 System for storage are:

i. vacuum drying system
ii. helium (He) backfill system with leakage detector
iii. lifting and handling systems
iv welding equipment
v. transfer vehicles/trailer

All MPCs have identical exterior dimensions which render them interchangeable. The outer diameter of the MPC is 68-3/8 inches[†] and the overall length is 190-1/2 inches. See Section 1.5 for the detailed design drawings. Due to the differing storage contents of each MPC, the maximum loaded weight differs between MPCs. See Table 3.2.1 for each MPC weight. However, the maximum weight of a loaded MPC is approximately 44-1/2 tons. Tables 1.2.1 and 1.2.2 contain the key parameters for the MPCs.

A single HI-STORM overpack design is provided which is capable of storing each type of MPC. The overpack inner cavity is sized to accommodate the MPCs. The inner diameter of the overpack inner shell is 73-1/2 inches and the height of the cavity is 191-1/2 inches. The overpack inner shell is provided with channels distributed around the inner cavity to present an inside diameter of 69-1/2 inches. The channels are intended to offer a flexible medium to absorb some of the impact during a non-mechanistic tip-over, while still allowing the cooling air flow through

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[†] *Dimensions discussed in this section are considered nominal values.*

the ventilated overpack. The outer diameter of the overpack is 132-1/2 inches. ~~and~~ The overall height *of the HI-STORM 100 and the JI-STORM 100S* is 239-1/2 inches *and 232 inches, respectively.* See Section 1.5 for the detailed design drawings. The weight of the overpack without an MPC is approximately 135 tons. See Table 3.2.1 for the detailed weights.

Before proceeding to present detailed physical data on the HI-STORM 100 System, it is of contextual importance to summarize the design attributes which enhance the performance and safety of the system. Some of the principal features of the HI-STORM 100 System which enhance its effectiveness as an SNF storage device and a safe SNF confinement structure are:

- the honeycomb design of the MPC fuel basket;
- the effective distribution of neutron and gamma shielding materials within the system;
- the high heat dissipation capability;
- engineered features to promote convective heat transfer;
- the structural robustness of the steel-concrete-steel overpack construction.

The honeycomb design of the MPC fuel baskets renders the basket into a multi-flange plate weldment where all structural elements (i.e., box walls) are arrayed in two orthogonal sets of plates. Consequently, the walls of the cells are either completely co-planar (i.e., no offset) or orthogonal with each other. There is complete edge-to-edge continuity between the contiguous cells.

Among the many benefits of the honeycomb construction is the uniform distribution of the metal mass of the basket over the entire length of the basket. Physical reasoning suggests that a uniformly distributed mass provides a more effective shielding barrier than can be obtained from a nonuniform basket. In other words, the honeycomb basket is a most effective radiation attenuation device. The complete cell-to-cell connectivity inherent in the honeycomb basket structure provides an uninterrupted heat transmission path, making the MPC an effective heat rejection device.

The composite shell construction in the overpack, steel-concrete-steel, allows ease of fabrication and eliminates the need for the sole reliance on the strength of concrete.

A description of each of the components is provided in the following sections, along with information with respect to its fabrication and safety features. This discussion is supplemented with the full set of Design Drawings and Bills-of-Material in Section 1.5.

1.2.1.1 Multi-Purpose Canisters

The MPCs are welded cylindrical structures as shown in cross sectional views of Figures 1.2.2 ~~and 1.2.4~~ *through 1.2.4.A*. The outer diameter and cylindrical height of each MPC are fixed. Each spent fuel MPC is an assembly consisting of a honeycombed fuel basket, a baseplate, canister shell, a lid, and a closure ring, as depicted in the MPC cross section elevation view, Figure 1.2.5. The number of spent nuclear fuel storage locations in each of the MPCs depends on the fuel assembly characteristics.

There are ~~three~~ *six* MPC models, distinguished by the type and number of fuel assemblies authorized for loading. The MPC-24 is designed to store up to 24 intact PWR fuel assemblies. *The MPC-24E is designed to store up to 24 total PWR fuel assemblies including up to four (4) damaged PWR fuel assemblies.* The MPC-68 is designed to store up to 68 ~~intact~~ *total BWR fuel assemblies including up to 68* damaged *Dresden Unit 1 or Humboldt Bay* BWR fuel assemblies. *Damaged BWR fuel assemblies other than Dresden Unit 1 and Humboldt Bay are limited to 16 fuel storage locations in the MPC-68 with the remainder being intact BWR fuel assemblies, up to a total of 68.* The MPC-68F is designed to store up to 68 intact or damaged *Dresden Unit 1 and Humboldt Bay* BWR fuel assemblies. ~~and~~ *U*p to four *of the 68 fuel storage locations in the MPC-68F may be Dresden Unit 1 and Humboldt Bay* BWR fuel assemblies classified as fuel debris. *The MPC-68FF is designed to store up to 68 total BWR fuel assemblies including up to 16 damaged BWR fuel assemblies. Up to eight (8) of the 16 BWR damaged fuel assembly storage locations may be filled with BWR fuel classified as fuel debris. In addition, all fuel loading combinations permitted in the MPC-68F are also permitted in the MPC-68FF.* Design Drawings for all of the MPCs are provided in Section 1.5.

The MPC provides the confinement boundary for the stored fuel. Figure 1.2.6 provides an elevation view of the MPC confinement boundary. The confinement boundary is defined by the MPC baseplate, shell, lid, port covers, and closure ring. The confinement boundary is a ~~*seal-*~~*strength*-welded enclosure of all stainless steel construction.

The ~~construction features of the~~ PWR MPC-24 and ~~the BWR MPC-68 are similar. However, the PWR MPC-24 canister in Figure 1.2.4, which is designed for high-enriched PWR fuel,~~ *MPC-24E* differs in construction from the MPC-68 *(including the MPC-68F and MPC-68FF)* in one important aspect: the fuel storage cells are physically separated from one another by a "flux trap", for criticality control. *The PWR MPC-32 is designed similar to the MPC-68 (without flux traps) and its design includes credit for soluble boron in the MPC water during wet fuel loading and unloading operations for criticality control.* All MPC baskets are formed from an array of plates welded to each other, such that a honeycomb structure is created which resembles a multiflanged, closed-section beam in its structural characteristics.

The MPC fuel basket is positioned and supported within the MPC shell by a set of basket supports welded to the inside of the MPC shell. Between the periphery of the basket, the MPC shell, and the basket supports, heat conduction elements are installed. These heat conduction elements are fabricated from thin aluminum alloy 1100 in shapes *and a design* which ~~enable~~ *allow* a snug fit in the confined spaces and ease of installation. The heat conduction elements are installed along the full length of the MPC basket *except at the drain pipe location* to create a nonstructural thermal connection which facilitates heat transfer from the basket to shell. In their ~~installed~~ *operating* condition, the heat conduction elements contact the MPC shell and basket walls.

Lifting lugs attached to the inside surface of the MPC canister shell serve to permit placement of the empty MPC into the HI-TRAC transfer cask. The lifting lugs also serve to axially locate the MPC lid prior to welding. These internal lifting lugs are not used to handle a loaded MPC. Since the MPC lid is installed prior to any handling of a loaded MPC, there is no access to the lifting lugs once the MPC is loaded.

The top end of the MPC incorporates a redundant closure system. Figure 1.2.6 shows the MPC closure details. The MPC lid is a circular plate edge-welded to the MPC outer shell. This plate is equipped with vent and drain ports which are utilized to remove moisture and air from the MPC, and backfill the MPC with a specified ~~mass~~ *pressure* of inert gas (helium). The vent and drain ports are covered and seal welded before the closure ring is installed. The closure ring is a circular ring edge-welded to the MPC shell and lid. The MPC lid provides sufficient rigidity to allow the entire MPC loaded with SNF to be lifted by threaded holes in the MPC lid.

To maintain a constant exterior axial length between the *PWR MPC's* ~~MPC-24~~ and *the BWR MPC's* ~~MPC-68~~, the thickness of the *PWR MPCs'* ~~MPC-24~~ lid is ½ inch thinner than the MPC-68s' lid to accommodate the longest PWR fuel assembly which is approximately a ½ inch longer than the longest BWR fuel assembly. For fuel assemblies that are shorter than the design basis length, upper and lower fuel spacers (as appropriate) maintain the axial position of the fuel assembly within the MPC basket. The upper fuel spacers are threaded into the underside of the MPC lid as shown in Figure 1.2.5. The lower fuel spacers are placed in the bottom of each fuel basket cell. The upper and lower fuel spacers are designed to withstand normal, off-normal, and accident conditions of storage. An axial clearance of approximately 2 inches is provided to account for the irradiation and thermal growth of the fuel assemblies. The *suggested values for the* upper and lower fuel spacer lengths are listed in Tables 2.1.9 and 2.1.10 for each fuel assembly type.

The MPC is constructed entirely from stainless steel alloy materials (except for the neutron absorber and aluminum heat conduction elements). No carbon steel parts are permitted in the MPC. Concerns regarding interaction of coated carbon steel materials and various MPC operating environments [1.2.1] are not applicable to the MPC. All structural components in a MPC shall be made of Alloy X, a designation which warrants further explanation.

Alloy X is a material which is expected to be acceptable as a Mined Geological Disposal System (MGDS) waste package and which meets the thermophysical properties set forth in this document.

document.

At this time, there is considerable uncertainty with respect to the material of construction for an MPC which would be acceptable as a waste package for the MGDS. Candidate materials being considered for acceptability by the DOE include:

- Type 316
- Type 316LN
- Type 304
- Type 304LN

The DOE material selection process is primarily driven by corrosion resistance in the potential environment of the MGDS. As the decision regarding a suitable material to meet disposal requirements is not imminent, this application requests approval for use of any one of the four Alloy X materials.

For the MPC design and analysis, Alloy X (as defined in this application) may be one of the following materials (only a single alloy from the list of acceptable Alloy X materials may be used in the fabrication of a single MPC *basket or shell - the basket and shell may be of different alloys*).

- Type 316
- Type 316LN
- Type 304
- Type 304LN

The Alloy X approach is accomplished by qualifying the MPC for all mechanical, structural, neutronic, radiological, and thermal conditions using material thermophysical properties which are the least favorable for the entire group for the analysis in question. For example, when calculating the rate of heat rejection to the outside environment, the value of thermal conductivity used is the lowest for the candidate material group. Similarly, the stress analysis calculations use the lowest value of the ASME Code allowable stress intensity for the entire group. Stated differently, we have defined a material, which is referred to as Alloy X, whose thermophysical properties, from the MPC design perspective, are the least favorable of the candidate materials.

The evaluation of the Alloy X constituents to determine the least favorable properties is provided in Appendix 1.A.

Other alloy materials which are identified to be more suitable by the DOE for the MGDS in the future and which are also bounded by the Alloy X properties set forth in Appendix 1.A can be used in the MPC after an amendment to this TSAR is approved.

The Alloy X approach is conservative because no matter which material is ultimately utilized in the MPC construction, the Alloy X approach guarantees that the performance of the MPC will exceed the analytical predictions contained in this document.

1.2.1.2 Overpacks

1.2.1.2.1 HI-STORM 100 Overpack (Storage)

The HI-STORM 100 *and 100S* overpacks ~~is a~~ *are* rugged, heavy-walled cylindrical vessels. Figures 1.2.7, ~~and~~ 1.2.8, *and 1.2.8.A* provide cross sectional views of the HI-STORM 100 System, *including both of the overpack designs*. The main structural function of the storage overpack is provided by carbon steel, and the main shielding function is provided by plain concrete. The overpack plain concrete is enclosed by cylindrical steel shells, a thick steel baseplate, and a top plate. The overpack lid has appropriate concrete shielding ~~attached to its underside and top~~ to provide neutron and gamma attenuation in the vertical direction.

The storage overpack provides an internal cylindrical cavity of sufficient height and diameter for housing an MPC. The inner shell of the overpack has channels attached to its inner diameter. The channels provide guidance for MPC insertion and removal and a flexible medium to absorb impact loads during the non-mechanistic tip-over, while still allowing the cooling air flow to circulate through the overpack. Stainless steel shims are attached to channels to allow the proper inner diameter dimension to be obtained and to provide a guiding surface for MPC insertion and removal.

The storage overpack has air ducts to allow for passive natural convection cooling of the contained MPC. Four air inlets and four air outlets are located at the lower and upper extremities of the overpack, respectively. The air inlets and outlets are covered by a fine mesh screen to reduce the potential for blockage. Routine inspection of the screens (or, alternatively, temperature monitoring) ensures that blockage of the screens themselves will be detected and removed in a timely manner. Analysis, provided in this TSAR, evaluates the effects of partial and complete blockage of the air ducts.

The four air inlets and four air outlets are penetrations through the thick concrete shielding provided by the HI-STORM *100* overpack. *The outlet air ducts for the HI-STORM 100S overpack are integral to the lid.* Within the air inlets and outlets, an array of gamma shield cross plates are installed. These gamma shield cross plates are designed to scatter any particles traveling through the ducts. The result of scattering the particles in the ducts is a significant decrease in the local dose rates around the four air inlets and four air outlets. The configuration of the gamma shield cross plates is such that the increase in the resistance to flow in the air inlets and outlets is minimized.

Four threaded anchor blocks at the top of the overpack are provided for lifting. The anchor blocks are integrally welded to the radial plates which in turn are full-length welded to the overpack inner shell, outer shell, and baseplate (see Figure 1.2.7). The four anchor blocks are located on 90° centers. The overpack may also be lifted from the bottom using specially-designed lifting transport devices, including hydraulic jacks, air pads, and Hillman rollers. Slings or other suitable devices mate with lifting lugs which are inserted into threaded holes in the top surface of the overpack lid to allow lifting of the overpack lid. After the lid is bolted to the storage overpack main body, these lifting bolts shall be removed and replaced with flush plugs.

The plain concrete between the overpack inner and outer steel shells is specified to provide the necessary shielding properties and compressive strength. The concrete shall be in accordance with the requirements specified in Appendix 1.D.

The principal function of the concrete is to provide shielding against gamma and neutron radiation. However, in an implicit manner it helps enhance the performance of the HI-STORM overpack in other respects as well. For example, the massive bulk of concrete imparts a large thermal inertia to the HI-STORM overpack, allowing it to moderate the rise in temperature of the system under hypothetical conditions when all ventilation passages are assumed to be blocked. The case of a postulated fire accident at the ISFSI is another example where the high thermal inertia characteristics of the HI-STORM concrete control the temperature of the MPC. Although the annular concrete mass in the overpack shell is not a structural member, it does act as an elastic/plastic filler of the inter-shell space, such that, while its cracking and crushing under a tip-over accident is not of significant consequence, its deformation characteristics are germane to the analysis of the structural members.

Density and compressive strength are the key parameters which delineate the performance of concrete in the HI-STORM System. The density of concrete used in the inter-shell annulus, pedestal, and HI-STORM lid has been set as defined in Appendix 1.D. For evaluating the

physical properties of concrete for completing the analytical models, conservative formulations of Reference [1.2.6] are used.

To ensure the stability of the concrete at temperature, the concrete composition has been specified in accordance with NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems" [1.2.10]. Thermal analyses, presented in Chapter 4, show that the temperatures during normal storage conditions do not threaten the physical integrity of the HI-STORM overpack concrete.

There are two HI-STORM overpack designs which differ only in height, top lid design, and pedestal height. The HI-STORM 100 overpack is approximately 240 inches high from the bottom of the baseplate to the top of the lid bolts. The HI-STORM 100S design was developed to accommodate users who plan to perform the inter-cask MPC transfer between the HI-TRAC transfer cask and the HI-STORM overpack inside the Part 50 facility. The HI-STORM 100S is approximately 232 inches high from the baseplate to the top of the lid bolts in its final storage configuration. However, the HI-STORM 100S design includes a temporary top closure plate and *bolts as ancillary equipment for use in moving the loaded overpack out of the Part 50 facility through existing, lower clearance doorways. In this temporary configuration the HI-STORM 100S overpack is approximately 215 inches high. Once outside, the permanent HI-STORM 100S overpack lid is installed using the permanent bolts to provide the final storage configuration. Users who require additional clearance based on their plant-specific configuration may move the loaded HI-STORM 100S overpack into or out of the Part 50 facility with neither the temporary nor the permanent lid installed. When moving the overpack to the ISFSI, the permanent lid should be installed as soon as practicable after the loaded overpack leaves the Part 50 facility.*

1.2.1.2.2 HI-TRAC (Transfer Cask)

Like the storage overpack, the HI-TRAC transfer cask is a rugged, heavy-walled cylindrical vessel. The main structural function of the transfer cask is provided by carbon steel, and the main neutron and gamma shielding functions are provided by water and lead, respectively. The transfer cask is a steel, lead, steel layered cylinder with a water jacket attached to the exterior. Figure 1.2.9 provides a typical cross section of a HI-TRAC with the pool lid installed.

The transfer cask provides an internal cylindrical cavity of sufficient size for housing an MPC. The top lid has additional neutron shielding to provide neutron attenuation in the vertical direction (from SNF in the MPC below). The MPC access hole through the HI-TRAC top lid is provided to allow the lowering/raising of the MPC between the HI-TRAC transfer cask, and the HI-STORM or HI-STAR overpacks. The HI-TRAC is provided with two bottom lids, each used separately. The pool lid is bolted to the bottom flange of the HI-TRAC and is utilized during MPC fuel loading and sealing operations. In addition to providing shielding in the axial direction, the pool lid incorporates a seal which is designed to hold clean demineralized water in the HI-TRAC inner cavity, thereby preventing contamination of the exterior of the MPC by the contaminated fuel pool water. After the MPC has been drained, dried, and sealed, the pool lid is removed and the HI-TRAC transfer lid is attached. The transfer lid incorporates two sliding doors which allow the opening of the HI-TRAC bottom for the MPC to be raised/lowered. Figure 1.2.10 provides a cross section of the HI-TRAC with the transfer lid installed.

Trunnions are provided for lifting and rotating the transfer cask body between vertical and horizontal positions. The lifting trunnions are located just below the top flange and the pocket trunnions are located above the bottom flange. The two lifting trunnions are provided to lift and vertically handle the HI-TRAC, and the pocket trunnions provide a pivot point for the rotation of the HI-TRAC for downending or upending.

Two HI-TRAC transfer casks of different weights are provided to house the MPCs. The 125 ton HI-TRAC weight does not exceed 125 tons during any loading or transfer operation. The 100 ton HI-TRAC weight does not exceed 100 tons during any loading or transfer operation. The internal cylindrical cavities of the two HI-TRACs are identical. However, the external dimensions are different. The 100 ton HI-TRAC has a reduced thickness of lead and water shielding and consequently, the external dimensions are different. The structural steel thickness is identical in the two HI-TRACs. This allows most structural analyses of the 125 ton HI-TRAC to bound the 100 ton HI-TRAC design. Additionally, as the two HI-TRACs are identical except for a reduced thickness of lead and water, the 125 ton HI-TRAC has a larger thermal resistance than the smaller and lighter 100 ton HI-TRAC. Therefore, for normal conditions the 125 ton HI-TRAC thermal analysis bounds that of the 100 ton HI-TRAC. Separate shielding analyses are performed for each HI-TRAC since the shielding thicknesses are different between the two.

1.2.1.3 Shielding Materials

The HI-STORM 100 System is provided with shielding to ensure the radiation and exposure requirements in 10CFR72.104 and 10CFR72.106 are met. This shielding is an important factor in minimizing the personnel doses from the gamma and neutron sources in the SNF in the MPC for ALARA considerations during loading, handling, transfer, and storage. The fuel basket structure of edge-welded composite boxes and Boral™ neutron poison panels attached to the fuel storage cell vertical surfaces provide the initial attenuation of gamma and neutron radiation emitted by the radioactive spent fuel. The MPC shell, baseplate, lid and closure ring provide additional thicknesses of steel to further reduce the gamma flux at the outer canister surfaces.

In the HI-STORM 100 storage overpack, the primary shielding in the radial direction is provided by concrete and steel. In addition, the storage overpack has a thick circular concrete slab attached to the underside of the lid, and a thick circular concrete pedestal upon which the MPC rests. These slabs provide gamma and neutron attenuation in the axial direction. The thick overpack lid and concrete shield ring atop the lid provide additional gamma attenuation in the upward direction, reducing both direct radiation and skyshine. Several steel plate and shell elements provide additional gamma shielding as needed in specific areas, as well as incremental improvements in the overall shielding effectiveness.

In the HI-TRAC transfer cask radial direction, gamma and neutron shielding consists of steel-lead-steel and water, respectively. In the axial direction, shielding is provided by the top lid, and the pool or transfer lid. In the HI-TRAC pool lid, layers of steel-lead-steel provide an additional measure of gamma shielding to supplement the gamma shielding at the bottom of the MPC. In the transfer lid, layers of steel-lead-steel provide gamma attenuation. For the 125 ton HI-TRAC transfer lid, the neutron shield material, Holtite-A, is also provided. The 125 ton HI-TRAC top lid is composed of steel-neutron shield-steel, with the neutron shield material being Holtite-A. The 100 ton HI-TRAC top lid is composed of steel only providing gamma attenuation.

1.2.1.3.1 Boral Neutron Absorber

Boral is a thermal neutron poison material composed of boron carbide and aluminum (aluminum powder and plate). Boron carbide is a compound having a high boron content in a physically stable and chemically inert form. The boron carbide contained in Boral is a fine granulated powder that conforms to ASTM C-750-80 nuclear grade Type III. The Boral cladding is made of alloy aluminum, a lightweight metal with high tensile strength which is protected from corrosion by a highly resistant oxide film. The two materials, boron carbide and aluminum, are chemically compatible and ideally suited for long-term use in the radiation, thermal, and chemical environment of a nuclear reactor, spent fuel pool, or dry cask.

The documented historical applications of Boral, in environments comparable to those in spent fuel pools and fuel storage casks, dates to the early 1950s (the U.S. Atomic Energy Commission's AE-6 Water-Boiler Reactor [1.2.2]). Technical data on the material was first printed in 1949, when the report "Boral: A New Thermal Neutron Shield" was published [1.2.3]. In 1956, the first edition of the Reactor Shielding Design Manual [1.2.4] was published and it contained a section on Boral and its properties.

In the research and test reactors built during the 1950s and 1960s, Boral was frequently the material of choice for control blades, thermal-column shutters, and other items requiring very good thermal-neutron absorption properties. It is in these reactors that Boral has seen its longest service in environments comparable to today's applications.

Boral found other uses in the 1960s, one of which was a neutron poison material in baskets used in the shipment of irradiated, enriched fuel rods from Canada's Chalk River laboratories to Savannah River. Use of Boral in shipping containers continues, with Boral serving as the poison in current British Nuclear Fuels Limited casks and the recently licensed Storable Transport Cask by Nuclear Assurance Corporation [1.2.5].

As indicated in Tables 1.2.3-1.2.5, Boral has been licensed by the NRC for use in numerous BWR and PWR spent fuel storage racks and has been extensively used in international nuclear installations.

Boral has been exclusively used in fuel storage applications in recent years. Its use in spent fuel pools as the neutron absorbing material can be attributed to its proven performance and several unique characteristics, such as:

- The content and placement of boron carbide provides a very high removal cross section for thermal neutrons.
- Boron carbide, in the form of fine particles, is homogeneously dispersed throughout the central layer of the Boral panels.
- The boron carbide and aluminum materials in Boral do not degrade as a result of long-term exposure to radiation.
- The neutron absorbing central layer of Boral is clad with permanently bonded surfaces of aluminum.

- Boral is stable, strong, durable, and corrosion resistant.

Boral absorbs thermal neutrons without physical change or degradation of any sort from the anticipated exposure to gamma radiation and heat. The material does not suffer loss of neutron attenuation capability when exposed to high levels of radiation dose.

Holtec International's QA Program ensures that Boral is manufactured under the control and surveillance of a Quality Assurance/Quality Control Program that conforms to the requirements of 10CFR72, Subpart G. Holtec International has procured over 200,000 panels of Boral from AAR Advanced Structures in over 30 projects. Boral has always been purchased with a minimum ^{10}B loading requirement. Coupons extracted from production runs were tested using the wet chemistry procedure. The actual ^{10}B loading, out of thousands of coupons tested, has never been found to fall below the design specification. The size of this coupon database is sufficient to provide reasonable assurance that all future Boral procurements will continue to yield Boral with full compliance with the stipulated minimum loading. Furthermore, the surveillance, coupon testing, and material tracking processes which have so effectively controlled the quality of Boral are expected to continue to yield Boral of similar quality in the future. Nevertheless, to add another layer of insurance, only 75% ^{10}B credit of the fixed neutron absorber is assumed in the criticality analysis in compliance with Chapter 6.0, IV, 4.c of NUREG-1536, Standard Review Plan for Dry Cask Storage Systems.

1.2.1.3.2 Neutron Shielding

The specification of the HI-STORM overpack and HI-TRAC transfer cask neutron shield material is predicated on functional performance criteria. These criteria are:

- Attenuation of neutron radiation to appropriate levels;
- Durability of the shielding material under normal conditions, in terms of thermal, chemical, mechanical, and radiation environments;
- Stability of the homogeneous nature of the shielding material matrix;
- Stability of the shielding material in mechanical or thermal accident conditions to the desired performance levels; and
- Predictability of the manufacturing process under adequate procedural control to yield an in-place neutron shield of desired function and uniformity.

Other aspects of a shielding material, such as ease of handling and prior nuclear industry use, are also considered, within the limitations of the main criteria. Final specification of a shield material is a result of optimizing the material properties with respect to the main criteria, along with the design of the shield system, to achieve the desired shielding results.

Neutron attenuation in the HI-STORM overpack is provided by the thick walls of concrete contained in the steel vessel, lid, and pedestal. Concrete is a shielding material with a long proven history in the nuclear industry. The concrete composition has been specified to ensure its continued integrity at the long term temperatures required for SNF storage.

The HI-TRAC transfer cask is equipped with a water jacket providing radial neutron shielding. Demineralized water will be utilized in the water jacket. To ensure operability for low temperature conditions, ethylene glycol (25% in solution) will be added to reduce the freezing point for low temperature operations (e.g., below 32°F) [1.2.7].

Neutron shielding in the 125 ton HI-TRAC transfer cask in the axial direction is provided by Holtite-A within the top lid and transfer lid. Holtite-A is a poured-in-place solid borated synthetic neutron-absorbing polymer commercially available under the trade name NS-4-FR (or equivalent) and will be specified with a ~~minimum~~ *nominal* B_4C loading of 1 weight percent for the HI-STORM 100 System. Appendix 1.B provides the Holtite-A material properties. Holtec has performed confirmatory qualification tests on Holtite-A under the company's QA program.

In the following, a brief summary of the performance characteristics and properties of Holtite-A is provided.

Density

The specific gravity of Holtite-A is 1.68 g/cm^3 as specified in Appendix 1.B. To conservatively bound any potential weight loss at the design temperature and any inability to reach the theoretical density, the density is reduced by 4% to 1.61 g/cm^3. The density used for the shielding analysis is conservatively assumed to be 1.61 g/cm^3 to underestimate the shielding capabilities of the neutron shield.

Hydrogen

The weight concentration of hydrogen is 6.0%. However, all shielding analyses conservatively assume 5.9% hydrogen by weight in the calculations.

Boron Carbide

Boron carbide dispersed within Holtite-A in finely dispersed powder form is present in 1% (~~minimum~~ *nominal*) weight concentration. Holtite-A may be specified with a B_4C content of up to 6.5 weight percent. For the HI-STORM 100 System, Holtite-A is specified with a ~~minimum~~ *nominal* B_4C weight percent of 1%.

Design Temperature

The design temperature of Holtite-A is set at 300°F. The maximum spatial temperature of Holtite-A under all normal operating conditions must be demonstrated to be below this design temperature.

Thermal Conductivity

Table 1.B.1 lists the thermal conductivity of Holtite-A specified by the manufacturer.

The Holtite-A neutron shielding material is stable below the design temperature for the long term and provides excellent shielding properties for neutrons. Technical papers provided in Appendix 1.B validate the neutron shield material's long-term stability within the design temperature and the material's ability to resist the effects of a fire accident. Holtite-A has been utilized in similar applications and has been licensed for use in a transportation cask under Docket No. 71-9235 and for storage in the HI-STAR 100 overpack under Docket No. 72-1008.

1.2.1.3.3 Gamma Shielding Material

For gamma shielding, the HI-STORM 100 storage overpack primarily relies on massive concrete sections contained in a robust steel vessel. A carbon steel plate, the shield shell, is located adjacent to the overpack inner shell to provide additional gamma shielding (Figure 1.2.7). Carbon steel supplements the concrete gamma shielding in most portions of the storage overpack, most notably the baseplate and the lid. To reduce the radiation streaming through the overpack air inlets and outlets, gamma shield cross plates are installed in the ducts (Figure 1.2.8) to scatter the radiation. This scattering acts to significantly reduce the local dose rates adjacent to the overpack air inlets and outlets.

In the HI-TRAC transfer cask, the primary gamma shielding is provided by lead. As in the storage overpack, carbon steel supplements the lead gamma shielding of the HI-TRAC transfer cask.

1.2.1.4 Lifting Devices

Lifting of the HI-STORM 100 System may be accomplished either by attachment at the top of the storage overpack ("top lift"), as would typically be done with a crane, or by attachment at the bottom ("bottom lift"), as would be effected by a number of lifting/handling devices.

For a top lift, the storage overpack is equipped with four threaded anchor blocks arranged circumferentially around the overpack. These anchor blocks are used for overpack lifting as well as securing the overpack lid to the overpack body. The anchor blocks are integrally welded to the overpack radial plates which in turn are full-length welded to the overpack inner shell, outer shell, and baseplate. Studs are threaded into the anchor blocks to secure the lid and provide for lifting. These four studs provide for direct attachment of lifting devices which, along with a specially-designed lift rig to ensure a vertical lift, allow lifting by a crane or similar equipment. The lift rig shall be designed to lift a fully-loaded storage overpack with margins of safety specified in ANSI N14.6 [1.2.9].

A bottom lift of the HI-STORM 100 storage overpack is effected by the insertion of four hydraulic jacks underneath the inlet vent horizontal plates (Figure 1.2.1). A slot in the overpack baseplate allows the hydraulic jacks to be placed underneath the inlet vent horizontal plate. The hydraulic jacks lift the loaded overpack to a sufficient height to allow air pads to be placed or removed from under the overpack baseplate.

The HI-TRAC transfer cask is equipped with two lifting trunnions and two pocket trunnions. The lifting trunnions are positioned just below the top forging. The two pocket trunnions are located above the bottom forging and attached to the outer shell. The pocket trunnions are designed to allow rotation of the HI-TRAC. All trunnions are built from a high strength alloy with proven corrosion and non-galling characteristics. The lifting trunnions are designed in accordance with NUREG-0612 and ANSI N14.6. The lifting trunnions are installed by threading into tapped holes just below the top forging. ~~The lifting trunnions feature a locking plate, which is placed onto the trunnion shaft and bolted to the HI-TRAC external surface to prevent the lifting trunnion from backing out.~~

The top of the MPC lid is equipped with four threaded holes that allow lifting of the loaded MPC. These holes allow the loaded MPC to be raised/lowered through the HI-TRAC transfer cask using lifting cleats. The threaded holes in the MPC lid are designed in accordance with NUREG-0612 and ANSI N14.6.

1.2.1.5 Design Life

The design life of the HI-STORM 100 System is 40 years. This is accomplished by using material of construction with a long proven history in the nuclear industry and specifying materials known to withstand their operating environments with little to no degradation. A maintenance program, as specified in Chapter 9, is also implemented to ensure the HI-STORM 100 System will exceed its design life of 40 years. The design considerations that assure the HI-STORM 100 System performs as designed throughout the service life include the following:

HI-STORM Overpack and HI-TRAC Transfer Cask

- Exposure to Environmental Effects
- Material Degradation
- Maintenance and Inspection Provisions

MPC

- Corrosion
- Structural Fatigue Effects
- Maintenance of Helium Atmosphere
- Allowable Fuel Cladding Temperatures
- Neutron Absorber Boron Depletion

The adequacy of the HI-STORM 100 System for its design life is discussed in Sections 3.4.11 and 3.4.12.

1.2.2 Operational Characteristics

1.2.2.1 Design Features

The HI-STORM 100 System incorporates some unique design improvements. These design innovations have been developed to facilitate the safe long term storage of SNF. Some of the design originality is discussed in Subsection 1.2.1 and below.

The free volume of the MPCs is inerted with 99.995% pure helium gas during the spent nuclear fuel loading operations. Table 1.2.2 specifies the helium fill ~~mass~~ *pressure* to be placed in the MPC internal cavity. ~~as a function of the free space. As the fill pressure is highly dependent on the MPC internal temperature, which increases because of the decay heat and the vacuum drying process, it is more accurate to measure the mass placed in the MPC internal cavity rather than pressure.~~

The HI-STORM overpack has been designed to synergistically combine the benefits of steel and concrete. The steel-concrete-steel construction of the HI-STORM overpack provides ease of fabrication, increased strength, and an optimal radiation shielding arrangement. The concrete is primarily provided for radiation shielding and the steel is primarily provided for structural functions.

The strength of concrete in tension and shear is conservatively neglected. Only the compressive strength of the concrete is accounted for in the analyses.

The criticality control features of the HI-STORM 100 are designed to maintain the neutron multiplication factor k-effective (including uncertainties and calculational bias) at less than 0.95 under all normal, off-normal, and accident conditions of storage as analyzed in Chapter 6. This level of conservatism and safety margins is maintained, while providing the highest storage capacity.

1.2.2.2 Sequence of Operations

Table 1.2.6 provides the basic sequence of operations necessary to defuel a spent fuel pool using the HI-STORM 100 System. The detailed sequence of steps for storage-related loading and handling operations is provided in Chapter 8 and is supported by the Design Drawings in Section 1.5. A summary of the *general actions needed for the* loading and unloading operations is provided below. Figures 1.2.16 and 1.2.17 provide a pictorial view of typical loading and unloading operations, respectively.

Loading Operations

At the start of loading operations, the HI-TRAC transfer cask is configured with the pool lid installed. The HI-TRAC water jacket is filled with demineralized water or a 25% ethylene glycol solution depending on the ambient temperature conditions. The lift yoke is used to position HI-TRAC in the designated preparation area or setdown area for HI-TRAC inspection and MPC insertion. The annulus is filled with plant demineralized water, and an inflatable annulus seal is installed. The inflatable seal prevents contact between spent fuel pool water and the MPC shell reducing the possibility of contaminating the outer surfaces of the MPC. The MPC is then filled with ~~spent fuel pool~~ water. *Based on the MPC model and fuel enrichment (as required by the CoC), this may be borated or unborated spent fuel pool water* or plant demineralized water. HI-TRAC and the MPC are lowered into the spent fuel pool for fuel loading using the lift yoke. Pre-selected assemblies are loaded into the MPC and a visual verification of the assembly identification is performed.

While still underwater, a thick shielding lid (the MPC lid) is installed. The lift yoke is remotely engaged to the HI-TRAC lifting trunnions and is used to lift the HI-TRAC close to the spent fuel pool surface. As an ALARA measure, dose rates are measured on the top of the HI-TRAC and MPC prior to removal from the pool to check for activated debris on the top surface. The MPC lift bolts (securing the MPC lid to the lift yoke) are removed. As HI-TRAC is removed from the spent fuel pool, the lift yoke and HI-TRAC are sprayed with demineralized water to help remove contamination.

HI-TRAC is removed from the pool and placed in the designated preparation area. The top surfaces of the MPC lid and the upper flange of HI-TRAC are decontaminated. The inflatable annulus seal is removed, and an annulus shield is installed. The annulus shield provides additional personnel shielding at the top of the annulus and also prevents small items from being dropped into the annulus. Dose rates are measured at the MPC lid and around the mid-height circumference of HI-TRAC to ensure that the dose rates are within expected values. The Automated Welding System baseplate shield *(if used)* is installed to reduce dose rates around the top of the cask. The MPC water level is lowered slightly and the MPC lid is seal-welded using the Automated Welding System (AWS) *or other approved welding process*. Liquid penetrant examinations are performed on the root and final passes. A *multi-layer liquid penetrant or* volumetric examination is also performed on the MPC lid-to-shell weld. The water level is raised to the top of the MPC and the weld is hydrostatically tested. Then a small volume of the water is displaced with helium gas. The helium gas is used for leakage testing. A helium leakage rate test is performed on the MPC lid confinement weld (lid-to-shell) to verify weld integrity and to ensure that ~~required~~ leakage rates are within acceptance criteria. ~~The water level is raised to the top of the MPC again and then the~~ *The* MPC water is displaced from the MPC by blowing pressurized helium or nitrogen gas into the vent port of the MPC, thus displacing the water through the drain line. ~~The volume of water displaced from the MPC is measured to determine the free volume inside the MPC. This information is used to determine the helium backfill requirements for the MPC.~~

The Vacuum Drying System (VDS) is connected to the MPC and is used to remove all liquid water from the MPC in a stepped evacuation process. The stepped evacuation process is used to preclude the formation of ice in the MPC and Vacuum Drying System lines. The internal pressure is reduced and held for a duration to ensure that all liquid water has evaporated.

Following this dryness test, the VDS is disconnected and the Helium Backfill System (HBS) is attached and the MPC is backfilled with a predetermined ~~amount~~ *pressure* of helium gas. The helium backfill ensures adequate heat transfer during storage, provides an inert atmosphere for long-term fuel integrity, and provides the means of future leakage rate testing of the MPC confinement boundary welds. Cover plates are installed and seal-welded over the MPC vent and drain ports with liquid penetrant examinations performed on the root and final passes. The cover plates are helium leakage tested to confirm that they meet the established leakage rate criteria.

The MPC closure ring is then placed on the MPC, aligned, tacked in place, and seal welded, providing redundant closure of the MPC lid and cover plates confinement closure welds. Tack welds are visually examined, and the root and final welds are inspected using the liquid penetrant examination technique to ensure weld integrity. The annulus shield is removed and the remaining water in the annulus is drained. The AWS Baseplate shield is removed. The MPC lid and accessible areas of the top of the MPC shell are smeared for removable contamination and HI-TRAC dose rates are measured. The HI-TRAC top lid is installed and the bolts are torqued. The MPC lift cleats are installed on the MPC lid. The MPC lift cleats are the primary lifting point of the MPC. Two cleats provide redundant support of the MPC when it is lifted or supported.

Two or four stays (depending on the site crane hook configuration) are installed between the MPC lift cleats and the lift yoke main pins. The stays secure the MPC within HI-TRAC while the pool lid is replaced with the transfer lid. The HI-TRAC is manipulated to replace the pool lid with the transfer lid. The MPC lift cleats and stays support the MPC during the transfer operations.

MPC transfer from the HI-TRAC transfer cask into the overpack may be performed inside or outside the fuel building. Similarly, HI-TRAC and HI-STORM may be transferred to the ISFSI in several different ways. The loaded HI-TRAC may be handled in the vertical or horizontal orientation. The loaded HI-STORM can only be handled vertically.

For MPC transfers inside the fuel building, the empty HI-STORM overpack is inspected and positioned in the truck bay with the lid removed and, *for the HI-STORM 100 overpack,* the vent duct shield inserts installed. The loaded HI-TRAC is placed using the fuel building crane on top of HI-STORM. Alignment pins help guide HI-TRAC during this operation.

After the HI-TRAC is positioned atop the HI-STORM, the MPC is raised slightly. The transfer lid door locking pins are removed and the doors are opened. The MPC is lowered into HI-STORM. Following verification that the MPC is fully lowered, slings are disconnected and lowered onto the MPC lid. *For the HI-STORM 100,* the doors are closed and the locking pins are installed. HI-TRAC is removed from on top of HI-STORM along with the vent shield inserts. *For the HI-STORM 100S, the HI-TRAC is lifted above the overpack to a height sufficient to allow closure of the transfer lid doors without interfering with the lift cleats. The HI-TRAC is then removed and placed in its designated storage location.* The MPC lift cleats and slings are removed from atop the MPC.

For the HI-STORM *100, the overpack* lid is installed, and the upper vent screens and gamma shield cross plates are installed. The HI-STORM lid studs *and nuts* are installed and torqued. *For the HI-STORM 100S, the temporary or permanent lid and the appropriate studs and nuts are installed and torqued. After the overpack has left the Part 50 facility, the permanent overpack lid is installed and the permanent studs and nuts are installed and torqued (if the temporary lid was used). Upper vent screens and gamma shield cross plates are installed. As plant-specific needs dictate, the loaded HI-STORM 100 or 100S overpack may be moved into or out of the Part 50 facility without the temporary or permanent lid installed. When moving the overpack to the ISFSI, the permanent lid should be installed as soon as practicable after the loaded overpack has left the Part 50 facility.*

For MPC transfers outside of the fuel building, the empty HI-STORM overpack is inspected and positioned in the cask transfer facility with the lid removed and, *for the HI-STORM 100,* the vent duct shield inserts installed. The loaded HI-TRAC is transported to the cask transfer facility in the vertical or horizontal orientation. A number of methods may be utilized as long as the handling limitations prescribed in the technical specifications are not exceeded.

To place the loaded HI-TRAC in a horizontal orientation, a transport frame or "cradle" is utilized. The cradle is equipped with rotation trunnions which engage the HI-TRAC pocket trunnions. While the loaded HI-TRAC is lifted by the lifting trunnions, the HI-TRAC is lowered onto the cradle rotation trunnions. Then, the crane lowers and the HI-TRAC pivots around the pocket trunnions and is placed in the horizontal position in the cradle.

If the loaded HI-TRAC is transferred to the cask transfer facility in the horizontal orientation, the HI-TRAC and cradle are placed on a transport vehicle. The transport vehicle may be an air pad, railcar, heavy-haul trailer, dolly, etc. If the loaded HI-TRAC is transferred to the cask transfer facility in the vertical orientation, the HI-TRAC may be lifted by the lifting trunnions or seated on the transport vehicle. During the transport of the loaded HI-TRAC, standard plant heavy load handling practices shall be applied including administrative controls for the travel path and tie-down mechanisms.

After the loaded HI-TRAC arrives at the cask transfer facility, the HI-TRAC is upended by a crane if the HI-TRAC is in a horizontal orientation. The loaded HI-TRAC is then placed, using the crane located in the transfer area, on top of HI-STORM. Alignment pins help guide HI-TRAC during this operation.

After the HI-TRAC is positioned atop the HI-STORM, the MPC is raised slightly. The transfer lid door locking pins are removed and the doors are opened. The MPC is lowered into HI-STORM. Following verification that the MPC is fully lowered, slings are disconnected and lowered onto the MPC lid. *For the HI-STORM 100,* the doors are closed and the locking pins are installed. HI-TRAC is removed from on top of HI-STORM along with the vent duct shield inserts. *For the HI-STORM 100S, the HI-TRAC is lifted above the overpack to a height sufficient to allow closure of the transfer lid doors without interfering with the lift cleats. The HI-TRAC is then removed and placed in its designated storage location.* The MPC lift cleats and slings are removed from atop the MPC. The HI-STORM lid is installed, and the upper vent screens and gamma shield cross plates are installed. The HI-STORM lid studs *and nuts* are installed and torqued.

After the HI-STORM has been loaded either within the fuel building or at a dedicated cask transfer facility, the HI-STORM is then moved to its designated position on the ISFSI pad. The HI-STORM overpack may be moved using a number of methods as long as the handling limitations listed in the technical specifications are not exceeded. The loaded HI-STORM must be handled in the vertical orientation. However, the loaded overpack may be lifted from the top through the lid studs or from the bottom by the inlet vents. After the loaded HI-STORM is lifted, it may be placed on a transport mechanism or continue to be lifted by the lid studs and transported to the storage location. The transport mechanism may be an air pad, crawler, railcar, heavy-haul trailer, dolly, etc. During the transport of the loaded HI-STORM, standard plant heavy load handling practices shall be applied including administrative controls for the travel path and tie-down mechanisms. Once in position at the storage pad, vent operability testing is performed to ensure that the system is functioning within its design parameters.

Unloading Operations

The HI-STORM 100 System unloading procedures describe the general actions necessary to prepare the MPC for unloading, cool the stored fuel assemblies in the MPC, flood the MPC cavity, remove the lid welds, unload the spent fuel assemblies, and recover HI-TRAC and empty the MPC. Special precautions are outlined to ensure personnel safety during the unloading operations, and to prevent the risk of MPC overpressurization and thermal shock to the stored spent fuel assemblies.

The MPC is recovered from HI-STORM either at the cask transfer facility or the fuel building using any of the methodologies described in Section 8.1. *If it hasn't already been removed prior to entering the Part 50 facility,* the HI-STORM lid is removed *and, for the HI-STORM 100,* the vent duct shield inserts are installed. The MPC lift cleats are attached to the MPC and the MPC lift slings are attached to the MPC lift cleats. *For the HI-STORM 100s, the transfer doors are opened to avoid interfering with the MPC lift cleats.* HI-TRAC is raised and positioned on top of HI-STORM. The MPC is raised into HI-TRAC. Once the MPC is raised into HI-TRAC, the HI-TRAC transfer lid doors are closed and the locking pins are installed. HI-TRAC is removed from on top of HI-STORM.

The HI-TRAC is brought into the fuel building and manipulated for bottom lid replacement. The transfer lid is replaced with the pool lid. The MPC lift cleats and stays support the MPC during the transfer operations.

HI-TRAC and its enclosed MPC are returned to the designated preparation area and the MPC stays, MPC lift cleats, and HI-TRAC top lid are removed. The annulus is filled with plant demineralized water. The annulus shield is installed *and pressurized* to protect the annulus from debris produced
from the lid removal process. Similarly, HI-TRAC top surfaces are covered with a protective fire-retarding blanket.

The MPC closure ring and vent and drain port cover plates are core drilled. Local ventilation is established around the MPC ports. The RVOAs are attached to the vent and drain port. The RVOAs allow access to the inner cavity of the MPC, while providing a hermetic seal. The MPC is cooled using a closed-loop heat exchanger to reduce the MPC internal temperature to allow water flooding. Following the fuel cool-down, the MPC is flooded with *borated or unborated* water *in accordance with the CoC.* The MPC lid-to-MPC shell weld is removed. Then, all weld removal equipment is removed with the MPC lid left in place.

~~The inflatable annulus seal is installed and pressurized~~. The MPC lid is rigged to the lift yoke and the lift yoke is engaged to HI-TRAC lifting trunnions. If weight limitations require, the neutron shield jacket is drained. HI-TRAC is placed in the spent fuel pool and the MPC lid is removed. All fuel assemblies are returned to the spent fuel storage racks and the MPC fuel cells are vacuumed to remove any assembly debris. HI-TRAC and MPC are returned to the designated preparation area where the MPC water is *removed* ~~pumped back into the spent fuel pool~~. The annulus water is drained and the MPC and HI-TRAC are decontaminated in preparation for re-utilization.

1.2.2.3 Identification of Subjects for Safety and Reliability Analysis

1.2.2.3.1 Criticality Prevention

Criticality is controlled by geometry and neutron absorbing materials in the fuel basket. The MPC-24 *and MPC-24E (with lower enriched fuel)* and MPC-68 do not rely on soluble boron credit during loading or the assurance that water cannot enter the MPC during storage to meet the stipulated criticality limits.

The MPC-68, *MPC-68FF, MPC-24E, and MPC-32* basket*s* *are* ~~is~~ equipped with Boral with a minimum ^{10}B areal density of 0.0372 g/cm^2. The MPC-24 basket is equipped with Boral with a minimum ^{10}B areal density of 0.0267 g/cm^2. Due to the lower reactivity of the fuel to be stored in the MPC-68F as specified by the ~~Technical Specifications in Chapter 12~~ *Appendix B to the CoC*, the MPC-68F is equipped with Boral with a minimum ^{10}B areal density of 0.01 g/cm^2.

The MPC-24 and MPC-24E (with higher enriched fuel) and the MPC-32 take credit for soluble boron in the MPC water for criticality prevention during wet loading and unloading operations. Boron credit is only necessary for these PWR MPCs during loading and unloading operations that take place under water. During storage, with the MPC cavity dry and sealed from the environment, criticality control measures beyond the fixed neutron poisons affixed to the storage cell walls are not necessary because of the low reactivity of the fuel in the dry, helium filled canister and the total assurance that no water can intrude into the canister during storage.

1.2.2.3.2 Chemical Safety

There are no chemical safety hazards associated with operations of the HI-STORM 100 dry storage system. A detailed evaluation is provided in Section 3.4.

1.2.2.3.3 Operation Shutdown Modes

The HI-STORM 100 System is totally passive and consequently, operation shutdown modes are unnecessary. Guidance is provided in Chapter 8, which outlines the HI-STORM 100 unloading procedures, and Chapter 11, which outlines the corrective course of action in the wake of postulated accidents.

1.2.2.3.4 Instrumentation

As stated earlier, the HI-STORM 100 confinement boundary is the MPC, which is seal welded and leak tested. The HI-STORM 100 is a completely passive system with appropriate margins of safety; therefore, it is not necessary to deploy any instrumentation to monitor the cask in the storage mode. At the option of the user, ~~a thermocouple~~ *temperature elements* may be utilized to monitor the air temperature of the HI-STORM overpack exit vent*s* in lieu of routinely inspecting the ducts for blockage. See Subsection 2.3.3.2 and the Technical Specifications in ~~Chapter 12~~ *Appendix A to the CoC* for additional details.

1.2.2.3.5 Maintenance Technique

Because of their passive nature, the HI-STORM 100 System requires minimal maintenance over its lifetime. No special maintenance program is required. Chapter 9 describes the acceptance criteria and maintenance program set forth for the HI-STORM 100.

1.2.3 Cask Contents

The HI-STORM 100 System is designed to house different types of MPCs. The MPCs are designed to store both BWR and PWR spent nuclear fuel assemblies. Tables 1.2.1 and 1.2.2 provide key design parameters for the MPCs. A description of acceptable fuel assemblies for storage in the MPCs is provided in Section 2.1 and ~~the Technical Specifications~~ *Approve Contents section of Appendix B to the CoC. This includes fuel assemblies classified as damaged fuel assemblies and fuel debris in accordance with the definitions of these terms in the CoC. A summary of the types of fuel authorized for storage in each MPC model is provided below. All fuel assemblies must meet the fuel specifications provided in Appendix B to the CoC. All fuel assemblies classified as damaged fuel or fuel debris must be stored in damage fuel containers.* The quantity of damaged fuel containers with fuel debris is limited to meet the off-site transportation requirements of 10CFR71, specifically, 10CFR71.63(b).

~~At this time, failed fuel assemblies discharged from Dresden Unit 1 and Humboldt Bay reactors have been evaluated and this application requests approval of these two types of damaged fuel assemblies and fuel debris as contents for storage in the MPC-68. Damaged fuel assemblies and fuel debris shall be placed in damaged fuel containers prior to loading into the MPC to facilitate handling and contain loose components. Any combination of damaged fuel assemblies in damaged fuel containers and intact fuel assemblies, up to a total of 68, may be stored in the standard MPC-68. The MPC-68 design to store fuel debris is almost identical to the MPC-68 design to store intact or damaged fuel, the sole difference being the former requires a lower minimum B^{10} areal density in the Boral. Therefore, an MPC-68 which is to store damaged fuel containers with fuel assemblies classified as fuel debris must be designated during fabrication to ensure the proper minimum B^{10} areal density criteria is applied. To distinguish an MPC-68 which is fabricated to store damaged fuel containers with fuel assemblies classified as fuel debris, the MPC shall be designated as an "MPC-68F".~~

~~Up to 4 damaged fuel containers with fuel assemblies classified as fuel debris and meeting the requirements in the Technical Specifications may be stored within an MPC-68F.~~

MPC-24

The MPC-24 is designed to accommodate up to twenty-four (24) PWR fuel assemblies classified as intact fuel assemblies, with or without non-fuel hardware.

MPC-24E

The MPC-24E is designed to accommodate up to twenty-four (24) PWR fuel assemblies, with or without non-fuel hardware. Up to four (4) fuel assemblies may be classified as damaged fuel assemblies, with the balance being classified as intact fuel asemblies. Damaged fuel assemblies must be stored in fuel storage locations 3, 6, 19, and/or 22 (see Figure 1.2.4A).

MPC-32

The MPC-32 is designed to accommodate up to thirty-two (32) PWR fuel assemblies classified as intact fuel assemblies, with or without non-fuel hardware.

MPC-68

The MPC-68 is designed to accommodate up to sixty-eight (68) BWR intact and/or damaged fuel assemblies, with or without channels. For the Dresden Unit 1 or Humboldt Bay plants, the number of damaged fuel assemblies may be up to a total of 68. For damaged fuel assemblies from plants other than Dresden Unit 1 and Humboldt Bay, the number of damaged fuel assemblies is limited to sixteen (16) and must be stored in fuel storage locations 1, 2, 3, 8, 9, 16, 25, 34, 35, 44, 53, 60, 61, 66, 67, and/or 68 (see Figure 1.2.2).

MPC-68F

The MPC-68F is designed to accommodate up to sixty-eight (68) Dresden Unit 1 or Humboldt Bay BWR fuel assemblies (with or without channels) made up of any combination of fuel assemblies classified as intact fuel assemblies, damaged fuel assemblies, and up to eight (8) fuel assemblies classified as fuel debris.

MPC-68FF

The MPC-68FF is designed to accommodate up to sixty-eight (68) BWR fuel assemblies with or without channels. Any number of these fuel assemblies may be Dresden Unit 1 or Humboldt Bay BWR fuel assemblies classified as intact fuel, damaged fuel, or fuel debris. For BWR fuel assemblies from plants other than Dresden Unit 1 and Humboldt Bay, the total number of fuel assemblies classified as damaged fuel assemblies or fuel debris is limited to sixteen (16), with up to eight (8) of the 16 fuel assemblies classified as fuel debris. These fuel assemblies must be stored in fuel storage locations 1, 2, 3, 8, 9, 16, 25, 34, 35, 44, 53, 60, 61, 66, 67, and/or 68 (see Figure 1.2.2). The balance of the fuel storage locations may be filled with intact BWR fuel assemblies, up to a total of 68.

Table 1.2.1

KEY SYSTEM DATA FOR HI-STORM 100 SYSTEM

ITEM	QUANTITY	NOTES
Types of MPCs included in this revision of the submittal	~~3~~ *6*	~~1~~ *3* for PWR ~~2~~ *3* for BWR
MPC storage capacity[†]:	MPC-24 *MPC-24E* *MPC-32*	Up to 24 intact zircaloy or stainless steel clad PWR fuel assemblies *with or without non-fuel hardware. Up to four damaged fuel assemblies may be stored in the MPC-24E* ~~Control components and non-fuel hardware are not authorized for loading.~~ *OR* *Up to 32 intact zircaloy or stainless steel clad PWR fuel assemblies*
	MPC-68	Any combination of *Dresden Unit 1 or Humboldt Bay* damaged fuel assemblies in damaged fuel containers and intact fuel assemblies, up to a total of 68 ~~in the MPC-68~~ . For damaged fuel other than Dresden Unit 1 and Humboldt Bay, the number of fuel assemblies is limited to 16, with the balance being intact fuel assemblies. OR

[†] *See Section 1.2.3 and Appendix Bb to the CoC for a complete description of cask contents and fuel specifications, respectively.*

Table 1.2.1 (continued)
KEY SYSTEM DATA FOR HI-STORM 100 SYSTEM

ITEM	QUANTITY	NOTES
MPC storage capacity:	MPC-68F *MPC-68FF*	Up to 4 damaged fuel containers with zircaloy clad *Dresden Unit 1 or Humboldt Bay* BWR fuel debris and the complement damaged zircaloy clad *Dresden Unit 1 or Humboldt Bay* BWR fuel assemblies in damaged fuel containers or intact *Dresden Unit 1 or Humboldt Bay* BWR intact fuel assemblies ~~within an MPC-68F~~. *OR* *As above for Dresden Unit 1 or Humboldt Bay fuel and up to 16 damaged fuel containers containing BWR damaged fuel and/or fuel debris with the complement intact fuel assemblies, up to a total of 68. The number of damaged fuel containers containing BWR fuel debris is limited to eight.*

Table 1.2.2
KEY PARAMETERS FOR HI-STORM 100 MULTI-PURPOSE CANISTERS

	PWR	BWR
Pre-disposal service life (years)	40	40
Design temperature, max./min. (°F)	725°[†]/-40°[††]	725°[†]/-40°[††]
Design internal pressure (psig)		
Normal conditions	100	100
Off-normal conditions	100	100
Accident Conditions	125	125
Total heat load, max. (kW)	~~20.88~~ *22.2* (MPC-24) *23.43 (MPC-24E)* *21.38 (MPC-32)*	21.4 (MPC-68, *MPC-68F, & MPC-68FF*)
Maximum permissible peak fuel cladding temperature:		
Normal (°F)	See Table 2.2.3	See Table 2.2.3
Short Term & Accident (°F)	1058°	1058°
MPC internal environment Helium fill (~~g-moles/l of free space~~ *psig*)	~~0.1212~~ *≤ 22.2* (MPC-24 & *MPC-24E*) *≤ 20.3 psig (MPC-32)*	~~0.1218~~ *≤ 28.5* (MPC-68, ~~&~~ MPC-68F, *& MPC-68FF*)
Maximum permissible multiplication factor (k_{eff}) including all uncertainties and biases	<0.95	<0.95
Boral ^{10}B Areal Density (g/cm^2)	0.0267 (MPC-24 & *MPC-24E*) *0.0372 (MPC-32)*	0.0372 (MPC-68 *& MPC-68FF*) 0.01 (MPC-68F)
End closure(s)	Welded	Welded
Fuel handling	Opening compatible with standard grapples	Opening compatible with standard grapples
Heat dissipation	Passive	Passive

[†] Maximum normal condition design temperatures for the MPC fuel basket. A complete listing of design temperatures for all components is provided in Table 2.2.3.

[††] Temperature based on off-normal minimum environmental temperatures specified in Section 2.2.2.2 and no fuel decay heat load.

Table 1.2.3

BORAL EXPERIENCE LIST
DOMESTIC PRESSURIZED WATER REACTORS

Plant	Utility
Donald C. Cook	American Electric Power
Indian Point 3	New York Power Authority
Maine Yankee	Maine Yankee Atomic Power
Salem 1,2	Public Service Electric and Gas
Sequoyah 1,2	Tennessee Valley Authority
Yankee Rowe	Yankee Atomic Power
Zion 1,2	Commonwealth Edison Company
Byron 1,2	Commonwealth Edison Company
Braidwood 1,2	Commonwealth Edison Company
Three Mile Island I	GPU Nuclear
Sequoyah (rerack)	Tennessee Valley Authority
D.C. Cook (rerack)	American Electric Power
Maine Yankee	Maine Yankee Atomic Power Company
Connecticut Yankee	Northeast Utilities Service Company
Salem Units 1 & 2 (rerack)	Public Service Electric & Gas Company

Table 1.2.4

BORAL EXPERIENCE LIST
DOMESTIC BOILING WATER REACTORS

Plant	Utility
Browns Ferry 1,2,3	Tennessee Valley Authority
Brunswick 1,2	Carolina Power & Light
Clinton	Illinois Power
Dresden 2,3	Commonwealth Edison Company
Duane Arnold Energy Center	Iowa Electric Light and Power
J.A. FitzPatrick	New York Power Authority
E.I. Hatch 1,2	Georgia Power Company
Hope Creek	Public Service Electric and Gas
Humboldt Bay	Pacific Gas and Electric Company
LaCrosse	Dairyland Power
Limerick 1,2	Philadelphia Electric Company
Monticello	Northern States Power
Peachbottom 2,3	Philadelphia Electric Company
Perry 1,2	Cleveland Electric Illuminating
Pilgrim	Boston Edison Company
Susquehanna 1,2	Pennsylvania Power & Light
Vermont Yankee	Vermont Yankee Atomic Power
Hope Creek	Public Service Electric and Gas Company
Shearon Harris Pool B	Carolina Power & Light Company
Duane Arnold	Iowa Electric Light and Power
Pilgrim	Boston Edison Company
LaSalle Unit 1	Commonwealth Edison Company
Millstone Point Unit One	Northeast Utilities Service Company

Table 1.2.5

BORAL EXPERIENCE LIST
FOREIGN PLANTS

INTERNATIONAL INSTALLATIONS USING BORAL	
COUNTRY	PLANT(S)
France	12 PWR Plants
South Africa	Koeberg 1,2
Switzerland	Beznau 1,2 Gosgen
Taiwan	Chin-Shan 1,2 Kuosheng 1,2
Mexico	Laguna Verde Units 1,2
Korea	Ulchin Units 1, 2
Brazil	Angra 1
United Kingdom	Sizewell B

Table 1.2.6

HI-STORM 100 OPERATIONS SEQUENCE

Site-specific handling and operations procedures will be prepared, reviewed, and approved by each owner/user.	
1	HI-TRAC and MPC lowered into the fuel pool without lids
2	Fuel assemblies transferred into the MPC fuel basket
3	MPC lid lowered onto the MPC
4	HI-TRAC/MPC assembly moved to the decon pit and MPC lid welded in place, volumetrically or multi-layer PTexamined, hydrostatically tested, and leak tested
5	MPC dewatered, vacuum dried, backfilled with helium, and the closure ring welded
6	HI-TRAC annulus drained and external surfaces decontaminated
7	MPC lifting cleats installed and MPC weight supported by rigging
8	HI-TRAC pool lid removed and transfer lid attached
9	MPC lowered and seated on HI-TRAC transfer lid
10	HI-TRAC/MPC assembly transferred to atop HI-STORM overpack
11	MPC weight supported by rigging and transfer lid doors opened
12	MPC lowered into HI-STORM overpack,~~HI-TRAC transfer lid doors closed,~~ and HI-TRAC removed from atop HI-STORM overpack
13	HI-STORM overpack lid installed and bolted in place
14	HI-STORM overpack placed in storage at the ISFSI pad

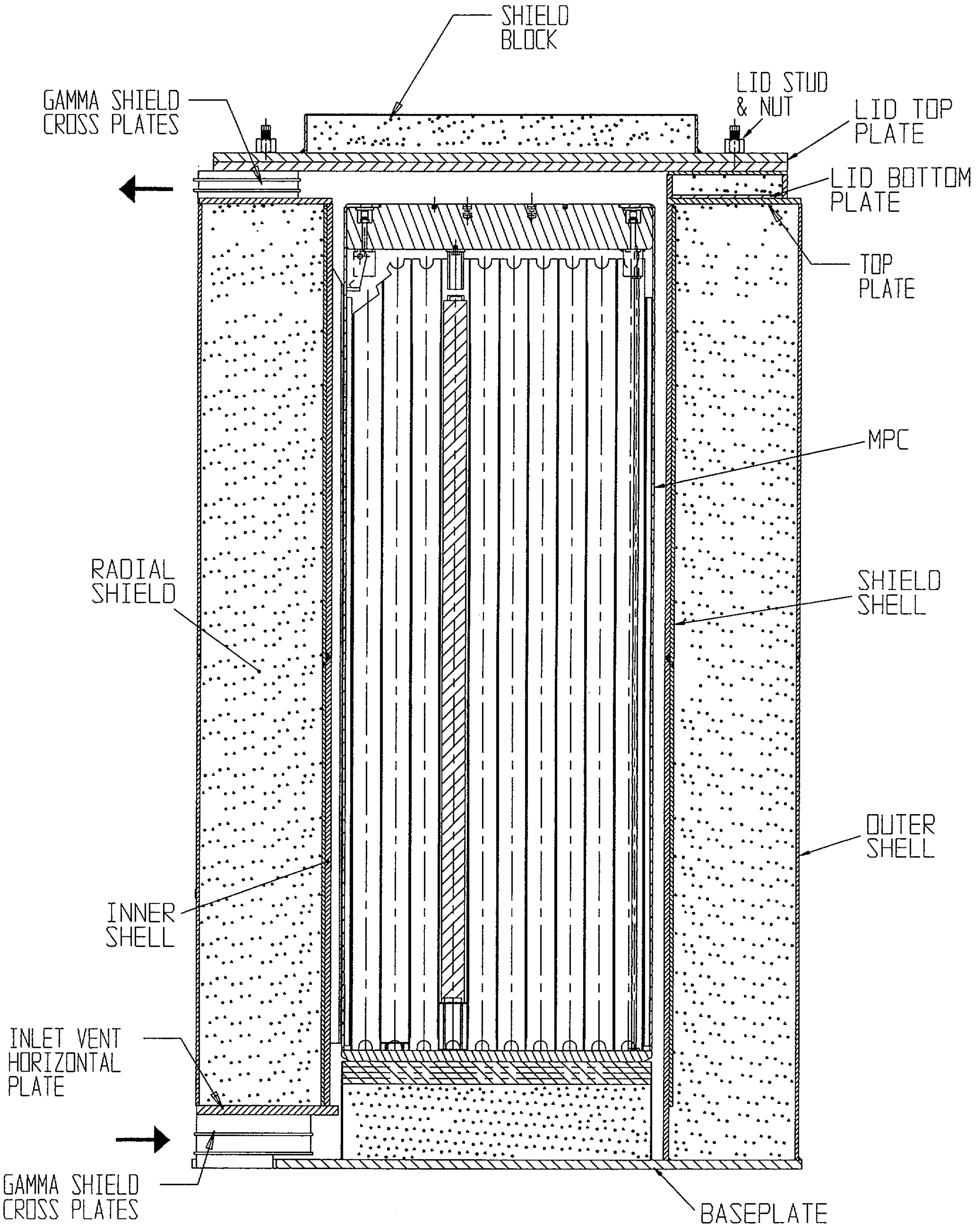

FIGURE 1.2.1A; CROSS SECTION VIEW OF THE HI-STORM 100S SYSTEM

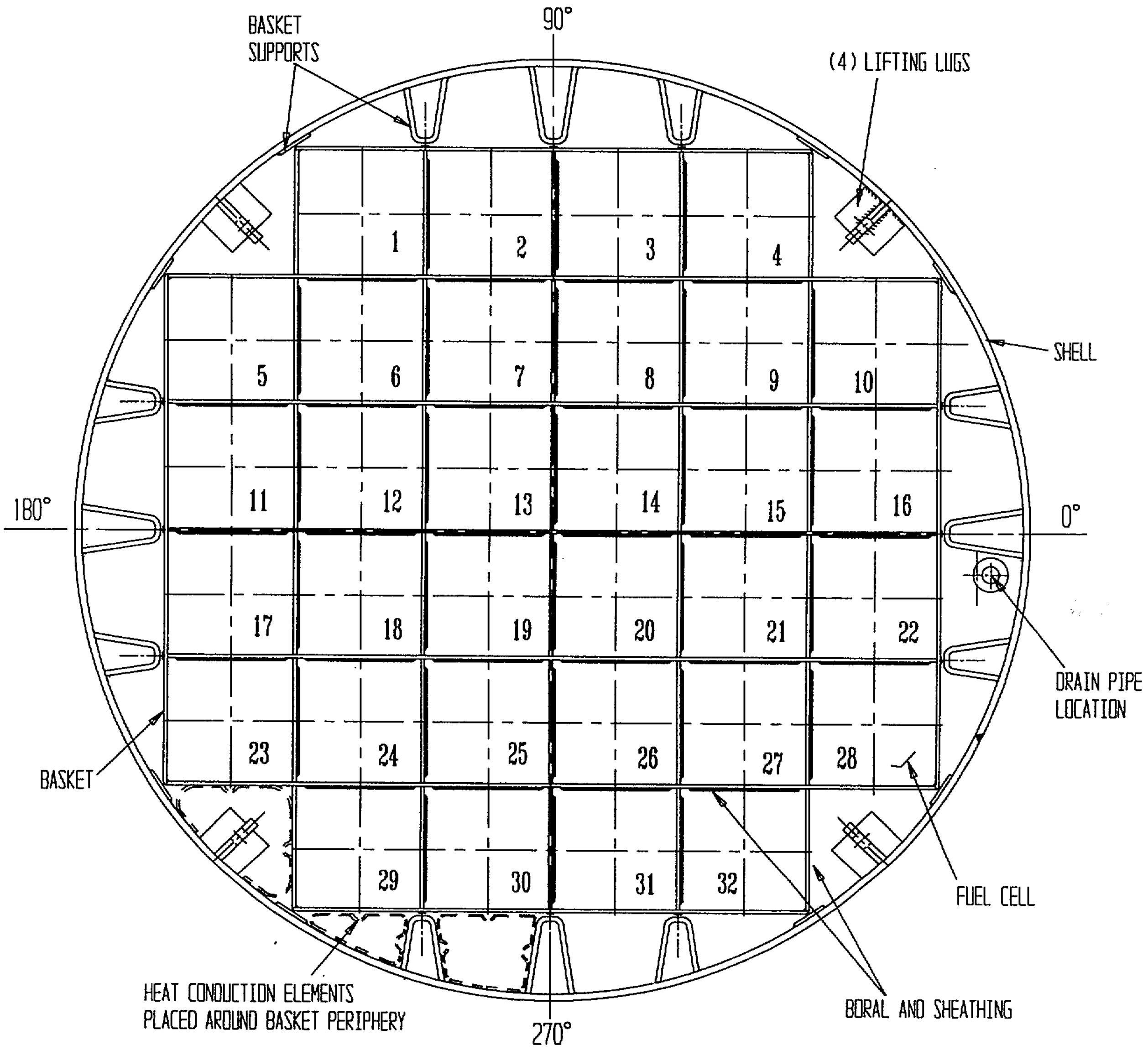

FIGURE 1.2.3; MPC-32 CROSS SECTION

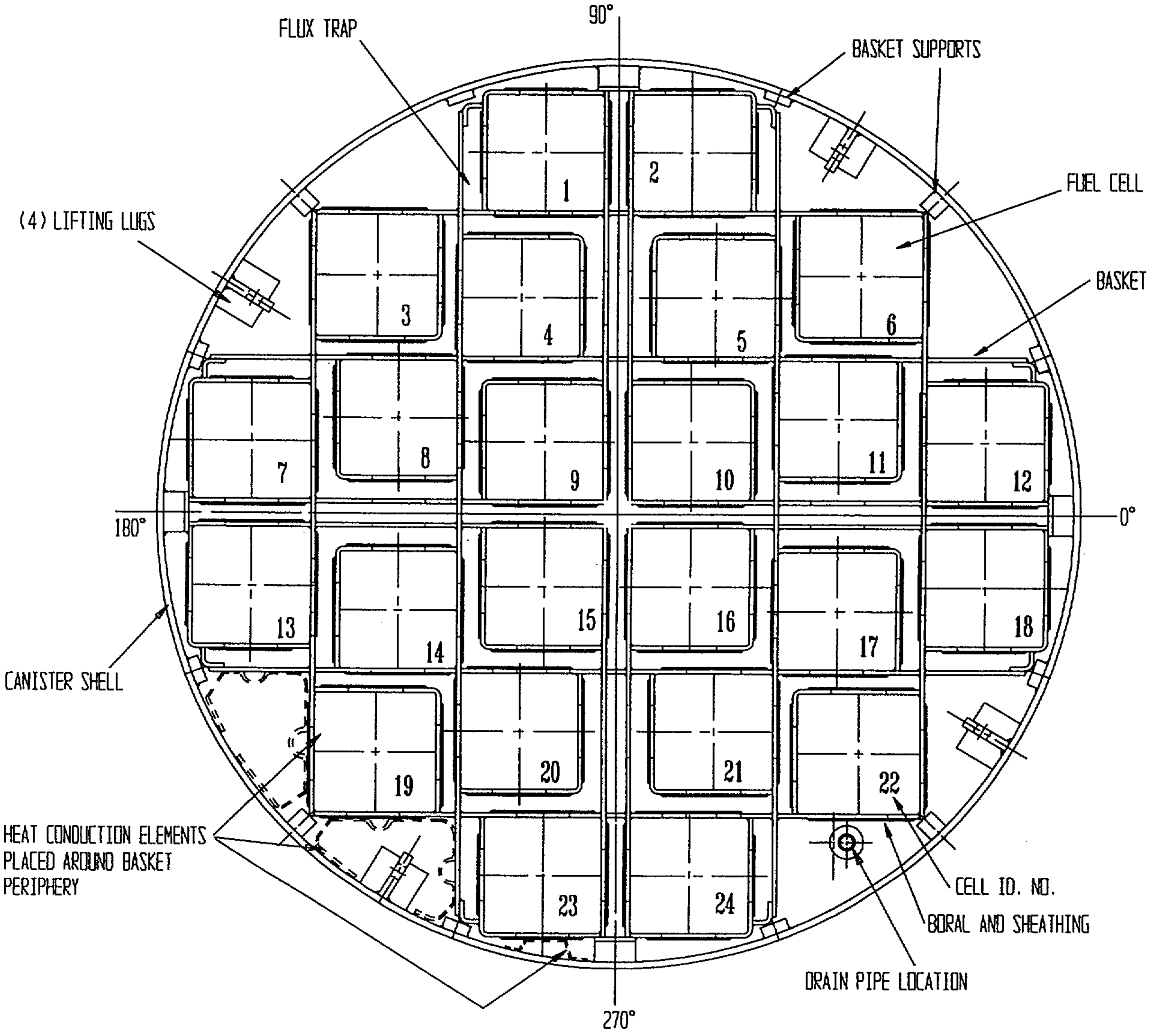

FIGURE 1.2.4A; MPC-24E CROSS SECTION VIEW

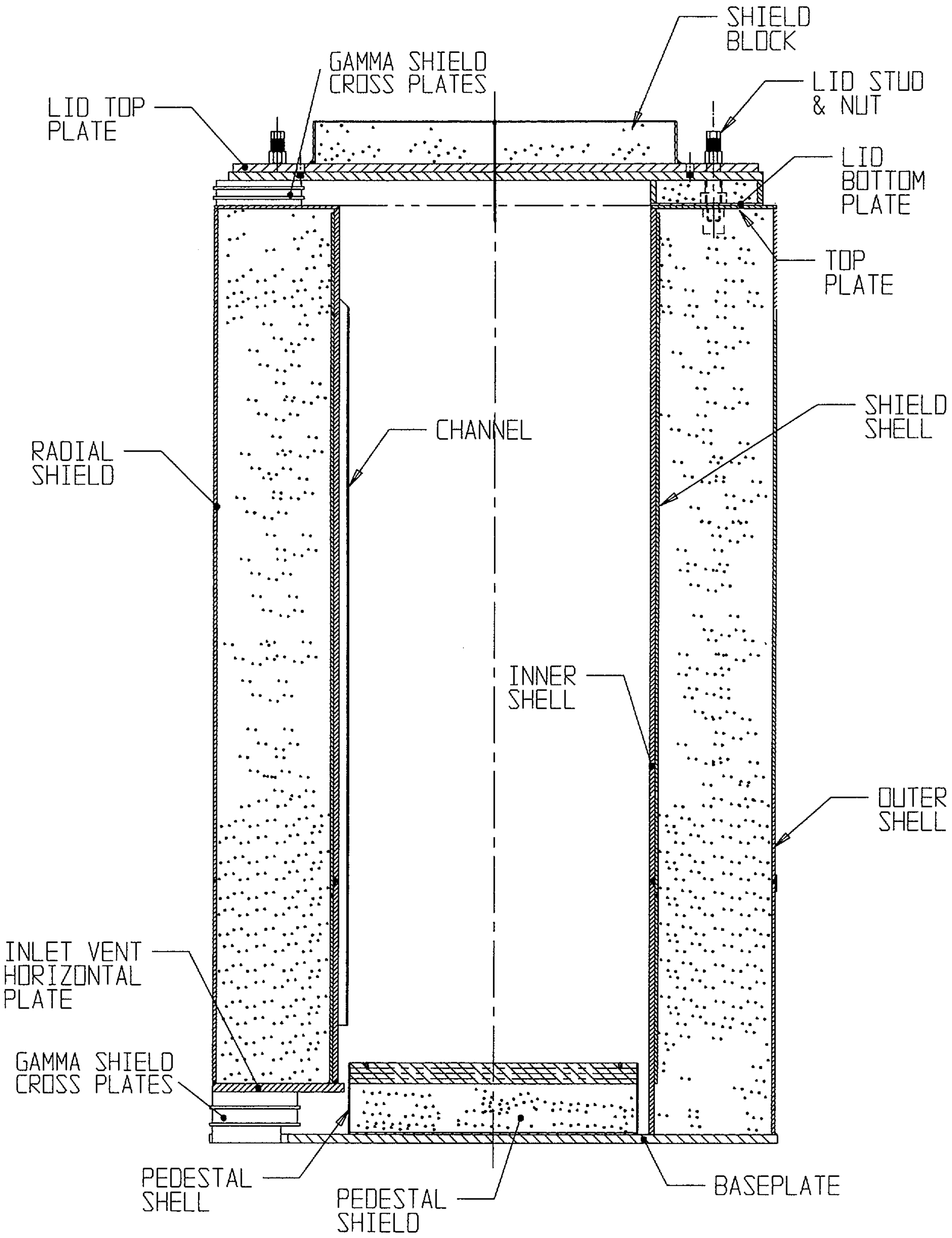

FIGURE 1.2.8A; HI-STORM 100S OVERPACK CROSS SECTIONAL ELEVATION VIEW

1.5 GENERAL ARRANGEMENT DRAWINGS

The following HI-STORM 100 System design drawings and bills of materials are provided on subsequent pages in this subsection:

Drawing Number/Sheet	Description	Rev.
5014-1392 Sht 1/4	*HI-STAR 100 MPC-32 Construction*	*10*
5014-1392 Sht 2/4	*HI-STAR 100 MPC-32 Construction*	*10*
5014-1392 Sht 3/4	*HI-STAR 100 MPC-32 Construction*	*10*
5014-1392 Sht 4/4	*HI-STAR 100 MPC-32 Construction*	*9*
5014-1393 Sht 1/6	*HI-STAR 100 MPC-32 Construction*	*11*
5014-1393 Sht 2/6	*HI-STAR 100 MPC-32 Construction*	*10*
5014-1393 Sht 3/6	*HI-STAR 100 MPC-32 Construction*	*10*
5014-1393 Sht 4/6	*HI-STAR 100 MPC-32 Construction*	*9*
5014-1393 Sht 5/6	*HI-STAR 100 MPC-32 Construction*	*8*
5014-1393 Sht 6/6	*HI-STAR 100 MPC-32 Construction*	*8*
5014-1395 Sht 1/4	HI-STAR 100 MPC-24 Construction	12
5014-1395 Sht 2/4	HI-STAR 100 MPC-24 Construction	*10*
5014-1395 Sht 3/4	HI-STAR 100 MPC-24 Construction	*11*
5014-1395 Sht 4/4	HI-STAR 100 MPC-24 Construction	*9*
5014-1396 Sht 1/6	HI-STAR 100 MPC-24 Construction	*14*
5014-1396 Sht 2/6	HI-STAR 100 MPC-24 Construction	*12*
5014-1396 Sht 3/6	HI-STAR 100 MPC-24 Construction	*11*
5014-1396 Sht 4/6	HI-STAR 100 MPC-24 Construction	*10*
5014-1396 Sht 5/6	HI-STAR 100 MPC-24 Construction	*9*
5014-1396 Sht 6/6	HI-STAR 100 MPC-24 Construction	*8*
5014-2889	*HI-STAR 100 MPC-24E Construction (1)*	*0*
5014-2890	*HI-STAR 100 MPC-24E Construction (2)*	*0*
5014-2891	*HI-STAR 100 MPC-24E Construction (3)*	*0*

Drawing Number/Sheet	**Description**	**Rev.**
5014-2892	*HI-STAR 100 MPC-24E Construction (4)*	*0*
5014-1401 Sht 1/4	HI-STAR 100 MPC-68 Construction	*13*
5014-1401 Sht 2/4	HI-STAR 100 MPC-68 Construction	*9*
5014-1401 Sht 3/4	HI-STAR 100 MPC-68 Construction	*10*
5014-1401 Sht 4/4	HI-STAR 100 MPC-68 Construction	*9*
5014-1402 Sht 1/6	HI-STAR 100 MPC-68 Construction	*15*
5014-1402 Sht 2/6	HI-STAR 100 MPC-68 Construction	*14*
5014-1402 Sht 3/6	HI-STAR 100 MPC-68 Construction	*13*
5014-1402 Sht 4/6	HI-STAR 100 MPC-68 Construction	*11*
5014-1402 Sht 5/6	HI-STAR 100 MPC-68 Construction	*10*
5014-1402 Sht 6/6	HI-STAR 100 MPC-68 Construction	*10*
5014-1495 Sht 1/6	HI-STORM 100 Assembly	*9*
5014-1495 Sht 2/6	Cross Section "Z" - "Z" View of HI-STORM	*10*
5014-1495 Sht 3/6	Section "Y" - "Y" of HI-STORM	*8*
5014-1495 Sht 4/6	Section "X" -"X" of HI-STORM	*9*
5014-1495 Sht 5/6	Section "W" -"W" of HI-STORM	*10*
~~5014-1495 Sht 6/6~~	~~HI-STORM Outlet Vent Thermocouple Mounting Hardware~~	~~2~~
5014-1561 Sht 1/5	View "A" -"A" of HI-STORM	*8*
5014-1561 Sht 2/5	Detail "B" of HI-STORM	*8*
5014-1561 Sht 3/5	Detail of Air Inlet of HI-STORM	*8*
5014-1561 Sht 4/5	Detail of Air Outlet of HI-STORM	*8*
~~5014-1561 Sht 5/5~~	~~Miscellaneous Detail of HI-STORM~~	~~7~~
5014-3067	*HI-STORM 100S Assembly*	*0*
5014-3068	*Cross Section "Z" - "Z" View of HI-STORM 100S*	*0*
5014-3069	*Section "Y" - "Y" of HI-STORM 100S*	*0*

Drawing Number/Sheet	**Description**	**Rev.**
5014-3070	*Section "X" -"X" of HI-STORM 100S*	*0*
5014-3071	*Section "W" -"W" of HI-STORM 100S*	*0*
5014-3072	*View "A" -"A" of HI-STORM 100S*	*0*
5014-3073	*Section B-B of Lid Shield of Hi-STORM 100S*	*0*
5014-3074	*Detail "B" of HI-STORM 100S*	*0*
5014-3075	*Detail of Air Inlet of HI-STORM 100S*	*0*
~~5014-1783 Sht 1/1~~	~~General Arrangement Damaged Fuel Container~~	~~2~~
~~5014-1784 Sht 1/1~~	~~Damaged Fuel Container Details~~	~~1~~
5014-1880 Sht 1/10	125 Ton HI-TRAC Outline with Pool Lid	*8*
5014-1880 Sht 2/10	125 Ton HI-TRAC Body Sectioned Elevation	*9*
5014-1880 Sht 3/10	125 Ton HI-TRAC Body Sectioned Elevation "B" - "B"	*8*
5014-1880 Sht 4/10	125 Ton Transfer Cask Detail of Bottom Flange	*9*
5014-1880 Sht 5/10	125 Ton Transfer Cask Detail of Pool Lid	*9*
5014-1880 Sht 6/10	125 Ton Transfer Cask Detail of Top Flange	*9*
5014-1880 Sht 7/10	125 Ton Transfer Cask Detail of Top Lid	*8*
5014-1880 Sht 8/10	125 Ton Transfer Cask View "Y" - "Y"	*8*
5014-1880 Sht 9/10	125 Ton Transfer Cask Lifting Trunnion and Locking Pad	*6*
5014-1880 Sht 10/10	125 Ton Transfer Cask View "Z" - "Z"	*8*
5014-1928 Sht 1/2	125 Ton HI-TRAC Transfer Lid Housing Detail	*10*
5014-1928 Sht 2/2	125 Ton HI-TRAC Transfer Lid Door Detail	*9*
5014-2145 Sht 1/10	100 Ton HI-TRAC Outline with Pool Lid	*7*
5014-2145 Sht 2/10	100 Ton HI-TRAC Body Sectioned Elevation	*7*
5014-2145 Sht 3/10	100 Ton HI-TRAC Body Sectioned Elevation 'B-B'	*7*
5014-2145 Sht 4/10	100 Ton HI-TRAC Detail of Bottom Flange	*6*
5014-2145 Sht 5/10	100 Ton HI-TRAC Detail of Pool Lid	*5*

Drawing Number/Sheet	**Description**	**Rev.**
5014-2145 Sht 6/10	100 Ton HI-TRAC Detail of Top Flange	7
5014-2145 Sht 7/10	100 Ton HI-TRAC Detail of Top Lid	7
5014-2145 Sht 8/10	100 Ton HI-TRAC View Y-Y	7
5014-2145 Sht 9/10	100 Ton HI-TRAC Lifting Trunnions and Locking Pad	4
5014-2145 Sht 10/10	100 Ton HI-TRAC View Z-Z	6
5014-2152 Sht 1/2	100 Ton HI-TRAC Transfer Lid Housing Detail	8
5014-2152 Sht 2/2	100 Ton HI-TRAC Transfer Lid Door Detail	7
BM-1477 Sht 1/2	*Bill-of-Materials for 32-Assembly HI-STAR 100 PWR MPC*	*9*
BM-1477 Sht 2/2	*Bill-of-Materials for 32-Assembly HI-STAR 100 PWR MPC*	*10*
BM-1478, Sht 1/2	Bill-of-Materials for 24-Assembly HI-STAR 100 PWR MPC	9
BM-1478, Sht 2/2	Bill-of-Material for 24-Assembly HI-STAR 100 PWR MPC	13
BM-2898	*Bill-of-Material for 24-Assembly HI-STAR 100 PWR MPC-24E. Sheet 1*	*0*
BM-2899	*Bill-of-Material for 24-Assembly HI-STAR 100 PWR MPC-24E. Sheet 2*	*0*
BM-1479, Sht 1/2	Bills-of-Material for 68-Assembly HI-STAR 100 BWR MPC	12
BM-1479, Sht 2/2	Bills-of-Material for 68-Assembly HI-STAR 100 BWR MPC	15
BM-1575, Sht 1/2	HI-STORM 100 Storage Overpack Bill of Materials	10
BM-1575, Sht 2/2	HI-STORM 100 Storage Overpack Bill of Materials	9
~~BM-1819, Sht 1/1~~	~~Bills-of-Materials for HI-STAR 100 System Failed Fuel Canister~~	~~1~~
BM-1880, Sht 1/2	Bill of Material for 125 Ton HI-TRAC	8
BM-1880, Sht 2/2	Bill of Material for 125 Ton HI-TRAC	6
BM-1928, Sht 1/1	Bill of Material for 125 Ton HI-TRAC Transfer Lid	9

Drawing Number/Sheet	**Description**	**Rev.**
BM-2145 Sht 1/2	Bills-of-Material for 100 Ton HI-TRAC	5
BM-2145 Sht 2/2	Bill-of-Material for 100 Ton HI-TRAC	4
BM-2152 Sht 1/1	Bill-of-Material for 100 Ton HI-TRAC Transfer Lid	7
BM-3065	*Bill-of-Material for HI-STORM 100S*	*0*
BM-3066	*Bill of Material for HI-STORM 100S*	*0*

Notes: 1. The HI-STAR 100 MPCs are identical to the MPCs used in the HI-STORM 100 System.

Table 1.B.1

PROPERTIES OF HOLTITE-A NEUTRON SHIELD

PHYSICAL PROPERTIES (Reference: NAC International Brochure)	
% ATH	62 maximum (confirmed by Holtec in independent analyses)
Specific Gravity	1.68 g/cc ~~maximum~~ *nominal*
Thermal Conductivity	0.373 Btu/hr/ft-EF
Max. Continuous Operating Temperature	300EF
Specific Heat[†]	0.39 Btu/lb-EF
Hydrogen Density	0.096 g/cc minimum (confirmed by Holtec in independent analyses)
Radiation Resistance	Excellent
Ultimate Tensile Strength	4,250 psi
Tensile elongation	0.65%
Ultimate Compression Strength	10,500 psi
Compression Yield Strength	8,780 psi
Compression Modulus	561,000 psi
CHEMICAL PROPERTIES (Nominal)	
wt% Aluminum	21.5 (confirmed by Holtec)
wt% Hydrogen	6.0 (confirmed by Holtec)
wt% Carbon	27.7
wt% Oxygen	42.8
wt% Nitrogen	2.0
wt% B_4C	up to 6.5 (Holtite-A uses 1% B_4C)

[H] BISCO Products Data from Docket M-55, NAC-STC TSAR.

Table 1.D.1: Requirements on Plain Concrete

ITEM	APPLICABLE LIMIT OR REFERENCE
Density (Minimum)	146 (lb/cubic feet)
Specified Compressive Strength	4,000 psi (min.)
Compressive and Bearing Stress Limit	Per ACI 318-95
Cement Type and Mill Test Report	Type II; Section 3.2 (ASTM C 150 or ASTM C595)
Aggregate Type	Section 3.3 (including ASTM C33(Note 2))
Nominal Maximum Aggregate Size	3/4 (inch)
Water Quality	Per Section 3.4
Material Testing	Per Section 3.1
Admixtures	Per Section 3.6
Air Content	6%[1] (Table 4.5.1)
Maximum Water to Cement Ratio	0.5 (Table 4.5.2)
Maximum Water Soluble Chloride Ion Cl in Concrete	1.00 percent by weight of cement (Table 4.5.4)
Concrete Quality	Per Chapter 4 of ACI 349
Mixing and Placing	Per Chapter 5 of ACI 349
Consolidation	Per ACI 309-87
Quality Assurance	Per Holtec Quality Assurance Manual, 10 CFR Part 72, Appendix G commitments
Maximum Local Temperature Limit Under ~~Normal and Off-normal~~ *Long Term* Conditions	200EF (See Note 3)
Maximum Local Temperature Limit Under ~~Accident~~ *Short Term* Conditions	350EF (Appendix A, Subsection A.4.2)
Aggregate Maximum Value[2] of Coefficient of Thermal Expansion (tangent in the range of 70EF to 100EF)	6E-06 inch/inch/EF (NUREG-1536, 3.V.2.b.i.(2)(c)2.b)

Notes:

1. All section and table references are to ACI 349 (85).
2. The coarse aggregate shall meet the requirements of ASTM C33 for class designation 1S from Table 3. However, if the requirements of ASTM C33 cannot be met, concrete that has been shown by special tests or actual service to produce concrete of adequate strength and durability meeting the requirements of Tables 1.D.1 and 1.D.2 is acceptable in accordance with ACI 349 Section 3.3.2.
3. The 200 EF long term temperature limit is specified in accordance with Paragraph A.4.3 of ACI 349 for normal conditions. The 200 EF long term temperature limit is based on (1) the use of Type II cement, specified aggregate criteria, and the specified compressive stress in Table 1.D.1, (2) the relatively small increase in long term temperature limit over the 150EF specified in Paragraph A.4.1, and (3) the very low maximum stresses calculated for normal and off-normal conditions in Section 3.4 of this TSAR.

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[1] This limit is specified to accommodate severe exposure to freezing and thawing (Table 4.5.1).

[2] The following aggregate types are a priori acceptable: limestone, dolomite, marble, basalt, granite, gabbro, or rhyolite. The thermal expansion coefficient limit does not apply when these aggregates are used. Careful consideration shall be given to the potential of long-term degradation of concrete due to chemical reactions between the aggregate and cement selected for HI-STORM 100 overpack concrete.

CHAPTER 2[†]: PRINCIPAL DESIGN CRITERIA

This chapter contains a compilation of design criteria applicable to the HI-STORM 100 System. The loadings and conditions prescribed herein for the MPC, particularly those pertaining to mechanical accidents, are far more severe in most cases than those required for 10CFR72 compliance. The MPC is designed to be in compliance with both 10CFR72 and 10CFR71 and therefore certain design criteria are overly conservative for storage. This chapter sets forth the loading conditions and relevant acceptance criteria; it does not provide results of any analyses. The analyses and results carried out to demonstrate compliance with the design criteria are presented in the subsequent chapters of this report.

This chapter is in full compliance with NUREG-1536, except for the exceptions and clarifications provided in Table 1.0.3. Table 1.0.3 provides the NUREG-1536 requirement, the justification for the exception or clarification, and the Holtec approach to meet the intent of the NUREG-1536 requirement.

2.0 PRINCIPAL DESIGN CRITERIA

The design criteria for the MPC, HI-STORM 100 Overpack, and HI-TRAC Transfer Cask are summarized in Tables 2.0.1, 2.0.2, and 2.0.3, respectively, and described in the sections that follow.

2.0.1 MPC Design Criteria

General

The MPC is designed for 40 years of service, while satisfying the requirements of 10CFR72. The adequacy of the MPC design for the design life is discussed in Section 3.4.12.

Structural

The MPC is classified as important to safety. The MPC structural components include the internal fuel basket and the enclosure vessel. The fuel basket is designed and fabricated as a core support structure, in accordance with the applicable requirements of Section III, Subsection NG

[†] This chapter has been prepared in the format and section organization set forth in Regulatory Guide 3.61. However, the material content of this chapter also fulfills the requirements of NUREG-1536. Pagination and numbering of sections, figures, and tables are consistent with the convention set down in Chapter 1, Section 1.0, herein. Finally, all terms-of-art used in this chapter are consistent with the terminology of the glossary (Table 1.0.1) and component nomenclature of the Bill-of-Materials (Section 1.5).

of the ASME Code, to the maximum extent practicable, as discussed in Section 2.2.4. The enclosure vessel is designed and fabricated as a Class 1 component pressure vessel in accordance with Section III, Subsection NB of the ASME Code, to the maximum extent practicable, as discussed in Section 2.2.4. The principal exception is the MPC lid, vent and drain cover plates, and closure ring welds to the MPC lid and shell, as discussed in Section 2.2.4. In addition, the threaded holes in the MPC lid are designed in accordance with the requirements of ANSI N14.6 for critical lifts to facilitate vertical MPC transfer.

The MPC closure welds are partial penetration welds that are structurally qualified by analysis, as presented in Chapter 3. The MPC lid and closure ring welds are inspected by performing a liquid penetrant examination of the root pass and final weld surface, in accordance with the Design Drawings contained in Section 1.5. The integrity of the MPC lid weld is further verified by performing a volumetric *(or multi-layer liquid penetrant)* examination, a hydrostatic pressure test and a helium leak test, in accordance with the Design Drawings and Technical Specification requirements contained in *Appendix A to the CoC* ~~Chapter 12.~~

The structural analysis of the MPC, in conjunction with the redundant closures and nondestructive examination, hydrostatic pressure testing, and helium leak testing performed during MPC fabrication and MPC closure, provides assurance of canister closure integrity in lieu of the specific weld joint requirements of Section III, Subsection NB.

Compliance with the ASME Code as it is applied to the design and fabrication of the MPC and the associated justification are discussed in Section 2.2.4. Compliance with the ASME Code is fully consistent with that used by other canister-based dry storage systems previously approved by the NRC.

The MPC is designed for all design basis normal, off-normal, and postulated accident conditions, as defined in Section 2.2. These design loadings include postulated drop accidents while in the cavity of the HI-STORM 100 Overpack or the HI-TRAC Transfer Cask. The load combinations for which the MPC is designed are defined in Section 2.2.7. The maximum allowable weight and dimensions of a fuel assembly to be stored in the MPC are limited in accordance with Section 2.1.5.

Thermal

The allowable zircaloy fuel cladding temperature limits to prevent cladding failure during long-term dry storage conditions for the MPC are based on LLNL Report [2.2.14]. To provide additional conservatism, the permissible fuel cladding temperature limits, which are lower than those calculated with the LLNL methodology, have been calculated based on PNL Report [2.0.3]. Stainless steel cladding is demonstrated to withstand higher temperatures than that of zircaloy cladding in EPRI Report [2.2.13]. However, the zircaloy fuel cladding temperature limits are conservatively applied to the stainless steel fuel cladding. The allowable fuel cladding temperatures which correspond to varying cooling times for the SNF to be stored in the MPCs are provided in Table 2.2.3.

The short-term allowable fuel cladding temperature that is applicable to off-normal and accident conditions, as well as the fuel loading, canister closure, and canister transfer operations in the HI-TRAC transfer cask, is 570°C (1058°F) based on PNL-4835 [2.2.15]. The MPC is backfilled with 99.995% pure helium at a ~~mass~~ *pressure* specified in ~~Chapter 12~~ *the Technical Specifications* during canister sealing operations to promote heat transfer and prevent cladding degradation.

The design temperatures for the structural steel components of the MPC are based on the temperature limits provided in ASME Section II, Part D, tables referenced in ASME Section III, Subsection NB and NG, for those load conditions under which material properties are relied on for a structural load combination. The specific design temperatures for the components of the MPC are provided in Table 2.2.3.

The MPCs are designed for a bounding thermal source term, as described in Section 2.1.6. The maximum allowable fuel assembly heat load for each MPC is limited in accordance with the *Allowable Contents limits specified in Appendix B to the CoC.* ~~Technical Specifications contained in Chapter 12.~~

Each MPC model allows for two fuel loading strategies. The first is uniform fuel loading, wherein any authorized fuel assembly may be stored in any fuel storage location, subject to other restrictions in the CoC, such as preferential fuel loading and location requirements for damaged fuel containers (DFCs) and fuel with integral non-fuel hardware (e.g., control rod assemblies). The second is regionalized fuel loading, wherein the basket is segregated into two regions as defined in Appendix B to the CoC. Region 1 is the inner region where fuel assemblies with higher decay heat load may be stored and Region 2 is the outer region where fuel assemblies with lower decay heat load are stored. Regionalized loading allows for storage of higher heat load assemblies (in Region 1) than would otherwise be authorized for loading under a uniform loading strategy. Regionalized loading strategies must also comply with other requirements of the CoC, such as those for DFCs and non-fuel hardware. Specific fuel assembly cooling time, burnup, and decay heat limtis for regionalized loading are provided in Appendix B to the CoC.The two fuel loading regions are defined in Table 2.1.13 (refer to Figures 1.2.2 through 1.2.4A).

Shielding

The allowable doses for an ISFSI using the HI-STORM 100 System are delineated in 10CFR72.104 and 72.106. Compliance with ~~this criteria~~ *these regulations for any particular* *array of casks at an ISFSI* is necessarily site-specific and is to be demonstrated by the licensee, as discussed in Chapters 5 and 12. *Compliance with these regulations for a single cask and several representative cask arrays at the minimum site boundary distance of 100 meters is demonstrated in Chapters 5 and 7.*

The MPC provides axial shielding at the top and bottom ends to maintain occupational exposures ALARA during canister closure and handling operations. The maximum allowable axial dose rates for the MPC are controlled in accordance with plant-specific procedures and ALARA requirements (discussed in Chapter 10).

The MPCs are designed for design basis fuel at the maximum burnup and minimum cooling times, as described in Sections 2.1.7 and 5.2. The radiological source term for the MPCs are limited based on the burnup and cooling times specified in *Appendix B to the CoC* ~~the Technical Specifications contained in Chapter 12.~~ Calculated dose rates for each MPC are provided in Section 5.1. These dose rates are used to perform an occupational exposure evaluation in accordance with 10CFR20, as discussed in Chapter 10.

Criticality

The MPCs provide criticality control for all design basis normal, off-normal, and postulated accident conditions, as discussed in Section 6.1. The effective neutron multiplication factor is limited to $k_{eff} < 0.95$ for fresh unirradiated intact fuel with optimum unborated water moderation *(except as described below)* and close reflection, including all biases, uncertainties, and MPC manufacturing tolerances. *Credit for soluble boron in the MPC water during PWR fuel wet loading and unloading operations is taken in the criticality analyses for the MPC-24 and MPC-24E (for higher enriched fuel) and for all fuel loaded into the MPC-32.*

Criticality control is maintained by the geometric spacing of the fuel assemblies, ~~and~~ fixed borated neutron absorbing materials (Boral) incorporated into the fuel basket assembly, *and, for certain MPC models, soluble boron in the MPC water.* The minimum specified boron concentration verified during Boral manufacture is further reduced by 25% for criticality analysis. No credit is taken for burnup. The maximum allowable initial enrichment for fuel assemblies to be stored in each MPC are limited in accordance with the *CoC.* ~~Technical Specifications contained in Chapter 12.~~ *Soluble boron concentration requirements are delineated in the Technical Specifications in Appendix A of the CoC.*

Confinement

The MPC provides for confinement of all radioactive materials for all deign basis normal, off-normal, and postulated accident conditions, as discussed in Section 7.1. A non-mechanistic breach of the canister and subsequent release of available fission products in accordance with specified release fractions is considered, as discussed in Section 7.3. The confinement function of the MPC is verified through hydrostatic testing, helium leak testing and weld examinations performed in accordance with the acceptance test program in Chapter 9 ~~and the Technical Specifications contained in Chapter 12~~.

Operations

There are no radioactive effluents that result from storage or transfer operations. Effluents generated during MPC loading are handled by the plant's radwaste system and procedures.

Generic operating procedures for the HI-STORM 100 System are provided in Chapter 8. Detailed operating procedures will be developed by the licensee based on site-specific requirements that comply with the 10CFR50 Technical Specifications for the plant and the 10CFR72 Technical Specifications for the HI-STORM 100 System contained in *Appendix A to the CoC.* ~~Chapter 12.~~

Acceptance Tests and Maintenance

The fabrication acceptance basis and maintenance program to be applied to the MPCs are described in Chapter 9. The operational controls and limits to be applied to the MPCs are contained in Chapter 12. Application of these requirements will assure that the MPC is fabricated, operated, and maintained in a manner that satisfies the design criteria defined in this chapter.

Decommissioning

The MPCs are designed to be transportable in the HI-STAR 100 Overpack and are not required to be unloaded prior to shipment off-site. Decommissioning of the HI-STORM 100 System is addressed in Section 2.4.

2.0.2 HI-STORM 100 Overpack Design Criteria

General

The HI-STORM 100 Overpack is designed for 40 years of service, while satisfying the requirements of 10CFR72. The adequacy of the overpack design for the design life is discussed in Section 3.4.11.

Structural

The HI-STORM 100 Overpack includes both concrete and structural steel components that are classified as important to safety.

The concrete material is defined as important to safety because of its importance to the shielding analysis. The primary function of the HI-STORM 100 Overpack concrete is shielding of the gamma and neutron radiation emitted by the spent nuclear fuel.

Unlike other concrete storage casks, the HI-STORM 100 Overpack concrete is enclosed in steel inner and outer shells connected to each other by four radial ribs, and top and bottom plates. Where typical concrete storage casks are reinforced by rebar, the HI-STORM 100 Overpack is supported by the inner and outer shells connected by four ribs. As the HI-STORM 100 Overpack concrete is not reinforced, the structural analysis of the overpack only credits the compressive strength of the concrete. Providing further conservatism, the structural analyses for normal conditions demonstrate that the allowable stress limits of the structural steel are met even with no credit for the strength of the concrete. During accident conditions (e.g., tornado missile, tip-over, end drop, and earthquake), only the compressive strength of the concrete is accounted for in the analysis to provide an appropriate simulation of the accident condition. Where applicable, the compressive strength of the concrete is calculated in accordance with ACI-318-95 [2.0.1].

In recognition of the conservative assessment of the HI-STORM 100 Overpack concrete strength and the primary function of the concrete being shielding, the applicable requirements of ACI-349 [2.0.2] are invoked in the design and construction of the HI-STORM 100 Overpack concrete as specified in Appendix 1.D.

Steel components of the storage overpack are designed and fabricated in accordance with the requirements of ASME Code, Section III, Subsection NF for Class 3 plate and shell components. Compliance with the ASME Code is fully consistent with those used by other canister-based dry storage systems previously approved by the NRC.

The overpack is designed for all normal, off-normal, and design basis accident condition loadings, as defined in Section 2.2. At a minimum, the overpack must protect the MPC from deformation, provide continued adequate performance, and allow the retrieval of the MPC under all conditions. These design loadings include a postulated drop accident from the maximum allowable handling height, consistent with the *Cask Transport Evaluation program described in* Technical Specification *Section 5.0* ~~requirements~~ contained in *Appendix A to the CoC.* ~~Chapter 12.~~ The load combinations for which the overpack is designed are defined in Section 2.2.7. The physical characteristics of the MPCs for which the overpack is designed are defined in Chapter 1.

Thermal

The allowable long-term temperature limit for the overpack concrete is less than the limit in NUREG-1536, which limits the local concrete temperature to 300°F, if Type II cement is used and aggregates are selected which are acceptable for concrete in this temperature range. Appendix 1.D specifies the cement and aggregate requirements to allow the utilization of the 300°F temperature limit of NUREG-1536; however, a conservative long-term temperature limit of 200°F is applied to the concrete. For short term conditions the concrete temperature limit of 350°F is specified in accordance with Appendix A of ACI 349. The allowable temperatures for the structural steel components are based on the maximum temperature for which material properties and allowable stresses are provided in Section II of the ASME Code. The specific allowable temperatures for the structural steel components of the overpack are provided in Table 2.2.3.

The overpack is designed for extreme cold conditions, as discussed in Section 2.2.2.2. The structural steel materials used for the storage cask that are susceptible to brittle fracture are discussed in Section 3.1.2.3.

The overpack is designed for the maximum allowable heat load for steady-state normal conditions, in accordance with Section 2.1.6. The thermal characteristics of the MPCs for which the overpack is designed are defined in Chapter 4.

Shielding

The off-site dose for normal operating conditions at the site boundary is limited by 10CFR72.104(a) to a maximum of 25 mrem/year whole body, 75 mrem/year thyroid, and 25 mrem/year for other *critical* organs, including contributions from all nuclear fuel cycle operations. Since these limits are dependent on plant operations as well as site-specific conditions (e.g., the ISFSI design and proximity to the site boundary, and the number and arrangement of loaded storage casks on the ISFSI pad), the determination and comparison of ISFSI doses to this limit are necessarily site-specific. Dose rates for a *single cask and a range of* typical ISFSIs using the HI-STORM 100 System are provided in Chapters 5 and 10. The determination of site-specific ISFSI dose rates at the site boundary and demonstration of compliance with regulatory limits is to be performed by the licensee in accordance with 10CFR72.212.

The overpack is designed to limit the calculated surface dose rate at the cask midplane for all MPCs to 35 mrem/hr or less, as defined in Section 2.3.5. The overpack is also designed to maintain occupational exposures ALARA during MPC transfer operations, in accordance with 10CFR20. The calculated overpack dose rates are determined in Section 5.1. These dose rates are used to perform a generic occupational exposure estimate for MPC transfer operations and a dose assessment for a typical ISFSI, as described in Chapter 10. In addition, overpack dose rates are limited in accordance with the Technical Specification*s* provided in *Appendix A to the CoC.* ~~Chapter 12.~~

Confinement

The overpack does not perform any confinement function. Confinement during storage is provided by the MPC and is addressed in Chapter 7. The overpack provides physical protection and biological shielding for the MPC confinement boundary during MPC dry storage operations.

Operations

There are no radioactive effluents that result from MPC transfer or storage operations using the overpack. Effluents generated during MPC loading and closure operations are handled by the plant's radwaste system and procedures under the licensee's 10CFR50 license.

Generic operating procedures for the HI-STORM 100 System are provided in Chapter 8. The licensee is required to develop detailed operating procedures based on site-specific conditions and requirements that also comply with the applicable 10CFR50 Technical Specification requirements for the site and the 10CFR72 Technical Specifications for the HI-STORM 100 System contained in *Appendix A to the CoC* ~~Chapter 12~~. *The bases for the technical Specification LCOs are provided in Appendix 12.A.*

Acceptance Tests and Maintenance

The fabrication acceptance basis and maintenance program to be applied to the overpack are described in Chapter 9. The operational controls and limits to be applied to the overpack are contained in Chapter 12. Application of these requirements will assure that the overpack is fabricated, operated, and maintained in a manner that satisfies the design criteria defined in this chapter.

Decommissioning

Decommissioning considerations for the HI-STORM 100 System, including the overpack, are addressed in Section 2.4.

2.0.3 HI-TRAC Transfer Cask Design Criteria

General

The HI-TRAC transfer cask is designed for 40 years of service, while satisfying the requirements of 10CFR72. The adequacy of the HI-TRAC design for the design life is discussed in Section 3.4.11.

Structural

The HI-TRAC Transfer Cask includes both structural and non-structural biological shielding components that are classified as important to safety. The structural steel components of the HI-TRAC, with the exception of the lifting trunnions, are designed and fabricated in accordance with the applicable requirements of Section III, Subsection NF, of the ASME Code, as discussed in Section 2.2.4. The lifting trunnions and associated attachments are designed in accordance with the requirements of NUREG-0612 and ANSI N14.6 for non-redundant lifting devices.

The HI-TRAC Transfer Cask is designed for all normal, off-normal, and design basis accident condition loadings, as defined in Section 2.2. At a minimum, the HI-TRAC transfer cask must protect the MPC from deformation, provide continued adequate performance, and allow the retrieval of the MPC under all conditions. These design loadings include a drop from the maximum allowable handling height, consistent with the Technical Specifications ~~contained in Chapter 12.~~ The load combinations for which the HI-TRAC is designed are defined in Section 2.2.7. The physical characteristics of each MPC for which the HI-TRAC is designed are defined in Chapter 1.

Thermal

The allowable temperatures for the HI-TRAC Transfer Cask structural steel components are based on the maximum temperature for material properties and allowable stress values provided in Section II of the ASME Code. The top lid incorporates Holtite-A shielding material. This material has a maximum allowable temperature in accordance with the manufacturer's test data. The specific allowable temperatures for the structural steel and shielding components of the HI-TRAC are provided in Table 2.2.3. The HI-TRAC is designed for off-normal environmental cold conditions, as discussed in Section 2.2.2.2. The structural steel materials susceptible to brittle fracture are discussed in Section 3.1.2.3.

The HI-TRAC is designed for the maximum allowable heat load provided in the Technical Specifications ~~contained in Chapter 12.~~ The HI-TRAC water jacket maximum allowable temperature is a function of the internal pressure. To preclude over pressurization of the water jacket due to boiling of the neutron shield liquid (water), the maximum temperature of the water is limited to less than the saturation temperature at the shell design pressure. In addition, the water is precluded from freezing during off-normal cold conditions by limiting the minimum allowable temperature and adding ethylene glycol. ~~The corresponding Technical Specifications applicable to the HI-TRAC during hot and cold conditions is contained in Chapter 12.~~ The thermal characteristics of the fuel for each MPC for which the transfer cask is designed are defined in Section 2.1.6. *The working area ambient temperature limit for loading operations is delineated in Appendix B to the CoC.*

Shielding

The HI-TRAC Transfer Cask provides shielding to maintain occupational exposures ALARA in accordance with 10CFR20, while also maintaining the maximum load on the plant's crane hook to below either 125 tons or 100 tons, or less, depending on whether the 125-ton or 100-ton HI-TRAC Transfer Cask is utilized. The HI-TRAC calculated dose rates are reported in Section 5.1. These dose rates are used to perform a generic occupational exposure estimate for MPC loading, closure, and transfer operations, as described in Chapter 10. A postulated HI-TRAC accident condition, which includes the loss of the liquid neutron shield (water), is also evaluated in Section 5.1.2. In addition, HI-TRAC dose rates are controlled in accordance with plant-specific procedures and ALARA requirements (discussed in Chapter 10).

The 125 ton HI-TRAC provides better shielding than the 100 ton HI-TRAC. Provided the licensee is capable of utilizing the 125 ton HI-TRAC, ALARA considerations would dictate that the 125 ton HI-TRAC should be used. However, sites may not be capable of utilizing the 125 ton HI-TRAC due to crane capacity limitations, floor loading considerations, or space envelope limitations in the fuel pool or air lock. As with other dose reduction-based plant modifications, individual users who cannot accommodate the 125 ton HI-TRAC due to plant design limitations must perform a cost-benefit analysis of the modifications which would be necessary to use the 125 ton HI-TRAC. The cost of the modification(s) would be weighed against the value of the projected reduction in radiation exposure and a decision made based on each plant's particular ALARA implementation philosophy.

The HI-TRAC provides a means to isolate the annular area between the MPC outer surface and the HI-TRAC inner surface to minimize the potential for surface contamination of the MPC by spent fuel pool water during wet loading operations. The HI-TRAC surfaces expected to require decontamination are coated. The maximum permissible surface contamination for the HI-TRAC is in accordance with plant-specific procedures and ALARA requirements (discussed in Chapter 10).

Confinement

The HI-TRAC Transfer Cask does not perform any confinement function. Confinement during MPC transfer operations is provided by the MPC, and is addressed in Chapter 7. The HI-TRAC provides physical protection and biological shielding for the MPC confinement boundary during MPC closure and transfer operations.

Operation

There are no radioactive effluents that result from MPC transfer operations using HI-TRAC. Effluents generated during MPC loading and closure operations are handled by the plant's radwaste system and procedures.

Generic operating procedures for the HI-STORM 100 System are provided in Chapter 8. The licensee will develop detailed operating procedures based on plant-specific requirements and in accordance with site and HI-STORM 100 System Technical Specification requirements contained in Chapter 12.

Acceptance Tests and Maintenance

The fabrication acceptance basis and maintenance program to be applied to the HI-TRAC Transfer Cask are described in Chapter 9. The operational controls and limits to be applied to the HI-TRAC are contained in Chapter 12. Application of these requirements will assure that the HI-TRAC is fabricated, operated, and maintained in a manner that satisfies the design criteria defined in this chapter.

Decommissioning

Decommissioning considerations for the HI-STORM 100 Systems, including the HI-TRAC Transfer Cask, are addressed in Section 2.4.

Table 2.0.1

MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Design Life:			
Design	40 yrs.	-	Table 1.2.2
License	20 yrs.	10CFR72.42(a) and 10CFR72.236(g)	-
Structural:			
Design ~~& Fabrication~~ Codes:			
Enclosure Vessel	ASME Code, Section III, Subsection NB	10CFR72.24(c)(4)	Section 2.0.1
Fuel Basket	ASME Code, Section III, Subsection NG	10CFR72.24(c)(4)	Section 2.0.1
MPC Lifting Points	ANSI N14.6/NUREG-0612	10CFR72.24(c)(4)	Section 1.2.1.4
Design Dead Weights:			
Max. Loaded Canister (dry)	79,987 lb. (MPC-24) *82,389 lb. (MPC-24E)* 87,241 lb. (MPC-68) *88,135 lb. (MPC-32)*	R.G. 3.61	Table 3.2.1

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Empty Canister (dry)	39,667 lb. (MPC-24) *42,069 lb. (MPC-24E)* 39,641 lb. (MPC-68) *34,375 lb. (MPC-32)*	R.G. 3.61	Table 3.2.1
Design Cavity Pressures:			
Normal:	100 psig	ANSI/ANS 57.9	Section 2.2.1.3
Off-Normal:	100 psig	ANSI/ANS 57.9	Section 2.2.2.1
Accident (Internal)	125 psig	ANSI/ANS 57.9	Section 2.2.3.8
Accident (External)	60 psig	ANSI/ANS 57.9	Sections 2.2.3.6 and 2.2.3.10
Response and Degradation Limits	SNF assemblies confined in dry, inert environment	10CFR72.122(h)(l)	Section 2.0.1
Thermal:			
Maximum Design Temperatures:			
Structural Materials:			
Stainless Steel (Normal)	725° F	ASME Code Section II, Part D	Table 2.2.3
Stainless Steel (Accident)	950° F	ASME Code Section II, Part D	Table 2.2.3
Neutron Poison:			

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Boral (normal)	800° F	See Section 4.3.1	Table 2.2.3
Boral (accident)	950° F	See Section 4.3.1	Table 2.2.3
PWR Fuel Cladding:			
5-year cooled	692° F	PNL-6189	Section 4.3
6-year cooled	677° F	PNL-6189	Section 4.3
7-year cooled	636° F	PNL-6189	Section 4.3
10-year cooled	626° F	PNL-6189	Section 4.3
15-year cooled	615° F	PNL-6189	Section 4.3
BWR Fuel Cladding:			
5-year cooled	742° F	PNL-6189	Section 4.3
6-year cooled	714° F	PNL-6189	Section 4.3
7-year cooled	671° F	PNL-6189	Section 4.3
10-year cooled	660° F	PNL-6189	Section 4.3
15-year cooled	648° F	PNL-6189	Section 4.3
Canister Backfill Gas	Helium	-	Section 12.3.3
Canister Backfill ~~Mass~~ *Pressure*	Varies by MPC	-	~~Section 12.3.3~~ *(Ch. 12 - TS)*
Short-Term Allowable Fuel Cladding Temperature	1058° F	PNL-4835	Sections 2.0.1 and 4.3

Table 2.0.1 (continued)

MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Insolation	Protected by Overpack or HI-TRAC	-	Section 4.3
Confinement:		10CFR72.128(a)(3) and 10CFR72.236(d) and (e)	
Closure Welds:			
Shell Seams and Shell-to-Baseplate	Full Penetration	-	Section 1.5 and Table 9.1.4
MPC Lid	Multi-pass Partial Penetration	10CFR72.236(e)	Section 1.5 and Table 9.1.4
MPC Closure Ring	Multi-pass Partial Penetration		
Port Covers	Full Penetration		
NDE:			
Shell Seams and Shell-to-Baseplate	100% RT or UT	-	Table 9.1.4
MPC Lid	Root Pass and Final Surface 100% PT; Volumetric Inspection or 100% Surface PT each 3/8" of weld depth	-	Chapter 8 and Table 9.1.4
Closure Ring	Root Pass *(if more than one pass is required)* and Final Surface 100% PT	-	Chapter 8 and Table 9.1.4

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Port Covers	Root Pass *(if more than one pass is required)* and Final Surface 100% PT	-	Chapter 8 and Table 9.1.4
Leak Testing:			
Welds Tested	Shell seams, shell-to-baseplate, MPC lid-to-shell, and port covers-to-MPC lid	-	Section 7.1 and Chapters 8, 9, and 12
Medium	Helium	-	Sections 7.2 and Chapter 12
Max. Leak Rate	5x10^{-6} *atm*-cm^{3}/sec (helium)	-	Chapter ~~8~~ *12 (TS)*
Monitoring System	None	10CFR72.128(a)(1)	Section 2.3.2.1
Hydrostatic Testing:			
Test Pressure	125 psig (+3, -0 psig)	-	Chapters 8 and 9
Welds Tested	MPC Lid-to-Shell, MPC Shell seams, MPC Shell-to-Baseplate	-	Section 8.1 and 9.1
Medium	Water	-	Section 8.1 and Chapter 9
Retrievability:			
Normal and Off-normal:	No Encroachment on Fuel Assemblies or Exceeding Fuel Assembly Deceleration Limits	10CFR72.122(f),(h)(1), & (l)	Sections 3.4, 3.5, and 3.1.2
Post (design basis) Accident			

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Criticality:		10CFR72.124 & 10CFR72.236(c)	
Method of Control	Fixed Borated Neutron Absorber & Geometry	-	Section 2.3.4
Min. Boron Loading	0.0267 g/cm^2 (MPC-24) 0.0372 g/cm^2 (MPC-68, *MPC-68FF, MPC-24E, and MPC-32*) 0.01 g/cm^2 (MPC-68F)	-	Section 2.1.8
Minimum Soluble Boron	*Varies By MPC*	-	*Section 6.1, CoC, Appendix B*
Max. k_{eff}	0.95	-	Sections 6.1 and 2.3.4
Min. Burnup	0.0 GWd/MTU (fresh fuel)	-	Section 6.1
Radiation Protection/Shielding:		10CFR72.126, & 10CFR72.128(a)(2)	
MPC: (normal/off-normal/accident)			
MPC Closure	ALARA	10CFR20	Sections 10.1, 10.2, & 10.3
MPC Transfer	ALARA	10CFR20	Sections 10.1, 10.2, & 10.3
Exterior of Shielding: (normal/off-normal/accident)			
Transfer Mode Position	See Table 2.0.3	10CFR20	Section 5.1.1

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Storage Mode Position	See Table 2.0.2	10CFR20	Section 5.1.1
ISFSI Controlled Area Boundary	See Table 2.0.2	10CFR72.104 & 10CFR72.106	Section 5.1.1 and Chapter 10
Design Bases:		10CFR72.236(a)	
Spent Fuel Specification:			
Assemblies/Canister	Up to 24 (MPC-24 *& MPC-24E*) *Up to 32 (MPC-32)* Up to 68 (MPC-68, *MPC-68F, & MPC-68FF*)	-	Table 1.2.1
Type of Cladding	Zircaloy *and Stainless Steel**	-	Table 2.1.6
Fuel Condition	Intact, *Damaged, and Debris**	-	Section 2.1.2 & Table 2.1.6
* ~~Also designed to accommodate failed fuel, stainless clad fuel, and MOX fuel (Tables 2.1.7 and 2.1.8 and Chapter 12)~~ *See Appendix B to the CoC for specific fuel condition requirements.*			
PWR Fuel Assemblies:			
Type/Configuration	Various**	-	Table 2.1.3
** ~~No control components are permitted.~~			
Max. Burnup	~~44,700~~ *45,000* MWD/MTU ~~(MPC-24)~~	-	~~Figure 2.1.6~~ *CoC, Appendix B*
Max. Enrichment	Varies by fuel design	-	Table 2.1.3

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	**Criteria**	**Basis**	**TSAR Reference**
Max. Decay Heat/Assembly[†]: *(Regionalized fuel loading)*			
5-year cooled	~~870~~ *1152* W (MPC-24) *1295 W (MPC-24E)* *846 W (MPC-32)*	-	Tables ~~4.4.20 and 2.2.3~~ *4.4.31*
6-year cooled	~~840.4~~ *1152* W (MPC-24) *1295 W (MPC-24E)* *813 W (MPC-32)*	-	Tables ~~4.4.20 and 2.2.3~~ *4.4.31*
7-year cooled	~~757.5~~ *942* W (MPC-24) *1062 W (MPC-24E)* *722 W (MPC-32)*	-	Tables ~~4.4.20 and 2.2.3~~ *4.4.31*
10-year cooled	~~738.3~~ *887* W (MPC-24) *1002 W (MPC-24E)* *700 W (MPC-32)*	-	Tables ~~4.4.20 and 2.2.3~~ *4.4.31*
15-year cooled	~~715.4~~ *827* W (MPC-24) *940 W (MPC-24E)* *675 W (MPC-32)*	-	Tables ~~4.4.20 and 2.2.3~~ *4.4.31*
Minimum Cooling Time:	5 years (Intact Zr Clad Fuel) 8 years (Intact SS Clad Fuel)		*CoC, Appendix B*
Max. Fuel Assembly Weight: *(including non-fuel hardware and DFC, as applicable)*	1,680 lb.	-	Table 2.1.6

[†] *The Approved Contents Section of Appendix B to the CoC provides the decay heat limits per assembly.*

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	**Criteria**	**Basis**	**TSAR Reference**
Max. Fuel Assembly Length: (Unirradiated Nominal)	176.8 in.	-	Table 2.1.6
Max. Fuel Assembly Width (Unirradiated Nominal)	8.54 in.	-	Table 2.1.6
Fuel Rod Fill Gas:			
Pressure (max.)	500 psig	-	Section 4.3 & Table 4.3.2
BWR Fuel Assemblies:			
Type	Various	-	Table 2.1.4
Max. Burnup	~~41,700~~ *45,000* MWD/MTU	-	~~Figure 2.1.6~~ *CoC, Appendix B*
Max. Enrichment	Varies by fuel design	-	Section 6.1, ~~and Chapter 12~~ *Table 2.1.4*
Max. Decay Heat/Assy[†].:			
5-year cooled	~~314.7~~ *905* W (MPC-68)	-	Tables ~~4.4.21 and 2.2.3~~ *4.4.31*
6-year cooled	~~298.7~~ *850* W (MPC-68)	-	Tables ~~4.4.21 and 2.2.3~~ *4.4.31*
7-year cooled	~~270.7~~ *765* W (MPC-68)	-	Tables ~~4.4.21 and 2.2.3~~ *4.4.31*
10-year cooled	~~264.0~~ *744* W (MPC-68)	-	Tables ~~4.4.21 and 2.2.3~~ *4.4.31*
15-year cooled	~~256.6~~ *720* W (MPC-68)	-	Tables ~~4.4.21 and 2.2.3~~ *4.4.31*

[†] *The Approved Contents Section of Appendix B to the CoC provides the decay heat limits per assembly.*

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Minimum Cooling Time:	5 yrs ~~(Intact Zr Clad Fuel)~~ ~~18 yrs. (Damaged Zr Clad Fuel)~~ ~~18 yrs. (Zr Clad Fuel Debris)~~ ~~10 yrs. (Intact SS Clad Fuel)~~		*CoC, Appendix B*
Max. Fuel Assembly Weight:			
w/channels *and DFC, as applicable*	700 lb.	-	Table 2.1.6
Max. Fuel Assembly Length (Unirradiated Nominal)	176.2 in.	-	Table 2.1.6
Max. Fuel Assembly Width (Unirradiated Nominal)	5.85 in.	-	Table 2.1.6
Fuel Rod Fill Gas:			
End-of-Life Hot Standby Pressure (max.)	147 psig	-	Table 4.3.5
Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Temperatures	See Tables 2.0.2 and 2.0.3	ANSI/ANS 57.9	Section 2.2.1.4
Handling:			Section 2.2.1.2
Handling Loads	115% of Dead Weight	CMAA #70	Section 2.2.1.2
Lifting Attachment Acceptance Criteria	1/10 Ultimate 1/6 Yield	NUREG-0612 ANSI N14.6	Section 3.4.3

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Attachment/Component Interface Acceptance Criteria	1/3 Yield	Regulatory Guide 3.61	Section 3.4.3
Away from Attachment Acceptance Criteria	ASME Code Level A	ASME Code	Section 3.4.3
Wet/Dry Loading	Wet or Dry	-	Section 1.2.2.2
Transfer Orientation	Vertical ~~or Horizontal~~	-	Section 1.2.2.2
Storage Orientation	Vertical	-	Section 1.2.2.2
Fuel Rod Rupture Releases:			
Fuel Rod Failures	1%	NUREG-1536	Section 2.2.1.3
Fill Gases	100%	NUREG-1536	Section 2.2.1.3
Fission Gases	30%	NUREG-1536	Section 2.2.1.3
Snow and Ice	Protected by Overpack	ASCE 7-88	Section 2.2.1.6
Off-Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Temperature	See Tables 2.0.2 and 2.0.3	ANSI/ANS 57.9	Section 2.2.2.2
Leakage of One Seal	No Loss of Confinement	ANSI/ANS 57.9	Section 2.2.2.4
Partial Blockage of Overpack Air Inlets	Two Air Inlets Blocked	-	Section 2.2.2.5
Fuel Rod Rupture Releases:			
Fuel Rod Failures	10%	NUREG-1536	Section 2.2.2.1
Fill Gases	100%	NUREG-1536	Section 2.2.2.1

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Fission Gases	30%	NUREG-1536	Section 2.2.2.1
Design-Basis (Postulated) Accident Design Events and Conditions:		10CFR72.24(d)(2) & 10CFR72.94	
Tip Over	See Table 2.0.2	-	Section 2.2.3.2
End Drop	See Table 2.0.2	-	Section 2.2.3.1
Side Drop	See Table 2.0.3	-	Section 2.2.3.1
Fire	See Tables 2.0.2 and 2.0.3	10CFR72.122(c)	Section 2.2.3.3
Fuel Rod Rupture Releases:			
Fuel Rod Failures *(including non-fuel hardware)*	100%	NUREG-1536	Section 2.2.3.8
Fill Gases	100%	NUREG-1536	Section 2.2.3.8
Fission Gases	30%	NUREG-1536	Section 2.2.3.8
Particulates & Volatiles	See Table 7.3.1	-	Sections 2.2.3.9 and 7.3
Confinement Boundary Leakage	7.5×10^{-6} *atm*-cm^3/sec (helium)	-	Sections 2.2.3.9 and 7.3
Explosive Overpressure	60 psig (external)	10CFR72.122(c)	Section 2.2.3.10
Airflow Blockage:			
Vent Blockage	100% of Overpack Air Inlets Blocked	10CFR72.128(a)(4)	Section 2.2.3.13
Partial Blockage of MPC Basket Vent Holes	*Crud Depth (Table 2.2.8)*	*ESEERCO Project EP91-29*	*Section 2.2.3.4*

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Design Basis Natural Phenomenon Design Events and Conditions:		10CFR72.92 & 10CFR72.122(b)(2)	
Flood Water Depth	125 ft.	ANSI/ANS 57.9	Section 2.2.3.6
Seismic	See Table 2.0.2	10CFR72.102(f)	Section 2.2.3.7
Wind	Protected by Overpack	ASCE-7-88	Section 2.2.3.5
Tornado & Missiles	Protected by Overpack	RG 1.76 & NUREG-0800	Section 2.2.3.5
Burial Under Debris	Maximum Decay Heat Load	-	Section 2.2.3.12
Lightning	See Table 2.0.2	NFPA 78	Section 2.2.3.11
~~Partial Blockage of MPC Basket Vent Holes~~	~~Crud Depth (Table 2.2.8)~~	~~ESEERCO Project EP91-29~~	~~Section 2.2.3.4~~
Extreme Environmental Temperature	See Table 2.0.2	-	Section 2.2.3.14

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Design Life:			
Design	40 yrs.	-	Section 2.0.2
License	20 yrs.	10CFR72.42(a) & 10CFR72.236(g)	
Structural:			
Design & Fabrication Codes:			
Concrete			
Design	ACI 349 as specified in Appendix 1.D	10CFR72.24(c)(4)	Section 2.0.2 and Appendix 1.D
Fabrication	ACI 349 as specified in Appendix 1.D	10CFR72.24(c)(4)	Section 2.0.2 and Appendix 1.D
Compressive Strength	ACI 318-95 as specified in Appendix 1.D	10CFR72.24(c)(4)	Section 2.0.2 and Appendix 1.D
Structural Steel			
Design	ASME Code Section III, Subsection NF	10CFR72.24(c)(4)	Section 2.0.2
Fabrication	ASME Code Section III, Subsection NF	10CFR72.24(c)(4)	Section 2.0.2

Table 2.0.2 (continued)

HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Design Weights:			
Max. Loaded MPC (Dry)	~~87,241~~ *88,135* lb. (MPC-~~68~~ *32*)	R.G. 3.61	Table 3.2.1
Max. Empty Overpack:			
Assembled with Top Cover *(100/100S)*	~~267,190~~ *265,866/252,377* lb.	R.G. 3.61	Table 3.2.1
Max. MPC/Overpack *(100/100S)*	~~354,431~~ *354,001/340,472* lb.	R.G. 3.61	Table 3.2.1
Design Cavity Pressures	N/A	-	Section 2.2.1.3
Response and Degradation Limits	Protect MPC from deformation	10CFR72.122(b) 10CFR72.122(c)	Sections 2.0.2 and 3.1
	Continued adequate performance of overpack	10CFR72.122(b) 10CFR72.122(c)	
	Retrieval of MPC	10CFR72.122(l)	
Thermal:			
Maximum Design Temperatures:			
Concrete			
Local Maximum (Normal)	200° F	ACI 349 Appendix A	Table 2.2.3
Local Maximum (Accident)	350° F	ACI 349 Appendix A	Table 2.2.3

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Steel Structure	350° F	ASME Code Section II, Part D	Table 2.2.3
Insolation:	Averaged Over 24 Hours	10CFR71.71	Section 4.4.1.1.8
Confinement:	None	10CFR72.128(a)(3) & 10CFR72.236(d) & (e)	N/A
Retrievability:			
Normal and Off-normal	No damage which precludes Retrieval of MPC or Exceeding Fuel Assembly Deceleration Limits	10CFR72.122(f),(h)(1), & (l)	Sections 3.5 and 3.4
Accident			Sections 3.5 and 3.4
Criticality:	Protection of MPC and Fuel Assemblies	10CFR72.124 & 10CFR72.236(c)	Section 6.1
Radiation Protection/Shielding:		10CFR72.126 & 10CFR72.128(a)(2)	
Overpack (Normal/Off-normal/Accident)			
Surface	ALARA	10CFR20	Chapters 5 and 10
Position	ALARA	10CFR20	Chapters 5 and 10
Beyond Controlled Area During Normal Operation and Anticipated Occurrences	25 mrem/yr. to whole body 75 mrem/yr. to thyroid 25 mrem/yr. to any *critical* organ	10CFR72.104	Sections 5.1.1, 7.2, and 10.1

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
~~On~~ *At* Controlled Area Boundary from Design Basis Accident	5 rem *TEDE* ~~to whole body or to any organ~~ *or sum of DDE and CDE to any individual organ or tissue (other than lens of eye) ≤ 50 rem. 15 rem lens dose. 50 rem shallow dose to skin or extremity.*	10CFR72.106	Sections 5.1.2, 7.3, and 10.1
Design Bases:			
Spent Fuel Specification	See Table 2.0.1	10CFR72.236(a)	Section 2.1
Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Outside Temperatures:			
Max.Yearly Average	80° F	ANSI/ANS 57.9	Section 2.2.1.4
Live Load:		ANSI/ANS 57.9	-
Loaded Transfer Cask (max.)	~~239,877~~ *240,758* lb. (125-ton HI-TRAC w/transfer lid)	R.G. 3.61	Table 3.2.2 Section 2.2.1.2
Dry Loaded MPC (max.)	~~87,241~~ *88,135* lb.	R.G. 3.61	Table 3.2.1 and Section 2.2.1.2
Handling:			Section 2.2.1.2
Handling Loads	115% of Dead Weight	CMAA #70	Section 2.2.1.2
Lifting Attachment Acceptance Criteria	1/10 Ultimate 1/6 Yield ANSI N14.6	NUREG-0612 ANSI N14.6	Section 3.4.3

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Attachment/Component Interface Acceptance Criteria	1/3 Yield	Regulatory Guide 3.61	Section 3.4.3
Away from Attachment Acceptance Criteria	ASME Code Level A	ASME Code	Section 3.4.3
Minimum Temperature During Handling Operations	0° F	ANSI/ANS 57.9	Section 2.2.1.2
Snow and Ice Load	100 lb./ft^2	ASCE 7-88	Section 2.2.1.6
Wet/Dry Loading	Dry	-	Section 1.2.2.2
Storage Orientation	Vertical	-	Section 1.2.2.2
Off-Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Temperature			
Minimum	-40° F	ANSI/ANS 57.9	Section 2.2.2.2
Maximum	100° F	ANSI/ANS 57.9	Section 2.2.2.2
Partial Blockage of Air Inlets	Two Air Inlet Ducts Blocked	-	Section 2.2.2.5
Design-Basis (Postulated) Accident Design Events and Conditions:		10CFR72.94	
Drop Cases:			
End	11 in.	-	Section 2.2.3.1
Tip-Over	Assumed (Non-mechanistic)	-	Section 2.2.3.2

Table 2.0.2 (continued)

HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Fire:			
Duration	217 seconds	10CFR72.122(c)	Section 2.2.3.3
Temperature	1,475° F	10CFR72.122(c)	Section 2.2.3.3
Fuel Rod Rupture	See Table 2.0.1	-	Section 2.2.3.8
Air Flow Blockage:			
Vent Blockage	100% of Air Inlets Blocked	10CFR72.128(a)(4)	Section 2.2.3.13
Ambient Temperature	80° F	10CFR72.128(a)(4)	Section 2.2.3.13
Explosive Overpressure External Pressure	*10 psid instantaneous, 5 psid steady state*	*10 CFR 72.128(a)(4)*	*Table 2.2.1*
Design-Basis Natural Phenomenon Design Events and Conditions:		10CFR72.92 & 10CFR72.122(b)(2)	
Flood			
Height	125 ft.	RG 1.59	Section 2.2.3.6
Velocity	15 ft/sec.	RG 1.59	Section 2.2.3.6
Seismic			
Resultant Max. ZPA Horizontal Ground (Max. ZPA Vertical Ground)	$G_H + 0.53G_V = 0.53$	10CFR72.102(f)	Section 3.4.7.1 .
Tornado			
Wind			

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Max. Wind Speed	360 mph	RG 1.76	Section 2.2.3.5
Pressure Drop	3.0 psi	RG 1.76	Section 2.2.3.5
Missiles			Section 2.2.3.5
Automobile			
Weight	1,800 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5
Rigid Solid Steel Cylinder			
Weight	125 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5
Diameter	8 in.	NUREG-0800	Table 2.2.5
Steel Sphere			
Weight	0.22 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5
Diameter	1 in.	NUREG-0800	Table 2.2.5
Burial Under Debris	Maximum Decay Heat Load	-	Section 2.2.3.12
Lightning	Resistance Heat-Up	NFPA 70 & 78	Section 2.2.3.11
Extreme Environmental Temperature	125° F	-	Section 2.2.3.14
Load Combinations:	See Table 2.2.14 and Table 3.1.5	ANSI/ANS 57.9 and NUREG-1536	Section 2.2.7

Table 2.0.3

HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Design Life:			
Design	40 yrs.	-	Section 2.0.3
License	20 yrs.	10CFR72.42(a) & 10CFR72.236(g)	
Structural:			
Design ~~& Fabrication~~ Codes:			
Structural Steel	ASME Code, Section III, Subsection NF	10CFR72.24(c)(4)	Section 2.0.3
Lifting Trunnions	NUREG-0612 & ANSI N14.6	10CFR72.24(c)(4)	Section 1.2.1.4
Design Weights:			
Max. Empty Cask:			
W/Pool Lid & No Top Lid	~~140,258~~ *140,246* lb. (125-ton HI-TRAC) ~~99,758~~ *99,246* lb. (100-ton HI-TRAC)	R.G. 3.61	Table 3.2.2
W/Top Lid & Transfer Lid	~~152,636~~ *152,624* lb. (125-ton HI-TRAC) ~~109,470~~ *108,626* lb. (100-ton HI-TRAC)	R.G. 3.61	Table 3.2.2

Table 2.0.3 (continued)

HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Max. MPC/HI-TRAC with Yoke (in-pool lift):			
Water Jacket Empty	~~199,394~~ *234,711* lb. (~~100~~ *125*-ton HI-TRAC)	R.G. 3.61	Table 3.2.4
Water Jacket Full	~~248,105~~ *248,601* lb. (125-ton HI-TRAC)	R.G. 3.61	Table 3.2.4
Design Cavity Pressures:			
HI-TRAC Cavity	Hydrostatic	ANSI/ANS 57.9	Section 2.2.1.3
Water Jacket Cavity	60 psig (internal)	ANSI/ANS 57.9	Section 2.2.1.3
Response and Degradation Limits	Protect MPC from deformation	10CFR72.122(b) 10CFR72.122(c)	Section 2.0.3
	Continued adequate performance of HI-TRAC transfer cask	10CFR72.122(b) 10CFR72.122(c)	
	Retrieval of MPC	10CFR72.122(l)	
Thermal:			
Maximum Design Temperature			
Structural Materials	400° F	ASME Code Section II, Part D	Table 2.2.3
Shielding Materials			

Table 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Lead	350° F (max.)	-	Table 2.2.3
Liquid Neutron Shield	307° F (max.)	-	Table 2.2.3
Solid Neutron Shield	300° F (max.)	Manufacturer Data	Table 2.2.3
Insolation:	Averaged Over 24 Hours	10CFR71.71	Section 4.5.1.1.3
Confinement:	None	10CFR72.128(a)(3) & 10CFR72.236(d) & (e)	N/A
Retrievability:			
Normal and Off-normal	No encroachment on MPC or Exceeding Fuel Assembly Deceleration Limits	10CFR72.122(f),(h)(1), & (l)	Sections 3.5 & 3.4
After Design-basis (Postulated) Accident			Section 3.5 & 3.4
Criticality:	Protection of MPC and Fuel Assemblies	10CFR72.124 & 10CFR72.236(c)	Section 6.1
Radiation Protection/Shielding:		10CFR72.126 & 10CFR72.128(a)(2)	
Transfer Cask (Normal/Off-normal/Accident)			
Surface	ALARA	10CFR20	Chapters 5 and 10
Position	ALARA	10CFR20	Chapters 5 and 10
Design Bases:			
Spent Fuel Specification	See Table 2.0.1	10CFR72.236(a)	Section 2.1

Table 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Temperatures:			
~~Lifetime~~ *Lifetime* Average	100° F	ANSI/ANS 57.9	Section 2.2.1.4
Live Load			
Max. Loaded Canister			
Dry	~~87,241~~ *88,135* lb.	R.G. 3.61	Table 3.2.1
Wet	~~103,898~~ *104,705* lb.	R.G. 3.61	Table 3.2.4
Handling:			Section 2.2.1.2
Handling Loads	115% of Dead Weight	CMAA #70	Section 2.2.1.2
Lifting Attachment Acceptance Criteria	1/10 Ultimate 1/6 Yield	NUREG-0612 ANSI N14.6	Section 3.4.3
Attachment/Component Interface Acceptance Criteria	1/3 Yield	Regulatory Guide 3.61	Section 3.4.3
Away from Attachment Acceptance Criteria	ASME Code Level A	ASME Code	Section 3.4.3
Minimum Temperature for Handling Operations	0° F	ANSI/ANS 57.9	Section 2.2.1.2
Wet/Dry Loading	Wet or Dry	-	Section 1.2.2.2
Transfer Orientation	Vertical ~~or Horizontal~~	-	Section 1.2.2.2
Test Loads:			

Table 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Trunnions	300% of vertical design load	NUREG-0612 & ANSI N14.6	Section 9.1.2.1
Off-Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Temperature			
Minimum	0° F	ANSI/ANS 57.9	Section 2.2.2.2
Maximum	100° F	ANSI/ANS 57.9	Section 2.2.2.2
Design-Basis (Postulated) Accident Design Events and Conditions:		10CFR72.24(d)(2) & 10CFR72.94	
Side Drop	42 in.	-	Section 2.2.3.1
Fire			
Duration	4.8 minutes	10CFR72.122(c)	Section 2.2.3.3
Temperature	1,475° F	10CFR72.122(c)	Section 2.2.3.3
Fuel Rod Rupture	See Table 2.0.1		Section 2.2.3.8
Design-Basis Natural Phenomenon Design Events and Conditions:		10CFR72.92 & 10CFR72.122(b)(2)	
Missiles			Section 2.2.3.5
Automobile			
Weight	1800 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5

Table 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Rigid Solid Steel Cylinder			
Weight	125 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5
Diameter	8 in.	NUREG-0800	Table 2.2.5
Steel Sphere			
Weight	0.22 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5
Diameter	1 in.	NUREG-0800	Table 2.2.5
Load Combinations:	See Table 2.2.14 and Table 3.1.5	ANSI/ANS-57.9 & NUREG-1536	Section 2.2.7

2.1 SPENT FUEL TO BE STORED

2.1.1 Determination of The Design Basis Fuel

The HI-STORM 100 System is designed to store most types of fuel assemblies generated in the commercial U.S. nuclear industry. Boiling-water reactor (BWR) fuel assemblies have been supplied by The General Electric Company (GE), Siemens, Exxon Nuclear, ANF, UNC, ABB Combustion Engineering, and Gulf Atomic. Pressurized-water reactor (PWR) fuel assemblies are generally supplied by Westinghouse, Babcock & Wilcox, ANF, and ABB Combustion Engineering. ANF, Exxon, and Siemens are historically the same manufacturing company under different ownership. Within this report, SPC is used to designate fuel manufactured by ANF, Exxon, or Siemens. Publications such as Refs. [2.1.1] and [2.1.2] provide a comprehensive description of fuel discharged from U.S. reactors. A central object in the design of the HI-STORM 100 System is to ensure that a majority of SNF discharged from the U.S. reactors can be stored in one of the MPCs.

The cell openings and lengths in the fuel basket have been sized to accommodate the BWR and PWR assemblies listed in Refs. [2.1.1] and [2.1.2] except as noted below. Similarly, the cavity length of the multi-purpose canisters has been set at a dimension which permits storing most types of PWR fuel assemblies and BWR fuel assemblies with or without fuel channels. The *one* exception~~s~~ *is* ~~are~~ as follows:

i. The South Texas Units 1 & 2 SNF, and CE 16x16 System 80 SNF are too long to be accommodated in the available MPC cavity length.

In addition to satisfying the cross sectional and length compatibility, the active fuel region of the SNF must be enveloped in the axial direction by the neutron absorber located in the MPC fuel basket. Alignment of the neutron absorber with the active fuel region is ensured by the use of upper and lower fuel spacers suitably designed to support the bottom and restrain the top of the fuel assembly. The spacers axially position the SNF assembly such that its active fuel region is properly aligned with the neutron absorber in the fuel basket. Figure 2.1.5 provides a pictorial representation of the fuel spacers positioning the fuel assembly active fuel region. Both the upper and lower fuel spacers are designed to perform their function under normal, off-normal, and accident conditions of storage.

In summary, the geometric compatibility of the SNF with the MPC designs does not require the definition of a design basis fuel assembly. This, however, is not the case for structural, confinement, shielding, thermal-hydraulic, and criticality criteria. In fact, a particular fuel type in a category (PWR or BWR) may not control the cask design in all of the above-mentioned criteria. To ensure that no SNF listed in Refs. [2.1.1] and [2.1.2] which is geometrically admissible in the MPC is precluded, it is necessary to determine the governing fuel specification for each analysis criterion. To make the necessary determinations, potential candidate fuel assemblies for each qualification criterion were considered. Table 2.1.1 lists the PWR fuel assemblies which were evaluated. These fuel assemblies were evaluated to define the governing design criteria for PWR fuel. The BWR fuel assembly designs evaluated are listed in Table 2.1.2. Tables 2.1.3 and 2.1.4 provide the fuel characteristics determined to be acceptable for storage in the HI-STORM 100 System. Any fuel assembly that has fuel characteristics within the range of Tables 2.1.3 and 2.1.4 *and Appendix B to the CoC* is acceptable for storage in the HI-STORM 100 System. Table 2.1.5 lists the BWR and PWR fuel assembly designs which are found to govern for three qualification criteria, namely reactivity, shielding, and decay heat generation. Substantiating results of analyses for the governing assembly types are presented in the respective chapters dealing with the specific qualification topic. Additional information on the design basis fuel definition is presented in the following subsections.

2.1.2 Intact SNF Specifications

Intact fuel assemblies are defined as fuel assemblies without known or suspected cladding defects greater than pinhole leaks and hairline cracks, and which can be handled by normal means. The design payload for the HI-STORM 100 System is intact zircaloy clad fuel assemblies with the characteristics listed in Table 2.1.6 or intact stainless steel clad fuel assemblies with the characteristics listed in Table 2.1.8. The placement of a single stainless steel clad fuel assembly in a MPC necessitates that all fuel assemblies (stainless steel clad or zircaloy clad) stored in that MPC meet the maximum heat generation requirements for stainless steel clad fuel specified in Table 2.1.8. Intact BWR MOX fuel assemblies shall meet the requirements of Table 2.1.7.

Intact fuel assemblies with missing pins cannot be loaded into the HI-STORM 100 unless dummy fuel pins, which occupy a volume greater than or equal to the original fuel pins, replace the missing pins prior to loading. Any intact fuel assembly which falls within the geometric, thermal, and nuclear limits established for the design basis intact fuel assembly, as defined in the ~~Technical Specifications of Chapter 12~~ *Approved Contents section of Appendix B to the CoC* can be safely stored in the HI-STORM 100 System.

The range of fuel characteristics specified in Tables 2.1.3 and 2.1.4 have been evaluated in this TSAR and are acceptable for storage in the HI-STORM 100 System.

2.1.3 Damaged SNF and Fuel Debris Specifications

Damaged fuel assemblies are defined as fuel assemblies with known or suspected cladding defects, *as determined by a review of records,* greater than pinhole leaks and hairline cracks or missing fuel rods that are not replaced with dummy fuel rods,~~ and which may have mechanical damage which would not allow it to~~ *or those that cannot* be handled by normal means; however, there shall be no loose components. No loose fuel debris is allowed with the damaged fuel assembly. *Fuel assemblies which cannot be handled by normal means due to fuel cladding damage are considered fuel debris.*

Fuel debris is defined as ~~fuel assemblies with known or suspected defects greater than pinhole leaks or hairline cracks such as~~ ruptured fuel rods, severed fuel rods, ~~or~~ loose fuel pellets, ~~and~~*or fuel assemblies with known or suspected defects* which cannot be handled by normal means *due to fuel cladding damage.*

To aid in loading and unloading, damaged fuel assemblies and fuel debris will be loaded into stainless steel damaged fuel containers (DFCs) provided with 250 x 250 fine mesh screens, prior to placement in the HI-STORM 100 System. ~~This application requests approval of Dresden Unit 1 (UO~~~~$_2$~~~~ rods and MOX fuel rods) and Humboldt Bay fuel arrays (Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A) are approved as damaged fuel assembly contents for storage in the MPC-68 and fuel debris as contents for storage in the MPC-68F. The design characteristics bounding Dresden Unit 1 and Humboldt Bay SNF are given in Table 2.1.7. The placement of a single damaged fuel assembly in an MPC-68 or a single fuel debris damaged fuel container in an MPC-68F necessitates that all fuel assemblies (intact, damaged, or debris) stored in that MPC meet the maximum heat generation requirements specified in Table 2.1.7. The fuel characteristics specified in Table 2.1.4 for Dresden 1 and Humboldt Bay fuel arrays have been evaluated in this TSAR and are acceptable for storage as damaged fuel or fuel debris in the HI-STORM 100 System. The DFC design is illustrated in Figure 2.1.1 and the Design Drawings are provided in Section 1.5. Because of the long cooling time, small size, and low weight of spent fuel assemblies qualified as damaged fuel or fuel debris, the DFC and its contents are bounded by the structural, thermal, and shielding analyses performed for the intact BWR design basis fuel. Separate criticality analysis of the bounding fuel assembly for the damaged fuel and fuel debris has been performed in Chapter 6.~~ *The MPC-24E is designed to accommodate PWR damaged fuel. The MPC-68F and MPC-68FF are designed to accommodate BWR damaged fuel and fuel debris. The appropriate structural, thermal, shielding, criticality, and confinement analyses have been performed to account for damaged fuel and fuel debris and are described in their respective chapters that follow. The limiting design characteristics for damaged fuel assemblies authorized for loading in the HI-STORM 100 System are provided in Table 2.1.7. Restrictions on the number and location of damaged fuel containers authorized for loading in each MPC model are provided in the Approved Contents section of Appendix B to the CoC.*

Dresden Unit 1 fuel assemblies contained in Transnuclear-design damaged fuel canisters and one Dresden Unit 1 thoria rod canister have been approved for storage directly in the HI-STORM 100 System without re-packaging (see Figures 2.1.2 and 2.1.2A). Additionally, the balance of PWR and BWR fuel assemblies classified as damaged fuel assemblies or fuel debris have been qualified for storage, in limited quantities, in damaged fuel containers in the MPC-24E and the MPC-68 and MPC-68FF (see Figures 2.1.2B and 2.1.2C).

2.1.4 Deleted

2.1.5 Structural Parameters for Design Basis SNF

The main physical parameters of a SNF assembly applicable to the structural evaluation are the fuel assembly length, envelope (cross sectional dimensions), and weight. These parameters, which define the mechanical and structural design, are listed in Tables 2.1.6, 2.1.7, and 2.1.8. The centers of gravity reported in Section 3.2 are based on the maximum fuel assembly weight. Upper and lower fuel spacers (as appropriate) maintain the axial position of the fuel assembly within the MPC basket and, therefore, the location of the center of gravity. The upper and lower fuel spacers are designed to withstand normal, off-normal, and accident conditions of storage. An axial clearance of approximately 2 inches is provided to account for the irradiation and thermal growth of the fuel assemblies. The *suggested* upper and lower fuel spacer lengths are listed in Tables 2.1.9 and 2.1.10. In order to qualify for storage in the MPC, the SNF must satisfy the physical parameters listed in Tables 2.1.6, 2.1.7, or 2.1.8.

2.1.6 Thermal Parameters for Design Basis SNF

The principal thermal design parameter for the stored fuel is the peak fuel cladding temperature, which is a function of the maximum heat generation rate per assembly, the allowable fuel cladding temperature based on cooling time, and the decay heat removal capabilities of the HI-STORM 100 System. The maximum heat generation rate per assembly for the design basis fuel assembly is based on the fuel assembly type with the highest decay heat for a given enrichment, burnup, and cooling time. This decay heat design basis fuel assembly is listed in Table 2.1.5. Section 5.2 describes the method used to determine the design basis fuel assembly type and calculate the decay heat load.

~~To ensure the allowable fuel cladding temperature limits are not exceeded, Table 2.0.1 specifies the allowable decay heat per assembly versus cooling time for zircaloy clad fuel in each MPC type. Tables 2.1.7 and 2.1.8 provide the maximum heat generation for damaged zircaloy clad fuel assemblies and stainless steel clad fuel assemblies, respectively. Due to the conservative thermal assessment and the long cooling time of the damaged and stainless steel clad fuel, a reduction in decay heat load is not required as the cooling time increases beyond the minimum specified.~~

To ensure the permissible fuel cladding temperature limits are not exceeded, the Approved Contents section of Appendix B to the CoC specified the allowable decay heat per assembly for each MPC model. For both uniform and regionalized loading of intact Zircaloy clad fuel assemblies, the allowable decay heat per assembly is a function of cooling time and is presented in Appendix B to the CoC in Tables 2.1-5 and 2.1-7. For stainless steel clad fuel assemblies and damaged fuel assemblies of both cladding types, the allowable decay heat per assembly is not dependent upon cooling time and is specified in Table 2.1-1 of Appendix B to the CoC. Due to the large conservatisms in the thermal evaluations and the relatively long cooling times and corresponding low decay heats for stainless steel clad and damaged fuel fuel assemblies, as age-dependent allowable decay heat limit is not necessary.

The specified decay heat load can be attained by varying burnups and cooling times. ~~Figure 2.1.6~~ *The Approved Contents section of Appendix B to the CoC* provides the burnup and cooling time characteristics for intact zircaloy clad fuel to meet the thermal requirements for the MPC-24, *MPC-24E, MPC-32,* ~~and~~ MPC-68, *MPC-68F and MPC-68FF.* ~~Any intact zircaloy clad fuel assembly with a burnup and cooling time which lies on or below the curve of Figure 2.1.6 is thermally acceptable for loading into the HI-STORM 100 System. Each point on the curve produces a decay heat equal to or below the value specified in Table 2.0.1.~~

The Approved Contents section of Appendix B to the CoC also includes separate cooling time, burnup, and decay heat limits for uniform fuel loading and regionalized fuel loading. Regionalized loading allows higher heat emitting fuel assemblies to be stored in the center fuel storage locations than would otherwise be authorized for storage under uniform loading conditions.

~~Figure 2.1.6 does not extend beyond 15 years of cooling time. For fuel assemblies with cooling times greater than 15 years, the maximum allowed burnup will be limited to maximum burnup value specified for 15 years. As shown in Figure 2.1.6 the allowable burnup increases as the cooling time increases due to the decay of radioactivity over time. Therefore, limiting the maximum burnup for fuel assemblies with more than 15 years of cooling time to the corresponding burnup value for 15 years ensures that the decay heat load from these older fuel assemblies will be less than the values analyzed in this TSAR.~~

The fuel rod cladding temperature is also affected by other factors. A governing geometry which maximizes the impedance to the transmission of heat out of the fuel rods has been defined. The governing thermal parameters to ensure that the range of SNF discussed previously are bounded by the thermal analysis are discussed in detail and specified in Chapter 4. By utilizing these bounding thermal parameters, the calculated peak fuel rod cladding temperatures are conservative for actual spent fuel assemblies which have greater thermal conductivities.

Finally, the axial variation in the heat generation rate in the design basis fuel assembly is defined based on the axial burnup distribution. For this purpose, the data provided in Refs. [2.1.7] and [2.1.8] are utilized and summarized in Table 2.1.11 and Figures 2.1.3 and 2.1.4 for reference. These distributions are representative of fuel assemblies with the design basis burnup levels considered. These distributions are used for analyses only, and do not provide a criteria for fuel assembly acceptability for storage in the HI-STORM 100 System.

Fuel may be stored in the MPC using one of two storage strategies, namely, uniform loading and regionalized loading. Uniform loading allows storage of any fuel assembly in any fuel storage location, subject to additional restrictions specified in the CoC for preferential fuel loading and loading of fuel assemblies containing non-fuel hardware such as Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Devices (TPDs), Control Rod Assemblies (CRAs), and Axial Power Shaping Rods (APSRs). Regionalized fuel loading allows for higher decay heat fuel assemblies to be stored in the central core basket storage locations with lower decay heat fuel *assemblies in the peripheral fuel storage locations. Regionalized loading allows storage of higher decay heat fuel assemblies than would otherwise be permitted using the uniform loading strategy. The definition of the regions for each MPC model and the associated burnup, cooling time, and decay heat limits are found in Appendix B to the CoC.*

2.1.7 Radiological Parameters for Design Basis SNF

The principal radiological design criteria for the HI-STORM 100 System are the 10CFR72.104 site boundary dose rate limits and maintaining operational dose rates as low as reasonably achievable (ALARA). The radiation dose is directly affected by the gamma and neutron source terms of the SNF assembly.

The gamma and neutron sources are separate and are affected differently by enrichment, burnup, and cooling time. It is recognized that, at a given burnup, the radiological source terms increase monotonically as the initial enrichment is reduced. The shielding design basis fuel assembly, therefore, is evaluated at the maximum burnup, minimum cooling time, and a conservative enrichment corresponding to the burnup. The shielding design basis fuel assembly thus bounds all other fuel assemblies.

The design basis dose rates can be met by a variety of burnup levels and cooling times. *The Approved Contents section of Appendix B to the CoC provides the burnup and cooling time limits for all of the authorized fuel assembly array/classes for both uniform fuel loading and regionalized loading.* ~~Table 2.1.7 provides the burnup and cooling time values which meet the radiological source term requirements for damaged BWR fuel in the MPC-68 and fuel debris in the MPC-68F. Table 2.1.8 provides the burnup and cooling time values which meet the radiological source term requirements for intact stainless steel clad fuel. Figure 2.1.6 provides illustrative burnup and cooling time values which meet the radiological source term requirements for zircaloy clad fuel in each MPC type.~~

Table 2.1.11 and Figures 2.1.3 and 2.1.4 provide the axial distribution for the radiological source terms for PWR and BWR fuel assemblies based on the axial burnup distribution. The axial burnup distributions are representative of fuel assemblies with the design basis burnup levels considered. These distributions are used for analyses only, and do not provide a criteria for fuel assembly acceptability for storage in the HI-STORM 100 System.

Thoria rods placed in Dresden Unit 1 Thoria Rod Canisters meeting the requirements of Table 2.1.12 and Dresden Unit 1 fuel assemblies with one Antimony-Beryllium neutron source have been qualified for storage. Up to one Thoria Rod Canister is authorized for storage in combination with other intact and damaged fuel, and fuel debris as specified in Appendix B to the CoC.

Non-fuel hardware, including BPRAs, TPDs, CRAs, and APSRs and other similarly designed hardware with different names is authorized for storage in the MPC-24, MPC-24E, and MPC-32 as specified in Appendix B to the CoC.

2.1.8 Criticality Parameters for Design Basis SNF

As discussed earlier, the MPC-68, *MPC-68F, MPC-68FF, and MPC-32* feature~~s~~ a basket without flux traps. In the *aforementioned* ~~MPC-68~~ basket*s*, there is one panel of neutron absorber between two adjacent fuel assemblies. The MPC-24 *and MPC-24E* employ~~s~~ a construction wherein two neighboring fuel assemblies are separated by two panels of neutron absorber with a water gap between them (flux trap construction).

The MPC-24 Boral ^{10}B areal density is specified at a minimum loading of 0.0267 g/cm^2. The MPC-68, *MPC-68FF, MPC-24E, and MPC-32* Boral ^{10}B areal density is specified at a minimum loading of 0.0372 g/cm^2. The MPC-68F Boral ^{10}B areal density is specified at a minimum loading of 0.01 g/cm^2.

For all MPCs, the ^{10}B areal density used for analysis is conservatively established at 75% of the minimum ^{10}B areal density to demonstrate that the reactivity under the most adverse accumulation of tolerances and biases is less than 0.95. This complies with NUREG-1536 [2.1.5] which requires a 25% reduction in ^{10}B areal density credit. A large body of sampling data accumulated by Holtec from thousands of manufactured Boral panels indicates the average ^{10}B areal densities to be approximately 15% greater than the specified minimum.

The criticality analyses for the MPC-24 and MPC-24E (with higher enriched fuel) and for the MPC-32 were performed with credit taken for soluble boron in the MPC water during wet loading and unloading operations. Table 2.1.14 provides the required soluble boron concentrations for these MPCs. Minumum soluble boron concentration is also included as Limiting Condition for Operation (LCO)3.3.1 in the Technical Specifications found in Appendix A to the CoC.

2.1.9 Summary of SNF Design Criteria

~~An intact zircaloy clad fuel assembly is acceptable for storage in a HI-STORM 100 System if it fulfills the following criteria :~~

~~a. It satisfies the physical characteristics listed in Tables 2.1.3 or 2.1.4, and 2.1.6.~~

~~b. Its initial enrichment is less than that indicated by Table 2.1.6 for the fuel assembly and MPC type.~~

~~c. The period from discharge is greater than or equal to the minimum cooling time listed in Table 2.1.6, and the decay heat is equal to or less than the maximum value stated in Table~~

~~2.0.1 for a given cooling time.~~

~~d. The average burnup of the fuel assembly is less than or equal to the burnup specified in Figure 2.1.6 for a given cooling time.~~

~~A damaged fuel assembly shall meet the characteristics specified in Table 2.1.7 for storage in the MPC-68. A fuel assembly classified as fuel debris shall meet the characteristics specified in Table 2.1.7 for storage in the MPC-68F.~~

~~Stainless steel clad fuel assemblies shall meet the characteristics specified in Table 2.1.8 for storage in the MPC-24 and MPC-68.~~

~~MOX BWR fuel assemblies shall meet the requirements of Tables 2.1.6 and 2.1.7 for intact and damaged fuel/fuel debris, respectively.~~

~~No PWR control components are to be included with the fuel assembly.~~

Tables 2.1.1 through 2.1.8 and Table 2.1.12 provide the design characteristics for spent fuel and certain non-fuel hardware authorized for storage in the HI-STORM 100 System. Much of this information is repeated in the Approved Contents section of Appendix B to the CoC. Only fuel meeting the specifications in these tables and the CoC is authorized for storage. Fuel classified as damaged fuel assemblies or fuel debris must be stored in damaged fuel containers for storage in the HI-STORM 100 System.

Table 2.1.1

PWR FUEL ASSEMBLIES EVALUATED TO DETERMINE DESIGN BASIS SNF

Assembly Class	**Array Type**
B&W 15x15	All
B&W 17x17	All
CE 14x14	All
CE 16x16	All *except System 80*^{TM}
WE 14x14	All
WE 15x15	All
WE 17x17	All
St. Lucie	All
Ft. Calhoun	All
Haddam Neck (Stainless Steel Clad)	All
San Onofre 1 (Stainless Steel Clad)	All
Indian Point 1	*All*

Table 2.1.2

BWR FUEL ASSEMBLIES EVALUATED TO DETERMINE DESIGN BASIS SNF

Assembly Class	**Array Type**			
GE BWR/2-3	All 7x7	All 8x8	All 9x9	All 10x10
GE BWR/4-6	All 7x7	All 8x8 ~~(except 8x8 WE (QUAD+))~~	All 9x9	All 10x10
Humboldt Bay	All 6x6	All 7x7 (Zircaloy Clad)		
Dresden-1	All 6x6	All 8x8		
LaCrosse (Stainless Steel Clad)	All			

Table 2.1.3
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**14x14 A**	**14x14 B**	**14x14 C**	**14x14 D**	***14x14E***
Clad Material (Note 2)	Zr	Zr	Zr	SS	*SS*
Design Initial U (kg/assy.) (Note 4)	~~≤ 402~~ *≤ 407*	~~≤ 402~~ *≤ 407*	~~≤ 410~~ *≤ 425*	≤ 400	*≤ 206*
Initial Enrichment *(MPC-24 and MPC-24E without soluble boron credit)* (wt % ^{235}U) *(Note 8)*	≤ 4.6 *(24)* *≤ 5.0 (24E)*	≤ 4.6 *(24)* *≤ 5.0 (24E)*	≤ 4.6 *(24)* *≤ 5.0 (24E)*	≤ 4.0 *(24)* *≤ 5.0 (24E)*	*≤ 4.0 (24)* *≤ 5.0 (24E)*
Initial Enrichment (MPC-24, 24E, or 32 with soluble boron credit - see Notes 6 and 8) (wt % ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rods	179	179	176	180	*173*
Clad O.D. (in.)	≥ 0.400	≥ 0.417	≥ 0.440	≥ 0.422	*≥ 0.3415*
Clad I.D. (in.)	≤ 0.3514	≤ 0.3734	~~≤ 0.3840~~ *≤ 0.3880*	≤ 0.3890	*≤ 0.3175*
Pellet Dia. (in.)	≤ 0.3444	≤ 0.3659	~~≤ 0.3770~~ *≤ 0.3805*	≤ 0.3835	*≤ 0.3130*
Fuel Rod Pitch (in.)	≤ 0.556	≤ 0.556	≤ 0.580	≤ 0.556	*Note 7*
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 144	
No. of Guide Tubes	17	17	5 (see Note 3)	16	
Guide Tube Thickness (in.)	≥ 0.017	≥ 0.017	~~≥ 0.040~~ *≥ 0.038*	≥ 0.0145	

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.
2. Zr designates cladding material made of Zirconium or Zirconium alloys.
3. Each guide tube replaces 4 fuel rods.
4. Design initial uranium weight is the nominal *uranium* weight specified for each assembly by the fuel manufacturer or reactor user. *For each PWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 2.0 percent for comparison with users' fuel records to account for manufacturer tolerances.*
5. Description of the fuel assembly class designation is provided in Chapter 6.
6. *Boron concentrations are provided in Table 2.1.14*
7. *This fuel assembly array/class includes only the Indian Point 1 fuel assembly. This fuel assembly has two pitches in different sectors of the assembly.*
8. *For those MPCs loaded with both intact fuel and damaged fuel, the maximum initial enrichment of the intact fuel is limited to the maximum initial enrichment of the damaged fuel (i.e., 4.0 wt.% ^{235}U).*

Table 2.1.3 (continued)
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**15x15 A**	**15x15 B**	**15x15 C**	**15x15 D**	**15x15 E**	**15x15 F**
Clad Material (Note 2)	Zr	Zr	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note 3)	~~≤ 420~~ *≤ 464*	≤ 464	≤ 464	≤ 475	≤ 475	≤ 475
Initial Enrichment *(MPC-24 and MPC-24E without soluble boron credit)* (wt % ^{235}U) *(See Note 6)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*	≤ 4.1 *(24)* *≤ 4.5 (24E)*
Initial Enrichment (MPC-24, 24E, or 32 with soluble boron credit - see Notes 5 and 6) (wt % ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rods	204	204	204	208	208	208
Clad O.D. (in.)	≥ 0.418	≥ 0.420	≥ 0.417	≥ 0.430	≥ 0.428	≥ 0.428
Clad I.D. (in.)	≤ 0.3660	≤ 0.3736	≤ 0.3640	≤ 0.3800	≤ 0.3790	≤ 0.3820
Pellet Dia. (in.)	≤ 0.3580	≤ 0.3671	≤ 0.3570	≤ 0.3735	≤ 0.3707	≤ 0.3742
Fuel Rod Pitch (in.)	≤ 0.550	≤ 0.563	≤ 0.563	≤ 0.568	≤ 0.568	≤ 0.568
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide Tubes	21	21	21	17	17	17
Guide Tube Thickness (in.)	≥ 0.0165	≥ 0.015	≥ 0.0165	≥ 0.0150	≥ 0.0140	≥ 0.0140

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.
2. Zr designates cladding material made of Zirconium or Zirconium alloys.
3. Design initial uranium weight is the nominal *uranium* weight specified for each assembly by the fuel manufacturer or reactor user. *For each PWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 2.0 percent for comparison with users' fuel records to account for manufacturer tolerances.*
4. Description of the fuel assembly class designation is provided in Chapter 6.
5. *Boron concentrations are provided in Table 2.1.14*
6. *For those MPCs loaded with both intact fuel and damaged fuel, the maximum initial enrichment of the intact fuel is limited to the maximum initial enrichment of the damaged fuel (i.e., 4.0 wt.% ^{235}U).*

Table 2.1.3 (continued)
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**15x15 G**	***15x15H***	**16x16 A**	**17x17A**	**17x17 B**	**17x17 C**
Clad Material (Note 2)	SS	*Zr*	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note 4)	≤ 420	*≤ 475*	~~≤430~~ *≤ 443*	~~≤450~~ *≤ 467*	~~≤464~~ *≤ 467*	~~≤460~~ *≤ 474*
Initial Enrichment *(MPC-24 and MPC-24E without soluble boron credit)* (wt % ^{235}U) *(Note 7)*	≤ 4.0 *(24)* *≤ 4.5 (24E)*	*≤ 3.8* *≤ 4.2 (24E)*	≤ 4.6 *≤ 5.0 (24E)*	≤ 4.0 *≤ 4.4 (24E)*	≤ 4.0 *≤ 4.4 (24E)*	≤ 4.0 *≤ 4.4 (24E)*
Initial Enrichment (MPC-24, 24E, or 32 with soluble boron credit - see Notes 6 and 7) (wt % ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rods	204	*≤ 5.0*	236	264	264	264
Clad O.D. (in.)	≥ 0.422	*≥ 0.414*	≥ 0.382	≥ 0.360	≥ 0.372	≥ 0.377
Clad I.D. (in.)	≤ 0.3890	*≤ 0.3700*	≤ 0.3320	≤ 0.3150	≤ 0.3310	≤ 0.3330
Pellet Dia. (in.)	≤ 0.3825	*≥ 0.3622*	≤ 0.3255	≤ 0.3088	≤ 0.3232	≤ 0.3252
Fuel Rod Pitch (in.)	≤ 0.563	*≤ 0.568*	≤ 0.506	≤ 0.496	≤ 0.496	≤ 0.502
Active Fuel Length (in.)	≤ 144	*≤ 150*	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide Tubes	21	*17*	5 (see note 3)	25	25	25
Guide Tube Thickness (in.)	≥ 0.0145	*≥ 0.140*	≥ 0.0400	≥ 0.016	≥ 0.014	≥ 0.020

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.
2. Zr designates cladding material made of Zirconium or Zirconium alloys.
3. Each guide tube replaces 4 fuel rods.
4. Design initial uranium weight is the nominal *uranium* weight specified for each assembly by the fuel manufacturer or reactor user. *For each PWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 2.0 percent for comparison with users' fuel records to account for manufacturer tolerances.*
5. Description of the fuel assembly class designation is provided in Chapter 6.
6. *Boron concentrations are provided in Table 2.1.14.*
7. *For those MPCs loaded with both intact fuel and damaged fuel, the maximum initial enrichment of the intact fuel is limited to the maximum initial enrichment of the damaged fuel (i.e., 4.0 wt.% ^{235}U).*

Table 2.1.4
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**6x6 A**	**6x6 B**	**6x6 C**	**7x7 A**	**7x7 B**	**8x8 A**
Clad Material (Note 2)	Zr	Zr	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note 4)	~~≤ 108~~ ≤ 110	~~≤ 108~~ ≤ 110	~~≤ 108~~ ≤ 110	≤ 100	≤ 195	≤ 120
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 7)	*≤ 2.7*	*≤ 2.7 for UO_2 rods. See Note 3 for MOX rods*	*≤ 2.7*	*≤ 2.7*	*≤ 4.2*	*≤ 2.7*
Initial Maximum Rod Enrichment (wt.% ^{235}U)	*≤ 4.0*	*≤ 4.0*	*≤ 4.0*	~~*≤ 4.0*~~ *≤ 5.5*	*≤ 5.0*	*≤ 4.0*
No. of Fuel Rods	*35 or* 36	*35 or* 36 (up to 9 MOX rods)	36	49	49	*63 or* 64
Clad O.D. (in.)	≥ 0.5550	≥ 0.5625	≥ 0.5630	≥ 0.4860	≥ 0.5630	≥ 0.4120
Clad I.D. (in.)	~~≤ 0.4945~~ *≤ 0.5105*	≤ 0.4945	≤ 0.4990	~~≤ 0.4200~~ *≤ 0.4204*	≤ 0.4990	≤ 0.3620
Pellet Dia. (in.)	~~≤ 0.4940~~ *≤ 0.4980*	≤ 0.4820	≤ 0.4880	≤ 0.4110	~~≤ 0.4880~~ *≤ 0.4910*	≤ 0.3580
Fuel Rod Pitch (in.)	~~0.694~~ ≤ 0.710	~~0.694~~ ≤ 0.710	≤ 0.740	≤ 0.631	≤ 0.738	≤ 0.523
Active Fuel Length (in.)	~~≤ 110~~ *≤ 120*	~~≤ 110~~ *≤ 120*	≤ 77.5	~~≤ 79~~ *≤ 80*	≤ 150	~~≤ 110~~ *≤ 120*
No. of Water Rods *(see note 6)*	*1 or* 0	*1 or* 0	0	0	0	*1 or* 0
Water Rod Thickness (in.)	~~N/A~~ *> 0*	~~N/A~~ *> 0*	N/A	N/A	N/A	~~N/A~~ *> 0*
Channel Thickness (in.)	≤ 0.060	≤ 0.060	≤ 0.060	≤ 0.060	≤ 0.120	≤ 0.100

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.
2. Zr designates cladding material made of Zirconium or Zirconium alloys.
3. ≤ ~~0.612~~ *0.635* wt. % ^{235}U and ≤ 1.578 wt. % total fissile plutonium (^{239}Pu and ^{241}Pu)*(wt. % of total fuel weight, i.e, UO_2 plus PuO_2)*.
4. Design initial uranium weight is the nominal weight specified for each assembly by the fuel manufacturer or reactor user. *For each BWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 1.5 percent for comparison with users' fuel records to account for manufacturer tolerances.*
5. Description of the fuel assembly class designation is provided in Chapter 6.
6. *These rods may also be sealed at both ends and contain Zr material in lieu of water.*
7. *For those MPCs loaded with both intact fuel and damaged fuel or fuel debris, the maximum initial enrichment of the intact fuel is limited to 3.7 wt.% ^{235}U, as applicable.*

Table 2.1.4 (continued)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**8x8 B**	**8x8 C**	**8x8 D**	**8x8 E**	***8x8F***	**9x9 A**
Clad Material (Note 2)	Zr	Zr	Zr	Zr	*Zr*	Zr
Design Initial U (kg/assy.) (Note 6)	~~≤ 185~~ *≤ 191*	~~≤ 185~~ *≤ 191*	~~≤ 185~~ *≤ 191*	~~≤ 180~~ *≤ 191*	*≤ 185*	~~≤ 173~~ *≤ 179*
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 10)	*≤ 4.2*	*≤ 4.2*	*≤ 4.2*	*≤ 4.2*	*≤ 3.6*	*≤ 4.2*
Initial Maximum Rod Enrichment (wt.% ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rods	63 *or 64*	62	60 *or 61*	59	*64*	74/66 (Note 3)
Clad O.D. (in.)	≥ 0.4840	≥ 0.4830	≥ 0.4830	≥ 0.4930	*≥ 0.4576*	≥ 0.4400
Clad I.D. (in.)	~~≤ 0.4250~~ *≤ 0.4295*	≤ 0.4250	~~≤ 0.4190~~ *≤ 0.4230*	≤ 0.4250	*≤ 0.3996*	≤ 0.3840
Pellet Dia. (in.)	~~≤ 0.4160~~ *≤ 0.4195*	≤ 0.4160	~~≤ 0.4110~~ *≤ 0.4140*	≤ 0.4160	*≤ 0.3913*	≤ 0.3760
Fuel Rod Pitch (in.)	~~0.636 - 0.641~~ *≤ 0.642*	~~0.636 -~~ ≤ 0.641	≤ 0.640	≤ 0.640	*≤ 0.609*	≤ 0.566
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	*≤ 150*	≤ 150
No. of Water Rods *(see note 8)*	1 *or 0*	2	1 - 4 (see note 5)	5	*N/A* *(see note 9)*	2
Water Rod Thickness (in.)	≥ 0.034	≥ 0.00	≥ 0.00	≥ 0.034	*≥ 0.0315*	≥ 0.00
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.100	*≤ 0.100*	≤ 0.120

Notes:
1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.
2. Zr designates cladding material made of Zirconium or Zirconium alloys.
3. This assembly class contains 74 total rods; 66 full length rods and 8 partial length rods.
4. Square, replacing 9 fuel rods.
5. Variable.
6. Design initial uranium weight is the nominal weight specified for each assembly by the fuel manufacturer or reactor user. *For each BWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 1.5 percent for comparison with users' fuel records to account for manufacturer tolerances.*
7. Description of the fuel assembly class designation is provided in Chapter 6.
8. *These rods may also be sealed at both ends and contain Zr material in lieu of water.*
9. *This assembly is known as "QUAD+." It has four rectangular water cross segments dividing the assembly into four quadrants.*
10. *For those MPCs loaded with both intact fuel and damaged fuel or fuel debris, the maximum initial enrichment of the intact fuel is limited to 3.7 wt.% ^{235}U, as applicable.*

Table 2.1.4 (continued)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**9x9 B**	**9x9 C**	**9x9 D**	**9x9 E** *(Note 6)*	**9x9 F** *(Note 6)*	*9x9 G*
Clad Material (Note 2)	Zr	Zr	Zr	Zr	Zr	*Zr*
Design Initial U (kg/assy.) (Note 4)	~~≤173~~ *≤ 179*	~~≤173~~ *≤ 179*	~~≤170~~ *≤ 179*	~~≤170~~ *≤ 179*	~~≤170~~ *≤ 179*	*≤ 179*
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 9)	*≤ 4.2*	*≤ 4.2*	*≤ 4.2*	~~≤4.2~~ *≤ 4.0*	~~≤4.2~~ *≤ 4.0*	*≤ 4.2*
Initial Maximum Rod Enrichment (wt.% ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rods	72	80	79	76	76	*72*
Clad O.D. (in.)	≥ 0.4330	≥ 0.4230	≥ 0.4240	≥ 0.4170	≥ 0.4430	*≥ 0.4240*
Clad I.D. (in.)	≤ 0.3810	≤ 0.3640	≤ 0.3640	~~≤0.3590~~ *≤ 0.3640*	~~≤0.3810~~ *≤ 0.3860*	*≤ 0.3640*
Pellet Dia. (in.)	≤ 0.3740	≤ 0.3565	≤ 0.3565	~~≤0.3525~~ *≤ 0.3530*	≤ 0.3745	*≤ 0.3565*
Fuel Rod Pitch (in.)	~~0.569~~ *≤ 0.572*	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572	*≤ 0.572*
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	*≤ 150*
No. of Water Rods *(see note 7)*	1 (see note 4)	1	2	5	5	*1* *(see note 8)*
Water Rod Thickness (in.)	≥ 0.00	0.020	~~≥0.0305~~ *≥ 0.0300*	~~≥0.0305~~ *≥ 0.0120*	~~≥0.0305~~ *≥ 0.0120*	*≥ 0.320*
Channel Thickness (in.)	≤ 0.120	≤ 0.100	≤ 0.100	~~≤0.100~~ ≤ 0.120	~~≤0.100~~ ≤ 0.120	*≤ 0.120*

Notes:
1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.
2. Zr designates cladding material made of Zirconium or Zirconium alloys.

3. This assembly class contains 92 total fuel rods; 78 full length rods and 14 partial length rods.
4. Design initial uranium weight is the nominal weight specified for each assembly by the fuel manufacturer or reactor user. *For each BWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 1.5 percent for comparison with users' fuel records to account for manufacturer tolerances.*
5. Description of the fuel assembly class designation is provided in Chapter 6.
6. *For the SPC 9x9 fuel assembly, each fuel rod must meet either the 9x9E or the 9x9F set of limits for clad O.D., clad I.D., and pellet diameter.*
7. *These rods may also be sealed at both ends and contain Zr material in lieu of water.*
8. *Square, replacing nine fuel rods.*
9. *For those MPCs loaded with both intact fuel and damaged fuel or fuel debris, the maximum initial enrichment of the intact fuel is limited to 3.7 wt.% ^{235}U, as applicable.*

Table 2.1.4 (continued)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**10x10 A**	**10x10 B**	**10x10 C**	**10x10 D**	**10x10 E**
Clad Material (Note 2)	Zr	Zr	Zr	SS	SS
Design Initial U (kg/assy.) (Note 6)	~~≤ 182~~ *≤ 188*	~~≤ 182~~ *≤ 188*	~~≤ 180~~ *≤ 188*	≤ 125	≤ 125
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 9)	*≤ 4.2*	*≤ 4.2*	*≤ 4.0*	*≤ 4.0*	*≤ 4.0*
Initial Maximum Rod Enrichment (wt.% ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rods	92/78 (Note 3)	91/83 (Note 3)	96	100	96
Clad O.D. (in.)	≥ 0.4040	≥ 0.3957	~~≥ 0.3790~~ *≥ 0.3780*	≥ 0.3960	≥ 0.3940
Clad I.D. (in.)	≤ 0.3520	≤ 0.3480	≤ 0.3294	≤ 0.3560	≤ 0.3500
Pellet Dia. (in.)	≤ 0.3455	≤ 0.3420	≤ 0.3224	≤ 0.3500	≤ 0.3430
Fuel Rod Pitch (in.)	≤ 0.510	≤ 0.510	≤ 0.488	≤ 0.565	≤ 0.557
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 83	≤ 83
No. of Water Rods *(see note 8)*	2	1 (Note 4)	5 (Note 5)	0	4
Water Rod Thickness (in.)	≥ 0.030	≥ 0.00	~~≥ 0.034~~ *≥ 0.031*	N/A	≥ 0.022
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.055	≤ 0.080	≤ 0.080

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.
2. Zr designates cladding material made of Zirconium or Zirconium alloys.
3. This assembly class contains 91 total fuel rods; 83 full length rods and 8 partial length rods.
4. Square, replacing nine fuel rods.
5. One diamond-shaped water rod replacing the four center fuel rods and four rectangular water rods dividing the assembly into four quadrants.
6. Design initial uranium weight is the nominal weight specified for each assembly by the fuel manufacturer or reactor user. *For each BWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 1.5 percent for comparison with users' fuel records to account for manufacturer tolerances.*
7. Description of the fuel assembly class designation is provided in Chapter 6.
8. *These rods may also be sealed at both ends and contain Zr material in lieu of water.*
9. *For those MPCs loaded with both intact fuel and damaged fuel or fuel debris, the maximum initial enrichment of the intact fuel is limited to 3.7 wt.% ^{235}U, as applicable.*

Table 2.1.5

DESIGN BASIS FUEL ASSEMBLY FOR EACH DESIGN CRITERION

Criterion	**MPC-68**	**MPC-24**	***MPC-24E***	***MPC-32***
Reactivity (Criticality)	GE12/14 10x10 with Partial Length Rods (Class 10x10A)	B&W 15x15 (Class 15x15F)	*B&W 15x15 (Class 15x15F)*	*B&W 15x15 (Class 15x15F)*
Source Term (Shielding)	GE 7x7 (Class 7x7B)	B&W 15x15 (Class 15x15F)	*B&W 15x15 (Class 15x15F)*	*B&W 15x15 (Class 15x15F)*
Decay Heat (Thermal-Hydraulic)	GE 7x7 (Class 7x7B)	B&W 15x15 (Class 15x15F)	*B&W 15x15 (Class 15x15F)*	*B&W 15x15 (Class 15x15F)*

Table 2.1.6

CHARACTERISTICS FOR DESIGN BASIS INTACT ZIRCALOY CLAD FUEL ASSEMBLIES[1]

	MPC-68/*68F/68FF*	**MPC-24**	***MPC-24E***	***MPC-32***
PHYSICAL PARAMETERS:				
Max. assembly width (in.)	5.85	8.54	*8.54*	*8.54*
Max. assembly length (in.)	176.2	176.8	*176.8*	*176.8*
Max. assembly weight[2] (lb.)	700	1680	*1680*	*1680*
Max. active fuel length (in.)	150	150	*150*	*150*
~~Fuel rod clad material~~	~~zircaloy~~	~~zircaloy~~		
RADIOLOGICAL AND THERMAL CHARACTERISTICS:				
	MPC-68	**MPC-24**	***MPC-24E***	***MPC-32***
Max. initial enrichment (wt% ^{235}U)	See Table 2.1.4	See Table 2.1.3	*See Table 2.1.3*	*See Table 2.1.3*
Max. heat generation (W)	Table 2.0.1 ~~115 (Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, 8x8A)~~	Table 2.0.1	*Table 2.0.1*	*Table 2.0.1*
Max. average burnup (MWD/MTU)	~~See Figure 2.1.6~~ ~~30,000 (Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, 8x8A)~~ *45,000*	~~See Figure 2.1.6~~ *45,000*	*45,000*	*42,600*
Min. cooling time (years)	~~See Figure 2.1.6~~ ~~18 (Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, 8x8A)~~ *5*	~~See Figure 2.1.6~~ *5*	*5*	*5*

Table 2.1.7

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[1] *These are limiting values for all authorized fuel assembly array/classes. Refer to the Approved Contents section of Appendix B to the CoC for specific limits for each fuel assembly array/class.*

[2] Fuel assembly weight including *non-fuel* hardware, *and channels, as applicable,* based on DOE MPC DPS [2.1.6].

DESIGN CHARACTERISTICS FOR DAMAGED ~~ZIRCALOY CLAD~~ FUEL ASSEMBLIES[1]

	MPC-68/*68FF* (Damaged Fuel *and Fuel Debris*)	MPC-68F (*Damaged Fuel and* Fuel Debris)	***MPC-24E (Damaged Fuel)***
PHYSICAL PARAMETERS:			
Max. assembly width (in.)	~~4.7~~ *5.5*	4.7	*8.54*
Max. assembly length (in.)	~~135~~ *176.2*	135	*173.75*
Max. assembly weight[2] (lb.)	~~400~~ *700*	400	*1680*
Max. active fuel length (in.)	~~110~~ *150*	110	*150*
Fuel rod clad material	zircaloy/*SS*	zircaloy	*zircaloy/SS*
RADIOLOGICAL AND THERMAL CHARACTERISTICS:			
Max. heat generation (W)	~~115~~ *356*	115	*927*
Min. cooling time (yr)	~~18~~ *5*	18	*5*
Max. initial enrichment (wt.% ^{235}U) for UO_2 rods	~~2.7~~ *4.0*	2.7	*4.0*
Max. initial enrichment for MOX rods	~~0.612~~ *0.635* wt.% ^{235}U 1.578 wt. % Total Fissile Plutonium	~~0.612~~ *0.635* wt.% ^{235}U 1.578 wt. % Total Fissile Plutonium	*N/A*
Max. average burnup (MWD/MTU)	~~30,000~~ *45,000*	30,000	*45,000*

Note: ~~A maximum of four (4) damaged fuel containers with BWR zircaloy clad fuel debris may be stored in the MPC-68F with the remaining locations filled with undamaged or damaged fuel assemblies meeting the maximum heat generation specifications of this table.~~ *Refer to the Approved Contents section of Appendix B to the CoC for restrictions on the number and location of damaged fuel assemblies authorized for loading in the HI-STORM 100 System.*

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[1] *These are limiting values for all authorized fuel assembly array/classes. Refer to the Approved Contents section of Appendix B to the CoC for specific limits for each fuel assembly array/class.*

[2] Fuel assembly weight including *non-fuel* hardware, *channels, and DFC, as applicable,* based on DOE MPC DPS [2.1.6].

Table 2.1.8

DESIGN CHARACTERISTICS FOR INTACT STAINLESS STEEL CLAD FUEL ASSEMBLIES[1]

	BWR MPC-68/*68FF*	PWR MPC-24/*24E*	*PWR MPC-32*
PHYSICAL PARAMETERS:			
Max. assembly width[2] (in.)	5.62	8.42	*8.42*
Max. assembly length[2] (in.)	102.5	138.8	*138.8*
Max. assembly weight[3] (lb.)	~~400~~ *700*	1421	*1421*
Max. active fuel length[2] (in.)	83	122	*122*
RADIOLOGICAL AND THERMAL CHARACTERISTICS :			
Max. heat generation (W)	95	710	*500*
Min. cooling time (yr)	10	8	*9*
Max. initial enrichment *without soluble boron credit* (wt.% ^{235}U)	4.0	~~4.0~~ *5.0*	*N/A*
Max. initial enrichment with soluble boron credit (wt.% ^{235}U)	*N/A*	*5.0*	*5.0*
Max. average burnup (MWD/MTU)	22,500	40,000	*40,000*

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[1] *These are limiting values for all authorized fuel assembly array/classes. Refer to the Approved Contents section of Appendix B to the CoC for specific limits for each fuel assembly array/class.*

[2] Unirradiated nominal dimensions are shown.

[3] Fuel assembly weight including *non-fuel* hardware *and channels, as applicable*, based on DOE MPC DPS [2.1.6].

Table 2.1.9

SUGGESTED PWR UPPER AND LOWER FUEL SPACER LENGTHS

Fuel Assembly Type	**Assembly Length w/o ~~C.C.~~*NFH*[1] (in.)**	**Location of Active Fuel from Bottom (in.)**	**Max. Active Fuel Length (in.)**	**Upper Fuel Spacer Length (in.)**	**Lower Fuel Spacer Length (in.)**
CE 14x14	157	4.1	137	9.5	10.0
CE 16x16	176.8	4.7	150	0	0
BW 15x15	165.7	8.4	141.8	6.7	4.1
W 17x17 OFA	159.8	3.7	144	8.2	8.5
W 17x17 Std	159.8	3.7	144	8.2	8.5
W 17x17 V5H	160.1	3.7	144	7.9	8.5
W 15x15	159.8	3.7	144	8.2	8.5
W 14x14 Std	159.8	3.7	145.2	9.2	7.5
W 14x14 OFA	159.8	3.7	144	8.2	8.5
Ft. Calhoun	146	6.6	128	10.25	20.25
St. Lucie 2	158.2	5.2	136.7	10.25	8.05
B&W 15x15 SS	137.1	3.873	120.5	19.25	19.25
W 15x15 SS	137.1	3.7	122	19.25	19.25
W 14x14 SS	137.1	3.7	120	19.25	19.25
Indian Point 1	*137.2*	*17.705*	*101.5*	*18.75*	*20.0*

Note: *Each user shall specify the fuel spacer length based on their fuel assembly length, presence of a DFC, and allowing an approximate two inch gap under the MPC lid.*

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[1] ~~C.C.~~ *NFH* is an abbreviation for ~~Control Components~~ *non-fuel hardware, including control components. Fuel assemblies with control components may require shorter fuel spacers.*

Table 2.1.10

SUGGESTED BWR UPPER AND LOWER FUEL SPACER LENGTHS

Fuel for Reactor Type	**Assembly Length (in.)**	**Location of Active Fuel from Bottom (in.)**	**Max. Active Fuel Length (in.)**	**Upper Fuel Spacer Length (in.)**	**Lower Fuel Spacer Length (in.)**
GE/2-3	171.2	7.3	150	4.8	0
GE/4-6	176.2	7.3	150	0	0
Dresden 1	134.4	11.2	110	18.0	23.6
Humboldt Bay	95.0	8.0	79	40.5	40.5
Dresden 1 Damaged Fuel or Fuel Debris	144.5[1]	11.2	110	17.0	14.5
Humboldt Bay Damaged Fuel or Fuel Debris	105.5[†]	8.0	79	35.25	35.25
LaCrosse	102.5	10.5	83	37.0	37.5

Note: *Each user shall specify the fuel spacer length based on their fuel assembly length, presence of a DFC, and allowing an approximate two inch gap under the MPC lid.*

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[1] Fuel assembly length includes the damaged fuel container.

Table 2.1.11
NORMALIZED DISTRIBUTION BASED ON BURNUP PROFILE

PWR DISTRIBUTION[1]

Interval	**Axial Distance From Bottom of Active Fuel (% of Active Fuel Length)**	**Normalized Distribution**
1	0% to 4-1/6%	0.5485
2	4-1/6% to 8-1/3%	0.8477
3	8-1/3% to 16-2/3%	1.0770
4	16-2/3% to 33-1/3%	1.1050
5	33-1/3% to 50%	1.0980
6	50% to 66-2/3%	1.0790
7	66-2/3% to 83-1/3%	1.0501
8	83-1/3% to 91-2/3%	0.9604
9	91-2/3% to 95-5/6%	0.7338
10	95-5/6% to 100%	0.4670

BWR DISTRIBUTION[2]

Interval	Axial Distance From Bottom of Active Fuel (% of Active Fuel Length)	Normalized Distribution
1	0% to 4-1/6%	0.2200
2	4-1/6% to 8-1/3%	0.7600
3	8-1/3% to 16-2/3%	1.0350
4	16-2/3% to 33-1/3%	1.1675
5	33-1/3% to 50%	1.1950
6	50% to 66-2/3%	1.1625
7	66-2/3% to 83-1/3%	1.0725
8	83-1/3% to 91-2/3%	0.8650
9	91-2/3% to 95-5/6%	0.6200
10	95-5/6% to 100%	0.2200

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[1] Reference 2.1.7

[2] Reference 2.1.8

Table 2.1.12

DESIGN CHARACTERISTICS FOR THORIA RODS IN D1 THORIA ROD CANISTERS

PARAMETER	***MPC-68 or MPC-68F***
Cladding Type	*Zircaloy (Zr)*
Composition	*98.2 wt.% ThO_2, 1.8 wt.% UO_2 with an enrichment of 93.5 wt. % ^{235}U*
Number of Rods Per Thoria Canister	*≤18*
Decay Heat Per Thoria Canister	*≤115 watts*
Post-Irradiation Fuel Cooling Time and Average Burnup Per Thoria Canister	*Cooling time ≥18 years and average burnup ≤16,000 MWD/MTIHM*
Initial Heavy Metal Weight	*≤27 kg/canister*
Fuel Cladding O.D.	*≥0.412 inches*
Fuel Cladding I.D.	*≤0.362 inches*
Fuel Pellet O.D.	*≤0.358 inches*
Active Fuel Length	*≤111 inches*
Canister Weight	*≤550 lbs., including Thoria Rods*

Table 2.1.13
MPC Fuel Loading Regions

MPC MODEL	***REGION 1 FUEL STORAGE LOCATIONS***	***REGION 2 FUEL STORAGE LOCATIONS***
MPC-24 and 24E	*9, 10, 15, and 16*	*All Other Locations*
MPC-32	*7, 8, 12 through 15, 18 through 21, 25, and 26*	*All Other Locations*
MPC-68/68F/68FF	*11 through 14, 18 through 23, 27 through 32, 37 through 42, 46 through 51, 55 through 58*	*All Other Locations*

Note: Refer to Figures 1.2.2 through 1.2.4A

Table 2.1.14

Soluble Boron Requirements for PWR Fuel Wet Loading and Unloading Operations

MPC MODEL	*FUEL ASSEMBLY MAXIMUM AVERAGE ENRICHMENT (wt % ^{235}U)*	*MINIMUM SOLUBLE BORON CONCENTRATION (ppmb)*
MPC-24	*All fuel assemblies with initial enrichment*[1] *less than the prescribed value for soluble boron credit*	*0*
MPC-24	*One or more fuel assemblies with an initial enrichment*[1] *greater than or equal to the prescribed value for no soluble boron credit AND ≤ 5.0 wt. %*	*≥ 400*
MPC-24E	*All fuel assemblies with initial enrichment*[1] *less than the prescribed value for soluble boron credit*	*0*
MPC-24E	*One or more fuel assemblies with an initial enrichment*[1] *greater than or equal to the prescribed value for no soluble boron credit AND ≤ 5.0 wt. %*	*≥ 300*
MPC-32	*All fuel assemblies with initial enrichment ≤ 4.0 wt. %*	*≥ 1800*
MPC-32	*One or more fuel assemblies with an initial enrichment > 4.0 and ≤ 5.0 wt. %*	*≥ 2600*

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[1] *Refer to Table 2.1-2 in the Approved Contents section of Appendix B to the CoC for these enrichments.*

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

FIGURE 2.1.1; HOLTEC DAMAGED FUEL CONTAINER FOR DRESDEN UNIT-1/ HUMBOLDT BAY SNF

FIGURE WITHHELD AS SENSITIVE
UNCLASSIFIED INFORMATION

FIGURE 2.1.2; TN DAMAGED FUEL CANISTER FOR DRESDEN UNIT-1

FIGURE WITHHELD AS SENSITIVE
UNCLASSIFIED INFORMATION

FIGURE 2.1.2A; TN THORIA ROD CANISTER FOR DRESDEN UNIT-1

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

FIGURE 2.1.2B; HOLTEC DAMAGED FUEL CONTAINER FOR PWR SNF IN MPC-24E

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

FIGURE 2.1.2C; HOLTEC DAMAGED FUEL CONTAINER FOR BWR SNF IN MPC-68/68FF

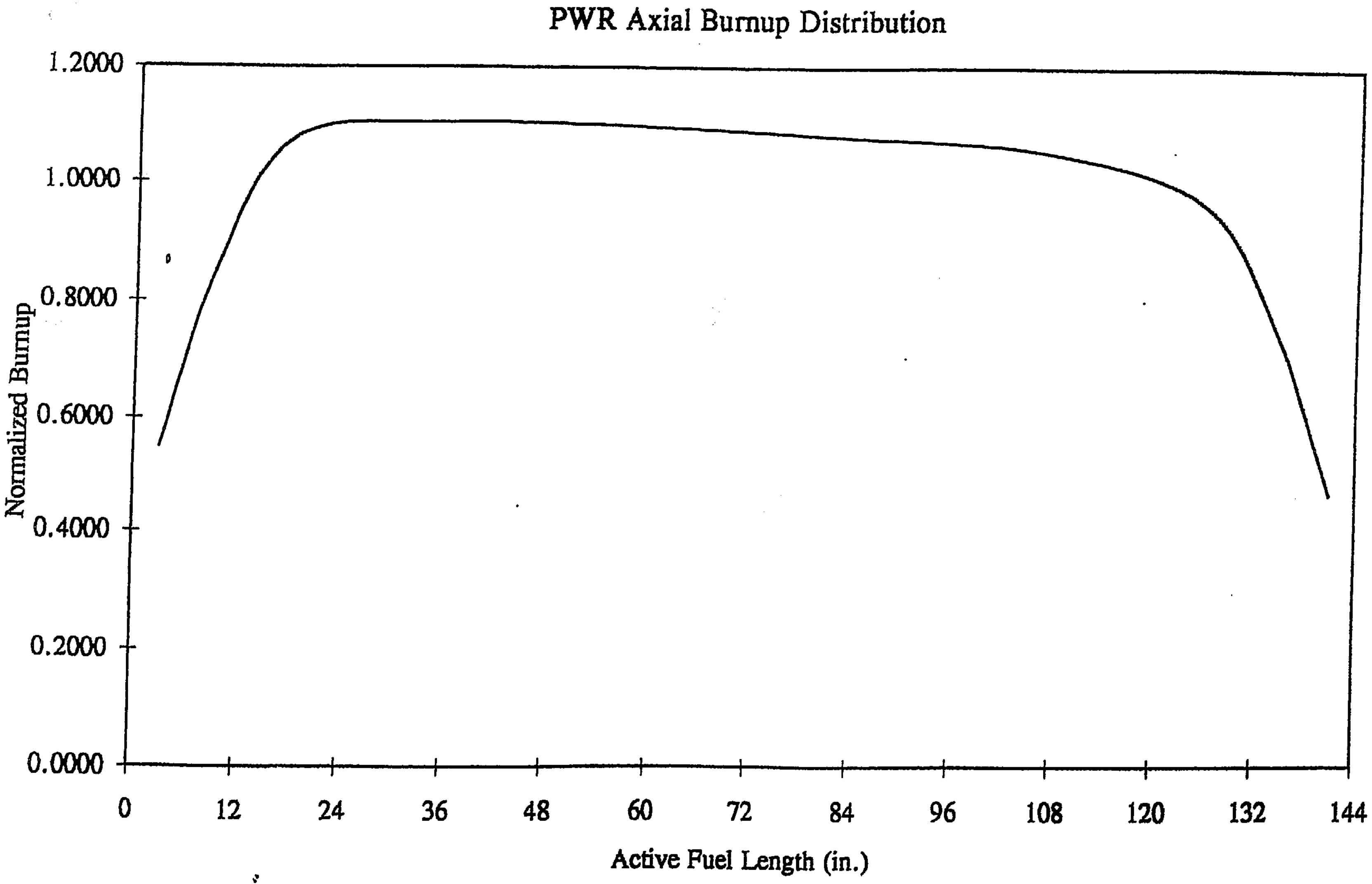

Figure 2.1.3; PWR Axial Burnup Profile with Normalized Distribution

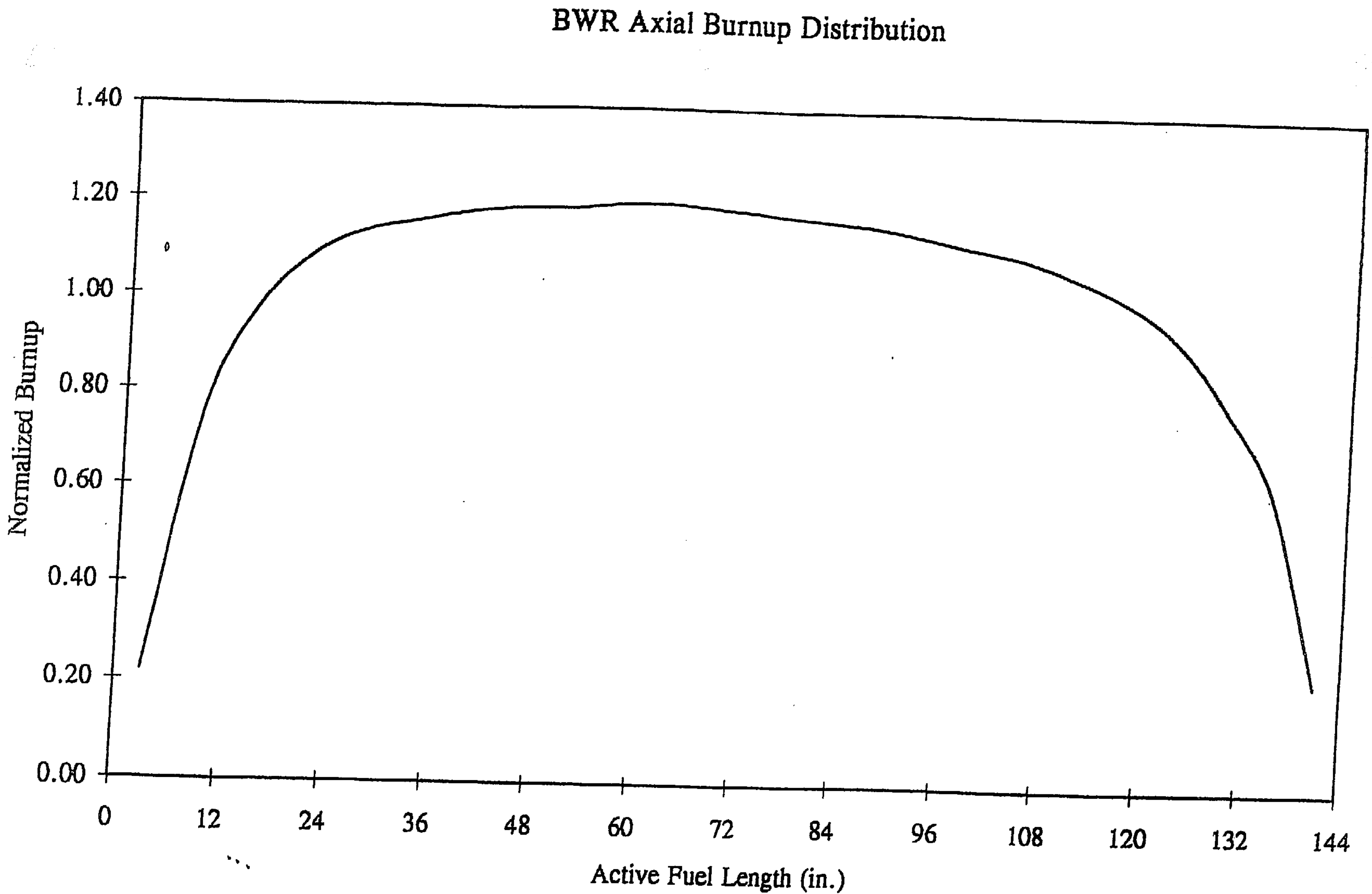

Figure 2.1.4; BWR Axial Burnup Profile with Normalized Distribution

DELETED

Figure 2.1.6

2.2.1 Normal Condition Design Criteria

2.2.1.1 Dead Weight

The HI-STORM 100 System must withstand the static loads due to the weights of each of its components, including the weight of the HI-TRAC with the loaded MPC atop the storage overpack.

2.2.1.2 Handling

The HI-STORM 100 System must withstand loads experienced during routine handling. Normal handling includes:

i. vertical lifting and transfer to the ISFSI of the HI-STORM 100 Overpack with loaded MPC
ii. lifting, upending/downending, and transfer to the ISFSI of the HI-TRAC with loaded MPC in the vertical or horizontal position
iii. lifting of the loaded MPC into and out of the HI-TRAC, HI-STORM, or HI-STAR Overpack

The loads shall be increased by 15% to include any dynamic effects from the lifting operations as directed by CMAA #70 [2.2.16].

Handling operations of the loaded HI-TRAC transfer cask or HI-STORM 100 Overpack is limited to *working area* ambient temperatures ~~above~~ *greater than or equal to* 0°F. This limitation is specified to ensure that a sufficient safety margin exists before brittle fracture might occur during handling operations. Subsection 3.1.2.3 provides the demonstration of the adequacy of the HI-TRAC transfer cask and the HI-STORM 100 Overpack for use during handling operations at a minimum service temperature of 0° F.

Lifting attachments and devices shall meet the requirements of ANSI N14.6† [2.2.3].

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† Yield and ultimate strength values used in the stress compliance demonstration per ANSI N14.6 shall utilize confirmed material test data through either independent coupon testing or material suppliers' CMTR or COC, as appropriate. To ensure consistency between the design and fabrication of a lifting component, compliance with ANSI N14.6 in this TSAR implies that the guidelines of ASME Section III, Subsection NF for Class 3 structures are followed for material procurement and testing, fabrication, and for NDE during manufacturing.

2.2.1.3 Pressure

The MPC internal pressure is dependent on the initial volume of cover gas (helium), the volume of fill gas in the fuel rods, the fraction of fission gas released from the fuel matrix, the number of fuel rods assumed to have ruptured, and temperature.

The normal condition MPC internal design pressure bounds the cumulative effects of the maximum fill gas volume, normal environmental ambient temperatures, the maximum MPC heat load, and an assumed 1% of the fuel rods ruptured with 100% of the fill gas and 30% of the significant radioactive gases (e.g., H^3, Kr, and Xe) released in accordance with NUREG-1536.

Table 2.2.1 provides the design pressures for the HI-STORM 100 System.

For the storage of damaged ~~Dresden Unit 1 or Humboldt Bay BWR~~ fuel assemblies or fuel debris ~~(Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A)~~ in a damaged fuel container, it is conservatively assumed that 100% of the fuel rods are ruptured with 100% of the rod fill gas and 30% of the significant radioactive gases (e.g., H^3, Kr, and Xe) released for both normal and off-normal conditions. *For PWR assemblies stored with non-fuel hardware, it is assumed that 100% of the gasses in the non-fuel hardware (e.g., BPRAs) is also released.* This condition is bounded by the pressure calculation for design basis intact fuel with 100% of the fuel rods ruptured in all ~~68~~ of the ~~BWR~~ fuel assemblies. It is shown in Chapter 4 that the normal condition design pressure is not exceeded with 100% of the fuel rods ruptured in all ~~68~~ of the design basis ~~BWR~~ fuel assemblies. Therefore, rupture of 100% of the fuel rods in the damaged fuel assemblies or fuel debris will not cause the MPC internal pressure to exceed the normal design pressure.

The MPC internal design pressure under accident conditions is discussed in Subsection 2.2.3.

The HI-STORM 100 Overpack and MPC external pressure is a function of environmental conditions which may produce a pressure loading. The normal and off-normal condition external design pressure is set at ambient standard pressure (1 atmosphere).

The HI-STORM 100 Overpack is not capable of retaining internal pressure due to its open design, and, therefore, no analysis is required or provided for the overpack internal pressure.

The HI-TRAC is not capable of retaining internal pressure due to its open design and, therefore, ambient and hydrostatic pressures are the only pressures experienced. Due to the thick steel walls of the HI-TRAC transfer cask, it is evident that the small hydrostatic pressure can be easily withstood; no analysis is required or provided for the HI-TRAC internal pressure. However, the HI-TRAC water jacket does experience internal pressure due to the heat-up of the water contained in the water jacket. Analysis is presented in Chapter 3 which demonstrates that the

2.2.2.4 Leakage of One Seal

The HI-STORM 100 System must withstand leakage of one seal in the radioactive material confinement boundary.

The confinement boundary is defined by the MPC shell, baseplate, MPC lid, port cover plates, and closure ring. Most confinement boundary welds are inspected by radiography or ultrasonic examination. Field welds are examined by the liquid penetrant method on the root and final pass. In addition to liquid penetrant examination, the MPC lid-to-shell weld is leakage tested, hydrostatic tested, and volumetrically examined or multi-pass liquid penetrant examined. The vent and drain port cover plates are leakage tested in addition to the liquid penetrant examination. These inspection and testing techniques are performed to verify the integrity of the confinement boundary.

Although leakage of one seal is not a credible accident, it is analyzed in Chapter 11.

2.2.2.5 Partial Blockage of Air Inlets

The HI-STORM 100 System must withstand the partial blockage of the overpack air inlets. This event is conservatively defined as a complete blockage of ~~one-half~~ *two* (2) of the four air inlets. Because the overpack air inlets and outlets are covered by fine mesh steel screens, located 90° apart, and inspected routinely (or alternatively, exit vent air temperature monitored), it is unlikely that all vents could become blocked by blowing debris, animals, etc. during normal and off-normal operations. ~~One-half~~ *Two* of the air inlets are conservatively assumed to be completely blocked to demonstrate the inherent thermal stability of the HI-STORM 100 System.

2.2.2.6 Off-Normal HI-TRAC Handling

During upending and/or downending of the HI-TRAC transfer cask, the total lifted weight is distributed among both the upper lifting trunnions and the lower pocket trunnions. Each of the four trunnions on the HI-TRAC therefore supports approximately one-quarter of the total weight. This even distribution of the load would continue during the entire rotation operation.

If the lifting device ~~is allowed~~ *cables begin* to "go slack", *the eccentricity of the pocket trunnions would immediately cause the cask to pivot, restoring tension on the cables.* ~~the total weight would be applied to the lower pocket trunnions only~~. *Nevertheless,* ~~Under this off-normal condition~~, the pocket trunnions *are conservatively analyzed* ~~would each be required~~ to support one-half of the total weight, doubling the load per trunnion. This condition is analyzed to demonstrate that the pocket trunnions possess sufficient strength to support the increased load under this off-normal condition.

2.2.3 Environmental Phenomena and Accident Condition Design Criteria

Environmental phenomena and accident condition design criteria are defined in the following subsections.

The minimum acceptance criteria for the evaluation of the accident conditions are that the MPC confinement boundary maintains radioactive material confinement, the MPC fuel basket structure maintains the fuel contents subcritical, the stored SNF can be retrieved by normal means, and the system provides adequate shielding.

A discussion of the effects of each environmental phenomenon and accident condition is provided in Section 11.2. The consequences of each accident or environmental phenomenon are evaluated against the requirements of 10CFR72.106 and 10CFR20. Section 11.2 also provides the corrective action for each event. The location of the detailed analysis for each event is referenced in Section 11.2.

2.2.3.1 Handling Accident

The HI-STORM 100 System must withstand loads due to a handling accident. Even though the *loaded* HI-STORM 100 System will be lifted in accordance with approved, written procedures and will use lifting equipment which complies with ANSI N14.6-1993 [2.2.3], certain drop events are considered herein to demonstrate the defense-in-depth features of the design.

The loaded HI-STORM 100 Overpack will be lifted so that the bottom of the cask is at a height less than the vertical lift limit (see Table 2.2.8) above the ground. For conservatism, the postulated drop event assumes that the loaded HI-STORM 100 Overpack falls freely from the vertical lift limit height before impacting a thick reinforced concrete pad. The deceleration of the MPC must be maintained below 60g's under axial loading to ensure the analysis performed in the HI-STAR Safety Analysis Reports [2.2.4 and 2.2.5] bounds the HI-STORM 100 Overpack vertical handling accident. Additionally, the overpack must continue to suitably shield the radiation emitted from the loaded MPC. The use of lifting equipment with redundant drop protection and lifting devices designed in accordance with the requirements specified in Section 2.3.3.1 to lift the loaded overpack will eliminate the lift height limit. The lift height limit is dependent on the characteristics of the impacting surface which are specified in Table 2.2.9. For site-specific conditions, which are not encompassed by Table 2.2.9, the licensee shall evaluate the site-specific conditions to ensure that the drop accident loads do not exceed 45 g's. The methodology used in this alternative analysis shall be commensurate with the analyses in Appendix 3.A and shall be reviewed by the Certificate Holder.

The loaded HI-TRAC will be lifted so that the side of the cask is at a height less than the calculated horizontal lift height limit (see Table 2.2.8) above the ground, when lifted horizontally outside of the reactor facility. For conservatism, the postulated drop event assumes that the loaded HI-TRAC falls freely from the horizontal lift height limit before impact. Analysis is provided which demonstrates that the HI-TRAC continues to suitably shield the radiation emitted from the loaded MPC, and that the HI-TRAC end plates (top lid and transfer lid) remain attached. Furthermore, the HI-TRAC inner shell is demonstrated by analysis to not deform sufficiently to affect retrieval of the MPC. The horizontal lift height limit is dependent on the characteristics of the impacting surface which are specified in Table 2.2.9. For site-specific conditions, which are not encompassed by Table 2.2.9, the licensee shall evaluate the site-specific conditions to ensure that the drop accident loads do not exceed 45 g's. The methodology used in this alternative analysis shall be commensurate with the analyses in Appendix 3.AN and shall be reviewed by the Certificate Holder. The use, during horizontal lifting of the loaded HI-TRAC outside of the reactor facilities, of lifting equipment with redundant drop protection and lifting devices designed in accordance with the requirements specified in Section 2.3.3.1, will eliminate the need for a horizontal lift height limit.

The loaded HI-TRAC, when lifted in the vertical position outside of the reactor facility shall be lifted by lifting equipment with redundant drop protection features and lifting devices designed in accordance with ANSI N14.6. Therefore, a vertical drop or tip-over is not a credible accident for the HI-TRAC transfer cask and no vertical lift height limit is provided. Likewise, while the loaded HI-TRAC is positioned atop the HI-STORM 100 Overpack for transfer of the MPC into the overpack, the lifting equipment will remain engaged with the lifting trunnions of the HI-TRAC transfer cask or suitable restraints will be provided to secure the HI-TRAC. This ensures that a tip-over or drop from atop the HI-STORM 100 Overpack is not a credible accident for the HI-TRAC transfer cask. This condition of use for MPC transfer operations from the HI-TRAC transfer cask to the HI-STORM 100 Overpack is specified in ~~the Technical Specifications in Chapter 12 and~~ Subsection 2.3.3.1, and is included in the operating procedures of Chapter 8.

The loaded MPC is lowered into the HI-STORM or HI-STAR Overpack or raised from the overpack using the HI-TRAC transfer cask and a MPC lifting system designed to be single failure proof and lifting devices designed in accordance with ANSI N14.6. Therefore, the possibility of a loaded MPC falling freely from its highest elevation during the MPC transfer operations into the HI-STORM or HI-STAR Overpacks is not credible.

The magnitude of loadings imparted to the HI-STORM 100 System due to drop events is heavily influenced by the compliance characteristics of the impacted surface. The concrete pad design for storing the HI-STORM 100 System shall comply with Table 2.2.9 and shall be reviewed by the Certificate Holder to ensure that impactive and impulsive loads under accident events such as cask drop and non-mechanistic tip-over are less than those calculated by the dynamic models used in the structural qualifications.

storage of damaged BWR fuel assemblies or fuel debris, the assemblies and fuel debris will be placed in damaged fuel containers prior to placement in the MPC. The damaged fuel container is equipped with fine mesh screens which ensure that the damaged fuel and fuel debris will not escape to block the MPC basket vent holes. In addition, each MPC will be loaded once for long-term storage and, therefore, buildup of crud in the MPC due to numerous loadings is precluded. Using crud quantities reported in an Empire State Electric Energy Research Corporation Report [2.2.6], a layer of crud of conservative depth is assumed to partially block the MPC basket vent holes. The crud depths for the different MPCs are listed in Table 2.2.8.

2.2.3.5 Tornado

The HI-STORM 100 System must withstand pressures, wind loads, and missiles generated by a tornado. The prescribed design basis tornado and wind loads for the HI-STORM 100 System are consistent with NRC Regulatory Guide 1.76 [2.2.7], ANSI 57.9 [2.2.8], and ASCE 7-88 [2.2.2]. Table 2.2.4 provides the wind speeds and pressure drops which the HI-STORM 100 Overpack must withstand while maintaining kinematic stability. The pressure drop is bounded by the accident condition MPC external design pressure.

The kinematic stability of the HI-STORM 100 Overpack, and continued integrity of the MPC confinement boundary, while within the storage overpack or HI-TRAC transfer cask, must be demonstrated under impact from tornado-generated missiles in conjunction with the wind loadings. Standard Review Plan (SRP) 3.5.1.4 of NUREG-0800 [2.2.9] stipulates that the postulated missiles include at least three objects: a massive high kinetic energy missile which deforms on impact (large missile); a rigid missile to test penetration resistance (penetrant missile); and a small rigid missile of a size sufficient to pass through any openings in the protective barriers (micro-missile). SRP 3.5.1.4 suggests an automobile for a large missile, a rigid solid steel cylinder for the penetrant missile, and a solid sphere for the small rigid missile, all impacting at 35% of the maximum horizontal wind speed of the design basis tornado. Table 2.2.5 provides the missile data used in the analysis, which is based on the above SRP guidelines. The effects of a large tornado missile are considered to bound the effects of a light general aviation airplane crashing on an ISFSI facility.

During horizontal handling of the loaded HI-TRAC transfer cask *outside the Part 50 facility*, tornado missile ~~shields~~ *protection* shall be *provided* ~~placed at either end of the HI-TRAC~~ to prevent tornado missiles from impacting either end of the HI-TRAC. The tornado missile ~~shield~~ *protection* shall be designed such that the large tornado missile cannot impact the bottom or top of the loaded HI-TRAC, while in the horizontal position. Also, the missile ~~shield positioned to protect~~ *protection for* the top of the HI-TRAC shall be designed to preclude the penetrant missile and micro-missile from passing through the penetration in the HI-TRAC top lid, while in the horizontal position. With the tornado missile ~~shields~~ *protection* in place, the impacting of a large tornado missile on either end of the loaded HI-TRAC or the penetrant missile or micro-missile

Analysis for each site for such transient hydrological loadings must be made for that site. It is expected that the plant licensee will perform this evaluation under the provisions of 10CFR72.212.

2.2.3.7 Seismic Design Loadings

The HI-STORM 100 must withstand loads arising due to a seismic event and must be shown not to tip over during a seismic event. Subsection 3.4.7 contains calculations based on conservative static "incipient tipping" calculations which demonstrate static stability. The calculations in Section 3.4.7 result in the values reported in Table 2.2.8, which provide the maximum horizontal zero period acceleration (ZPA) versus vertical acceleration multiplier above which static incipient tipping would occur. This conservatively assumes the peak acceleration values of each of the two horizontal earthquake components occur simultaneously. The maximum horizontal ZPA provided in Table 2.2.8 is the vector sum of two horizontal earthquakes.

2.2.3.8 100% Fuel Rod Rupture

The HI-STORM 100 System must withstand loads due to 100% fuel rod rupture. For conservatism, 100 percent of the fuel rods are assumed to rupture with 100 percent of the fill gas and 30% of the significant radioactive gases (e.g., H^3, Kr, and Xe) released in accordance with NUREG-1536. *All of the fill gas contained in non-fuel hardware, such as Burnable Poison Rod Assemblies (BPRAs) is also assumed to be released in analyzing this event.*

2.2.3.9 Confinement Boundary Leakage

No credible scenario has been identified that would cause failure of the confinement system. To demonstrate the overall safety of the HI-STORM 100 System, the largest test leakage rate for the confinement boundary plus 50% for conservatism is assumed as the maximum credible confinement boundary leakage rate and 100 percent of the fuel rods are assumed to have failed. Under this accident condition, doses to an individual located at the boundary of the controlled area are calculated.

2.2.3.10 Explosion

The HI-STORM 100 System must withstand loads due to an explosion. The accident condition MPC external pressure and overpack pressure differential specified in Table 2.2.1 bounds all credible external explosion events. There are no credible internal explosive events since all materials are compatible with the various operating environments, as discussed in Section 3.4.1. The MPC is composed of stainless steel, Boral, and aluminum alloy 1100, all of which have a long proven history of use in fuel pools at nuclear power plants. For these materials there is no credible cause for an internal explosive event.

Table 2.2.2

ENVIRONMENTAL TEMPERATURES

Condition	**Temperature (° F)**	**Comments**
HI-STORM 100 Overpack		
Normal Ambient (Bounding Annual Average)	80	
Normal Soil Temperature (Bounding Annual Average)	77	
Off-Normal Ambient (3-Day Average)	-40 and 100	• -40° with no insolation • 100° with insolation
Extreme Accident Level Ambient (3-Day Average)	125	• 125° with insolation starting at steady-state off-normal high environment temperature
HI-TRAC Transfer Cask		
Normal (Bounding Annual Average)	100	
Off-Normal (3-Day Average)	0 and 100	• 0° F with no insolation • 100° F with insolation

Note:

1. Handling operations with the loaded HI-STORM 100 Overpack and HI-TRAC transfer cask are limited to *working area ambient* ~~environmental~~ temperatures greater than *or equal to* 0°F as specified in Subsection 2.2.1.2 and the *Design Features section of Appendix B to the CoC.* ~~Technical Specifications in Chapter 12~~.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM

MPC(1,2)

Primary Function	Component(3)	Safety Class(4)	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
~~Helium Retention~~ *Confinement*	Shell	A	ASME Section III; Subsection NB	Alloy X(5)	See Appendix 1.A	NA	NA
~~Helium Retention~~ *Confinement*	Baseplate	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
~~Helium Retention~~ *Confienment*	Lid	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
~~Helium Retention~~ *Confinement*	Closure Ring	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
~~Helium Retention~~ *Confinement*	Port Cover Plates	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
Criticality Control	Basket Cell Plates	A	ASME Section III; Subsection NG	Alloy X	See Appendix 1.A	NA	NA
Criticality Control	Boral	A	Non-code	NA	NA	NA	Aluminum/SS
Shielding	Drain and Vent Shield Block	C	Non-code	Alloy X	See Appendix 1.A	NA	NA
Shielding	Plugs for Drilled Holes	NITS	Non-code	Alloy X	See Appendix 1.A	NA	NA

Notes:
1) There are no known residuals on finished component surfaces.
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
~~4)~~ *3)* Component nomenclature taken from Bill of Materials in Chapter 1.
~~3)~~ *4)* A,B and C denote important to safety classifications as described in Chapter 13. NITS stands for Not Important To Safety.
~~4)~~ *5)* For details on Alloy X material, see Appendix 1.A.
6) Must be Type 304, 304LN, 316, or 316LN with tensile strength ≥ 75 ksi, yield strength ≥ 30 ksi and chemical properties per ASTM A554

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM

MPC $^{(1,2)}$

Primary Function	Component $^{(3)}$	Safety Class $^{(4)}$	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	Upper Fuel Spacer Column	B	ASME Section III; Subsection NG (only for stress analysis)	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Sheathing	A	Non-code	Alloy X	See Appendix 1.A	Aluminum/SS	NA
Structural Integrity	Shims	NITS	Non-code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Basket Supports (Angled Plates)	A	ASME Section III; Subsection NG	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Basket Supports (Flat Plates)	B	ASME Section III; Subsection NG	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Lift Lug	C	Non-code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Lift Lug Baseplate	C	Non-code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Upper Fuel Spacer Bolt	NITS	Non-code	A193-B8	Per ASME Section II	NA	NA
Structural Integrity	Upper Fuel Spacer End Plate	B	Non-code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Lower Fuel Spacer Column	B	ASME Section III; Subsection NG (only for stress analysis)	~~Alloy X~~ *Stainless Steel. See Note 6*	See Appendix 1.A	NA	NA
Structural Integrity	Lower Fuel Spacer End Plate	B	Non-code	Alloy X	See Appendix 1.A	NA	NA

Notes: 1) There are no known residuals on finished component surfaces.

2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.

~~4)~~ *3)* Component nomenclature taken from Bill of Materials in Chapter 1.

~~3)~~ *4)* A,B and C denote important to safety classifications as described in Chapter 13. NITS stands for Not Important To Safety.

~~4)~~ *5)* For details on Alloy X material, see Appendix 1.A.

6) Must be Type 304, 304LN, 316, or 316LN with tensile strength ≥ 75 ksi, yield strength ≥ 30 ksi and chemical properties per ASTM A554

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM

OVERPACK (1,2)

Primary Function	Component (3)	Safety Class (4)	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	Lid Shell	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Inlet Vent Vertical & Horizontal Plates	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Thermal	Exit Vent Vertical & Horizontal Plates	B	See Note 6	SA516-70	See Table 3.3.2	See Note 5	
Structural Integrity	Top Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Lid Top Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Radial Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Lid Stud & Nut	B	ASME Section III; Subsection NF	SA564-630 *(stud)* *SA 194-2H (nut)*	See Table 3.3.4	Threads to have cadmium coating (or similar)	NA
Structural Integrity	Bolt Anchor Block	A	ASME Section III; Subsection NF ANSI N14.6	SA350-LF3 Or SA203E	See Table 3.3.3	See Note 5	NA

Notes:
1) There are no known residuals on finished component surfaces.
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A,B and C denote important to safety classifications as described in Chapter 13. NITS stands for Not Important To Safety.
5) All exposed steel surfaces (except threaded holes) to be painted with Carboline 890.
6) Welds will meet AWS D1.1 requirements for prequalified welds, except that welder qualification and weld procedures of ASME Code Section IX may be substituted.

LE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM

HI-TRAC TRANSFER CASK [(1,2)]

Primary Function	Component [(3)]	Safety Class [(4)]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	Pool Lid Outer Ring	B	ASME Section III; Subsection NF	*SA 516 Gr. 70 or SA 203E, or* SA350-LF3	See Table 3.3.3	See Note 5	NA
Structural Integrity	Pool Lid Top Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Top Lid Outer Ring	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Top Lid Inner Ring	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Top Lid Top Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Top Lid Bottom Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Fill Port Caps	C	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Pool Lid Bolt	B	ASME Section III; Subsection NF	SA193-B7	See Table 3.3.4	NA	NA
Structural Integrity	Lifting Trunnion Block	B	ASME Section III; Subsection NF ANSI 14.6	SA350-LF3	See Table 3.3.3	See Note 5	NA

Notes:
1) There are no known residuals on finished component surfaces.
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A,B and C denote important to safety classifications as described in Chapter 13. NITS stands for Not Important To Safety.
5) All external surfaces to be painted with Carboline 890. Inside surface of overpack and to be painted with Thermaline 450.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM

HI-TRAC TRANSFER CASK [(1,2)]

Primary Function	Component [(3)]	Safety Class [(4)]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	Lifting Trunnion	A	ANSI N14.6	SB637 (N07718)	See Table 3.3.4	NA	NA
Structural Integrity	Pocket Trunnion	B	ASME Section III; Subsection NF ANSI 14.6	SA350-LF3	See Table 3.3.3	See Note 5	NA
Structural Integrity	Dowel Pins	B	ASME Section III; Subsection NF	SA564-630	See Table 3.3.4	NA	SA350-LF3
Structural Integrity	Water Jacket End Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Pool Lid Bottom Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Top Lid Lifting Block	C	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Thermal Expansion Foam	NITS	Non-code	Silicone or similar	NA	NA	NA
Operations	Top Lid Stud	B	ASME Section III; Subsection NF	SA193-B7	See Table 3.3.4	NA	NA
Operations	Top Lid Nut	B	ASME Section III; Subsection NF	~~SA193-2H~~ *SA194-2H*	NA	NA	NA
Operations	Pool Lid Gasket	NITS	Non-code	Elastomer	NA	NA	NA
Operations	Pool Lid & Top Lid Tongues	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	NA	NA

Notes:
1) There are no known residuals on finished component surfaces.
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A,B and C denote important to safety classifications as described in Chapter 13. NITS stands for Not Important To Safety.
5) All external surfaces to be painted with Carboline 890. Inside surface of overpack and to be painted with Thermaline 450.

Table 2.2.8

ADDITIONAL DESIGN INPUT DATA FOR NORMAL, OFF-NORMAL, AND ACCIDENT CONDITIONS

Item	**Condition**	**Value**
Snow Pressure Loading (lb./ft^2)	Normal	100
Constriction of MPC Basket Vent Opening By Crud Settling (Depth of Crud, in.)	Accident	0.85 (MPC-68) 0.36 (MPC-24)
Cask Environment During the Postulated Fire Event (°F)	Accident	1475
HI-STORM 100 Overpack Fire Duration (seconds)	Accident	217
HI-TRAC Transfer Cask Fire Duration (minutes)	Accident	4.8
Maximum submergence depth due to flood (ft)	Accident	125
Flood water velocity (ft/s)	Accident	15
Interaction Relation for Horizontal & Vertical ZPA (Zero Period Acceleration) for HI-STORM[†]	Accident	$G_H + 0.53G_V = 0.53$[††]
HI-STORM 100 Overpack Vertical Lift Height Limit (in.)	Accident	11
HI-TRAC Transfer Cask Horizontal Lift Height Limit (in.)	Accident	42

[†] The maximum horizontal ZPA is specified as the vector sum of the ZPA g-loading in two orthogonal directions.

[††] See Subsection 3.4.7.1 for definition of G_H and G_V. ~~The coefficient 0.53 may be increased based on testing described in Subsection 3.4.7.1~~. |

Component	Reference ASME Code Section/Article	Code Requirement	Exception, Justification & Compensatory Measures
MPC Closure Ring, Vent and Drain Cover Plate Welds	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required.	Root *(if more than one weld pass is required)* and final liquid penetrant examination to be performed in accordance with NB-5245. The MPC vent and drain cover plate welds are leak tested. The closure ring provides independent redundant closure for vent and drain cover plates.
MPC Lid Weld	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required.	Only UT or multi-layer liquid penetrant (PT) examination is permitted. If PT examination alone is used, at a minimum, it will include the root and final weld layers and each approx. 3/8" of weld depth.

2.3 SAFETY PROTECTION SYSTEMS

2.3.1 General

The HI-STORM 100 System is engineered to provide for the safe long-term storage of spent nuclear fuel (SNF). The HI-STORM 100 will withstand all normal, off-normal, and postulated accident conditions without any uncontrolled release of radioactive material or excessive radiation exposure to workers or members of the public. Special considerations in the design have been made to ensure long-term integrity and confinement of the stored SNF throughout all cask operating conditions. The design considerations which have been incorporated into the HI-STORM 100 System to ensure safe long-term fuel storage are:

1. The MPC confinement barrier is an enclosure vessel designed in accordance with the ASME Code, Subsection NB with confinement welds inspected by radiography (RT) or ultrasonic testing (UT). Where RT or UT is not possible, a redundant closure system is provided with field welds which are hydrostatically tested, helium leakage tested and inspected by the liquid penetrant method.

2. The MPC confinement barrier is surrounded by the HI-STORM overpack which provides for the physical protection of the MPC.

3. The HI-STORM 100 System is designed to meet the requirements of storage while maintaining the safety of the SNF.

4. The SNF once initially loaded in the MPC does not require opening of the canister for repackaging to transport the SNF.

5. The decay heat emitted by the SNF is rejected from the HI-STORM 100 System through passive means. No active cooling systems are employed.

It is recognized that a rugged design with large safety margins is essential, but that is not sufficient to ensure acceptable performance over the service life of any system. A carefully planned oversight and surveillance plan which does not diminish system integrity but provides reliable information on the effect of passage of time on the performance of the system is essential. Such a surveillance and performance assay program will be developed to be compatible with the specific conditions of the licensee's facility where the HI-STORM 100 System is installed. The general requirements for the acceptance testing and maintenance programs are provided in Chapter 9. Surveillance requirements are specified in *the Technical Specifications in Appendix A to the CoC.* ~~Chapter 12~~.

The structures, systems, and components of the HI-STORM 100 System designated as important to safety are identified in Table 2.2.6. Similar categorization of structures, systems, and components, which are part of the ISFSI, but not part of the HI-STORM 100 System, will be the responsibility of the 10CFR72 licensee.

2.3.2 Protection by Multiple Confinement Barriers and Systems

2.3.2.1 Confinement Barriers and Systems

The radioactivity which the HI-STORM 100 System must confine originates from the spent fuel assemblies and, to a lesser extent, the contaminated water in the fuel pool. This radioactivity is confined by multiple confinement barriers.

Radioactivity from the fuel pool water is minimized by preventing contact, removing the contaminated water, and decontamination.

An inflatable seal in the annular gap between the MPC and HI-TRAC, and the elastomer seal in the HI-TRAC pool lid prevent the fuel pool water from contacting the exterior of the MPC and interior of the HI-TRAC while submerged for fuel loading. The fuel pool water is drained from the interior of the MPC and the MPC internals are dried. The exterior of the HI-TRAC has a painted surface which is decontaminated to acceptable levels. Any residual radioactivity deposited by the fuel pool water is confined by the MPC confinement boundary along with the spent nuclear fuel.

The HI-STORM 100 System is designed with several confinement barriers for the radioactive fuel contents. Intact fuel assemblies have cladding which provides the first boundary preventing release of the fission products. Fuel assemblies classified as damaged fuel or fuel debris are placed in a damaged fuel container which restricts the release of fuel debris. The MPC is a seal welded enclosure which provides the confinement boundary. The MPC confinement boundary is defined by the MPC baseplate, shell, lid, closure ring, and port cover plates.

The MPC confinement boundary has been designed to withstand any postulated off-normal operations, internal change, or external natural phenomena. The MPC is designed to endure normal, off-normal, and accident conditions of storage with the maximum decay heat loads without loss of confinement. Designed in accordance with the ASME Code, Section III, Subsection NB to the maximum extent practical, the MPC confinement boundary provides assurance that there will be no release of radioactive materials from the cask under all postulated loading conditions. Redundant closure of the MPC is provided by the MPC closure ring welds which provide a second barrier to the release of radioactive material from the MPC internal cavity. Therefore, no monitoring system for the confinement boundary is required.

Confinement is discussed further in Chapter 7. MPC field weld examinations, hydrostatic testing, and helium leak testing are performed to verify the confinement function ~~in accordance with the~~

~~Technical Specifications contained in Chapter 12.~~ Fabrication inspections and tests are also performed, as discussed in Chapter 9, to verify the confinement boundary.

2.3.2.2 Cask Cooling

To facilitate the passive heat removal capability of the HI-STORM 100, several thermal design criteria are established for normal and off-normal conditions. They are as follows:

- The heat rejection capacity of the HI-STORM 100 System is deliberately understated by conservatively determining the design basis fuel. The decay heat value in Table 2.1.6 is developed by computing the decay heat from the design basis fuel assembly which produces the highest heat generation rate for a given burnup. Additional margin is built into the calculated cask cooling rate by using a design basis fuel assembly which offers maximum resistance to the transmission of heat (minimum thermal conductivity).

- The MPC fuel basket is formed by a honeycomb structure of stainless steel plates with full-length edge-welded intersections, which allows the unimpaired conduction of heat.

- The MPC confinement boundary ensures that the helium atmosphere inside the MPC is maintained during normal, off-normal, and accident conditions of storage and transfer. The MPC confinement boundary maintains the helium confinement atmosphere below the design temperatures and pressures stated in Table 2.2.3 and Table 2.2.1, respectively.

- The MPC thermal design maintains the fuel rod cladding temperatures below the values stated in Chapter 4 such that fuel cladding is not degraded during the long term storage period.

- The HI-STORM is optimally designed with cooling vents and a MPC to overpack annulus which maximize air flow, while providing superior radiation shielding. The vents and annulus allow cooling air to circulate past the MPC removing the decay heat.

- HI-TRAC lifter(s): The HI-TRAC lifter is the mechanical lifting device, typically consisting of jacks or hoists, that is utilized to lift a loaded or unloaded HI-TRAC to the required elevation in the CTF so that it can be mounted on the overpack.[†]

- Lifter Mount: A beam-like structure (part of the CTF structure) that supports the HI-TRAC and MPC lifter(s).

- Lift Platform: The lift platform is the intermediate structure that transfers the vertical load of the HI-TRAC transfer cask to the HI-TRAC lifters.

- Mobile crane: A mobile crane is a device defined in ASME B30.5-1994, Mobile and Locomotive Cranes. A mobile crane may be used in lieu of the HI-TRAC lifter and/or an MPC lifter provided all requirements set forth in this subsection are satisfied.

- MPC lifter: The MPC lifter is a mechanical lifting device, typically consisting of jacks or hoists, that is utilized to vertically transfer the MPC between the HI-TRAC transfer cask and the overpack.

- Pier: The portion of the reinforced concrete foundation which projects above the concrete floor of the CTF.

- Single-Failure-Proof (SFP): A single-failure-proof handling device is one wherein all directly loaded tension and compression members are engineered to satisfy the enhanced safety criteria given in of NUREG-0612.

- Translocation Device: A low vertical profile device used to laterally position an overpack such that the bottom surface of the overpack is fully supported by the top surface of the device. Typical translocation devices are air pads and Hillman rollers.

iv. Important to Safety Designation:

[†] The term overpack is used in this specification as a generic term for the HI-STAR 100, ~~and~~ HI-STORM 100, *and HI-STORM 100S* overpacks.

Additional control methods used to prevent criticality for the MPC-24 and MPC-24E (with higher enriched fuel), and the MPC-32 are the following:

a. *Loading of irradiated fuel assemblies with enrichments greater than 1.9 wt% ^{235}U must be performed in water with a minimum boron content as specified in Table 2.1.14.*

b. *Prevention of fresh water entering the MPC internals.*

Administrative controls specified as Technical Specifications *and Approved Contents* are provided in *Appendices A and B to the CoC, respectively,* ~~Chapter 12~~ and shall be used to ensure that fuel placed in the HI-STORM 100 System meets the requirements described in Chapters 2 and 6. All appropriate criticality analyses are presented in Chapter 6.

2.3.4.2 Error Contingency Criteria

Provision for error contingency is built into the criticality analyses performed in Chapter 6. Because biases and uncertainties are explicitly evaluated in the analysis, it is not necessary to introduce additional contingency for error.

2.3.4.3 Verification Analyses

In Chapter 6, critical experiments are selected which reflect the design configurations. These critical experiments are evaluated using the same calculation methods, and a suitable bias is incorporated in the reactivity calculation.

2.3.5 Radiological Protection

2.3.5.1 Access Control

As required by 10CFR72, uncontrolled access to the ISFSI is prevented through physical protection means. A peripheral fence with an appropriate locking and monitoring system is a standard approach to limit access. The details of the access control systems and procedures, including division of the site into radiation protection areas, will be developed by the licensee (user) of the ISFSI utilizing the HI-STORM 100 System.

2.3.5.2 Shielding

The shielding design is governed by 10CFR72.104 and 10CFR72.106 which provide radiation dose limits for any real individual located at or beyond the nearest boundary of the controlled area. The individual must not receive an annual dose equivalent greater than the values stated below for normal and off-normal conditions. Further, an individual located at the site boundary must not receive a dose to the whole body or any organ from any design basis accident greater than the values listed in Table 2.3.1.

The objective of shielding is to assure that radiation dose rates at key locations are below acceptable levels for those locations. Three locations are of particular interest in the storage mode:

- immediate vicinity of the cask
- restricted area boundary
- controlled area (site) boundary

Dose rates in the immediate vicinity of the loaded overpack are important in consideration of occupational exposure. A design objective for the maximum average radial surface dose rate has been established as ~~40~~ *50* mrem/hr. Areas adjacent to the inlet and exit vents which pass through the radial shield are limited to 60 mrem/hr. The average dose rate at the top of the overpack is limited to below 10 mrem/hr. Chapter 5 of this TSAR presents the analyses and evaluations to establish HI-STORM 100 compliance with these design objectives.

Because of the passive nature of the HI-STORM 100, human activity related to the system is infrequent and of short duration. Personnel exposures due to operational and maintenance activities are discussed in Chapter 10. Chapter 10 also provides information concerning temporary shielding which may be utilized to reduce the personnel dose during loading, unloading, transfer, and handling operations. The estimated occupational doses for personnel comply with the requirements of 10CFR20.

For the loading and unloading of the HI-STORM overpack with the MPC two transfer cask designs are provided (i.e.,125 ton HI-TRAC and 100 ton HI-TRAC). The 125 ton HI-TRAC provides better shielding than the 100 ton HI-TRAC due to the increased shielding thickness and corresponding greater weight. Provided the licensee is capable of utilizing the 125 ton HI-TRAC, ALARA considerations would dictate that the 125 ton HI-TRAC should be used. However, sites may not be capable of utilizing the 125 ton HI-TRAC due to crane capacity limitations, floor loading considerations, or space envelope limitations in the fuel pool or air lock. As with other dose reduction-based plant modifications, individual users who cannot accommodate the 125 ton HI-TRAC due to plant design limitations must perform a cost-benefit analysis of the modifications which would be necessary to use the 125 ton HI-TRAC. The cost of the modification(s) would be weighed against the value of the projected reduction in radiation exposure and a decision made based on each plant's particular ALARA implementation philosophy.

Dose rates at the restricted area and site boundaries shall be in accordance with applicable regulations. Licensees shall demonstrate compliance with 10CFR72.104 and 10CFR72.106 for the actual fuel being stored, the ISFSI storage array, and the controlled area boundary distances.

Table 2.3.1

RADIOLOGICAL SITE BOUNDARY REQUIREMENTS

BOUNDARY OF CONTROLLED AREA (m) (minimum)	100
NORMAL AND OFF-NORMAL CONDITIONS:	
Whole Body (mrem/yr)	25
Thyroid (mrem/yr)	75
Any Other *Critical* Organ (mrem/yr)	25
DESIGN BASIS ACCIDENT:	
~~Whole Body~~ *TEDE* (rem)	5
DDE + CDE to any individual organ or tissue (other than lens of the eye) (rem)	*50*
Lens dose equivalent (rem)	*15*
Shallow dose equivalent to skin or any extremity (rem)	*50*
~~Any Organ (rem)~~	~~5~~

“	Material Testing and Analysis		9.1; Table 9.1.1;1.D
“	Material Traceability		9.1.1
“	Material Long Term Performance	3.3; 3.4.11; 3.4.12	9.2
“	Materials Appropriate to Load Conditions		Chap. 1
“	Restrictions on Use		Chap. 12
“	Temperature Limits	Table 3.1.17	Table 2.2.3
“	Creep/Slump	3.4.4.3.3.2; 3.F	
“	Brittle Fracture Considerations	3.1.2.3; Table 3.1.18	
“	Low Temperature Handling		2.2.1.2
V.1.d.i.(1)	Normal Load Conditions		2.2.1; Tables 2.2.13,2.2.14
“	Fatigue	3.1.2.4	
“	Internal Pressures/Temperatures for Hot and Cold Conditions	3.4.4.1	2.2.2; Tables 2.2.1,2.2.3
“	Required Evaluations		
“	Weight+Pressure	3.4.4.3.1.2	
“	Weight/Pressure/Temp.	3.4.4.3.1.2	
“	Free Thermal Expansion	3.4.4.2; 3.U; **3.V**;3.W; 3.I;3.AF; **3.AQ**	Tables 4.4.15, 4.5.4

Table continued on following page

TABLE 3.0.1 (CONTINUED)

V.1.d.i.(2)	Off-Normal Conditions		2.2.2; Tables 2.2.13, 2.2.14; 11.1
V.1.d.i.(3)	Accident Level Events and Conditions	Tables 3.1.1, 3.1.2	2.2.3; Tables 2.2.13, 2.2.14; 11.2
V.1.d.i.(3).(a)	Storage Cask Vertical Drop	3.1.2.1.1.2; 3.4.10; 3.A	2.2.3.1
"	Storage Cask Tipover	3.1.2.1.1.1; 3.4.10; 3.A	2.2.3.2
"	Transfer Cask Horizontal Drop	3.4.9; 3.Z; 3.AL; **3.AN**	2.2.3.1
V.1.d.i.(3).(b)	Explosive Overpressure	3.1.2.1.1.4;3AK	2.2.3.10
V.1.d.i.(3).(c)	Fire		
"	Structural Evaluations	3.4.4.2	2.2.3.3
"	Material Properties		11.2
"	Material Suitability	3.1.2.2; 3.3.1.1	Table 2.2.3;11.2
V.1.d.i.(3).(d)	Flood		
"	Identification	3.1.2.1.1.3; 3.4.6	2.2.3.6
"	Cask Tipover	3.4.6	
"	Cask Sliding	3.4.6	
"	Hydrostatic Loading	3.1.2.1.1.3; 3.4.6	72-1008(3.H)
"	Consequences		11.2
V.1.d.i.(3).(e)	Tornado Winds		
"	Specification	3.1.2.1.1.5	2.2.3.5; Table 2.2.4
"	Drag Coefficients	3.4.8; 3.C	
"	Load Combination	3.4.8; 3.C	

Table continued on following page

TABLE 3.0.1 (CONTINUED)

“	Overturning	3.C	
“	Overturning –Transfer	NA	
V.1.d.i.(3).(f)	Tornado Missiles		
“	Missile Parameters	3.1.2.1.1.5	Table 2.2.5
“	Tipover	3.4.8; 3.C	
“	Damage	3.B; 3.G; 3.H; 3Z; 3.AM	
“	Consequences	3.4.8.1; 3.4.8.2	11.2
V.1.d.i.(3).(g)	Earthquakes		
“	Definition of DBE	3.1.2.1.1.6; 3.4.7	2.2.3.7; Table 2.2.8
“	Sliding	3.4.7	
“	Overturning	3.4.7	
“	Structural Evaluations	3.4.7; 3B	11.2
V.1.d.i.(4).(a)	Lifting Analyses		
“	Trunnions		
“	Requirements	3.1.2.1.2; 3.4.3.1;3.4.3.2	72-1008(3.4.3);2.2.1.2
“	Analyses	3.4.3.1; 3.4.3.2; 3.D;3.E; 3.AC; 3.AE	72-1008(3.4.3)
“	Other Lift Analyses	3.4.3.7-3.4.3.9; 3.D; 3.AB; 3.AC; 3.AE; 3.AD; 3.AI; 3.AJ	
V.1.d.i.(4).(b)	Fuel Basket		
“	Requirements	3.1.2.1.2; Table 3.1.3	
“	Specific Analyses	3.4.4.2; 3.4.4.3; 3.6.3; 3.U; 3.W; 3.I; 3.N-3.T; 3.Y	72-1008(3.4.4.3.1.2; 3.4.4.3.1.6; 3.AA; 3.M; 3.H; 3.I)
“	Dynamic Amplifiers	3.X	

Table continued on following page

TABLE 3.0.1 (CONTINUED)

“	Stability	3.4.4.3; 3.4.4.4; 3.AK	72-1008(Figures 3.4.27-32)
V.1.d.i.(4).(c)	Confinement Closure Lid Bolts		
“	Pre-Torque	NA	
“	Analyses	NA	
“	Engagement Length	NA	
“	Miscellaneous Bolting		
“	Pre-Torque	3.AC	
“	Analyses	3.L	
“	Engagement Length	3.AC; 3.D	
V.1.d.i.(4)	Confinement		
“	Requirements	3.1.2.1.2; Table 3.1.4	Chap. 7
“	Specific Analyses	3.6.3; Tables 3.4.3, 3.4.4; 3.D; 3.N-3.T	72-1008(3.E; 3.K; 3.I; 3.AA 3.4.4.3.1.5)
“	Dynamic Amplifiers	3.X; 3.4.4.1	
“	Stability	3.4.4.3.1	72-1008(3.H)
“	Overpack		
“	Requirements	3.1.2.1.2; Tables 3.1.1, 3.1.5	
“	Specific Analyses	3.6.3; 3.B; 3.D; 3.L; 3.M; 3.AC; 3.D;3.4.4.3; 3.K; 3.AK; **3.AR; 3.AS**	

Table continued on following page

TABLE 3.0.1 (CONTINUED)

“	Dynamic Amplifiers	3.4.4.3.2; 3.X	
“	Stability	3.4.4.3; Table 3.1.1; 3.4.4.5; 3.AK	
“	Transfer Cask		
“	Requirements	3.1.2.1.2; Table 3.1.5	
“	Specific Analyses	3.4.4.3; 3.6.3; 3.E; 3.H; 3.I; 3.Z; 3.AD; 3.AE; 3.AA; 3.AI; 3.AB; 3.AD; 3.AG; 3.F; 3.AH; 3.AJ; 3.AL; 3.AM**; 3.AO; 3.AP**	
“	Dynamic Amplifiers	3.X	
“	Stability	NA	2.2.3.1

† Legend for Table 3.0.1

Per the nomenclature defined in Chapter 1, the first digit refers to the chapter number, the second digit is the section number within the chapter; an alphabetic character in the second place means it is an appendix to the chapter.

72-1008	HI-STAR 100 Docket Number where the referenced item is located
NA	Not Applicable for this item

MPC is horizontal) or tip-over. Under the side drop or tip-over condition the flat panels of the fuel basket are subject to an equivalent pressure loading that simulates the deceleration-magnified inertia load from the stored fuel and the MPC's own metal mass.

The MPC fuel basket maintains the spent nuclear fuel in a subcritical arrangement. Its safe operation is assured by maintaining the physical configuration of the storage cell cavities intact in the aftermath of a drop event. This requirement is considered to be satisfied if the MPC fuel basket meets the stress intensity criteria set forth in the ASME Code, Section III, Subsection NG. Therefore, the demonstration that the fuel basket meets Subsection NG limits ensures that there is no impairment of ready retrievability (as required by NUREG-1536), and that there is no unacceptable effect on the subcritical arrangement.

The MPC confinement boundary contains no valves or other pressure relief devices. The MPC enclosure vessel is shown to meet the stress intensity criteria of the ASME Code, Section III, Subsection NB for all service conditions. Therefore, the demonstration that the enclosure vessel meets Subsection NB limits ensures that there is no unacceptable release of radioactive materials.

The HI-STORM 100 storage overpack is a steel cylindrical structure consisting of inner and outer low carbon steel shells, a lid, and a baseplate. Between the two shells is a thick cylinder of unreinforced (plain) concrete. Additional regions of fully confined (by enveloping steel structure) unreinforced concrete are attached to the lid and to the baseplate. The storage overpack serves as a missile and radiation barrier, provides flow paths for natural convection, provides kinematic stability to the system, and acts as a cushion for the MPC in the event of a tip-over accident. The storage overpack is not a pressure vessel since it contains cooling vents which do not allow for a differential pressure to develop across the overpack wall. The structural steel components of the HI-STORM 100 Overpack are designed to meet the stress limits of the ASME Code, Section III, Subsection NF, Class 3. A short version of the HI-STORM 100 **overpack, designated as the HI-STORM 100S, is introduced in this revision. To accommodate nuclear plants with limited height access, the HI-STORM 100S has a re-configured lid and a lower overall height. There are minor weight redistributions but the overall bounding weight of the system is unchanged. Therefore, structural analyses are revisited if and only if the modified configuration cannot be demonstrated to be bounded by the original calculation. New or modified calculations focused on the HI-STORM 100 are clearly identified within the text of this chapter. Unless otherwise designated, general statements using the terminology "HI-STORM 100" also apply to the HI-STORM 100S. The HI-STORM 100S can carry all MPC's and transfer casks that are able to be carried in the HI-STORM 100.**

As discussed in Chapters 1 and 2, and Section 3.0, the principal shielding material utilized in the HI-STORM 100 Overpack is plain concrete. Plain concrete was selected for the HI-STORM 100 Overpack in lieu of reinforced concrete, because there is no structural imperative for incorporating tensile load bearing strength into the contained concrete. From a purely practical standpoint, the absence of rebars facilitate pouring and curing of concrete with minimal voids, which is an important consideration in light of its shielding function in the HI-STORM 100 Overpack. Plain concrete, The individual loads applicable to the HI-STORM 100 System and the HI-TRAC cask are defined in Section 2.2 of this report (Table 2.2.13). Load combinations are developed by assembling the individual loads which may act concurrently, and possibly, synergistically (Table 2.2.14). In this subsection, the individual loads are further clarified as appropriate and the required load combinations are identified. Table 3.1.1 contains the load combinations for the storage overpack where kinematic stability is of primary importance. The load combinations where stress or load level is of primary importance are set forth in Table 3.1.3 for the MPC fuel basket, in Table 3.1.4 for the MPC confinement boundary, and in Table 3.1.5 for the storage overpack and the HI-TRAC transfer cask. Load combinations are applied to the mathematical models of the MPCs, the overpack, and the HI-TRAC. Results of the analyses carried out under bounding load combinations are compared with their respective allowable stresses (or stress intensities, as applicable). The analysis results from the bounding load combinations are also assessed, where warranted, to ensure satisfaction of the functional performance criteria discussed in the preceding subsection.

3.1.2.1.1 Individual Load Cases

The individual loads that address each design criterion applicable to the structural design of the HI-STORM 100 System are catalogued in Table 2.2.13. Each load is given a symbol for subsequent use in the load combination listed in Table 2.2.14.

Accident condition and natural phenomena-induced events, collectively referred to as the "Level D" condition in Section III of the ASME Boiler & Pressure Vessel Codes, *in general* do not have a universally prescribed limit. For example, the impact load from a tornado-borne missile, or the overturning load under flood or tsunami, cannot be prescribed as design basis values with absolute certainty that all ISFSI sites will be covered. Therefore, as applicable, allowable magnitudes of such loadings are postulated for the HI-STORM 100 System. The allowable values are drawn from regulatory and industry documents (such as for tornado missiles and wind) or from an intrinsic limitation in the system (such as the permissible "drop height" under a postulated handling accident). In the following, the essential characteristic of each "Level D" type loading is explained.

3.1.2.1.1.1 Tip-Over

It is required to demonstrate that the HI-STORM 100 storage overpack, containing a loaded MPC, will not tip over as a result of a postulated natural phenomenon event, including tornado wind, a tornado-generated missile, a seismic or a hydrological event (flood). However, to demonstrate the defense-in-depth features of the design, a non-mechanistic tip-over scenario per NUREG-1536 is analyzed. **Since the HI-STORM 100S has an overall length that is less than the regular HI-STORM 100, the maximum impact velocity of the overpack will be reduced. Therefore, the results of the tipover analysis for the HI-STORM 100 (reported in Appendix 3.A) are bounding for the HI-STORM 100S.** The potential of the HI-STORM 100 Overpack tipping over during the lowering (or raising) of the loaded MPC into (or out of) it with the HI-TRAC cask mounted on it is ruled out because of the safeguards and devices mandated by this TSAR for such operations (Subsection 2.3.3.1 and Technical Specification 4.9). The physical and procedural barriers under the MPC handling operations have been set down in the TSAR to preclude overturning of the HI-STORM/HI-TRAC assemblage with an extremely high level of certainty. Much of the ancillary equipment needed for the MPC transfer operations must be custom engineered to best accord with the structural and architectural exigencies of the ISFSI site. Therefore, with the exception of the HI-TRAC cask, their design can not be prescribed *a priori* in this TSAR. However, carefully drafted Design Criteria and conditions of use set forth in this TSAR eliminate the potential of weakening of the safety measures contemplated herein to preclude an overturning event during MPC transfer operations. Subsection 2.3.3.1 contains a comprehensive set of design criteria for the ancillary equipment and components required for MPC transfer operations- to ensure that the design objective of precluding a kinematic instability event during MPC transfer operations is met. Further information on the steps taken to preclude system overturning during MPC transfer operations may be found in Chapter 8, Section 8.0.

3.1.2.1.1.2 Handling Accident

A handling accident during transport of a loaded HI-STORM 100 storage overpack is assumed to result in a vertical drop. The HI-STORM 100 storage overpack will not be handled in a horizontal position while containing a loaded MPC. Therefore, a side drop is not considered a credible event.

HI-TRAC can be carried in a horizontal orientation while housing a loaded MPC. Therefore, a handling accident during transport of a loaded HI-TRAC in a horizontal orientation is considered to be a **credible**~~postulable~~ accident event.

As discussed in the foregoing, the vertical drop of the HI-TRAC and the tip-over of the assemblage of a loaded HI-TRAC on the top of the HI-STORM 100 storage overpack during MPC transfer operations do not need to be considered.

3.1.2.1.1.3 Flood

The postulated flood event results into two discrete scenarios which must be considered; namely,

1. stability of the HI-STORM 100 System due to flood water velocity, and
2. structural effects of hydrostatic pressure and water velocity induced lateral pressure.

The maximum hydrostatic pressure on the cask in a flood where the water level is conservatively set at 125 feet is calculated as follows:

Using

p = the maximum hydrostatic pressure on the system (psi),
γ = weight density of water = 62.4 lb/ft^3
h = the height of the water level = 125 ft;

The results obtained for the HI-STORM 100 bound the corresponding results for HI-STORM 100S because of the reduced height.

3.1.2.1.1.6 Earthquake

Subsections 2.2.3.7 and 3.4.7 contain the detailed specification of the seismic inputs applied to the HI-STORM 100 System. The design basis earthquake is assumed to be at the top of the ISFSI pad. Potential consequences of a seismic event are sliding/overturning, and lateral force on the overpack causing excessive stress and deformation of the storage overpack.

3.1.2.1.1.7 Lightning

The HI-STORM 100 Overpack contains over 25,000 lb of highly conductive carbon steel with over 700 square feet of external surface area. Such a large surface area and metal mass is adequate to dissipate any lightning which may strike the HI-STORM 100 System. There are no combustible materials on the HI-STORM 100 surface. Therefore, lightning will not impair the structural performance of components of the HI-STORM 100 System that are important to safety.

3.1.2.1.1.8 Fire

The potential structural consequences of a fire are: the possibility of an interference developing between the storage overpack and the loaded MPC due to free thermal expansion; and, the degradation of material properties to the extent that their structural performance is affected during a subsequent recovery action. The fire condition is addressed to the extent necessary to demonstrate that these adverse structural consequences do not materialize.

3.1.2.1.1.9 100% Fuel Rod Rupture

The effect on structural performance by 100% fuel rod rupture is felt as an increase in internal pressure. The accident internal pressure limit set in Chapter 2 bounds the pressure from 100% fuel rod rupture. Therefore, no new load condition has been identified.

3.1.2.1.2 Load Combinations

Load combinations are created by summing the effects of several individual loads. The load combinations are selected for the normal, off-normal, and accident conditions. The loadings appropriate for HI-STORM 100 under the various conditions are presented in Table 2.2.14. These loadings are combined into meaningful combinations for the various HI-STORM 100 System components in Tables 3.1.1, and 3.1.3-3.1.5. Table 3.1.1 lists the load combinations that address overpack stability. Tables 3.1.3 through 3.1.5 list the applicable load combinations for the fuel basket, the enclosure vessel, and the overpack and HI-TRAC, respectively.

As discussed in Subsection 2.2.7, the number of discrete load combinations for each situational condition (i.e., normal, off-normal, etc.) is consolidated by defining bounding loads for certain groups of loadings. Thus, the accident condition pressure P_o^* bounds the surface loadings arising from accident and extreme natural phenomenon events, namely, tornado wind W', flood F, and explosion E^*.

As noted previously, certain loads, namely earthquake E, flowing water under flood condition F, force from an explosion pressure pulse F*, and tornado missile M, act to destabilize a cask. Additionally, these loads act on the overpack and produce essentially localized stresses at the HI-STORM 100 System to ISFSI interface. Table 3.1.1 provides the load combinations which are relevant to the stability analyses. The site ISFSI DBE zero period acceleration (ZPA) must be bounded by the design basis seismic ZPA defined by the Load Combination C of Table 3.1.1 to demonstrate that the margin against tip-over during a seismic event is maintained.

The major constituents in the HI-STORM 100 System are: (i) the fuel basket, (ii) the enclosure vessel, (iii) the HI-STORM 100 **(or HI-STORM 100S)** Overpack, and (iv) the HI-TRAC transfer cask. The fuel basket and the enclosure vessel (EV) together constitute the multi-purpose canister. The multi-purpose canister (MPC) is common to HI-STORM 100 and HI-STAR 100, and as such, has been extensively analyzed in the storage TSAR and transport SAR (Dockets 72-1008 and 71-9261) for HI-STAR 100. Many of the loadings on the MPC (fuel basket and enclosure vessel) are equal to or bounded by loadings already considered in the HI-STAR 100 SAR documents. Where such analyses have been performed, their location in the HI-STAR 100 SAR documents is indicated in this HI-STORM 100 SAR for continuity in narration. A complete account of analyses and results for all load combinations for all four constituents parts is provided in Section 3.4 as required by Regulatory Guide 3.61.

In the following, the loadings listed as applicable for each situational condition in Table 2.2.14 are addressed in meaningful load combinations for the fuel basket, enclosure vessel, and the overpack. Each component is considered separately.

Fuel Basket

Table 3.1.3 summarizes all loading cases (derived from Table 2.2.14) which are germane to demonstrating compliance of the fuel baskets to Subsection NG when these baskets are housed within HI-STORM 100 or HI-TRAC.

The fuel basket is not a pressure vessel; therefore, the pressure loadings are not meaningful loads for the basket. Further, the basket is structurally decoupled from the enclosure vessel. The gap between the basket and the enclosure vessel is sized to ensure that no constraint of free-end thermal expansion of the basket occurs. The demonstration of the adequacy of the basket-to the-enclosure vessel (EV) gap to ensure absence of interference is a physical problem that must be analyzed.

The normal handling loads on the fuel basket in an MPC within the HI-STORM 100 System or the

- Under a non-mechanistic postulated tip-over of a fully loaded HI-STORM 100 Overpack, the overpack lid must not dislodge.

- Accident condition stress levels must not be exceeded in the steel and compressive stress levels in the concrete must remain within allowable limits.

- Accident condition induced gross general deformations of the storage overpack must be limited to values that do not preclude ready retrievability of the MPC.

As noted earlier, analyses performed using the HI-STORM 100 generally provide results that are identical to or bound results for the shorter HI-STORM 100S; in,general, therefore, analyses will not be repeated specifically for the HI-STORM 100S unless the specific geometry changes significantly influence the safety factors.

HI-TRAC Transfer Cask

Table 3.1.5 identifies load cases applicable to the HI-TRAC transfer cask.

The HI-TRAC transfer cask must provide radiation protection, must act as a handling cask when carrying a loaded MPC, and in the event of a postulated accident must not suffer permanent deformation to the extent that ready retrievability of the MPC is compromised. This submittal includes both a 125 ton HI-TRAC and a 100 ton HI-TRAC as detailed in the design drawings in Section 1.5. The same steel structures (i.e., shell thicknesses, lid thicknesses, etc.) are maintained with the only major differences being in the amount of lead shielding, the water jacket configuration, and the lower dead weight loading. Therefore, all structural analyses performed for the 125 ton HI-TRAC are repeated for the 100 ton HI-TRAC only if it cannot be clearly demonstrated that the 125 ton unit calculation is bounding.

3.1.2.2 Allowables

The important to safety components of the HI-STORM 100 System are listed in Table 2.2.6. Allowable stresses, as appropriate, are tabulated for these components for all service conditions.

In Subsection 2.2.5, the applicable service level from the ASME Code for determination of allowables is listed. Table 2.2.14 provides a tabulation of normal, off-normal, and accident conditions and the service levels defined in the ASME Code, along with the applicable loadings for each service condition.

Allowable stresses and stress intensities are calculated using the data provided in the ASME Code and Tables 2.2.10 through 2.2.12. Tables 3.1.6 through 3.1.16 contain numerical values of the stresses/stress intensities for all MPC, overpack, and HI-TRAC load bearing materials as a function of temperature.

for the MPC baseplate and the MPC lid are 400 degrees F and 550 degrees F, respectively, as specified in Table 2.2.3.

Finally, the lift devices in the HI-STORM 100 Overpack and HI-TRAC casks and the multi-purpose canisters, collectively referred to as "trunnions", are subject to specific limits set forth by NUREG-0612: the primary stresses in a trunnion must be less than the smaller of 1/10 of the material ultimate strength and 1/6 of the material yield strength under a normal handling condition (Load Case 01 in Table 3.1.5). The load combination D+H in Table 3.1.5 is equivalent to 1.15D. This is further explained in Subsection 3.4.3.

The region around the trunnions is part of the NF structure in HI-STORM 100 and HI-TRAC and NB pressure boundary in the MPC, and as such, must satisfy the applicable stress (or stress intensity) limits for the load combination. In addition to meeting the applicable Code limits, it is further required that the ~~local~~ primary stresse **required tos**– **maintain equilibrium** at the **defined** trunnion/mother structure interface must not exceed the material yield stress at three times the handling condition load (1.15D). This criterion, mandated by Regulatory Guide 3.61, Section 3.4.3, **insures that a large safety factor exists on non-local**~~eliminates the potential~~ **section**~~of local~~ yielding at the trunnion/mother structure interface **that would lead to unacceptable section displacement and rotation.**

3.1.2.3 Brittle Fracture

The MPC canister and basket are constructed from a series of stainless steels termed Alloy X. These stainless steel materials do not undergo a ductile-to-brittle transition in the minimum temperature range of the HI-STORM 100 System. Therefore, brittle fracture is not a concern for the MPC components. Such an assertion can not be made a priori for the HI-STORM storage overpack and HI-TRAC transfer cask that contain ferritic steel parts. In normal storage mode, the lowest service temperature (LST) of the HI-STORM storage overpack structural members may reach -40°F in the limiting condition wherein the spent nuclear fuel (SNF) in the contained MPCs emits no (or negligible) heat and the ambient temperature is at -40°F (design minimum per Chapter 2: Principal Design Criteria). During the HI-STORM handling operations, the applicable lowest service temperature is 0°F (which is the threshold ambient temperature below which lifting and handling of the HI-STORM 100 Overpack or the HI-TRAC cask is not permitted by the Technical Specification). Therefore, two distinct LSTs are applicable to load bearing metal parts within the HI-STORM 100 Overpack and the HI-TRAC cask; namely,

LST = 0°F for parts used to lift the overpack or transfer cask (see Table 2.2.2 and Chapter 12). This includes the anchor block in the HI-STORM 100 Overpack, and pocket trunnions, lifting trunnions and the lifting trunnion block in HI-TRAC. Such items will henceforth be referred to as "significant-to-handling" (STH) parts. The applicable code for these elements of the structure is ANSI N14.6.

LST = -40°F for all HI-STORM "NF" components and 0°F for all HI-TRAC "NF"

Table 3.2.1
HI-STORM 100 OVERPACK WEIGHT DATA

	WEIGHT (lb)[†]		
Item	Component (lb.)	Assembly (lb.)	—Bounding Weight[††] (lb.)
HI-STORM 100 Overpack		**265,866**~~8,334~~	270,000
· Overpack top lid	21,638		23,000
HI-STORM 100S Overpack		**252,423**	270,000
· Overpack top lid	24,771~~498~~		25,500
MPC-24			
· Without SNF		39,667	
· Fully loaded with SNF		79,987	90,000
Overpack (100) with fully loaded MPC-24		**345,853**~~8,321~~	360,000
(100S) with loaded MPC-24		**332,410**	**360,000**
MPC-68			
· Without SNF		39,641	
· Fully loaded with SNF		87,241	90,000
Overpack (100) with fully loaded MPC-68		**353,107**~~5,575~~	360,000
(100S) with loaded MPC-68		**339,664**	**360,000**
Overpack (100) with **empty MPC-68**~~lower bound weightminimum weight MPC without SNF~~		**304,507**~~307,975~~	303~~0~~3,000 (Lower Bound)
MPC-32			
· Without SNF		34,375	
· Fully loaded with SNF		88,135	90,000
Overpack (100) with **fully** loaded MPC-32		**354,001**~~6,469~~	360,000
(100S) with loaded MPC-32		**340,558**	**360,000**
MPC-24E			
· Without SNF		42,069	
· Fully loaded with SNF		82,389	90,000
Overpack (100) with **fully** loaded MPC-24E		**—348,255**	360,000
(100S) with loaded MPC-24E		**334,812**~~350,723~~	360,000

[†] All calculated weights are rounded up to the nearest pound

[††] Bounding weights or calculated weights may be used for analytical calculations, as appropriate, to ensure conservatism in the results.

Table 3.2.2

125-TON HI-TRAC TRANSFER CASK WEIGHT DATA

ITEM	WEIGHT (lb)†		
	Component	Assembly	Bounding Weight††
125-Ton HI-TRAC Transfer Cask with Pool Lid		142,976~~88~~	143,500
· Pool Lid · Top Lid	12,031~~1~~ 2,730		12,500 2,750
125-Ton HI-TRAC Transfer Cask with Transfer Lid		154,373~~2,636~~	1553,000
· Transfer Lid · Top Lid	23,428~~1,679~~ 2,730		24,5~~2,0~~00 2,750
MPC-24			
· Without SNF · Fully loaded with SNF		39,667 79,987	80,000
125-Ton HI-TRAC with Pool Lid with loaded MPC-24		222,963~~75~~	223,500
125-Ton HI-TRAC with Transfer Lid w/ loaded MPC-24		234,359~~2,623~~	2353,000
MPC-68			
· Without SNF · Fully loaded with SNF		39,641 87,241	90,000
125-Ton HI-TRAC with Pool Lid with loaded MPC-68		230,217~~29~~	233,500
125-Ton HI-TRAC with Transfer Lid w/ loaded MPC-68		241,613~~39,877~~	243,000
MPC-32			
· Without SNF · Fully loaded with SNF		34,375 88,135	90,000
125-Ton HI-TRAC with Pool Lid with loaded MPC-32		231,111~~23~~	233,500
125-Ton HI-TRAC with Transfer Lid w/ loaded MPC-32		242,507~~0,771~~	243,000
MPC-24E			
· Without SNF · Fully loaded with SNF		42,069 82,389	90,000
125-Ton HI-TRAC with Pool Lid with loaded MPC-24E		225,365~~77~~	226,000
125-Ton HI-TRAC with Transfer Lid w/ loaded MPC-24E		236,761~~5,035~~	2376,5000

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† All calculated weights are rounded up to the nearest pound

†† Bounding weights or calculated weights may be used for analytical calculations, as appropriate, to insure conservatism in the results.

Table 3.2.2 (continued)
100-TON HI-TRAC TRANSFER CASK WEIGHT DATA[†]

	WEIGHT (lb)		
ITEM	Component	Assembly	Bounding Weight[††]
100-Ton HI-TRAC Transfer Cask with Pool Lid		100,449~~960~~	102,000
• Removable trunnion	255		
· Pool Lid	7,915		8,000
· Top Lid	1,203~~2~~		1,5~~2,~~400
100-Ton HI-TRAC Transfer Cask with Transfer Lid		108,626~~267~~	111,000
• Removable trunnion	255		
· Transfer Lid	16,092~~425~~		17~~8~~,000
· Top Lid	1,203~~2~~		1,5~~2,~~400
MPC-24			
· Without SNF		39,667	
· Fully loaded with SNF		79,987	80,000
100-Ton HI-TRAC with Pool Lid with loaded MPC-24		183,636~~0,947~~	184~~82~~,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-24		191,812~~89,457~~	192~~1~~,000
MPC-68			
· Without SNF		39,641	
· Fully loaded with SNF		87,241	90,000
100-Ton HI-TRAC with Pool Lid with loaded MPC-68		190,890~~88,201~~	192,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-68		199,066~~6,711~~	201,000
MPC-32			
· Without SNF		34,375	90,000
· Fully loaded with SNF		88,135	
100-Ton HI-TRAC with Pool Lid with loaded MPC-32		191,784~~89,095~~	192,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-32		199,960~~6,402~~	201,000
MPC-24E			
· Without SNF		42,069	
· Fully loaded with SNF		82,389	90,000
100-Ton HI-TRAC with Pool Lid with loaded MPC-24E		186,038~~3,349~~	187~~4~~,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-24E		194,214~~0,656~~	195~~2~~,000

[†] All calculated weights are rounded up to the nearest pound.

[††] Bounding weights or calculated weights may be used for analytical calculations, as appropriate, to ensure conservatism in the results.

Table 3.2.3
CENTERS OF GRAVITY OF HI-STORM 100 CONFIGURATIONS

Component	**Height of CG Above Datum, inches**
HI-STORM 100 Overpack empty	116.8
HI-STORM 100S Overpack empty	**111.4**
125-Ton HI-TRAC with Pool Lid empty	90.56~~1~~
125-Ton HI-TRAC with Transfer Lid empty	88.24~~19~~
MPC-24 Empty (See Note 2.)	108.9
MPC-68 Empty (See Note 2.)	109.9
MPC-32 Empty (See Note 2.)	109.3
MPC-24E Empty (See Note 2.)	107.9
MPC-24 with Fuel in Overpack (100)	118.47~~39~~
MPC-68 with Fuel in Overpack (100)	118.51~~38~~
MPC-32 with Fuel in Overpack (100)	118.50~~42~~
MPC-24E with Fuel in Overpack (100)	**118.44**
MPC-24 with Fuel in Overpack (100S)	**113.05**
MPC-68 with Fuel in Overpack (100S)	**113.09**
MPC-32 with Fuel in Overpack (100S)	**113.07**
MPC-24E with Fuel in Overpack (100S)	**113.01**
125-Ton HI-TRAC w/Pool Lid and MPC-24 w/fuel	93.91~~88~~
125-Ton HI-TRAC w/Pool Lid and MPC-68 w/fuel	93.98~~5~~
125-Ton HI-TRAC w/Pool Lid and MPC-32 w/fuel	**93.97**
125-Ton HI-TRAC w/Pool Lid and MPC-24E w/fuel	**93.86**
125-Ton HI-TRAC w/Transfer Lid and MPC-24 w/fuel	91.01~~66~~
125-Ton HI-TRAC w/Transfer Lid and MPC-68 w/fuel	**91.74**~~2.34~~
125-Ton HI-TRAC w/Transfer Lid and MPC-32 w/fuel	**91.74**
125-Ton HI-TRAC w/Transfer Lid and MPC-24E w/fuel	**91.10**
100-Ton HI-TRAC w/Pool Lid Empty	85.99~~57~~
100-Ton HI-TRAC w/Transfer Lid Empty	86.35~~5.73~~
100-Ton HI-TRAC w/Pool Lid and MPC-24 w/fuel	90.55~~31~~

Table 3.2.3 - Continued	
Component	**Height of CG Above Datum, Inches**
100-Ton HI-TRAC w/Pool Lid and MPC-68 w/fuel	90.77~~54~~
100-Ton HI-TRAC w/Pool Lid and MPC-32 w/fuel	**90.76**
100-Ton HI-TRAC w/Pool Lid and MPC-24E w/fuel	**90.54**
100-Ton HI-TRAC w/Transfer Lid and MPC-24 w/fuel	91.62~~24~~
100-Ton HI-TRAC w/Transfer Lid and MPC-68 w/fuel	**92.29**~~1.92~~
100-Ton HI-TRAC w/Transfer Lid and MPC-32 w/fuel	**92.27**
100-Ton HI-TRAC w/Transfer Lid and MPC-24E w/fuel	**91.60**

Note:

1. The datum used for calculations involving the overpack is the bottom of the overpack baseplate. The datum used for calculations involving the HI-TRAC is the bottom of the pool lid or transfer lid.

2. The datum used for calculations involving only the MPC is the bottom of the MPC baseplate.

Table 3.2.4

LIFT WEIGHT ABOVE POOL WITH 125-TON HI-TRAC

Item	Weight (lb.)	Bounding Weight[†]
Total weight of 125-Ton HI-TRAC w/Pool Lid	142,976~~88~~	
Total weight of MPC-32 + fuel	88,135[††]	
125-Ton HI-TRAC Top Lid	-2,730[†††]	
Water in MPC and 125-Ton HI-TRAC	16,570~~956~~	17,000
Lift yoke	3,600	
Inflatable annulus seal	50	
TOTAL	248,601~~999~~	250,000

[†] Bounding weights or calculated weights may be used for analytical calculations, as appropriate, to ensure conservatism in the results.

[††] Includes MPC closure ring.

[†††] HI-TRAC top lid weight is included in total weight. However, the top lid is not installed during in-pool operations.

Table 3.2.4 (continued)

LIFT WEIGHT ABOVE POOL WITH 100-TON HI-TRAC

Item	**Weight (lb.)**	**Bounding Weight**[†]
Total weight of 100-Ton HI-TRAC w/Pool Lid	100,**194**~~960~~	
Total weight of MPC-**32**~~68~~ + fuel	88,135[††]	
100-Ton HI-TRAC Top Lid	-1,203~~2~~[†††]	
Water in MPC and 100-Ton HI-TRAC	16,570~~956~~	17,000
Water in Water Jacket	-7,556[††††]	
Lift yoke	3,2~~6~~00	
Inflatable annulus seal	50	
TOTAL	199,390~~200, 5943~~	201,000~~250~~

Note: HI-TRAC 100 body weight is without removable portion of pocket trunnion

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[†] Bounding weights or calculated weights may be used for analytical calculations, as appropriate, to ensure conservatism in the results.

[††] Includes MPC closure ring.

[†††] HI-TRAC top lid weight is included in total weight. However, the top lid is not installed during in-pool operations.

[††††] Total weight of 100-Ton HI-TRAC includes water in water jacket, but during removal from fuel pool, no water is in the water jacket as the water within the MPC cavity provides sufficient shielding.

3.4 GENERAL STANDARDS FOR CASKS

3.4.1 Chemical and Galvanic Reactions

In this section, it is shown that there is no credible mechanism for chemical or galvanic reactions in the HI-STORM 100 System.

The MPC, which is filled with helium, provides a nonaqueous and inert environment. Insofar as corrosion is a long-term time-dependent phenomenon, the inert gas environment in the MPC precludes the incidence of corrosion during storage on the ISFSI. Furthermore, the only dissimilar material groups in the MPC are: (1) Boral™ and stainless steel and (2) aluminum and stainless steel. Boral and stainless steel have been used in close proximity in wet storage for over 30 years. Many spent fuel pools at nuclear plants contain fuel racks, which are fabricated from Boral and stainless steel materials, with geometries similar to the MPC. Not one case of chemical or galvanic degradation has been found in fuel racks built by Holtec. This experience provides a sound basis to conclude that corrosion will not occur in these materials. Additionally, the aluminum conduction inserts and stainless steel basket are very close on the galvanic series chart. Aluminum, like other metals of its genre (e.g., titanium and magnesium) rapidly passivates in an aqueous environment, leading to a thin ceramic (Al_2O_3) ~~barrier which~~**barrier, which** renders the material essentially inert and corrosion-free over long periods of application. The physical properties of the material, e.g., thermal expansion coefficient, diffusivity, and thermal conductivity, are essentially unaltered by the exposure of the aluminum metal stock to an aqueous environment. In order to eliminate the incidence of aluminum water reaction inside the MPC during fuel loading operation (when the MPC is flooded with pool water) *all* aluminum surfaces will be pre-passivated or anodized before installation of Boral or conduction inserts in the MPC.

The HI-STORM 100 storage overpack and the HI-TRAC transfer cask each combine low alloy and nickel alloy steels, carbon steels, neutron and gamma shielding materials, and bolting materials. All of these materials have a long history of nongalvanic behavior within close proximity of each other. The internal and external steel surfaces of each of the storage overpacks are sandblasted and coated to preclude surface oxidation. The HI-TRAC coating does not chemically react with borated water. Therefore, chemical or galvanic reactions involving the storage overpack materials are highly unlikely and are not expected.

In accordance with NRC Bulletin 96-04 [3.4.7], a review of the potential for chemical, galvanic, or other reactions among the materials of the HI-STORM 100 System, its contents and the operating ~~environments which may produce adverse reactions~~**environments, which may produce adverse reactions,** has been performed. Table 3.4.2 provides a listing of the materials of fabrication for the HI-STORM 100 System and evaluates the performance of the material in the expected operating environments during short-term loading/unloading operations and long-term storage operations. As a result of this review, no operations were identified which could produce adverse reactions beyond those conditions already analyzed in this TSAR.

3.4.2 Positive Closure

There are no quick-connect/disconnect ports in the confinement boundary of the HI-STORM 100 System. The only access to the MPC is through the storage overpack lid, which weighs over 23,000 pounds (see Table 3.2.1). The lid is fastened to the storage overpack with large bolts. Inadvertent opening of the storage overpack is not feasible; opening a storage overpack requires mobilization of special tools and heavy-load lifting equipment.

3.4.3 Lifting Devices

As required by Reg. Guide 3.61, in this subsection, analyses for all lifting operations applicable to the deployment of a HI-STORM 100 System are presented to demonstrate compliance with applicable codes and standards.

The HI-STORM 100 System has the following components and devices participating in lifting operations: lifting trunnions located at the top of the HI-TRAC transfer cask, lid lifting connections for the HI-STORM 100 lid and for other lids in the HI-TRAC transfer cask, connections for lifting and carrying a loaded HI-STORM 100 vertically, and lifting connections for the loaded MPC.

Analyses of HI-STORM 100 storage overpack and HI-TRAC transfer cask lifting devices are provided in this submittal. ~~Analysis of MPC lifting operations are~~**Analyses of MPC lifting operations are** presented in the HI-STAR 100 TSAR (Docket Number 72-1008, Subsection 3.4.3) and are also applicable here.

The evaluation of the adequacy of the lifting devices entails careful consideration of the applied loading and associated stress limits. The load combination D+H, where H is the "handling load", is the generic case for all lifting adequacy assessments. The term D denotes the dead load. Quite obviously, D must be taken as the bounding value of the dead load of the component being lifted. In all lifting analyses considered in this document, the handling load H is assumed to be 0.15D. In other words, the inertia amplifier during the lifting operation is assumed to be equal to 0.15g. This value is consistent with the guidelines of the Crane Manufacturer's Association of America (CMAA), Specification No. 70, 1988, Section 3.3, which stipulates a dynamic factor equal to 0.15 for slowly executed lifts. Thus, the "apparent dead load" of the component for stress analysis purposes is $D^* = 1.15D$. Unless otherwise stated, all lifting analyses in this report use the "apparent dead load", D^*, as the lifted load.

Analysis methodology to evaluate the adequacy of the lifting device may be analytical or numerical. For the analysis of the trunnion, an accepted conservative technique for computing the bending stress is to assume that the lifting force is applied at the tip of the trunnion "cantilever" and that the stress state is fully developed at the base of the cantilever. This conservative technique, recommended in NUREG-1536, is applied to all trunnion analyses presented in this SAR and has also been applied to the trunnions analyzed in the HI-STAR 100 TSAR.

In general, the stress analysis to establish safety pursuant to NUREG-0612, Regulatory Guide 3.61, and the ASME Code, requires evaluation of three discrete zones which may be referred to as (i) the trunnion, (ii) the trunnion/component interface, hereinafter referred to as Region A, and (iii) the rest of the component, specifically the stressed metal zone adjacent to Region A, herein referred to as Region B. During this discussion, the term "trunnion" applies to any device used for lifting (i.e., trunnions, lift bolts, etc.)

Stress limits germane to each of the above three areas are discussed below:

i. Trunnion: NUREG-0612 requires that under the "apparent dead load", D^*, the maximum primary stress in the trunnion be less than 10% of the trunnion material ultimate strength *and* less than 1/6th of the trunnion material yield strength. Because of the materials of construction selected for trunnions in all HI-STORM 100 System components, the ultimate strength-based limit is more restrictive in every case. Therefore, all trunnion safety factors reported in this document pertain to the ultimate strength-based limit.

ii. Region A: Trunnion/Component Interface: Stresses in Region A must meet ASME Code Level A limits under applied load D*. Additionally, Regulatory Guide 3.61 requires that the ~~maximum~~ primary stress under 3D***, associated with the cross-section,** be less than the yield strength **of the applicable material**~~of the weaker of the two materials at the trunnion/component interface~~. In cases involving section bending, the developed section moment may be compared against the plastic moment at yield. **The circumferential extent of the characteristic cross-section at the trunnion/component interface is calculated based on definitions from ASME Section III, Subsection NB and is defined in terms of the shell thickness and radius of curvature at the connection to the trunnion block. By virtue of the construction geometry, only the mean shell stress is categorized as "primary" for this evaluation.**

iii. Region B: Typically, the stresses in the component in the vicinity of the trunnion/component interface are higher than elsewhere. However, exceptional situations exist. For example, when lifting a loaded MPC, the MPC baseplate, which supports the entire weight of the fuel and the fuel basket, is a candidate location for high stress even though it is far removed from the lifting location (which is located in the top lid).

    Even though the baseplate in the MPC would normally belong to the Region B category, for conservatism it was considered as Region A in the HI-STAR 100 SAR. The pool lid and the transfer lid of the HI-TRAC transfer cask also fall into this dual category. In general, however, all locations of high stress in the component under D^* must also be checked for compliance with ASME Code Level A stress limits.

Unless explicitly stated otherwise, all analyses of lifting operations presented in this report follow the load definition and allowable stress provisions of the foregoing. Consistent with the practice adopted throughout this chapter, results are presented in dimensionless form, as safety factors, defined as

$$\text{Safety Factor, } \beta = \frac{\text{Allowable Stress in the Region Considered}}{\text{Computed Maximum Stress in the Region}}$$

The safety factor, defined in the manner of the above, is the added margin over what is mandated by the applicable code (NUREG-0612 or Regulatory Guide 3.61).

In the following subsections, we briefly describe each of the lifting analyses performed to demonstrate compliance with regulations. Summary results are presented for each of the analyses.

It is recognized that stresses in Region A are subject to two distinct criteria, namely Level A stress limits under D* and yield strength at 3D*. We will identify the applicable criteria in the summary tables, under the column heading "Item", using the "3D*" identifier.

All of the lifting analyses reported on in this Subsection are designated as Load Case 01 in Table 3.1.5.

3.4.3.1 125 Ton HI-TRAC Lifting Analysis - Trunnions

The lifting device in the ~~125 ton~~**125-ton** HI-TRAC cask is presented in Holtec Drawing 1880 (Section 1.5 herein). The two lifting trunnions for HI-TRAC are spaced at 180 degrees. The trunnions are designed for a two-point lift in accordance with the aforementioned NUREG-0612 criteria. Figure 3.4.21 shows the overall lifting configuration. Appendix 3.E contains the lifting trunnion stress analysis for the 125 Ton HI-TRAC. Figures within that appendix provide details to support the analysis. It is demonstrated in Appendix 3.E that the stresses in the trunnions, computed using the conservative methodology described previously, comply with NUREG-0612 provisions.

Specifically, the following results are obtained:

125 Ton HI-TRAC Lifting Trunnions†

	Value (ksi)	Safety Factor
Bending stress	16.98	1.07
Shear stress	7.23	1.5

† The lifted load is 245,000 lb.(a value that bounds the actual lifted weight from the pool after the lift yoke weight is eliminated per Table 3.2.4).

3.4.3.2 125 Ton HI-TRAC Lifting - Trunnion Lifting Block Welds, Bearing, and Thread Shear Stress (Region A)

Appendix 3.E contains calculations that analyze the weld group connecting the lifting trunnion block to the inner and outer shells and to the HI-TRAC top flange. ~~Aanalysis~~**Conservative analyses** are also performed to determine safety factors for bearing stress and **for** thread shear stress at the interface between the trunnion and the trunnion block. The following results are obtained:

125 Ton HI-TRAC Lifting Trunnion Block (Region A Evaluation)			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
Trunnion Block Bearing Stress	5.94	11.4	1.92
Trunnion Block Thread Shear Stress	5.19	6.84	1.32
Weld Shear Stress (3D*)	8.03†	11.4	1.42

† A quality factor of 0.45 has been applied to the weld group. We have followed the guidance of ASME Code, Section III, Subsection NG-3352-1 (other referenced codes such as Subsection NF or NUREG-0612 do not apply penalty factors to the structural welds).

3.4.3.3 125 Ton HI-TRAC Lifting - Structure near Trunnion (Region B/Region A)

Appendix 3.AE contains results of a finite element analysis of the region in the 125 Ton HI-TRAC structure adjacent to the lifting trunnions. Appendix 3.AE shows that the primary stresses in the 125 Ton HI-TRAC structure comply with the Level A stress limits for Subsection NF structures.

A three-dimensional elastic model of the 125 Ton HI-TRAC metal components is analyzed using the ANSYS finite element code. Figure 3.AE.1 shows details of the one-quarter symmetry model using a color-coding to identify the various modeled parts. The structural model includes, in addition to the trunnion and the trunnion block, a portion of the inner and outer HI-TRAC shells and the HI-TRAC top flange. In Appendix 3.AE,~~-~~ **stress results over the characteristic interface section are summarized and compared with allowable strength limits per ASME Section III, Subsection NF, and per Regulatory Guide 3.61.** ~~a stress intensity plot of the HI-TRAC shells and top flange summarizes the results of the analysis. The analysis conservatively omits the effect of the stiffeners under the trunnion block and, therefore, predicts a conservative value for the safety factors.~~

The results from the analysis in Appendix 3.AE are summarized below:

125 Ton HI-TRAC Trunnion Region (Regions A and B)‡			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
Membrane **Stress** ~~Stress Intensity~~	**6.1859**~~10.5~~	17.5	**2.83**~~1.67~~
Membrane plus Bending Stress~~s~~ ~~Intensity~~	**8.1919**~~191.912.5~~	26.**25**~~3~~	**3.2**~~2.10~~
Membrane Stress ~~Intensity~~ (3D*)	**18.56**~~25.83~~	34**.6**~~3.15~~	1.**86**~~.15~~

~~‡ Results presented in this table are conservative: the presence of gussets positioned under the trunnion block is neglected; and, the assumed position of the lifting load does not reflect the material thickness of the lifting device (which would reduce the input moment arm).~~

3.4.3.4 100 Ton HI-TRAC Lifting Analysis

The lifting trunnions **and the trunnion blocks** for the 100 Ton HI-TRAC are identical to the trunnions analyzed in Appendices 3.E and 3.AE for the 125 Ton HI-TRAC. However, the **outer shell**~~attachment~~ **geometry (outer diameter) is different**~~details of the lifting trunnions to the HI-TRAC body differ between the 125 Ton and the 100 Ton units~~. A calculation performed in the spirit of strength-of-materials provides justification that, despite the difference in local structure at the attachment points, the~~ HI-TRAC~~ stresses in the body of the **HI-TRAC** 100 Ton unit meet the allowables set forth in Subsection 3.1.2.2.

Figure 3.4.10 illustrates the differences in geometry, loads, and trunnion moment arms between the body of the 125-Ton HI-TRAC and the body of the 100-Ton HI-TRAC. It is reasonable to assume that the level of stress in the 100 Ton HI-TRAC body, in the immediate vicinity of the **interface**~~loaded region~~ (Section X-X in Figure 3.4.10), is proportional to **the applied force and** the bending moment applied.~~ and the half thickness of the section.~~ In what follows, the subscripts 1 and 0 refer to 100 Ton and 125 Ton casks, respectively~~, as indicated in Figure 3.4.10~~. **Figure 3.4.10 shows the location of the area centroid (with respect to the outer surface) and the loads and moment arms associated with each construction. Conservatively, neglecting all other interfaces between the top of the trunnion block and the top flange and between the sides of the trunnion block and the shells, equilibrium is maintained by developing a force and a moment in the section comprised of the two shell segments interfacing with the base of the trunnion block.**

The most limiting stress state is in the outer shell at the trunnion block base interface. The stress level **in the outer shell at**~~at~~ Section X-X ~~in the body~~ is proportional to P/A + Mc/I. **Evaluating the stress for a unit width of section permits an estimate of the stress state in the**

HI-TRAC 100 outer shell if the corresponding stress state in the HI-TRAC 125 is known (the only changes are the applied load, the moment arm and the geometry. Using the geometry shown in Figure 3.4.10 gives the result as:~~/c. That is, if A represents the characteristic metal area contributing to the calculation of the section moment of inertia, I = Ac², then~~

~~$\sigma \approx \frac{Mc}{I} \approx \frac{M}{Ac}$~~

~~Since A is the same for both units (same inner and outer shell thickness), the stress level in the 100 Ton HI-TRAC is (subscripts 1 and 0, respectively, refer to the 100 Ton and 125 Ton HI-TRAC structures):~~

~~$\sigma_1 \approx \frac{M_1}{c_1} \approx \frac{M_0}{c_0}\left(\frac{M_1}{M_0}\frac{c_0}{c_1}\right)$~~

~~or~~

~~$\sigma_1 = \sigma_0\left(\frac{709{,}781}{781{,}250} x \frac{3.125''}{2.3125''}\right) = 1.228\sigma_0$~~

~~where the numerical data is taken from Figure 3.4.10. Note that in Figure 3.4.10, the trunnion load for the 125 ton unit has been obtained from conservatively large value used in Appendix 3.AE, which is then divided by 1.51 to reflect the actual lifted load, and then further divided by 2 to obtain the actual load on one of the trunnions.~~

Stress (HI-TRAC 100 outer shell) = 1.236 x Stress (HI-TRAC 125 outer shell)

~~Therefore, the stress level in the 100-Ton cask at Section X-X will be 1.176 times that of the 125-Ton cask.~~ The tabular results in the previous subsection **can be** ~~(based on 376,296 lb./1.51 can be~~ adjusted accordingly and are reported below:

100 Ton HI-TRAC Near Trunnion (Region A and Region B)	
Item	Safety Factor
Membrane Stress ~~Intensity~~	**2.29**~~1.42~~
Membrane plus Bending Stress ~~Intensity~~	**2.59**~~1.78~~
Membrane Stress ~~Intensity~~ (3D*)	1.50~~09~~

3.4.3.5 HI-STORM 100 Lifting Analyses

There are two vertical lifting scenarios for the HI-STORM 100 storage overpack carrying a fully loaded MPC. Figure 3.4.17 shows a schematic of these lifting scenarios. Both lifting scenarios are examined in Appendix 3.D using finite element models that focus on the local regions near the lift points. **The analysis in Appendix 3.D is based on the geometry of the HI-STORM 100; The alterations to the lid and to the length of the overpack barrel to configure the HI-STORM 100S have no effect on the conclusions. The removal of the outlet vents from the overpack cylindrical barrel to the lid in the HI-STORM 100S has little effect on the local state of stress near the lift lugs. Therefore, there is no separate analysis for the lifting of the HI-STORM 100S as the results are identical to or bounded by the results documented in Appendix 3.D.**

Scenario #1 considers a "bottom lift" where the fully loaded HI-STORM 100 storage overpack is lifted vertically by four synchronized hydraulic jacks each positioned at one of the four inlet air vents. This lift allows for installation and removal of "air pads" which may be used for horizontal positioning of HI-STORM 100 at the ISFSI pad.

Scenario #2, labeled the "top lift scenario" considers the lifting of a fully loaded HI-STORM 100 vertically through the four lifting lugs located at the top end.

No structural credit is assumed for the HI-STORM concrete in either of the two lifting scenarios except as a vehicle to transfer compressive loads.

For the bottom lift, a three-dimensional one-quarter symmetry finite element model of the bottom region of the HI-STORM 100 storage overpack is constructed. The model includes the inner shell, the outer shell, the baseplate, the inlet vent side and top plates, and the radial plates connecting the inner and outer shells. Further details of the model are provided in Appendix 3.D. The key results are contained in Figure 3.D.3 that shows the stress intensity distribution on the HI-STORM 100 storage overpack.

For the analysis of the "top lift" scenario, a three-dimensional 1/8-symmetry finite element model of the top segment of HI-STORM 100 storage overpack is constructed. The metal HI-STORM 100 material is modeled (shells, radial plates, lifting block, ribs, vent plates, etc.) using shell or solid elements. Color-coded views of the model are given in Figure 3.D.2. Lumped weights are used to ensure that portions of the structure not modeled are, in fact, properly represented as part of a lifted load. The model is supported vertically at the lifting lug.

Figures 3.D.4(a) through 3.D.4(c) and Figure 3.D.5(a) through 3.D.5(c) show the stress intensity results under the lifted load and in the baseplate region, respectively.

To provide an alternate calculation to demonstrate that the bolt anchor blocks are adequate, we compute the average normal stress in the net metal area of the block under three times the lifted load. Further conservatism is introduced by including an additional 15% for dynamic amplification, i.e., the total load is equal to 3D*.

The average normal load in one bolt anchor block is

Load = 3 x 1.15 x 360,000 lb./4 = 310,500 lb. (Weight comes from Table 3.2.1)

The net area of the bolt anchor block is

Area = 5" x 5" – (3.14159/4)/4 x (**3.254**" x **3.254**") = **16.70**~~2.43~~ sq. inch (Dimensions from BM-1575)

Therefore, the safety factor (yield strength at 350 degrees F/calculated stress from Table 3.3.3) is

SF = 32,700 psi/ (Load/Area) = 1.76~~31~~

Appendix 3.D also examines the shear stress in the threads of the lifting block. This analysis considers a cylindrical area of material under an axial load resisting the load by shearing action. The diameter of the area is the basic pitch diameter of the threads, and the length of the cylinder is the thread engagement length.

Appendix 3.D also examines the capacity of major welds in the load path and the compression capacity of the pedestal shield and pedestal shield shell.

The table below summarizes key results obtained from the analyses reported in detail in Appendix 3.D

HI-STORM 100 Top and Bottom Lifting Analyses†‡			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
Primary Membrane plus Bending - Bottom Lift - Inlet Vent Plates - Region B	8.0	26.3	3.28
Primary Membrane - Top Lift - Radial Rib Under Lifting Block - Region B	6.67	17.5	2.63
Primary Membrane plus Bending – Top Lift - Baseplate – Region B	7.0	26.3	3.75
Primary Membrane Region A (3D*)	19.97	33.15	1.66
Primary Membrane plus Bending Region A (3D*)	24.02	33.15	1.38
Lifting Block Threads - Top Lift –Region A (3D*)	10~~1~~.67~~1~~	19.62	1.84~~69~~
Lifting Stud - Top Lift –Region A (3D*)	43~~9~~.733~~085~~	108.8	2.49~~217~~
Welds – Anchor Block-to-Radial Rib Region B	5.74	19.695	3.43
Welds – Anchor Block-to-Radial Rib Region A (3D*)	17.21	19.62	1.14
Weld – Baseplate-to Inner Shell Region A (3D*)	1.56	19.89	12.78
Weld – Baseplate-to-Inlet Vent Region A (3D*)	15.05	19.89	1.32
Pedestal Shield Concrete (3D*)	0.096	1.535	16.03
Pedestal Shell (3D*)	1.095	33.15	30.27

† Regions A and B are defined at beginning of Subsection 3.4.3

‡ The lifted load is 360000 lb. and an inertia amplification of 15% is included.

It is concluded that all structural integrity requirements are met during a lift of the HI-STORM 100 storage overpack under either the top lift or the bottom lift scenario. All factors of safety are greater than 1.0 using criteria from the ASME Code Section III, Subsection NF for Class 3 plate and shell supports and from USNRC Regulatory Guide 3.61.

3.4.3.6 MPC Lifting Analysis

The MPC lifting analyses are found in the HI-STAR 100 TSAR (Docket-72-1008). Some results of the analyses in that document (Appendices 3.K, 3.E, 3.I and 3.Y Docket-72-1008) are summarized here for completeness.

Summary of MPC Lifting Analyses			
Item	Thread Engagement Safety Factor (NUREG- 0612)	Region A Safety Factor	Region B Safety Factor†
MPC	1.08	1.09	1.56

† The factor reported here is for the MPC baseplate considered under a load equal to 3D*.

3.4.3.7 Miscellaneous Lid Lifting Analyses

Appendix 3.AC contains analyses of lifting attachments for various lid lifting operations.

The HI-STORM 100 lid lifting analysis is performed to ensure that the threaded connections provided in the lid are adequately sized. The lifting analysis of the top lid is based on a vertical orientation of loading from an attached lifting device. The top lid of the HI-STORM 100 storage overpack is lifted using four lugs that are threaded into holes in the top plate of the lid (Holtec Drawing 1495, Section 1.5). It is noted that failure of the lid attachment would not result in any event of safety consequence because a free-falling HI-STORM 100 lid cannot strike a stored MPC (due to its size and orientation). Operational limits on the carry height of the HI-STORM 100 lid above the top of the storage overpack containing a loaded MPC preclude any significant lid rotation out of the horizontal plane in the event of a handling accident. Therefore, contact between the top of the MPC and the edge of a dropped lid due to uncontrolled lowering of the lid during the lid placement operation is judged to be a non-credible scenario. Appendix 3.AC provides an example of a commercially available item that has the appropriate safety factors to serve as a lifting device for the HI-STORM 100 overpack top lid. **Except for location of the lift points, the lifting device for the HI-STORM 100S lid is the same as for the regular HI-STORM 100 lid. Since the lid weight for the HI-STORM 100S bounds the HI-STORM 100, the calculated safety factors for the lifting of the HI-STORM 100S lid are reduced and are also reported in the summary table below.**

In addition to the HI-STORM 100 top lid lifting analysis, Appendix 3.AC also contains details of the strength qualification of other lid lifting holes and associated lid lifting devices. The qualification is based on the Regulatory Guide 3.61 requirement that a load factor of 3 results in stresses less than the yield stress. Lifting of the HI-TRAC pool lid and top lid are considered in Appendix 3.AC. Example commercially available lifting structures are considered in Appendix 3.AC and it is shown that thread engagement lengths are acceptable. Loads to lifting devices are permitted to be at a maximum angle of 45 degrees from vertical. A summary of results from Appendix 3.AC, pertaining to the various lid lifting operations, is given in the table below:

Summary of HI-STORM 100 Lid Lifting Analyses		
Item	Dead Load (lb)	Minimum Safety Factor
HI-STORM 100 **(100S)** Top Lid Lifting	23,000 **(25,500)**	2.731 **(2.464)**
HI-TRAC Pool Lid Lifting	12,500	4.73
HI-TRAC Top Lid Lifting	2,750	11.38

Appendix 3.AC demonstrates that thread engagement is sufficient for the threaded holes used solely for lid lifting and that commercially available lifting devices engaging the threaded holes, are available. We note that all reported safety factors are based on an allowable strength equal to 33.3% of the yield strength of the lid material when evaluating shear capacity of the internal threads and based on the working loads of the commercially available lifting devices associated with the respective threaded holes.

3.4.3.8 HI-TRAC Pool Lid Analysis - Lifting MPC From the Spent Fuel Pool (Load Case 01 in Table 3.1.5)

During lifting of the MPC from the spent fuel pool, the HI-TRAC pool lid supports the weight of a loaded MPC plus water (see Figure 3.4.21). Appendix 3.AB details the calculations performed to show structural integrity under this condition for both 100 Ton and 125 Ton HI-TRAC transfer casks. In accordance with the general guidelines set down at the beginning of Subsection 3.4.3, the pool lid is considered as both Region A and Region B for evaluating safety factors. The analysis in Appendix 3.AB shows that the stress in the pool lid top plate is less than the Level A allowable stress under pressure equivalent to the heaviest MPC, contained water, and lid self weight (Region B evaluation). Stresses in the lids and bolts are also shown to be below yield under three times the applied lifted load (Region A evaluation using Regulatory Guide 3.61 criteria). The threaded holes in the HI-TRAC pool lid are also examined for acceptable engagement length under the condition of lifting the MPC from the pool. This analysis is performed in Appendix 3.AC. It is demonstrated in Appendix 3.AC that the pool lid peripheral bolts have adequate engagement length into the pool lid to permit the transfer of the required load. The safety factor is defined based on the strength limits imposed by Regulatory Guide 3.61.

The following table summarizes the results of the analyses performed in Appendix 3.AB and the thread engagement calculation in Appendix 3.AC. Results given in the following table compare calculated stress and allowable stress except for the final table item that compares thread engagement analysis where a comparison is made of calculated load: and allowable load. In all cases, the safety factor is defined as the allowable value divided by the calculated value.

HI-TRAC Pool Lid Lifting a Loaded MPC Evaluation†

Item	Value (ksi)	Allowable (ksi)	Safety Factor
Lid Bending Stress -125 ton HI-TRAC - Region B Analysis - Pool Lid Top Plate	10.1	26.3	2.604
Lid Bending Stress -125 ton HI-TRAC - Region B Analysis - Pool Lid Bottom Plate	5.05	26.3	5.208
Lid Bending Stress -100 ton HI-TRAC - Region B Analysis- Pool Lid Top Plate	10.06	26.3	2.614
Lid Bending Stress -100 ton HI-TRAC - Region B Analysis- Pool Lid Bottom Plate	6.425	26.3	4.093
Lid Bolt Stress -125 ton HI-TRAC – (3D*)	18.92	95.0	5.02
Lid Bolt Stress -100 ton HI-TRAC – (3D*)	18.21	95.0	5.216
Lid Bending Stress -125 ton HI-TRAC - Region A Analysis - Pool Lid Top Plate (3D*)	30.3	33.15	1.094
Lid Bending Stress -125 ton HI-TRAC - Region A Analysis - Pool Lid Bottom Plate (3D*)	15.15	33.15	2.188
Lid Bending Stress –100 ton HI-TRAC – Region A Analysis- Pool Lid Top Plate (3D*)	30.19	33.15	1.098
Lid Bending Stress –100 ton HI-TRAC – Region A Analysis- Pool Lid Bottom Plate (3D*)	19.28	33.15	1.72
Lid Thread Engagement Length (125 ton HI-TRAC)	137.5‡	324.6‡	2.362

† Region A and B defined at beginning of Subsection 3.4.3.
‡ Calculated and allowable value for this item in (kips).

3.4.3.9 HI-TRAC Transfer Lid Analysis - Lifting MPC Away from Spent Fuel Pool (Load Case 01 in Table 3.1.5)

During transfer to or from a storage overpack, the HI-TRAC transfer lid supports the weight of a loaded MPC. Figure 3.4.21 illustrates the lift operation. In accordance with the general lifting analysis guidelines, the transfer lid should be considered as both a Region A (Regulatory Guide 3.61 criteria) and a Region B location (ASME Section III, Subsection NF for Class- 3 plate and shell

125 Ton HI-TRAC Transfer Lid – Lifting Evaluation†			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
125 Ton HI-TRAC - Door Plate – (3D*)	9.381~~758875~~	32.7	3.486~~839~~
125 Ton HI-TRAC - Door Plate – Region B	3.127~~95~~	26.25	8.39~~44~~
125 Ton HI-TRAC – Wheel Track (3D*)	26.91~~88926~~	36.0	1.338~~974~~
125 Ton HI-TRAC - Door Housing Bottom Plate-Region B	7.701~~6927024~~	26.25	3.409~~13087~~
125 Ton HI-TRAC - Door Housing Bottom Plate-(3D*)	23.103~~076112~~	32.7	1.415~~752~~
125 Ton HI-TRAC - Door Housing Stiffeners- (3D*)	4.131~~283~~	32.7	7.913~~21~~
125 Ton HI-TRAC - Housing Bolts-Region B	29.96~~825~~	57.5	1.91~~296~~
125 Ton HI-TRAC – Housing Bolts (3D*)	89.88~~46538~~	95.0	1.057~~621~~
125 Ton HI-TRAC – Lid Top Plate (3D*)	30.907	32.7	1.058~~6~~

† Region A and B defined at beginning of Subsection 3.4.3

100 Ton HI-TRAC Transfer Lid – Lifting Evaluation†			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
100 Ton HI-TRAC - Door Plate – (3D*)	20.697~~43376~~	32.7	1.586~~597~~
100 Ton HI-TRAC - Door Plate – Region B	6.899~~113~~	26.25	3.805~~5445~~
100 Ton HI-TRAC – Wheel Track (3D*)	26.03~~5.82~~	36.0	1.383~~94~~
100 Ton HI-TRAC – Door Housing Bottom Plate-Region B	7.447~~388~~	26.25	3.525~~53~~
100 Ton HI-TRAC – Door Housing Bottom Plate-(3D*)	22.336~~169~~	32.7	1.464~~75~~
100 Ton HI-TRAC – Door Housing Stiffeners- (3D*)	4.917~~87~~	32.7	6.65~~7~~
100 Ton HI-TRAC - Housing Bolts-Region B	22.478~~382~~	57.5	2.558~~69~~
100 Ton HI-TRAC – Housing Bolts (3D*)	67.423~~138~~	95.0	1.409~~15~~
100 Ton HI-TRAC – Lid Top Plate (3D*)	19.395~~24~~	32.7	1.686~~7~~

† Region A and B defined at beginning of Subsection 3.4.3

3.4.3.10 HI-TRAC Bottom Flange Evaluation during Lift (Load Case 01 in Table 3.1.5)

During a lifting operation, the HI-TRAC transfer cask body supports the load of a loaded MPC, and the transfer lid (away from the spent fuel pool) or the pool lid plus contained water (lifting from the spent fuel pool). In either case, the load is transferred to the bottom flange of HI-TRAC through the bolts and a state of stress in the flange and the supporting inner and outer shells is developed. Figure 3.4.21 illustrates the lifting operation. Appendix 3.AE provides the evaluation of this area of the HI-TRAC to demonstrate that required limits on stress are maintained for both ASME and Regulatory Guide 3.61. The bottom flange is considered as an annular plate subject to a total bolt load acting at the bolt circle and supported by reaction loads developed in the inner and outer shells of HI-TRAC. The solution for maximum flange bending stress is found in the classical literature and stresses and corresponding safety factors developed for the bottom flange and for the outer and inner shell direct stress. The loaded welds are full penetration in this area so they do not require separate investigation.

3.U, **3.V**, ~~and~~ 3.W, **and 3.AQ** (HI-STORM 100 storage overpack with MPC-24, **MPC-32,**~~-and~~ MPC-68, **and 24E** respectively). The results are summarized in the tables given below for normal storage conditions. The worst-case MPC is evaluated in the HI-TRAC transfer cask, in lieu of all MPC designs. **In all cases, the minimal initial radial gap between MPC and overpack is used as the initial point.**

THERMOELASTIC DISPLACEMENTS IN THE MPC AND HI-STORM 100 STORAGE OVERPACK UNDER HOT TEMPERATURE ENVIRONMENT CONDITION

CANISTER – FUEL BASKET

	Radial Direction (in.)		Axial Direction (in.)	
Unit	Initial Clearance	Final Clearance	Initial Clearance	Final Clearance
MPC-24	0.1875	0.098~~5~~	2.0	1.552~~37~~
MPC-24E	**0.1875**	**0.098**	**2.0**	**1.555**
MPC-32	**0.1875**	**0.106**	**2.0**	**1.596**
MPC-68	0.1875	0.102~~0~~	2.0	1.576~~62~~

CANISTER – STORAGE OVERPACK

Unit	Radial Direction (in.)		Axial Direction (in.)	
	Initial Clearance	Final Clearance	Initial Clearance	Final Clearance
MPC-24	0.5~~40625~~	0.445~~348~~	1.0	0.691~~74~~
MPC-24E	**0.5**	**0.443**	**1.0**	**0.678**
MPC-32	**0.5**	**0.446**	**1.0**	**0.695**
MPC-68	0.5~~40625~~	0.439~~349~~	1.0	0.654~~58~~

THERMOELASTIC DISPLACEMENTS IN THE MPC AND HI-TRAC UNDER HOT TEMPERATURE ENVIRONMENT CONDITION

CANISTER - FUEL BASKET

	Radial Direction (in.)		Axial Direction (in.)	
Unit	Initial Clearance	Final Clearance	Initial Clearance	Final Clearance
MPC (worst case)	0.1875	0.088~~92~~	2.0	1.524~~2~~

CANISTER - HI-TRAC

	Radial Direction (in.)		Axial Direction (in.)	
Unit	Initial Clearance	Final Clearance	Initial Clearance	Final Clearance
MPC (worst case)	0.125~~1875~~	0.125~~185~~	0.75	0.743~~30~~

It can be verified by referring to the Design Drawings provided in Section 1.5 of this report and the foregoing table, that the clearances between the MPC basket and canister structure, as well as that between the MPC shell and storage overpack or HI-TRAC inside surface, are sufficient to preclude a temperature induced interference from differential thermal expansions under normal operating conditions.

3.4.4.2.2 Fire Accident

It is shown in Chapter 11 that the fire accident has a small effect on the MPC temperatures because of the short duration of the fire accidents and the large thermal inertia of the storage overpack. Therefore, a structural evaluation of the MPC under the postulated fire event is not required. The conclusions reached in Subsection 3.4.4.2.1 are also appropriate for the fire accident with the MPC housed in the storage overpack. Analysis of fire accident temperatures of the MPC housed within the HI-TRAC for thermal expansion is unnecessary, as the HI-TRAC, directly exposed to the fire, expands to increase the gap between the HI-TRAC and MPC.

As expected, the external surfaces of the HI-STORM 100 storage overpack that are directly exposed to the fire event experience maximum rise in temperature. The outer shell and top plate in the top lid are the external surfaces that are in direct contact with heated air from fire. The table below, extracted from data provided in Chapter 11, provides the maximum temperatures attained at the key locations in HI-STORM 100 storage overpack under the postulated fire event.

Component	Maximum Fire Condition Temperature (Deg. F)
Storage Overpack Inner Shell	300
Storage Overpack Radial Concrete Mid-Depth	173~~.5~~
Storage Overpack Outer Shell	570
Storage Overpack Lid	<570

The following conclusions are readily reached from the above table.

- The maximum metal temperature of the carbon steel shell most directly exposed to the combustion air is well below 600°F (Table 2.2.3 applicable short-term temperature limit). 600°F is well below the permissible temperature limit in the ASME Code for the outer shell material.

- The bulk temperature of concrete is well below the normal condition temperature limit of 300°F specified in Table 2.2.3 and Appendix 1.D. ACI-349 permits 350°F as the short-term temperature limit; the shielding concrete in the HI-STORM 100 Overpack, as noted in Appendix 1.D, will comply with the specified compositional and manufacturing provisions of ACI-349. As the detailed information in Section 11.2 shows, the radial extent in the concrete where the local temperature exceeds 350°F begins at the outer shell/concrete interface and ends in less than one-ovalization under a horizontal drop event is less effective. For this reason, the MPC stress analysis for lateral loading scenarios must be performed anew for the HI-STORM 100 storage overpack; the results from the HI-STAR 100 analyses will not be conservative. The HI-TRAC transfer casks and HI-STAR 100 overpack inner diameters are identical. Therefore, the analysis of the MPC in the HI-STAR 100 overpack under 60g's for the side impact (Docket 72-1008) bounds the analysis of the MPC in the HI-TRAC under 45g's.

Description of- Finite Element Models of the MPCs Under Lateral Loading

A finite element model of each MPC is used to assess the effects of the accident loads. The models are constructed using ANSYS [3.4.1], and they are identical to the models used in Holtec's HI-STAR 100 submittals in Docket Numbers 72-1008 and 71-9261. The following model description is common to all MPCs.

The MPC structural model is two-dimensional. It represents a one-inch long cross section of the MPC fuel basket and MPC canister.

The MPC model includes the fuel basket, the basket support structures, and the MPC shell. A basket support is defined as any structural member that is welded to the inside surface ~~of the~~**of the** MPC shell. A portion of the storage overpack inner surface is modeled to provide the correct restraint conditions for the MPC. Figures 3.4.1 through 3.4.9 show **typical**~~the~~ MPC models. Detailed element numbers for the fuel basket and the enclosure vessel are provided in Appendices, 3.N through 3.S, inclusive, **for the MPC-68, MPC-32, and MPC-24.**

The fuel basket support structure shown in the figures is a multi-plate structure consisting of solid shims or support members having two separate compressive load supporting members. For conservatism in the finite element model some dual path compression members (i.e., "V" angles) are simulated as single columns. Therefore, the calculated stress intensities in the fuel basket angle supports, reported in Appendix 3.T from the finite element solution, are conservatively overestimated in some locations.

The ANSYS model is not intended to resolve the detailed stress distributions in weld areas. Individual welds are not included in the finite element model. A separate analysis for basket welds and for the basket support "V" angles is contained in Appendix 3.Y.

No credit is taken for any load support offered by the Boral panels, sheathing, and the aluminum heat conduction elements. Therefore, these so-called non-structural members are not represented in the model. The bounding MPC weight used, however, does include the mass contributions of these non-structural components.

The model is built using five ANSYS element types: BEAM3, PLANE82, CONTAC12, CONTAC26, and COMBIN14. The fuel basket and MPC shell are modeled entirely with two-dimensional beam elements (BEAM3). Plate-type basket supports are also modeled with BEAM3 elements. Eight-node plane elements (PLANE82) are used for the solid-type basket supports. The gaps between the fuel basket and the basket supports are represented by two-dimensional point-to-point contact elements (CONTAC12). Contact between the MPC shell and the storage overpack is modeled using two-dimensional point-to-ground contact elements (CONTAC26) with an appropriate clearance gap.

Two orientations of the deceleration vector are considered. The 0-degree drop model includes the storage overpack-MPC interface in the basket orientation illustrated in Figure 3.1.2. The 45-degree drop model represents the storage overpack-MPC interface with the basket oriented in the manner of Figure 3.1.3. The 0-degree and the 45-degree drop models are shown in Figures 3.4.1 through 3.4.6. Table 3.4.1 lists**, for example**~~information~~**,** the element types and number of elements for ~~all models for all fuel storage~~**the**~~-~~ MPC-24**, and MPC-68.**~~-types~~.

A contact surface is provided in the model **is**~~els~~ used for drop analyses to represent the storage overpack channels. As the MPC makes contact with the storage overpack, the MPC shell deforms to mate with the channels **that**~~which~~ are welded at equal intervals around the storage overpack inner surface. The nodes that define the elements representing the fuel basket and the MPC shell are located along the centerline of the plate material. As a result, the line of nodes that forms the perimeter of the MPC ~~s~~shell is inset from the real boundary by a distance that is equal to half of the shell thickness. In order to maintain the specified MPC shell/storage overpack gap dimension, the radius of the storage overpack channels is decreased by an equal amount in the model.

The three discrete components of the HI-STORM 100 System, namely the fuel basket, the MPC shell, and the storage overpack or HI-TRAC transfer cask, are engineered with small diametral clearances which are large enough to permit unconstrained thermal expansion of the three components under the rated (maximum) heat duty condition. A small diametral gap under ambient conditions is also necessary to assemble the system without physical interference between the contiguous surfaces of the three components. The required gap to ensure unrestricted thermal expansion between the basket and the MPC shell is small and will further decrease under maximum heat load conditions, but will introduce a physical nonlinearity in the structural events involving lateral loading (such as side drop of the system) under ambient conditions. It is evident from the system design drawings that the fuel basket that is non-radially symmetric is in proximate contact with the MPC shell at a discrete number of locations along the circumferences. At these locations, the MPC shell, backed by the channels attached to the storage overpack, provides a support line to the fuel basket during lateral drop events. Because the fuel basket, the MPC shell, and the storage overpack or HI-TRAC are all three-dimensional structural weldments, their inter-body clearances may be somewhat uneven at different azimuthal locations. As the lateral loading is increased, clearances close at the support locations, resulting in the activation of the support from the storage overpack or HI-TRAC.

The bending stresses in the basket and the MPC shell at low lateral loading levels which are too small to close the support location clearances are secondary stresses since further increase in the loading will activate the storage overpack's or HI-TRAC's transfer cask support action, mitigating further increase in the stress. Therefore, to compute primary stresses in the basket and the MPC shell under lateral drop events, the gaps should be assumed to be closed. However, **in the analyses**~~, of the **MPC-24, MPC-32, and MPC-68,** for conservatism,~~ **we have conservatively**~~it is~~ assumed that an initial gap of 0.1875" exists, in the direction of the applied deceleration, at all support locations between the fuel basket and the MPC shell and that the **clearance**~~diametrical~~ gap between the shell and the storage overpack ~~or HI-TRAC~~ at the support locations is **3/16**~~9/32~~". **In the evaluation of safety factors for the MPC-24, MPC-32, and MPC-68, the total stress state**~~All stresses~~ produced by the applied loading on the**i**~~se~~ configurations **is**~~are~~ conservatively compared with primary stress levels, even though the self-limiting stresses should be considered secondary in the strict definition of the Code. **To illustrate the conservatism** ~~**in the above analyses, for the MPC-24E,**~~ **we have eliminated**~~**removed**~~ **the secondary stress (that develops to close the clearances) in the comparison with primary stress allowable values**~~**that develops to close the gaps**~~ **and report safety factors for the MPC-24E that are based only on primary stresses necessary to maintain equilibrium with the inertia forces.**

ANSYS requires that for a static solution all bodies **be**~~are~~ constrained to prevent rigid body motion. Therefore, in the 0 degree and 45 degree drop models, two-dimensional linear spring elements (COMBIN14) join the various model components, i.e., fuel basket and enclosure vessel, at the point of initial contact. This provides the necessary constraints for the model components in the direction of the impact. By locating the springs at the points of initial contact, where the gaps remain closed, the behavior of the springs is identical to the behavior of a contact element. Linear springs and contact elements that connect the same two components have equal stiffness values.

Description of Individual Loads and Boundary Conditions Applied to the MPCs

The method of applying each individual load to the MPC model is described in this subsection. The individual loads are listed in Table 2.2.14. A free-body diagram of the MPC corresponding to each individual load is given in Figures 3.4.7-3.4.9. In the following discussion, ~~reference to vertical and horizontal orientations are~~**reference to vertical and horizontal orientations** is made. Vertical refers to the direction along the cask axis, and horizontal refers to a radial direction.

Quasi-static structural analysis methods are used. The effects of any dynamic load factors (DLFs) are included in the final evaluation of safety factors. All analyses are carried out using the design basis decelerations in Table 3.1.2.

The MPC models used for side drop evaluations are shown in Figures 3.4.1 through 3.4.6. In each model, the fuel basket and the enclosure vessel are constrained to move only in the direction that is parallel to the acceleration vector. The storage overpack inner shell, which is defined by three nodes needed to represent the contact surface, is fixed in all degrees of freedom. The fuel basket, enclosure vessel, and storage overpack inner shell~~ll~~ are all connected at one location by linear springs, as described in Subsection 3.4.4.3.1.1 (see Figure 3.4.1, for example). Detailed side drop evaluations here focus on an MPC within a HI-STORM 100 storage overpack. Since the analyses performed in Docket Number 72-1008 for the side drop condition in the HI-STAR 100 storage overpack demonstrates a safe condition under a 60g deceleration, no new analysis is required for the MPC and contained fuel basket and fuel during a side drop in the HI-TRAC, which is limited to a 45g numerically satisfy equilibrium.

Temperature

Temperature distributions are developed in Chapter 4 and applied as nodal temperatures to the finite element model of the MPC enclosure vessel (confinement boundary). Maximum design heat load has been used to develop the temperature distribution used to demonstrate compliance with ASME Code stress intensity levels.

Analysis Procedure

The analysis procedure for this set of load cases is as follows:

1. The stress intensity and deformation field due to the combined loads is determined by the finite element solution. Results are postprocessed and **tabulated**~~listed~~ in Appendix ~~3.T~~ **3.T only for the MPC-24, MPC-32, and MPC-68. The corresponding information for the MPC-24E is** **~~contained~~** **in the**~~-supporting~~ **calculation package associated with this TSAR.**

2. The results for each load combination are compared to allowables. The comparison with allowable values is made in Subsection 3.4.4.4.

3.4.4.3.1.2 Analysis of Load Cases E1.a and E1.c (Table 3.1.4)

Since the MPC shell is a pressure vessel, the classical Lame's calculations should be performed to demonstrate the shell's performance as a pressure vessel. We note that dead load has an insignificant effect on this stress state. We first perform calculations for the shell under internal pressure. Subsequently, we examine the entire confinement boundary as a pressure vessel subject to both internal pressure and temperature gradients. Finally, we perform confirmatory hand calculations to gain confidence in the finite element predictions.

The stress from internal pressure is found for normal and accident pressures conditions using classical formulas:

Define the following quantities:

P = pressure, r = MPC radius, and t = shell thickness.

Using classical thin shell theory, the circumferential stress, $\sigma_1 = Pr/t$, the axial stress $\sigma_2 = Pr/2t$, and the radial stress $\sigma_3 = -P$ are computed for both normal and accident internal pressures. The results are given in the following table:

Combining the two contributions to the shell bending stress gives the total extreme fiber stress in the longitudinal direction as 51,116 psi.

The baseplate stress value, 23,142 psi, compares well with the finite element result 20,528 psi (Table 3.4.7). The shell joint stress, 51,116 psi, is greater than the finite element result (43,986 psi in Table 3.4.7). This is due to the local effects of the shell-to-baseplate connection offset. That is, the connection between shell and baseplate in the finite element model is at the surface of the baseplate, not at the middle surface of the baseplate. This offset will cause an additional bending moment that will reduce the rotation of the plate and hence, reduce the stress in the shell due to the rotation of the baseplate.

In summary, the approximate closed form solution confirms the accuracy of the finite element analysis in the baseplate region.

3.4.4.3.1.3 Elastic Stability and Yielding of the MPC Basket under Compression Loads (Load Case F3 in Table 3.1.3)

This load case corresponds to the scenario wherein the loaded MPC is postulated to drop causing a compression state in the fuel basket panels.

a. Elastic Stability

Following the provisions of Appendix F of the ASME Code [3.4.3] for stability analysis of Subsection NG structures, (F-1331.5(a)(1)), a comprehensive buckling analysis is performed using ANSYS. For this analysis, ANSYS's large deformation capabilities are used. This feature allows ANSYS to account for large nodal rotations in the fuel basket, which are characteristic of column buckling. The interaction between compressive and lateral loading, caused by the deformation, is exactly included. Subsequent to the large deformation analysis, the basket panel that is most susceptible to buckling failure is identified by a review of the results. The lateral displacement of a node located at the mid-span of the panel is measured for the range of impact decelerations. The buckling or collapse load is defined as the impact deceleration for which a slight increase in its magnitude results in a disproportionate increase in the lateral displacement.

The stability requirement for the MPC fuel basket under lateral loading is satisfied if two-thirds of the collapse deceleration load is greater than the design basis horizontal acceleration (Table 3.1.2). This analysis was performed for the HI-STAR 100 submittal (Docket Number 72-1008) under a 60g deceleration loading. Within the HI-STAR 100 TSAR (Docket Number 72-1008), Figures 3.4.27 through 3.4.32 are plots of lateral displacement versus impact deceleration **for the MPC-24, MPC-32, and MPC-68**. It should be noted that the displacements (in the HI-STAR 100 TSAR) in Figures 3.4.27 through 3.4.31 are expressed in $1\text{x}10^{-1}$ inch and Figure 3.4.32 is expressed in $1\text{x}10^{-2}$ inch. The plots in the HI-STAR 100 TSAR clearly show that the large deflection collapse load of the MPC fuel basket is greater than 1.5 times the design basis deceleration for all baskets in all orientations. **The results for the MPC-24E-are similar.** Thus, the requirements of Appendix F are met for lateral deceleration loading under Subsection NG stress limits for faulted conditions.

An alternative solution for the stability of the fuel basket panel is obtained using the methodology espoused in NUREG/CR-6322 [3.4.13]. In particular, we consider the fuel basket panels as wide plates in accordance with Section 5 of NUREG/CR-6322. We use eq.(19) in that section with the "K" factor set to the value appropriate to a clamped panel. Material properties are selected corresponding to a metal temperature of 500 degrees F which bounds computed metal temperatures at the periphery of the basket. In general, the basket periphery sees the largest loading in an impact scenario. The critical buckling stress is:

$$\sigma_{cr} = \left(\pi/_{K} \right)^2 \frac{E}{12\left(1-\nu^2\right)} \left(\frac{h}{a} \right)^2$$

where h is the panel thickness, a is the unsupported panel length, E is the Young's Modulus of Alloy X at 500 degrees F, ν is Poisson's Ratio, and K=0.65 (per Figure 6 of NUREG/CR-6322).

The MPC-24 has a **small**~~the smallest~~ h/a ratio; the results of the finite element stress analyses under design basis deceleration load show that this basket is subject to the highest compressive load in the panel. Therefore, the critical buckling load is computed using the geometry of the MPC-24. The following table shows the results from the finite element stress analysis and from the stability calculation.

Panel Buckling Results From NUREG/CR-6322			
Item	Finite Element Stress (ksi)	Critical Buckling Stress (ksi)	Factor of Safety
Stress	13.717	49.22	3.588

For a stainless steel member under an accident condition load, the recommended safety factor is 2.12. We see that the calculated safety factor exceeds this value; therefore, we have independently confirmed the stability predictions of the large deflection analysis based on classical plate stability analysis by employing a simplified method.

Stability of the basket panels, under longitudinal deceleration loading, is demonstrated in the following manner. Under 60g deceleration in Docket Number 72-1008, the axial compressive stress in the baskets were ~~computed~~ **computed for the MPC-24, 68, and 32,** as:

MPC-24	3,458 psi

MPC-68	3,739 psi
MPC-32	**4,001 psi**

For the 45g design basis decelerations for HI-STORM 100, the basket axial stresses are reduced by 25%.

The above values represent the amplified weight, including the nonstructural sheathing and the Boral, divided by the bearing area resisting axial movement of the basket. To demonstrate that elastic instability is not a concern, the buckling stress for **an MPC-24** flat panel is computed.

For elastic stability, Reference [3.4.8] provides the formula for critical axial stress as

$$\sigma_{cr} = \frac{4\pi^2 E}{12(1-\nu^2)}\left(\frac{T}{W}\right)^2$$

where T is the panel thickness and W is the width of the panel, E is the Young's Modulus at the metal temperature and ν is the metal Poisson's Ratio. The following table summarizes the calculation for the critical buckling stress using the formula given above:

Elastic Stability Result for a Flat Panel	
Reference Temperature	725 degrees F
T (MPC-24)	5/16 inch
W	10.777 inch
E	24,600,000 psi
Critical Axial Stress	74,781 psi

It is noted the critical axial stress is an order of magnitude greater than the computed basket axial stress reported in the foregoing and demonstrates that elastic stability under longitudinal deceleration load is not a concern **for any of the fuel basket configurations.**

b. Yielding

The safety factor against yielding of the basket under longitudinal compressive stress from a design basis inertial loading is given, **using the results for the MPC-32,** by

SF = 17,100/**4,001**~~3,739~~ = 4.**274**~~57~~

Therefore, plastic deformation of the fuel basket under design basis deceleration is not credible.

3.4.4.3.1.4 MPC Baseplate Analysis (Load Case E2)

A bounding analysis is performed in the HI-STAR 100 TSAR (Docket Number 72-1008, Appendix 3.I) to evaluate the stresses in the MPC baseplate during the handling of a loaded MPC. The stresses in the MPC baseplate calculated in that appendix are compared to Level A stress limits and remain unchanged whether the overpack is HI-STAR 100, HI-STORM 100, or HI-TRAC. Therefore, no new analysis is needed. We have reported results for this region in Subsection 3.4.3 where an evaluation has been performed for stresses under three times the supported load.

3.4.4.3.1.5 Analysis of the MPC Top Closure (Load Case E2)

The TSAR for the HI-STAR 100 System (Docket Number 72-1008, Appendix 3.E) contains stress analysis of the MPC top closure during lifting. Loadings in that analysis are also valid for the HI-STORM 100 System.

3.4.4.3.1.6 Structural Analysis of the Fuel Support Spacers (Load Case E3.a)

Upper and lower fuel support spacers are utilized to position the active fuel region of the spent nuclear fuel within the poisoned region of the fuel basket. It is necessary to ensure that the spacers will continue to maintain their structural integrity after an accident event. Ensuring structural integrity implies that the spacer will not buckle under the maximum compressive load, and that the maximum compressive stress will not exceed the compressive strength of the spacer material (Alloy X). Detailed calculations in Docket Number 72-1008, Appendix 3.J, demonstrate that large structural margins in the fuel spacers are available for the entire range of spacer lengths which may be used in HI-STORM 100 applications (for the various acceptable fuel types). The calculations for the HI-STORM 100 45g load are bounded by those for the HI-STAR 100 60g load.

3.4.4.3.1.7 External Pressure (Load Case E1.b, Table 3.1.4)

Design external pressure is applied to the MPC model. The outer surface of the MPC shell is subject to external pressure. The magnitude of the external pressure applied to the model is taken from Table 2.2.1. Analysis of the MPC under the external pressure is provided in the HI-STAR 100 TSAR Docket Number 72-1008 (Appendix 3.H) and therefore, is not repeated here.

3.4.4.3.2 HI-STORM 100 Storage Overpack Stress Calculations

The structural functions of the storage overpack are stated in Section 3.1. The analyses presented here demonstrate the ability of components of the HI-STORM 100 storage overpack to perform their structural functions in the storage mode. Load Cases considered are given in Table 3.1.5. The nomenclature used to identify the load cases (Load Case Identifier) considered is also given in Table 3.1.5.

The purpose of the analyses is to provide the necessary assurance that there will be no unacceptable release of radioactive material, unacceptable radiation levels, or impairment of ready retrievability of the MPC from the storage overpack. **Results obtained using the HI-STORM 100 configuration are identical to or bound results for the HI-STORM 100S configuration.**

3.4.4.3.2.1 HI-STORM 100 Compression Under the Static Load of a Fully Loaded HI-TRAC Positioned on the Top of HI-STORM 100 (Load Case 01 in Table 3.1.5)

During the loading of HI-STORM 100, a HI-TRAC transfer cask with a fully loaded MPC may be placed on the top of a HI-STORM 100 storage overpack. During this operation, the HI-TRAC may be held by a single-failure-proof lifting device so a handling accident is not credible. The HI-STORM 100 storage overpack must, however, possess the compression capacity to support the additional dead load. The following analysis provides the necessary structural integrity demonstration; **results for the HI-STORM 100 overpack are equal to or bound those for the HI-STORM 100S.**

Define the following quantities for analysis purposes:

$$W_{HT} = \text{Weight of HI-TRAC (loaded)} = 243{,}000 \text{ lb (Table 3.2.2)}$$

The dimensions of the compression components of HI-STORM 100 are as follows:

outer diameter of outer shell = $D_o = 132.5"$
thickness of outer shell = $t_o = 0.75"$
outer diameter of inner shell = $D_i = 76"$
thickness of inner shell = $t_i = 1.25"$
thickness of radial ribs = $t_r = 0.75"$

The metal area of the outer metal shell is

$$A_o = \frac{\pi}{4}(D_o^2 - (D_o - 2t_o)^2) = \frac{\pi}{4}(132.5^2 - 131^2)$$
$$= 310.43 \text{ in}^2$$

The metal area of the radial ribs is

$$A_r = 4\,t_r\,(D_o - 2\,t_o - D_i)/2 = \frac{3}{2}(131 - 76) = 82.5\,\text{in}^2$$

The metal area of the inner shell is

$$A_i = \frac{\pi}{4}(D_i^2 - (D_i - 2\,t_i)^2) = \frac{\pi}{4}(76^2 - 73.5^2)$$
$$= 293.54\,\text{in}^2$$

There are four radial ribs that extend full length and can carry load. The concrete radial shield can also support compression load. The area of concrete available to support compressive loading is

$$A_{concrete} = \frac{\pi}{4}((D_o - 2\,t_o)^2 - (D_i)^2) - A_r$$
$$= \frac{\pi}{4}(131^2 - 76^2)\ - 82.5\,\text{in}^2$$
$$= (8{,}994 - 82.5)\,\text{in}^2 = 8{,}859.5\,\text{in}^2$$

The areas computed above are calculated at a section below the air outlet vents. To correct the above areas for the presence of the air outlet vents **(HI-STORM 100 only since HI-STORM 100S has the air outlet vents located in the lid)**, we note that Bill-of-Materials 1575 in Chapter 1 gives the size of the horizontal plate of the air outlet vents as:

Peripheral width = w = 16.5”
Radial depth = d = 27.5” (over concrete in radial shield)

Using these values, the following final areas are obtained:

$A_o = A_o(\text{no vent}) - 4t_o w = 260.93$ sq. inch

$A_i = A_i(\text{no vent}) - 4t_i w = 211.04$ sq. inch

$A_{concrete} = A_{concrete}(\text{no vent}) - 4dw = 7044.2$ sq. inch slightly larger metal area (because the width of the air-inlet ducts is smaller) but will be subject to additional dead load from the weight of the supported metal components of the HI-STORM storage overpack plus the loaded HI-TRAC weight. At the base of the storage overpack, the additional stress in the outer shell and the radial plates is due solely to the weight of the component. The additional stress in these components is computed as:

$\Delta\sigma$ = (150 lb./cu.ft.) x 18.71 ft./144 sq.in./sq.ft. = 19.5 psi

This stress will be further increased by a small amount because of the material cut away by the air-inlet ducts; however, the additional stress still remains small. The inner shell, however, is subject to additional loading from the top lid of the storage overpack and from the radial shield. From the Structural Calculation Package (HI-981928)(see Subsection 3.6.4 for the reference), and from Table 3.2.1, the following weights are obtained **(using the higher 100S lid weight)**:

HI-STORM 100S Top Lid weight < 25,5~~3,0~~00 lb.
HI-STORM 100 Inner Shell weight < 19,000 lb.
HI-STORM 100 Shield Shell weight < 11,000 lb.

Using the calculated inner shell area at the top of the storage overpack for conservatism, gives the metal area of the inner shell as:

$A_i = A_i(\text{no vent}) - 4t_i w = 211.04$ sq. inch

Therefore, the additional stress from the HI-STORM 100S storage overpack components, at the base of the overpack, is:

$\Delta\sigma$ = **263**~~51~~ psi

and a maximum compressive stress in the inner shell predicted as:

Maximum stress = 438 psi + **263**~~51~~ psi = **701**~~689~~ psi

The safety factor at the base of the storage overpack inner shell (minimum section) is

SF = 17,500psi/**701**~~689~~psi = **24.96**~~5.4~~

The preceding analysis is bounding for the 100 Ton HI-TRAC transfer cask because of the lower HI-TRAC weight.

The preceding analysis is valid for both the HI-STORM 100 and the HI-STORM 100S since the bounding lid weight has been used.

3.4.4.3.2.2 HI-STORM 100 Lid Integrity Evaluation (Load Case 02.c, Table 3.1.5)

A non-mechanistic tip over of the HI-STORM 100 results in high decelerations at the top of the storage overpack. The storage overpack lid diameter is less than the storage overpack outer diameter. This ensures that the storage overpack lid does not directly strike the ground but requires analysis to demonstrate that the lid remains intact and does not separate from the body of the storage overpack. Figure 3.4.19 shows the scenario.

Appendix 3.K presents details of the~~-~~ **HI-STORM 100** storage overpack lid stress response to the tip-over deceleration loading directed in the plane of the lid. This accident condition of storage deceleration level bounds all other decelerations, directed in the plane of the lid, experienced under other accident conditions such as flood or earthquake as can be demonstrated by evaluating the loads resulting from these natural phenomena events. **Appendix 3.AO evaluates the stress response at key locations for the HI-STORM 100S lid.**

Appendix 3.L presents details of a calculation that demonstrates that the four studs hold the storage overpack lid in place, relative to the HI-STORM 100 body, after a HI-STORM 100 tip-over event. It is shown that the weight of the HI-STORM 100 lid, amplified by the design basis deceleration, can be supported by the shear capacity available in the four studs. The detailed calculations in Appendix 3.L demonstrate that if only a single stud is loaded initially during a tipover (because of tolerances), the stud hole will enlarge rather than the stud fail in shear. Therefore, it is assured that all four bolts will resist the tipover load regardless of the initial position of the HI-STORM 100 lid. ~~To provide further assurances that the tolerances cannot compromise the design, the installation procedure for the lid requires shimming "as necessary" to minimize clearances due to the tolerances.~~

Appendix 3.AP provides details of the identical calculations for the HI-STORM 100S stud and lid configuration. Because of the lid configuration, a longer stud length is required. To preclude bending of the studs due to lid movement, relative to the body of the HI-STORM 100S, clearance holes are provided to insure that the studs take minimal or no load due to the tipover event and shear bars are set in place around the outer periphery to assure that the lid maintains its position. The shear bars are sized to resist 100% of the amplified load from the lid.~~Although the details of the structure are different, the same conclusions are reached.~~

The following tables summarizes the limiting results obtained from the detailed analyses in Appendices 3.K,~~-and~~ 3.L **for the HI-STORM 100, and in Appendices 3.AO and 3.AP for the HI-STORM 100S**:

HI-STORM 100 Top Lid Integrity			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
Lid Shell-**Lid Top Plate** Weld Shear Stress	**6.529**~~8.94~~	29.4	**4.503**~~3.292~~
Lid Shell-Lid Top Plate Combined Stress	**8.84**	**29.4**	**3.326**
Attachment Bolt Shear Stress	34.3~~3.62~~	60.9	1.776~~812~~
Attachment Bolt Combined Shear and ~~Tension~~ ~~Interaction~~**Tension Interaction** at interface with Anchor Block	-------	------	1.27~~91~~

HI-STORM 100S Top Lid Integrity			
Item	**Value (ksi)**	**Allowable (ksi)**	**Safety Factor**
Inner and Outer Shell Weld to Base	**8.572~~1~~**	**29.4~~29.4~~**	**3.43~~3.43~~**
Shield Block Shell-to-Lid Weld Shear Stress	**5.955~~5.96~~**	**29.4~~29.4~~**	**4.94~~4.937~~**
Attachment Bolt Tensile~~Shear~~ Stress	**48.8~~37.27~~**	**145.5~~60.9~~**	**3.0~~1.634~~**
Shear Bar Weld Stress ~~Attachment Bolt~~ ~~Combined Shear and Tension Interaction at interface with Anchor Block~~	**31.7~~------~~**	**42.0~~------~~**	**1.325~~45~~**

3.4.4.3.2.3 Vertical Drop of HI-STORM 100 Storage overpack (Load Case 02.a of Table 3.1.5)

A loaded HI-STORM 100, with the top lid in place, drops vertically and impacts the ISFSI. Figure 3.4.20 illustrates the drop scenario. The regions of the structure that require detailed examination are the storage overpack top lid, the inlet vent horizontal plate, the pedestal shield and shield shell, the inlet vent vertical plate, and all welds in the load path. Appendix 3.M examines the Level D event of a HI-STORM 100 drop developing the design basis deceleration.

The table **provided** below summarizes the results of the analyses detailed in Appendix 3.M **for the weight and configuration of the HI-STORM 100. The results for the HI-STORM 100S are bounded by the results given below. Any calculation pertaining to the pedestal is bounding since the pedestal dimensions and corresponding weights are less in the HI-STORM 100S.** **~~The safety factor for the 2" thick plates in the top lid may be decreased slightly for the HI-STORM 100S since the total lid weight is increased. As the increase in total bounding lid weight is only 1.16%, the safety factors require minimal alteration~~** ~~:~~

HI-STORM 100 Load Case 02.a Evaluation

Item	Value (ksi)	Allowable (ksi)	Safety Factor
Lid Bottom Plate Bending Stress Intensity	27.69	59.65	2.15†
Weld- lid bottom plate-to-lid shell	21.62	29.4	1.36
Lid Shell – Membrane Stress Intensity	1.856	39.75	21.42
Lid Top (2" thick) Plate Bending Stress Intensity	11.27	59.65	5.294*
Inner Shell –Membrane Stress Intensity	11.33	39.75	3.508
Outer Shell –Membrane Stress Intensity	3.401	39.75	11.686
Inlet Vent Horizontal Plate Bending Stress Intensity	35.25	59.65	1.692
Inlet Vent Vertical Plate Membrane Stress Intensity	9.998	39.75	3.976
Pedestal Shield – Compression	1.249	1.535	1.229
Pedestal Shell – Circumferential Stress	14.28	33.15	2.321
Weld – outer shell-to-baseplate	3.854	29.4	7.629
Weld – inner shell-to-baseplate	7.321	29.4	4.016
Weld-Pedestal shell-to-baseplate	1.138	29.4	25.828

† Note that Appendix 3.X shows that the dynamic load factor for the lid top plate is negligible and for the lid bottom plate is 1.06. This dynamic load factor has been incorporated in the above table.

* **For the HI-STORM 100S, this safety factor is conservatively evaluated in Appendix 3.M to be 1.658 because of increased load on the upper of the two lid plates.**

Appendix 3.AK contains an assessment of the potential for instability of the compressed inner and outer shells under the compressive loading during the drop event. The methodology is from ASME Code Case N-284 (Metal Containment Shell Buckling Design Methods, Division I, Class MC (8/80)). This Code Case has been previously accepted by the NRC as an acceptable method for evaluation of stability in vessels. The results obtained are conservative in that the loading in the shells is assumed to be uniformly distributed over the entire length of the shells. In reality, the component due to the amplified weight of the shell varies from zero at the top of the shell to the maximum value at the base of the shell. It is concluded in Appendix 3.AK that large factors of safety exist so that elastic or plastic instability of the inner and outer shells does not provide a limiting condition. **The results for the HI-STORM 100 bound similar results for the HI-STORM 100S since the total weight of the "S" configuration is substantially decreased (see Subsection 3.2)**

The results from Appendix 3.M and 3.AK do not show any gross regions of stress above the material yield point that would imply the potential for gross deformation of the storage overpack subsequent to the handling accident. MPC stability has been evaluated in the HI-STAR 100 TSAR for a drop event with 60g deceleration and shown to satisfy the Code Case N-284 criteria. Therefore, ready retrievability of the MPC is maintained as well as the continued performance of the HI-STORM 100 storage overpack as the primary shielding device.

3.4.4.3.3 HI-TRAC Transfer Cask Stress Calculations

The structural functions of the transfer cask are stated in Section 3.1. The analyses presented here demonstrate the ability of components of the HI-TRAC transfer cask to perform their structural functions in the transfer mode. Load Cases considered are given in Table 3.1.5.

The purpose of the analyses is to provide the necessary assurance that there will be no unacceptable release of radioactive material, unacceptable radiation levels, or impairment of ready retrievability.

3.4.4.3.3.1 Analysis of Pocket Trunnions (Load Case 01 of Table 3.1.5)

HI-TRAC has pocket trunnions attached to the outer shell and to the water jacket. During the rotation of HI-TRAC from horizontal to vertical or vice versa (see Figure 3.4.18), these trunnions serve to define the axis of rotation. The HI-TRAC is also supported by the lifting trunnions during this operation. Two load conditions are considered: Level A when all four trunnions support load during the rotation; and, Level B when the hoist cable is assumed slack so that ~~all of the~~**the entire** load is supported by the rotation trunnions. A dynamic amplification of 15% is assumed in both cases appropriate to a low-speed operation. Appendices 3.AA and 3.AI (for the 125 Ton and 100 Ton units, respectively) present the analysis of the pocket trunnion. Figure 3.4.23 shows a free body of the trunnion and shows how the applied force and moment are assumed to be resisted by the weld group that connects the trunnion to the outer shell. Drawings 1880 (sheet 10) and 2145 (sheet 10) show the configuration. An optional construction for the 100 Ton HI-TRAC permits the pocket trunnion base to be split to reduce the "envelope" of the HI-TRAC. For that construction, bolts and dowel pins are used to insure that the force and moment applied to the pocket trunnions are transferred properly to the body of the transfer cask. Appendix 3.AI also evaluates the bolts and dowel pins and demonstrates that safety factors greater than 1.0 exist for bolt loads, dowel bearing and tear-out, and dowel shear. Allowable strengths and loads are computed using applicable sections of ASME Section III, Subsection NF.

ITEM – 125 Ton HI-TRAC	CALCULATED VALUE	ALLOWABLE VALUE
Longitudinal Stress - (ksi) (Primary Stress –Inner Shell)	-0.956	23.275
Tangential Stress (ksi) (Primary Stress - Inner Shell)	-1.501	23.275
Longitudinal Stress (ksi) (Primary Stress – Outer Shell)	-0.830	23.275
Tangential Stress (ksi) (Primary Stress - Outer Shell)	-0.436	23.275
Longitudinal Stress - (ksi) (Primary Stress – Radial Channels)	2.305	23.275
Tangential Stress (ksi) (Primary Stress - Radial Channels)	-0.631	23.275
Longitudinal Stress - (ksi) (Primary plus Secondary Stress - Inner Shell)	1.734	No Limit (34.9~~125~~)*
Tangential Stress (ksi) (Primary plus Secondary Stress - Inner Shell)	-1.501	NL
Longitudinal Stress (ksi) (Primary plus Secondary Stress - Outer Shell)	2.484	NL
Tangential Stress (ksi) (~~Primary -plus~~**Primary plus** Secondary Stress - Outer Shell)	-2.973	NL
Longitudinal Stress - (ksi) (Primary plus Secondary Stress - Radial Channels)	-13.87	NL
Tangential Stress (ksi) (Primary plus Secondary Stress - Radial Channels)	-2.303	NL

* The NF Code sets no limits (NL) for primary plus secondary stress (see Table 3.1.17). Nevertheless, to demonstrate the robust design with its large margins of safety, we list here, for information only, the allowable value for Primary Membrane plus Primary Bending Stress appropriate to temperatures up to 650 degrees F.

The only stress of any significance is the longitudinal stress in the radial channels. This stress occurs immediately adjacent to the trunnion block/radial channel interface and by its localized nature is identifiable as a stress arising at the gross structural discontinuity (secondary stress).

The finite element analysis has also been performed for the 100 Ton HI-TRAC transfer cask; results are reported in Appendix 3.AI. The following table summarizes the results:

ITEM – 100 Ton HI-TRAC	CALCULATED VALUE	ALLOWABLE VALUE
Longitudinal Stress - (ksi) (Primary Stress –Inner Shell)	-0.756	23.275
Tangential Stress (ksi) (Primary Stress - Inner Shell)	-2.157	23.275
Longitudinal Stress (ksi) (Primary Stress – Outer Shell)	-0.726	23.275
Tangential Stress (ksi) (Primary Stress - Outer Shell)	-0.428	23.275
Longitudinal Stress - (ksi) (Primary Stress – Radial Channels)	2.411	23.275
Tangential Stress (ksi) (Primary Stress - Radial Channels)	-0.5305	23.275
Longitudinal Stress - (ksi) (Primary plus Secondary Stress - Inner Shell)	2.379	NL
Tangential Stress (ksi) (Primary plus Secondary Stress - Inner Shell)	-2.157	NL
Longitudinal Stress (ksi) (Primary plus Secondary Stress - Outer Shell)	3.150	NL
Tangential Stress (ksi) (~~Primary plus~~**Primary plus** Secondary Stress - Outer Shell)	-3.641	NL
Longitudinal Stress - (ksi) (Primary plus Secondary Stress - Radial Channels)	-15.51	NL
Tangential Stress (ksi) (Primary plus Secondary Stress - Radial Channels)	-2.294	NL

The finite element analyses of the metal structure adjacent to the trunnion block did not include the state of stress arising from the water jacket internal pressure. These stresses are computed in Appendix 3.AG and are conservatively computed based on a two-dimensional strip model that neglects the lower annular plate. The water jacket bending stresses calculated in Appendix ~~3.AG are~~**3.AG are** summarized below:

Transfer Lid Attachment Integrity Under Side Drop			
Item – Shear Capacity	Value (**kip**~~lb~~) or (ksi)	Capacity (**kip**~~lb~~) or (ksi)	Safety Factor= Capacity/Value
125 Ton Attachment (kip)	~~7~~**1,272.0**~~,654.5~~	**1,770**~~9,135~~.0	**1.392**~~19~~
125 Ton Door Lock Bolts (ksi)	**20.24**~~2.0916~~	48.3	**2.387**~~198~~
100 Ton Attachment ~~(bolts and tongue)~~ (kip)	**1,129.0**~~6,331.5~~	**1,729.0**~~9,135.0~~	1.53442
100 Ton Door Lock Bolts (ksi)	13.**81**~~687~~	48.3	3.**497**~~529~~

All safety factors are greater than 1.0 **and are based on actual interface loads.**~~. It is noted that the input load used to compute the tongue/groove capacity is a conservatively large bounding load~~. The actual interface load for both transfer casks is computed in Appendix 3.AN. For the 125-Ton and 100-Ton HI-TRACs, the actual interface load **(primary impact at transfer lid)** computed from the handling accident analysis is bounded by the values given below:

BOUNDING INTERFACE LOADS COMPUTED FROM HANDLING ACCIDENT ANALYSES	
Item	Bounding Value from Appendix 3.AN (kip)
125-Ton HI-TRAC	1,300
100-Ton HI-TRAC	1,150~~200~~

~~On the basis of the actual calculated interface loads, the tabulated safety factors can be multiplied by 5.~~

3.4.4.3.3.4 Stress Analysis of the HI-TRAC Water Jacket (Load Case 03 in Table 3.1.5)

The water jacket is assumed subject to internal pressure from pressurized water and gravity water head. Calculations to determine the water jacket stress under internal pressure plus hydrostatic load are performed in Appendix 3.AG. Results are obtained for the water jacket configuration and the connecting welds for both HI-TRAC transfer casks. The table below summarizes the results of the analysis performed in Appendix 3.AG.

Water Jacket Stress Evaluation			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
125 Ton HI-TRAC Water Jacket Enclosure Shell Panel Bending Stress	18.41	26.25	1.426
100 Ton HI-TRAC Water Jacket Enclosure Shell Panel Bending Stress	22.47	26.25	1.168
125 Ton HI-TRAC Bottom Flange Bending Stress	18.3	26.25	1.434
100 Ton HI-TRAC Water Jacket Bottom Flange Bending Stress	16.92	26.25	1.551
125 Ton HI-TRAC Weld Stress -Enclosure Panel Single Fillet Weld	2.22	21.0	9.454
100 Ton HI-~~TRAC Weld~~TRAC Weld Stress – Enclosure Panel Single Fillet Weld	1.841	21.0	11.408
125 Ton HI-TRAC Weld Stress – Bottom Flange-to Outer Shell Double Fillet Weld	14.79	21.0	1.42
125 Ton HI-TRAC - Enclosure Panel Direct Stress	1.571	17.5	11.142
100 Ton HI-TRAC - Enclosure Panel Direct Stress	1.736	17.5	10.84

3.4.4.3.3.5 HI-TRAC Top Lid Separation (Load Case 02.b in Table 3.1.5)

Appendix 3.AH examines the potential of top lid separation under a 45g deceleration side drop event. It is concluded that the ~~tongue and groove~~ connection provides acceptable protection against top lid separation. It is also shown that the bolts and the lid contain the MPC within the HI-TRAC cavity during and after a drop event. The results from the 125 Ton HI-TRAC bound the corresponding results from the 100 Ton HI-TRAC because the top lid bolts are identical in the two units and the 125 Ton HI-TRAC top lid weighs more. The table below provides the results of the analysis.

HI-TRAC Top Lid Separation Analysis			
Item	Value	Capacity	Safety Factor= Capacity/Value
Attachment Shear Force (lb.)	123,750~~39~~	**958,651**~~3,115,000~~	**7.747**~~25.17~~
Tensile Force in Stud (lb.)	132~~40~~,000	**1,118,436**~~199,200~~	**8.473**~~1.423~~
Bending Stress in Lid (ksi)	35.56~~7.71~~	58.7	1.651~~56~~
Shear Load per unit Circumferential Length in Lid (lb./in)	**533.548**~~65.88~~	29,400	**55.103**~~1.95~~

3.4.4.4 Comparison with Allowable Stresses

Consistent with the formatting guidelines of Reg. Guide 3.61, calculated stresses and stress intensities from the finite element and other analyses are compared with the allowable stresses and stress intensities defined in Subsection 3.1.2.2 per the applicable sections of [3.4.2] and [3.4.4] for defined normal and off-normal events and [3.4.3] for accident events (Appendix F).

3.4.4.4.1 MPC

Table 3.4.6 provides summary data extracted from Appendix 3.T for the fuel basket, enclosure vessel, and fuel basket supports based on the design basis deceleration. The results presented in Table 3.4.6 do not include any dynamic amplification due to internal elasticity of the structure (i.e., local inertia effects). Appendix 3.X suggests that a uniform conservative dynamic amplifier ~~would be~~**would be** 1.08 independent of the duration of impact. If we recognize that the tip-over event for HI-STORM 100 is a long duration event, then a dynamic amplifier of 1.04 is appropriate. The summary data provided in Table 3.4.3 and 3.4.4 gives the lowest safety factor computed for the fuel basket and for the MPC, respectively. Modification of the fuel basket safety factor for dynamic amplification leaves considerable margin.

Factors of safety greater than 1 indicate that calculated results are less than the allowable strengths. Detailed plots showing the location and the number of all finite elements for the different MPC's are provided in Appendices 3.N through 3.S.

A perusal of the results for Tables 3.4.3 and 3.4.4 under different load combinations for the fuel basket and the enclosure vessel reveals that all factors of safety are above 1.0 even if we use the most conservative value for dynamic amplification factor. The relatively modest factor of safety in the fuel basket under side drop events (Load Case F3.b and F3.c) in Table 3.4.3 warrants further explanation since a very conservative finite element model of the structure has been utilized in the analysis.

The wall thickness of the storage cells, which is by far the most significant variable in a fuel basket's structural strength, is significantly greater in the MPCs than in comparable fuel baskets licensed in the past. For example, the cell wall thickness in the TN-32 basket (Docket No. 72-1021, M-56), is 0.1 inch and that in the NAC-STC basket (Docket No. 71-7235) is 0.048 inch. In contrast, the cell wall thickness in the MPC-68 is 0.25 inch. In spite of their relatively high flexural rigidities, computed margins in the fuel baskets are rather modest. This is because of some assumptions in the ~~analysis which~~**analysis that** lead to an overstatement of the state of stress in the fuel basket. For example:

i. The section properties of longitudinal fillet welds that attach contiguous cell walls to each other are completely neglected in the finite element model (Figure 3.4.7). The fillet welds strengthen the cell wall section modulus at the very locations where maximum stresses develop.

ii. The radial gaps at the fuel basket-MPC shell and at the MPC shell-storage overpack interface are explicitly modeled. As the applied loading is incrementally increased, the MPC shell and fuel basket deform until a "rigid" backing surface of the storage overpack is contacted, making further unlimited deformation under lateral loading impossible. Therefore, some portion of the fuel basket and enclosure vessel (EV) stress has the characteristics of secondary stresses (which by definition, are self-limited by deformation in the structure to achieve compatibility). For conservativeness in the incremental analysis, we make no distinction between deformation controlled (secondary) stress and load controlled (primary) stress in the stress categorization **of the MPC-24**~~,32~~**, 32, and 68 fuel baskets**. We treat all stresses, regardless of their origin, as primary stresses. Such a conservative interpretation of the Code has a direct (adverse) effect on the computed safety factors. **As noted earlier, the results for the MPC-24E are properly based only on primary stresses to illustrate the conservatism in the reporting of results for the MPC-24, 32, and 68 baskets.**

~~The above remarks can be illustrated simply by a simple closed-form bounding calculation. If all deformation necessary to close the gaps is eliminated from consideration, then the capacity of the fuel basket cell wall under loads which induce primary bending stress can be ascertained by considering a clamped beam (cell wall) subject to a lateral pressure representing the amplified weight of fuel assembly plus self-weight of the cell wall (e.g., see Figure 3.4.7).~~

~~Using the cell wall thickness and unsupported length for the MPC-24, for example, the fixed edge bending stress is computed as approximately 578 psi (using the actual fuel weights and cell wall weights, an unsupported length of 10.777", and a wall~~

~~thickness of 0.3125"). This implies a safety factor of 2.13 for a Level D event (for a 45g deceleration, SF = 55,400/(578 x 45) = 2.13) where the allowable bending stress intensity for Alloy X at 725 degrees F (Table 3.1.16) has been used.~~

~~The above scoping calculation demonstrates the inherent safety margin under accident loading is considerably greater than is implied by the result in Table 3.4.6 (SF=1.28) for the MPC-24.~~

iii. A uniform pressure simulates the SNF inertia loading on the cell panels, which is a most conservative approach for incorporating the SNF/cell wall structure interaction.

The above assumptions act to depress the computed values of factors of safety in the fuel basket finite element analysis and render conservative results.

Detailed results of the analyses of the MPC**-24, 32, and 68,**~~s~~ under the appropriate load combinations, are presented in Tables 3.T.1 through 3.T.36 of Appendix 3.T.

The reported values do not include the effect of dynamic load amplifiers. As noted in Appendices 3.A and 3.X, the duration of impact and the predominant natural frequency of the basket panels under drop events result in the dynamic load ~~factors which~~**factors that** do not exceed 1.08. Therefore, since all reported factors of safety are greater than the DLF, the MPC is structurally adequate for its intended functions.

Tables 3.4.7 and 3.4.8 report stress intensities and safety factors for the confinement boundary subject to internal pressure alone and internal pressure plus the normal operating condition temperature with the most severe thermal gradient. The final values for safety factors in the various locations of the confinement boundary provide assurance that the MPC enclosure vessel is a robust pressure vessel.

3.4.4.4.2 Storage Overpack and HI-TRAC

The result from analyses of the storage overpack and the HI-TRAC transfer cask is shown in Table 3.4.5. The location of each result is indicated in the table. Safety factors for lifting operations where three times the lifted load is applied are reported in Section 3.4.3.

The table shows that all allowable stresses are much greater than their associated calculated stresses and that safety factors are above the limit of 1.0.

3.4.4.5 Elastic Stability Considerations

3.4.4.5.1 MPC Elastic Stability

Stability calculations for the MPC have been carried out in the HI-STAR 100 TSAR, Docket Number 72-1008, Appendix 3.H. The calculations in that submittal bound calculations for the MPC in HI-STORM 100 since all loadings are identical except for the peak deceleration under accident events, which has been reduced from 60g's to 45g's.

3.4.4.5.2 HI-STORM 100 Storage Overpack Elastic Stability

HI-STORM 100 **(and 100S)** storage overpack shell buckling is not a credible scenario since the two steel shells plus ~~all of the~~**the entire** radial shielding act to resist vertical compressive loading. Subsection 3.4.4.3.2.3 develops values for compressive stress in the steel shells of the storage overpack. Because of the low value for compressive stress coupled with the fact that the ~~steel shells are backed by the concrete shielding~~**concrete shielding backs the steel shells**, we can conclude that instability is unlikely. Note that the entire weight of the storage overpack can also be supported by the concrete shielding acting in compression. Therefore, in the unlikely event that a stability limit in the steel was approached, the load would simply shift to the massive concrete shielding. Notwithstanding the above comments, stability analyses of the storage overpack have been performed for bounding cases of longitudinal compressive stress with nominal circumferential compressive stress and for bounding circumferential compressive stress with nominal axial compressive stress. This latter case is for a bounding all-around external pressure on the HI-STORM 100 outer shell. The latter case is listed as Load Case 05 in Table 3.1.5 and is performed to demonstrate that explosions or other environmental events that could lead to an all-around external pressure on the outer shell do not cause a buckling instability. ASME Code Case N-284, a methodology accepted by the NRC, has been used for this analysis. Appendix 3.AK reports results of all stability analyses performed in support of this TSAR. In that appendix, the storage overpack shells are examined individually assuming that the four radial plates provide circumferential support against a buckling deformation mode. The analysis of the storage overpack outer shell for a bounding external pressure of

$$p_{ext} = 30 \text{ psi}$$

that, together with a nominal compressive axial load that bounds the dead weight load at the base of the outer shell, gives a safety factor against an instability of (see Load Case 3 in Appendix 3.AK):

$$\text{Safety Factor} = (1/0.466) \times 1.34 = 2.88$$

The factor 1.34 is included in the above result since the analysis methodology of Code Case N-284 builds in this factor for a stability analysis for an accident condition.

The external pressure for the overpack stability considered here significantly bounds the short-time 10 psi differential pressure (between outer shell and internal annulus) specified in Table 2.2.1.

The same postulated external pressure condition can also act on the HI-TRAC during movement from the plant to the ISFSI pad. In this case, the lead shielding acts as a backing for the outer shell of the HI-TRAC transfer cask just as the concrete does for the storage overpack. The water jacket metal structure provides considerable additional structural support to the extent that it is reasonable to state that instability under external pressure is not credible. If it is assumed that the all-around water jacket support is equivalent to the four locations of radial support provided in the storage overpack, then it

As no liquids are included in the HI-STORM 100 storage overpack design, loads due to expansion of freezing liquids are not considered. The HI-TRAC transfer cask utilizes demineralized water in the water jacket. However, the specified lowest service temperature for the HI-TRAC is 0 degrees F and a 25% ethylene glycol solution is required for the temperatures from 0 degrees F to 32 degrees F. Therefore, loads due to expansion of freezing liquids are not considered.

There is one condition, however, that does require examination to insure ready retrievability of the fuel. Under a postulated loading of an MPC from a HI-TRAC transfer cask into a cold HI-STORM 100 storage overpack, it must be demonstrated that sufficient clearances are available to preclude interference when the "hot" MPC is inserted into a "cold" storage overpack. To this end, an analysis for free thermal expansions under cold conditions of storage has been performed in Appendix 3.AF. The storage overpack is assumed to have been uniformly cooled to 0 degrees F from its normal assembly temperature (assumed as 70 degrees F in all analyses). The MPC is assumed to have the temperature distribution associated with being contained within a HI-TRAC transfer cask. For additional conservatism in the analysis, the MPC temperatures for the "hot condition of storage" (100 degrees F ambient) in a HI-TRAC are used to maximize the radial and axial growth of the loaded MPC. These MPC temperatures are available in Appendix 3.I. The results from the evaluation of free thermal expansion described above and carried out in detail in Appendix 3.AF for this "cold condition of transfer" are summarized in the table below:

THERMOELASTIC DISPLACEMENTS IN ~~THE HOT~~**THE HOT** MPC AND ~~COLD HI~~**COLD** HI-STORM STORAGE OVERPACK UNDER COLD TEMPERATURE TRANSFER CONDITION				
HOT CANISTER – COLD HI-STORM				
	Radial Direction (in.)		Axial Direction (in.)	
Unit	Initial Clearance	Final Clearance	Initial Clearance	Final Clearance
~~MPC(~~**MPC** (worst case)	0.**545**~~30625~~	0.**351**~~04269~~	**1.0**~~0.75~~	0.**163**~~233~~

The final radial clearance (greater than 0.25" radial) is sufficient to preclude jamming of the MPC upon insertion into a cold HI-STORM 100 storage overpack.

3.4.6 HI-STORM 100 Kinematic Stability under Flood Condition (Load Case A in Table 3.1.1)~~)~~

The flood condition subjects the HI-STORM 100 System to external pressure, together with a horizontal load due to water velocity. Because the HI-STORM 100 storage overpack is equipped with ventilation openings, the hydrostatic pressure from flood submergence acts only on the MPC. As stated in subsection 3.1.2.1.1.3, the design external pressure for the MPC bounds the hydrostatic pressure from flood submergence. Subsection 3.4.4.5.2 has reported a positive safety factor against ~~an instability~~**instability** from external pressure in excess of that expected from a complete submergence in a flood. **The analysis performed below is also valid for the HI-STORM 100S.**

The water velocity associated with flood produces a horizontal drag force, which may act to cause sliding or tip-over. In accordance with the provisions of ANSI/ANS 57.9, the acceptable upper bound flood velocity, V, must provide a minimum factor of safety of 1.1 against overturning and sliding. For HI-STORM 100, we set the upper bound flood velocity design basis at 15 feet/sec. Subsequent calculations conservatively assume that the flow velocity is uniform over the height of the storage overpack.

The overturning horizontal force, F, due to hydraulic drag, is given by the classical formula:

$$F = C_d\, A\, V^*$$

where:

V^* is the velocity head = $\frac{\rho V^2}{2g}$; (ρ is water weight density, and g is acceleration due to gravity).

A: projected area of the HI-STORM 100 cylinder perpendicular to the fluid velocity vector.

Cd: drag coefficient

The value of Cd for flow past a cylinder at Reynolds number above 5E+05 is given as 0.5 in the literature (viz. Hoerner, Fluid Dynamics, 1965).

The drag force tending to cause HI-STORM 100's sliding is opposed by the friction force, which is given by

$$F_f = \mu K\, W$$

where:

μ = limiting value of the friction coefficient at the HI-STORM 100/ISFSI pad interface (conservatively taken as 0.25, although literature citations give higher values).

K = buoyancy coefficient (documented in HI-981928, Structural Calculation Package for HI-STORM 100 (see citation in Subsection 3.6.4).

W: Minimum weight of HI-STORM 100 with an empty MPC.

Sliding Factor of Safety

The factor of safety against sliding, β_1, is given by

$$\beta_1 = \frac{F_f}{F} = \frac{\mu KW}{Cd\,A\,V^*}$$

It is apparent from the above equation, β, will be minimized if ~~a~~the lower bound weight of HI-STORM 100 is used in the above equation.

As stated previously, $\mu = 0.25$, $Cd = 0.5$.

V^* corresponding to 15 ft./sec. water velocity is 218.01 lb per sq. ft.

A = length x diameter of HI-STORM 100 = 132.5" x 231.25"/144 sq. in./sq.ft. = 212.78 sq. ft.

K = buoyancy factor = 0.64 (per calculations in HI-981928)

W = 303,000 lbs. (Table 3.2.1 **with empty MPC-68)**

Substituting in the above formula for β, we have

$\beta_1 = 2.09 > 1.1$ (required)

The HI-STORM 100S has a lower weight and if coupled with an empty MPC-32 reduces the value of "W" to 286,798 lb. The safety factor against sliding is reduced to 1.979 for this configuration.

Overturning Factor of Safety

For determining the margin of safety against overturning β_2, the cask is assumed to pivot about a fixed point located at the outer edge of the contact circle at the interface between HI-STORM 100 and the ISFSI. The overturning moment due to a force F_T applied at height H^* is balanced by a restoring moment from the reaction to the cask buoyant force KW acting at radius D/2.

$$F_T\,H^* = KW\frac{D}{2}$$

$$F_T = \frac{K\,W\,D}{2H^*}$$

W is the minimum weight of the storage overpack with an empty MPC.

We have,

$W =$ 303,000 lb. (Table 3.2.1)

$H^* =$ 118.64~~6~~" (maximum height of mass center per Table 3.2.3)

$D =$ 132.5" (Holtec Drawing 1495)

$K =$ 0.64 (calculated in HI-981928)

$F_T =$ 108,396~~452~~ lb.

F_T is the horizontal drag force at incipient tip-over.

$F =$ $C_d A V^*$ = 23,194 lbs. (drag force at 15 feet/sec)

The safety factor against overturning, β_2, is given as:

$$\beta_2 = \frac{F_T}{F} = 4.67 > 1.1 \text{ (required)}$$

Use of the minimum weight HI-STORM 100S in the above calculation results in minimal change to the result since the weight reduction also results in a lowering of the center of gravity, and F_T is not significantly changed.

In the next subsection, results are presented to show that the load F (equivalent to an inertial deceleration of F/360,000 lb = 0.0644 g's applied to the loaded storage overpack) does not lead to large global circumferential stress or ovalization of the storage overpack that could prevent ready retrievability of the MPC. It is shown in Subsection 3.4.7 that a horizontal load equivalent to 0.47g's does not lead to circumferential stress levels and ovalization of the HI-STORM storage overpack to prevent ready retrievability of the MPC. The load used for that calculation clearly bounds the side load induced by flood.

3.4.7 Seismic Event and Explosion - HI-STORM 100

3.4.7.1 Seismic Event (Load Case C in Table 3.1.1)

The HI-STORM 100 System plus its contents may be assumed to be subject to a seismic event consisting of three orthogonal statistically independent acceleration time-histories. For the purpose of performing a conservative analysis to determine the maximum ZPA that will not cause incipient tipping, the HI-STORM 100 System is considered as a rigid body subject to a net horizontal quasi-static inertia force and a vertical quasi-static inertia force. This is consistent with the approach used in previously licensed dockets. The vertical seismic load is conservatively assumed to act in the most unfavorable direction (upwards) at the same instant. The vertical seismic load is assumed to be equal to or less than the net horizontal load with ε being the ratio of vertical component to one of the horizontal components. For use in calculations, define D_{BASE} as the contact patch diameter, and H_{CG} as the height of the centroid of an empty HI-STORM 100 System (no fuel). Conservatively, assume

D_{BASE} = 132.5" (Drawing 1495, Sheet 1 specifies 133.875" including overhang for welding)

Tables 3.2.1 and 3.2.3 give HI-STORM 100 weight data and center-of-gravity heights.

The weights and center-of-gravity heights are reproduced here for calculation of the composite center-of-gravity height of the storage overpack together with an empty MPC.

Weight (pounds)	C.G. Height (Inches); H
Overpack - W_o = **265,866**~~70,000~~	116.8
MPC-24 - W_{24} = 39,667	108.9 + 24 = 132.9†
MPC-68 - W_{68} = 39,641	109.9 + 24 = 133.9
MPC-32 –W_{32} = 34,375	**109.3 + 24 = 133.3**
MPC-24E – W_{24E} = 42,069	**107.9 + 24 = 131.9**

The height of the composite centroid, H_{CG}, is determined from the equation

$$H_{cg} = \frac{W_o \text{ x } 116.8 + W_{MPC} \text{ x } H}{W_o + W_{MPC}}$$

Performing the calculations for all of the MPCs gives the following results:

	H_{cg} (inches)
MPC-24 with storage overpack	118.89~~86~~
MPC-68 with storage overpack	119.02~~8.98~~
MPC-32 with storage overpack	**118.69**
MPC-24E with storage overpack	**118.86**

A conservative overturning stability limit is achieved by using the largest value of H_{CG} (call it H) from the above. Because the HI-STORM 100 System is a radially symmetric structure, the two horizontal seismic accelerations can be combined vectorially and applied as an overturning force at the C.G. of the cask. The net overturning static moment is

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† From Table 3.2.3, it is noted that MPC C.G. heights are measured from the base of the MPC. Therefore, the thickness of the overpack baseplate and the concrete MPC pedestal must be added (Drawing 1495, Sheet 2) to determine the height above ground.

$$W G_H H$$

where W is the total system weight and G_H is the resultant zero period acceleration seismic loading (vectorial sum of two orthogonal seismic loads) so that WG_H is the inertia load due to the resultant horizontal acceleration. The overturning moment is balanced by a vertical reaction force, acting at the outermost contact patch radial location $r = D_{BASE}/2$. The resistive moment is minimized when the vertical zero period acceleration G_V tends to reduce the apparent weight of the cask. At that instant, the moment that resists "incipient tipping" is:

$$W (1 - G_V) r$$

Performing a static moment balance and eliminating W results in the following inequality to ensure a "no-overturning condition:

$$G_H + \frac{r}{H} G_V \leq \frac{r}{H}$$

Using the values of r and H for the HI-STORM 100 (r = 66.25", H = 119.**02**~~8.98~~"), representative combinations of G_H and G_V that satisfy the limiting equality relation are computed and tabulated below:

Acceptable Net Horizontal G~~g~~-Level (**HI-STORM100**), G_H	Acceptable Vertical G~~g~~-Level, G_V
0.468~~7~~	0.16
0.445	0.20
0.417	0.25
0.358	**0.357**

We repeat the above computations using the weight and c.g. location of the HI-STORM 100S. Because of the lowered center of gravity positions, the maximum net horizontal "G" levels are slightly increased.

Performing the calculations for all of the MPCs gives the following results:

	H_{cg} (inches)
MPC-24 with storage overpack	**113.55**

MPC-68 with storage overpack	**113.69**
MPC-32 with storage overpack	**113.34**
MPC-24E with storage overpack	**113.53**

Using the values of r and H for the HI-STORM 100 (r = 66.25", H = 113.69"), representative combinations of G_H and G_V that satisfy the limiting equality relation are computed and tabulated below:

Acceptable Net Horizontal G-Level (HI-STORM 100S), G_H	**Acceptable Vertical G-Level, G_V**
0.489	**0.16**
0.466	**0.20**
0.437	**0.25**
0.368	**0.368**

Primary Stresses in the HI-STORM 100 Structure Under Net Lateral Load Over 180 degrees of the Periphery

Under a lateral loading, the storage overpack will experience axial primary membrane stress in the inner and outer shells as it resists bending as a "beam-like" structure. Under the same kind of lateral loading over one-half of the periphery of the cylinder, the shells will tend to ovalize under the loading and develop circumferential stress. Calculations for stresses in both the axial and circumferential direction are required to demonstrate satisfaction of the Level D structural integrity requirements and to provide confidence that the MPC will be readily removable after a seismic event, if necessary. An assessment of the stress state in the structure under the seismic induced load will be shown to bound the results for any other condition that induces a peripheral load around part of the HI-STORM 100 storage overpack perimeter. **The specific analyses are performed using the geometry and loading for the HI-STORM 100; the results obtained for stress levels and the safety assessment are also applicable to an assessment of the HI-STORM 100S.**

A simplified calculation to assess the flexural bending stress in the HI-STORM 100 structure under the limiting seismic event (at which tipping is incipient) is presented in the following:

From the acceptable acceleration table presented above, the maximum horizontal acceleration is bounded by 0.47g. The corresponding lateral seismic load, F, is given by

$$F = 0.47\ W$$

This load will be maximized if the upper bound HI-STORM 100 weight (W = 360,000 lbs. (Table

MPC is maintained after the seismic event.

Because of the low values for the calculated axial stress, the conclusions of the previous section are also valid for the HI-STORM 100S.

Potential for Concrete Cracking

It can be readily shown that the concrete shielding material contained within the HI-STORM 100 structure will not crack due to the flexuring action of HI-STORM 100 during a bounding seismic event that leads to a maximum axial stress in the storage overpack. For this purpose, the maximum axial strain in the steel shell is computed by dividing the tensile stress developed by the seismic G forces **(for the HI-STORM 100, for example)** by the Young's Modulus of steel.

$$\zeta = \frac{1{,}321}{28\,\mathrm{E}+06} = 47.\mathrm{E}\text{-}06$$

where the Young's Modulus of steel is taken from Table 3.3.2 at 350 degrees F.

The acceptable concrete strain in tension is estimated from information in ACI-318.1 for plain concrete. The ratio of allowable tensile stress to concrete Young' Modulus is computed as

$$\text{Allowable ConcreteStrain} = (5 \times (0.75) \times (f)^{1/2})/(57{,}000(f)^{1/2}) = 65.8\mathrm{E}\text{-}06$$

In the above expression, f is the concrete compressive strength.

Therefore, we conclude that considerable margins against tensile cracking of concrete under the bounding seismic event exist.

Sliding Analysis

An assessment of sliding of the HI-STORM 100 System on the ISFSI pad during a postulated limiting seismic event is performed using a one-dimensional "slider block on friction supported surface~~" dynamic~~" **dynamic** model. **The results for the shorter HI-STORM 100S are comparable.** The HI-STORM 100 is simulated as a rigid block of mass *m* placed on a surface which is subject to a sinusoidal acceleration of amplitude *a*. The coefficient of friction of the block is assumed to be reduced by a factor α to recognize the contribution of vertical acceleration in the most adverse manner (vertical acceleration acts to reduce the downward force on the friction interface).

$$m\ddot{x} = R + m\,a \sin \omega t$$

The equation of motion for such a "slider block" is given by:

of friction, μ, as high as 0.7 are obtained at steel/concrete interfaces.

To ensure against unreasonably low coefficients of friction, the reference pad design (Table 2.2.9) stipulates that the top surface of the concrete pad shall receive a "broom finish". The bottom surface of the HI-STORM 100 is manufactured from plate stock (i.e. non-machine finish). With these measures, a coefficient of friction value of 0.53 is considered to be a conservative numerical value for the purpose of ascertaining the potential for incipient sliding of the HI-STORM 100 System **at any site.**

The relationship between the vertical ZPA, G_V, (conservatively assumed to act opposite to the normal gravitational acceleration), and the resultant horizontal ZPA G_H to insure against incipient sliding is given from static equilibrium considerations as:

$$G_H + \mu G_V \le \mu$$

Using a conservative value of μ equal to 0.53, the above relationship provides governing ZPA limits for a HI-STORM 100 **(or 100S)** System arrayed in a freestanding configuration. The table below gives representative combinations that meet the above limit.

G_H (in g's)	G_V (in g's)
0.445	0.16
0.424	0.20
0.397	0.25
0.350	**0.34**

If the values for the DBE event at an ISFSI site satisfy the above inequality relationship for incipient sliding with coefficient of friction equal to 0.53, then the non-sliding criterion set forth in NUREG-1536 is assumed to be satisfied a'priori. However, if the ZPA values violate the inequality by a small amount, then it is permissible to satisfy the non-sliding criterion by implementing measures to roughen the HI-STORM 100/ISFSI pad interface to elevate the value of μ to be used in the inequality relation. To demonstrate that the value of μ for the ISFSI pad meets the required value implied by the above inequality, a series of Coulomb friction (under the QA program described in Chapter 13) shall be performed as follows:

Pour a concrete block with horizontal dimensions no less than 2' x 2' and a block thickness no less than 0.5'. Finish the top surface of the block in the same manner as the ISFSI pad surface will be prepared.

Prepare a 6" x 6" x 2" SA516 Grade 70 plate specimen (approximate weight = 20.25 lb.) to simulate the bottom plate of the HI-STORM 100 overpack. Using a calibrated friction gage attached to the steel plate, perform a minimum of twenty (20) pull tests to measure the static coefficient of friction at the interface between the concrete block and the steel plate. The pull tests shall be performed on at least ten (10) different locations on the block using varying orientations for the pull direction.

The coefficient of friction to be used in the above sliding inequality relationship will be set as the average of the results from the twenty tests.

The satisfaction of the "no-sliding" criterion set down in the foregoing shall be carried out along with the "no-overturning" qualification (using the static moment balance method in the manner described at the beginning of this subsection) and documented as part of the ISFSI facility's CFR72.212 evaluation.

3.4.7.2 Explosion (Load Case 05 in Table 3.1.5)

In the preceding subsection, it has been demonstrated that incipient tipping of the storage overpack will not occur under a side load equal to 0.47 times the weight of the cask. For a fully loaded cask, this side load is equal to
F = 169,200 lb.

If it is assumed that this side load is uniformly distributed over the height of the cask and that the cask centroid is approximately at the half-height of the overpack, then an equivalent pressure, P, acting over 180 degrees of storage overpack periphery, can be defined as follows:

$P \times (DH) = F$

Where D = overpack outside diameter, and H = height of storage overpack

For D = 132.5" and H = 235", the equivalent pressure is

$P = 169{,}200 \text{ lb}/(132.5" \times 235") = 5.43 \text{ psi}$

Therefore, establishing 5 psi as the design basis steady state pressure differential (Table 2.2.1) across the overpack diameter ensures that incipient tipping will not occur.

Since the actual explosion produces a transient wave, the use of a static incipient tip calculation is very conservative. To evaluate the margin against tip-over from a short-time pressure pulse, a Working Model analysis of the two-dimensional dynamic motion of the HI-STORM subject to a given initial angular velocity is carried out. Figures 3.4.25 and 3.4.26 provide details of the model and the solution for a HI-STORM 100 System (simulated as a rigid body) having a weight and inertia property appropriate to a minimum weight cask. The results show that an initial angular velocity of 0.626 radians/second does not lead to a tipover of the storage overpack. **The results bound ~~those obtained~~those obtained for the HI-STORM 100S since the overall cask height is reduced.**

The initial angular velocity can be related to a square wave pressure pulse of magnitude P and time duration T by the following formula:

3.4.8 Tornado Wind and Missile Impact (Load Case B in Table 3.1.1 and Load Case 04 in Table 3.1.5)

During a tornado event, the HI-STORM 100 System is assumed to be subjected to a constant wind force. It is also subject to impacts by postulated missiles. The maximum wind speed is specified in Table 2.2.4 and the three missiles, designated as large, intermediate, and small, are described in Table 2.2.5.

The post impact response of the HI-STORM 100 System is required to assess stability. Both the HI-STORM 100 storage overpack, and the HI-TRAC transfer cask are assessed for missile penetration.

Appendix 3.C contains results for the post-impact response of the HI-STORM 100 storage overpack where it is demonstrated there that the combination of tornado missile plus either steady tornado wind or instantaneous tornado pressure drop causes a rotation of the HI-STORM 100 to a maximum angle of inclination less than 3 degrees from vertical. This is much less than the angle required to overturn the cask. The appropriate value for the drag coefficient used in the computation of the lateral force on the storage overpack from tornado wind is justified in Appendix 3.C. **The results for the HI-STORM 100 are bounding since the HI-STORM 100S is shorter and its center of gravity is closer to ground.**

Appendix 3.C computes the maximum force (not including the initial pulse due to missile impact) acting on the projected area of the storage overpack to be:

F = 91,920 lbs.

The instantaneous impulsive force due to the missile strike is not computed here; its effect is felt as an initial angular velocity imparted to the storage overpack at time equal to zero. The net resultant force due to the simultaneous pressure drop is not an all-around distributed loading that has a net resultant, but rather is more likely to be distributed only over 180 degrees (or less) of the storage overpack periphery. The circumferential stress and deformation field will be of the same order of magnitude as that induced by a seismic loading. Since the magnitude of the force due to F is less than the magnitude of the net seismically induced force considered in Subsection 3.4.7, the storage overpack global stress analysis performed in Subsection 3.4.7 remains governing. In the next subsection, results are provided for the circumferential stress and ovalization of the portion of the storage overpack due to the bounding estimate for the impact force of the intermediate missile.

3.4.8.1 HI-STORM 100 Storage Overpack

Appendix 3.C considers the post impact behavior of the HI-STORM 100 System after impact from tornado missiles. During an impact, the system consisting of missile plus storage overpack and MPC satisfies conservation of linear and angular momentum. The large missile impact is assumed to be inelastic. This assumption conservatively transfers all of the momentum from the missile to the system. The intermediate missile and the small missile are assumed to be unyielding and hence the entire initial kinetic energy is assumed to be absorbed by motion of the cask and local yielding and denting of the storage overpack surface. It is shown that cask stability is maintained under the postulated wind and large missile loads. **The conclusion is also valid for the HI-STORM 100S since the lowered total height and the center of gravity location inherently provides additional stability margin.**

The penetration potential of the missile strikes (Load Case 04 in Table 3.1.5) is examined in Appendix 3.G. It is shown in Appendix 3.G that there will be no penetration through the concrete surrounding the inner shell of the storage overpack or penetration of the top closure plate. Therefore, there will be no impairment to the confinement boundary due to missile strikes during a tornado. Since the inner shell is not compromised by the missile strike, there will be no permanent deformation of the inner shell. Therefore, ready retrievability is assured after the missile strike. The following results summarize the work in Appendix 3.G.

a. The small missile will dent any surface it impacts, but no significant puncture force is generated. The 1" missile can enter the air ducts, but geometry prevents a direct impact with the MPC.

b. The following table summarizes the denting and penetration analysis performed for the intermediate missile in Appendix 3.G. Denting is used to connote a local deformation mode encompassing material beyond the impacting missile envelope, while penetration is used to connote a plug type failure mechanism involving only the target material immediately under the impacting missile.

Location	Denting (in.)	Thru-Thickness Penetration
Storage overpack outer Shell	5.67	Yes (>0.75 in.)
Radial Concrete	7.65	No (<27.25 in.)
Storage overpack Top Lid	0.4	No (<4 in.)

The primary stresses that arise due to an intermediate missile strike on the side of the storage overpack and in the center of the storage overpack top lid are also determined in Appendix 3.G. **The analysis of the storage lid for the HI-STORM 100 bounds that for the HI-STORM 100S; because of the additional energy absorbing material (concrete) in the direct path of a potential missile strike on the top lid of the HI-STORM 100S lid, the energy absorbing requirements of the circular plate structure are much reduced.** It is demonstrated there that Level D stress limits are not exceeded in either the overpack outer shell or the top lid. The safety factor in the storage overpack, considered as a cantilever beam under tip load, is computed, as is the safety factor in the top lids, considered as two centrally loaded plates. The applied load, in each case, is the missile impact load. A summary of the results for axial stress in the storage overpack, as obtained from

Appendix 3.G, is given in the table below:

HI-STORM 100 MISSILE IMPACT - Global Axial Stress Results			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
Outer Shell – Side Strike	15.01	39.75	2.648
Top Lid - (End Strike)	44.14	59.65	1.351

~~**The results summarized above are based on the HI-STORM 100 configuration. These results will bound the corresponding results for the HI-STORM 100S since the HI-STORM 100S top lid contains additional energy absorbing material that prevents a direct strike on the lid metal surface.**~~

To demonstrate ready retrievability of the MPC, we must show that the storage overpack suffers no permanent deformation of the inner shell that would prevent removal of the MPC after the missile strike. To demonstrate ready retrievability **(for both HI-STORM 100 and for HI-STORM 100S)**, we undertake a conservative evaluation of the circumferential stress and deformation state due to the missile strike on the outer shell. Appendix 3.G calculates a conservative estimate for the 8" diameter missile impact force, "Pi", on the side of the storage overpack as:

Pi = 881,900 lb.

This force is conservative in that the target overpack is assumed rigid; any elasticity serves to reduce the peak magnitude of the force and increase the duration of the impact. The use of the upper bound value is the primary reason for the high axial stresses resulting from this force. To demonstrate continued ability to retrieve the MPC subsequent to the strike, circumferential stress and deformation that occurs locally in the ring section near the location of the missile strike are investigated.

Results in Appendix 3.B are presented under different ring loadings for a composite ring of unit width consisting of the inner and outer shells of the storage overpack. The solutions in Appendix 3.B assume that the net loading is 56,184 lb. applied on the 1" wide ring (equivalent to a 45G deceleration applied uniformly along the height on a storage overpack weight of 270,000 lb.). The solution for case1 in Appendix 3.B can be applied directly to evaluate the circumferential stress and deformation caused by a tornado missile strike on the outer shell. Using the results in Appendix 3.B, an attenuation factor to adjust the results from case 1 in Appendix 3.B is developed that reflects the difference in load magnitude and the width of the ring that is effective in resisting the missile strike force. The strike force Pi is resisted by a combination of inertia force and shear resistance from the portion of the storage overpack above and below the location of the strike. The ring theory solution to determine the circumferential stress and deformation conservatively assumes that inertia alone, acting on an effective length of ring, balances the applied point load Pi. The effective width of ring it is sufficient to take a free-body of the transfer lid and write the dynamic force equilibrium equation for the lid. Figure 3.4.29 shows the free body with appropriate notation. The equation of equilibrium is:

$$M_{TL}a_{TL} = F_I - G_I$$

where

M_{TL} = the mass of the transfer lid
a_{TL} = the time varying acceleration of the centroid of the transfer lid
F_I = the time varying contact force at the interface with the target
G_I = the time varying interface force at the bottom flange/transfer lid interface

Solving for the interface force give the result

$$G_I = F_I - M_{TL}a_{TL}$$

Using the appropriate transfer lid mass and acceleration, together with the target interface force at the limiting time instant, provides values for the interface force. The table below provides the results of this calculation for both HI-TRAC transfer casks. ~~The allowable values given in the table are the bounding values used as input loads in Appendices 3.AD and 3.AJ (0.7 x HI-TRAC loaded weight x 45g).~~

Item	Calculated from Equilibrium (kips)
125 Ton HI-TRAC – Trunnions Horizontal	1,183.
125 Ton HI-TRAC – Trunnions Vertical	1,272.
100 Ton HI-TRAC – Trunnions Horizontal	1,129.
100 Ton HI-TRAC – Trunnions Vertical	1,070.

~~As noted earlier in this chapter, the interface forces given above provide additional safety margin that has been conservatively neglected in the analyses and results presented in Appendices 3.AD and 3.AJ and summarized earlier in this chapter.~~

3.4.10 HI-STORM 100 Non-Mechanistic Tip-over and Vertical Drop Event (Load Cases 02.a and 02.c in Table 3.1.5)

Pursuant to the provision in NUREG-1536, a non-mechanistic tip-over of a loaded HI-STORM 100 System on to the ISFSI pad is considered in this report. Analyses are also performed to determine the maximum deceleration sustained by a vertical free fall of a loaded HI-STORM 100 System from an 11" height onto the ISFSI pad. The objective of the analyses is to demonstrate that the plastic deformation in the fuel basket is sufficiently limited to permit the stored SNF to be retrieved by normal means, does not have a adverse effect on criticality safety, and that there is no significant loss of radiation shielding in the system.

Ready retrievability of the fuel is presumed to be ensured: if global stress levels in the MPC structure meet Level D stress limits during the postulated drop events; if any plastic deformations are localized; and if no significant permanent ovalization of the overpack into the MPC envelope space, remains after the event.

Subsequent to the accident events, the storage overpack must be shown to contain the shielding so that unacceptable radiation levels do not result from the accident.

Appendix 3.A provides a description of the dynamic finite element analyses undertaken to establish the decelerations resulting from the postulated event. A non-mechanistic tip-over is considered together with an end drop of a loaded HI-STORM 100 System. A dynamic finite element analysis of each event is performed using a commercial finite element code well suited for such dynamic analyses with interface impact and non-linear material behavior. This code and methodology have been fully benchmarked against Lawrence Livermore Laboratories test data and correlation [3.4.12].

It is shown in Appendix 3.A that the peak deceleration is less than 45g's at the top of the fuel basket for tip-over. Table 3.A.4 shows that the maximum deceleration level at the top of the cask is 48.48 g's, while the corresponding deceleration level at the top of the fuel basket is 43.19 g's. For the case of a vertical drop of 11", the maximum longitudinal deceleration is 44.13 g's.

Based on the above results, it is concluded that the design basis rigid body deceleration limit of 45g's (Table 3.1.2) at the top of the stored fuel is not exceeded during the drop and tip-over.

The tipover analysis performed in Appendix 3.A is based on the HI-STORM 100 geometry and a bounding weight. The fact that the HI-STORM 100S is shorter and has a lower center of gravity suggests~~would indicate~~ that the impact kinetic energy is reduced so that the target would absorb the energy with~~while producing~~ a lower maximum deceleration. However, since the actual weight of a HI-STORM 100S is less than that of a HI-STORM 100, the predicted maximum rigid body deceleration would tend to increase slightly. Since there are two competing mechanisms at work, it is not a foregone conclusion that the maximum rigid body deceleration level is, in fact, reduced if a HI-STORM 100S suffers a non-mechanistic tipover

onto the identical target as the HI-STORM 100. In what follows, we present a summary of the analysis undertaken to demonstrate conclusively that -the result~~s~~ for maximum deceleration level in the HI-STORM 100 tipover event does bound the corresponding value for the HI-STORM 100S, and, therefore, we need only perform a detailed dynamic finite element analysis for the HI-STORM 100.

Appendix 3.A presents a result for~~development of~~ the angular velocity of the cylindrical body representing a HI-STORM 100 just prior to impact with the defined target. The result is expressed in Subsection 3.A.6 in terms of the cask geometry~~-and~~, and the ratio of the mass divided by~~, and~~ the mass moment- of inertia about the corner point that serves as the rotation origin.~~,~~ Since the mass moment of inertia is also linearly related to the mass, the angular velocity at the instant just prior to target contact is independent of the cask mass. Subsequent to target impact, we investigate post-impact response by considering the cask as a cylinder rotating into a target that provides a resistance force that varies linearly with distance from the rotation point. We measure "time" as starting at the instant of impact, and develop a one-degree-of freedom equation for the post-impact response (for the rotation angle into the target) as:

$$\ddot{\theta} + \omega^2\theta = 0$$

where

$$\omega^2 = \frac{kL^3}{3I_A}$$

The initial conditions at time=0 are: the initial angle is zero and the initial angular velocity is equal to the rigid body angular velocity acquired by the tipover from the center-of-gravity over corner position. In the above relation, L is the length of the overpack, I is the mass moment of inertia defined in Appendix 3.A, and k is a "spring constant"associated with the target resistance. If we solve for the maximum angular acceleration subsequent to time =0, we obtain the result in terms of the initial angular velocity as:

$$\ddot{\theta}_{\max} = \omega\dot{\theta}_0$$

If we form the maximum linear acceleration at the top of the ~~four inch~~four-inch thick lid of the overpack, we can finally relate the decelerations of the HI-STORM 100 and the HI-STORM 100S solely in terms of their geometry properties and their mass ratio. The value of "k", the target spring rate is the same for both overpacks so it does not appear in the relationship between the two decelerations. After substituting the appropriate geometry and calculated masses, we determine that the ratio of maximum rigid body decelerations at the top surface of the four-inch thick top lid plates is:

$A_{\text{HI-STORM 100S}}/A_{\text{HI-STORM 100}} = 0.946$

Therefore, as postulated, there is no need to perform a separate DYNA3D analysis for the HI-STORM 100S hypothetical tipover.

Appendix 3.B contains a simple elastic strength of materials calculation to demonstrate that the cylindrical storage overpack will not permanently deform to the extent that the MPC cannot be removed by normal means after a tip-over event. It is demonstrated in that appendix that the maximum diametrical closure of the cylindrical cavity is less than the initial clearance between the overpack MPC support channels and the MPC canister. Primary circumferential membrane stresses in the MPC shell remain in the elastic range during a tip-over (see Table 3.4.6 summary safety factors); therefore, no permanent global ovalization of the MPC shell occurs as a result of the drop.

To demonstrate that the shielding material will continue to perform its function after a tip-over accident, the stress and strain levels in the metal components of the storage overpack are examined at the end of the tip-over event. The results obtained in Appendix 3.A for impact decelerations conservatively assumed a rigid storage overpack model to concentrate nearly all energy loss in the target. However, to assess the state of stress and strain in the storage overpack after an accident causing a tip-over, the tip-over analysis was also performed using a non-rigid storage overpack model using overpack material properties listed in Appendix 3.A. Figure 3.4.13 shows the calculated von Mises stress in the top lid and outer shell at 0.08 seconds after the initiation of impact. Figure 3.4.14 shows the residual plastic strains in the same components. Figures 3.4.15 and 3.4.16 provide similar results for the inner shell, the radial plates, and the support channels. The results show that while some plastic straining occurs, accompanied by stress levels above the yield stress of the material, there is no tearing in the metal structure which confines the radiation shielding (concrete). Therefore, there is no gross failure of the metal shells enclosing the concrete. The shielding concrete will remain inside the confines of the storage overpack and maintain its performance after the tipover event.

3.4.11 Storage Overpack and HI-TRAC Transfer Cask Service Life

The term of the 10CFR72, Subpart L C of C, granted by the NRC is 20 years; therefore, the License Life (please see glossary) of all components is 20 years. Nonetheless, the HI-STORM 100 **and 100S** Storage overpacks and the HI-TRAC transfer cask are engineered for 40 years of design life, while satisfying the conservative design requirements defined in Chapter 2, including the regulatory requirements of 10CFR72. In addition, the storage overpack and HI-TRAC are designed, fabricated, and inspected under the comprehensive Quality Assurance Program discussed in Chapter 13 and in accordance with the applicable requirements of the ACI and ASME Codes. This assures high design margins, high quality fabrication, and verification of compliance through rigorous inspection and testing, as describe in Chapter 9 and the design drawings in Section 1.5. Technical Specifications defined in Chapter 12 assure that the integrity of the cask and the contained MPC are maintained throughout the components' design life. The design life of a component, as defined in the Glossary, is the minimum duration for which the equipment or system is engineered to perform its intended function if operated and maintained in accordance with the TSAR. The design life is essentially the lower bound value of the service life, which is the expected functioning life of the component or system. Therefore, component longevity should be: licensed life < design life < service life. (The licensed life, enunciated by the USNRC, is the most pessimistic estimate of a component's life span.) For purposes of further discussion, we principally focus on the service life of the HI-STORM 100 System components **that**~~which~~, as stated earlier, is the reasonable expectation of ~~an equipment's~~**equipment's** functioning life span.

The service life of the storage overpack and HI-TRAC transfer cask is further discussed in the following sections.

3.4.11.1 Storage Overpack

The principal design considerations that bear on the adequacy of the storage overpack for the service life are addressed as follows:

Exposure to Environmental Effects

In the following text, all references to HI-STORM 100 also apply to HI-STORM 100S. All exposed surfaces of HI-STORM 100 are made from ferritic steels that are readily painted. Concrete, which serves strictly as a shielding material, is completely encased in steel. Therefore, the potential of environmental vagaries such as spalling of concrete, are ruled out for HI-STORM 100. Under normal storage conditions, the bulk temperature of the HI-STORM 100 storage overpack will, because of its large thermal inertia, change very gradually with time. Therefore, material degradation from rapid thermal ramping conditions is not credible for the HI-STORM 100 storage overpack. Similarly, corrosion of structural steel embedded in the concrete structures due to salinity in the environment at coastal sites is not a concern for HI-STORM 100 because HI-STORM 100 does not rely on rebars (indeed, it contains no rebars). As discussed in Appendix 1.D, the aggregates, cement and water used in the storage cask concrete are carefully controlled to provide high durability and resistance to temperature effects. The configuration of the storage overpack assures resistance to freeze-thaw degradation. In addition, the storage overpack is specifically designed for a full range of enveloping design basis natural phenomena **that**~~which~~ could occur over the 40-year design life of the storage overpack as defined in Subsection 2.2.3 and evaluated in Chapter 11.

Material Degradation

The relatively low neutron flux to which the storage overpack is subjected cannot produce measurable degradation of the cask's material properties and impair its intended safety function. Exposed carbon steel components are coated to prevent corrosion. The controlled environment of the ISFSI storage pad mitigates damage due to direct exposure to corrosive chemicals that may be present in other industrial applications.

Maintenance and Inspection Provisions

the material used in the criticality safety analysis is conservatively based on the minimum specified boron areal density (rather than the nominal), which is further reduced by 25% for analysis purposes, as described in Section 6.1. Analysis discussed in Section 6.2 demonstrates that the boron depletion in the Boral is negligible over a 50-year duration. Thus, sufficient levels of boron are present in the fuel basket neutron absorbing material to maintain criticality safety functions over the 40-year design life of the MPC.

The above findings are consistent with those of the NRC's Waste Confidence Decision Review, which concluded that dry storage systems designed, fabricated, inspected, and operated in the manner of the requirements set down in this document are adequate for a 100-year service life, while satisfying the requirements of 10CFR72.

3.4.13 Design and Service Life

The discussion in the preceding sections seeks to provide the logical underpinnings for setting the design life of the storage overpacks, the HI-TRAC transfer cask, and the MPCs as forty years. Design life, as stated earlier, is a lower bound value for the expected performance life of a component (service life). If operated and maintained in accordance with this Topical Safety Analysis Report, Holtec International expects the service life of its HI-STORM 100 **and HI-STORM 100S** components to substantially exceed their design life values.

Table 3.4.1

FINITE ELEMENTS IN **REPRESENTATIVE**~~THE~~ MPC STRUCTURAL MODELS

MPC Type Element Type	Model Type Basic	 0 Degree Drop	 45 Degree Drop
MPC-24	1542	1773	1772
BEAM3	1498	1498	1498
PLANE82	8	8	8
CONTAC12	36	34	34
CONTAC26	0	230	230
COMBIN14	0	3	2
MPC-68	1842	2066	2063
BEAM3	1782	1782	1782
PLANE82	16	16	16
CONTAC12	44	43	40
CONTAC26	0	223	222
COMBIN14	0	2	3

Table 3.4.3

FUEL BASKET RESULTS - MINIMUM SAFETY FACTORS

Load Case I.D.	**Loading†**	**Safety Factor**	**Location in TSAR Where the Analysis is Performed**
F1	T, T'	No interference	3.I, 3.U, 3.W,3.AF
F2	D + H	2.79	3.AA of Docket 72-1008
F3			
F3.a	D + H' (end drop)	3.59	F3.a 3.4.4.3.1.3
F3.b	D + H' (side drop 0 deg.)	1.43	Appendix 3.T, Table 3.T.2, **Table 3.4.6**
F3.c	D + H' (side drop 45 deg.)	1.28	**F3.c Appendix 3.T, Tables 3.T.8, Table 3.4.6** ~~F3.c Appendix 3.T, Tables 3.T.8~~

---

† The symbols used for the loadings are defined in Table 2.2.13.

Table 3.4.4 (continued)
MPC RESULTS - MINIMUM SAFETY FACTOR

Load Case I.D.	**Load Combination**[†,††]	**Safety Factor**	**Location in TSAR Where the Analysis is Performed**	
E3				
E3.a	$(P_i,P_o) + D + H'$, end drop	2.8 1.28 1.21 N/A	E.a	Lid 3.E.8.2.1-2 of Docket 72-1008 Baseplate 3.I.8.3 of Docket 72-1008 Shell 3.H (Case 5) (buckling) of Docket 72-1008 Supports
E3.b	$(P_i,P_o) + D + H'$, side drop 0 deg.	2.8 1.28 1.1 1.18 1.**82**~~91~~	E.b	Lid end drop bounds Baseplate end drop bounds Shell Appendix 3.T, Table 3.T.28, **Table 3.4.6** Supports App.~~endix~~ 3.T, Table 3.T.30**, 3.4.6, Table 3.4.6** Basket Supports: Appendix 3.Y
E3.c	$(P_i,P_o) + D + H'$, side drop 45 deg.	2.8 1.28 1.46 1.56	E.c.	Lid end drop bounds Baseplate end drop bounds Shell Appendix 3.T, Table 3.T.22 Supports Appendix 3.T, Table 3.T.36**, Table 3.4.6**

[†] The symbols used for the loadings are defined in Table 2.2.13

[††] Note that in analyses, bounding pressures are applied, i.e., in buckling calculations P_o is used, and in stress evaluations either P_o or P_i is appropriate

Table 3.4.5
HI-STORM 100 STORAGE OVERPACK AND HI-TRAC RESULTS - MINIMUM SAFETY FACTORS

Load Case I.D.	**Loading**†	**Safety Factor**	**Location in TSAR**
01	D + H + T + (P_o, P_i)	 1.32 N/A 1.67(125 T);1.42(100 T) **2.60**~~12.60~~4 (ASME Code limit) **2.61**~~1.93~~ (ASME Code limit) N/A 5.31; 1.11(optional bolts) Tables in 3.4.3	Overpack Shell (inlet vent)/Base———— ——— 3.D Top Lid N/A HI-TRAC Shell~~L~~ 3.AB Pool ~~Transfer~~ Lid 3.AB~~D~~ Top Lid 3.AB~~N/A~~ Pocket Trunnion 3.AA; 3.AI Lifting Calculations 3.4.3
02 02.a 02.b	 D + H' + (P_o,P_i) (end drop/tip-over) D + H' + (P_o,P_i) (side drop)	 1.36(weld) 1.08(bolt) 2.09 1.392~~193~~ 1.651~~423~~	 Overpack Shell/Base 3.M;3.4.4.3.2.3 Top Lid 3.K/3.L;3.4.4.3.2.2 HI-TRAC Shell 3.Z;3.4.9 Transfer Lid 3.AD;3.4.4.3.3.3 Top Lid 3.AH;3.4.4.3.3.5
03	D (water jacket)	1.168	3.AG; 3.4.4.3.3.4
04	M (small and medium penetrant missiles)	2.65 (Side Strike); 1.35(End strike) 1.23 (End Strike)	

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† The symbols used for the loadings are defined in Table 2.2.13.

TABLE 3.4.6 (continued)
MINIMUM SAFETY FACTORS FOR MPC COMPONENTS DURING TIP-OVER 45g DECELERATIONS

Component - Stress Result	MPC-32	
	0 Degrees	45 Degrees
Fuel Basket - Primary Membrane (P_m)	3.51 (715) [3.T.13]	4.96 (366) [3.T.19]
Fuel Basket - Local Membrane Plus Primary Bending (P_L+P_b)	1.51 (390) [3.T.14]	1.28 (19) [3.T.20]
Enclosure Vessel - Primary Membrane (P_m)	4.11 (1091) [3.T.15]	5.59 (1222) [3.T.21]
Enclosure Vessel - Local Membrane Plus Primary Bending (P_L+P_b)	1.11 (1031) [3.T.16]	1.46 (1288) [3.T.22]
Basket Supports - Primary Membrane (P_m)	3.44 (905) [3.T.17]	4.85 (905) [3.T.23]
Basket Supports - Local Membrane Plus Primary Bending (P_L+P_b)	1.30 (901) [3.T.18]	1.71 (908) [3.T.24]

Notes:

1. **Corresponding ANSYS element number shown in parentheses.**
2. **Corresponding appendix table shown in brackets.**

TABLE 3.4.6 (continued)
MINIMUM SAFETY FACTORS FOR MPC24E COMPONENTS DURING TIP-OVER 45g DECELERATIONS

Component – Stress Result	0 Degrees	45 Degrees
Fuel Basket – Primary Membrane (P_m)	-10,050 (3.67)	-7,021 (5.26)
Fuel Basket – Primary Membrane plus Primary Bending ($P_L + P_b$)	31,912 (1.73)	30,436 (1.82)
Enclosure Vessel – Primary Membrane (P_m)	6,586 (6.59)	6,534 (6.65)
Enclosure Vessel – Primary Membrane plus Primary Bending ($P_L + P_b$)	23,100 (2.82)	17,124 (3.80)

Notes: 1. All stresses are reported in psi units and are based on closed gaps (primary stresses only).
2. The numbers shown in parentheses are the corresponding safety factors.

Table 3.4.9

SAFETY FACTORS FROM SUPPLEMENTARY CALCULATIONS

Item	Loading	Safety Factor	TSAR Location Where Details are Provided
HI-TRAC Top Lid Weld Shear	Tipover	3.29	3.K
HI-STORM Lid Bottom Plate	End Drop	2.15	3.M; 3.X
HI-STORM Lid Bottom Plate Welds	End Drop	1.36	3.M
Pedestal Shell Compression	End Drop	1.23	3.M
HI-STORM Inlet Vent Plate Bending Stress	End Drop	1.69	3.M
HI-STORM Lid Top Plate Bending	End Drop –100 **100S**	5.29 **1.658**	3.M
HI-TRAC Pocket Trunnion Weld	HI-TRAC Rotation	4.37	3.AA
HI-TRAC 100 Optional Bolts - Tension	HI-TRAC Rotation	1.11	3.AI
HI-STORM 100 Shell	Seismic Event	18.6	3.4.7
HI-TRAC Transfer Lid Door Lock Bolts	Side Drop	2.387~~18~~	3.AD
HI-TRAC Transfer Lid Separation	Side Drop	1.329~~193~~	3.AD
HI-STORM 100 Top Lid	Missile Impact	1.35	3.G
HI-STORM 100 Shell	Missile Impact	2.65	3.G
HI-TRAC Water Jacket –Enclosure Shell Bending	Pressure	1.17	3.AG
HI-TRAC Water Jacket – Enclosure Shell Bending	Pressure plus Handling	1.14	Subsection 3.4.4.3.3.1
HI-TRAC Water Jacket – Bottom Flange Bending	Pressure	1.434	3.AG
HI-TRAC Water Jacket - Weld	Pressure	1.42	3.AG
Fuel Basket Support Plate Bending	Side Drop	1.91	3.Y
Fuel Basket Support Welds	Side Drop	2.09	3.Y
MPC Cover Plates in MPC Lid	Accident Condition Internal Pressure	1.39	3.Y
MPC Cover Plate Weld	Accident Condition Internal Pressure	6.04	3.Y
HI-STORM Storage Overpack	External Pressure	2.88	3.AK
HI-STORM Storage Overpack Circumferential Stress	Missile Strike	2.49	3.4.8.1; 3.B
HI-TRAC Transfer Cask Circumferential Stress	Missile Strike	2.61	3.4.8.2; 3.AM
HI-TRAC Transfer Cask Axial Membrane Stress	Side Drop	2.09	3.Z; 3.4.9

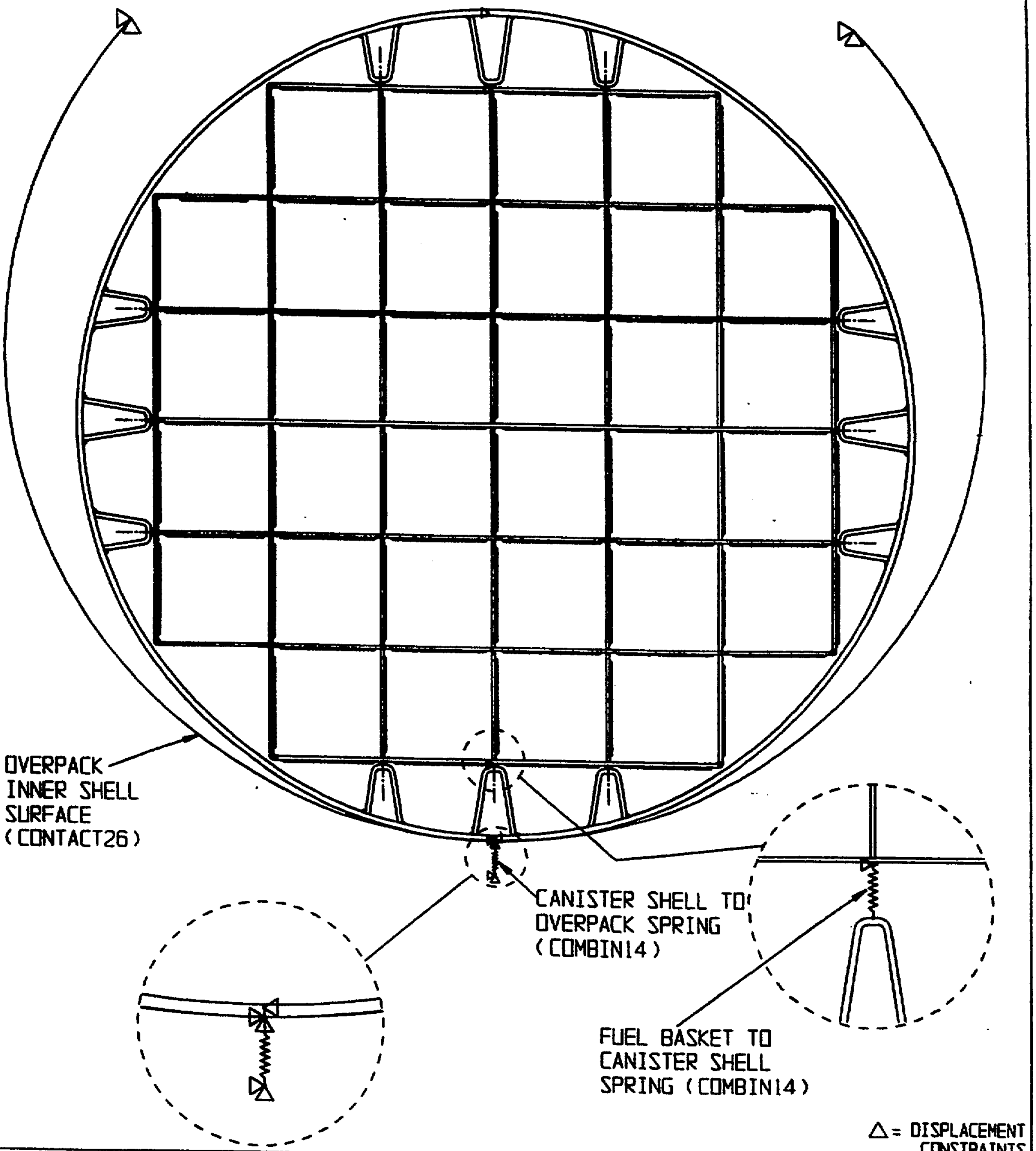


FIGURE 3.4.2; FINITE ELEMENT MODEL OF MPC-32

(0 DEGREE DROP MODEL)

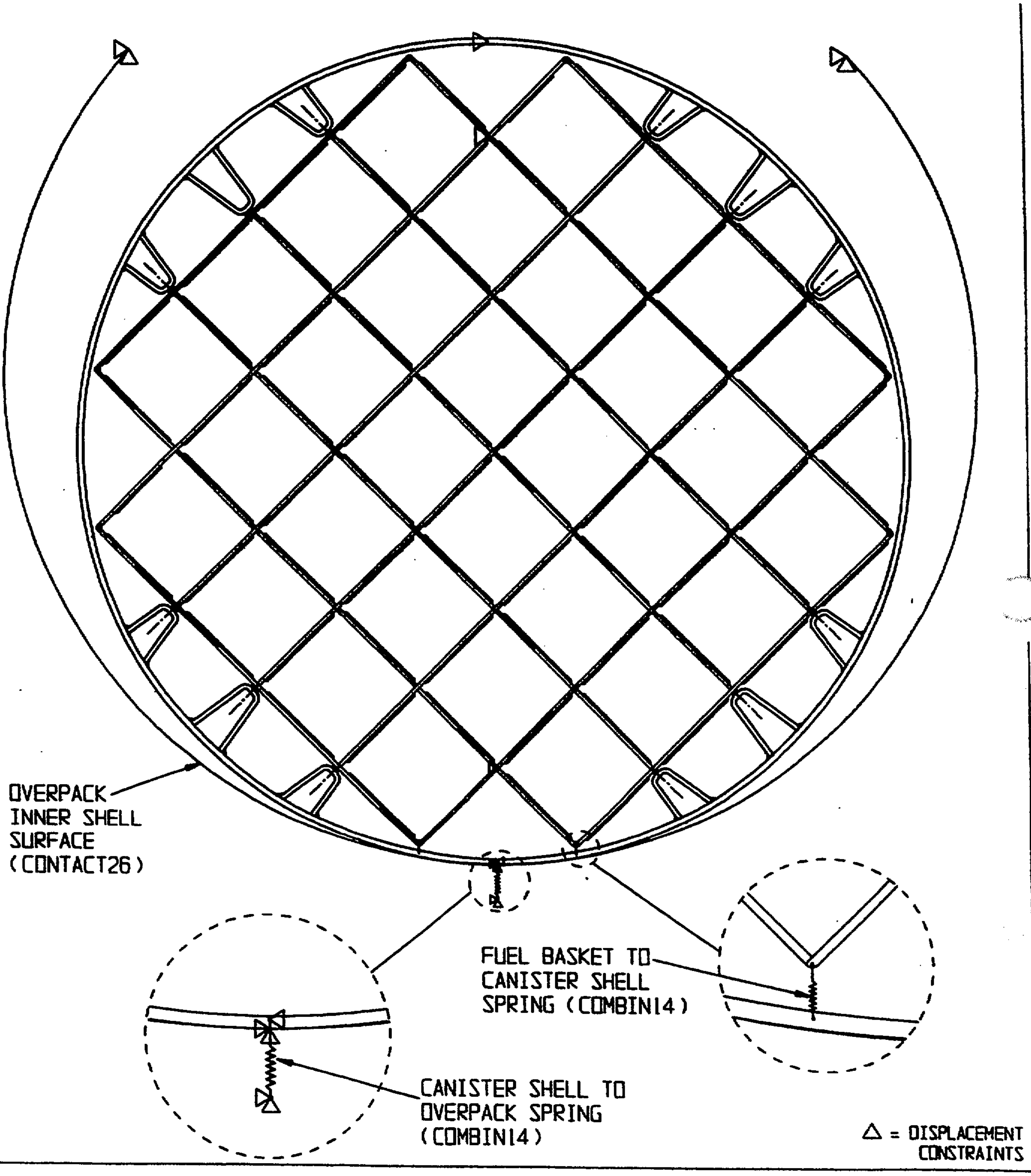


FIGURE 3.4.5; FINITE ELEMENT MODEL OF MPC-32

(45 DEGREE DROP MODEL)

FIGURE WITHHELD AS SENSITIVE
UNCLASSIFIED INFORMATION

tip-over scenario for the HI-STORM 100. Benchmarking of DYNA3D for these storage analyses is discussed and documented in Appendix 3.A.

3.6.3 Appendices Included in Chapter 3

3.A	HI-STORM Deceleration Under Postulated Vertical Drop Event and Tipover
3.B	HI-STORM 100 Overpack Deformation in Non-Mechanistic Tipover Event
3.C	Response of Cask to Tornado Wind Load and Large Missile Impact
3.D	Vertical Handling of Overpack with Heaviest MPC
3.E	Lifting Trunnion Stress Analysis for HI-TRAC
3.F	Lead Slump Analysis (HI-TRAC Side Drop)
3.G	Missile Penetration Analysis for HI-STORM 100
3.H	Missile Penetration Analysis for HI-TRAC
3.I	HI-TRAC - Free Thermal Expansions
3.J	Deleted
3.K	HI-STORM Tipover – Lid Analysis
3.L	HI-STORM Lid Top Plate Bolting
3.M	Vertical Drop of Overpack
3.N	Detailed Finite Element Listings for MPC-24 Fuel Basket
3.O	Detailed Finite Element Listings for MPC-24 Enclosure Vessel
3.P	**Detailed Finite Element Listings for MPC-32 Fuel Basket** ~~Deleted~~
3.Q	~~Deleted~~ **Detailed Finite Element Listings for MPC-32 Enclosure Vessel**
3.R	Detailed Finite Element Listings for MPC-68 Fuel Basket
3.S	Detailed Finite Element Listings for MPC-68 Enclosure Vessel
3.T	ANSYS Finite Element Results for the MPCs
3.U	HI-STORM 100 Component Thermal Expansions - MPC-24~~ and 24E~~
3.V	~~Deleted~~**HI-STORM 100 Component Thermal Expansions - MPC-32**
3.W	HI-STORM 100 Component Thermal Expansions - MPC-68
3.X	Calculation of Dynamic Load Factors
3.Y	Miscellaneous Calculations
3.Z	HI-TRAC Horizontal Drop Analysis
3.AA	HI-TRAC 125 - Rotation Trunnion Weld Analysis
3.AB	HI-TRAC Pool Lid Stress and Closure Analysis
3.AC	Lifting Calculations
3.AD	125-Ton HI-TRAC Transfer Lid Stress Analysis
3.AE	Global Analysis of HI-TRAC Lift
3.AF	MPC Transfer from HI-TRAC to HI-STORM 100 Under Cold Conditions of Storage
3.AG	Stress Analysis of the HI-TRAC Water Jacket
3.AH	HI-TRAC Top Lid Separation Analyses
3.AI	HI-TRAC 100 - Rotation Trunnion Weld Analysis

3.AJ 100-Ton HI-TRAC Transfer Lid Stress Analysis
3.AK Code Case N-284 Stability Calculations
3.AL HI-TRAC Lumped Parameters for Side Drop Analysis
3.AM HI-TRAC 100 Transfer Cask Circumferential Deformation and Stress
3.AN DYNA3D Analyses of HI-TRAC Side Drops and Impact by a Large Tornado Missile
3.AO HI-STORM Tipover – 100S Lid Analysis
3.AP HI-STORM 100S Lid Top Plate Bolting
3.AQ HI-STORM 100 Component Thermal Expansions; MPC-24E
3.AR Analysis of Transnuclear Damaged Fuel Canister and Thoria Rod Canister
3.AS Analysis of Generic PWR and BWR Damaged Fuel Canister

3.6.4 Calculation Package

In addition to the calculations presented in Chapter 3 and the Appendices,~~;~~ a supporting calculation package has been prepared to document other information pertinent to the analyses. This calculation package is a Holtec Report.

HI-981928, Structural Calculation Package for HI-STORM 100

The calculation package contains additional details on component weights, supporting calculations for some results summarized in the chapter, and miscellaneous supporting data that supplements the results summarized in the TSAR Chapter 3. **All of the finite element tabular output for the MPC-24E fuel basket is contained in the revision of HI-981928 that supports this TSAR.**

Table 3.A.1: Essential Variables for Reference ISFSI Pad Data (from [3.A.2] and [3.A.4])

Thickness of concrete	36 inches
Nominal compressive strength of concrete	4,200 psi at 28 days
Concrete mass density	2.097E-04 lb-sec^2/in^4
Concrete Poisson's ratio	0.22
Mass density of the soil	1.872E-04 lb.-sec^2/in^4
Effective modulus of elasticity of the subgrade soil	28,000 psi
Poisson's ratio of the soil	0.4

Note 1: The concrete Young's Modulus is derived from the American Concrete Institute recommended formula $57000(f)^{1/2}$ where f is the nominal compressive strength of the concrete (psi).

Note 2: The effective modulus of elasticity of the subgrade soil is to be measured by ~~aan appropriate~~ "plate test" **or other appropriate means** before pouring of the concrete ISFSI pad.

Note 3: The pad thickness of 36", concrete compressive strength of 4200 psi (nom.) at 28 days of curing, and the subgrade soil effective modulus of 28000 psi are the upper bound values to ensure that the deceleration limits under the postulated impact events set forth in Table 3.1.2 are satisfied.

d. The geometry of the HI-STORM 100 is considered for the analysis of the top lift. This is conservative since the HI-STORM 100S is lighter and the outlet air ducts are moved to the lid in the "S" unit.

3.D.3 Analysis Methodology - Bottom Lift at the Inlet Vents

A 3-D, 1/4-symmetry, finite element model of the bottom segment of the HI-STORM 100 storage overpack is constructed using the ANSYS 3-D elastic shell element SHELL63. ANSYS is a general purpose finite element program. The Young's modulus, at 300 degree F, the Poisson's ratio, and material density for SA516-70 steel are respectively taken as 29.34E+06 psi, 0.29, and 0.288 pounds per-cubic-inch. The respective thickness of the HI-STORM 100 components are also appropriately considered, i.e., 1.25 inches for the inner shell, 0.75 inches for the outer shell, 2.0 inches for the baseplate, 0.5[1] inches for the radial ribs, 2 inches for the inlet vent horizontal plate, and 0.75 inches for the inlet vent vertical plates. The model is terminated approximately 20 inches above the base of the HI-STORM 100 storage overpack with the weight of the sections of the HI-STORM 100 storage overpack not modeled lumped at the top end of the finite element model. The contact surface between the inlet horizontal plate and hydraulic jack is fixed vertically.

An equivalent pressure load of 31.61 psi from the weights of the heaviest MPC and the pedestal shield is applied on the HI-STORM 100 baseplate over the surface area covered by the pedestal (the applied total load is 116,067 lb. based on a 68.375" outer diameter). The equivalent pressure load of 20.55 psi from the weight of the radial concrete shielding is applied on the baseplate as well as the inlet vent horizontal plates. The applied equivalent pressure loads include the 15% load increase above the dead load to account for inertia effects developed during a lift operation Figure 3.D.1 shows the plot of the finite element model for the bottom lift scenario. Figure 3.D.1 is color-coded to differentiate cask components as follows:

Figure 3.D.1 Cask Component Color Codes

Component	Color
Baseplate	Blue-Purple-Red
Inner Shell	Green
Outer Shell	Magenta
Rib	Dark Blue
Inlet Vent Vertical Plate	Mustard

---

[1] Analysis is conservative since final radial rib thickness is 0.75 inch.

SF(primary membrane plus primary bending stress intensity in baseplate) = 26,250psi/7000psi = 3.75

For the bottom lift,

SF(primary membrane plus primary bending in inlet vent horizontal plate) = 26,250psi/8000 psi = 3.28

The previous calculations have been based on an applied load of 115% of the lifted load with safety factors developed in accordance with ASME Section III, Subsection NF for Class 3 plate and shell support structures. To also demonstrate compliance with Regulatory Guide 3.61, safety factors based on 33.3% of the material yield strength are presented. These safety factors can be easily derived from the previous results by replacing the allowable stress by 33.3% of the material yield strength (1/3 x 33,150 psi from Table 3.3.2 for SA-516). Therefore, the following bounding results are obtained:

SF(membrane - 3W) = 2.63 x 33,150psi/(3 x 17,500 psi) = 1.66

SF(membrane plus bending - 3W) = 3.28 x 33,150 psi/(3 x 26,250 psi) = 1.38

3.D.6 Bolt and Anchor Block Thread Stress Analysis under Three Times Lifted Load

In this section, the threads of the bolt and the bolt anchor block are analyzed under three times the lifted load. The thread system is modeled as a cylindrical area of material under an axial load. The diameter of the cylinder area is the basic pitch diameter of the threads, and the length of the cylinder is the length of engagement of the threads. See Holtec HI-STORM 100 drawing numbers 1495~~1~~ (sheets 2 and 3) and 1561 (sheet 2) for details.

3.D.6.1 Geometry

The basic pitch diameter of the threads is: d_p = **3.0876**~~2.838~~"

The thread engagement length is: L = 3 in.

The shear area of the cylinder that represents the threads: A = 3.14159xL x d_p

The shear stress on this cylinder under three times the load is: 3W x 1.15/nA = **10,670**~~1,608~~ psi where, the total weight, *W*, and the number of lift points, *n*, are 360,000 pounds and 4, respectively, and the 1.15 represents the inertia amplification.

3.D.6.2 Stress Evaluation

The yield strength of the anchor block material at 350 degrees F is taken as 32,700 psi per Table 3.3.3. Assuming the yield strength in shear to be 60% of the yield strength in tension gives the thread shear stress safety factor under three times the lifted load as:

SF(thread shear - 3 x lifted load) = .6 x 32,700/1**0,670**~~1,608~~ = **1.84**~~1.69~~

The lifting stud material is SA564 630 (age hardened at 1075 degrees F). The yield strength of the stud material at 350 degrees F is 108,800 psi per Table 3.3.4.

The load per lift stud is P = 3W/4 x 1.15 = 310,500 lb.

The stud tensile **stress** area is **(see Machinery's Handbook, 23rd Edition, p. 1484)**~~computed using the mean diameter of the threads~~

A = **7.10**~~6.3258~~ sq. inch.

Therefore, the tensile stress in the stud under three times the lifted load is

Stress = P/A = 43,733~~9,085~~ psi

The factor of safety on tensile stress in the lifting stud, based on three times the lifted load, is:

SF(stud tension – 3 x lifted load) = 108,800/43,733~~9,085~~ = 2.49~~217~~

It is concluded that thread shear in the anchor block governs the design.

3.D.7 Weld Evaluation

In this section, weld stress evaluations are performed for the weldments considered to be in the primary load path during lifting operations. The allowable stress for the welds is obtained from Reference [3].

3.D.7.1 Anchor Block-to-Radial Rib (Lift from Top)

Hoop Stress = $p_{confine}$ x R/t = 1,095 psi

This gives a safety factor based on the Regulatory Guide 3.61 criteria equal to

SF = 33,150 psi/Hoop Stress = 30.27

This results is bounding for the HI-STORM 100S since the height and weight of the concrete pedestal is reduced.

3.D.9 Conclusion

The design of the HI-STORM 100 is adequate for the bottom end lift through the inlet vents. The design of the HI-STORM 100 is also adequate for the top end lift through the lifting lugs. Safety factors are established based on requirements of the ASME Code Section III, Subsection NF for Class 3 plate and shell supports and also on the requirements of USNRC Regulatory Guide 3.61. **The conclusions also apply to the HI-STORM 100S.**

3.D.10 References

1. ANSYS 5.3, A General Purpose Finite Element Code, ANSYS, Inc.

2. Crane Manufacturer's Association of America (CMAA), Specification #70, 1988, Section 3.3.

3. ASME Code Section III, Subsection NF-3324.5, Table NF-3324.5(a)-1, 1995

APPENDIX 3.I: HI-TRAC FREE THERMAL EXPANSIONS

3.I.1 Scope

In this calculation, estimates of operating gaps, both radially and axially, are computed for the fuel basket-to-MPC shell, and for the MPC shell-to-HI-TRAC. The temperature distribution used as input is derived from a hypothetical worst case MPC thermal load. This calculation is in support of the results presented in Section 3.4.4.2.

3.I.2 Methodology

Bounding temperatures are used to construct temperature distributions that will permit calculation of differential thermal expansions both radially and axially for the basket-to-MPC gaps, and for the MPC-to-HI-TRAC gaps. Reference temperatures are set at 70°F for all components. Temperature distributions are computed at the middle of the HI-TRAC System where the temperatures are highest. A comprehensive nomenclature listing is provided in Section 3.I.6.

3.I.3 References

[3.I.1] Boley and Weiner, Theory of Thermal Stresses, John Wiley, 1960, Sec. 9.10, pp. 288-291.

[3.I.2] Burgreen, Elements of Thermal Stress Analysis, Arcturus Publishers, Cherry Hill NJ, 1988.

3.I.4 Calculations for Hot Components (Middle of System)

3.I.4.1 Input Data

Based on thermal calculations in Chapter 4, the following temperatures are appropriate at the middle of the HI-TRAC (see Figure 3.I.1 and Table 4.5.2).

The temperature change at the inside surface of the HI-TRAC, $\Delta T_{1h} := 354 - 70$

The temperature change at the inside of the water jacket, $\Delta T_{2h} := 345 - 70$

The temperature change at the mean radius of the MPC shell, $\Delta T_{3h} := 498 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (576 - 70)\cdot 1.1$

The temperature change at the center of the basket, $\Delta T_{5h} := 934 - 70$

Note that the outer basket temperature is conservatively amplified by 10% to insure a bounding parabolic distribution. This conservatism serves to maximize the growth of the basket.

The geometry of the components are as follows (refering to Figure 3.I.1)

The outer radius of the outer shell, $b := 40.625 \cdot in$

The inner radius of the HI-TRAC, $a := 34.375 \cdot in$

The mean radius of the MPC shell, $R_{mpc} := \dfrac{68.375 \cdot in - 0.5 \cdot in}{2}$ $\quad R_{mpc} = 33.938\,in$

The initial MPC-to-overpack minimal radial clearance, $RC_{mo} := .5 \cdot (68.75 - 68.5) \cdot in$

$RC_{mo} = 0.125\,in$

For axial growth calculations of the MPC-to-HI-TRAC top flange clearance, the axial length of the HI-TRAC is defined as the distance from the bottom flange to the top flange, and the axial length of the MPC is defined as the overall MPC height.

The axial length of the HI-TRAC, $L_{ovp} := 191.25 \cdot in$

The axial length of the MPC, $L_{mpc} := 190.5 \cdot in$

The initial MPC-to-HI-TRAC nominal axial clearance, $AC_{mo} := L_{ovp} - L_{mpc}$

$AC_{mo} = 0.75\,in$

For growth calculations for the fuel basket-to-MPC shell clearances, the axial length of the basket is defined as the total length of the basket and the outer radius of the basket is defined as the mean radius of the MPC shell minus one-half of the shell thickness minus the initial basket-to-shell radial clearance.

The axial length of the basket, $L_{bas} := 176.5 \cdot in$

The initial basket-to-MPC lid nominal axial clearance, $AC_{bm} := 2 \cdot in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875 \cdot in$

The outer radius of the basket, $R_b := R_{mpc} - \dfrac{0.5}{2} \cdot in - RC_{bm}$ $\quad R_b = 33.5\,in$

The coefficients of thermal expansion used in the subsequent calculations are based on the mean temperatures of the MPC shell and a bounding mean temperature for the basket.

The coefficient of thermal expansion for the MPC shell, $\alpha_{mpc} := 9.338 \cdot 10^{-6}$

The coefficient of thermal expansion for the basket, $\alpha_{bas} := 9.90 \cdot 10^{-6}$ 800 deg. F

3.I.4.2 Thermal Growth of the Overpack

Results for thermal expansion deformation and stress in the overpack are obtained here. The system is replaced by a equivalent uniform hollow cylinder with approximated average properties.

Based on the given inside and outside surface temperatures, the temperature solution in the cylinder is given in the form:

$$C_a + C_b \cdot \ln\left(\frac{r}{a}\right)$$

wher-
e,

$$C_a := \Delta T_{1h} \qquad C_a = 284$$

$$C_b := \frac{\Delta T_{2h} - \Delta T_{1h}}{\ln\left(\frac{b}{a}\right)} \qquad C_b = -53.875$$

Next, form the integral relationship:

$$Int := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\, dr$$

The Mathcad program, which was used to create this appendix, is capable of evaluating the integral "Int" either numerically or symbolically. To demonstrate that the results are equivalent, the integral is evaluated both ways in order to qualify the accuracy of any additional integrations that are needed.

The result obtained through numerical integration, $Int = 6.545 \times 10^4 in^2$

To perform a symbolic evaluation of the solution the integral "Ints" is defined. This integral is then evaluated using the Maple symbolic math engine built into the Mathcad program as:

$$Int_s := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\, dr$$

$$Int_s := \frac{1}{2} \cdot C_b \cdot \ln\left(\frac{b}{a}\right) \cdot b^2 + \frac{1}{2} \cdot C_a \cdot b^2 - \frac{1}{4} \cdot C_b \cdot b^2 + \frac{1}{4} \cdot C_b \cdot a^2 - \frac{1}{2} \cdot C_a \cdot a^2 \qquad Int_s = 6.545 \times 10^4 in^2$$

We note that the values of Int and Ints are identical. The average temperature in the overpack cylinder (T_{bar}) is therefore determined as:

$$T_{bar} := \frac{2}{\left(b^2 - a^2\right)} \cdot Int$$

$$T_{bar} = 279.25$$

We estimate the average coefficient of thermal expansion for the HI-TRAC by weighting the volume of the various layers. A total of three layers are identified for this calculation. They are:

1) the inner shell
2) the radial lead shield
3) the outer shell

Thermal properties are based on estimated temperatures in the component and coefficient of thermal expansion values taken from the tables in Chapter 3. The following averaging calculation involves the thicknesses (t) of the various components, and the estimated coefficients of thermal expansion at the components' mean radial positions. The results of the weighted average process yields an effective coefficient of linear thermal expansion for use in computing radial growth of a solid cylinder (the overpack).

The thicknesses of each component are defined as:

$$t_1 := 0.75 \cdot in$$

$$t_2 := 4.5 \cdot in$$

$$t_3 := 1.0 \cdot in$$

and the corresponding mean radii can therefore be defined as:

$$r_1 := a + .5 \cdot t_1$$

$$r_2 := r_1 + .5 \cdot t_1 + .5 \cdot t_2$$

$$r_3 := r_2 + .5 \cdot t_2 + .5 \cdot t_3$$

To check the accuracy of these calculations, the outer radius of the HI-TRAC is calculated from r_3 and t_3, and the result is compared with the previously defined value (b).

$$b_1 := r_3 + 0.5 \cdot t_3$$

$$b_1 = 40.625\, in$$

$$b = 40.625\, in$$

We note that the calculated value b_l is identical to the previously defined value b. The coefficients of thermal expansion for each component, estimated based on the temperature gradient, are defined as:

$$\alpha_1 := 6.3382 \cdot 10^{-6}$$

$$\alpha_2 := 17.2 \cdot 10^{-6} \qquad \text{@300 deg F}$$

$$\alpha_3 := 6.311 \cdot 10^{-6}$$

Thus, the average coefficient of thermal expansion of the HI-TRAC is determined as:

$$\alpha_{avg} := \frac{r_1 \cdot t_1 \cdot \alpha_1 + r_2 \cdot t_2 \cdot \alpha_2 + r_3 \cdot t_3 \cdot \alpha_3}{\frac{a+b}{2} \cdot \left(t_1 + t_2 + t_3\right)}$$

$$\alpha_{avg} = 1.413 \times 10^{-5}$$

Reference 3.I.1 gives an expression for the radial deformation due to thermal growth. At the inner radius of the HI-TRAC (r = a), the radial growth is determined as:

$$\Delta R_{ah} := \alpha_{avg} \cdot a \cdot T_{bar} \qquad \Delta R_{ah} = 0.136\,\text{in}$$

Similarly, an overestimate of the axial growth of the HI-TRAC can be determined by applying the average temperature (T_{bar}) over the entire length of the overpack as:

$$\Delta L_{ovph} := L_{ovp} \cdot \alpha_{avg} \cdot T_{bar}$$

$$\Delta L_{ovph} = 0.755\,\text{in}$$

Estimates of the secondary thermal stresses that develop in the HI-TRAC due to the radial temperature variation are determined using a conservatively high value of E as based on the temperature of the steel. The circumferential stress at the inner and outer surfaces (σ_{ca} and σ_{cb}, respectively) are determined as:

The Young's Modulus of the material, $E := 28600000 \cdot \text{psi}$

$$\sigma_{ca} := \alpha_{avg} \cdot \frac{E}{a^2} \cdot \left[2 \cdot \frac{a^2}{\left(b^2 - a^2\right)} \cdot \text{Int} - \left(C_a\right) \cdot a^2 \right] \qquad \sigma_{ca} = -1919\,\text{psi}$$

$$\sigma_{cb} := \alpha_{avg} \cdot \frac{E}{b^2} \cdot \left[2 \cdot \frac{b^2}{\left(b^2 - a^2\right)} \cdot \mathrm{Int} - \left[C_a + C_b \cdot \left(\ln\left(\frac{b}{a}\right)\right)\right] \cdot b^2 \right] \qquad \sigma_{cb} = 1717\,\mathrm{psi}$$

The radial stress due to the temperature gradient is zero at both the inner and outer surfaces of the HI-TRAC. The radius where a maximum radial stress is expected, and the corresponding radial stress, are determined by trial and error as:

$$N := 0.47$$

$$r := a \cdot (1 - N) + N \cdot b$$

$$r = 37.313\,\mathrm{in}$$

$$\sigma_r := \alpha_{avg} \cdot \frac{E}{r^2} \cdot \left[\frac{r^2 - a^2}{2} \cdot T_{bar} - \int_a^r \left[C_a + C_b \cdot \left(\ln\left(\frac{y}{a}\right)\right)\right] \cdot y \, dy \right]$$

$$\sigma_r = -75.813\,\mathrm{psi}$$

The axial stress developed due to the temperature gradient is equal to the sum of the radial and tangential stresses at any radial location. (see eq. 9.10.7) of [3.I.1]. Therefore, the axial stresses are available from the above calculations. The stress intensities in the HI-TRAC due to the temperature distribution are below the Level A membrane stress.

3.I.4.3 Thermal Growth of the MPC Shell

The radial and axial growth of the MPC shell (ΔR_{mpch} and ΔL_{mpch}, respectively) are determined as:

$$\Delta R_{mpch} := \alpha_{mpc} \cdot R_{mpc} \cdot \Delta T_{3h}$$

$$\Delta R_{mpch} = 0.136\,\mathrm{in}$$

$$\Delta L_{mpch} := \alpha_{mpc} \cdot L_{mpc} \cdot \Delta T_{3h}$$

$$\Delta L_{mpch} = 0.761\,\mathrm{in}$$

3.I.4.4 Clearances Between the MPC Shell and HI-TRAC

The final radial and axial MPC shell-to-HI-TRAC clearances (RG_{moh} and AG_{moh}, respectively) are determined as:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch}$$

$$RG_{moh} = 0.125\,in$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch}$$

$$AG_{moh} = 0.743\,in$$

Note that this axial clearance (AG_{moh}) is based on the temperature distribution at the top end of the system.

3.I.4.5 Thermal Growth of the MPC Basket

Using formulas given in [3.I.2] for a solid body of revolution, and assuming a parabolic temperature distribution in the radial direction with the center and outer temperatures given previously, the following relationships can be developed for free thermal growth.

Define $\Delta T_{bas} := \Delta T_{5h} - \Delta T_{4h}$

$$\Delta T_{bas} = 307.4$$

Then the mean temperature can be defined as $T_{bar} := \frac{2}{R_b^{2}} \cdot \int_{0}^{R_b} \left(\Delta T_{5h} - \Delta T_{bas} \cdot \frac{r^2}{R_b^{2}} \right) \cdot r\, dr$

Using the Maple symbolic engine again, the closed form solution of the integral is:

$$T_{bar} := \frac{2}{R_b^{2}} \cdot \left(\frac{-1}{4} \cdot \Delta T_{bas} \cdot R_b^{2} + \frac{1}{2} \cdot \Delta T_{5h} \cdot R_b^{2} \right)$$

$$T_{bar} = 710.3$$

The corresponding radial growth at the periphery (ΔR_{bh}) is therefore determined as:

$$\Delta R_{bh} := \alpha_{bas} \cdot R_b \cdot T_{bar} \qquad \Delta R_{bh} = 0.236\,in$$

and the corresponding axial growth (ΔL_{bas}) is determined from [3.I.2] as:

$$\Delta L_{bh} := \Delta R_{bh} \cdot \frac{L_{bas}}{R_b} \qquad \Delta L_{bh} = 1.241\,in$$

Note that the coefficient of thermal expansion for the hottest basket temperature has been used, and the results are therefore conservative.

3.I.4.6 Clearances Between the Fuel Basket and MPC Shell

The final radial and axial fuel basket-to-MPC shell and lid clearances (RG_{bmh} and AG_{bmh}, respectively) are determined as:

$$RG_{bmh} := RC_{bm} - \Delta R_{bh} + \Delta R_{mpch}$$

$$RG_{bmh} = 0.088\,\text{in}$$

$$AG_{bmh} := AC_{bm} - \Delta L_{bh} + \Delta L_{mpch}$$

$$AG_{bmh} = 1.52\,\text{in}$$

3.I.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-HI-TRAC	Fuel Basket-to-MPC Shell
$RG_{moh} = 0.125\,\text{in}$	$RG_{bmh} = 0.088\,\text{in}$
$AG_{moh} = 0.743\,\text{in}$	$AG_{bmh} = 1.52\,\text{in}$

3.I.6 Nomenclature

a is the inner radius of the HI-TRAC
AC_{bm} is the initial fuel basket-to-MPC axial clearance.
AC_{mo} is the initial MPC-to-HI-TRAC axial clearance.
AG_{bmh} is the final fuel basket-to-MPC shell axial gap for the hot components.
AG_{moh} is the final MPC shell-to-HI-TRAC axial gap for the hot components.
b is the outer radius of the HI-TRAC
L_{bas} is the axial length of the fuel basket.
L_{mpc} is the axial length of the MPC.
L_{ovp} is the axial length of the HI-TRAC.
r_1 (r_2,r_3) is mean radius of the HI-TRAC inner shell (radial lead shield, outer shell).
R_b is the outer radius of the fuel basket.
R_{mpc} is the mean radius of the MPC shell.
RC_{bm} is the initial fuel basket-to-MPC radial clearance.
RC_{mo} is the initial MPC shell-to-HI-TRAC radial clearance.
RG_{bmh} is the final fuel basket-to-MPC shell radial gap for the hot components.
RG_{moh} is the final MPC shell-to-HI-TRAC radial gap for the hot components.
t_1 (t_2,t_3) is the thickness of the HI-TRAC inner shell (radial lead shield, outer shell).
T_{bar} is the average temperature of the HI-TRAC cylinder.
α_1 (α_2,α_3) is the coefficient of thermal expansion of the HI-TRAC inner shell (radial lead shield,
outer shell).
α_{avg} is the average coefficient of thermal expansion of the HI-TRAC.
α_{bas} is the coefficient of thermal expansion of the HI-TRAC.
α_{mpc} is the coefficient of thermal expansion of the MPC.
ΔL_{bh} is the axial growth of the fuel basket for the hot components.

ΔL_{mpch} the the axial growth of the MPC for the hot components.

ΔL_{ovph} is the axial growth of the HI-TRAC for the hot components.

ΔR_{ah} is the radial growth of the HI-TRAC inner radius for the hot components.

ΔR_{bh} is the radial growth of the fuel basket for the hot components.

ΔR_{mpch} is the radial growth of the MPC shell for the hot components.

ΔT_{1h} is the temperature change at the HI-TRAC inside surface for hot components.

ΔT_{2h} is the temperature change at the inside of the water jackets for hot components.

ΔT_{3h} is the temperature change at the MPC shell mean radius for hot components.

ΔT_{4h} is the temperature change at the MPC basket periphery for hot components.

ΔT_{5h} is the temperature change at the MPC basket centerline for hot components.

ΔT_{bas} is the fuel basket centerline-to-periphery temperature gradient.

σ_{ca} is the circumferential stress at the HI-TRAC inner surface.

σ_{cb} is the circumferential stress at the HI-TRAC outer surface.

σ_r is the maximum radial stress of the HI-TRAC.

$\tau_1 := \frac{Vo}{.7071 \cdot t_w}$ $\tau_1 = 1.138 \times 10^3 \, psi$

The weld capacity over the same unit width is

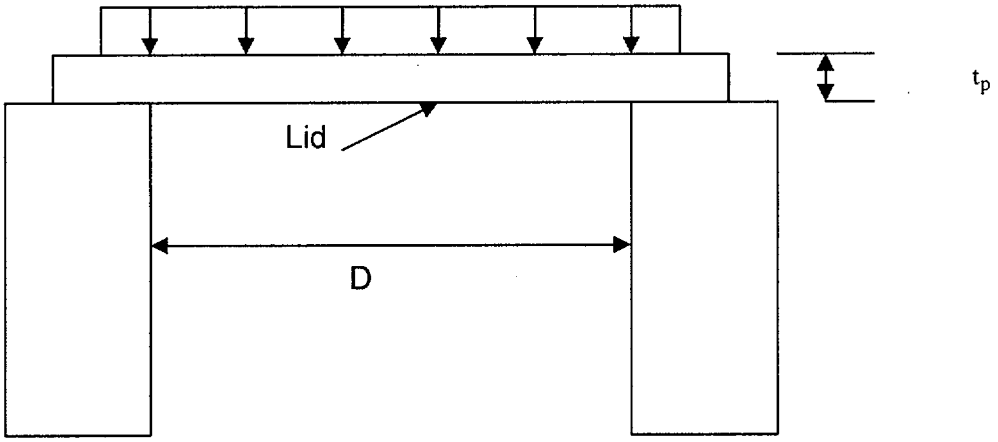
$Weld\_Capacity := \tau_{allow} \cdot .7071 \cdot t_w$ $Weld\_Capacity = 5.197 \times 10^3 \, \frac{lbf}{in}$

Therefore the safety factor on the pedestal shell-to-baseplate weld is

$SF_{weld} := \frac{Weld\_Capacity}{Vo}$ $SF_{weld} = 25.828$

3.M.4 Analysis of Bending of HI-STORM 100S Top Lid

Consider the following configuration for analysis (the upper of the two lid plates is most heavily loaded):



The thickness of the upper of two lids is

$t_{tp} = 2 \, in$

$D := 73.5 \cdot in$ Assume the pinned support is at the inner edge.

The weight of the shield block concrete and the surrounding metal shell is obtained from the detailed weight analysis archived in the calculation package. The total weight of this component is

$W := 5716 \cdot lbf$

The equivalent uniform pressure is

$$q1 := \frac{W \cdot G}{\left(\frac{\pi \cdot D^2}{4}\right)} \qquad q1 = 60.623\,\text{psi}$$

The amplified pressure due to the lid plate self weight is

$$q2 := G \cdot .283 \cdot \frac{\text{lbf}}{\text{in}^3} \cdot t_{tp} \qquad q2 = 25.47\,\text{psi}$$ (density from Subsection 3.3.1.1)

Therefore, the total amplified pressure on the upper of two top lids (conservatively assume it carries all of the load from the shield block and neglect any resisting interface pressure from the lower plate) is

$$q := q1 + q2$$

The bending stress in the center of the plate is

$$\sigma := \frac{3 \cdot (3 + \nu)}{8} \cdot q \cdot \left(\frac{D}{2 \cdot t_{tp}}\right)^2$$

$$\sigma = 3.597 \times 10^4\,\text{psi}$$

$$SF_{lid\_top\_plate} := \frac{S_a}{\sigma}$$

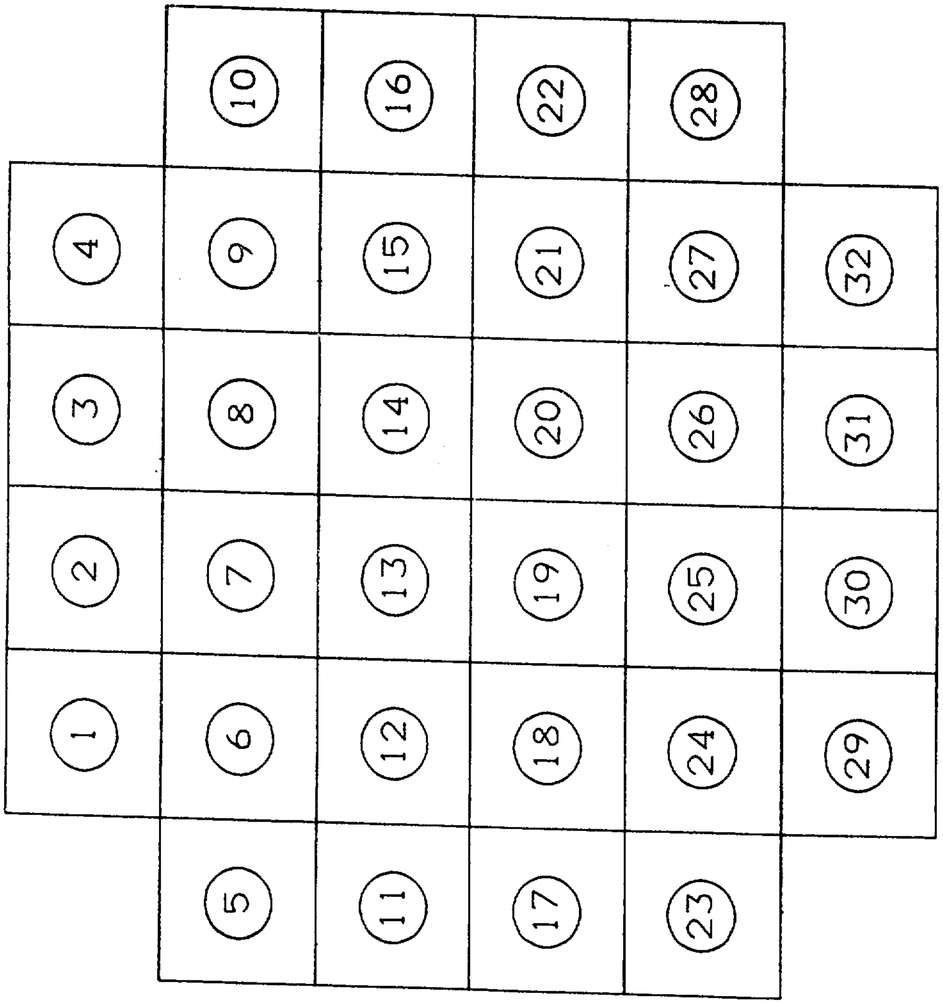
$$SF_{lid\_top\_plate} = 1.658$$

3.M.4 Conclusion

The HI-STORM 100 storage overpack meets Level D requirements for Load Case 02.a in Table 3.1.5. Even under the postulated accident condition loads, the calculated stress levels do not imply that any significant deformations occur that would preclude removal of a loaded MPC. Thus ready retrievability of fuel is maintained after such an event. The results for the HI-STORM 100 will bound the results for the HI-STORM 100S.

Appendix 3.P - Detailed Finite Element Listings for the MPC-32 Fuel Basket

Thirty-four (34) pages total including cover page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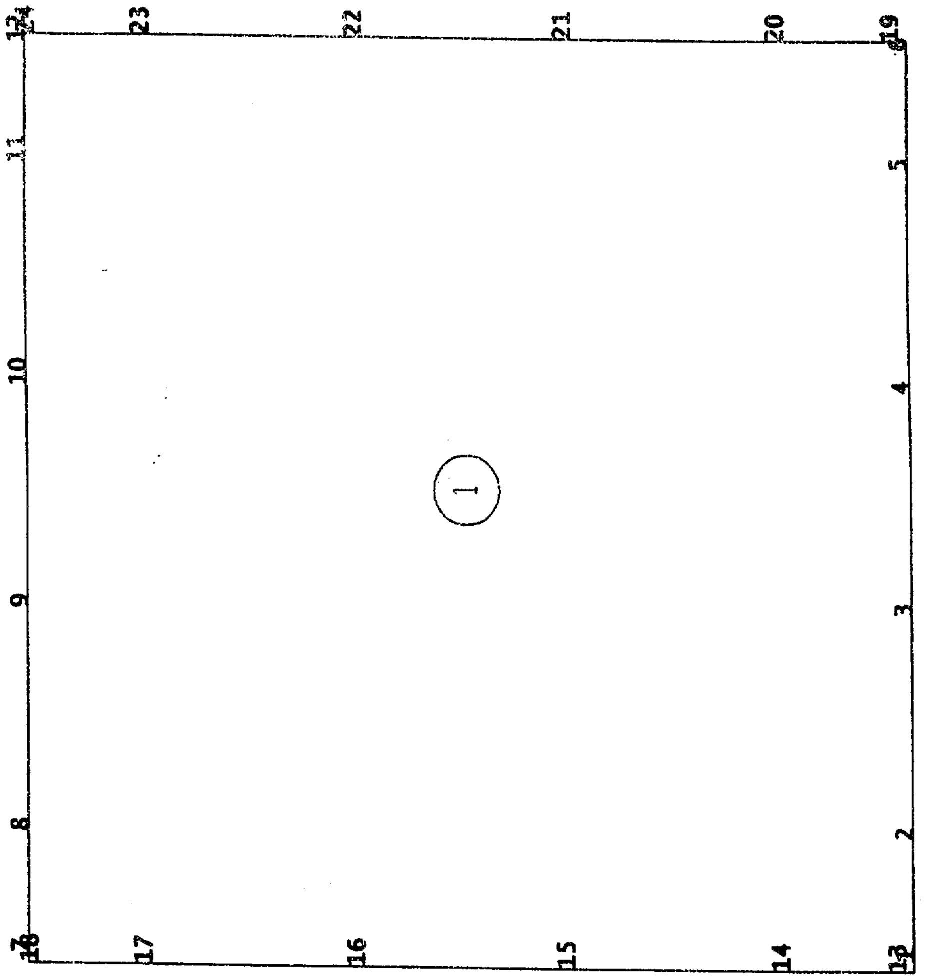
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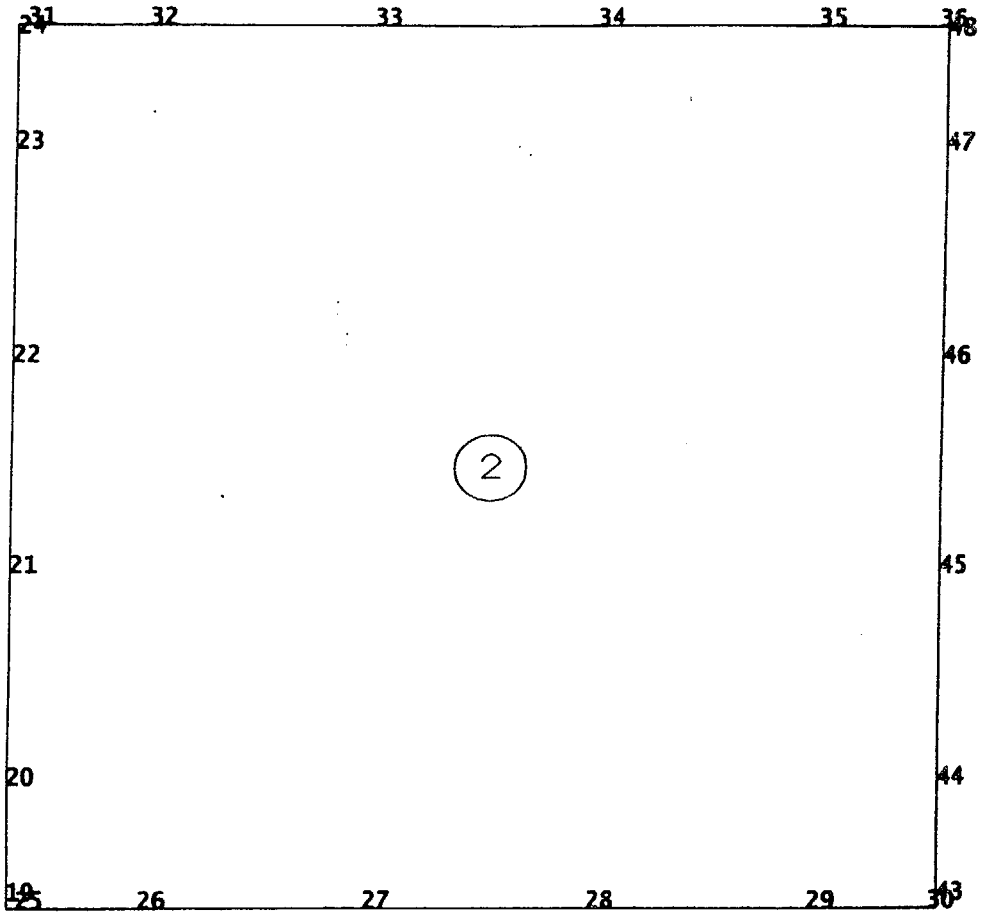
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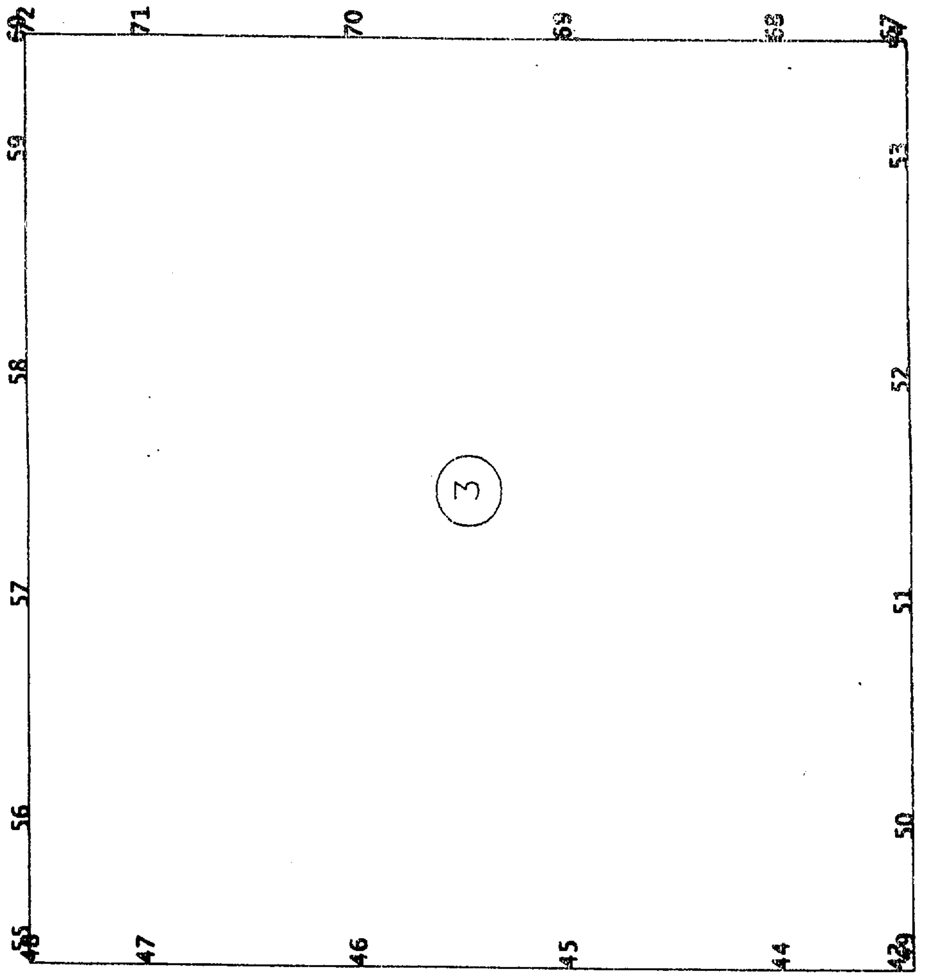
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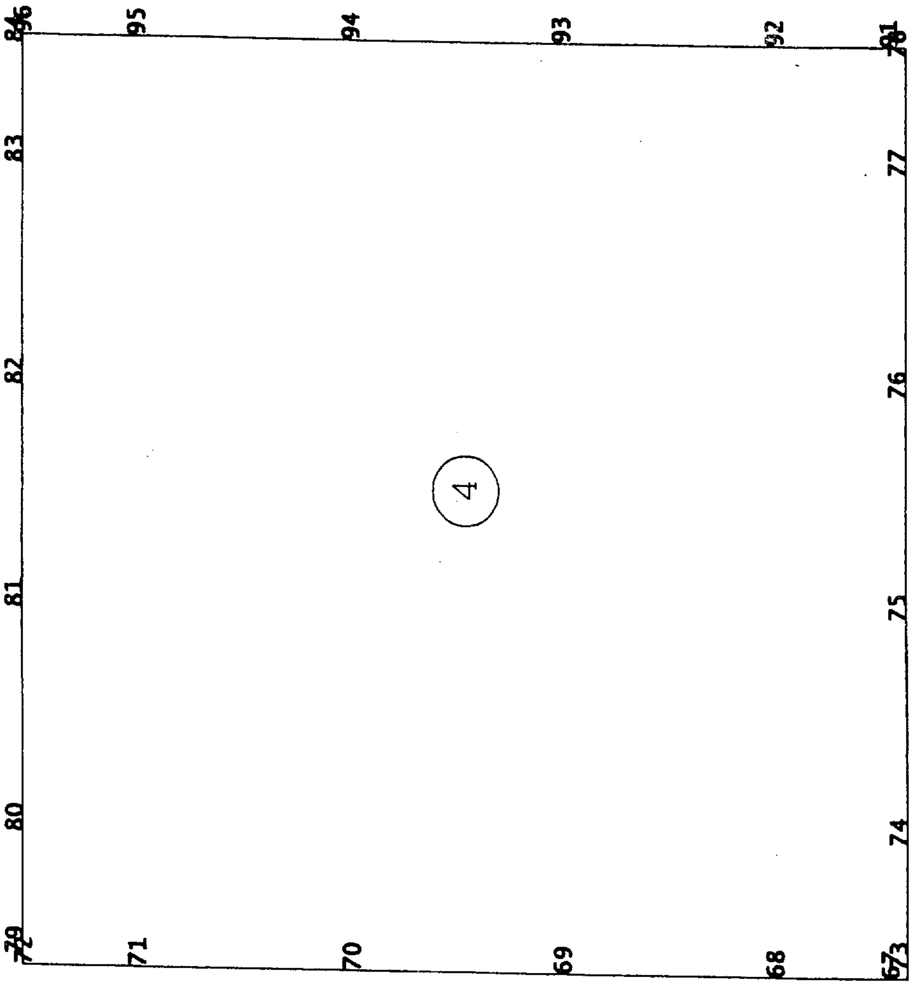
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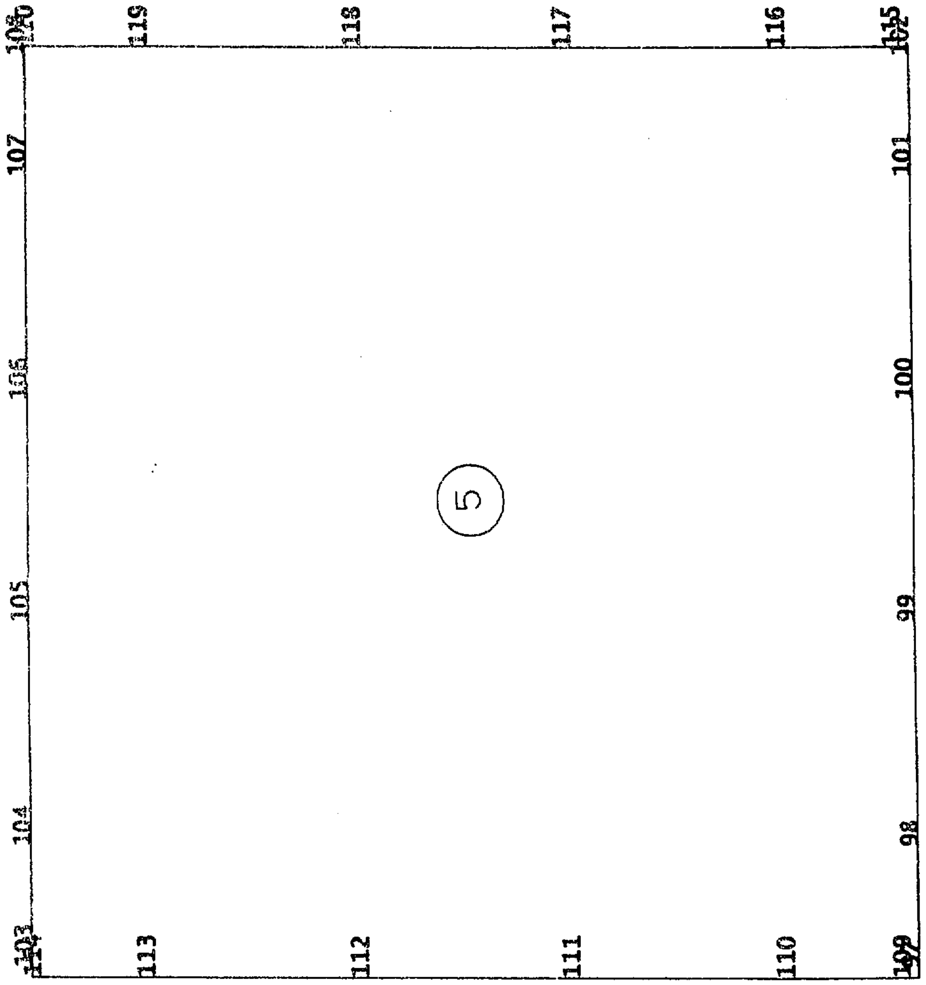

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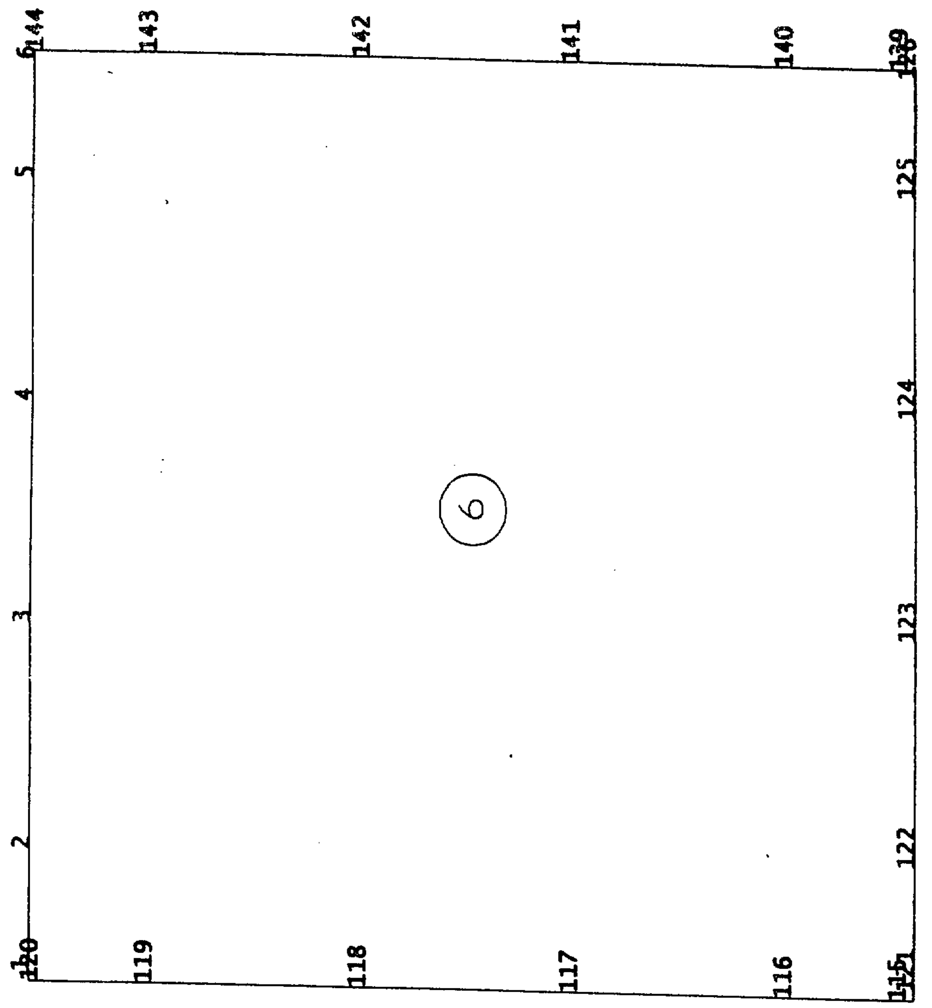
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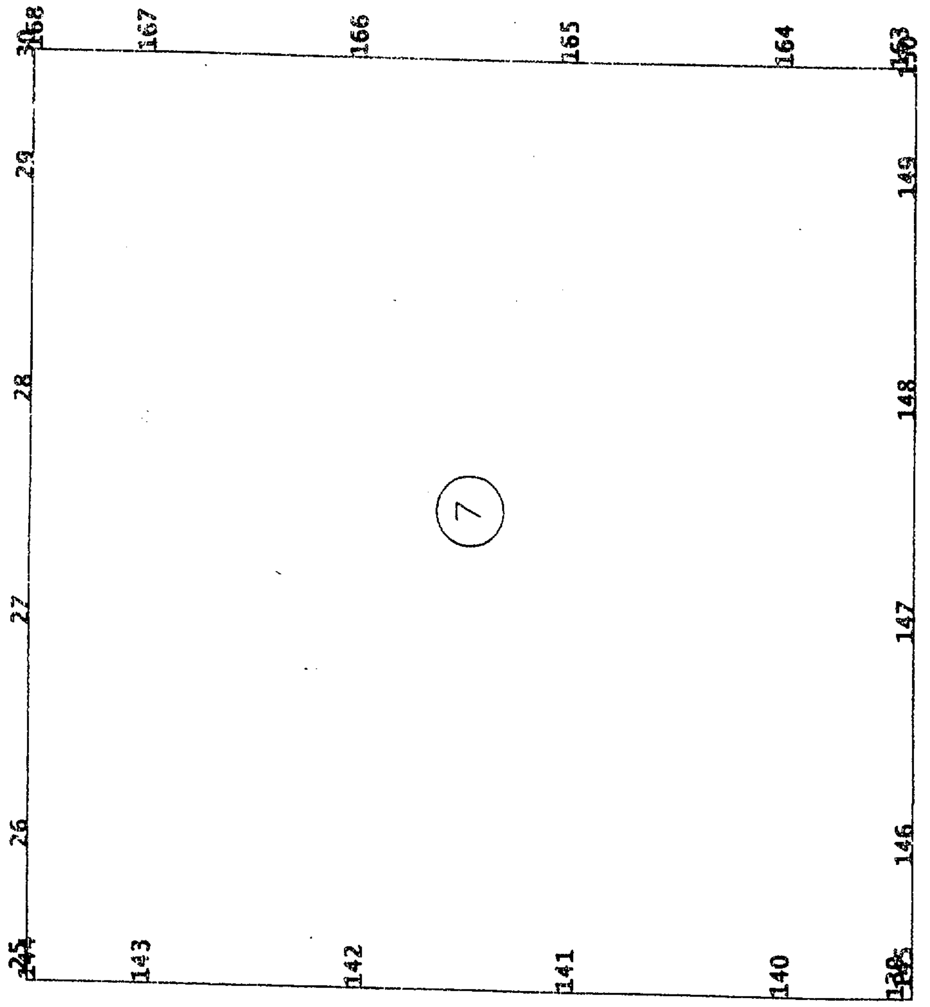
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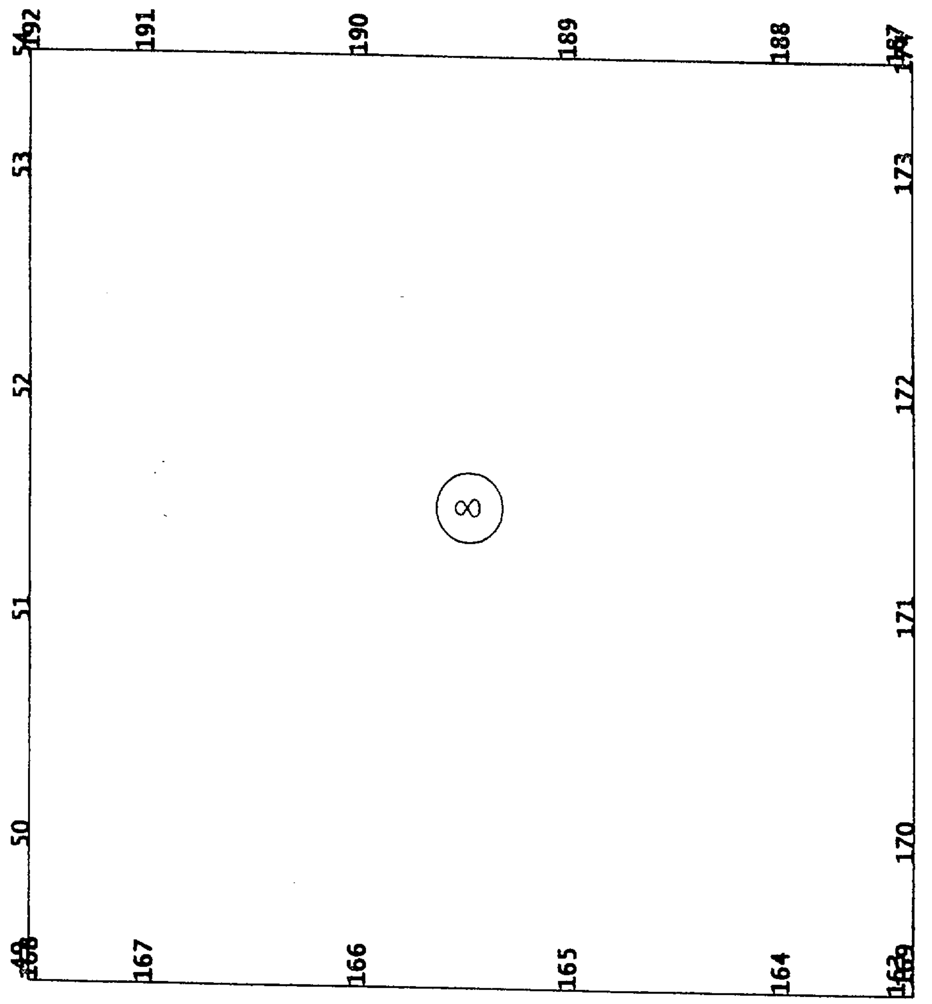
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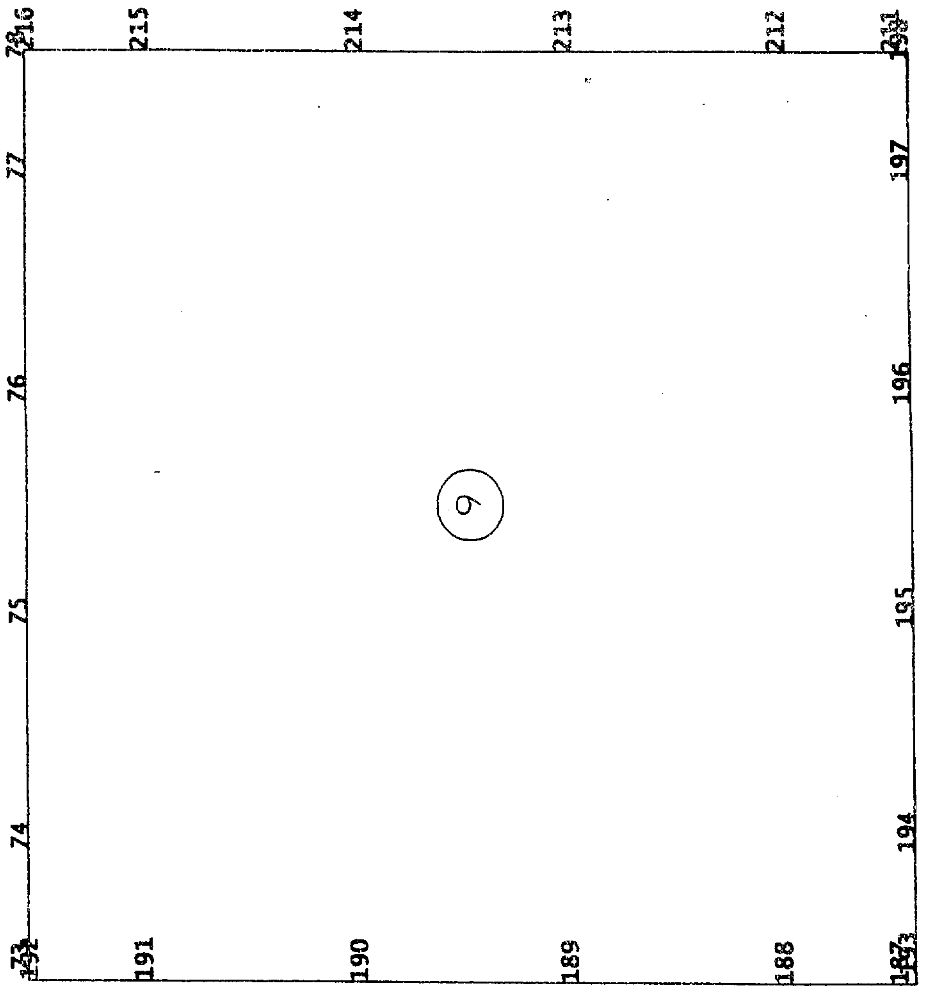
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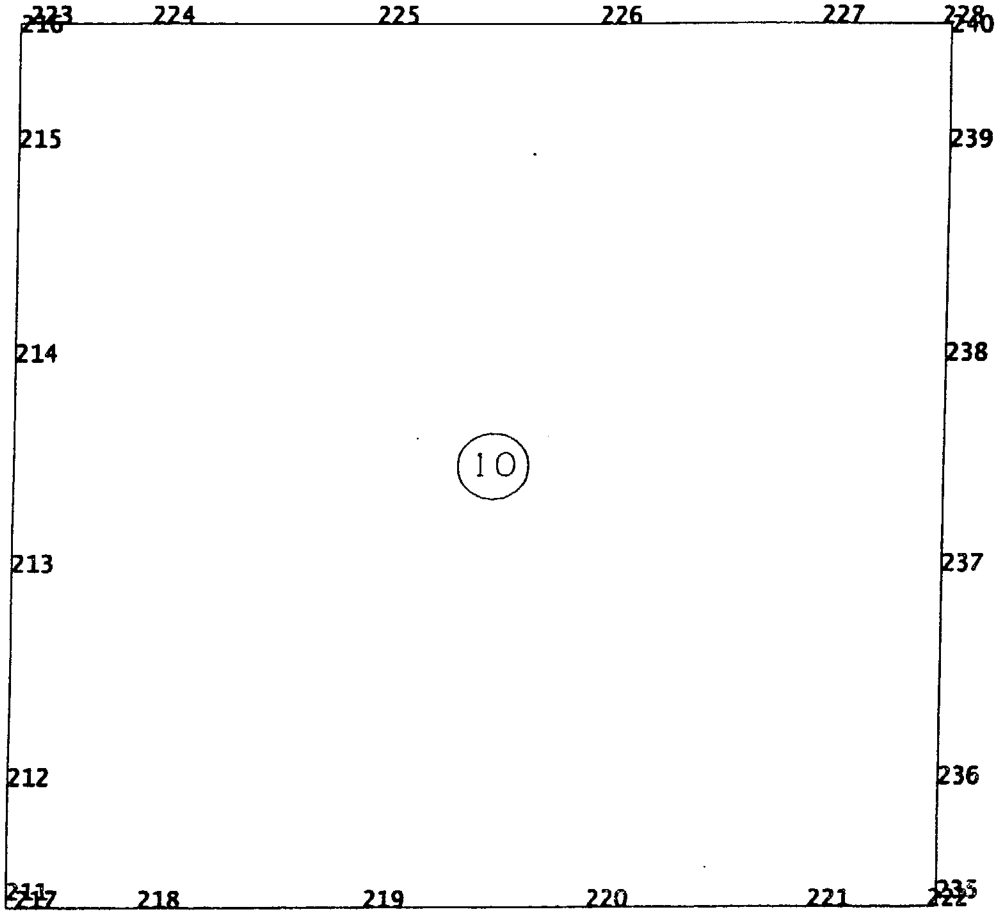
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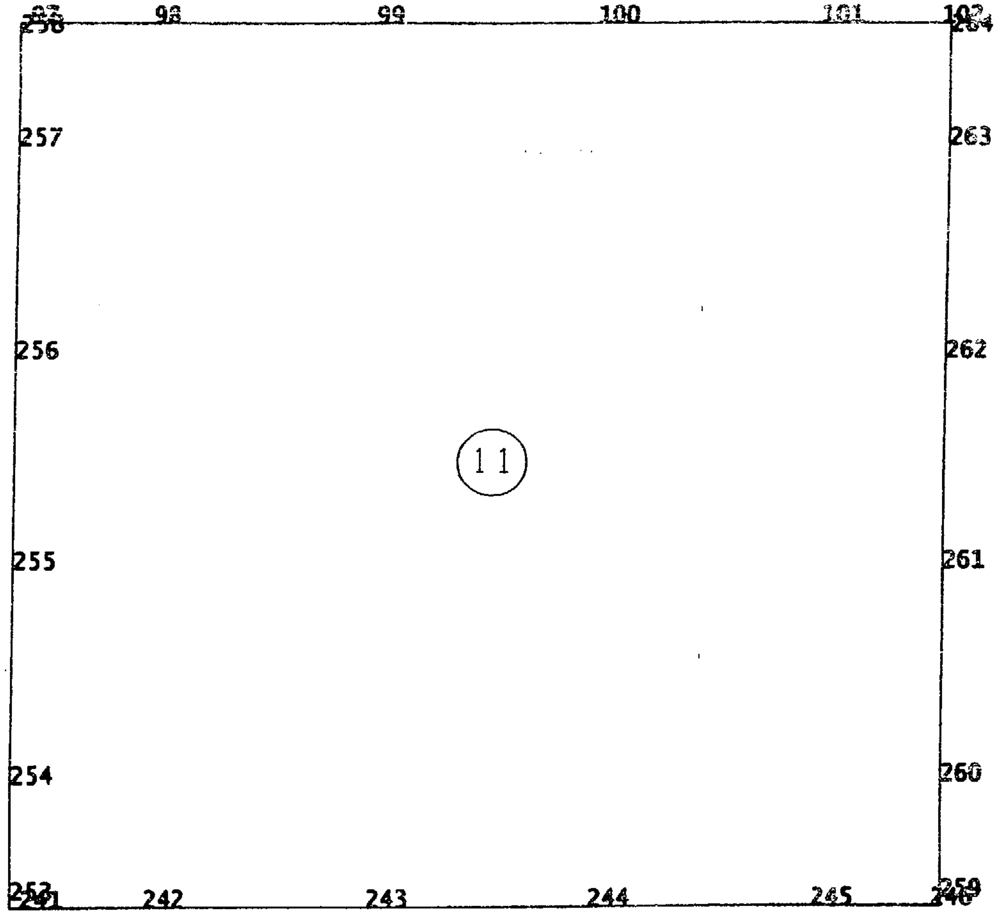
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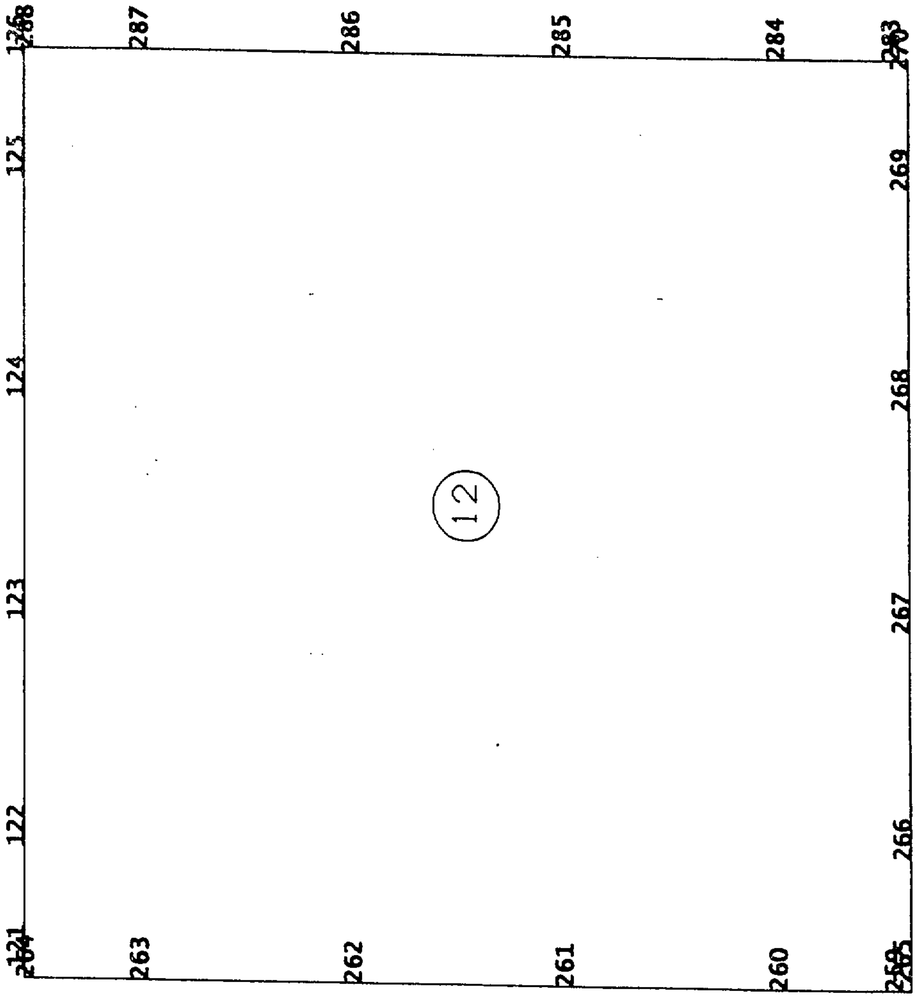
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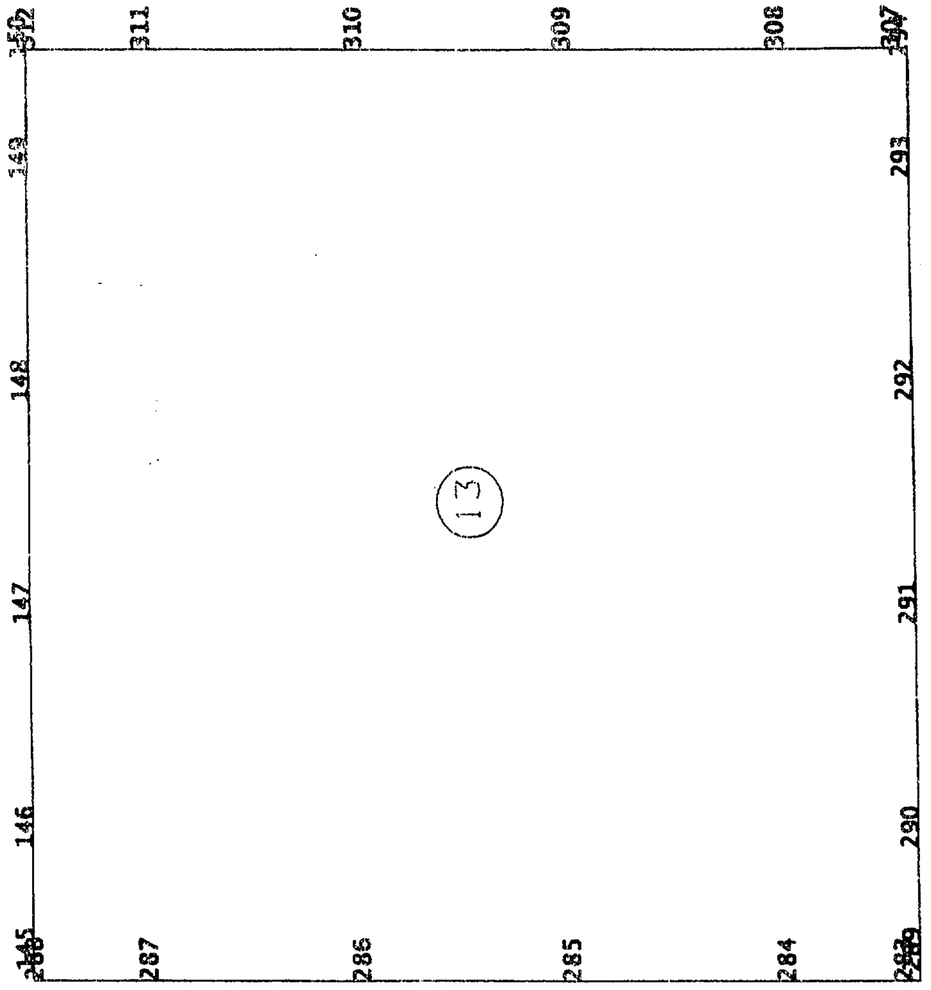
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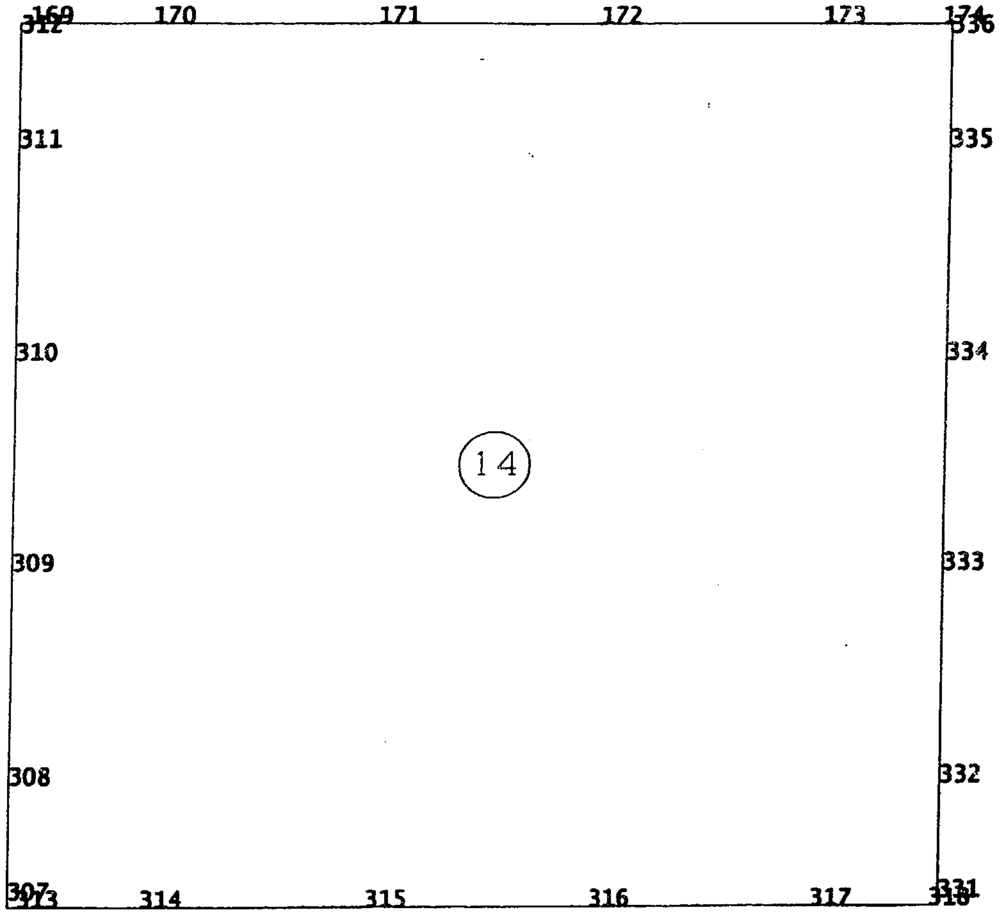
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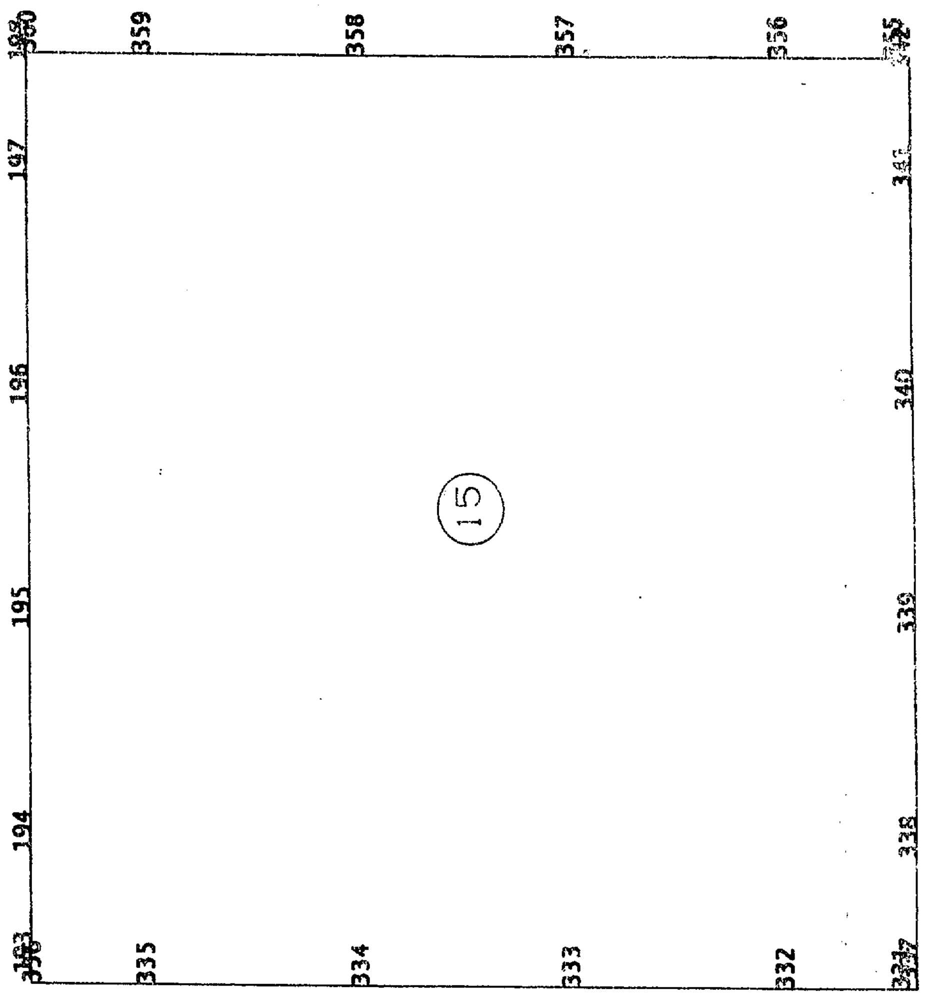
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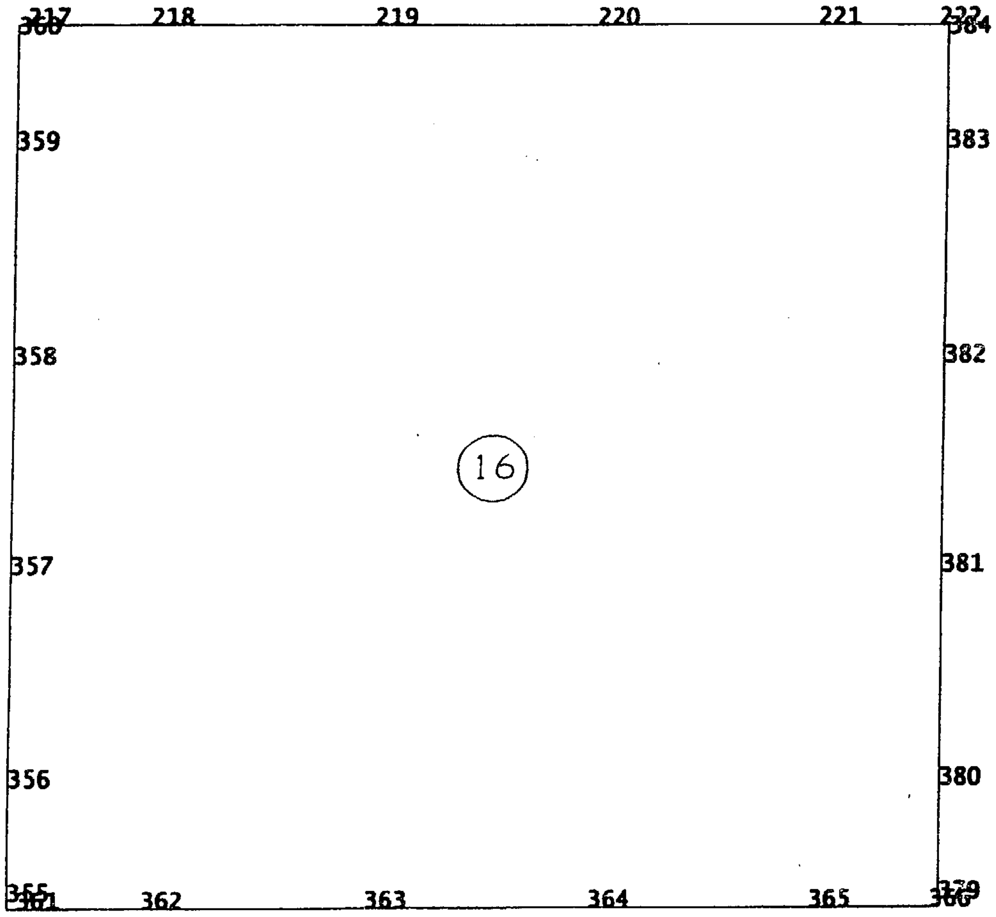
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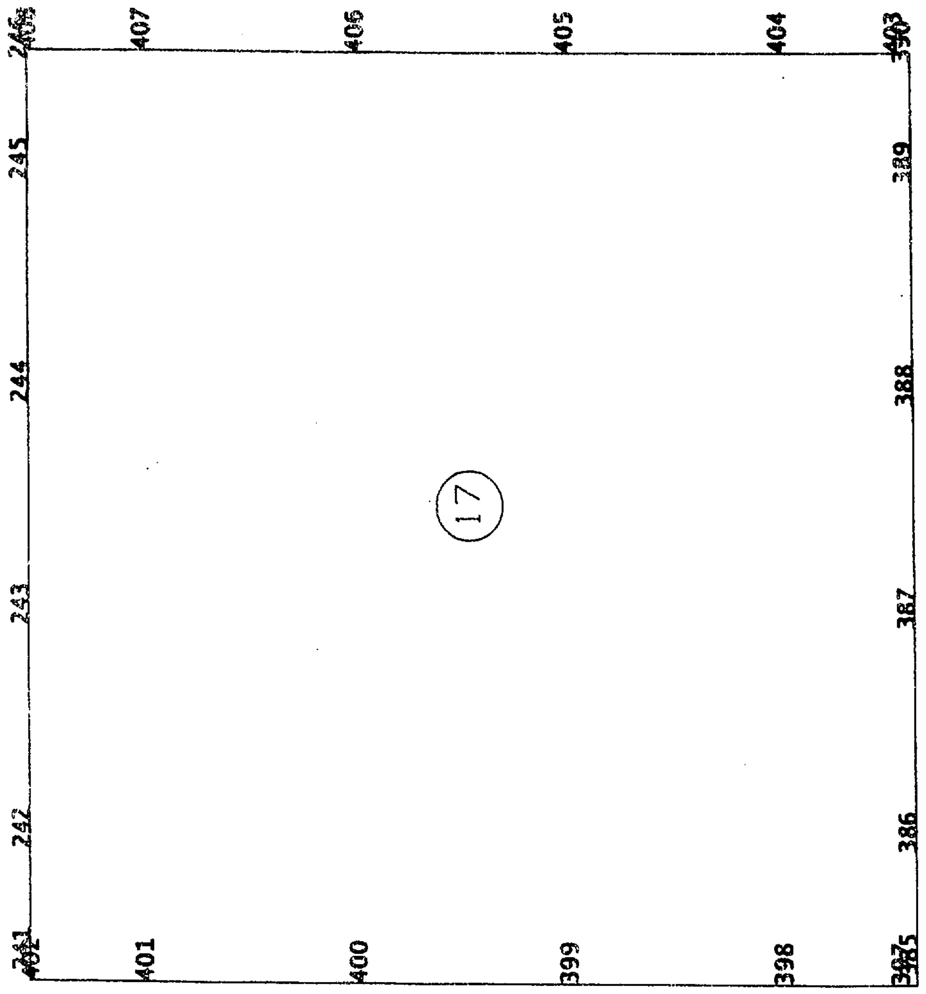
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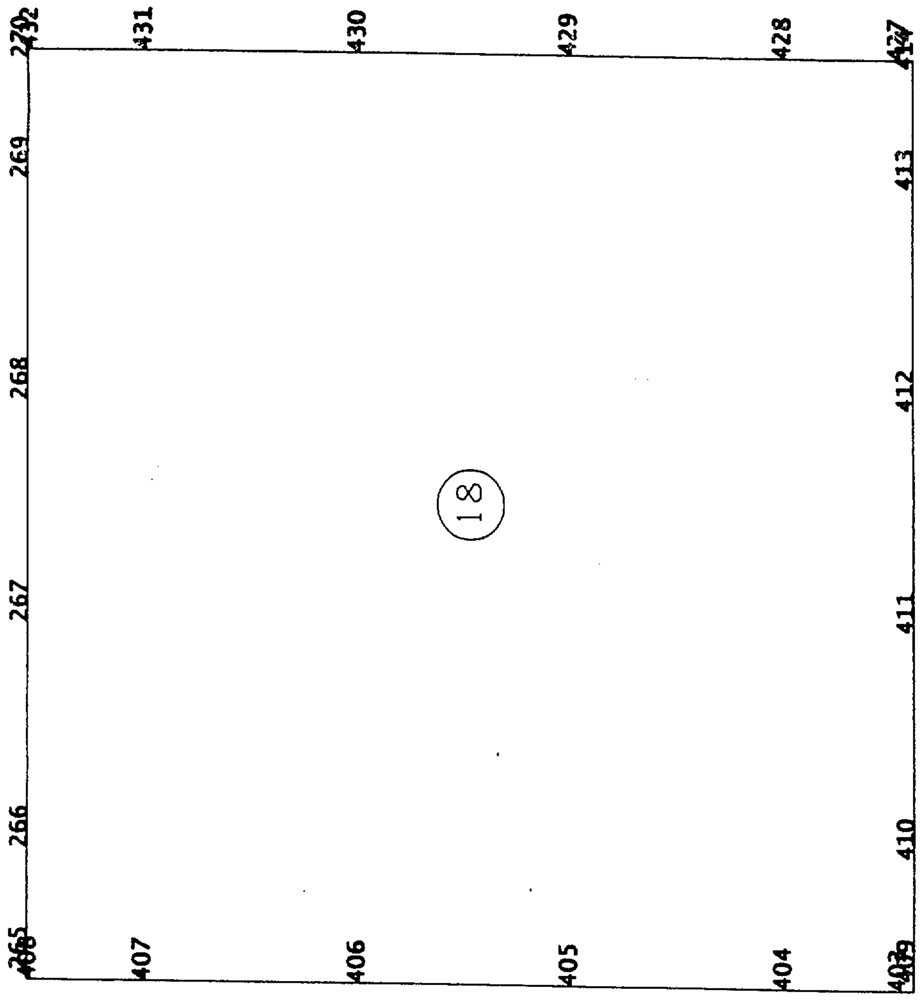
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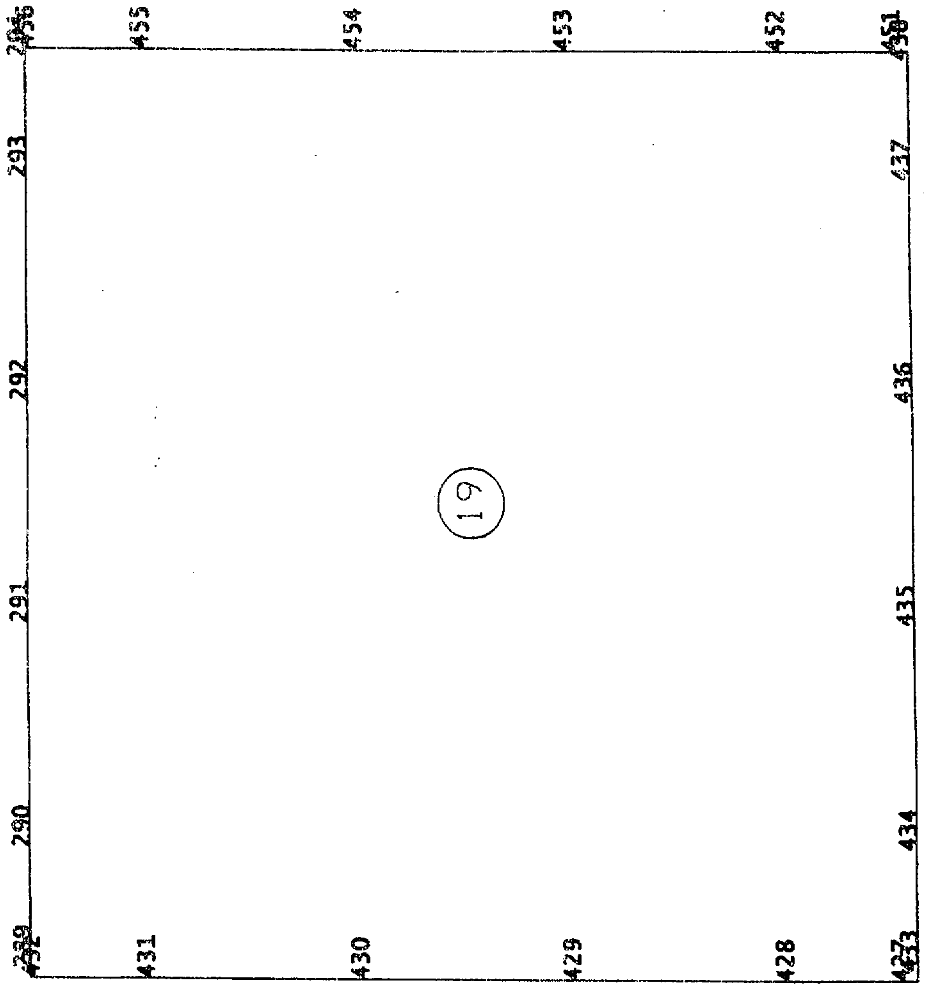
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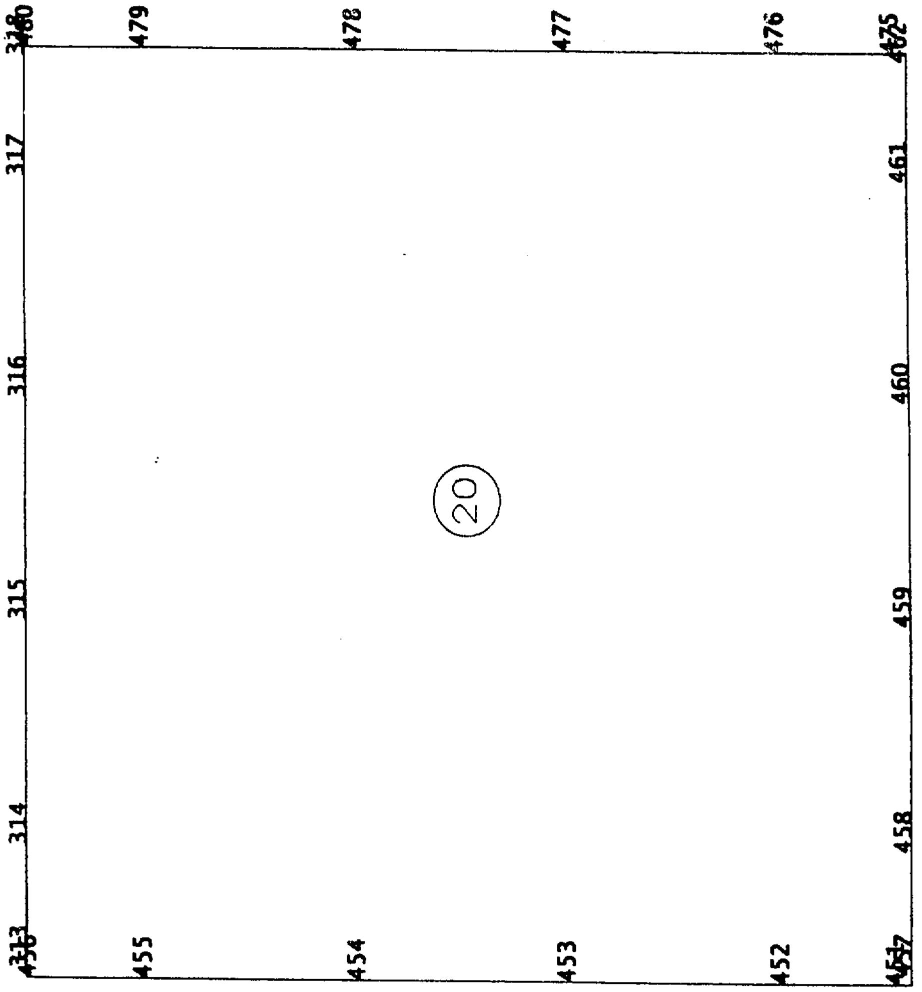
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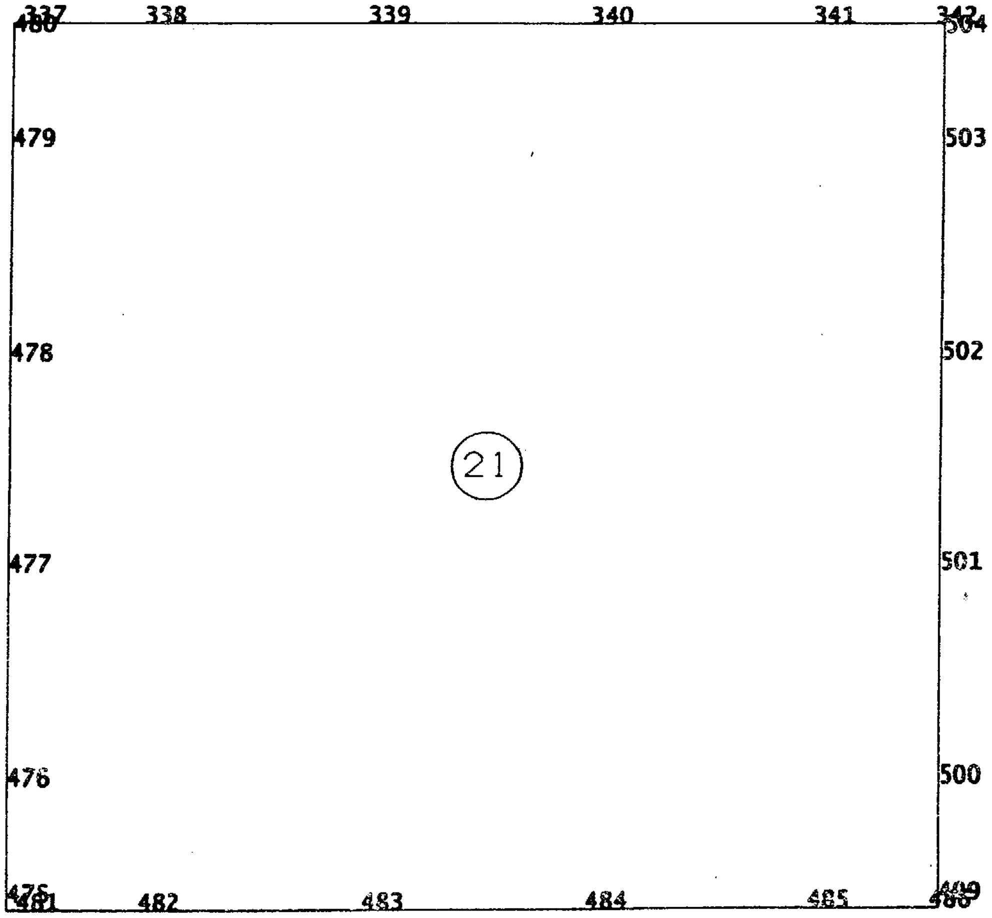
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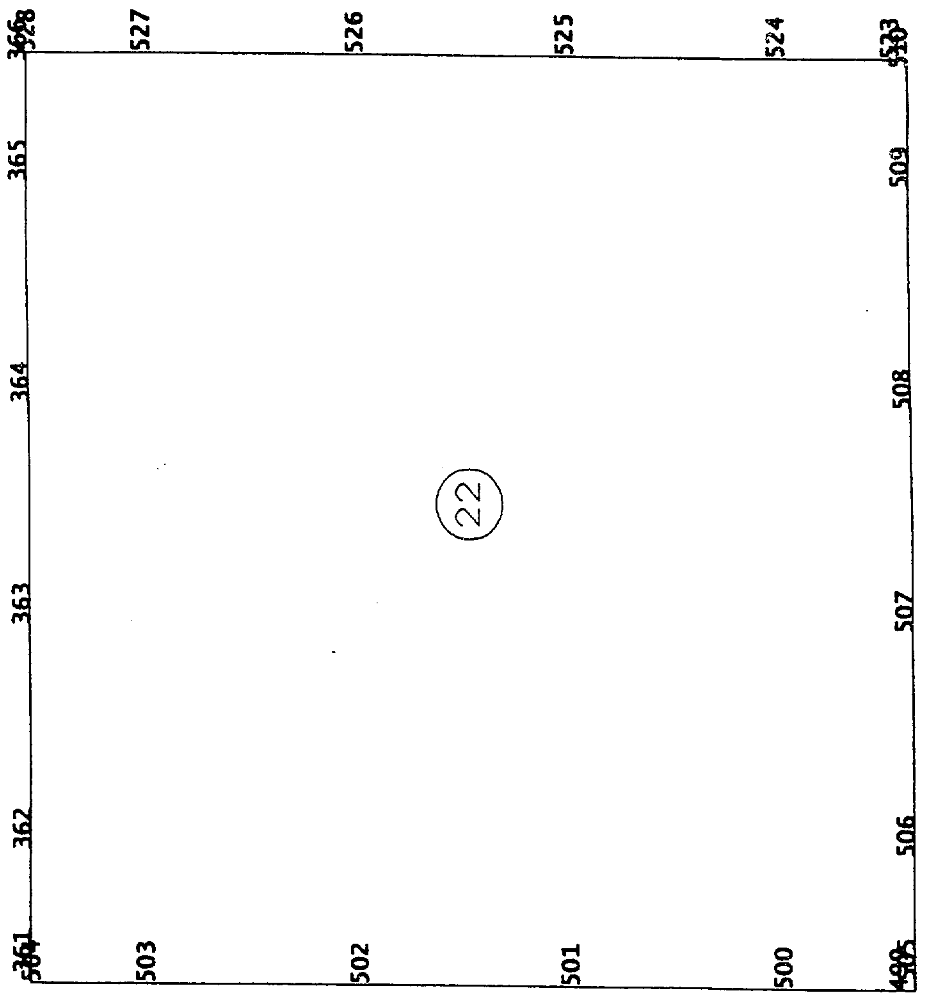
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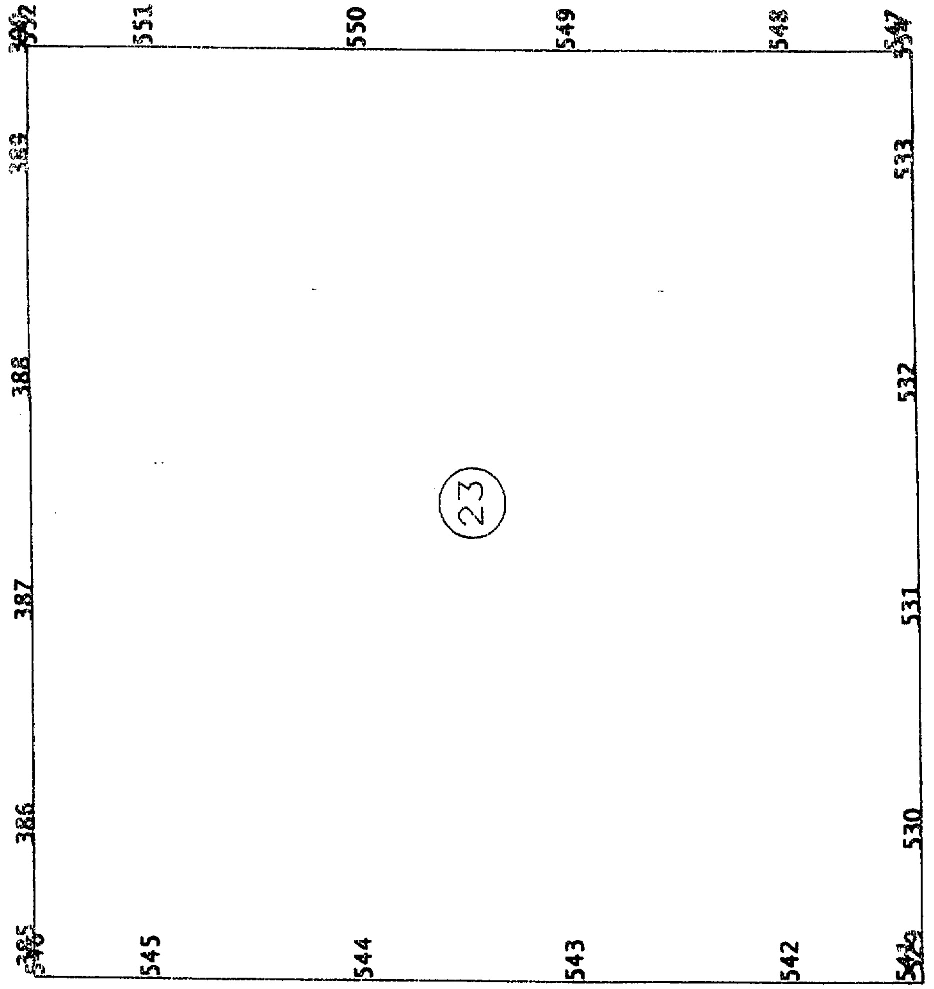

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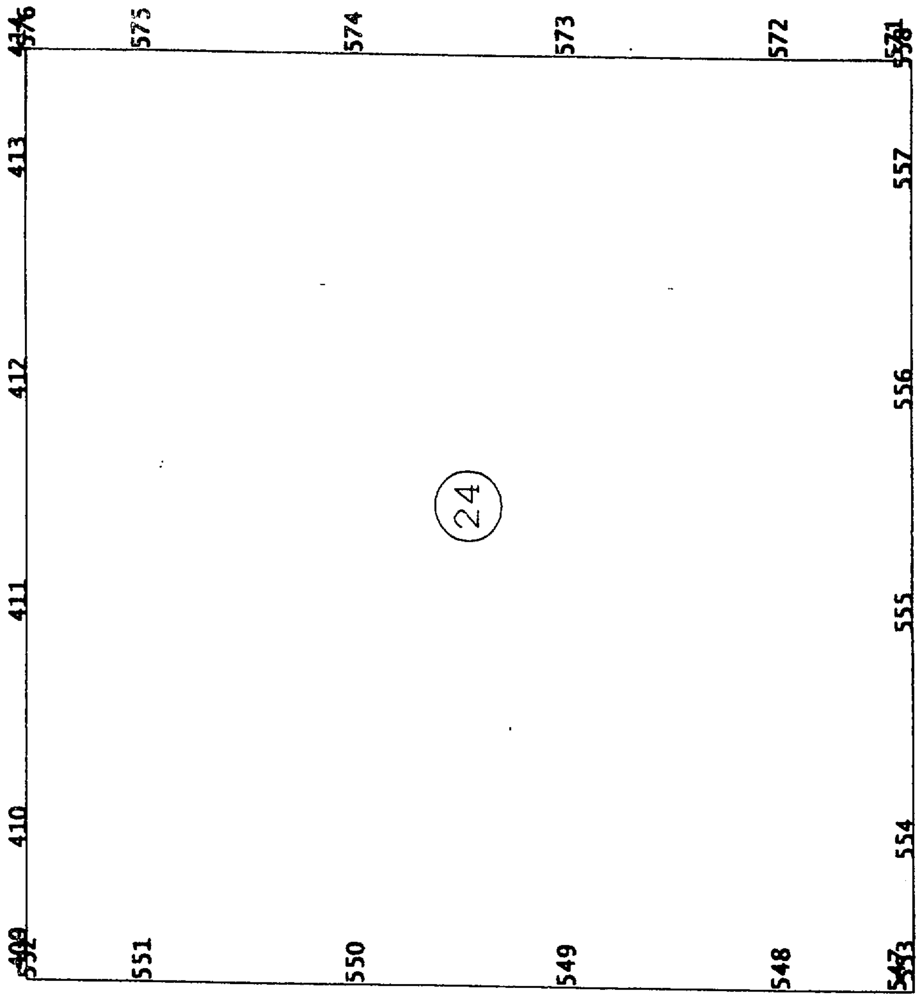
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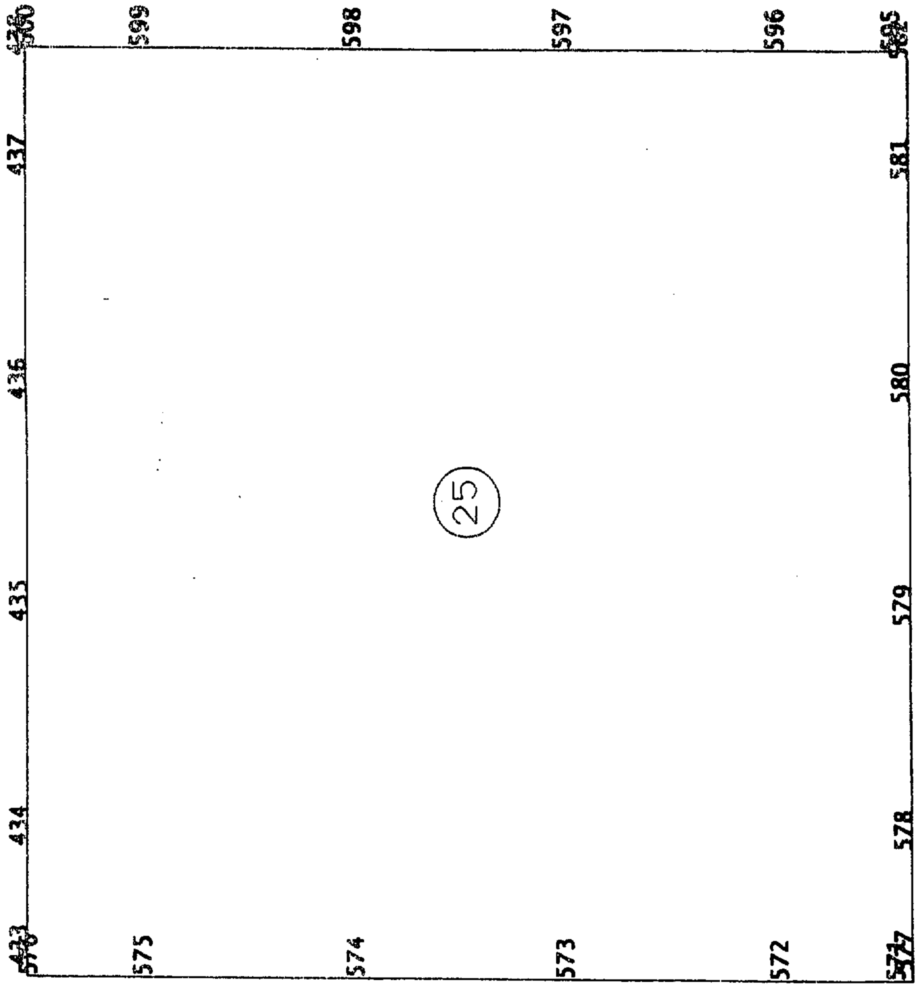
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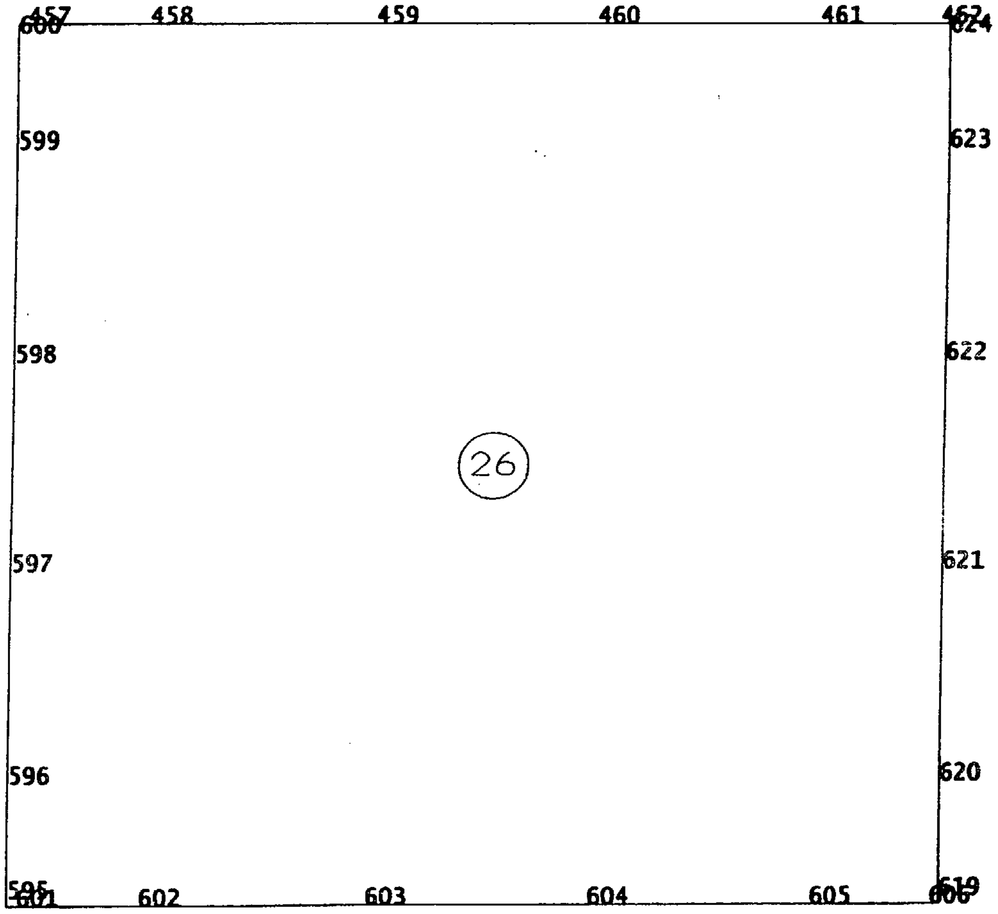
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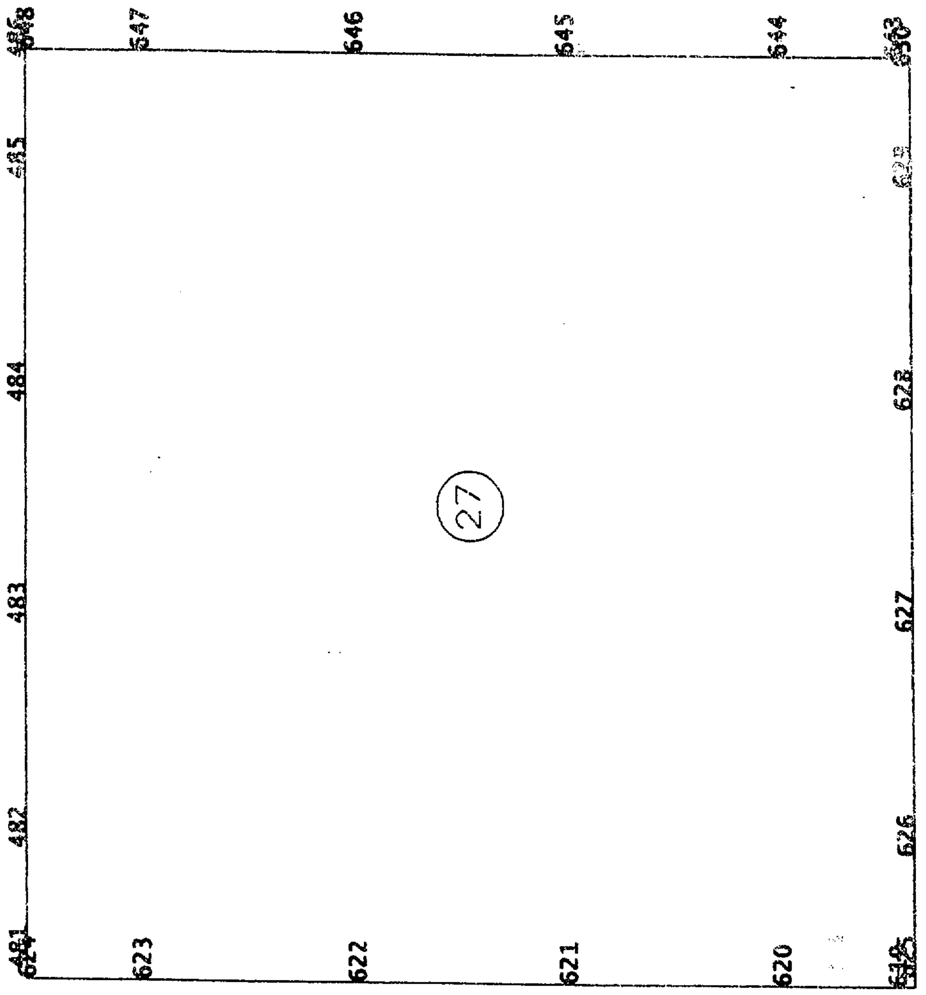
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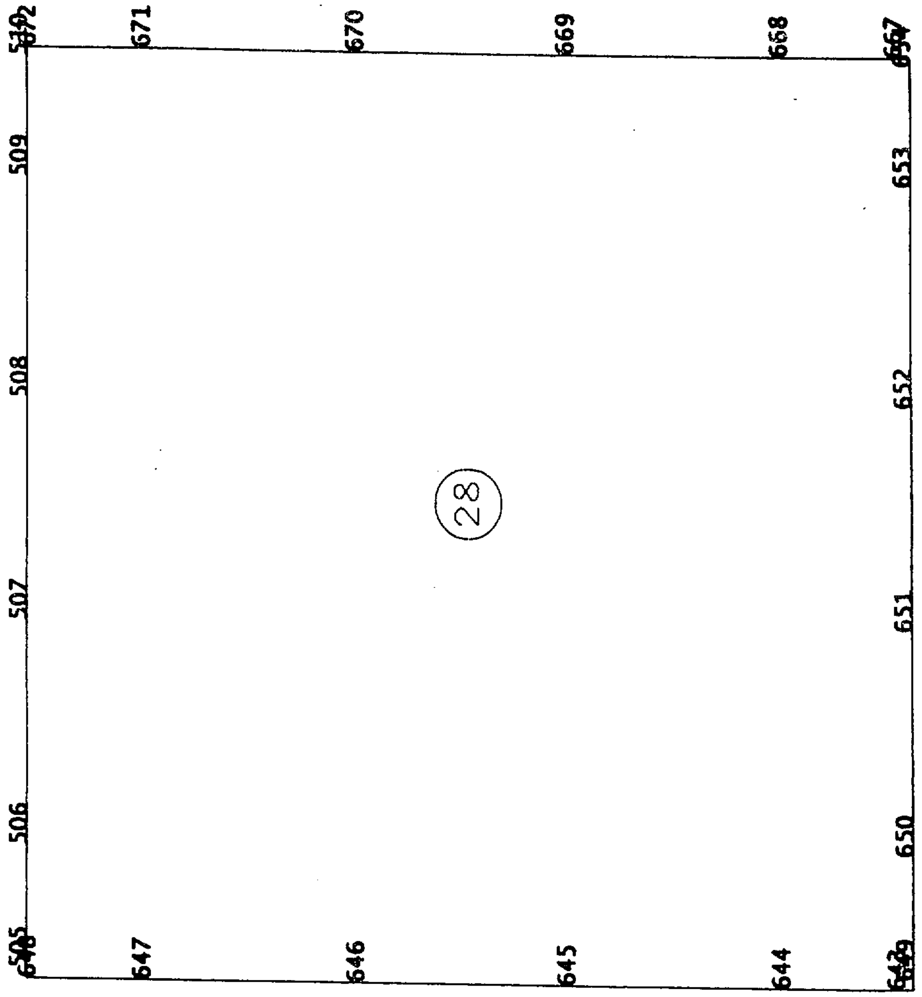
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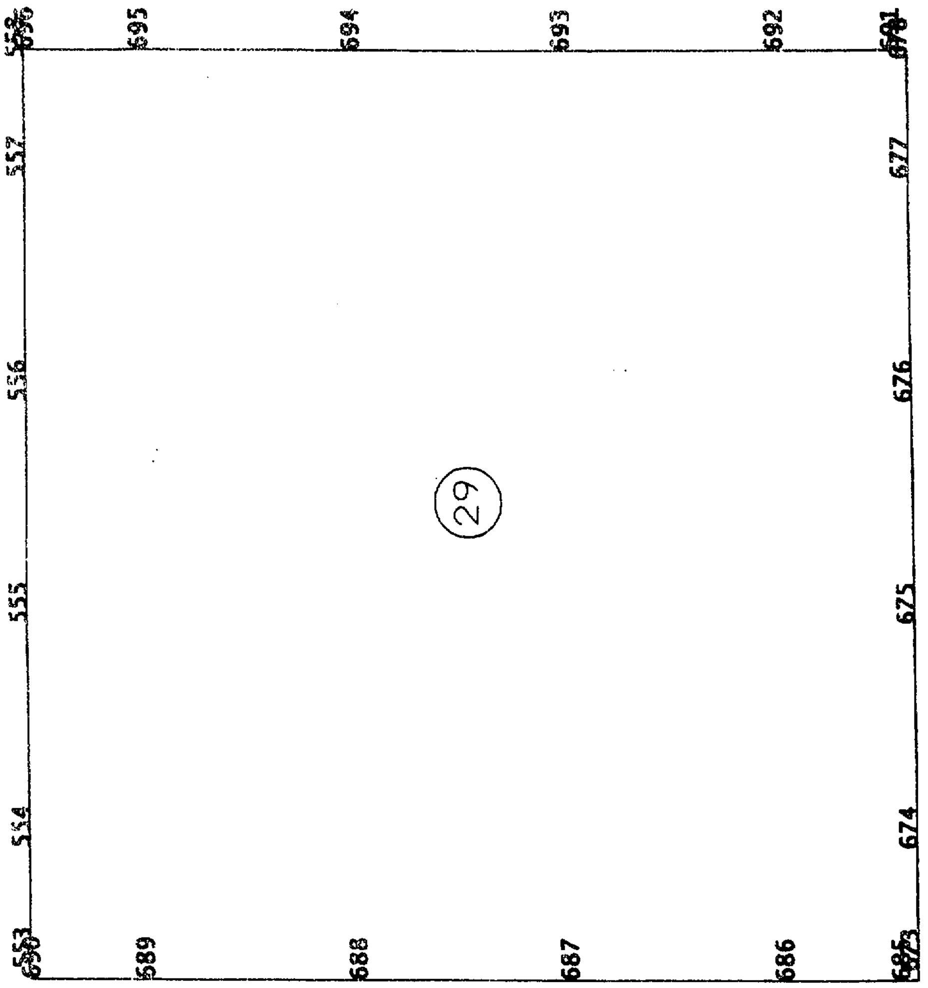
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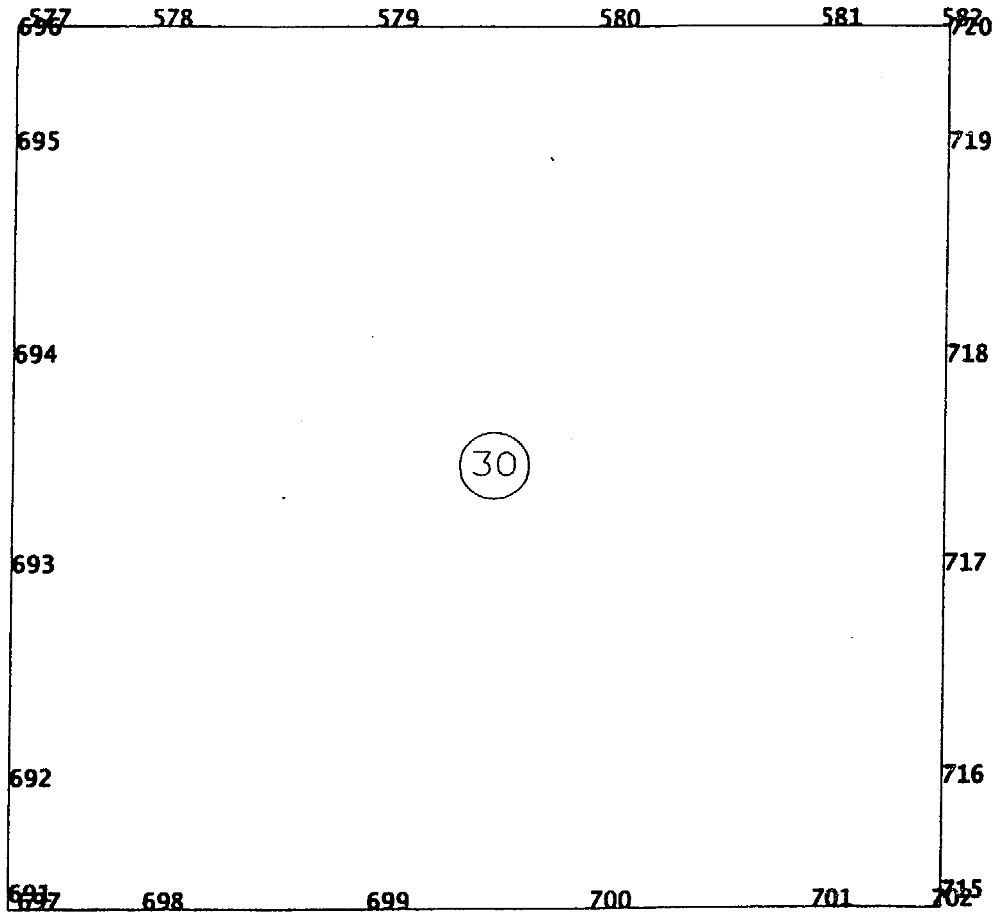
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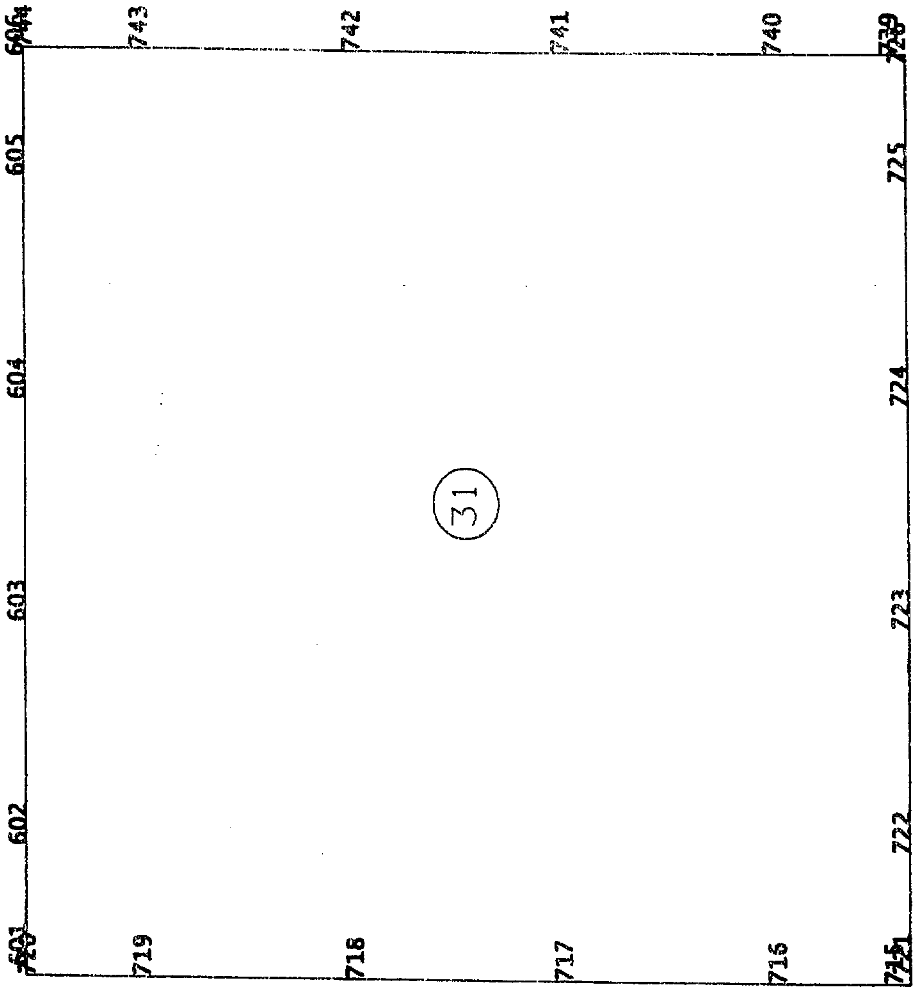
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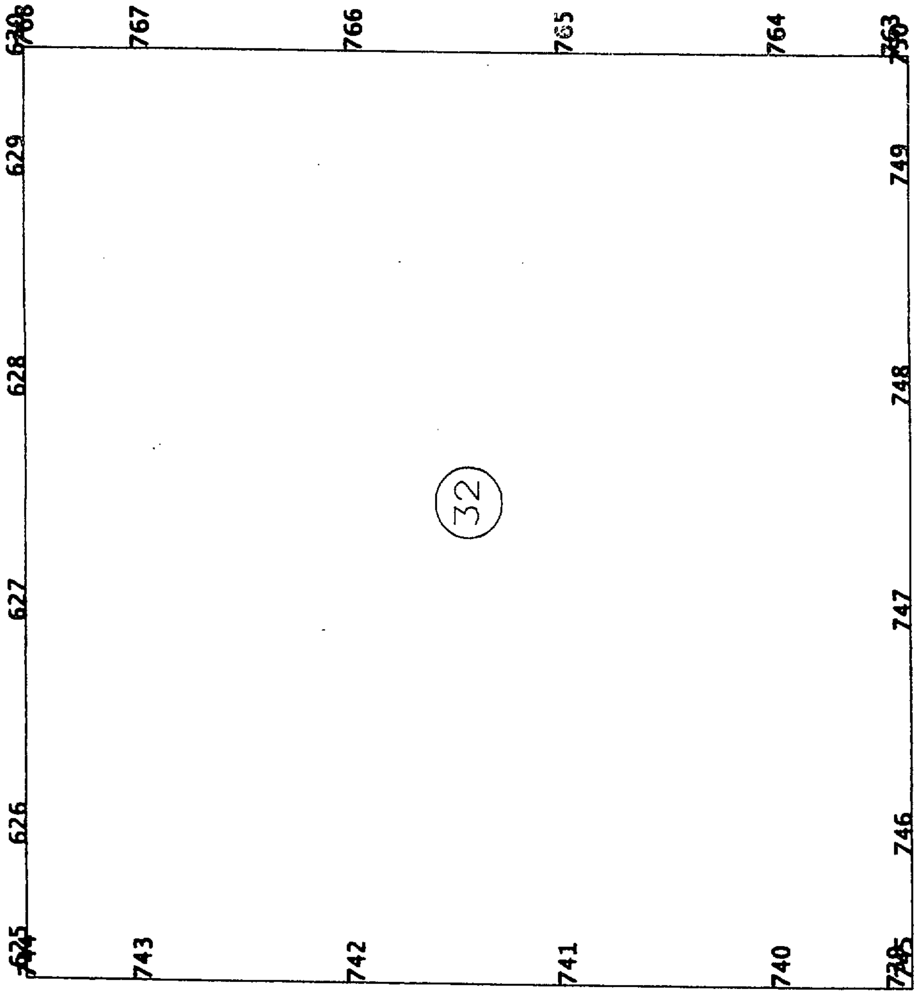
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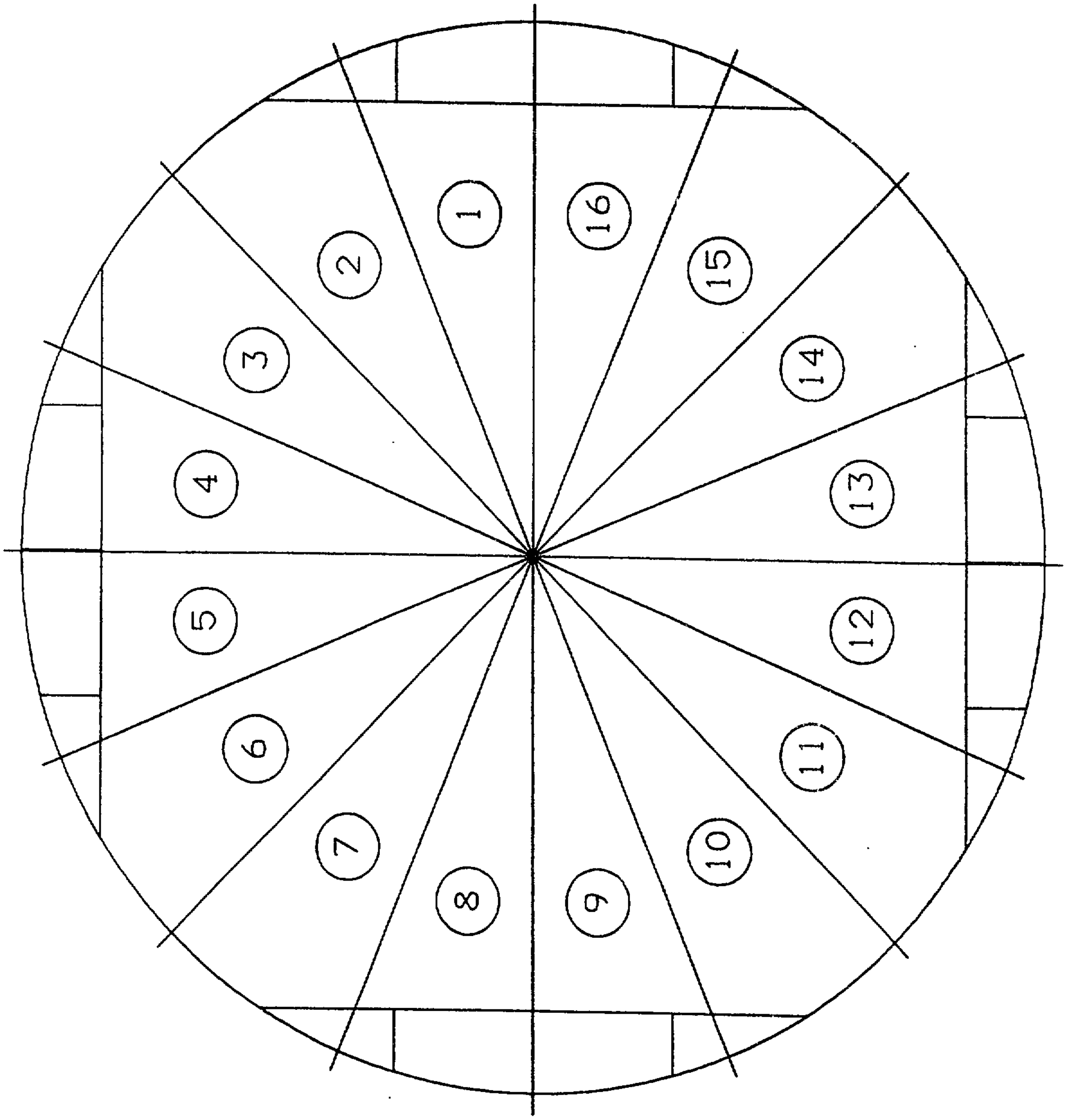
Appendix 3.Q - Detailed Finite Element Listings for the MPC-32 Enclosure Vessel

Eighteen (18) pages total including cover page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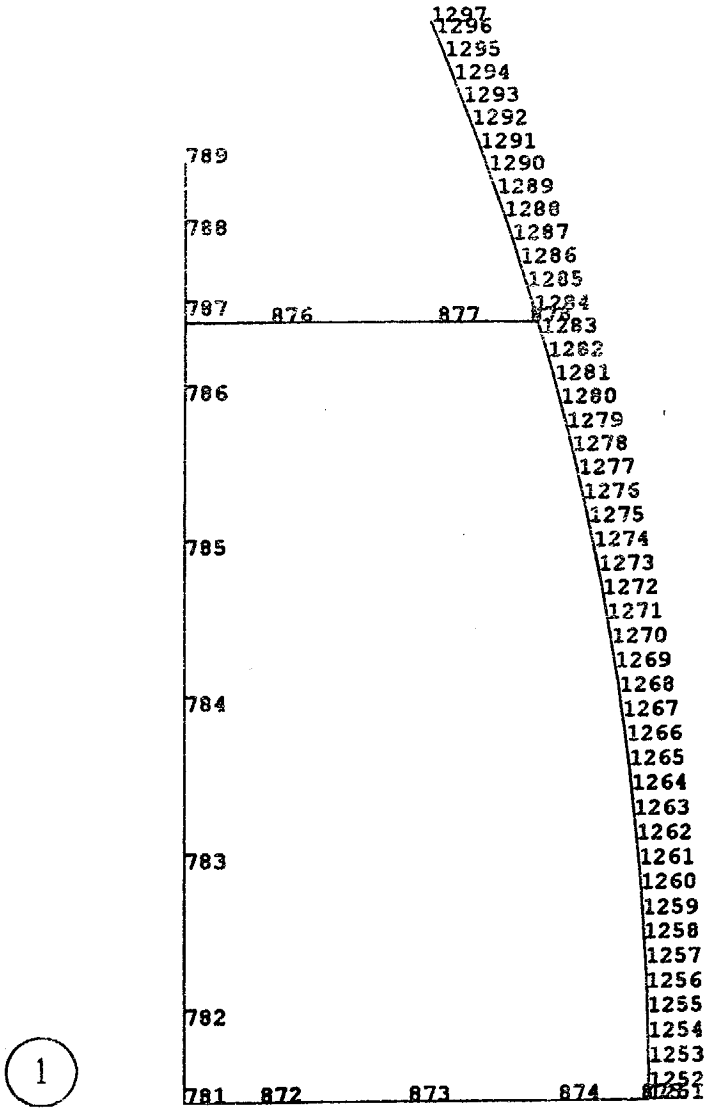
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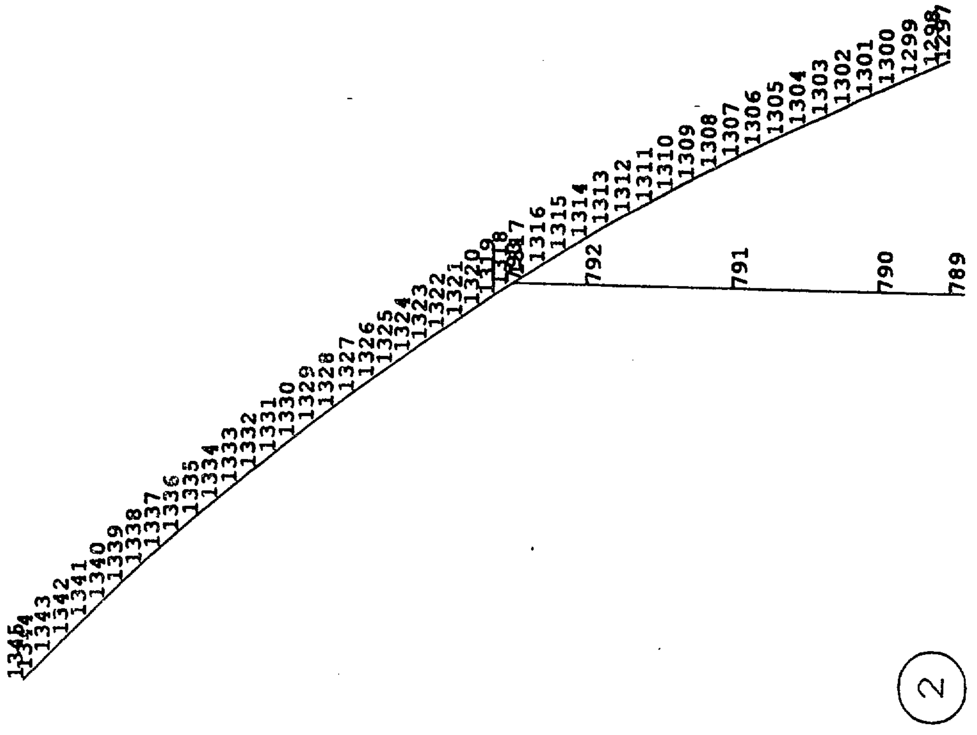
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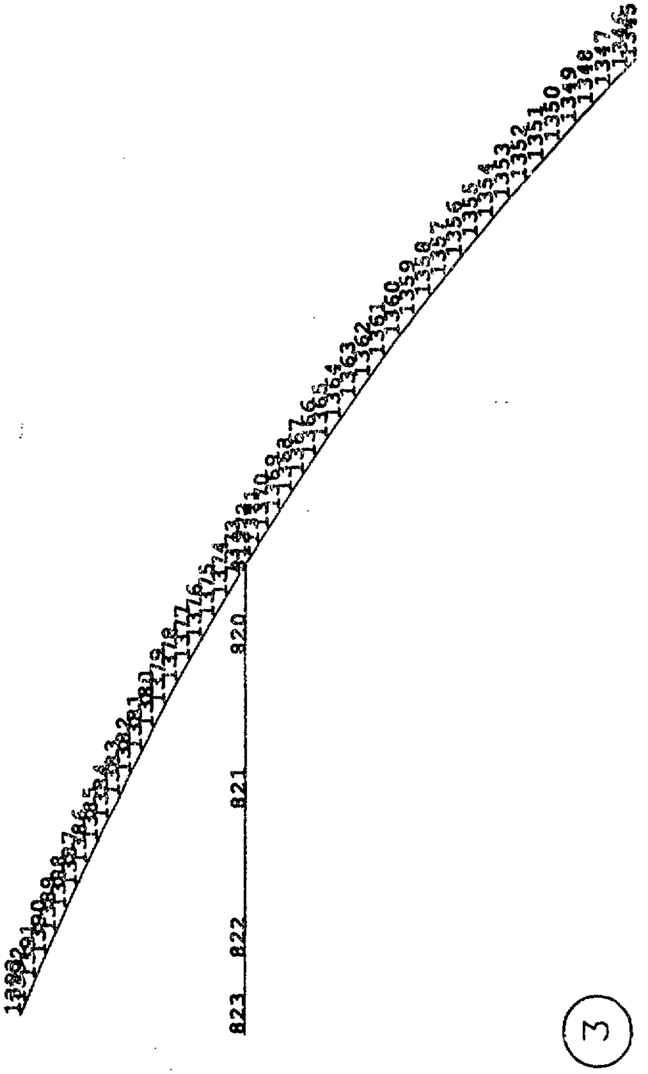

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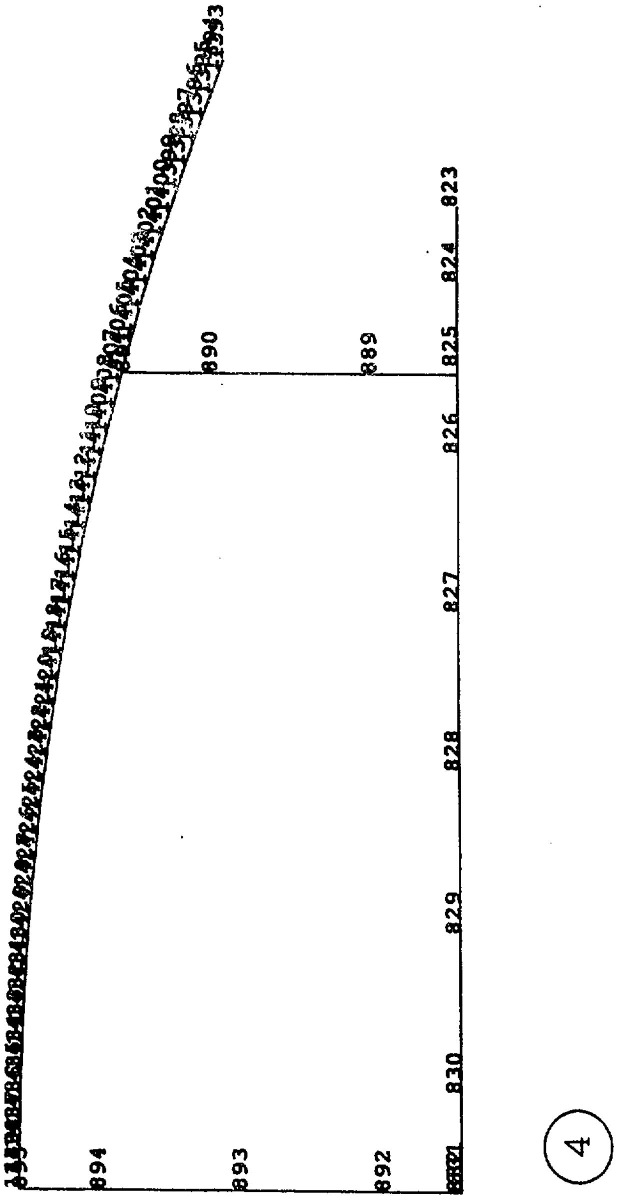
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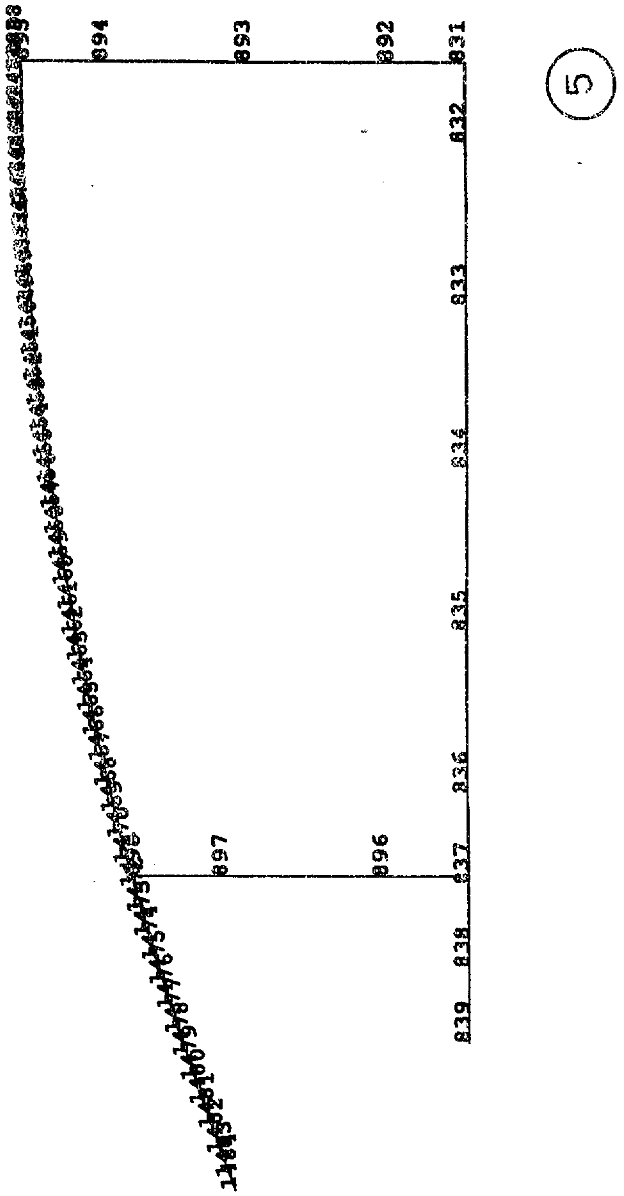
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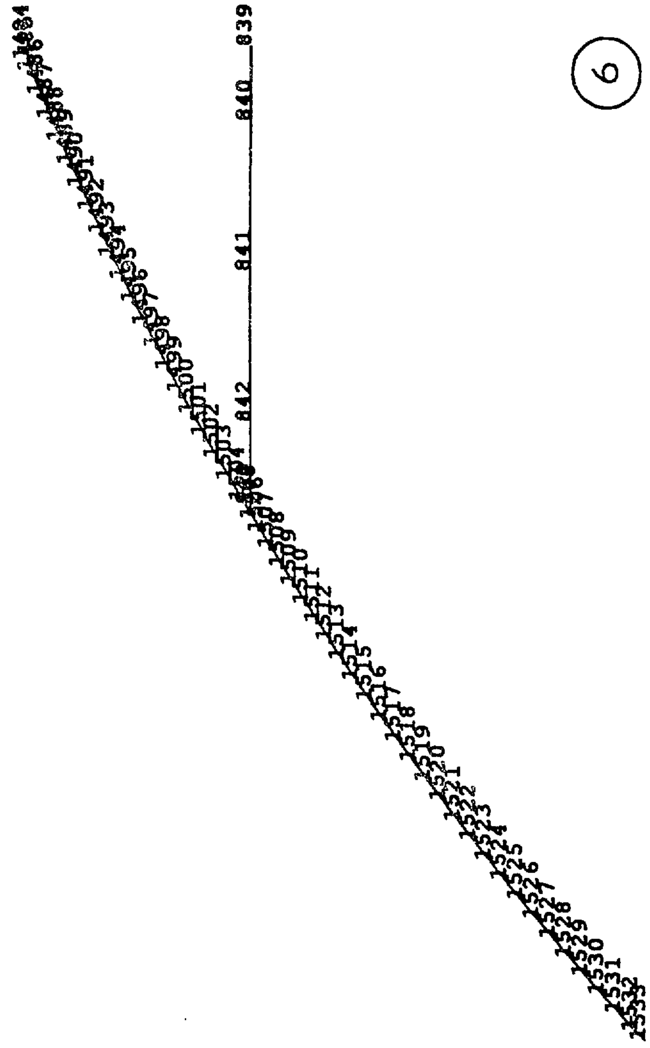
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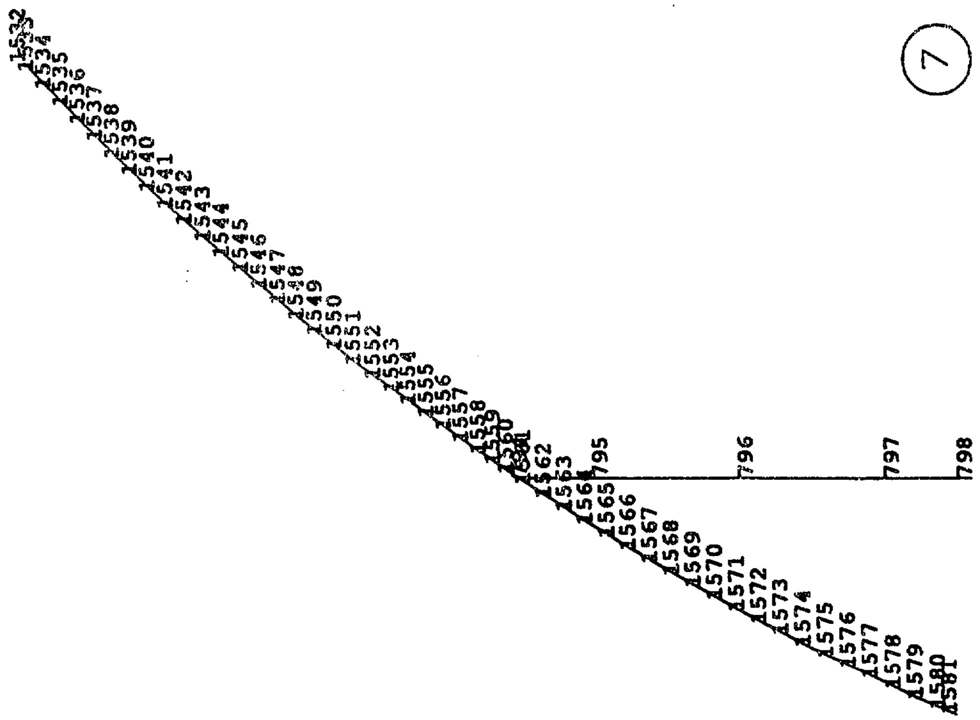
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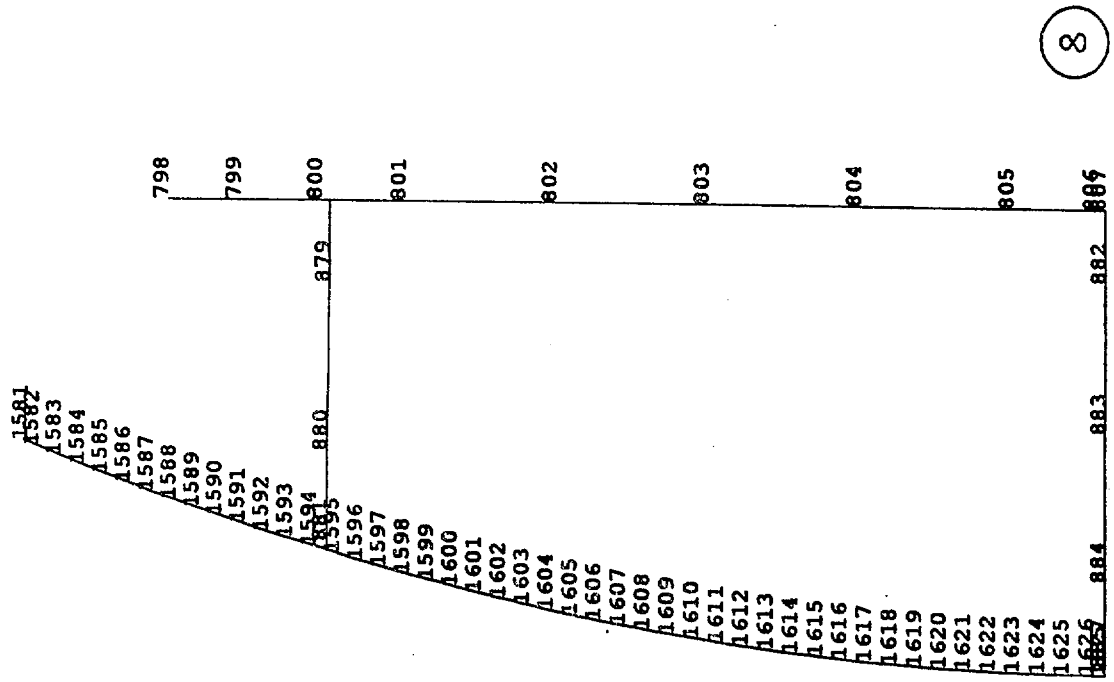
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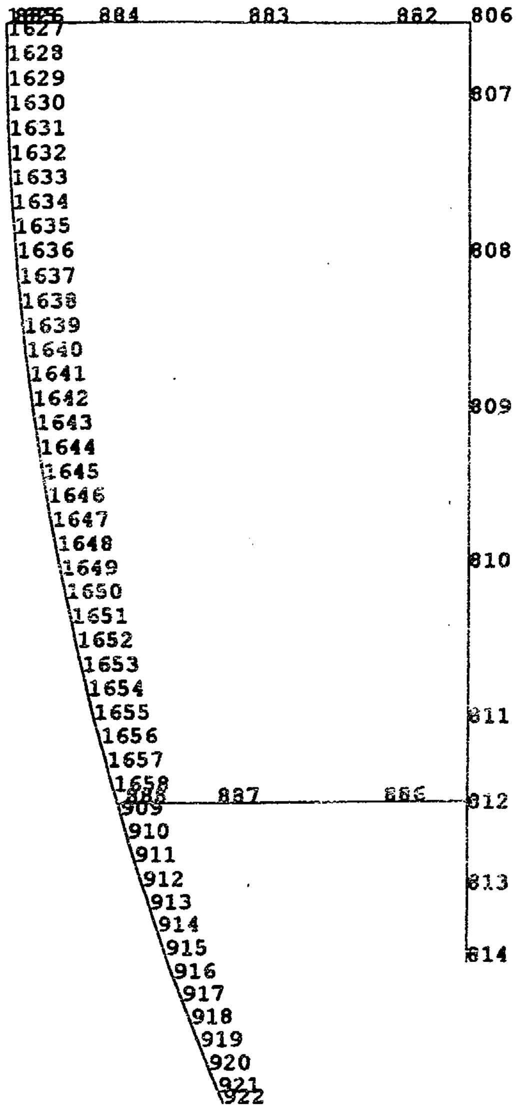
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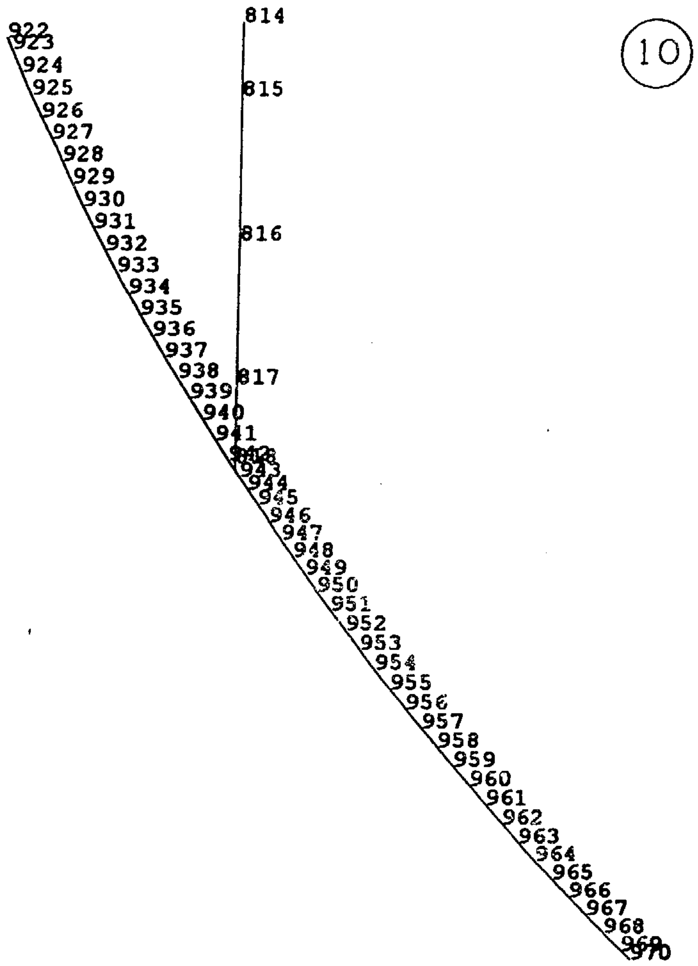
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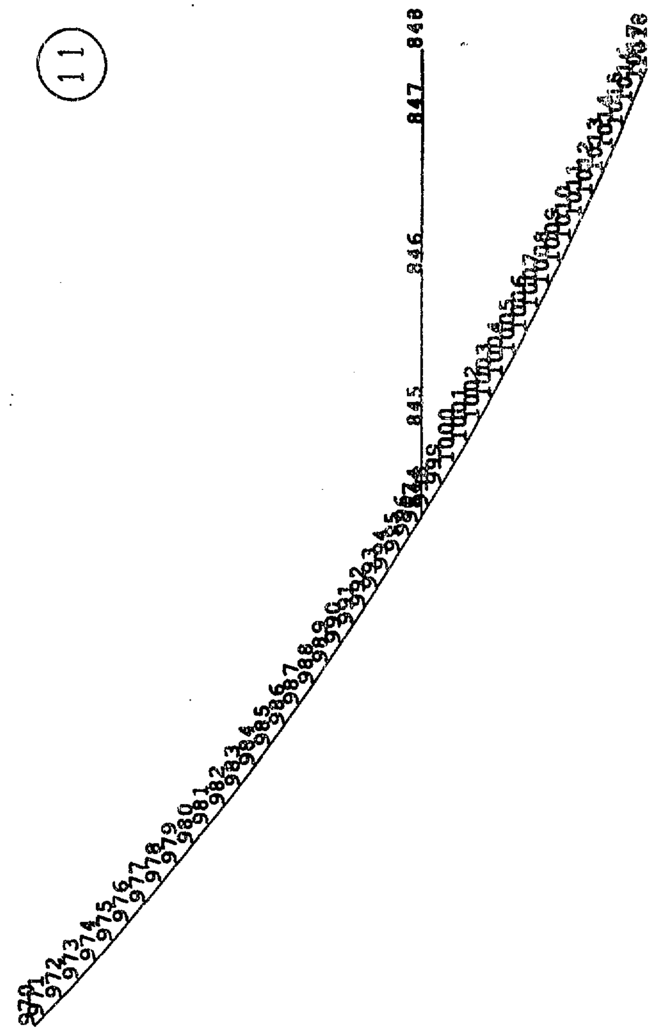
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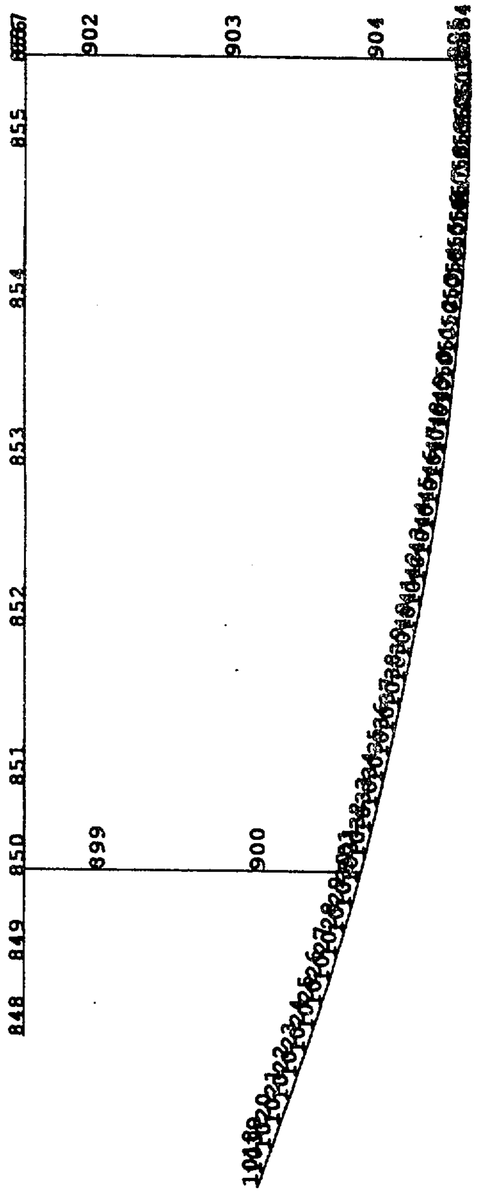

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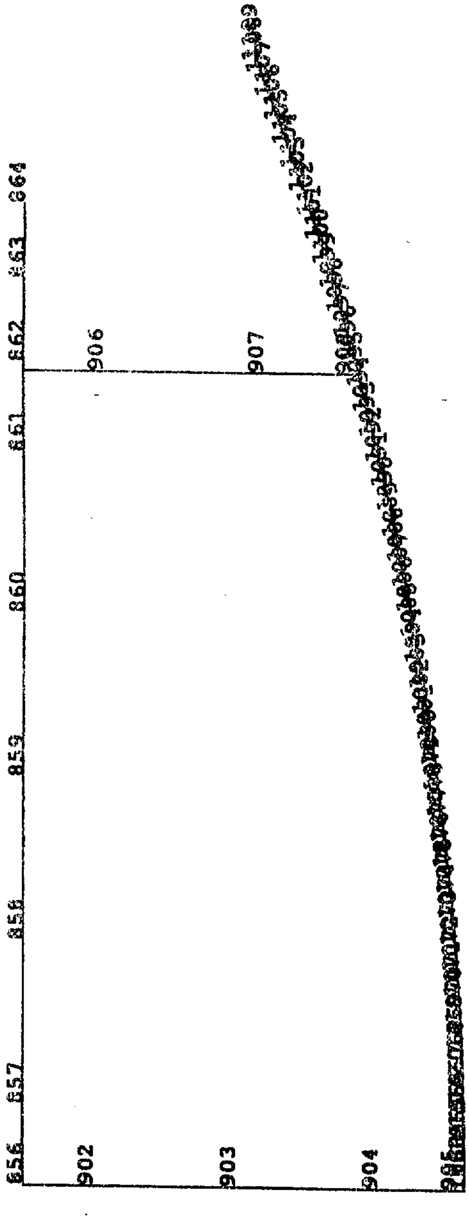

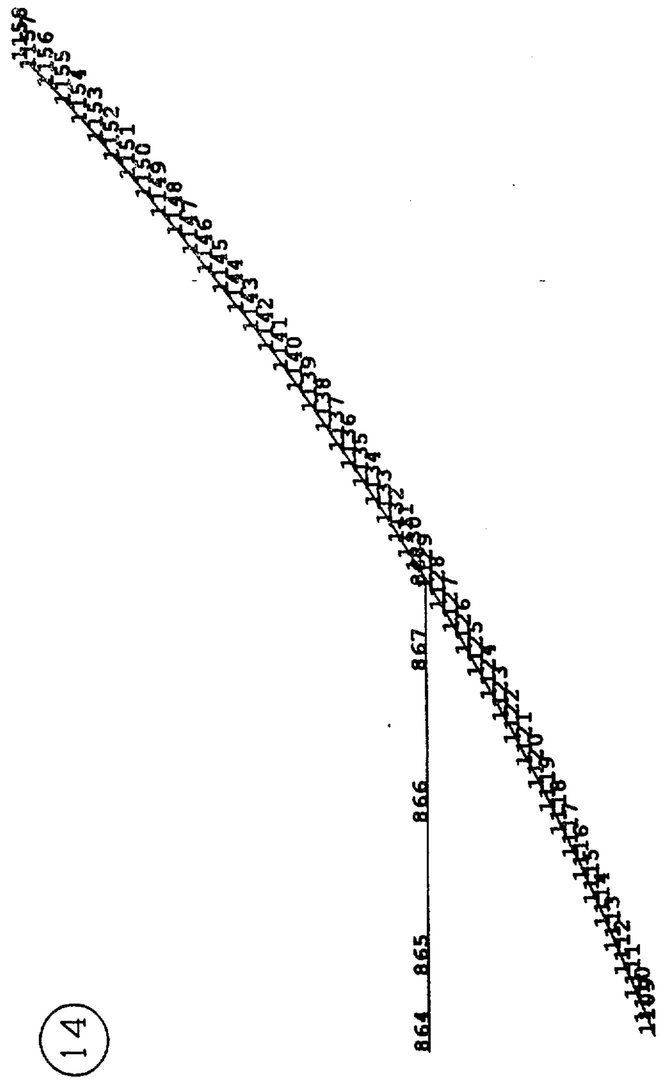
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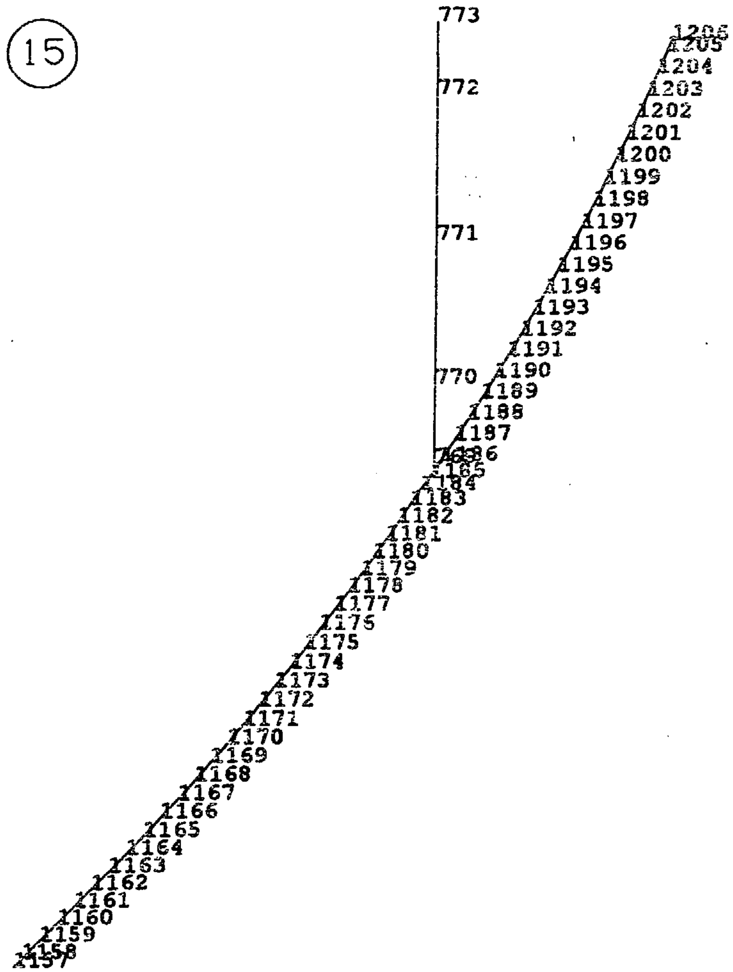
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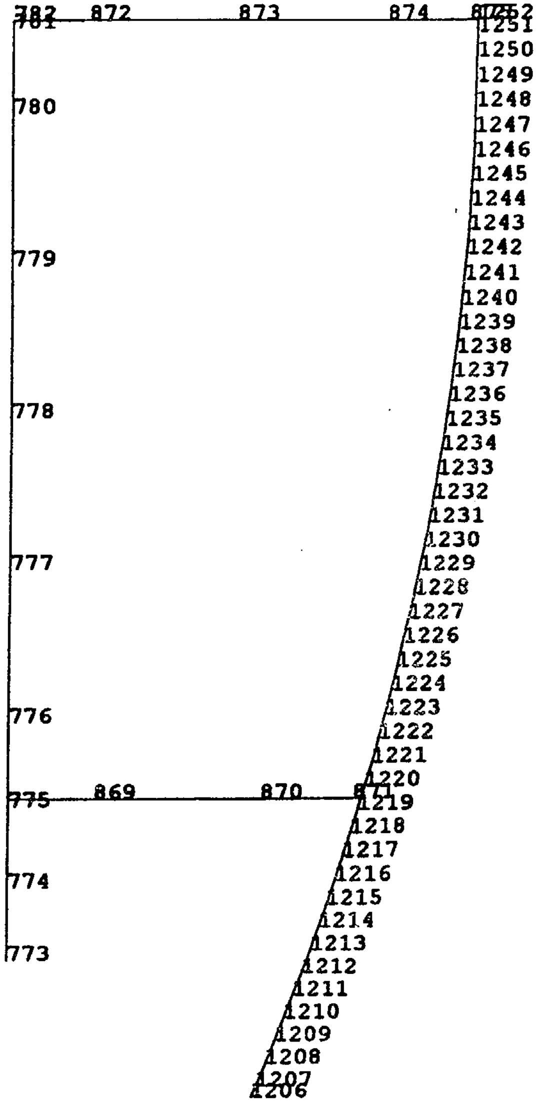
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Table 3.T.13

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Fuel Basket
SUBTITLE  2 =
Load Combination: F3.b (See Table 3.1.3)
SUBTITLE  3 =
Stress Result: Primary Membrane (PM)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT     CURRENT     CURRENT      PREVIOUS     PREVIOUS
   ELEM     REF TEMP    PM           ALLOW        SF
    715    725.00     -10523.       36950.       3.5114
    716    725.00     -10520.       36950.       3.5124
    717    725.00     -10482.       36950.       3.5252
    718    725.00     -10444.       36950.       3.5381
    719    725.00     -10405.       36950.       3.5510
    720    725.00     -10367.       36950.       3.5641
    691    725.00     -9712.6       36950.       3.8043
    692    725.00     -9709.4       36950.       3.8056
    739    725.00     -9709.2       36950.       3.8057
    740    725.00     -9706.0       36950.       3.8069
    693    725.00     -9671.1       36950.       3.8206
    741    725.00     -9667.7       36950.       3.8220
    694    725.00     -9632.9       36950.       3.8358
    742    725.00     -9629.4       36950.       3.8372
    695    725.00     -9594.8       36950.       3.8510
    743    725.00     -9591.4       36950.       3.8524
    696    725.00     -9556.7       36950.       3.8664
    744    725.00     -9553.3       36950.       3.8678
    763    725.00     -9393.1       36950.       3.9338
    685    725.00     -9390.6       36950.       3.9348
    764    725.00     -9390.0       36950.       3.9351
    686    725.00     -9387.5       36950.       3.9361
    765    725.00     -9351.6       36950.       3.9512
    687    725.00     -9349.1       36950.       3.9522
    766    725.00     -9313.2       36950.       3.9675
    688    725.00     -9310.6       36950.       3.9686
    767    725.00     -9274.8       36950.       3.9839
    689    725.00     -9272.3       36950.       3.9850
    768    725.00     -9236.7       36950.       4.0004
    690    725.00     -9234.2       36950.       4.0014
    595    725.00     -8479.9       36950.       4.3574
    596    725.00     -8476.8       36950.       4.3590
    597    725.00     -8438.6       36950.       4.3787
    598    725.00     -8400.5       36950.       4.3986
    599    725.00     -8362.3       36950.       4.4186
    600    725.00     -8324.2       36950.       4.4389
    571    725.00     -7864.5       36950.       4.6983
    619    725.00     -7861.7       36950.       4.7000
    572    725.00     -7861.3       36950.       4.7002
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Table 3.T.13 (continued)

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573	725.00	-7823.2	36950.	4.7231
621	725.00	-7820.4	36950.	4.7248
574	725.00	-7785.0	36950.	4.7463
622	725.00	-7782.2	36950.	4.7480
575	725.00	-7746.9	36950.	4.7696
623	725.00	-7744.1	36950.	4.7714
576	725.00	-7708.8	36950.	4.7932
624	725.00	-7706.0	36950.	4.7950
643	725.00	-7354.1	36950.	5.0244
547	725.00	-7352.2	36950.	5.0257
644	725.00	-7350.9	36950.	5.0266
548	725.00	-7348.9	36950.	5.0280
645	725.00	-7312.5	36950.	5.0530
549	725.00	-7310.6	36950.	5.0543
646	725.00	-7274.3	36950.	5.0795
550	725.00	-7272.4	36950.	5.0809
647	725.00	-7236.3	36950.	5.1062
551	725.00	-7234.3	36950.	5.1076
648	725.00	-7198.2	36950.	5.1332
552	725.00	-7196.3	36950.	5.1346
451	725.00	-6461.8	36950.	5.7182
452	725.00	-6458.7	36950.	5.7210
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454	725.00	-6382.4	36950.	5.7893
455	725.00	-6344.3	36950.	5.8242
456	725.00	-6306.1	36950.	5.8594
427	725.00	-5979.7	36950.	6.1793
475	725.00	-5977.4	36950.	6.1816
428	725.00	-5976.5	36950.	6.1825
476	725.00	-5974.3	36950.	6.1849
429	725.00	-5938.3	36950.	6.2223
477	725.00	-5936.1	36950.	6.2246
430	725.00	-5900.2	36950.	6.2625
478	725.00	-5897.9	36950.	6.2649
431	725.00	-5862.1	36950.	6.3032
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499	725.00	-5356.8	36950.	6.8978
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500	725.00	-5353.6	36950.	6.9018
404	725.00	-5352.1	36950.	6.9039
501	725.00	-5315.5	36950.	6.9514
405	725.00	-5313.9	36950.	6.9535
502	725.00	-5277.3	36950.	7.0017
406	725.00	-5275.7	36950.	7.0038
503	725.00	-5239.2	36950.	7.0526
407	725.00	-5237.6	36950.	7.0547
504	725.00	-5201.1	36950.	7.1043
408	725.00	-5199.5	36950.	7.1064
307	725.00	-4440.0	36950.	8.3221
308	725.00	-4436.9	36950.	8.3280

Table 3.T.13 (continued)

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312	725.00	-4284.3	36950.	8.6246
283	725.00	-4099.0	36950.	9.0145
331	725.00	-4097.3	36950.	9.0181
284	725.00	-4095.8	36950.	9.0214
332	725.00	-4094.2	36950.	9.0251
285	725.00	-4057.6	36950.	9.1063
333	725.00	-4056.0	36950.	9.1100
286	725.00	-4019.5	36950.	9.1927
334	725.00	-4017.8	36950.	9.1965
287	725.00	-3981.4	36950.	9.2807
335	725.00	-3979.7	36950.	9.2846
288	725.00	-3943.2	36950.	9.3705
336	725.00	-3941.6	36950.	9.3744
355	725.00	-3357.5	36950.	11.005
259	725.00	-3356.3	36950.	11.009
356	725.00	-3354.3	36950.	11.016
260	725.00	-3353.1	36950.	11.020
357	725.00	-3316.0	36950.	11.143
261	725.00	-3314.9	36950.	11.147
358	725.00	-3277.9	36950.	11.272
262	725.00	-3276.8	36950.	11.276
359	725.00	-3239.9	36950.	11.405
263	725.00	-3238.7	36950.	11.409
360	725.00	-3201.8	36950.	11.540
264	725.00	-3200.6	36950.	11.545
667	725.00	-2989.8	36950.	12.359
541	725.00	-2989.6	36950.	12.360
668	725.00	-2986.3	36950.	12.373
542	725.00	-2986.0	36950.	12.374
669	725.00	-2947.6	36950.	12.536
543	725.00	-2947.4	36950.	12.537
670	725.00	-2909.3	36950.	12.701
544	725.00	-2909.1	36950.	12.702
671	725.00	-2871.5	36950.	12.868
545	725.00	-2871.3	36950.	12.869
672	725.00	-2833.6	36950.	13.040
546	725.00	-2833.4	36950.	13.041
163	725.00	-2413.8	36950.	15.308
164	725.00	-2410.6	36950.	15.328
165	725.00	-2372.5	36950.	15.574
166	725.00	-2334.3	36950.	15.829
167	725.00	-2296.2	36950.	16.092
168	725.00	-2258.0	36950.	16.364
139	725.00	-2229.4	36950.	16.574
187	725.00	-2228.4	36950.	16.582
140	725.00	-2226.2	36950.	16.597
188	725.00	-2225.2	36950.	16.605
141	725.00	-2188.1	36950.	16.887
189	725.00	-2187.0	36950.	16.895
142	725.00	-2149.9	36950.	17.187

Table 3.T.13 (continued)

190	725.00	-2148.9	36950.	17.195
143	725.00	-2111.8	36950.	17.497
191	725.00	-2110.8	36950.	17.505
144	725.00	-2073.7	36950.	17.818
192	725.00	-2072.7	36950.	17.827
523	725.00	-2047.2	36950.	18.049
397	725.00	-2047.1	36950.	18.050
524	725.00	-2043.9	36950.	18.078
398	725.00	-2043.8	36950.	18.079
525	725.00	-2005.6	36950.	18.424
399	725.00	-2005.5	36950.	18.424
526	725.00	-1967.4	36950.	18.781
400	725.00	-1967.4	36950.	18.781
527	725.00	-1929.5	36950.	19.150
401	725.00	-1929.4	36950.	19.151
528	725.00	-1891.5	36950.	19.535
402	725.00	-1891.4	36950.	19.536
211	725.00	-1344.1	36950.	27.491
115	725.00	-1343.3	36950.	27.507
212	725.00	-1340.9	36950.	27.556
116	725.00	-1340.2	36950.	27.571
213	725.00	-1302.8	36950.	28.362
117	725.00	-1302.1	36950.	28.378
214	725.00	-1264.7	36950.	29.217
118	725.00	-1263.9	36950.	29.234
215	725.00	-1226.5	36950.	30.126
119	725.00	-1225.8	36950.	30.144
216	725.00	-1188.4	36950.	31.092
120	725.00	-1187.7	36950.	31.112
379	725.00	-1105.3	36950.	33.430
253	725.00	-1105.3	36950.	33.431
380	725.00	-1101.9	36950.	33.533
254	725.00	-1101.9	36950.	33.533
381	725.00	-1063.5	36950.	34.744
255	725.00	-1063.5	36950.	34.745
382	725.00	-1025.4	36950.	36.035
256	725.00	-1025.4	36950.	36.036
383	725.00	-987.60	36950.	37.414
257	725.00	-987.58	36950.	37.415
384	725.00	-949.74	36950.	38.906
258	725.00	-949.70	36950.	38.907
43	725.00	-406.19	36950.	90.967
44	725.00	-403.05	36950.	91.676
45	725.00	-364.91	36950.	101.26
46	725.00	-326.76	36950.	113.08
47	725.00	-288.62	36950.	128.02
19	725.00	-287.29	36950.	128.61
67	725.00	-286.83	36950.	128.82
20	725.00	-284.09	36950.	130.06
68	725.00	-283.64	36950.	130.27
48	725.00	-250.48	36950.	147.52
21	725.00	-245.88	36950.	150.27
69	725.00	-245.43	36950.	150.55

Table 3.T.13 (continued)

91	725.00	-225.03	36950.	164.20
13	725.00	-224.71	36950.	164.43
92	725.00	-221.85	36950.	166.56
14	725.00	-221.54	36950.	166.79
22	725.00	-207.74	36950.	177.86
70	725.00	-207.29	36950.	178.25
93	725.00	-183.65	36950.	201.20
15	725.00	-183.34	36950.	201.54
23	725.00	-169.67	36950.	217.78
71	725.00	-169.21	36950.	218.37
235	725.00	-168.01	36950.	219.93
109	725.00	-168.00	36950.	219.94
236	725.00	-164.84	36950.	224.16
110	725.00	-164.83	36950.	224.17
94	725.00	-145.47	36950.	254.00
16	725.00	-145.16	36950.	254.54
24	725.00	-131.58	36950.	280.81
72	725.00	-131.12	36950.	281.80
237	725.00	-126.65	36950.	291.76
111	725.00	-126.64	36950.	291.77
654	725.00	126.40	36950.	292.33
529	725.00	126.22	36950.	292.73
653	725.00	125.70	36950.	293.96
530	725.00	125.58	36950.	294.24
650	725.00	125.31	36950.	294.88
533	725.00	125.12	36950.	295.32
651	725.00	124.82	36950.	296.02
532	725.00	124.62	36950.	296.50
652	725.00	123.29	36950.	299.70
531	725.00	123.12	36950.	300.11
649	725.00	120.75	36950.	306.01
534	725.00	120.56	36950.	306.48
95	725.00	-107.32	36950.	344.29
17	725.00	-107.01	36950.	345.29
238	725.00	-88.462	36950.	417.69
112	725.00	-88.458	36950.	417.71
217	725.00	-84.963	36950.	434.90
102	725.00	-84.962	36950.	434.90
220	725.00	-81.587	36950.	452.89
99	725.00	-81.577	36950.	452.95
100	725.00	-80.671	36950.	458.03
219	725.00	-80.658	36950.	458.11
101	725.00	-80.563	36950.	458.65
750	725.00	80.526	36950.	458.86
218	725.00	-80.496	36950.	459.03
673	725.00	80.145	36950.	461.04
221	725.00	-79.770	36950.	463.21
98	725.00	-79.704	36950.	463.59
222	725.00	-79.484	36950.	464.87
97	725.00	-79.473	36950.	464.94
749	725.00	79.289	36950.	466.02
746	725.00	78.881	36950.	468.42
674	725.00	78.814	36950.	468.82

Table 3.T.13 (continued)

677	725.00	78.487	36950.	470.78
747	725.00	78.147	36950.	472.83
676	725.00	77.718	36950.	475.44
748	725.00	76.426	36950.	483.48
675	725.00	76.055	36950.	485.83
745	725.00	74.355	36950.	496.94
678	725.00	73.961	36950.	499.59
96	725.00	-69.183	36950.	534.09
18	725.00	-68.870	36950.	536.52
239	725.00	-50.290	36950.	734.74
113	725.00	-50.284	36950.	734.82
505	725.00	-44.628	36950.	827.96
390	725.00	-44.514	36950.	830.08
150	725.00	-41.161	36950.	897.70
169	725.00	-41.152	36950.	897.88
508	725.00	-40.472	36950.	912.97
387	725.00	-40.345	36950.	915.85
506	725.00	-39.854	36950.	927.14
389	725.00	-39.801	36950.	928.37
507	725.00	-39.641	36950.	932.12
388	725.00	-39.553	36950.	934.20
510	725.00	-39.155	36950.	943.68
385	725.00	-39.032	36950.	946.67
509	725.00	-38.931	36950.	949.12
386	725.00	-38.789	36950.	952.58
145	725.00	-37.926	36950.	974.27
174	725.00	-37.912	36950.	974.61
147	725.00	-36.913	36950.	1001.0
172	725.00	-36.893	36950.	1001.5
149	725.00	-36.827	36950.	1003.3
170	725.00	-36.815	36950.	1003.7
171	725.00	-36.519	36950.	1011.8
148	725.00	-36.511	36950.	1012.0
146	725.00	-36.146	36950.	1022.3
173	725.00	-36.144	36950.	1022.3
457	725.00	-32.458	36950.	1138.4
438	725.00	-32.453	36950.	1138.6
553	725.00	-29.757	36950.	1241.7
630	725.00	-29.646	36950.	1246.4
433	725.00	-29.483	36950.	1253.3
462	725.00	-29.482	36950.	1253.3
242	725.00	29.420	36950.	1255.9
365	725.00	29.382	36950.	1257.6
366	725.00	29.113	36950.	1269.2
241	725.00	29.110	36950.	1269.3
126	725.00	-29.020	36950.	1273.3
193	725.00	-29.001	36950.	1274.1
198	725.00	-28.966	36950.	1275.6
121	725.00	-28.952	36950.	1276.3
558	725.00	-28.891	36950.	1278.9
363	725.00	28.782	36950.	1283.8
244	725.00	28.751	36950.	1285.2
625	725.00	-28.740	36950.	1285.7

Table 3.T.13 (continued)

362	725.00	28.658	36950.	1289.3
245	725.00	28.593	36950.	1292.3
435	725.00	-28.245	36950.	1308.2
460	725.00	-28.243	36950.	1308.3
458	725.00	-28.195	36950.	1310.5
437	725.00	-28.170	36950.	1311.7
83	725.00	-28.103	36950.	1314.8
84	725.00	-28.097	36950.	1315.1
82	725.00	-28.069	36950.	1316.4
81	725.00	-27.982	36950.	1320.5
459	725.00	-27.895	36950.	1324.6
436	725.00	-27.881	36950.	1325.3
80	725.00	-27.880	36950.	1325.3
8	725.00	-27.850	36950.	1326.7
7	725.00	-27.847	36950.	1326.9
79	725.00	-27.827	36950.	1327.9
9	725.00	-27.818	36950.	1328.3
10	725.00	-27.729	36950.	1332.5
11	725.00	-27.628	36950.	1337.4
243	725.00	27.624	36950.	1337.6
364	725.00	27.623	36950.	1337.6
12	725.00	-27.573	36950.	1340.1
434	725.00	-27.567	36950.	1340.4
461	725.00	-27.559	36950.	1340.8
123	725.00	-26.231	36950.	1408.6
196	725.00	-26.230	36950.	1408.7
124	725.00	-26.195	36950.	1410.6
195	725.00	-26.193	36950.	1410.7
554	725.00	-26.095	36950.	1416.0
197	725.00	-26.004	36950.	1421.0
556	725.00	-25.999	36950.	1421.2
629	725.00	-25.990	36950.	1421.7
122	725.00	-25.952	36950.	1423.8
555	725.00	-25.937	36950.	1424.6
125	725.00	-25.930	36950.	1425.0
194	725.00	-25.894	36950.	1427.0
627	725.00	-25.853	36950.	1429.2
628	725.00	-25.825	36950.	1430.8
557	725.00	-25.786	36950.	1433.0
626	725.00	-25.695	36950.	1438.0
361	725.00	23.722	36950.	1557.6
246	725.00	23.711	36950.	1558.4
34	725.00	19.939	36950.	1853.1
35	725.00	19.865	36950.	1860.1
33	725.00	19.792	36950.	1866.9
36	725.00	19.660	36950.	1879.5
32	725.00	19.651	36950.	1880.3
31	725.00	19.568	36950.	1888.3
57	725.00	19.558	36950.	1889.3
56	725.00	19.486	36950.	1896.2
58	725.00	19.412	36950.	1903.4
55	725.00	19.281	36950.	1916.4
59	725.00	19.273	36950.	1917.2

Table 3.T.13 (continued)

60	725.00	19.190	36950.	1925.5
223	725.00	-19.025	36950.	1942.2
108	725.00	-18.995	36950.	1945.3
228	725.00	-18.568	36950.	1990.0
224	725.00	-18.564	36950.	1990.5
227	725.00	-18.558	36950.	1991.0
107	725.00	-18.546	36950.	1992.4
103	725.00	-18.540	36950.	1993.0
104	725.00	-18.532	36950.	1993.9
226	725.00	-18.381	36950.	2010.2
105	725.00	-18.356	36950.	2013.0
225	725.00	-18.281	36950.	2021.3
106	725.00	-18.256	36950.	2024.0
481	725.00	-16.965	36950.	2178.0
414	725.00	-16.924	36950.	2183.3
30	725.00	-16.264	36950.	2272.0
49	725.00	-16.221	36950.	2277.9
486	725.00	-16.198	36950.	2281.1
409	725.00	-16.125	36950.	2291.5
484	725.00	-14.256	36950.	2591.9
411	725.00	-14.191	36950.	2603.8
483	725.00	-14.131	36950.	2614.8
412	725.00	-14.078	36950.	2624.7
482	725.00	-13.795	36950.	2678.5
413	725.00	-13.746	36950.	2688.1
485	725.00	-13.720	36950.	2693.2
25	725.00	-13.634	36950.	2710.1
410	725.00	-13.620	36950.	2713.0
54	725.00	-13.586	36950.	2719.7
27	725.00	-12.147	36950.	3042.0
240	725.00	-12.136	36950.	3044.6
114	725.00	-12.127	36950.	3047.0
29	725.00	-12.092	36950.	3055.7
52	725.00	-12.091	36950.	3056.0
50	725.00	-12.041	36950.	3068.6
28	725.00	-11.817	36950.	3126.7
51	725.00	-11.793	36950.	3133.3
26	725.00	-11.537	36950.	3202.7
53	725.00	-11.505	36950.	3211.6
723	725.00	11.026	36950.	3351.0
722	725.00	10.788	36950.	3425.2
725	725.00	10.724	36950.	3445.6
724	725.00	10.677	36950.	3460.8
700	725.00	10.269	36950.	3598.3
701	725.00	10.119	36950.	3651.5
698	725.00	9.9345	36950.	3719.4
699	725.00	9.9285	36950.	3721.6
317	725.00	8.0676	36950.	4580.1
290	725.00	8.0462	36950.	4592.2
315	725.00	7.9222	36950.	4664.1
292	725.00	7.9207	36950.	4665.0
338	725.00	7.7564	36950.	4763.8
269	725.00	7.7298	36950.	4780.2

Table 3.T.13 (continued)

266	725.00	7.6719	36950.	4816.3
341	725.00	7.6419	36950.	4835.2
726	725.00	7.6120	36950.	4854.1
293	725.00	7.5773	36950.	4876.4
314	725.00	7.5773	36950.	4876.4
339	725.00	7.4413	36950.	4965.5
268	725.00	7.4282	36950.	4974.3
316	725.00	7.3052	36950.	5058.1
291	725.00	7.2846	36950.	5072.3
340	725.00	7.1464	36950.	5170.4
267	725.00	7.1395	36950.	5175.4
721	725.00	6.8912	36950.	5361.9
697	725.00	6.8501	36950.	5394.0
318	725.00	6.1546	36950.	6003.7
702	725.00	6.1371	36950.	6020.7
289	725.00	6.1354	36950.	6022.4
605	725.00	6.0319	36950.	6125.8
2	725.00	6.0059	36950.	6152.3
77	725.00	5.9969	36950.	6161.5
578	725.00	5.9622	36950.	6197.4
603	725.00	5.7900	36950.	6381.7
580	725.00	5.7707	36950.	6403.0
74	725.00	5.4714	36950.	6753.3
5	725.00	5.3928	36950.	6851.7
581	725.00	5.3921	36950.	6852.6
602	725.00	5.3520	36950.	6904.0
78	725.00	5.1869	36950.	7123.7
75	725.00	5.1790	36950.	7134.6
1	725.00	5.1636	36950.	7155.9
4	725.00	5.1466	36950.	7179.6
604	725.00	5.0651	36950.	7295.0
579	725.00	5.0536	36950.	7311.6
265	725.00	4.9715	36950.	7432.4
342	725.00	4.9675	36950.	7438.3
606	725.00	4.4179	36950.	8363.7
577	725.00	4.3990	36950.	8399.6
76	725.00	4.3564	36950.	8481.8
337	725.00	4.3475	36950.	8499.1
270	725.00	4.3207	36950.	8551.8
3	725.00	4.3194	36950.	8554.5
313	725.00	3.0631	36950.	12063.
294	725.00	3.0516	36950.	12108.
73	725.00	1.3056	36950.	28300.
6	725.00	1.2516	36950.	29522.
582	725.00	-.35319	36950.	.10462E+06
601	725.00	-.33870	36950.	.10909E+06

Table 3.T.14

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Fuel Basket
SUBTITLE  2 =
Load Combination: F3.b (See Table 3.1.3)
SUBTITLE  3 =
Stress Result: Local Membrane Plus Primary Bending (PL+PB)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT     CURRENT      CURRENT      PREVIOUS     PREVIOUS
   ELEM     REF TEMP     PL+PB        ALLOW        SF
    390   725.00       36619.       55450.       1.5142
    505   725.00       36611.       55450.       1.5146
    246   725.00       36204.       55450.       1.5316
    361   725.00       36201.       55450.       1.5317
    217   725.00       35860.       55450.       1.5463
    102   725.00       35860.       55450.       1.5463
    678   725.00       35487.       55450.       1.5625
    534   725.00       35472.       55450.       1.5632
    649   725.00       35452.       55450.       1.5641
    745   725.00       35423.       55450.       1.5654
    582   725.00       35217.       55450.       1.5745
    601   725.00       35201.       55450.       1.5752
    169   725.00       34675.       55450.       1.5991
    150   725.00       34665.       55450.       1.5996
    313   725.00       34487.       55450.       1.6078
    294   725.00       34480.       55450.       1.6082
    457   725.00       34417.       55450.       1.6111
    438   725.00       34414.       55450.       1.6113
     49   725.00       34026.       55450.       1.6296
     30   725.00       34013.       55450.       1.6302
      6   725.00       33540.       55450.       1.6532
     73   725.00       33496.       55450.       1.6554
    389   725.00       32887.       55450.       1.6861
    506   725.00       32879.       55450.       1.6865
    245   725.00       32482.       55450.       1.7071
    362   725.00       32480.       55450.       1.7072
    702   725.00       32234.       55450.       1.7202
    721   725.00       32218.       55450.       1.7211
    218   725.00       32108.       55450.       1.7270
    101   725.00       32108.       55450.       1.7270
    533   725.00       31684.       55450.       1.7501
    650   725.00       31665.       55450.       1.7511
    677   725.00       31643.       55450.       1.7523
    581   725.00       31625.       55450.       1.7533
    602   725.00       31610.       55450.       1.7542
    746   725.00       31582.       55450.       1.7558
    630   725.00       31167.       55450.       1.7791
    170   725.00       31106.       55450.       1.7826
    149   725.00       31097.       55450.       1.7831
```

Table 3.T.14 (continued)

553	725.00	31096.	55450.	1.7832
314	725.00	30937.	55450.	1.7924
293	725.00	30930.	55450.	1.7928
458	725.00	30865.	55450.	1.7966
437	725.00	30862.	55450.	1.7967
414	725.00	30513.	55450.	1.8172
50	725.00	30494.	55450.	1.8184
29	725.00	30482.	55450.	1.8191
270	725.00	30470.	55450.	1.8198
481	725.00	30462.	55450.	1.8203
337	725.00	30423.	55450.	1.8227
126	725.00	30070.	55450.	1.8440
193	725.00	30025.	55450.	1.8468
5	725.00	29922.	55450.	1.8531
74	725.00	29880.	55450.	1.8557
558	725.00	29731.	55450.	1.8650
625	725.00	29657.	55450.	1.8697
726	725.00	28952.	55450.	1.9152
697	725.00	28950.	55450.	1.9153
198	725.00	28907.	55450.	1.9182
121	725.00	28865.	55450.	1.9210
701	725.00	28821.	55450.	1.9240
722	725.00	28805.	55450.	1.9250
629	725.00	27782.	55450.	1.9959
554	725.00	27713.	55450.	2.0009
342	725.00	27563.	55450.	2.0117
265	725.00	27518.	55450.	2.0150
486	725.00	27149.	55450.	2.0425
409	725.00	27100.	55450.	2.0461
413	725.00	27090.	55450.	2.0469
269	725.00	27063.	55450.	2.0489
482	725.00	27040.	55450.	2.0506
338	725.00	27017.	55450.	2.0524
125	725.00	26690.	55450.	2.0775
194	725.00	26647.	55450.	2.0809
557	725.00	26403.	55450.	2.1002
626	725.00	26331.	55450.	2.1059
725	725.00	25668.	55450.	2.1603
698	725.00	25666.	55450.	2.1604
197	725.00	25573.	55450.	2.1683
122	725.00	25533.	55450.	2.1717
25	725.00	25182.	55450.	2.2020
54	725.00	25162.	55450.	2.2037
433	725.00	24531.	55450.	2.2604
462	725.00	24520.	55450.	2.2615
341	725.00	24270.	55450.	2.2847
289	725.00	24255.	55450.	2.2861
318	725.00	24240.	55450.	2.2876
266	725.00	24227.	55450.	2.2888
145	725.00	23980.	55450.	2.3123
174	725.00	23962.	55450.	2.3141
485	725.00	23859.	55450.	2.3241
410	725.00	23812.	55450.	2.3286

Table 3.T.14 (continued)

606	725.00	22892.	55450.	2.4223
577	725.00	22883.	55450.	2.4232
26	725.00	22002.	55450.	2.5203
53	725.00	21982.	55450.	2.5225
434	725.00	21372.	55450.	2.5946
461	725.00	21361.	55450.	2.5959
290	725.00	21107.	55450.	2.6271
317	725.00	21092.	55450.	2.6290
146	725.00	20837.	55450.	2.6611
173	725.00	20819.	55450.	2.6634
676	725.00	20408.	55450.	2.7171
747	725.00	20407.	55450.	2.7171
675	725.00	20407.	55450.	2.7172
748	725.00	20406.	55450.	2.7173
78	725.00	19950.	55450.	2.7795
1	725.00	19908.	55450.	2.7853
764	725.00	19859.	55450.	2.7922
763	725.00	19859.	55450.	2.7922
686	725.00	19792.	55450.	2.8017
685	725.00	19792.	55450.	2.8017
605	725.00	19785.	55450.	2.8027
578	725.00	19776.	55450.	2.8039
765	725.00	19684.	55450.	2.8170
687	725.00	19644.	55450.	2.8228
651	725.00	19074.	55450.	2.9071
532	725.00	19073.	55450.	2.9072
652	725.00	19073.	55450.	2.9073
531	725.00	19072.	55450.	2.9074
510	725.00	17656.	55450.	3.1406
385	725.00	17638.	55450.	3.1438
99	725.00	17570.	55450.	3.1559
100	725.00	17569.	55450.	3.1561
220	725.00	17567.	55450.	3.1565
219	725.00	17566.	55450.	3.1566
366	725.00	17292.	55450.	3.2067
241	725.00	17284.	55450.	3.2082
77	725.00	16866.	55450.	3.2876
2	725.00	16826.	55450.	3.2955
766	725.00	16777.	55450.	3.3051
688	725.00	16775.	55450.	3.3055
244	725.00	16533.	55450.	3.3538
243	725.00	16533.	55450.	3.3540
363	725.00	16530.	55450.	3.3544
364	725.00	16530.	55450.	3.3546
75	725.00	16519.	55450.	3.3567
76	725.00	16519.	55450.	3.3568
4	725.00	16518.	55450.	3.3569
3	725.00	16518.	55450.	3.3570
674	725.00	16484.	55450.	3.3638
749	725.00	16452.	55450.	3.3703
387	725.00	16209.	55450.	3.4210
388	725.00	16208.	55450.	3.4211
508	725.00	16204.	55450.	3.4220

Table 3.T.14 (continued)

507	725.00	16203.	55450.	3.4221
691	725.00	16182.	55450.	3.4266
692	725.00	16124.	55450.	3.4391
739	725.00	16113.	55450.	3.4414
667	725.00	16067.	55450.	3.4512
740	725.00	16055.	55450.	3.4537
541	725.00	16048.	55450.	3.4553
222	725.00	15898.	55450.	3.4879
97	725.00	15892.	55450.	3.4892
668	725.00	15681.	55450.	3.5361
542	725.00	15663.	55450.	3.5403
547	725.00	14893.	55450.	3.7233
643	725.00	14868.	55450.	3.7295
548	725.00	14749.	55450.	3.7597
644	725.00	14725.	55450.	3.7658
509	725.00	14677.	55450.	3.7781
386	725.00	14659.	55450.	3.7826
693	725.00	14507.	55450.	3.8222
530	725.00	14474.	55450.	3.8309
484	725.00	14467.	55450.	3.8328
483	725.00	14467.	55450.	3.8329
653	725.00	14466.	55450.	3.8332
411	725.00	14466.	55450.	3.8333
412	725.00	14465.	55450.	3.8333
741	725.00	14463.	55450.	3.8339
365	725.00	14315.	55450.	3.8736
242	725.00	14307.	55450.	3.8758
696	725.00	14261.	55450.	3.8882
339	725.00	14253.	55450.	3.8905
340	725.00	14253.	55450.	3.8905
268	725.00	14251.	55450.	3.8908
267	725.00	14251.	55450.	3.8908
603	725.00	14196.	55450.	3.9060
604	725.00	14196.	55450.	3.9061
744	725.00	14194.	55450.	3.9065
580	725.00	14193.	55450.	3.9070
579	725.00	14192.	55450.	3.9071
695	725.00	14056.	55450.	3.9450
172	725.00	14007.	55450.	3.9589
171	725.00	14006.	55450.	3.9590
147	725.00	14003.	55450.	3.9600
148	725.00	14002.	55450.	3.9601
743	725.00	13990.	55450.	3.9635
315	725.00	13883.	55450.	3.9941
316	725.00	13882.	55450.	3.9942
292	725.00	13879.	55450.	3.9953
291	725.00	13878.	55450.	3.9954
460	725.00	13836.	55450.	4.0076
459	725.00	13836.	55450.	4.0077
196	725.00	13834.	55450.	4.0082
195	725.00	13834.	55450.	4.0082
123	725.00	13833.	55450.	4.0086
124	725.00	13833.	55450.	4.0086

Table 3.T.14 (continued)

435	725.00	13832.	55450.	4.0088
436	725.00	13832.	55450.	4.0089
52	725.00	13673.	55450.	4.0554
51	725.00	13673.	55450.	4.0555
27	725.00	13670.	55450.	4.0565
28	725.00	13669.	55450.	4.0566
654	725.00	13203.	55450.	4.1997
529	725.00	13184.	55450.	4.2057
552	725.00	13092.	55450.	4.2353
672	725.00	13067.	55450.	4.2435
648	725.00	13063.	55450.	4.2449
546	725.00	13051.	55450.	4.2489
221	725.00	12937.	55450.	4.2861
98	725.00	12932.	55450.	4.2879
627	725.00	12886.	55450.	4.3032
628	725.00	12886.	55450.	4.3032
556	725.00	12885.	55450.	4.3035
555	725.00	12885.	55450.	4.3035
551	725.00	12863.	55450.	4.3107
647	725.00	12834.	55450.	4.3204
723	725.00	12666.	55450.	4.3777
724	725.00	12666.	55450.	4.3778
700	725.00	12658.	55450.	4.3806
699	725.00	12658.	55450.	4.3806
671	725.00	12637.	55450.	4.3880
545	725.00	12621.	55450.	4.3935
768	725.00	12554.	55450.	4.4169
690	725.00	12487.	55450.	4.4407
223	725.00	12296.	55450.	4.5098
108	725.00	12294.	55450.	4.5103
549	725.00	12245.	55450.	4.5286
645	725.00	12235.	55450.	4.5322
767	725.00	12108.	55450.	4.5795
689	725.00	12042.	55450.	4.6046
224	725.00	11719.	55450.	4.7317
107	725.00	11717.	55450.	4.7323
694	725.00	11573.	55450.	4.7914
384	725.00	11571.	55450.	4.7921
258	725.00	11568.	55450.	4.7936
742	725.00	11566.	55450.	4.7943
383	725.00	11194.	55450.	4.9534
257	725.00	11191.	55450.	4.9549
379	725.00	10572.	55450.	5.2451
253	725.00	10569.	55450.	5.2464
715	725.00	10540.	55450.	5.2611
716	725.00	10536.	55450.	5.2629
669	725.00	10496.	55450.	5.2831
717	725.00	10491.	55450.	5.2855
543	725.00	10485.	55450.	5.2885
718	725.00	10445.	55450.	5.3089
750	725.00	10429.	55450.	5.3170
719	725.00	10416.	55450.	5.3233
720	725.00	10384.	55450.	5.3399

Table 3.T.14 (continued)

673	725.00	10362.	55450.	5.3512
576	725.00	10339.	55450.	5.3630
624	725.00	10313.	55450.	5.3766
575	725.00	10294.	55450.	5.3868
623	725.00	10268.	55450.	5.4003
380	725.00	10185.	55450.	5.4443
254	725.00	10182.	55450.	5.4457
571	725.00	9980.7	55450.	5.5557
619	725.00	9958.5	55450.	5.5681
572	725.00	9898.2	55450.	5.6020
620	725.00	9876.8	55450.	5.6142
528	725.00	9684.7	55450.	5.7255
402	725.00	9679.2	55450.	5.7288
550	725.00	9595.8	55450.	5.7786
646	725.00	9577.8	55450.	5.7894
574	725.00	9464.1	55450.	5.8590
622	725.00	9445.9	55450.	5.8703
523	725.00	9427.1	55450.	5.8820
397	725.00	9425.6	55450.	5.8829
527	725.00	9411.9	55450.	5.8915
401	725.00	9406.5	55450.	5.8948
427	725.00	9341.1	55450.	5.9361
475	725.00	9321.4	55450.	5.9487
428	725.00	9241.0	55450.	6.0005
476	725.00	9221.8	55450.	6.0129
524	725.00	9145.5	55450.	6.0631
398	725.00	9144.2	55450.	6.0640
432	725.00	9076.7	55450.	6.1091
480	725.00	9055.9	55450.	6.1231
408	725.00	8994.2	55450.	6.1651
431	725.00	8977.5	55450.	6.1765
504	725.00	8969.5	55450.	6.1821
479	725.00	8957.2	55450.	6.1905
403	725.00	8947.4	55450.	6.1973
499	725.00	8923.5	55450.	6.2140
407	725.00	8885.2	55450.	6.2407
503	725.00	8861.2	55450.	6.2576
404	725.00	8826.1	55450.	6.2825
500	725.00	8802.9	55450.	6.2990
573	725.00	8704.0	55450.	6.3707
621	725.00	8693.6	55450.	6.3783
264	725.00	8685.0	55450.	6.3845
360	725.00	8664.4	55450.	6.3997
263	725.00	8515.1	55450.	6.5120
359	725.00	8495.2	55450.	6.5272
595	725.00	8481.0	55450.	6.5382
596	725.00	8477.9	55450.	6.5405
597	725.00	8440.5	55450.	6.5695
598	725.00	8402.4	55450.	6.5993
599	725.00	8363.7	55450.	6.6299
600	725.00	8324.7	55450.	6.6609
259	725.00	8225.0	55450.	6.7417
355	725.00	8205.3	55450.	6.7579

Table 3.T.14 (continued)

260	725.00	8038.2	55450.	6.8983
356	725.00	8019.2	55450.	6.9146
429	725.00	7769.6	55450.	7.1368
477	725.00	7758.6	55450.	7.1469
55	725.00	7749.9	55450.	7.1549
36	725.00	7741.4	55450.	7.1628
430	725.00	7538.9	55450.	7.3552
478	725.00	7526.3	55450.	7.3675
406	725.00	7312.3	55450.	7.5831
502	725.00	7299.7	55450.	7.5962
56	725.00	7275.0	55450.	7.6220
35	725.00	7267.1	55450.	7.6303
405	725.00	7115.7	55450.	7.7926
501	725.00	7104.1	55450.	7.8053
670	725.00	7081.1	55450.	7.8307
544	725.00	7073.5	55450.	7.8391
283	725.00	7060.0	55450.	7.8541
331	725.00	7044.9	55450.	7.8710
284	725.00	6963.0	55450.	7.9635
332	725.00	6948.3	55450.	7.9803
288	725.00	6759.5	55450.	8.2033
336	725.00	6743.6	55450.	8.2226
287	725.00	6664.5	55450.	8.3202
335	725.00	6649.1	55450.	8.3395
382	725.00	6498.3	55450.	8.5330
256	725.00	6496.3	55450.	8.5356
451	725.00	6464.9	55450.	8.5770
452	725.00	6461.7	55450.	8.5813
453	725.00	6422.6	55450.	8.6336
454	725.00	6382.9	55450.	8.6872
455	725.00	6345.3	55450.	8.7387
456	725.00	6308.5	55450.	8.7897
262	725.00	6231.3	55450.	8.8987
358	725.00	6221.1	55450.	8.9132
526	725.00	5921.0	55450.	9.3650
400	725.00	5917.0	55450.	9.3714
144	725.00	5906.4	55450.	9.3882
192	725.00	5892.7	55450.	9.4100
143	725.00	5783.4	55450.	9.5878
191	725.00	5770.2	55450.	9.6097
225	725.00	5694.6	55450.	9.7374
106	725.00	5692.6	55450.	9.7407
285	725.00	5632.7	55450.	9.8442
333	725.00	5624.5	55450.	9.8587
261	725.00	5574.7	55450.	9.9467
357	725.00	5565.6	55450.	9.9629
399	725.00	5545.3	55450.	9.9995
525	725.00	5544.8	55450.	10.000
139	725.00	5508.5	55450.	10.066
187	725.00	5495.2	55450.	10.091
286	725.00	5375.4	55450.	10.316
140	725.00	5373.5	55450.	10.319
334	725.00	5366.2	55450.	10.333

Table 3.T.14 (continued)

381	725.00	5365.7	55450.	10.334
255	725.00	5364.6	55450.	10.336
235	725.00	5361.6	55450.	10.342
188	725.00	5360.7	55450.	10.344
109	725.00	5359.6	55450.	10.346
236	725.00	5289.7	55450.	10.483
110	725.00	5287.8	55450.	10.486
19	725.00	4822.4	55450.	11.498
67	725.00	4810.6	55450.	11.527
91	725.00	4761.9	55450.	11.644
13	725.00	4740.3	55450.	11.698
24	725.00	4713.5	55450.	11.764
72	725.00	4699.9	55450.	11.798
92	725.00	4652.8	55450.	11.918
20	725.00	4640.9	55450.	11.948
14	725.00	4632.1	55450.	11.971
68	725.00	4629.6	55450.	11.977
23	725.00	4537.1	55450.	12.221
71	725.00	4524.0	55450.	12.257
307	725.00	4444.9	55450.	12.475
308	725.00	4441.7	55450.	12.484
309	725.00	4401.5	55450.	12.598
237	725.00	4400.7	55450.	12.600
111	725.00	4400.1	55450.	12.602
310	725.00	4360.8	55450.	12.715
311	725.00	4324.7	55450.	12.822
216	725.00	4316.4	55450.	12.846
215	725.00	4302.3	55450.	12.888
120	725.00	4296.6	55450.	12.906
312	725.00	4288.7	55450.	12.929
119	725.00	4283.2	55450.	12.946
142	725.00	4191.8	55450.	13.228
190	725.00	4184.4	55450.	13.252
214	725.00	4075.6	55450.	13.605
118	725.00	4065.6	55450.	13.639
213	725.00	3747.3	55450.	14.797
117	725.00	3746.6	55450.	14.800
12	725.00	3659.2	55450.	15.154
141	725.00	3648.8	55450.	15.197
189	725.00	3641.8	55450.	15.226
79	725.00	3625.5	55450.	15.294
112	725.00	3492.1	55450.	15.879
238	725.00	3491.5	55450.	15.881
116	725.00	3333.6	55450.	16.633
212	725.00	3324.9	55450.	16.677
93	725.00	3312.2	55450.	16.741
15	725.00	3303.1	55450.	16.787
11	725.00	3303.0	55450.	16.788
80	725.00	3270.5	55450.	16.954
115	725.00	2838.8	55450.	19.533
211	725.00	2820.9	55450.	19.657
113	725.00	2575.6	55450.	21.529
239	725.00	2573.7	55450.	21.545

Table 3.T.14 (continued)

57	725.00	2482.5	55450.	22.337
34	725.00	2481.7	55450.	22.344
21	725.00	2420.7	55450.	22.906
163	725.00	2419.1	55450.	22.921
164	725.00	2415.8	55450.	22.953
69	725.00	2415.3	55450.	22.958
22	725.00	2389.6	55450.	23.205
70	725.00	2382.4	55450.	23.275
165	725.00	2375.4	55450.	23.344
166	725.00	2334.6	55450.	23.751
167	725.00	2298.5	55450.	24.124
168	725.00	2262.8	55450.	24.506
16	725.00	1954.9	55450.	28.365
94	725.00	1952.1	55450.	28.405
58	725.00	1735.3	55450.	31.953
59	725.00	1735.3	55450.	31.953
33	725.00	1722.7	55450.	32.188
32	725.00	1722.7	55450.	32.189
114	725.00	1659.2	55450.	33.419
240	725.00	1656.0	55450.	33.484
82	725.00	1655.5	55450.	33.493
81	725.00	1655.5	55450.	33.494
9	725.00	1652.1	55450.	33.563
10	725.00	1652.1	55450.	33.563
104	725.00	1622.3	55450.	34.179
103	725.00	1622.3	55450.	34.179
227	725.00	1619.1	55450.	34.248
228	725.00	1619.1	55450.	34.248
226	725.00	1468.4	55450.	37.761
105	725.00	1466.0	55450.	37.824
8	725.00	1399.5	55450.	39.621
83	725.00	1388.1	55450.	39.946
60	725.00	1124.0	55450.	49.333
31	725.00	1104.2	55450.	50.218
96	725.00	1026.2	55450.	54.036
18	725.00	998.22	55450.	55.549
84	725.00	988.23	55450.	56.110
7	725.00	960.34	55450.	57.740
95	725.00	920.03	55450.	60.270
17	725.00	893.04	55450.	62.091
43	725.00	413.79	55450.	134.01
44	725.00	410.32	55450.	135.14
45	725.00	368.22	55450.	150.59
46	725.00	327.45	55450.	169.34
47	725.00	293.28	55450.	189.07
48	725.00	259.04	55450.	214.06

Table 3.T.15

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Enclosure Vessel
SUBTITLE  2 =
Load Combination: E3.b (See Table 3.1.4)
SUBTITLE  3 =
Stress Result: Primary Membrane (PM)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT     CURRENT      MIXED        PREVIOUS     PREVIOUS
   ELEM     REF TEMP     PM           ALLOW        SF
   1091    450.00      -10556.       43450.       4.1160
   1092    450.00      -10556.       43450.       4.1161
   1036    450.00      -10556.       43450.       4.1162
   1035    450.00      -10555.       43450.       4.1164
   1090    450.00      -10555.       43450.       4.1164
   1037    450.00      -10555.       43450.       4.1167
   1093    450.00      -10554.       43450.       4.1169
   1034    450.00      -10553.       43450.       4.1172
   1089    450.00      -10553.       43450.       4.1175
   1038    450.00      -10552.       43450.       4.1177
   1094    450.00      -10551.       43450.       4.1183
   1033    450.00      -10550.       43450.       4.1186
   1088    450.00      -10548.       43450.       4.1192
   1039    450.00      -10548.       43450.       4.1194
   1095    450.00      -10545.       43450.       4.1203
   1032    450.00      -10545.       43450.       4.1206
   1087    450.00      -10542.       43450.       4.1214
   1040    450.00      -10542.       43450.       4.1216
   1086    450.00      -10535.       43450.       4.1242
   1041    450.00      -10535.       43450.       4.1244
   1085    450.00      -10527.       43450.       4.1276
   1042    450.00      -10526.       43450.       4.1278
   1084    450.00      -10517.       43450.       4.1314
   1043    450.00      -10516.       43450.       4.1316
   1063    450.00      -10514.       43450.       4.1325
   1064    450.00      -10514.       43450.       4.1325
   1083    450.00      -10506.       43450.       4.1358
   1044    450.00      -10505.       43450.       4.1359
   1062    450.00      -10494.       43450.       4.1403
   1065    450.00      -10494.       43450.       4.1404
   1082    450.00      -10494.       43450.       4.1405
   1045    450.00      -10493.       43450.       4.1407
   1061    450.00      -10481.       43450.       4.1454
   1066    450.00      -10481.       43450.       4.1455
   1081    450.00      -10481.       43450.       4.1457
   1046    450.00      -10480.       43450.       4.1458
   1060    450.00      -10470.       43450.       4.1500
   1067    450.00      -10470.       43450.       4.1501
   1080    450.00      -10467.       43450.       4.1512
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Table 3.T.15 (continued)

1047	450.00	-10467.	43450.	4.1513
1059	450.00	-10457.	43450.	4.1549
1068	450.00	-10457.	43450.	4.1550
1079	450.00	-10452.	43450.	4.1570
1048	450.00	-10452.	43450.	4.1571
1058	450.00	-10444.	43450.	4.1601
1069	450.00	-10444.	43450.	4.1601
1078	450.00	-10437.	43450.	4.1630
1049	450.00	-10437.	43450.	4.1631
1070	450.00	-10431.	43450.	4.1655
1057	450.00	-10431.	43450.	4.1655
1077	450.00	-10422.	43450.	4.1692
1050	450.00	-10421.	43450.	4.1694
1071	450.00	-10417.	43450.	4.1710
1056	450.00	-10417.	43450.	4.1710
1076	450.00	-10406.	43450.	4.1756
1051	450.00	-10405.	43450.	4.1757
1072	450.00	-10403.	43450.	4.1767
1055	450.00	-10403.	43450.	4.1767
1075	450.00	-10390.	43450.	4.1821
1052	450.00	-10389.	43450.	4.1821
1073	450.00	-10388.	43450.	4.1825
1054	450.00	-10388.	43450.	4.1826
1074	450.00	-10374.	43450.	4.1885
1053	450.00	-10373.	43450.	4.1886
1031	450.00	-8970.7	43450.	4.8435
1096	450.00	-8970.3	43450.	4.8437
1129	450.00	-8966.8	43450.	4.8457
998	450.00	-8966.2	43450.	4.8460
1128	450.00	-8963.5	43450.	4.8474
999	450.00	-8962.8	43450.	4.8478
1127	450.00	-8959.1	43450.	4.8498
1000	450.00	-8958.4	43450.	4.8502
1126	450.00	-8953.8	43450.	4.8527
1001	450.00	-8953.0	43450.	4.8531
1125	450.00	-8947.5	43450.	4.8561
1002	450.00	-8946.6	43450.	4.8566
1124	450.00	-8940.3	43450.	4.8600
1003	450.00	-8939.3	43450.	4.8605
1123	450.00	-8932.4	43450.	4.8643
1004	450.00	-8931.3	43450.	4.8649
1113	450.00	-8928.4	43450.	4.8665
1114	450.00	-8928.2	43450.	4.8666
1112	450.00	-8927.9	43450.	4.8668
1014	450.00	-8927.9	43450.	4.8668
1013	450.00	-8927.5	43450.	4.8670
1015	450.00	-8927.4	43450.	4.8670
1115	450.00	-8927.0	43450.	4.8672
1111	450.00	-8926.6	43450.	4.8675
1012	450.00	-8926.3	43450.	4.8676
1016	450.00	-8926.1	43450.	4.8677
1116	450.00	-8925.1	43450.	4.8683
1110	450.00	-8924.4	43450.	4.8686

Table 3.T.15 (continued)

1011	450.00	-8924.3	43450.	4.8687
1017	450.00	-8924.1	43450.	4.8688
1122	450.00	-8923.6	43450.	4.8691
1005	450.00	-8922.5	43450.	4.8697
1117	450.00	-8922.3	43450.	4.8698
1109	450.00	-8921.6	43450.	4.8702
1010	450.00	-8921.4	43450.	4.8703
1018	450.00	-8921.3	43450.	4.8704
1118	450.00	-8918.7	43450.	4.8718
1108	450.00	-8918.0	43450.	4.8722
1009	450.00	-8917.8	43450.	4.8723
1019	450.00	-8917.8	43450.	4.8723
1119	450.00	-8914.3	43450.	4.8742
1121	450.00	-8914.3	43450.	4.8742
1107	450.00	-8913.7	43450.	4.8745
1020	450.00	-8913.6	43450.	4.8746
1008	450.00	-8913.3	43450.	4.8747
1006	450.00	-8913.0	43450.	4.8749
1106	450.00	-8908.8	43450.	4.8772
1021	450.00	-8908.7	43450.	4.8772
1120	450.00	-8904.3	43450.	4.8797
1022	450.00	-8903.3	43450.	4.8802
1105	450.00	-8903.2	43450.	4.8802
1007	450.00	-8903.0	43450.	4.8804
1030	450.00	-8902.1	43450.	4.8809
1097	450.00	-8901.8	43450.	4.8810
1023	450.00	-8897.3	43450.	4.8835
1104	450.00	-8897.2	43450.	4.8836
1024	450.00	-8890.8	43450.	4.8871
1103	450.00	-8890.7	43450.	4.8871
1025	450.00	-8883.9	43450.	4.8908
1102	450.00	-8883.7	43450.	4.8910
1026	450.00	-8876.7	43450.	4.8948
1101	450.00	-8876.4	43450.	4.8950
1027	450.00	-8861.6	43450.	4.9032
1100	450.00	-8861.2	43450.	4.9034
1029	450.00	-8840.1	43450.	4.9151
1098	450.00	-8839.8	43450.	4.9152
1028	450.00	-8785.1	43450.	4.9459
1099	450.00	-8784.9	43450.	4.9460
1316	450.00	7357.7	43450.	5.9054
1315	450.00	7357.7	43450.	5.9054
1317	450.00	7357.6	43450.	5.9055
1314	450.00	7357.5	43450.	5.9055
1313	450.00	7357.3	43450.	5.9057
1562	450.00	7357.3	43450.	5.9057
1563	450.00	7357.3	43450.	5.9057
1561	450.00	7357.2	43450.	5.9058
1564	450.00	7357.1	43450.	5.9058
1312	450.00	7357.0	43450.	5.9059
1565	450.00	7356.9	43450.	5.9060
1311	450.00	7356.6	43450.	5.9063
1566	450.00	7356.6	43450.	5.9063

Table 3.T.15 (continued)

1567	450.00	7356.1	43450.	5.9066
1310	450.00	7356.0	43450.	5.9067
1568	450.00	7355.6	43450.	5.9071
1309	450.00	7355.4	43450.	5.9072
1569	450.00	7355.0	43450.	5.9075
1308	450.00	7354.7	43450.	5.9078
1570	450.00	7354.3	43450.	5.9081
1307	450.00	7353.9	43450.	5.9084
1571	450.00	7353.5	43450.	5.9088
1306	450.00	7353.0	43450.	5.9091
1572	450.00	7352.6	43450.	5.9095
1305	450.00	7352.0	43450.	5.9099
1573	450.00	7351.6	43450.	5.9102
1304	450.00	7351.0	43450.	5.9108
1574	450.00	7350.6	43450.	5.9111
1303	450.00	7349.8	43450.	5.9117
1575	450.00	7349.4	43450.	5.9120
1302	450.00	7348.6	43450.	5.9127
1576	450.00	7348.2	43450.	5.9130
1301	450.00	7347.3	43450.	5.9137
1577	450.00	7346.9	43450.	5.9140
1300	450.00	7345.9	43450.	5.9149
1578	450.00	7345.5	43450.	5.9152
1299	450.00	7344.4	43450.	5.9161
1579	450.00	7344.1	43450.	5.9163
1298	450.00	7342.9	43450.	5.9173
1580	450.00	7342.5	43450.	5.9176
1297	450.00	7341.2	43450.	5.9186
1581	450.00	7340.9	43450.	5.9189
1296	450.00	7339.6	43450.	5.9200
1582	450.00	7339.2	43450.	5.9202
1295	450.00	7337.8	43450.	5.9214
1583	450.00	7337.5	43450.	5.9217
1294	450.00	7335.9	43450.	5.9229
1584	450.00	7335.6	43450.	5.9231
1293	450.00	7334.0	43450.	5.9244
1585	450.00	7333.7	43450.	5.9247
1292	450.00	7332.1	43450.	5.9260
1586	450.00	7331.8	43450.	5.9263
1291	450.00	7330.0	43450.	5.9277
1587	450.00	7329.7	43450.	5.9279
1290	450.00	7327.9	43450.	5.9294
1588	450.00	7327.6	43450.	5.9296
1289	450.00	7325.7	43450.	5.9312
1589	450.00	7325.5	43450.	5.9314
1288	450.00	7323.5	43450.	5.9330
1590	450.00	7323.2	43450.	5.9332
1287	450.00	7321.2	43450.	5.9348
1591	450.00	7321.0	43450.	5.9350
1286	450.00	7318.8	43450.	5.9367
1592	450.00	7318.6	43450.	5.9369
1285	450.00	7316.4	43450.	5.9387
1593	450.00	7316.2	43450.	5.9389

Table 3.T.15 (continued)

1284	450.00	7313.9	43450.	5.9407
1594	450.00	7313.7	43450.	5.9409
1283	450.00	7072.8	43450.	6.1432
1595	450.00	7072.4	43450.	6.1436
1282	450.00	7070.1	43450.	6.1456
1596	450.00	7069.6	43450.	6.1460
1281	450.00	7067.2	43450.	6.1481
1597	450.00	7066.8	43450.	6.1485
1280	450.00	7064.4	43450.	6.1506
1598	450.00	7064.0	43450.	6.1509
1279	450.00	7061.5	43450.	6.1531
1599	450.00	7061.1	43450.	6.1535
1278	450.00	7058.6	43450.	6.1556
1600	450.00	7058.2	43450.	6.1560
1277	450.00	7055.6	43450.	6.1582
1601	450.00	7055.2	43450.	6.1586
1276	450.00	7052.6	43450.	6.1608
1602	450.00	7052.2	43450.	6.1612
1275	450.00	7049.6	43450.	6.1635
1603	450.00	7049.2	43450.	6.1638
1274	450.00	7046.5	43450.	6.1662
1604	450.00	7046.1	43450.	6.1665
1273	450.00	7043.4	43450.	6.1689
1605	450.00	7043.0	43450.	6.1692
1272	450.00	7040.3	43450.	6.1716
1606	450.00	7039.9	43450.	6.1720
1271	450.00	7037.1	43450.	6.1744
1607	450.00	7036.8	43450.	6.1747
1270	450.00	7033.9	43450.	6.1772
1608	450.00	7033.6	43450.	6.1775
1269	450.00	7030.7	43450.	6.1800
1609	450.00	7030.4	43450.	6.1803
1268	450.00	7027.5	43450.	6.1829
1610	450.00	7027.1	43450.	6.1832
1267	450.00	7024.2	43450.	6.1858
1611	450.00	7023.9	43450.	6.1861
1266	450.00	7020.9	43450.	6.1887
1612	450.00	7020.6	43450.	6.1890
1265	450.00	7017.5	43450.	6.1916
1613	450.00	7017.2	43450.	6.1919
1264	450.00	7014.2	43450.	6.1946
1614	450.00	7013.9	43450.	6.1948
1263	450.00	7010.8	43450.	6.1976
1615	450.00	7010.5	43450.	6.1978
1262	450.00	7007.4	43450.	6.2006
1616	450.00	7007.1	43450.	6.2008
1261	450.00	7004.0	43450.	6.2036
1617	450.00	7003.7	43450.	6.2038
1260	450.00	7000.6	43450.	6.2066
1618	450.00	7000.3	43450.	6.2069
1259	450.00	6997.1	43450.	6.2097
1619	450.00	6996.8	43450.	6.2099
1258	450.00	6993.6	43450.	6.2128

Table 3.T.15 (continued)

1620	450.00	6993.4	43450.	6.2130
1257	450.00	6990.1	43450.	6.2159
1621	450.00	6989.9	43450.	6.2161
1256	450.00	6986.6	43450.	6.2190
1622	450.00	6986.4	43450.	6.2193
1255	450.00	6983.1	43450.	6.2222
1623	450.00	6982.8	43450.	6.2224
1254	450.00	6979.5	43450.	6.2254
1624	450.00	6979.3	43450.	6.2255
1253	450.00	6976.0	43450.	6.2285
1625	450.00	6975.7	43450.	6.2287
1252	450.00	6972.4	43450.	6.2317
1626	450.00	6972.2	43450.	6.2319
1251	450.00	6843.1	43450.	6.3495
1627	450.00	6841.4	43450.	6.3510
1250	450.00	6839.5	43450.	6.3528
1628	450.00	6837.9	43450.	6.3543
1249	450.00	6836.0	43450.	6.3561
1629	450.00	6834.4	43450.	6.3576
1248	450.00	6832.4	43450.	6.3594
1630	450.00	6830.8	43450.	6.3608
1247	450.00	6828.9	43450.	6.3627
1631	450.00	6827.3	43450.	6.3641
1246	450.00	6825.3	43450.	6.3660
1632	450.00	6823.8	43450.	6.3674
1245	450.00	6821.8	43450.	6.3693
1633	450.00	6820.2	43450.	6.3707
1244	450.00	6818.2	43450.	6.3726
1634	450.00	6816.7	43450.	6.3740
1243	450.00	6814.7	43450.	6.3759
1635	450.00	6813.2	43450.	6.3774
1242	450.00	6811.1	43450.	6.3792
1636	450.00	6809.6	43450.	6.3807
1241	450.00	6807.6	43450.	6.3826
1637	450.00	6806.1	43450.	6.3840
1240	450.00	6804.1	43450.	6.3859
1638	450.00	6802.6	43450.	6.3873
1239	450.00	6800.6	43450.	6.3892
1639	450.00	6799.1	43450.	6.3906
1238	450.00	6797.0	43450.	6.3925
1640	450.00	6795.5	43450.	6.3939
1237	450.00	6793.5	43450.	6.3958
1641	450.00	6792.0	43450.	6.3972
1236	450.00	6790.0	43450.	6.3991
1642	450.00	6788.5	43450.	6.4005
1235	450.00	6786.5	43450.	6.4024
1643	450.00	6785.0	43450.	6.4038
1234	450.00	6783.0	43450.	6.4057
1644	450.00	6781.5	43450.	6.4071
1233	450.00	6779.5	43450.	6.4090
1645	450.00	6778.1	43450.	6.4104
1232	450.00	6776.1	43450.	6.4123
1646	450.00	6774.6	43450.	6.4137

Table 3.T.15 (continued)

1231	450.00	6772.6	43450.	6.4155
1647	450.00	6771.1	43450.	6.4169
1230	450.00	6769.2	43450.	6.4188
1648	450.00	6767.7	43450.	6.4202
1229	450.00	6765.8	43450.	6.4220
1649	450.00	6764.3	43450.	6.4235
1228	450.00	6762.3	43450.	6.4253
1650	450.00	6760.8	43450.	6.4267
1227	450.00	6758.9	43450.	6.4285
1651	450.00	6757.4	43450.	6.4300
1226	450.00	6755.6	43450.	6.4317
1652	450.00	6754.0	43450.	6.4332
1225	450.00	6752.2	43450.	6.4349
1653	450.00	6750.7	43450.	6.4364
1224	450.00	6748.8	43450.	6.4381
1654	450.00	6747.3	43450.	6.4396
1223	450.00	6745.5	43450.	6.4413
1655	450.00	6744.0	43450.	6.4428
1222	450.00	6742.2	43450.	6.4445
1656	450.00	6740.7	43450.	6.4460
1221	450.00	6738.9	43450.	6.4476
1657	450.00	6737.4	43450.	6.4491
1220	450.00	6735.6	43450.	6.4508
1658	450.00	6734.1	43450.	6.4523
1219	450.00	6612.1	43450.	6.5713
1218	450.00	6609.4	43450.	6.5739
909	450.00	6607.3	43450.	6.5760
1217	450.00	6606.8	43450.	6.5766
910	450.00	6604.7	43450.	6.5787
1216	450.00	6604.1	43450.	6.5792
911	450.00	6602.0	43450.	6.5813
1215	450.00	6601.6	43450.	6.5818
912	450.00	6599.4	43450.	6.5839
1214	450.00	6599.0	43450.	6.5843
913	450.00	6596.8	43450.	6.5865
1213	450.00	6596.5	43450.	6.5869
914	450.00	6594.3	43450.	6.5891
1212	450.00	6594.0	43450.	6.5894
915	450.00	6591.7	43450.	6.5916
1211	450.00	6591.5	43450.	6.5918
916	450.00	6589.3	43450.	6.5941
1210	450.00	6589.1	43450.	6.5943
917	450.00	6586.8	43450.	6.5965
1209	450.00	6586.6	43450.	6.5967
918	450.00	6584.4	43450.	6.5989
1208	450.00	6584.3	43450.	6.5990
919	450.00	6582.0	43450.	6.6013
1207	450.00	6581.9	43450.	6.6014
920	450.00	6579.7	43450.	6.6037
1206	450.00	6579.7	43450.	6.6037
1205	450.00	6577.4	43450.	6.6060
921	450.00	6577.3	43450.	6.6060
1204	450.00	6575.2	43450.	6.6082

Table 3.T.15 (continued)

922	450.00	6575.1	43450.	6.6083
1203	450.00	6573.0	43450.	6.6104
923	450.00	6572.8	43450.	6.6106
1202	450.00	6570.8	43450.	6.6126
924	450.00	6570.6	43450.	6.6128
1201	450.00	6568.7	43450.	6.6147
925	450.00	6568.4	43450.	6.6150
1200	450.00	6566.6	43450.	6.6168
926	450.00	6566.3	43450.	6.6171
1199	450.00	6564.6	43450.	6.6189
927	450.00	6564.2	43450.	6.6192
1198	450.00	6562.5	43450.	6.6209
928	450.00	6562.1	43450.	6.6213
1197	450.00	6560.6	43450.	6.6229
929	450.00	6560.1	43450.	6.6234
1195	450.00	6559.0	43450.	6.6245
1196	450.00	6558.6	43450.	6.6248
930	450.00	6558.1	43450.	6.6254
931	450.00	6556.2	43450.	6.6274
933	450.00	6554.8	43450.	6.6288
932	450.00	6554.2	43450.	6.6293
1194	450.00	6548.3	43450.	6.6354
934	450.00	6543.9	43450.	6.6398
1193	450.00	6537.4	43450.	6.6464
935	450.00	6532.9	43450.	6.6509
1192	450.00	6526.5	43450.	6.6575
936	450.00	6521.9	43450.	6.6622
1191	450.00	6515.5	43450.	6.6687
1505	450.00	6514.3	43450.	6.6699
1372	450.00	6514.0	43450.	6.6702
1506	450.00	6511.6	43450.	6.6727
1371	450.00	6511.2	43450.	6.6731
937	450.00	6510.8	43450.	6.6735
1507	450.00	6508.5	43450.	6.6759
1370	450.00	6507.7	43450.	6.6767
1508	450.00	6504.6	43450.	6.6798
1190	450.00	6504.4	43450.	6.6801
1369	450.00	6503.8	43450.	6.6807
1509	450.00	6500.7	43450.	6.6839
1368	450.00	6499.8	43450.	6.6848
938	450.00	6499.6	43450.	6.6850
1510	450.00	6496.8	43450.	6.6879
1367	450.00	6495.9	43450.	6.6889
1189	450.00	6493.3	43450.	6.6915
1511	450.00	6492.8	43450.	6.6920
1366	450.00	6491.9	43450.	6.6930
1512	450.00	6488.8	43450.	6.6961
939	450.00	6488.4	43450.	6.6966
1365	450.00	6487.8	43450.	6.6972
1513	450.00	6484.6	43450.	6.7005
1364	450.00	6483.2	43450.	6.7019
1188	450.00	6482.1	43450.	6.7031
1514	450.00	6480.0	43450.	6.7053

Table 3.T.15 (continued)

1363	450.00	6478.4	43450.	6.7069
940	450.00	6477.1	43450.	6.7083
1515	450.00	6475.3	43450.	6.7101
1362	450.00	6473.5	43450.	6.7119
1187	450.00	6470.8	43450.	6.7148
1516	450.00	6470.6	43450.	6.7150
1361	450.00	6468.6	43450.	6.7170
1517	450.00	6465.8	43450.	6.7200
941	450.00	6465.7	43450.	6.7201
1360	450.00	6463.7	43450.	6.7222
1518	450.00	6460.9	43450.	6.7250
1186	450.00	6459.5	43450.	6.7265
1359	450.00	6458.6	43450.	6.7274
1519	450.00	6456.1	43450.	6.7301
942	450.00	6454.3	43450.	6.7320
1358	450.00	6453.6	43450.	6.7327
1520	450.00	6451.2	43450.	6.7352
1357	450.00	6448.5	43450.	6.7380
1521	450.00	6446.2	43450.	6.7404
1356	450.00	6443.3	43450.	6.7434
1522	450.00	6441.2	43450.	6.7456
1355	450.00	6438.1	43450.	6.7488
1523	450.00	6436.2	43450.	6.7509
1354	450.00	6432.9	43450.	6.7543
1524	450.00	6431.1	43450.	6.7563
1353	450.00	6427.6	43450.	6.7599
1525	450.00	6425.9	43450.	6.7617
1352	450.00	6422.3	43450.	6.7655
1526	450.00	6420.8	43450.	6.7671
1351	450.00	6416.9	43450.	6.7712
1527	450.00	6415.5	43450.	6.7726
1350	450.00	6411.5	43450.	6.7769
1528	450.00	6410.3	43450.	6.7782
1349	450.00	6406.1	43450.	6.7826
1529	450.00	6405.0	43450.	6.7838
1348	450.00	6400.6	43450.	6.7885
1530	450.00	6399.7	43450.	6.7894
1347	450.00	6395.0	43450.	6.7943
1531	450.00	6394.3	43450.	6.7951
1346	450.00	6389.5	43450.	6.8003
1532	450.00	6388.9	43450.	6.8009
1345	450.00	6383.9	43450.	6.8062
1533	450.00	6383.4	43450.	6.8067
1344	450.00	6378.2	43450.	6.8123
1534	450.00	6377.9	43450.	6.8126
1343	450.00	6372.5	43450.	6.8183
1535	450.00	6372.4	43450.	6.8185
1536	450.00	6366.8	43450.	6.8244
1342	450.00	6366.8	43450.	6.8244
1537	450.00	6361.2	43450.	6.8304
1341	450.00	6361.1	43450.	6.8306
1538	450.00	6355.6	43450.	6.8365
1340	450.00	6355.3	43450.	6.8368

Table 3.T.15 (continued)

1539	450.00	6349.9	43450.	6.8426
1339	450.00	6349.5	43450.	6.8431
1540	450.00	6344.2	43450.	6.8487
1338	450.00	6343.6	43450.	6.8494
1541	450.00	6338.5	43450.	6.8549
1337	450.00	6337.7	43450.	6.8557
1542	450.00	6332.8	43450.	6.8611
1336	450.00	6331.8	43450.	6.8621
1543	450.00	6327.0	43450.	6.8674
1335	450.00	6325.9	43450.	6.8686
1544	450.00	6321.2	43450.	6.8737
1334	450.00	6320.0	43450.	6.8750
1545	450.00	6315.3	43450.	6.8801
1333	450.00	6314.0	43450.	6.8815
1546	450.00	6309.5	43450.	6.8864
1332	450.00	6308.0	43450.	6.8881
1547	450.00	6303.6	43450.	6.8929
1331	450.00	6302.0	43450.	6.8947
1548	450.00	6297.7	43450.	6.8993
1330	450.00	6295.9	43450.	6.9013
1549	450.00	6291.8	43450.	6.9058
1329	450.00	6289.9	43450.	6.9079
1550	450.00	6285.9	43450.	6.9123
1328	450.00	6283.8	43450.	6.9146
1551	450.00	6279.9	43450.	6.9189
1327	450.00	6277.7	43450.	6.9213
1552	450.00	6274.0	43450.	6.9254
1326	450.00	6271.6	43450.	6.9281
1553	450.00	6268.2	43450.	6.9318
1325	450.00	6266.2	43450.	6.9341
1554	450.00	6263.0	43450.	6.9376
1324	450.00	6260.9	43450.	6.9399
1555	450.00	6257.7	43450.	6.9434
1323	450.00	6255.7	43450.	6.9457
1556	450.00	6252.5	43450.	6.9493
1322	450.00	6250.4	43450.	6.9515
1557	450.00	6247.2	43450.	6.9551
1321	450.00	6245.2	43450.	6.9574
1558	450.00	6242.0	43450.	6.9610
1320	450.00	6239.9	43450.	6.9632
1559	450.00	6237.1	43450.	6.9664
1319	450.00	6235.8	43450.	6.9678
1560	450.00	6233.3	43450.	6.9706
1318	450.00	6232.0	43450.	6.9721
1438	450.00	5483.4	43450.	7.9240
1437	450.00	5482.7	43450.	7.9249
1439	450.00	5482.6	43450.	7.9251
1436	450.00	5482.1	43450.	7.9258
1440	450.00	5482.0	43450.	7.9260
1435	450.00	5481.5	43450.	7.9267
1441	450.00	5481.4	43450.	7.9269
1434	450.00	5480.9	43450.	7.9276
1442	450.00	5480.8	43450.	7.9277

Table 3.T.15 (continued)

1433	450.00	5480.3	43450.	7.9283
1443	450.00	5480.2	43450.	7.9285
1432	450.00	5479.8	43450.	7.9291
1444	450.00	5479.7	43450.	7.9292
1431	450.00	5479.4	43450.	7.9298
1445	450.00	5479.3	43450.	7.9299
1430	450.00	5478.9	43450.	7.9304
1446	450.00	5478.8	43450.	7.9305
1429	450.00	5478.5	43450.	7.9310
1447	450.00	5478.4	43450.	7.9311
1428	450.00	5478.1	43450.	7.9315
1470	450.00	5478.1	43450.	7.9316
1448	450.00	5478.0	43450.	7.9317
1407	450.00	5477.9	43450.	7.9319
1427	450.00	5477.8	43450.	7.9320
1469	450.00	5477.8	43450.	7.9321
1449	450.00	5477.7	43450.	7.9322
1408	450.00	5477.6	43450.	7.9323
1426	450.00	5477.5	43450.	7.9325
1468	450.00	5477.5	43450.	7.9325
1450	450.00	5477.4	43450.	7.9326
1409	450.00	5477.3	43450.	7.9327
1425	450.00	5477.2	43450.	7.9329
1467	450.00	5477.2	43450.	7.9329
1451	450.00	5477.1	43450.	7.9330
1410	450.00	5477.1	43450.	7.9330
1424	450.00	5477.0	43450.	7.9332
1466	450.00	5476.9	43450.	7.9333
1411	450.00	5476.9	43450.	7.9334
1452	450.00	5476.9	43450.	7.9334
1423	450.00	5476.8	43450.	7.9335
1465	450.00	5476.7	43450.	7.9336
1412	450.00	5476.7	43450.	7.9336
1453	450.00	5476.6	43450.	7.9337
1422	450.00	5476.6	43450.	7.9338
1464	450.00	5476.5	43450.	7.9338
1413	450.00	5476.5	43450.	7.9338
1454	450.00	5476.5	43450.	7.9339
1421	450.00	5476.5	43450.	7.9340
1414	450.00	5476.4	43450.	7.9340
1463	450.00	5476.4	43450.	7.9340
1420	450.00	5476.4	43450.	7.9341
1455	450.00	5476.3	43450.	7.9341
1415	450.00	5476.3	43450.	7.9342
1419	450.00	5476.3	43450.	7.9342
1462	450.00	5476.3	43450.	7.9342
1416	450.00	5476.3	43450.	7.9342
1418	450.00	5476.2	43450.	7.9343
1417	450.00	5476.2	43450.	7.9343
1456	450.00	5476.2	43450.	7.9343
1461	450.00	5476.2	43450.	7.9344
1457	450.00	5476.2	43450.	7.9344
1460	450.00	5476.1	43450.	7.9344

Table 3.T.15 (continued)

1458	450.00	5476.1	43450.	7.9345
1459	450.00	5476.1	43450.	7.9345
943	450.00	5467.4	43450.	7.9470
1185	450.00	5466.5	43450.	7.9484
944	450.00	5464.0	43450.	7.9521
1184	450.00	5463.2	43450.	7.9533
945	450.00	5460.3	43450.	7.9574
1183	450.00	5458.8	43450.	7.9596
946	450.00	5455.7	43450.	7.9641
1182	450.00	5454.4	43450.	7.9661
947	450.00	5451.2	43450.	7.9707
1181	450.00	5450.0	43450.	7.9725
948	450.00	5446.9	43450.	7.9771
1180	450.00	5445.8	43450.	7.9787
949	450.00	5442.6	43450.	7.9833
1179	450.00	5441.7	43450.	7.9847
950	450.00	5438.5	43450.	7.9894
1178	450.00	5437.7	43450.	7.9906
1504	450.00	5286.7	43450.	8.2188
1503	450.00	5285.8	43450.	8.2201
1373	450.00	5285.3	43450.	8.2209
1502	450.00	5285.0	43450.	8.2213
1374	450.00	5284.5	43450.	8.2222
1501	450.00	5284.2	43450.	8.2226
1375	450.00	5283.7	43450.	8.2234
1500	450.00	5283.5	43450.	8.2238
1376	450.00	5283.0	43450.	8.2245
1499	450.00	5282.7	43450.	8.2249
1377	450.00	5282.2	43450.	8.2257
1498	450.00	5282.0	43450.	8.2261
1378	450.00	5281.5	43450.	8.2268
1497	450.00	5281.3	43450.	8.2272
1379	450.00	5280.8	43450.	8.2279
1496	450.00	5280.6	43450.	8.2282
1380	450.00	5280.2	43450.	8.2289
1495	450.00	5280.0	43450.	8.2292
1381	450.00	5279.5	43450.	8.2299
1494	450.00	5279.3	43450.	8.2302
1382	450.00	5278.9	43450.	8.2309
1493	450.00	5278.8	43450.	8.2311
1383	450.00	5278.3	43450.	8.2318
1492	450.00	5278.2	43450.	8.2320
1384	450.00	5277.7	43450.	8.2327
1491	450.00	5277.7	43450.	8.2328
1385	450.00	5277.2	43450.	8.2335
1490	450.00	5277.2	43450.	8.2336
1386	450.00	5276.7	43450.	8.2343
1489	450.00	5276.7	43450.	8.2343
1488	450.00	5276.3	43450.	8.2350
1387	450.00	5276.2	43450.	8.2350
1487	450.00	5275.9	43450.	8.2356
1388	450.00	5275.8	43450.	8.2357
1486	450.00	5275.5	43450.	8.2361

Table 3.T.15 (continued)

1389	450.00	5275.4	43450.	8.2363
1471	450.00	5275.3	43450.	8.2365
1485	450.00	5275.2	43450.	8.2366
1390	450.00	5275.1	43450.	8.2369
1472	450.00	5275.0	43450.	8.2369
1484	450.00	5275.0	43450.	8.2370
1406	450.00	5274.9	43450.	8.2371
1473	450.00	5274.8	43450.	8.2373
1483	450.00	5274.7	43450.	8.2374
1391	450.00	5274.7	43450.	8.2374
1405	450.00	5274.6	43450.	8.2376
1474	450.00	5274.6	43450.	8.2376
1482	450.00	5274.5	43450.	8.2377
1392	450.00	5274.4	43450.	8.2378
1475	450.00	5274.4	43450.	8.2379
1481	450.00	5274.4	43450.	8.2379
1476	450.00	5274.3	43450.	8.2381
1404	450.00	5274.3	43450.	8.2381
1480	450.00	5274.3	43450.	8.2381
1477	450.00	5274.2	43450.	8.2382
1479	450.00	5274.2	43450.	8.2382
1478	450.00	5274.2	43450.	8.2382
1393	450.00	5274.2	43450.	8.2382
1403	450.00	5274.1	43450.	8.2384
1394	450.00	5274.0	43450.	8.2385
1402	450.00	5273.9	43450.	8.2387
1395	450.00	5273.8	43450.	8.2388
1401	450.00	5273.7	43450.	8.2390
1396	450.00	5273.7	43450.	8.2390
1400	450.00	5273.6	43450.	8.2391
1397	450.00	5273.6	43450.	8.2391
1399	450.00	5273.6	43450.	8.2392
1398	450.00	5273.6	43450.	8.2392
960	450.00	3799.8	43450.	11.435
1168	450.00	3797.8	43450.	11.441
959	450.00	3792.1	43450.	11.458
961	450.00	3792.0	43450.	11.458
1169	450.00	3790.2	43450.	11.464
1167	450.00	3789.9	43450.	11.465
962	450.00	3787.3	43450.	11.473
1166	450.00	3785.3	43450.	11.479
958	450.00	3784.3	43450.	11.482
963	450.00	3782.7	43450.	11.486
1170	450.00	3782.4	43450.	11.487
1165	450.00	3780.8	43450.	11.492
964	450.00	3778.4	43450.	11.500
1164	450.00	3776.6	43450.	11.505
957	450.00	3776.4	43450.	11.506
1171	450.00	3774.7	43450.	11.511
965	450.00	3774.3	43450.	11.512
1163	450.00	3772.5	43450.	11.517
966	450.00	3770.5	43450.	11.524
1162	450.00	3768.7	43450.	11.529

Table 3.T.15 (continued)

956	450.00	3768.6	43450.	11.529
1172	450.00	3767.0	43450.	11.534
967	450.00	3766.9	43450.	11.535
1161	450.00	3765.1	43450.	11.540
968	450.00	3763.5	43450.	11.545
1160	450.00	3761.8	43450.	11.550
955	450.00	3760.8	43450.	11.553
969	450.00	3760.3	43450.	11.555
1173	450.00	3759.3	43450.	11.558
1159	450.00	3758.6	43450.	11.560
970	450.00	3757.4	43450.	11.564
1158	450.00	3755.7	43450.	11.569
971	450.00	3754.7	43450.	11.572
954	450.00	3753.1	43450.	11.577
1157	450.00	3753.0	43450.	11.577
972	450.00	3752.3	43450.	11.580
1174	450.00	3751.7	43450.	11.582
1156	450.00	3750.5	43450.	11.585
973	450.00	3750.0	43450.	11.587
1155	450.00	3748.3	43450.	11.592
974	450.00	3748.1	43450.	11.593
975	450.00	3746.3	43450.	11.598
1154	450.00	3746.2	43450.	11.598
953	450.00	3745.5	43450.	11.601
976	450.00	3744.8	43450.	11.603
1153	450.00	3744.4	43450.	11.604
1175	450.00	3744.1	43450.	11.605
977	450.00	3743.6	43450.	11.607
980	450.00	3743.4	43450.	11.607
1152	450.00	3742.9	43450.	11.609
978	450.00	3742.5	43450.	11.610
979	450.00	3741.7	43450.	11.612
1151	450.00	3741.5	43450.	11.613
1147	450.00	3740.7	43450.	11.615
1150	450.00	3740.4	43450.	11.616
1149	450.00	3739.5	43450.	11.619
1148	450.00	3738.8	43450.	11.621
952	450.00	3737.9	43450.	11.624
1176	450.00	3736.6	43450.	11.628
981	450.00	3731.7	43450.	11.643
951	450.00	3730.5	43450.	11.647
1146	450.00	3729.3	43450.	11.651
1177	450.00	3729.2	43450.	11.651
982	450.00	3720.2	43450.	11.680
1145	450.00	3718.0	43450.	11.686
983	450.00	3708.7	43450.	11.716
1144	450.00	3706.8	43450.	11.722
984	450.00	3697.2	43450.	11.752
1143	450.00	3695.6	43450.	11.757
985	450.00	3685.9	43450.	11.788
1142	450.00	3684.5	43450.	11.793
986	450.00	3674.7	43450.	11.824
1141	450.00	3673.6	43450.	11.828

Table 3.T.15 (continued)

987	450.00	3663.7	43450.	11.860
1140	450.00	3662.8	43450.	11.863
988	450.00	3652.8	43450.	11.895
1139	450.00	3652.1	43450.	11.897
989	450.00	3642.2	43450.	11.930
1138	450.00	3641.6	43450.	11.931
990	450.00	3632.3	43450.	11.962
1137	450.00	3632.1	43450.	11.963
991	450.00	3623.5	43450.	11.991
1136	450.00	3623.2	43450.	11.992
992	450.00	3614.9	43450.	12.020
1135	450.00	3614.6	43450.	12.021
993	450.00	3606.5	43450.	12.048
1134	450.00	3606.1	43450.	12.049
994	450.00	3598.3	43450.	12.075
1133	450.00	3597.8	43450.	12.077
995	450.00	3590.3	43450.	12.102
1132	450.00	3589.7	43450.	12.104
997	450.00	550.29	43450.	78.959
1130	450.00	548.47	43450.	79.220
996	450.00	526.87	43450.	82.468
1131	450.00	525.13	43450.	82.741

Table 3.T.16

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Enclosure Vessel
SUBTITLE  2 =
Load Combination: E3.b (See Table 3.1.4)
SUBTITLE  3 =
Stress Result: Local Membrane Plus Primary Bending (PL+PB)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT    CURRENT      MIXED        PREVIOUS     PREVIOUS
   ELEM    REF TEMP     PL+PB        ALLOW        SF
   1031   450.00       58346.       65200.       1.1175
   1100   450.00       58306.       65200.       1.1182
   1096   450.00       58249.       65200.       1.1193
   1027   450.00       58241.       65200.       1.1195
   1099   450.00       58229.       65200.       1.1197
   1028   450.00       58163.       65200.       1.1210
   1101   450.00       56830.       65200.       1.1473
   1026   450.00       56758.       65200.       1.1487
   1102   450.00       52212.       65200.       1.2488
   1025   450.00       52161.       65200.       1.2500
   1054   450.00       51883.       65200.       1.2567
   1053   450.00       51869.       65200.       1.2570
   1073   450.00       51865.       65200.       1.2571
   1074   450.00       51851.       65200.       1.2575
   1035   450.00       51269.       65200.       1.2717
   1036   450.00       51269.       65200.       1.2717
   1092   450.00       51245.       65200.       1.2723
   1091   450.00       51245.       65200.       1.2723
   1034   450.00       51180.       65200.       1.2739
   1093   450.00       51154.       65200.       1.2746
   1037   450.00       50834.       65200.       1.2826
   1090   450.00       50812.       65200.       1.2832
   1033   450.00       50568.       65200.       1.2893
   1094   450.00       50540.       65200.       1.2901
   1038   450.00       49877.       65200.       1.3072
   1089   450.00       49857.       65200.       1.3077
   1032   450.00       49435.       65200.       1.3189
   1095   450.00       49405.       65200.       1.3197
   1039   450.00       48400.       65200.       1.3471
   1088   450.00       48383.       65200.       1.3476
   1055   450.00       48093.       65200.       1.3557
   1072   450.00       48078.       65200.       1.3561
   1103   450.00       47885.       65200.       1.3616
   1024   450.00       47855.       65200.       1.3624
   1040   450.00       46407.       65200.       1.4050
   1087   450.00       46393.       65200.       1.4054
   1041   450.00       43903.       65200.       1.4851
   1086   450.00       43890.       65200.       1.4855
   1104   450.00       43857.       65200.       1.4867
```

Table 3.T.16 (continued)

1023	450.00	43849.	65200.	1.4869
1052	450.00	43654.	65200.	1.4936
1075	450.00	43639.	65200.	1.4941
1056	450.00	41197.	65200.	1.5826
1071	450.00	41184.	65200.	1.5831
1042	450.00	40892.	65200.	1.5944
1085	450.00	40882.	65200.	1.5948
1022	450.00	40150.	65200.	1.6239
1105	450.00	40136.	65200.	1.6245
1043	450.00	37382.	65200.	1.7441
1084	450.00	37375.	65200.	1.7445
1318	450.00	37102.	65200.	1.7573
1560	450.00	37044.	65200.	1.7600
995	450.00	36928.	65200.	1.7656
1132	450.00	36804.	65200.	1.7716
1021	450.00	36764.	65200.	1.7735
1106	450.00	36729.	65200.	1.7752
1372	450.00	36679.	65200.	1.7776
1505	450.00	36670.	65200.	1.7780
1319	450.00	36468.	65200.	1.7879
1559	450.00	36412.	65200.	1.7906
996	450.00	36207.	65200.	1.8008
1131	450.00	36082.	65200.	1.8070
1371	450.00	35946.	65200.	1.8138
1506	450.00	35937.	65200.	1.8143
1320	450.00	35830.	65200.	1.8197
1051	450.00	35796.	65200.	1.8214
1076	450.00	35783.	65200.	1.8221
1558	450.00	35775.	65200.	1.8225
1370	450.00	35211.	65200.	1.8517
1507	450.00	35202.	65200.	1.8521
1321	450.00	34935.	65200.	1.8663
1557	450.00	34882.	65200.	1.8691
994	450.00	34801.	65200.	1.8735
1057	450.00	34662.	65200.	1.8810
1070	450.00	34653.	65200.	1.8815
1133	450.00	34637.	65200.	1.8824
1369	450.00	34188.	65200.	1.9071
1508	450.00	34180.	65200.	1.9075
1030	450.00	34174.	65200.	1.9079
1097	450.00	34083.	65200.	1.9130
1322	450.00	34033.	65200.	1.9158
1556	450.00	33981.	65200.	1.9187
1020	450.00	33699.	65200.	1.9348
1107	450.00	33642.	65200.	1.9380
1044	450.00	33381.	65200.	1.9532
1083	450.00	33376.	65200.	1.9535
1368	450.00	33162.	65200.	1.9661
1509	450.00	33155.	65200.	1.9665
1323	450.00	33123.	65200.	1.9684
1555	450.00	33073.	65200.	1.9714
1098	450.00	33067.	65200.	1.9718
1317	450.00	33048.	65200.	1.9729

Table 3.T.16 (continued)

1561	450.00	32995.	65200.	1.9760
1029	450.00	32994.	65200.	1.9761
993	450.00	32585.	65200.	2.0009
1134	450.00	32380.	65200.	2.0136
1324	450.00	32205.	65200.	2.0246
1554	450.00	32156.	65200.	2.0276
1367	450.00	32133.	65200.	2.0291
1510	450.00	32127.	65200.	2.0295
1316	450.00	31847.	65200.	2.0473
1562	450.00	31798.	65200.	2.0504
1325	450.00	31279.	65200.	2.0845
1553	450.00	31232.	65200.	2.0876
1366	450.00	31102.	65200.	2.0964
1511	450.00	31096.	65200.	2.0968
1019	450.00	30960.	65200.	2.1059
1108	450.00	30882.	65200.	2.1113
1373	450.00	30728.	65200.	2.1218
1504	450.00	30720.	65200.	2.1224
1315	450.00	30672.	65200.	2.1257
1563	450.00	30627.	65200.	2.1288
950	450.00	30423.	65200.	2.1431
1326	450.00	30346.	65200.	2.1485
1552	450.00	30301.	65200.	2.1518
992	450.00	30281.	65200.	2.1531
1365	450.00	30068.	65200.	2.1684
1512	450.00	30062.	65200.	2.1688
1135	450.00	30036.	65200.	2.1708
1178	450.00	30029.	65200.	2.1712
949	450.00	29909.	65200.	2.1799
1179	450.00	29559.	65200.	2.2058
1314	450.00	29523.	65200.	2.2085
1564	450.00	29481.	65200.	2.2116
1374	450.00	29436.	65200.	2.2149
1503	450.00	29429.	65200.	2.2155
948	450.00	29357.	65200.	2.2209
1327	450.00	29247.	65200.	2.2293
1551	450.00	29231.	65200.	2.2305
1063	450.00	29093.	65200.	2.2411
1064	450.00	29075.	65200.	2.2425
1180	450.00	29050.	65200.	2.2444
1364	450.00	29031.	65200.	2.2459
1513	450.00	29027.	65200.	2.2462
1045	450.00	28898.	65200.	2.2562
1082	450.00	28895.	65200.	2.2564
947	450.00	28766.	65200.	2.2666
951	450.00	28718.	65200.	2.2704
998	450.00	28688.	65200.	2.2727
1129	450.00	28559.	65200.	2.2830
1018	450.00	28552.	65200.	2.2835
1058	450.00	28504.	65200.	2.2874
1181	450.00	28502.	65200.	2.2876
1069	450.00	28498.	65200.	2.2879
1109	450.00	28453.	65200.	2.2915

Table 3.T.16 (continued)

1313	450.00	28399.	65200.	2.2959
1565	450.00	28361.	65200.	2.2989
1177	450.00	28324.	65200.	2.3020
1050	450.00	28311.	65200.	2.3030
1077	450.00	28300.	65200.	2.3039
1375	450.00	28172.	65200.	2.3143
1502	450.00	28165.	65200.	2.3149
1550	450.00	28152.	65200.	2.3160
1328	450.00	28138.	65200.	2.3171
946	450.00	28136.	65200.	2.3173
1182	450.00	27916.	65200.	2.3356
991	450.00	27890.	65200.	2.3377
1514	450.00	27843.	65200.	2.3417
1363	450.00	27817.	65200.	2.3439
1136	450.00	27604.	65200.	2.3619
945	450.00	27469.	65200.	2.3736
997	450.00	27311.	65200.	2.3873
1312	450.00	27300.	65200.	2.3883
1183	450.00	27293.	65200.	2.3889
1566	450.00	27266.	65200.	2.3913
1130	450.00	27213.	65200.	2.3959
1549	450.00	27064.	65200.	2.4091
1329	450.00	27021.	65200.	2.4130
1376	450.00	26936.	65200.	2.4205
1501	450.00	26929.	65200.	2.4212
999	450.00	26894.	65200.	2.4243
942	450.00	26858.	65200.	2.4275
1128	450.00	26809.	65200.	2.4320
944	450.00	26764.	65200.	2.4361
1186	450.00	26755.	65200.	2.4369
1515	450.00	26658.	65200.	2.4458
1184	450.00	26631.	65200.	2.4483
1362	450.00	26599.	65200.	2.4512
1017	450.00	26480.	65200.	2.4622
1110	450.00	26360.	65200.	2.4735
943	450.00	26233.	65200.	2.4854
1311	450.00	26226.	65200.	2.4861
1567	450.00	26195.	65200.	2.4890
1185	450.00	26132.	65200.	2.4950
1548	450.00	25969.	65200.	2.5107
1330	450.00	25895.	65200.	2.5179
1377	450.00	25728.	65200.	2.5342
1500	450.00	25721.	65200.	2.5349
1516	450.00	25469.	65200.	2.5599
990	450.00	25413.	65200.	2.5656
1361	450.00	25380.	65200.	2.5690
1310	450.00	25177.	65200.	2.5897
1568	450.00	25149.	65200.	2.5925
1137	450.00	25087.	65200.	2.5989
952	450.00	24927.	65200.	2.6157
1547	450.00	24866.	65200.	2.6220
1008	450.00	24768.	65200.	2.6324
1331	450.00	24761.	65200.	2.6331

Table 3.T.16 (continued)

1007	450.00	24759.	65200.	2.6333
1016	450.00	24748.	65200.	2.6345
1000	450.00	24692.	65200.	2.6405
1127	450.00	24652.	65200.	2.6448
1111	450.00	24606.	65200.	2.6497
1176	450.00	24578.	65200.	2.6527
1378	450.00	24548.	65200.	2.6561
1499	450.00	24541.	65200.	2.6568
1119	450.00	24452.	65200.	2.6664
1120	450.00	24444.	65200.	2.6673
1517	450.00	24279.	65200.	2.6855
1360	450.00	24157.	65200.	2.6990
1309	450.00	24152.	65200.	2.6996
1569	450.00	24127.	65200.	2.7023
1046	450.00	23943.	65200.	2.7231
1081	450.00	23942.	65200.	2.7232
941	450.00	23803.	65200.	2.7391
1546	450.00	23756.	65200.	2.7446
1187	450.00	23737.	65200.	2.7468
1332	450.00	23620.	65200.	2.7604
1379	450.00	23396.	65200.	2.7868
1498	450.00	23389.	65200.	2.7876
1009	450.00	23375.	65200.	2.7893
1015	450.00	23359.	65200.	2.7912
1112	450.00	23197.	65200.	2.8108
1308	450.00	23152.	65200.	2.8162
1570	450.00	23130.	65200.	2.8188
1518	450.00	23087.	65200.	2.8242
1118	450.00	23077.	65200.	2.8253
1359	450.00	22933.	65200.	2.8430
989	450.00	22852.	65200.	2.8532
1059	450.00	22735.	65200.	2.8678
1068	450.00	22733.	65200.	2.8681
1545	450.00	22639.	65200.	2.8800
1138	450.00	22486.	65200.	2.8996
1333	450.00	22471.	65200.	2.9015
1010	450.00	22328.	65200.	2.9202
1014	450.00	22315.	65200.	2.9217
1380	450.00	22273.	65200.	2.9273
1497	450.00	22266.	65200.	2.9282
1307	450.00	22175.	65200.	2.9402
1571	450.00	22157.	65200.	2.9427
1113	450.00	22133.	65200.	2.9459
1126	450.00	22090.	65200.	2.9516
1001	450.00	22085.	65200.	2.9522
1117	450.00	22047.	65200.	2.9573
1519	450.00	21892.	65200.	2.9782
1358	450.00	21707.	65200.	3.0036
1011	450.00	21627.	65200.	3.0148
1013	450.00	21619.	65200.	3.0158
1544	450.00	21515.	65200.	3.0305
960	450.00	21464.	65200.	3.0376
961	450.00	21459.	65200.	3.0383

Table 3.T.16 (continued)

1114	450.00	21416.	65200.	3.0444
1116	450.00	21365.	65200.	3.0517
1334	450.00	21316.	65200.	3.0588
1012	450.00	21275.	65200.	3.0647
1306	450.00	21223.	65200.	3.0721
1049	450.00	21216.	65200.	3.0732
1078	450.00	21207.	65200.	3.0744
1572	450.00	21207.	65200.	3.0745
1381	450.00	21179.	65200.	3.0786
1496	450.00	21172.	65200.	3.0796
1168	450.00	21164.	65200.	3.0807
1167	450.00	21159.	65200.	3.0815
1115	450.00	21049.	65200.	3.0975
953	450.00	21026.	65200.	3.1009
940	450.00	20731.	65200.	3.1451
1175	450.00	20730.	65200.	3.1452
1188	450.00	20701.	65200.	3.1496
1520	450.00	20697.	65200.	3.1502
962	450.00	20570.	65200.	3.1697
1357	450.00	20480.	65200.	3.1836
980	450.00	20460.	65200.	3.1867
979	450.00	20456.	65200.	3.1873
1543	450.00	20384.	65200.	3.1985
1305	450.00	20294.	65200.	3.2127
1573	450.00	20281.	65200.	3.2148
1166	450.00	20271.	65200.	3.2164
1147	450.00	20246.	65200.	3.2204
1148	450.00	20242.	65200.	3.2211
1335	450.00	20154.	65200.	3.2352
1382	450.00	20114.	65200.	3.2416
1495	450.00	20107.	65200.	3.2427
963	450.00	19771.	65200.	3.2978
988	450.00	19751.	65200.	3.3011
978	450.00	19663.	65200.	3.3159
1006	450.00	19527.	65200.	3.3390
1521	450.00	19500.	65200.	3.3436
1165	450.00	19470.	65200.	3.3487
1149	450.00	19437.	65200.	3.3545
1139	450.00	19419.	65200.	3.3575
1304	450.00	19389.	65200.	3.3627
1574	450.00	19378.	65200.	3.3646
1121	450.00	19255.	65200.	3.3862
1356	450.00	19251.	65200.	3.3868
1542	450.00	19248.	65200.	3.3873
1062	450.00	19227.	65200.	3.3911
1065	450.00	19215.	65200.	3.3933
1125	450.00	19129.	65200.	3.4085
1002	450.00	19079.	65200.	3.4173
1383	450.00	19078.	65200.	3.4175
1494	450.00	19071.	65200.	3.4187
964	450.00	19063.	65200.	3.4202
1336	450.00	18985.	65200.	3.4342
977	450.00	18964.	65200.	3.4382

Table 3.T.16 (continued)

1164	450.00	18756.	65200.	3.4762
1150	450.00	18721.	65200.	3.4827
1080	450.00	18529.	65200.	3.5189
1047	450.00	18527.	65200.	3.5192
1303	450.00	18507.	65200.	3.5230
1575	450.00	18499.	65200.	3.5246
965	450.00	18448.	65200.	3.5343
976	450.00	18358.	65200.	3.5515
1522	450.00	18302.	65200.	3.5624
1163	450.00	18129.	65200.	3.5964
1541	450.00	18106.	65200.	3.6009
1151	450.00	18095.	65200.	3.6032
1384	450.00	18072.	65200.	3.6078
1493	450.00	18065.	65200.	3.6091
1355	450.00	18021.	65200.	3.6179
966	450.00	17925.	65200.	3.6375
975	450.00	17847.	65200.	3.6532
1337	450.00	17811.	65200.	3.6606
1189	450.00	17649.	65200.	3.6943
1302	450.00	17648.	65200.	3.6945
1576	450.00	17642.	65200.	3.6957
939	450.00	17641.	65200.	3.6959
1162	450.00	17591.	65200.	3.7065
1152	450.00	17559.	65200.	3.7133
933	450.00	17525.	65200.	3.7204
932	450.00	17521.	65200.	3.7213
967	450.00	17494.	65200.	3.7269
974	450.00	17431.	65200.	3.7405
1067	450.00	17370.	65200.	3.7535
1060	450.00	17370.	65200.	3.7537
1195	450.00	17265.	65200.	3.7763
1196	450.00	17262.	65200.	3.7772
968	450.00	17157.	65200.	3.8001
1161	450.00	17141.	65200.	3.8038
1153	450.00	17112.	65200.	3.8101
973	450.00	17109.	65200.	3.8109
1523	450.00	17104.	65200.	3.8121
1385	450.00	17096.	65200.	3.8138
1492	450.00	17089.	65200.	3.8153
954	450.00	17019.	65200.	3.8310
1540	450.00	16959.	65200.	3.8445
969	450.00	16914.	65200.	3.8548
931	450.00	16896.	65200.	3.8589
972	450.00	16881.	65200.	3.8623
1301	450.00	16812.	65200.	3.8782
1577	450.00	16808.	65200.	3.8791
1354	450.00	16791.	65200.	3.8830
1174	450.00	16779.	65200.	3.8857
1160	450.00	16779.	65200.	3.8858
970	450.00	16765.	65200.	3.8891
1154	450.00	16756.	65200.	3.8912
959	450.00	16750.	65200.	3.8925
971	450.00	16748.	65200.	3.8930

Table 3.T.16 (continued)

1197	450.00	16651.	65200.	3.9156
1338	450.00	16632.	65200.	3.9201
1169	450.00	16541.	65200.	3.9417
987	450.00	16538.	65200.	3.9424
1159	450.00	16507.	65200.	3.9498
1155	450.00	16490.	65200.	3.9540
981	450.00	16400.	65200.	3.9756
1158	450.00	16324.	65200.	3.9941
1156	450.00	16313.	65200.	3.9967
930	450.00	16283.	65200.	4.0041
1146	450.00	16266.	65200.	4.0082
1140	450.00	16245.	65200.	4.0134
1157	450.00	16231.	65200.	4.0171
1386	450.00	16149.	65200.	4.0374
1491	450.00	16143.	65200.	4.0390
1198	450.00	16053.	65200.	4.0615
1300	450.00	15998.	65200.	4.0755
1578	450.00	15996.	65200.	4.0759
1524	450.00	15905.	65200.	4.0994
1539	450.00	15807.	65200.	4.1246
1124	450.00	15774.	65200.	4.1333
929	450.00	15683.	65200.	4.1574
1003	450.00	15680.	65200.	4.1582
1353	450.00	15560.	65200.	4.1902
1199	450.00	15467.	65200.	4.2153
1339	450.00	15448.	65200.	4.2207
1387	450.00	15233.	65200.	4.2802
1490	450.00	15227.	65200.	4.2820
1579	450.00	15207.	65200.	4.2875
1299	450.00	15207.	65200.	4.2875
928	450.00	15095.	65200.	4.3194
1200	450.00	14893.	65200.	4.3778
1525	450.00	14705.	65200.	4.4337
1538	450.00	14651.	65200.	4.4502
1005	450.00	14647.	65200.	4.4515
1190	450.00	14581.	65200.	4.4717
938	450.00	14536.	65200.	4.4855
1048	450.00	14526.	65200.	4.4885
1079	450.00	14519.	65200.	4.4905
927	450.00	14519.	65200.	4.4908
1580	450.00	14440.	65200.	4.5153
1298	450.00	14438.	65200.	4.5159
1122	450.00	14418.	65200.	4.5222
1388	450.00	14347.	65200.	4.5445
1489	450.00	14341.	65200.	4.5465
1201	450.00	14331.	65200.	4.5495
1352	450.00	14329.	65200.	4.5502
934	450.00	14312.	65200.	4.5557
1340	450.00	14258.	65200.	4.5727
1194	450.00	14091.	65200.	4.6269
926	450.00	13954.	65200.	4.6724
1202	450.00	13781.	65200.	4.7312
1581	450.00	13695.	65200.	4.7610

Table 3.T.16 (continued)

1297	450.00	13691.	65200.	4.7623
1526	450.00	13506.	65200.	4.8274
1389	450.00	13492.	65200.	4.8327
1537	450.00	13490.	65200.	4.8332
1488	450.00	13485.	65200.	4.8349
925	450.00	13402.	65200.	4.8649
1203	450.00	13242.	65200.	4.9237
986	450.00	13215.	65200.	4.9339
1351	450.00	13098.	65200.	4.9778
1061	450.00	13082.	65200.	4.9841
1066	450.00	13074.	65200.	4.9870
1341	450.00	13065.	65200.	4.9905
1582	450.00	12971.	65200.	5.0267
1141	450.00	12967.	65200.	5.0281
1296	450.00	12965.	65200.	5.0288
955	450.00	12906.	65200.	5.0518
924	450.00	12861.	65200.	5.0695
1173	450.00	12729.	65200.	5.1221
1204	450.00	12715.	65200.	5.1280
1390	450.00	12667.	65200.	5.1473
1487	450.00	12661.	65200.	5.1498
982	450.00	12435.	65200.	5.2433
1145	450.00	12378.	65200.	5.2674
923	450.00	12332.	65200.	5.2870
1536	450.00	12325.	65200.	5.2900
1527	450.00	12307.	65200.	5.2976
1583	450.00	12269.	65200.	5.3144
1295	450.00	12262.	65200.	5.3174
1205	450.00	12198.	65200.	5.3449
958	450.00	12128.	65200.	5.3761
1123	450.00	12033.	65200.	5.4186
1170	450.00	12006.	65200.	5.4305
1004	450.00	11893.	65200.	5.4820
1391	450.00	11873.	65200.	5.4915
1350	450.00	11868.	65200.	5.4940
1342	450.00	11867.	65200.	5.4941
1486	450.00	11867.	65200.	5.4943
922	450.00	11814.	65200.	5.5188
1206	450.00	11693.	65200.	5.5758
1584	450.00	11587.	65200.	5.6268
1294	450.00	11579.	65200.	5.6309
1191	450.00	11497.	65200.	5.6711
937	450.00	11414.	65200.	5.7121
1595	450.00	11347.	65200.	5.7462
1283	450.00	11320.	65200.	5.7597
921	450.00	11308.	65200.	5.7660
1207	450.00	11199.	65200.	5.8217
1535	450.00	11157.	65200.	5.8440
935	450.00	11112.	65200.	5.8677
1392	450.00	11110.	65200.	5.8687
1528	450.00	11109.	65200.	5.8690
1485	450.00	11104.	65200.	5.8718
1596	450.00	10975.	65200.	5.9407

Table 3.T.16 (continued)

1282	450.00	10947.	65200.	5.9557
1193	450.00	10930.	65200.	5.9653
1585	450.00	10927.	65200.	5.9668
1293	450.00	10918.	65200.	5.9721
920	450.00	10812.	65200.	6.0303
1208	450.00	10716.	65200.	6.0842
1343	450.00	10666.	65200.	6.1128
1349	450.00	10638.	65200.	6.1291
1597	450.00	10616.	65200.	6.1418
1281	450.00	10587.	65200.	6.1585
1393	450.00	10378.	65200.	6.2825
1484	450.00	10372.	65200.	6.2861
919	450.00	10327.	65200.	6.3133
1586	450.00	10288.	65200.	6.3376
1292	450.00	10277.	65200.	6.3443
1598	450.00	10268.	65200.	6.3496
1209	450.00	10244.	65200.	6.3647
1280	450.00	10239.	65200.	6.3680
1534	450.00	9984.8	65200.	6.5299
1599	450.00	9932.4	65200.	6.5644
1529	450.00	9911.9	65200.	6.5780
1279	450.00	9902.0	65200.	6.5846
918	450.00	9853.6	65200.	6.6169
985	450.00	9783.0	65200.	6.6646
1210	450.00	9782.0	65200.	6.6653
1394	450.00	9677.3	65200.	6.7374
1483	450.00	9671.5	65200.	6.7414
1587	450.00	9668.9	65200.	6.7432
1291	450.00	9657.0	65200.	6.7516
1600	450.00	9607.9	65200.	6.7861
1142	450.00	9585.9	65200.	6.8017
1252	450.00	9584.5	65200.	6.8027
1278	450.00	9576.8	65200.	6.8081
1626	450.00	9575.3	65200.	6.8092
1658	450.00	9503.8	65200.	6.8604
1253	450.00	9495.3	65200.	6.8665
1625	450.00	9483.4	65200.	6.8752
1344	450.00	9461.6	65200.	6.8910
1220	450.00	9440.0	65200.	6.9068
1348	450.00	9409.1	65200.	6.9295
1254	450.00	9400.6	65200.	6.9357
917	450.00	9390.3	65200.	6.9433
1624	450.00	9386.1	65200.	6.9465
1657	450.00	9335.7	65200.	6.9840
1211	450.00	9330.5	65200.	6.9878
1255	450.00	9300.0	65200.	7.0108
1601	450.00	9294.5	65200.	7.0149
1623	450.00	9282.9	65200.	7.0236
1221	450.00	9278.3	65200.	7.0272
1277	450.00	9262.9	65200.	7.0388
1284	450.00	9213.8	65200.	7.0763
1256	450.00	9193.2	65200.	7.0922
1594	450.00	9189.5	65200.	7.0950

Table 3.T.16 (continued)

1622	450.00	9173.9	65200.	7.1071
1656	450.00	9172.8	65200.	7.1080
1222	450.00	9121.6	65200.	7.1479
1257	450.00	9080.2	65200.	7.1804
1588	450.00	9070.4	65200.	7.1882
1621	450.00	9058.6	65200.	7.1976
1290	450.00	9057.5	65200.	7.1985
1655	450.00	9014.8	65200.	7.2325
1395	450.00	9008.1	65200.	7.2379
1482	450.00	9002.4	65200.	7.2425
1602	450.00	8992.2	65200.	7.2508
1223	450.00	8969.7	65200.	7.2689
1258	450.00	8960.6	65200.	7.2763
1276	450.00	8960.2	65200.	7.2766
916	450.00	8937.6	65200.	7.2950
1620	450.00	8936.9	65200.	7.2956
1212	450.00	8889.2	65200.	7.3347
1654	450.00	8861.7	65200.	7.3575
1259	450.00	8834.3	65200.	7.3803
1224	450.00	8822.4	65200.	7.3902
1533	450.00	8810.0	65200.	7.4007
1619	450.00	8808.6	65200.	7.4019
1448	450.00	8764.4	65200.	7.4392
1449	450.00	8764.3	65200.	7.4393
1428	450.00	8762.8	65200.	7.4406
1429	450.00	8762.7	65200.	7.4406
1450	450.00	8761.5	65200.	7.4416
1427	450.00	8759.5	65200.	7.4433
1285	450.00	8756.4	65200.	7.4460
1447	450.00	8740.4	65200.	7.4597
1430	450.00	8739.3	65200.	7.4606
1593	450.00	8732.3	65200.	7.4665
1451	450.00	8732.0	65200.	7.4668
1426	450.00	8729.5	65200.	7.4689
1530	450.00	8715.7	65200.	7.4807
1653	450.00	8713.1	65200.	7.4830
1260	450.00	8701.0	65200.	7.4934
1603	450.00	8700.5	65200.	7.4938
956	450.00	8690.4	65200.	7.5025
1446	450.00	8689.6	65200.	7.5032
1431	450.00	8689.1	65200.	7.5036
1225	450.00	8679.6	65200.	7.5119
1452	450.00	8675.7	65200.	7.5152
1618	450.00	8673.4	65200.	7.5172
1425	450.00	8672.7	65200.	7.5178
1275	450.00	8668.3	65200.	7.5217
1432	450.00	8612.3	65200.	7.5706
1445	450.00	8612.1	65200.	7.5707
1453	450.00	8592.6	65200.	7.5879
1424	450.00	8589.1	65200.	7.5910
1144	450.00	8582.4	65200.	7.5969
1172	450.00	8580.9	65200.	7.5983
1652	450.00	8568.9	65200.	7.6089

Table 3.T.16 (continued)

983	450.00	8567.8	65200.	7.6098
1261	450.00	8560.5	65200.	7.6164
1226	450.00	8541.0	65200.	7.6338
1617	450.00	8531.2	65200.	7.6426
1433	450.00	8508.8	65200.	7.6627
1444	450.00	8508.0	65200.	7.6634
915	450.00	8495.1	65200.	7.6750
1589	450.00	8492.0	65200.	7.6778
1454	450.00	8482.6	65200.	7.6863
1423	450.00	8478.7	65200.	7.6898
1289	450.00	8478.2	65200.	7.6903
1213	450.00	8458.0	65200.	7.7087
1407	450.00	8432.7	65200.	7.7318
1651	450.00	8428.8	65200.	7.7353
1470	450.00	8423.0	65200.	7.7407
1604	450.00	8419.5	65200.	7.7440
1262	450.00	8412.5	65200.	7.7503
1227	450.00	8406.3	65200.	7.7561
1192	450.00	8398.5	65200.	7.7633
1274	450.00	8387.1	65200.	7.7739
1616	450.00	8381.6	65200.	7.7789
1434	450.00	8378.6	65200.	7.7817
1443	450.00	8377.2	65200.	7.7830
1396	450.00	8370.4	65200.	7.7894
1481	450.00	8364.7	65200.	7.7946
1455	450.00	8345.9	65200.	7.8123
1422	450.00	8341.5	65200.	7.8163
1650	450.00	8292.7	65200.	7.8623
1286	450.00	8279.9	65200.	7.8745
936	450.00	8277.9	65200.	7.8764
1228	450.00	8275.5	65200.	7.8787
1263	450.00	8256.9	65200.	7.8964
1592	450.00	8256.1	65200.	7.8972
1345	450.00	8254.0	65200.	7.8992
1615	450.00	8224.5	65200.	7.9275
1435	450.00	8221.9	65200.	7.9300
1442	450.00	8219.8	65200.	7.9320
1456	450.00	8182.3	65200.	7.9685
1347	450.00	8181.7	65200.	7.9690
1421	450.00	8177.5	65200.	7.9731
1649	450.00	8160.4	65200.	7.9898
1605	450.00	8148.7	65200.	8.0013
1229	450.00	8148.2	65200.	8.0018
1273	450.00	8116.3	65200.	8.0332
1264	450.00	8093.5	65200.	8.0559
914	450.00	8062.8	65200.	8.0866
1614	450.00	8059.7	65200.	8.0896
1436	450.00	8038.7	65200.	8.1107
1214	450.00	8036.7	65200.	8.1128
1441	450.00	8035.9	65200.	8.1136
1627	450.00	8035.8	65200.	8.1136
1648	450.00	8031.5	65200.	8.1180
1230	450.00	8024.3	65200.	8.1254

Table 3.T.16 (continued)

1457	450.00	7991.9	65200.	8.1583
1251	450.00	7987.1	65200.	8.1632
1420	450.00	7986.8	65200.	8.1635
1590	450.00	7933.5	65200.	8.2183
1628	450.00	7922.1	65200.	8.2302
1265	450.00	7921.9	65200.	8.2303
1288	450.00	7918.9	65200.	8.2335
1647	450.00	7905.9	65200.	8.2470
1231	450.00	7903.5	65200.	8.2495
1606	450.00	7888.0	65200.	8.2657
1613	450.00	7886.9	65200.	8.2669
1250	450.00	7874.6	65200.	8.2798
1408	450.00	7870.8	65200.	8.2838
1469	450.00	7861.1	65200.	8.2940
1272	450.00	7855.8	65200.	8.2996
1437	450.00	7829.1	65200.	8.3279
1440	450.00	7825.5	65200.	8.3317
1629	450.00	7809.7	65200.	8.3486
1232	450.00	7785.6	65200.	8.3744
1287	450.00	7784.1	65200.	8.3760
1646	450.00	7783.5	65200.	8.3767
1458	450.00	7774.7	65200.	8.3862
1419	450.00	7769.3	65200.	8.3920
1397	450.00	7764.3	65200.	8.3975
1249	450.00	7763.6	65200.	8.3982
1591	450.00	7760.7	65200.	8.4013
1480	450.00	7758.7	65200.	8.4034
1266	450.00	7742.1	65200.	8.4215
1612	450.00	7705.9	65200.	8.4610
1630	450.00	7698.3	65200.	8.4694
1233	450.00	7670.5	65200.	8.5001
1645	450.00	7663.9	65200.	8.5074
1248	450.00	7653.8	65200.	8.5186
913	450.00	7640.4	65200.	8.5336
1607	450.00	7637.3	65200.	8.5371
1532	450.00	7632.4	65200.	8.5425
1215	450.00	7625.1	65200.	8.5507
1271	450.00	7605.3	65200.	8.5730
957	450.00	7599.8	65200.	8.5792
1438	450.00	7593.0	65200.	8.5868
1439	450.00	7588.7	65200.	8.5917
1631	450.00	7587.8	65200.	8.5927
1171	450.00	7561.1	65200.	8.6231
1234	450.00	7557.8	65200.	8.6268
1267	450.00	7553.7	65200.	8.6316
1644	450.00	7547.0	65200.	8.6392
1247	450.00	7545.1	65200.	8.6414
909	450.00	7541.3	65200.	8.6457
1459	450.00	7530.8	65200.	8.6578
1418	450.00	7525.0	65200.	8.6645
1219	450.00	7523.1	65200.	8.6666
1531	450.00	7521.1	65200.	8.6690
1611	450.00	7516.5	65200.	8.6742

Table 3.T.16 (continued)

1632	450.00	7478.0	65200.	8.7189
1235	450.00	7447.4	65200.	8.7547
1246	450.00	7437.2	65200.	8.7667
1643	450.00	7432.5	65200.	8.7723
1608	450.00	7396.2	65200.	8.8154
1633	450.00	7368.6	65200.	8.8483
1270	450.00	7364.5	65200.	8.8533
1268	450.00	7356.5	65200.	8.8629
1236	450.00	7339.1	65200.	8.8839
1409	450.00	7335.0	65200.	8.8889
1245	450.00	7329.9	65200.	8.8950
1468	450.00	7325.4	65200.	8.9006
1642	450.00	7320.2	65200.	8.9069
1610	450.00	7318.5	65200.	8.9089
1460	450.00	7260.1	65200.	8.9806
1634	450.00	7259.4	65200.	8.9814
1417	450.00	7254.0	65200.	8.9881
1237	450.00	7232.7	65200.	9.0147
912	450.00	7227.9	65200.	9.0206
1216	450.00	7223.1	65200.	9.0266
1244	450.00	7223.0	65200.	9.0267
1641	450.00	7210.0	65200.	9.0431
1398	450.00	7189.9	65200.	9.0683
1479	450.00	7184.4	65200.	9.0752
1609	450.00	7164.5	65200.	9.1004
910	450.00	7161.0	65200.	9.1049
1218	450.00	7152.3	65200.	9.1160
1269	450.00	7150.4	65200.	9.1184
1635	450.00	7150.2	65200.	9.1186
1238	450.00	7127.8	65200.	9.1473
1243	450.00	7116.3	65200.	9.1621
1640	450.00	7101.5	65200.	9.1812
1471	450.00	7092.4	65200.	9.1930
1406	450.00	7090.0	65200.	9.1960
1346	450.00	7043.7	65200.	9.2564
1636	450.00	7040.8	65200.	9.2603
1239	450.00	7024.4	65200.	9.2820
1242	450.00	7009.4	65200.	9.3018
1639	450.00	6994.6	65200.	9.3215
1461	450.00	6962.7	65200.	9.3641
1416	450.00	6956.4	65200.	9.3727
1637	450.00	6930.9	65200.	9.4072
1240	450.00	6922.1	65200.	9.4191
1241	450.00	6902.3	65200.	9.4461
1638	450.00	6889.0	65200.	9.4643
1217	450.00	6830.5	65200.	9.5454
1410	450.00	6825.3	65200.	9.5527
911	450.00	6825.0	65200.	9.5532
1467	450.00	6815.8	65200.	9.5660
1472	450.00	6806.5	65200.	9.5791
1405	450.00	6803.9	65200.	9.5828
1399	450.00	6647.3	65200.	9.8085
1478	450.00	6642.0	65200.	9.8164

Table 3.T.16 (continued)

1462	450.00	6638.7	65200.	9.8212
1415	450.00	6632.1	65200.	9.8310
1473	450.00	6488.4	65200.	10.049
1404	450.00	6485.5	65200.	10.053
1411	450.00	6341.9	65200.	10.281
1466	450.00	6332.5	65200.	10.296
1463	450.00	6288.1	65200.	10.369
1414	450.00	6281.2	65200.	10.380
984	450.00	6245.0	65200.	10.440
1474	450.00	6138.1	65200.	10.622
1400	450.00	6136.6	65200.	10.625
1403	450.00	6135.0	65200.	10.628
1477	450.00	6131.4	65200.	10.634
1143	450.00	6103.8	65200.	10.682
1464	450.00	5910.9	65200.	11.030
1413	450.00	5903.9	65200.	11.044
1412	450.00	5884.8	65200.	11.079
1465	450.00	5875.6	65200.	11.097
1475	450.00	5755.6	65200.	11.328
1402	450.00	5752.3	65200.	11.335
1401	450.00	5657.9	65200.	11.524
1476	450.00	5652.9	65200.	11.534

Table 3.T.17

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Basket Supports
SUBTITLE  2 =
Load Combination: E3.b (See Table 3.1.4)
SUBTITLE  3 =
Stress Result: Primary Membrane (PM)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT     CURRENT     MIXED        PREVIOUS     PREVIOUS
   ELEM     REF TEMP    PM           ALLOW        SF
    905    450.00     -12608.       43450.       3.4464
    904    450.00     -12605.       43450.       3.4470
    903    450.00     -12583.       43450.       3.4531
    902    450.00     -12561.       43450.       3.4591
    901    450.00     -11628.       43450.       3.7367
    908    450.00     -11624.       43450.       3.7379
    900    450.00     -11622.       43450.       3.7386
    907    450.00     -11618.       43450.       3.7398
    899    450.00     -11593.       43450.       3.7480
    906    450.00     -11589.       43450.       3.7491
    847    450.00       9368.6      43450.       4.6378
    848    450.00       9368.5      43450.       4.6379
    846    450.00       9368.5      43450.       4.6379
    849    450.00       9368.5      43450.       4.6379
    850    450.00       9368.4      43450.       4.6380
    845    450.00       9368.0      43450.       4.6381
    844    450.00       9367.4      43450.       4.6384
    865    450.00       9365.7      43450.       4.6393
    864    450.00       9365.7      43450.       4.6393
    866    450.00       9365.6      43450.       4.6393
    863    450.00       9365.6      43450.       4.6393
    862    450.00       9365.5      43450.       4.6394
    867    450.00       9365.2      43450.       4.6395
    868    450.00       9364.6      43450.       4.6398
    858    450.00       8796.6      43450.       4.9394
    859    450.00       8796.6      43450.       4.9394
    857    450.00       8796.6      43450.       4.9394
    860    450.00       8796.5      43450.       4.9395
    861    450.00       8796.4      43450.       4.9395
    854    450.00       8796.0      43450.       4.9397
    853    450.00       8796.0      43450.       4.9398
    855    450.00       8796.0      43450.       4.9398
    852    450.00       8795.9      43450.       4.9398
    856    450.00       8795.8      43450.       4.9398
    851    450.00       8795.8      43450.       4.9399
    889    450.00      -3199.5      43450.       13.580
    896    450.00      -3199.1      43450.       13.582
    892    450.00      -3181.4      43450.       13.658
    890    450.00      -3174.9      43450.       13.685
```

Table 3.T.17 (continued)

897	450.00	-3174.4	43450.	13.688
893	450.00	-3159.3	43450.	13.753
891	450.00	-3150.6	43450.	13.791
898	450.00	-3150.5	43450.	13.791
894	450.00	-3137.2	43450.	13.850
895	450.00	-3115.2	43450.	13.948
787	450.00	-2424.3	43450.	17.923
788	450.00	-2421.9	43450.	17.941
800	450.00	-2418.2	43450.	17.968
799	450.00	-2416.0	43450.	17.984
789	450.00	-2399.4	43450.	18.108
798	450.00	-2393.6	43450.	18.153
790	450.00	-2377.2	43450.	18.278
797	450.00	-2371.3	43450.	18.324
791	450.00	-2355.2	43450.	18.448
796	450.00	-2349.1	43450.	18.497
792	450.00	-2333.4	43450.	18.621
795	450.00	-2327.1	43450.	18.672
793	450.00	-2311.5	43450.	18.797
794	450.00	-2305.4	43450.	18.847
782	450.00	-2177.3	43450.	19.956
806	450.00	-2170.5	43450.	20.019
805	450.00	-2168.2	43450.	20.040
783	450.00	-2153.2	43450.	20.180
804	450.00	-2144.5	43450.	20.261
776	450.00	-2142.8	43450.	20.278
811	450.00	-2133.5	43450.	20.366
784	450.00	-2129.1	43450.	20.408
803	450.00	-2120.9	43450.	20.486
777	450.00	-2119.1	43450.	20.504
810	450.00	-2109.3	43450.	20.599
785	450.00	-2105.0	43450.	20.641
802	450.00	-2097.4	43450.	20.716
778	450.00	-2095.4	43450.	20.735
809	450.00	-2085.1	43450.	20.838
786	450.00	-2081.1	43450.	20.879
769	450.00	-2077.1	43450.	20.919
770	450.00	-2074.7	43450.	20.943
801	450.00	-2073.9	43450.	20.951
779	450.00	-2071.8	43450.	20.972
818	450.00	-2061.9	43450.	21.073
808	450.00	-2061.1	43450.	21.081
817	450.00	-2059.5	43450.	21.097
771	450.00	-2052.3	43450.	21.171
780	450.00	-2048.3	43450.	21.213
816	450.00	-2037.2	43450.	21.329
807	450.00	-2037.1	43450.	21.329
772	450.00	-2030.0	43450.	21.404
781	450.00	-2024.6	43450.	21.461
815	450.00	-2014.8	43450.	21.565
773	450.00	-2007.7	43450.	21.642
814	450.00	-1992.5	43450.	21.807
774	450.00	-1985.3	43450.	21.885

Table 3.T.17 (continued)

813	450.00	-1970.2	43450.	22.054
775	450.00	-1963.0	43450.	22.134
812	450.00	-1947.8	43450.	22.307
832	450.00	-1170.1	43450.	37.133
835	450.00	-1170.0	43450.	37.136
836	450.00	-1170.0	43450.	37.136
833	450.00	-1170.0	43450.	37.136
834	450.00	-1170.0	43450.	37.136
826	450.00	-1169.8	43450.	37.142
831	450.00	-1169.8	43450.	37.143
827	450.00	-1169.8	43450.	37.144
828	450.00	-1169.7	43450.	37.146
829	450.00	-1169.6	43450.	37.148
830	450.00	-1169.6	43450.	37.149
843	450.00	-866.08	43450.	50.169
842	450.00	-865.94	43450.	50.177
841	450.00	-865.66	43450.	50.193
819	450.00	-865.50	43450.	50.202
840	450.00	-865.30	43450.	50.214
837	450.00	-865.28	43450.	50.215
820	450.00	-865.26	43450.	50.216
838	450.00	-865.17	43450.	50.221
839	450.00	-865.08	43450.	50.227
821	450.00	-864.86	43450.	50.239
825	450.00	-864.63	43450.	50.253
822	450.00	-864.51	43450.	50.260
824	450.00	-864.34	43450.	50.270
823	450.00	-864.30	43450.	50.272
878	450.00	-75.705	43450.	573.94
881	450.00	-75.273	43450.	577.24
877	450.00	-74.238	43450.	585.28
876	450.00	-73.936	43450.	587.67
880	450.00	-73.716	43450.	589.43
879	450.00	-73.409	43450.	591.89
871	450.00	-39.789	43450.	1092.0
888	450.00	-39.709	43450.	1094.2
870	450.00	-39.210	43450.	1108.1
887	450.00	-39.079	43450.	1111.9
869	450.00	-38.995	43450.	1114.3
886	450.00	-38.983	43450.	1114.6
875	450.00	-9.9422	43450.	4370.2
874	450.00	-9.3257	43450.	4659.2
872	450.00	-9.2171	43450.	4714.0
873	450.00	-9.0548	43450.	4798.6
885	450.00	-8.9800	43450.	4838.6
882	450.00	-8.2760	43450.	5250.1
884	450.00	-8.2141	43450.	5289.7
883	450.00	-8.1982	43450.	5300.0

Table 3.T.18

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Basket Supports
SUBTITLE  2 =
Load Combination: E3.b (See Table 3.1.4)
SUBTITLE  3 =
Stress Result: Local Membrane Plus Primary Bending (PL+PB)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT     CURRENT      MIXED        PREVIOUS     PREVIOUS
   ELEM     REF TEMP     PL+PB        ALLOW        SF
    901   450.00       49960.       65200.       1.3050
    908   450.00       49757.       65200.       1.3104
    900   450.00       48176.       65200.       1.3534
    907   450.00       47986.       65200.       1.3587
    899   450.00       26113.       65200.       2.4968
    906   450.00       26079.       65200.       2.5000
    844   450.00       22676.       65200.       2.8753
    868   450.00       22495.       65200.       2.8985
    845   450.00       21809.       65200.       2.9896
    867   450.00       21638.       65200.       3.0133
    881   450.00       19524.       65200.       3.3395
    878   450.00       19492.       65200.       3.3450
    793   450.00       18690.       65200.       3.4885
    794   450.00       18659.       65200.       3.4942
    792   450.00       18300.       65200.       3.5628
    795   450.00       18271.       65200.       3.5685
    880   450.00       17895.       65200.       3.6435
    877   450.00       17865.       65200.       3.6495
    850   450.00       16808.       65200.       3.8792
    862   450.00       16736.       65200.       3.8958
    849   450.00       16480.       65200.       3.9563
    863   450.00       16413.       65200.       3.9724
    846   450.00       15261.       65200.       4.2724
    866   450.00       15161.       65200.       4.3006
    857   450.00       14988.       65200.       4.3501
    856   450.00       14941.       65200.       4.3638
    891   450.00       14826.       65200.       4.3975
    898   450.00       14808.       65200.       4.4030
    855   450.00       14519.       65200.       4.4907
    791   450.00       14343.       65200.       4.5457
    796   450.00       14323.       65200.       4.5520
    819   450.00       14056.       65200.       4.6386
    843   450.00       14050.       65200.       4.6404
    879   450.00       14044.       65200.       4.6427
    876   450.00       14017.       65200.       4.6515
    820   450.00       13701.       65200.       4.7587
    842   450.00       13695.       65200.       4.7608
    848   450.00       13664.       65200.       4.7718
    890   450.00       13640.       65200.       4.7801
```

Table 3.T.18 (continued)

864	450.00	13637.	65200.	4.7810
897	450.00	13622.	65200.	4.7862
905	450.00	12664.	65200.	5.1485
904	450.00	12658.	65200.	5.1507
903	450.00	12605.	65200.	5.1726
902	450.00	12585.	65200.	5.1806
851	450.00	12182.	65200.	5.3521
861	450.00	12118.	65200.	5.3805
885	450.00	12023.	65200.	5.4230
875	450.00	11869.	65200.	5.4933
888	450.00	11757.	65200.	5.5458
858	450.00	11578.	65200.	5.6316
871	450.00	11455.	65200.	5.6919
854	450.00	11373.	65200.	5.7327
884	450.00	11147.	65200.	5.8489
874	450.00	11004.	65200.	5.9253
865	450.00	10993.	65200.	5.9310
847	450.00	10985.	65200.	5.9356
887	450.00	10828.	65200.	6.0214
889	450.00	10602.	65200.	6.1499
896	450.00	10586.	65200.	6.1588
870	450.00	10549.	65200.	6.1806
821	450.00	10228.	65200.	6.3748
841	450.00	10222.	65200.	6.3787
852	450.00	10167.	65200.	6.4130
860	450.00	10104.	65200.	6.4529
790	450.00	9914.6	65200.	6.5762
797	450.00	9903.9	65200.	6.5832
859	450.00	9864.8	65200.	6.6094
853	450.00	9806.3	65200.	6.6488
787	450.00	9781.0	65200.	6.6660
800	450.00	9763.1	65200.	6.6782
882	450.00	9488.1	65200.	6.8717
872	450.00	9358.2	65200.	6.9672
788	450.00	9279.2	65200.	7.0265
799	450.00	9262.0	65200.	7.0395
801	450.00	8675.5	65200.	7.5154
786	450.00	8643.3	65200.	7.5434
811	450.00	8080.7	65200.	8.0686
776	450.00	7957.3	65200.	8.1937
825	450.00	7789.0	65200.	8.3708
837	450.00	7787.5	65200.	8.3724
806	450.00	7515.9	65200.	8.6749
782	450.00	7502.6	65200.	8.6904
805	450.00	7287.6	65200.	8.9467
824	450.00	7097.1	65200.	9.1869
838	450.00	7095.7	65200.	9.1887
802	450.00	6524.8	65200.	9.9926
886	450.00	6468.2	65200.	10.080
785	450.00	6456.8	65200.	10.098
822	450.00	6416.5	65200.	10.161
840	450.00	6412.8	65200.	10.167
869	450.00	6273.0	65200.	10.394

Table 3.T.18 (continued)

810	450.00	6201.4	65200.	10.514
777	450.00	6159.0	65200.	10.586
807	450.00	6147.4	65200.	10.606
781	450.00	6046.0	65200.	10.784
780	450.00	5860.7	65200.	11.125
789	450.00	5182.8	65200.	12.580
798	450.00	5178.7	65200.	12.590
783	450.00	5127.3	65200.	12.716
831	450.00	4989.4	65200.	13.068
832	450.00	4978.5	65200.	13.096
804	450.00	4932.6	65200.	13.218
830	450.00	4582.4	65200.	14.228
778	450.00	4203.4	65200.	15.511
803	450.00	4193.3	65200.	15.548
808	450.00	4170.6	65200.	15.633
809	450.00	4152.8	65200.	15.700
784	450.00	4085.7	65200.	15.958
779	450.00	3957.1	65200.	16.477
883	450.00	3479.1	65200.	18.740
873	450.00	3427.0	65200.	19.025
892	450.00	3192.0	65200.	20.426
893	450.00	3162.1	65200.	20.619
894	450.00	3142.4	65200.	20.748
895	450.00	3128.2	65200.	20.843
828	450.00	2796.5	65200.	23.315
834	450.00	2749.3	65200.	23.715
818	450.00	2674.3	65200.	24.380
817	450.00	2651.3	65200.	24.591
769	450.00	2558.4	65200.	25.485
770	450.00	2538.7	65200.	25.683
812	450.00	2427.5	65200.	26.859
816	450.00	2427.0	65200.	26.865
813	450.00	2409.0	65200.	27.065
775	450.00	2380.1	65200.	27.394
774	450.00	2365.7	65200.	27.561
771	450.00	2347.2	65200.	27.778
814	450.00	2227.3	65200.	29.273
773	450.00	2223.0	65200.	29.329
815	450.00	2190.9	65200.	29.760
772	450.00	2147.4	65200.	30.363
823	450.00	2100.8	65200.	31.036
839	450.00	2098.7	65200.	31.067
833	450.00	1372.8	65200.	47.495
829	450.00	1142.1	65200.	57.089
826	450.00	1124.1	65200.	58.004
827	450.00	1124.0	65200.	58.005
835	450.00	1109.2	65200.	58.779
836	450.00	1109.2	65200.	58.782

Table 3.T.19

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Fuel Basket
SUBTITLE  2 =
Load Combination: F3.c (See Table 3.1.3)
SUBTITLE  3 =
Stress Result: Primary Membrane (PM)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT     CURRENT     CURRENT      PREVIOUS     PREVIOUS
   ELEM     REF TEMP    PM           ALLOW        SF
    366   725.00      -7440.2       36950.       4.9663
    715   725.00      -7440.2       36950.       4.9663
    365   725.00      -7435.6       36950.       4.9693
    716   725.00      -7435.6       36950.       4.9693
    364   725.00      -7409.0       36950.       4.9872
    717   725.00      -7409.0       36950.       4.9872
    363   725.00      -7382.4       36950.       5.0052
    718   725.00      -7382.4       36950.       5.0052
    362   725.00      -7354.6       36950.       5.0241
    719   725.00      -7354.6       36950.       5.0241
    361   725.00      -7328.6       36950.       5.0419
    720   725.00      -7328.6       36950.       5.0419
    691   725.00      -7002.0       36950.       5.2771
    222   725.00      -7002.0       36950.       5.2771
    692   725.00      -6996.5       36950.       5.2812
    221   725.00      -6996.5       36950.       5.2812
    510   725.00      -6975.3       36950.       5.2972
    739   725.00      -6975.3       36950.       5.2972
    509   725.00      -6971.7       36950.       5.3000
    740   725.00      -6971.7       36950.       5.3000
    693   725.00      -6969.1       36950.       5.3020
    220   725.00      -6969.1       36950.       5.3020
    508   725.00      -6945.8       36950.       5.3198
    741   725.00      -6945.8       36950.       5.3198
    694   725.00      -6942.8       36950.       5.3221
    219   725.00      -6942.8       36950.       5.3221
    507   725.00      -6918.8       36950.       5.3405
    742   725.00      -6918.8       36950.       5.3405
    695   725.00      -6914.9       36950.       5.3436
    218   725.00      -6914.9       36950.       5.3436
    506   725.00      -6891.2       36950.       5.3619
    743   725.00      -6891.2       36950.       5.3619
    696   725.00      -6888.2       36950.       5.3642
    217   725.00      -6888.2       36950.       5.3642
    505   725.00      -6865.9       36950.       5.3817
    744   725.00      -6865.9       36950.       5.3817
    228   725.00      -6767.7       36950.       5.4598
    685   725.00      -6767.7       36950.       5.4598
    227   725.00      -6765.5       36950.       5.4615
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Table 3.T.19 (continued)

686	725.00	-6765.5	36950.	5.4615
226	725.00	-6738.7	36950.	5.4832
687	725.00	-6738.7	36950.	5.4833
225	725.00	-6711.8	36950.	5.5053
688	725.00	-6711.8	36950.	5.5053
224	725.00	-6684.7	36950.	5.5275
689	725.00	-6684.7	36950.	5.5275
223	725.00	-6657.7	36950.	5.5499
690	725.00	-6657.7	36950.	5.5500
763	725.00	-6640.2	36950.	5.5646
654	725.00	-6640.2	36950.	5.5646
764	725.00	-6635.5	36950.	5.5685
653	725.00	-6635.5	36950.	5.5685
765	725.00	-6608.3	36950.	5.5915
652	725.00	-6608.3	36950.	5.5915
766	725.00	-6581.6	36950.	5.6141
651	725.00	-6581.6	36950.	5.6141
767	725.00	-6554.2	36950.	5.6376
650	725.00	-6554.2	36950.	5.6376
768	725.00	-6528.4	36950.	5.6599
649	725.00	-6528.4	36950.	5.6599
342	725.00	-6010.0	36950.	6.1481
595	725.00	-6010.0	36950.	6.1481
341	725.00	-6004.5	36950.	6.1538
596	725.00	-6004.5	36950.	6.1538
340	725.00	-5976.7	36950.	6.1823
597	725.00	-5976.7	36950.	6.1823
339	725.00	-5950.4	36950.	6.2097
598	725.00	-5950.4	36950.	6.2097
338	725.00	-5922.7	36950.	6.2387
599	725.00	-5922.7	36950.	6.2387
337	725.00	-5896.0	36950.	6.2669
600	725.00	-5896.0	36950.	6.2669
571	725.00	-5642.7	36950.	6.5483
198	725.00	-5642.7	36950.	6.5483
572	725.00	-5636.6	36950.	6.5554
197	725.00	-5636.6	36950.	6.5554
486	725.00	-5634.5	36950.	6.5578
619	725.00	-5634.5	36950.	6.5578
485	725.00	-5629.5	36950.	6.5636
620	725.00	-5629.5	36950.	6.5636
573	725.00	-5608.4	36950.	6.5883
196	725.00	-5608.4	36950.	6.5883
484	725.00	-5602.2	36950.	6.5957
621	725.00	-5602.2	36950.	6.5957
574	725.00	-5582.2	36950.	6.6192
195	725.00	-5582.2	36950.	6.6192
483	725.00	-5575.6	36950.	6.6270
622	725.00	-5575.6	36950.	6.6270
575	725.00	-5554.5	36950.	6.6523
194	725.00	-5554.5	36950.	6.6523
482	725.00	-5548.1	36950.	6.6599
623	725.00	-5548.1	36950.	6.6599

Table 3.T.19 (continued)

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576   725.00     -5527.5      36950.       6.6848
193   725.00     -5527.5      36950.       6.6848
481   725.00     -5521.9      36950.       6.6915
624   725.00     -5521.9      36950.       6.6915
 78   725.00     -5293.8      36950.       6.9799
547   725.00     -5293.8      36950.       6.9799
643   725.00     -5288.7      36950.       6.9866
630   725.00     -5288.7      36950.       6.9866
 77   725.00     -5287.9      36950.       6.9876
548   725.00     -5287.9      36950.       6.9877
644   725.00     -5284.1      36950.       6.9926
629   725.00     -5284.1      36950.       6.9926
 76   725.00     -5260.2      36950.       7.0244
549   725.00     -5260.2      36950.       7.0244
645   725.00     -5257.0      36950.       7.0287
628   725.00     -5257.0      36950.       7.0287
 75   725.00     -5234.1      36950.       7.0594
550   725.00     -5234.1      36950.       7.0595
646   725.00     -5230.4      36950.       7.0645
627   725.00     -5230.4      36950.       7.0645
 74   725.00     -5206.2      36950.       7.0974
551   725.00     -5206.1      36950.       7.0974
647   725.00     -5203.0      36950.       7.1017
626   725.00     -5203.0      36950.       7.1017
 73   725.00     -5179.0      36950.       7.1345
552   725.00     -5179.0      36950.       7.1346
648   725.00     -5177.1      36950.       7.1372
625   725.00     -5177.1      36950.       7.1372
318   725.00     -4580.3      36950.       8.0672
451   725.00     -4580.3      36950.       8.0672
317   725.00     -4575.0      36950.       8.0764
452   725.00     -4575.0      36950.       8.0764
316   725.00     -4547.5      36950.       8.1254
453   725.00     -4547.5      36950.       8.1254
315   725.00     -4521.0      36950.       8.1730
454   725.00     -4521.0      36950.       8.1730
314   725.00     -4493.4      36950.       8.2231
455   725.00     -4493.4      36950.       8.2231
313   725.00     -4467.0      36950.       8.2717
456   725.00     -4467.0      36950.       8.2717
427   725.00     -4312.5      36950.       8.5682
174   725.00     -4312.5      36950.       8.5682
428   725.00     -4306.8      36950.       8.5795
173   725.00     -4306.8      36950.       8.5795
462   725.00     -4293.0      36950.       8.6071
475   725.00     -4293.0      36950.       8.6071
461   725.00     -4288.4      36950.       8.6163
476   725.00     -4288.4      36950.       8.6163
429   725.00     -4278.9      36950.       8.6355
172   725.00     -4278.9      36950.       8.6355
460   725.00     -4261.2      36950.       8.6712
477   725.00     -4261.2      36950.       8.6712
430   725.00     -4252.5      36950.       8.6890
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Table 3.T.19 (continued)

171	725.00	-4252.5	36950.	8.6890
459	725.00	-4234.6	36950.	8.7258
478	725.00	-4234.6	36950.	8.7258
431	725.00	-4224.9	36950.	8.7458
170	725.00	-4224.9	36950.	8.7458
458	725.00	-4207.2	36950.	8.7825
479	725.00	-4207.2	36950.	8.7825
432	725.00	-4198.1	36950.	8.8015
169	725.00	-4198.1	36950.	8.8015
457	725.00	-4181.3	36950.	8.8369
480	725.00	-4181.3	36950.	8.8369
499	725.00	-3868.7	36950.	9.5510
606	725.00	-3868.7	36950.	9.5510
500	725.00	-3864.4	36950.	9.5616
605	725.00	-3864.4	36950.	9.5616
501	725.00	-3837.5	36950.	9.6287
604	725.00	-3837.5	36950.	9.6287
54	725.00	-3830.8	36950.	9.6456
403	725.00	-3830.8	36950.	9.6456
53	725.00	-3824.5	36950.	9.6614
404	725.00	-3824.5	36950.	9.6614
502	725.00	-3810.7	36950.	9.6963
603	725.00	-3810.7	36950.	9.6963
52	725.00	-3796.1	36950.	9.7336
405	725.00	-3796.1	36950.	9.7336
503	725.00	-3783.5	36950.	9.7661
602	725.00	-3783.5	36950.	9.7661
51	725.00	-3769.9	36950.	9.8014
406	725.00	-3769.9	36950.	9.8014
504	725.00	-3757.8	36950.	9.8328
601	725.00	-3757.8	36950.	9.8328
50	725.00	-3742.2	36950.	9.8738
407	725.00	-3742.2	36950.	9.8738
49	725.00	-3715.2	36950.	9.9457
408	725.00	-3715.2	36950.	9.9457
294	725.00	-3151.7	36950.	11.724
307	725.00	-3151.7	36950.	11.724
293	725.00	-3144.7	36950.	11.750
308	725.00	-3144.7	36950.	11.750
292	725.00	-3116.0	36950.	11.858
309	725.00	-3115.9	36950.	11.858
291	725.00	-3090.1	36950.	11.958
310	725.00	-3090.1	36950.	11.958
290	725.00	-3062.5	36950.	12.065
311	725.00	-3062.5	36950.	12.065
289	725.00	-3035.1	36950.	12.174
312	725.00	-3035.1	36950.	12.174
283	725.00	-2975.9	36950.	12.417
150	725.00	-2975.9	36950.	12.417
284	725.00	-2968.2	36950.	12.449
149	725.00	-2968.2	36950.	12.449
438	725.00	-2946.6	36950.	12.540
331	725.00	-2946.6	36950.	12.540

Table 3.T.19 (continued)

437	725.00	-2940.2	36950.	12.567
332	725.00	-2940.2	36950.	12.567
285	725.00	-2939.0	36950.	12.572
148	725.00	-2939.0	36950.	12.572
286	725.00	-2913.3	36950.	12.683
147	725.00	-2913.3	36950.	12.683
436	725.00	-2912.1	36950.	12.688
333	725.00	-2912.1	36950.	12.688
435	725.00	-2886.1	36950.	12.803
334	725.00	-2886.1	36950.	12.803
287	725.00	-2885.8	36950.	12.804
146	725.00	-2885.8	36950.	12.804
434	725.00	-2858.5	36950.	12.926
335	725.00	-2858.5	36950.	12.926
288	725.00	-2858.1	36950.	12.928
145	725.00	-2858.1	36950.	12.928
433	725.00	-2831.5	36950.	13.050
336	725.00	-2831.5	36950.	13.050
355	725.00	-2466.4	36950.	14.981
582	725.00	-2466.4	36950.	14.981
356	725.00	-2460.4	36950.	15.018
581	725.00	-2460.4	36950.	15.018
750	725.00	-2452.8	36950.	15.065
667	725.00	-2452.8	36950.	15.065
749	725.00	-2448.1	36950.	15.093
668	725.00	-2448.1	36950.	15.093
357	725.00	-2432.5	36950.	15.190
580	725.00	-2432.5	36950.	15.190
748	725.00	-2421.3	36950.	15.261
669	725.00	-2421.3	36950.	15.261
358	725.00	-2406.3	36950.	15.355
579	725.00	-2406.3	36950.	15.355
747	725.00	-2394.9	36950.	15.428
670	725.00	-2394.9	36950.	15.428
359	725.00	-2378.9	36950.	15.533
578	725.00	-2378.9	36950.	15.533
746	725.00	-2366.9	36950.	15.611
671	725.00	-2366.9	36950.	15.611
30	725.00	-2361.3	36950.	15.648
259	725.00	-2361.3	36950.	15.648
29	725.00	-2353.1	36950.	15.703
260	725.00	-2353.1	36950.	15.703
360	725.00	-2352.0	36950.	15.710
577	725.00	-2352.0	36950.	15.710
745	725.00	-2340.1	36950.	15.790
672	725.00	-2340.1	36950.	15.790
28	725.00	-2323.5	36950.	15.903
261	725.00	-2323.5	36950.	15.903
27	725.00	-2297.9	36950.	16.080
262	725.00	-2297.9	36950.	16.080
26	725.00	-2270.5	36950.	16.274
263	725.00	-2270.5	36950.	16.274
25	725.00	-2242.6	36950.	16.477

Table 3.T.19 (continued)

264	725.00	-2242.5	36950.	16.477
726	725.00	-1738.2	36950.	21.257
523	725.00	-1738.2	36950.	21.257
725	725.00	-1732.4	36950.	21.329
524	725.00	-1732.3	36950.	21.329
270	725.00	-1716.7	36950.	21.524
163	725.00	-1716.7	36950.	21.524
269	725.00	-1710.5	36950.	21.602
164	725.00	-1710.5	36950.	21.602
724	725.00	-1704.0	36950.	21.684
525	725.00	-1704.0	36950.	21.684
268	725.00	-1682.4	36950.	21.962
165	725.00	-1682.4	36950.	21.962
723	725.00	-1677.6	36950.	22.025
526	725.00	-1677.6	36950.	22.025
267	725.00	-1656.3	36950.	22.308
166	725.00	-1656.3	36950.	22.308
722	725.00	-1650.1	36950.	22.393
527	725.00	-1650.1	36950.	22.393
139	725.00	-1640.1	36950.	22.530
126	725.00	-1640.1	36950.	22.530
140	725.00	-1633.4	36950.	22.621
125	725.00	-1633.4	36950.	22.621
266	725.00	-1628.8	36950.	22.686
167	725.00	-1628.8	36950.	22.686
721	725.00	-1623.3	36950.	22.762
528	725.00	-1623.3	36950.	22.762
141	725.00	-1605.0	36950.	23.022
124	725.00	-1605.0	36950.	23.022
265	725.00	-1601.8	36950.	23.068
168	725.00	-1601.8	36950.	23.068
414	725.00	-1597.7	36950.	23.127
187	725.00	-1597.7	36950.	23.127
413	725.00	-1592.3	36950.	23.206
188	725.00	-1592.3	36950.	23.206
142	725.00	-1579.0	36950.	23.402
123	725.00	-1579.0	36950.	23.402
541	725.00	-1570.9	36950.	23.522
84	725.00	-1570.9	36950.	23.522
542	725.00	-1568.6	36950.	23.555
83	725.00	-1568.6	36950.	23.555
412	725.00	-1564.7	36950.	23.615
189	725.00	-1564.7	36950.	23.615
143	725.00	-1551.4	36950.	23.817
122	725.00	-1551.4	36950.	23.817
543	725.00	-1541.7	36950.	23.966
82	725.00	-1541.7	36950.	23.966
411	725.00	-1538.4	36950.	24.019
190	725.00	-1538.4	36950.	24.019
144	725.00	-1524.2	36950.	24.243
121	725.00	-1524.2	36950.	24.243
544	725.00	-1514.8	36950.	24.392
81	725.00	-1514.8	36950.	24.392

Table 3.T.19 (continued)

410	725.00	-1511.0	36950.	24.454
191	725.00	-1511.0	36950.	24.454
545	725.00	-1487.9	36950.	24.833
80	725.00	-1487.9	36950.	24.833
409	725.00	-1484.4	36950.	24.891
192	725.00	-1484.4	36950.	24.891
546	725.00	-1461.0	36950.	25.291
79	725.00	-1461.0	36950.	25.291
211	725.00	-1077.1	36950.	34.306
558	725.00	-1077.1	36950.	34.306
212	725.00	-1071.5	36950.	34.484
557	725.00	-1071.5	36950.	34.484
213	725.00	-1044.0	36950.	35.392
556	725.00	-1044.0	36950.	35.392
214	725.00	-1017.9	36950.	36.301
555	725.00	-1017.9	36950.	36.301
397	725.00	-1012.4	36950.	36.497
60	725.00	-1012.4	36950.	36.497
398	725.00	-1010.2	36950.	36.577
59	725.00	-1010.2	36950.	36.577
215	725.00	-990.22	36950.	37.315
554	725.00	-990.22	36950.	37.315
399	725.00	-983.29	36950.	37.578
58	725.00	-983.29	36950.	37.578
702	725.00	-971.54	36950.	38.032
379	725.00	-971.54	36950.	38.032
701	725.00	-964.44	36950.	38.312
380	725.00	-964.44	36950.	38.312
216	725.00	-963.26	36950.	38.359
553	725.00	-963.26	36950.	38.359
400	725.00	-956.37	36950.	38.636
57	725.00	-956.37	36950.	38.636
700	725.00	-935.50	36950.	39.498
381	725.00	-935.50	36950.	39.498
401	725.00	-929.49	36950.	39.753
56	725.00	-929.49	36950.	39.753
699	725.00	-909.56	36950.	40.624
382	725.00	-909.56	36950.	40.624
402	725.00	-902.66	36950.	40.935
55	725.00	-902.65	36950.	40.935
698	725.00	-882.10	36950.	41.889
383	725.00	-882.10	36950.	41.889
6	725.00	-862.79	36950.	42.826
115	725.00	-862.78	36950.	42.826
5	725.00	-855.48	36950.	43.192
116	725.00	-855.47	36950.	43.193
697	725.00	-854.80	36950.	43.226
384	725.00	-854.80	36950.	43.226
4	725.00	-826.54	36950.	44.704
117	725.00	-826.53	36950.	44.705
3	725.00	-800.65	36950.	46.150
118	725.00	-800.64	36950.	46.151
2	725.00	-773.13	36950.	47.793

Table 3.T.19 (continued)

119	725.00	-773.12	36950.	47.793
1	725.00	-745.59	36950.	49.558
120	725.00	-745.58	36950.	49.559
253	725.00	-491.25	36950.	75.216
36	725.00	-491.25	36950.	75.217
254	725.00	-488.89	36950.	75.579
35	725.00	-488.89	36950.	75.579
255	725.00	-461.95	36950.	79.987
34	725.00	-461.95	36950.	79.987
256	725.00	-435.17	36950.	84.909
33	725.00	-435.17	36950.	84.909
257	725.00	-408.42	36950.	90.471
32	725.00	-408.42	36950.	90.471
258	725.00	-381.64	36950.	96.818
31	725.00	-381.64	36950.	96.818
19	725.00	-299.45	36950.	123.39
102	725.00	-299.45	36950.	123.39
20	725.00	-290.39	36950.	127.24
101	725.00	-290.39	36950.	127.24
246	725.00	-280.05	36950.	131.94
43	725.00	-280.05	36950.	131.94
245	725.00	-271.97	36950.	135.86
44	725.00	-271.97	36950.	135.86
21	725.00	-260.72	36950.	141.72
100	725.00	-260.72	36950.	141.72
244	725.00	-242.88	36950.	152.13
45	725.00	-242.88	36950.	152.13
22	725.00	-236.03	36950.	156.55
99	725.00	-236.03	36950.	156.55
390	725.00	-219.58	36950.	168.27
67	725.00	-219.58	36950.	168.27
243	725.00	-217.70	36950.	169.73
46	725.00	-217.70	36950.	169.73
389	725.00	-212.51	36950.	173.88
68	725.00	-212.51	36950.	173.88
23	725.00	-208.87	36950.	176.90
98	725.00	-208.87	36950.	176.90
242	725.00	-190.25	36950.	194.22
47	725.00	-190.25	36950.	194.22
388	725.00	-184.22	36950.	200.58
69	725.00	-184.22	36950.	200.58
24	725.00	-180.11	36950.	205.15
97	725.00	-180.11	36950.	205.15
91	725.00	-170.49	36950.	216.73
534	725.00	-170.49	36950.	216.73
92	725.00	-162.40	36950.	227.52
533	725.00	-162.40	36950.	227.52
241	725.00	-161.88	36950.	228.26
48	725.00	-161.88	36950.	228.26
387	725.00	-158.79	36950.	232.70
70	725.00	-158.78	36950.	232.70
678	725.00	-156.19	36950.	236.56
235	725.00	-156.19	36950.	236.57

Table 3.T.19 (continued)

677	725.00	-149.24	36950.	247.58
236	725.00	-149.24	36950.	247.58
93	725.00	-133.14	36950.	277.53
532	725.00	-133.14	36950.	277.53
386	725.00	-131.14	36950.	281.75
71	725.00	-131.14	36950.	281.75
676	725.00	-120.85	36950.	305.76
237	725.00	-120.84	36950.	305.76
94	725.00	-107.82	36950.	342.69
531	725.00	-107.82	36950.	342.69
385	725.00	-103.05	36950.	358.57
72	725.00	-103.05	36950.	358.57
7	725.00	98.008	36950.	377.01
114	725.00	98.008	36950.	377.01
8	725.00	95.952	36950.	385.09
113	725.00	95.951	36950.	385.09
675	725.00	-95.393	36950.	387.34
238	725.00	-95.393	36950.	387.34
95	725.00	-80.409	36950.	459.52
530	725.00	-80.409	36950.	459.52
9	725.00	69.415	36950.	532.31
112	725.00	69.414	36950.	532.31
674	725.00	-67.655	36950.	546.16
239	725.00	-67.655	36950.	546.16
108	725.00	-67.308	36950.	548.97
13	725.00	-67.308	36950.	548.97
107	725.00	-64.151	36950.	575.99
14	725.00	-64.151	36950.	575.99
96	725.00	-52.194	36950.	707.93
529	725.00	-52.194	36950.	707.94
18	725.00	46.265	36950.	798.65
103	725.00	46.265	36950.	798.66
17	725.00	44.374	36950.	832.70
104	725.00	44.374	36950.	832.70
10	725.00	42.916	36950.	860.99
111	725.00	42.915	36950.	861.00
673	725.00	-39.496	36950.	935.54
240	725.00	-39.496	36950.	935.54
106	725.00	-36.345	36950.	1016.7
15	725.00	-36.344	36950.	1016.7
16	725.00	-18.078	36950.	2043.9
105	725.00	18.078	36950.	2043.9
11	725.00	16.139	36950.	2289.5
110	725.00	-16.139	36950.	2289.5
109	725.00	-14.018	36950.	2635.8
12	725.00	-14.018	36950.	2635.9

Table 3.T.20

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Fuel Basket
SUBTITLE  2 =
Load Combination: F3.c (See Table 3.1.3)
SUBTITLE  3 =
Stress Result: Local Membrane Plus Primary Bending (PL+PB)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT     CURRENT      CURRENT      PREVIOUS     PREVIOUS
   ELEM     REF TEMP     PL+PB        ALLOW        SF
     19    725.00       43120.       55450.       1.2859
    102    725.00       43120.       55450.       1.2859
    259    725.00       42382.       55450.       1.3083
     30    725.00       42382.       55450.       1.3083
    283    725.00       40925.       55450.       1.3549
    150    725.00       40925.       55450.       1.3549
     91    725.00       39787.       55450.       1.3937
    534    725.00       39787.       55450.       1.3937
     43    725.00       39741.       55450.       1.3953
    246    725.00       39741.       55450.       1.3953
     20    725.00       39736.       55450.       1.3955
    101    725.00       39736.       55450.       1.3955
    260    725.00       39315.       55450.       1.4104
     29    725.00       39315.       55450.       1.4104
    307    725.00       38784.       55450.       1.4297
    294    725.00       38784.       55450.       1.4297
    284    725.00       37959.       55450.       1.4608
    149    725.00       37959.       55450.       1.4608
      6    725.00       37548.       55450.       1.4768
    115    725.00       37548.       55450.       1.4768
    198    725.00       37479.       55450.       1.4795
    571    725.00       37479.       55450.       1.4795
    379    725.00       36960.       55450.       1.5003
    702    725.00       36960.       55450.       1.5003
     92    725.00       36596.       55450.       1.5152
    533    725.00       36596.       55450.       1.5152
    403    725.00       36538.       55450.       1.5176
     54    725.00       36538.       55450.       1.5176
     44    725.00       36530.       55450.       1.5179
    245    725.00       36530.       55450.       1.5179
    308    725.00       35904.       55450.       1.5444
    293    725.00       35904.       55450.       1.5444
     67    725.00       35892.       55450.       1.5449
    390    725.00       35892.       55450.       1.5449
     78    725.00       35827.       55450.       1.5477
    547    725.00       35827.       55450.       1.5477
    126    725.00       35727.       55450.       1.5520
    139    725.00       35727.       55450.       1.5520
    678    725.00       35666.       55450.       1.5547
```

Table 3.T.20 (continued)

235	725.00	35666.	55450.	1.5547
691	725.00	35621.	55450.	1.5567
222	725.00	35620.	55450.	1.5567
331	725.00	35569.	55450.	1.5589
438	725.00	35569.	55450.	1.5589
342	725.00	35409.	55450.	1.5660
595	725.00	35409.	55450.	1.5660
197	725.00	34780.	55450.	1.5943
572	725.00	34780.	55450.	1.5943
5	725.00	34567.	55450.	1.6041
116	725.00	34567.	55450.	1.6041
427	725.00	34510.	55450.	1.6068
174	725.00	34510.	55450.	1.6068
380	725.00	34030.	55450.	1.6294
701	725.00	34030.	55450.	1.6294
270	725.00	33809.	55450.	1.6401
163	725.00	33809.	55450.	1.6401
404	725.00	33791.	55450.	1.6410
53	725.00	33791.	55450.	1.6410
355	725.00	33739.	55450.	1.6435
582	725.00	33739.	55450.	1.6435
726	725.00	33197.	55450.	1.6703
523	725.00	33197.	55450.	1.6703
77	725.00	33103.	55450.	1.6751
548	725.00	33103.	55450.	1.6751
692	725.00	32999.	55450.	1.6803
221	725.00	32999.	55450.	1.6803
125	725.00	32866.	55450.	1.6872
140	725.00	32866.	55450.	1.6872
68	725.00	32827.	55450.	1.6891
389	725.00	32827.	55450.	1.6891
332	725.00	32787.	55450.	1.6912
437	725.00	32787.	55450.	1.6912
341	725.00	32786.	55450.	1.6913
596	725.00	32786.	55450.	1.6913
318	725.00	32624.	55450.	1.6997
451	725.00	32624.	55450.	1.6997
677	725.00	32599.	55450.	1.7010
236	725.00	32599.	55450.	1.7010
486	725.00	32342.	55450.	1.7145
619	725.00	32341.	55450.	1.7145
763	725.00	31962.	55450.	1.7349
654	725.00	31962.	55450.	1.7349
428	725.00	31846.	55450.	1.7412
173	725.00	31846.	55450.	1.7412
715	725.00	31591.	55450.	1.7552
366	725.00	31591.	55450.	1.7552
269	725.00	31018.	55450.	1.7877
164	725.00	31018.	55450.	1.7877
356	725.00	31000.	55450.	1.7887
581	725.00	31000.	55450.	1.7887
725	725.00	30466.	55450.	1.8201
524	725.00	30466.	55450.	1.8201

Table 3.T.20 (continued)

558	725.00	30452.	55450.	1.8209
211	725.00	30452.	55450.	1.8209
414	725.00	30425.	55450.	1.8225
187	725.00	30425.	55450.	1.8225
630	725.00	30117.	55450.	1.8412
643	725.00	30117.	55450.	1.8412
317	725.00	30038.	55450.	1.8460
452	725.00	30038.	55450.	1.8460
485	725.00	29801.	55450.	1.8607
620	725.00	29801.	55450.	1.8607
764	725.00	29494.	55450.	1.8801
653	725.00	29494.	55450.	1.8801
475	725.00	29201.	55450.	1.8989
462	725.00	29201.	55450.	1.8989
716	725.00	29071.	55450.	1.9074
365	725.00	29071.	55450.	1.9074
505	725.00	28206.	55450.	1.9659
744	725.00	28205.	55450.	1.9659
750	725.00	27774.	55450.	1.9965
667	725.00	27774.	55450.	1.9965
413	725.00	27762.	55450.	1.9974
188	725.00	27762.	55450.	1.9974
557	725.00	27710.	55450.	2.0011
212	725.00	27710.	55450.	2.0011
629	725.00	27631.	55450.	2.0068
644	725.00	27631.	55450.	2.0068
499	725.00	27116.	55450.	2.0449
606	725.00	27116.	55450.	2.0449
476	725.00	26714.	55450.	2.0757
461	725.00	26714.	55450.	2.0757
739	725.00	26003.	55450.	2.1325
510	725.00	26003.	55450.	2.1325
506	725.00	25729.	55450.	2.1551
743	725.00	25729.	55450.	2.1551
749	725.00	25139.	55450.	2.2058
668	725.00	25139.	55450.	2.2058
649	725.00	24786.	55450.	2.2372
768	725.00	24785.	55450.	2.2372
361	725.00	24713.	55450.	2.2438
720	725.00	24713.	55450.	2.2438
500	725.00	24675.	55450.	2.2472
605	725.00	24675.	55450.	2.2472
740	725.00	23588.	55450.	2.3508
509	725.00	23588.	55450.	2.3508
648	725.00	23057.	55450.	2.4049
625	725.00	23057.	55450.	2.4049
601	725.00	23015.	55450.	2.4093
504	725.00	23015.	55450.	2.4093
650	725.00	22527.	55450.	2.4614
767	725.00	22527.	55450.	2.4615
362	725.00	22385.	55450.	2.4771
719	725.00	22385.	55450.	2.4771
457	725.00	22079.	55450.	2.5114

Table 3.T.20 (continued)

480	725.00	22079.	55450.	2.5114
624	725.00	21614.	55450.	2.5655
481	725.00	21614.	55450.	2.5655
647	725.00	20794.	55450.	2.6666
626	725.00	20794.	55450.	2.6666
602	725.00	20712.	55450.	2.6772
503	725.00	20712.	55450.	2.6772
217	725.00	20338.	55450.	2.7265
696	725.00	20338.	55450.	2.7265
508	725.00	20045.	55450.	2.7663
741	725.00	20045.	55450.	2.7663
507	725.00	20045.	55450.	2.7663
742	725.00	20045.	55450.	2.7663
458	725.00	19827.	55450.	2.7967
479	725.00	19827.	55450.	2.7967
718	725.00	19756.	55450.	2.8068
363	725.00	19756.	55450.	2.8068
717	725.00	19755.	55450.	2.8068
364	725.00	19755.	55450.	2.8068
623	725.00	19405.	55450.	2.8576
482	725.00	19405.	55450.	2.8576
456	725.00	19296.	55450.	2.8737
313	725.00	19296.	55450.	2.8737
600	725.00	19215.	55450.	2.8857
337	725.00	19215.	55450.	2.8857
22	725.00	18835.	55450.	2.9440
99	725.00	18835.	55450.	2.9440
23	725.00	18834.	55450.	2.9441
98	725.00	18834.	55450.	2.9441
694	725.00	18642.	55450.	2.9744
219	725.00	18642.	55450.	2.9744
693	725.00	18642.	55450.	2.9745
220	725.00	18642.	55450.	2.9745
13	725.00	18214.	55450.	3.0443
108	725.00	18214.	55450.	3.0444
218	725.00	18154.	55450.	3.0545
695	725.00	18154.	55450.	3.0545
14	725.00	17401.	55450.	3.1867
107	725.00	17401.	55450.	3.1867
455	725.00	17144.	55450.	3.2344
314	725.00	17144.	55450.	3.2344
75	725.00	17113.	55450.	3.2403
550	725.00	17113.	55450.	3.2403
76	725.00	17112.	55450.	3.2404
549	725.00	17112.	55450.	3.2404
599	725.00	17082.	55450.	3.2461
338	725.00	17082.	55450.	3.2461
766	725.00	16889.	55450.	3.2832
651	725.00	16889.	55450.	3.2832
765	725.00	16889.	55450.	3.2832
652	725.00	16889.	55450.	3.2832
169	725.00	16737.	55450.	3.3131
432	725.00	16737.	55450.	3.3131

Table 3.T.20 (continued)

598	725.00	16733.	55450.	3.3139
339	725.00	16733.	55450.	3.3139
597	725.00	16732.	55450.	3.3140
340	725.00	16732.	55450.	3.3140
576	725.00	16465.	55450.	3.3678
193	725.00	16465.	55450.	3.3678
574	725.00	16194.	55450.	3.4241
195	725.00	16194.	55450.	3.4241
573	725.00	16194.	55450.	3.4242
196	725.00	16194.	55450.	3.4242
483	725.00	16169.	55450.	3.4293
622	725.00	16169.	55450.	3.4293
484	725.00	16169.	55450.	3.4294
621	725.00	16169.	55450.	3.4294
646	725.00	15778.	55450.	3.5144
627	725.00	15778.	55450.	3.5144
645	725.00	15778.	55450.	3.5145
628	725.00	15778.	55450.	3.5145
243	725.00	15659.	55450.	3.5412
46	725.00	15658.	55450.	3.5412
242	725.00	15658.	55450.	3.5414
47	725.00	15658.	55450.	3.5414
552	725.00	15529.	55450.	3.5708
73	725.00	15529.	55450.	3.5708
747	725.00	15061.	55450.	3.6816
670	725.00	15061.	55450.	3.6816
748	725.00	15061.	55450.	3.6818
669	725.00	15061.	55450.	3.6818
192	725.00	14799.	55450.	3.7470
409	725.00	14799.	55450.	3.7470
672	725.00	14770.	55450.	3.7543
745	725.00	14770.	55450.	3.7543
315	725.00	14732.	55450.	3.7638
454	725.00	14732.	55450.	3.7638
316	725.00	14732.	55450.	3.7639
453	725.00	14732.	55450.	3.7639
27	725.00	14713.	55450.	3.7687
262	725.00	14713.	55450.	3.7687
26	725.00	14713.	55450.	3.7688
263	725.00	14713.	55450.	3.7688
170	725.00	14660.	55450.	3.7824
431	725.00	14660.	55450.	3.7824
74	725.00	14595.	55450.	3.7991
551	725.00	14595.	55450.	3.7991
94	725.00	14524.	55450.	3.8178
531	725.00	14524.	55450.	3.8178
95	725.00	14523.	55450.	3.8180
530	725.00	14523.	55450.	3.8180
171	725.00	14478.	55450.	3.8300
430	725.00	14478.	55450.	3.8300
172	725.00	14477.	55450.	3.8301
429	725.00	14477.	55450.	3.8301
575	725.00	14414.	55450.	3.8469

Table 3.T.20 (continued)

194	725.00	14414.	55450.	3.8469
459	725.00	14410.	55450.	3.8481
478	725.00	14410.	55450.	3.8481
460	725.00	14410.	55450.	3.8481
477	725.00	14410.	55450.	3.8481
286	725.00	14128.	55450.	3.9249
147	725.00	14128.	55450.	3.9249
287	725.00	14127.	55450.	3.9251
146	725.00	14127.	55450.	3.9251
603	725.00	14064.	55450.	3.9427
502	725.00	14064.	55450.	3.9427
604	725.00	14064.	55450.	3.9427
501	725.00	14064.	55450.	3.9427
675	725.00	13971.	55450.	3.9688
238	725.00	13971.	55450.	3.9688
674	725.00	13971.	55450.	3.9691
239	725.00	13971.	55450.	3.9691
49	725.00	13968.	55450.	3.9696
408	725.00	13968.	55450.	3.9697
70	725.00	13828.	55450.	4.0099
387	725.00	13828.	55450.	4.0099
71	725.00	13827.	55450.	4.0102
386	725.00	13827.	55450.	4.0102
51	725.00	13710.	55450.	4.0444
406	725.00	13710.	55450.	4.0444
52	725.00	13710.	55450.	4.0446
405	725.00	13710.	55450.	4.0446
100	725.00	13650.	55450.	4.0624
21	725.00	13650.	55450.	4.0624
528	725.00	13458.	55450.	4.1202
721	725.00	13458.	55450.	4.1202
577	725.00	13339.	55450.	4.1569
360	725.00	13339.	55450.	4.1569
310	725.00	13270.	55450.	4.1785
291	725.00	13270.	55450.	4.1785
309	725.00	13270.	55450.	4.1787
292	725.00	13270.	55450.	4.1787
311	725.00	13148.	55450.	4.2175
290	725.00	13148.	55450.	4.2175
334	725.00	13087.	55450.	4.2370
435	725.00	13087.	55450.	4.2370
333	725.00	13086.	55450.	4.2373
436	725.00	13086.	55450.	4.2373
285	725.00	13070.	55450.	4.2424
148	725.00	13070.	55450.	4.2424
191	725.00	12718.	55450.	4.3599
410	725.00	12718.	55450.	4.3599
237	725.00	12672.	55450.	4.3756
676	725.00	12672.	55450.	4.3756
671	725.00	12603.	55450.	4.3998
746	725.00	12603.	55450.	4.3998
244	725.00	12584.	55450.	4.4065
45	725.00	12584.	55450.	4.4065

Table 3.T.20 (continued)

388	725.00	12554.	55450.	4.4168
69	725.00	12554.	55450.	4.4168
28	725.00	12537.	55450.	4.4230
261	725.00	12537.	55450.	4.4230
358	725.00	12436.	55450.	4.4588
579	725.00	12436.	55450.	4.4588
357	725.00	12435.	55450.	4.4590
580	725.00	12435.	55450.	4.4590
433	725.00	12399.	55450.	4.4721
336	725.00	12399.	55450.	4.4721
7	725.00	12111.	55450.	4.5783
114	725.00	12111.	55450.	4.5783
18	725.00	12060.	55450.	4.5980
103	725.00	12060.	55450.	4.5980
214	725.00	12016.	55450.	4.6147
555	725.00	12016.	55450.	4.6147
213	725.00	12016.	55450.	4.6149
556	725.00	12016.	55450.	4.6149
50	725.00	11984.	55450.	4.6272
407	725.00	11984.	55450.	4.6272
8	725.00	11929.	55450.	4.6482
113	725.00	11929.	55450.	4.6482
267	725.00	11757.	55450.	4.7163
166	725.00	11757.	55450.	4.7163
268	725.00	11756.	55450.	4.7165
165	725.00	11756.	55450.	4.7165
93	725.00	11716.	55450.	4.7328
532	725.00	11716.	55450.	4.7328
17	725.00	11676.	55450.	4.7489
104	725.00	11676.	55450.	4.7489
142	725.00	11513.	55450.	4.8161
123	725.00	11513.	55450.	4.8161
141	725.00	11513.	55450.	4.8164
124	725.00	11513.	55450.	4.8164
335	725.00	11476.	55450.	4.8319
434	725.00	11476.	55450.	4.8319
527	725.00	11459.	55450.	4.8392
722	725.00	11459.	55450.	4.8392
411	725.00	11412.	55450.	4.8588
190	725.00	11412.	55450.	4.8588
412	725.00	11412.	55450.	4.8589
189	725.00	11412.	55450.	4.8589
216	725.00	11392.	55450.	4.8675
553	725.00	11392.	55450.	4.8675
578	725.00	11334.	55450.	4.8924
359	725.00	11334.	55450.	4.8924
168	725.00	11295.	55450.	4.9091
265	725.00	11295.	55450.	4.9091
3	725.00	11132.	55450.	4.9810
118	725.00	11132.	55450.	4.9810
2	725.00	11132.	55450.	4.9813
119	725.00	11132.	55450.	4.9813
723	725.00	10928.	55450.	5.0743

Table 3.T.20 (continued)

526	725.00	10928.	55450.	5.0743
724	725.00	10927.	55450.	5.0745
525	725.00	10927.	55450.	5.0745
122	725.00	10690.	55450.	5.1869
143	725.00	10690.	55450.	5.1869
4	725.00	10640.	55450.	5.2116
117	725.00	10640.	55450.	5.2116
226	725.00	10276.	55450.	5.3963
687	725.00	10276.	55450.	5.3963
225	725.00	10276.	55450.	5.3963
688	725.00	10276.	55450.	5.3963
382	725.00	10240.	55450.	5.4149
699	725.00	10240.	55450.	5.4149
381	725.00	10240.	55450.	5.4153
700	725.00	10240.	55450.	5.4153
383	725.00	10154.	55450.	5.4612
698	725.00	10154.	55450.	5.4612
266	725.00	10009.	55450.	5.5398
167	725.00	10009.	55450.	5.5398
227	725.00	9863.4	55450.	5.6218
686	725.00	9863.4	55450.	5.6218
24	725.00	9807.8	55450.	5.6537
97	725.00	9807.8	55450.	5.6537
289	725.00	9717.0	55450.	5.7065
312	725.00	9717.0	55450.	5.7065
144	725.00	9484.4	55450.	5.8464
121	725.00	9484.4	55450.	5.8465
554	725.00	9425.1	55450.	5.8832
215	725.00	9425.1	55450.	5.8832
9	725.00	9042.8	55450.	6.1320
112	725.00	9042.8	55450.	6.1320
689	725.00	8767.8	55450.	6.3243
224	725.00	8767.8	55450.	6.3243
15	725.00	8211.5	55450.	6.7528
106	725.00	8211.4	55450.	6.7528
223	725.00	8003.2	55450.	6.9284
690	725.00	8003.2	55450.	6.9285
12	725.00	7848.8	55450.	7.0648
109	725.00	7848.8	55450.	7.0648
697	725.00	7743.9	55450.	7.1604
384	725.00	7743.9	55450.	7.1604
228	725.00	7611.4	55450.	7.2852
685	725.00	7611.3	55450.	7.2852
11	725.00	7238.8	55450.	7.6601
110	725.00	7238.8	55450.	7.6602
145	725.00	7178.0	55450.	7.7249
288	725.00	7178.0	55450.	7.7250
253	725.00	7153.7	55450.	7.7512
36	725.00	7153.7	55450.	7.7512
254	725.00	6801.4	55450.	8.1527
35	725.00	6801.4	55450.	8.1528
16	725.00	6330.9	55450.	8.7586
105	725.00	6330.9	55450.	8.7587

Table 3.T.20 (continued)

120	725.00	5924.8	55450.	9.3590
1	725.00	5924.8	55450.	9.3590
111	725.00	4896.3	55450.	11.325
10	725.00	4896.3	55450.	11.325
402	725.00	4720.2	55450.	11.747
55	725.00	4720.2	55450.	11.747
241	725.00	4548.0	55450.	12.192
48	725.00	4548.0	55450.	12.192
401	725.00	4459.6	55450.	12.434
56	725.00	4459.6	55450.	12.434
25	725.00	4066.9	55450.	13.634
264	725.00	4066.9	55450.	13.635
546	725.00	3449.9	55450.	16.073
79	725.00	3449.9	55450.	16.073
545	725.00	3228.9	55450.	17.173
80	725.00	3228.9	55450.	17.173
96	725.00	3191.9	55450.	17.372
529	725.00	3191.8	55450.	17.372
255	725.00	3181.7	55450.	17.428
34	725.00	3181.7	55450.	17.428
84	725.00	3150.4	55450.	17.601
541	725.00	3150.4	55450.	17.601
83	725.00	2940.4	55450.	18.858
542	725.00	2940.4	55450.	18.858
82	725.00	2541.3	55450.	21.819
543	725.00	2541.3	55450.	21.819
81	725.00	2541.3	55450.	21.819
544	725.00	2541.3	55450.	21.819
397	725.00	2159.6	55450.	25.675
60	725.00	2159.6	55450.	25.676
398	725.00	1996.7	55450.	27.770
59	725.00	1996.7	55450.	27.770
400	725.00	1953.6	55450.	28.384
57	725.00	1953.6	55450.	28.384
58	725.00	1262.4	55450.	43.926
399	725.00	1262.4	55450.	43.926
673	725.00	1139.6	55450.	48.657
240	725.00	1139.6	55450.	48.658
257	725.00	1116.6	55450.	49.661
256	725.00	1116.6	55450.	49.661
32	725.00	1116.6	55450.	49.661
33	725.00	1116.6	55450.	49.661
72	725.00	947.27	55450.	58.537
385	725.00	947.25	55450.	58.538
258	725.00	876.62	55450.	63.254
31	725.00	876.62	55450.	63.255

Table 3.T.21

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Enclosure Vessel
SUBTITLE  2 =
Load Combination: E3.c (See Table 3.1.4)
SUBTITLE  3 =
Stress Result: Primary Membrane (PM)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT    CURRENT     MIXED       PREVIOUS     PREVIOUS
   ELEM    REF TEMP    PM          ALLOW        SF
   1222   450.00      -7764.1      43450.       5.5963
   1221   450.00      -7763.6      43450.       5.5966
   1223   450.00      -7763.5      43450.       5.5967
   1093   450.00      -7762.2      43450.       5.5976
   1220   450.00      -7761.9      43450.       5.5978
   1094   450.00      -7761.7      43450.       5.5980
   1224   450.00      -7761.7      43450.       5.5980
   1092   450.00      -7761.5      43450.       5.5981
   1095   450.00      -7760.1      43450.       5.5991
   1091   450.00      -7759.7      43450.       5.5994
   1225   450.00      -7758.8      43450.       5.6001
   1090   450.00      -7756.8      43450.       5.6016
   1226   450.00      -7754.7      43450.       5.6031
   1089   450.00      -7752.6      43450.       5.6045
   1227   450.00      -7749.4      43450.       5.6069
   1088   450.00      -7747.4      43450.       5.6083
   1228   450.00      -7743.1      43450.       5.6114
   1087   450.00      -7741.0      43450.       5.6130
   1229   450.00      -7735.7      43450.       5.6168
   1086   450.00      -7733.6      43450.       5.6184
   1230   450.00      -7727.3      43450.       5.6230
   1085   450.00      -7725.1      43450.       5.6245
   1231   450.00      -7717.8      43450.       5.6298
   1084   450.00      -7715.6      43450.       5.6314
   1232   450.00      -7707.4      43450.       5.6374
   1083   450.00      -7705.2      43450.       5.6390
   1233   450.00      -7696.2      43450.       5.6457
   1082   450.00      -7693.9      43450.       5.6473
   1234   450.00      -7684.1      43450.       5.6545
   1081   450.00      -7681.8      43450.       5.6562
   1235   450.00      -7671.3      43450.       5.6640
   1080   450.00      -7669.0      43450.       5.6657
   1251   450.00      -7658.5      43450.       5.6734
   1236   450.00      -7657.8      43450.       5.6739
   1064   450.00      -7655.9      43450.       5.6754
   1079   450.00      -7655.5      43450.       5.6757
   1250   450.00      -7646.9      43450.       5.6821
   1065   450.00      -7644.2      43450.       5.6840
   1237   450.00      -7643.8      43450.       5.6844
```

Table 3.T.21 (continued)

1078	450.00	-7641.4	43450.	5.6861
1249	450.00	-7640.1	43450.	5.6871
1066	450.00	-7637.5	43450.	5.6890
1248	450.00	-7634.2	43450.	5.6915
1067	450.00	-7631.6	43450.	5.6934
1252	450.00	-7630.8	43450.	5.6940
1238	450.00	-7629.2	43450.	5.6952
1063	450.00	-7628.1	43450.	5.6961
1247	450.00	-7627.7	43450.	5.6964
1077	450.00	-7626.8	43450.	5.6970
1068	450.00	-7625.1	43450.	5.6983
1246	450.00	-7620.5	43450.	5.7017
1069	450.00	-7618.0	43450.	5.7036
1253	450.00	-7614.3	43450.	5.7064
1239	450.00	-7614.3	43450.	5.7064
1245	450.00	-7612.9	43450.	5.7074
1076	450.00	-7611.9	43450.	5.7082
1062	450.00	-7611.5	43450.	5.7084
1070	450.00	-7610.3	43450.	5.7093
1244	450.00	-7604.7	43450.	5.7135
1254	450.00	-7602.5	43450.	5.7152
1071	450.00	-7602.2	43450.	5.7154
1061	450.00	-7599.8	43450.	5.7173
1240	450.00	-7599.0	43450.	5.7179
1075	450.00	-7596.6	43450.	5.7197
1243	450.00	-7596.2	43450.	5.7199
1276	450.00	-7594.8	43450.	5.7210
1277	450.00	-7594.8	43450.	5.7210
1275	450.00	-7593.8	43450.	5.7218
1072	450.00	-7593.8	43450.	5.7218
1278	450.00	-7593.7	43450.	5.7219
1274	450.00	-7591.7	43450.	5.7233
1039	450.00	-7591.6	43450.	5.7234
1038	450.00	-7591.6	43450.	5.7234
1255	450.00	-7591.5	43450.	5.7235
1279	450.00	-7591.5	43450.	5.7235
1040	450.00	-7590.6	43450.	5.7242
1037	450.00	-7590.4	43450.	5.7243
1060	450.00	-7588.8	43450.	5.7256
1273	450.00	-7588.6	43450.	5.7257
1041	450.00	-7588.6	43450.	5.7257
1036	450.00	-7588.2	43450.	5.7260
1280	450.00	-7588.1	43450.	5.7261
1242	450.00	-7588.1	43450.	5.7261
1073	450.00	-7585.6	43450.	5.7279
1042	450.00	-7585.5	43450.	5.7280
1035	450.00	-7584.8	43450.	5.7285
1272	450.00	-7584.6	43450.	5.7287
1281	450.00	-7583.7	43450.	5.7294
1241	450.00	-7583.5	43450.	5.7296
1043	450.00	-7581.5	43450.	5.7311
1074	450.00	-7581.0	43450.	5.7314
1034	450.00	-7580.4	43450.	5.7319

Table 3.T.21 (continued)

1256	450.00	-7579.9	43450.	5.7323
1271	450.00	-7579.7	43450.	5.7324
1282	450.00	-7578.1	43450.	5.7336
1059	450.00	-7577.1	43450.	5.7344
1044	450.00	-7576.6	43450.	5.7348
1033	450.00	-7574.8	43450.	5.7361
1270	450.00	-7573.9	43450.	5.7368
1283	450.00	-7571.5	43450.	5.7386
1045	450.00	-7570.8	43450.	5.7392
1032	450.00	-7568.2	43450.	5.7411
1257	450.00	-7567.7	43450.	5.7415
1269	450.00	-7567.3	43450.	5.7418
1058	450.00	-7564.9	43450.	5.7437
1046	450.00	-7564.2	43450.	5.7442
1268	450.00	-7560.0	43450.	5.7474
1047	450.00	-7556.9	43450.	5.7497
1258	450.00	-7554.9	43450.	5.7512
1057	450.00	-7552.1	43450.	5.7534
1267	450.00	-7552.0	43450.	5.7535
1048	450.00	-7549.0	43450.	5.7557
1266	450.00	-7543.4	43450.	5.7600
1259	450.00	-7541.7	43450.	5.7613
1049	450.00	-7540.5	43450.	5.7623
1056	450.00	-7538.8	43450.	5.7635
1265	450.00	-7534.4	43450.	5.7669
1050	450.00	-7531.4	43450.	5.7692
1260	450.00	-7528.1	43450.	5.7717
1055	450.00	-7525.2	43450.	5.7739
1264	450.00	-7525.0	43450.	5.7741
1051	450.00	-7522.0	43450.	5.7764
1263	450.00	-7515.2	43450.	5.7816
1261	450.00	-7514.8	43450.	5.7819
1052	450.00	-7512.3	43450.	5.7839
1054	450.00	-7511.9	43450.	5.7841
1262	450.00	-7505.2	43450.	5.7893
1053	450.00	-7502.3	43450.	5.7916
1186	450.00	-6738.9	43450.	6.4476
1129	450.00	-6738.0	43450.	6.4485
1187	450.00	-6734.9	43450.	6.4515
1128	450.00	-6734.0	43450.	6.4524
1188	450.00	-6730.0	43450.	6.4562
1127	450.00	-6729.1	43450.	6.4571
1189	450.00	-6724.3	43450.	6.4617
1126	450.00	-6723.3	43450.	6.4626
1190	450.00	-6717.8	43450.	6.4679
1125	450.00	-6716.8	43450.	6.4688
1191	450.00	-6710.6	43450.	6.4748
1124	450.00	-6709.6	43450.	6.4758
1192	450.00	-6702.7	43450.	6.4825
1123	450.00	-6701.6	43450.	6.4835
1193	450.00	-6694.1	43450.	6.4908
1122	450.00	-6693.0	43450.	6.4919
1219	450.00	-6686.9	43450.	6.4978

Table 3.T.21 (continued)

1096	450.00	-6685.1	43450.	6.4995
1194	450.00	-6684.9	43450.	6.4998
1121	450.00	-6683.8	43450.	6.5008
1199	450.00	-6682.7	43450.	6.5019
1200	450.00	-6682.5	43450.	6.5021
1198	450.00	-6682.2	43450.	6.5024
1201	450.00	-6681.5	43450.	6.5030
1116	450.00	-6681.4	43450.	6.5031
1115	450.00	-6681.2	43450.	6.5033
1197	450.00	-6681.0	43450.	6.5035
1117	450.00	-6681.0	43450.	6.5036
1114	450.00	-6680.2	43450.	6.5043
1202	450.00	-6679.9	43450.	6.5046
1118	450.00	-6679.8	43450.	6.5047
1196	450.00	-6679.1	43450.	6.5053
1113	450.00	-6678.6	43450.	6.5059
1119	450.00	-6678.0	43450.	6.5065
1203	450.00	-6677.6	43450.	6.5069
1112	450.00	-6676.2	43450.	6.5082
1195	450.00	-6675.1	43450.	6.5093
1204	450.00	-6674.5	43450.	6.5098
1120	450.00	-6674.0	43450.	6.5104
1111	450.00	-6673.1	43450.	6.5112
1205	450.00	-6670.8	43450.	6.5135
1110	450.00	-6669.4	43450.	6.5148
1206	450.00	-6666.4	43450.	6.5178
1109	450.00	-6664.9	43450.	6.5192
1207	450.00	-6661.3	43450.	6.5227
1108	450.00	-6659.9	43450.	6.5242
1208	450.00	-6655.6	43450.	6.5283
1107	450.00	-6654.1	43450.	6.5298
1209	450.00	-6649.3	43450.	6.5345
1106	450.00	-6647.8	43450.	6.5360
1210	450.00	-6642.4	43450.	6.5413
909	450.00	6641.7	43450.	6.5420
1218	450.00	-6641.3	43450.	6.5424
1105	450.00	-6640.9	43450.	6.5428
1097	450.00	-6639.6	43450.	6.5441
1406	450.00	6638.4	43450.	6.5452
910	450.00	6636.7	43450.	6.5469
1211	450.00	-6635.0	43450.	6.5486
1104	450.00	-6633.5	43450.	6.5501
1405	450.00	6633.4	43450.	6.5502
911	450.00	6631.7	43450.	6.5518
1404	450.00	6628.4	43450.	6.5551
1212	450.00	-6627.1	43450.	6.5564
912	450.00	6626.7	43450.	6.5568
1103	450.00	-6625.5	43450.	6.5580
1403	450.00	6623.4	43450.	6.5601
913	450.00	6621.7	43450.	6.5618
1213	450.00	-6618.7	43450.	6.5647
1402	450.00	6618.3	43450.	6.5651
1102	450.00	-6617.1	43450.	6.5663

Table 3.T.21 (continued)

914	450.00	6616.6	43450.	6.5668
1401	450.00	6613.3	43450.	6.5701
915	450.00	6611.5	43450.	6.5719
1214	450.00	-6609.9	43450.	6.5734
1101	450.00	-6608.3	43450.	6.5751
1400	450.00	6608.2	43450.	6.5752
916	450.00	6606.4	43450.	6.5769
1399	450.00	6603.0	43450.	6.5803
917	450.00	6601.3	43450.	6.5821
1217	450.00	-6598.9	43450.	6.5844
1398	450.00	6597.9	43450.	6.5854
1215	450.00	-6597.3	43450.	6.5861
1098	450.00	-6597.2	43450.	6.5861
918	450.00	6596.1	43450.	6.5872
1100	450.00	-6595.6	43450.	6.5877
1397	450.00	6592.7	43450.	6.5906
919	450.00	6590.9	43450.	6.5924
1396	450.00	6587.5	43450.	6.5958
920	450.00	6585.8	43450.	6.5976
1395	450.00	6582.3	43450.	6.6010
921	450.00	6580.5	43450.	6.6028
1394	450.00	6577.1	43450.	6.6063
922	450.00	6575.3	43450.	6.6080
1393	450.00	6571.9	43450.	6.6115
923	450.00	6570.1	43450.	6.6133
1392	450.00	6566.6	43450.	6.6168
924	450.00	6564.8	43450.	6.6186
1391	450.00	6561.3	43450.	6.6221
1216	450.00	-6560.0	43450.	6.6235
925	450.00	6559.6	43450.	6.6239
1099	450.00	-6558.3	43450.	6.6252
1390	450.00	6556.1	43450.	6.6275
926	450.00	6554.3	43450.	6.6293
1389	450.00	6550.8	43450.	6.6328
927	450.00	6549.0	43450.	6.6346
1388	450.00	6545.4	43450.	6.6382
928	450.00	6543.7	43450.	6.6400
1387	450.00	6540.1	43450.	6.6436
929	450.00	6538.4	43450.	6.6454
1386	450.00	6534.8	43450.	6.6490
930	450.00	6533.0	43450.	6.6508
1385	450.00	6529.5	43450.	6.6544
931	450.00	6527.7	43450.	6.6563
1627	450.00	6527.3	43450.	6.6566
1438	450.00	6524.6	43450.	6.6594
1384	450.00	6524.1	43450.	6.6599
1628	450.00	6523.8	43450.	6.6602
932	450.00	6522.4	43450.	6.6617
1437	450.00	6521.2	43450.	6.6629
1629	450.00	6520.3	43450.	6.6638
1383	450.00	6518.8	43450.	6.6654
1436	450.00	6517.6	43450.	6.6665
933	450.00	6517.0	43450.	6.6672

Table 3.T.21 (continued)

1630	450.00	6516.8	43450.	6.6674
1435	450.00	6514.1	43450.	6.6702
1382	450.00	6513.4	43450.	6.6708
1631	450.00	6513.3	43450.	6.6710
934	450.00	6511.7	43450.	6.6726
1434	450.00	6510.5	43450.	6.6738
1632	450.00	6509.7	43450.	6.6747
1381	450.00	6508.1	43450.	6.6763
1433	450.00	6506.9	43450.	6.6775
935	450.00	6506.3	43450.	6.6781
1633	450.00	6506.1	43450.	6.6784
1432	450.00	6503.3	43450.	6.6812
1380	450.00	6502.7	43450.	6.6818
1634	450.00	6502.5	43450.	6.6821
936	450.00	6501.0	43450.	6.6836
1431	450.00	6499.6	43450.	6.6850
1635	450.00	6498.8	43450.	6.6858
1379	450.00	6497.4	43450.	6.6873
1430	450.00	6495.9	43450.	6.6888
937	450.00	6495.6	43450.	6.6891
1636	450.00	6495.1	43450.	6.6896
1429	450.00	6492.2	43450.	6.6926
1378	450.00	6492.0	43450.	6.6929
1637	450.00	6491.4	43450.	6.6934
938	450.00	6490.3	43450.	6.6946
1428	450.00	6488.5	43450.	6.6964
1638	450.00	6487.7	43450.	6.6973
1377	450.00	6486.6	43450.	6.6984
939	450.00	6484.9	43450.	6.7002
1427	450.00	6484.8	43450.	6.7003
1639	450.00	6484.0	43450.	6.7012
1376	450.00	6481.3	43450.	6.7039
1426	450.00	6481.0	43450.	6.7042
1595	450.00	6480.5	43450.	6.7047
1640	450.00	6480.2	43450.	6.7051
940	450.00	6479.6	43450.	6.7057
1470	450.00	6478.7	43450.	6.7066
1596	450.00	6478.4	43450.	6.7069
1425	450.00	6477.2	43450.	6.7081
1469	450.00	6476.5	43450.	6.7089
1641	450.00	6476.4	43450.	6.7090
1597	450.00	6476.2	43450.	6.7092
1375	450.00	6475.9	43450.	6.7095
1468	450.00	6474.2	43450.	6.7112
941	450.00	6474.2	43450.	6.7112
1598	450.00	6473.9	43450.	6.7115
1424	450.00	6473.4	43450.	6.7121
1642	450.00	6472.6	43450.	6.7129
1467	450.00	6472.0	43450.	6.7136
1599	450.00	6471.6	43450.	6.7139
1374	450.00	6470.6	43450.	6.7150
1466	450.00	6469.7	43450.	6.7159
1423	450.00	6469.6	43450.	6.7160

Table 3.T.21 (continued)

1600	450.00	6469.3	43450.	6.7163
942	450.00	6468.9	43450.	6.7167
1643	450.00	6468.8	43450.	6.7169
1465	450.00	6467.4	43450.	6.7184
1601	450.00	6467.0	43450.	6.7187
1422	450.00	6465.8	43450.	6.7200
1373	450.00	6465.2	43450.	6.7205
1464	450.00	6465.0	43450.	6.7208
1644	450.00	6464.9	43450.	6.7209
1602	450.00	6464.6	43450.	6.7212
1463	450.00	6462.6	43450.	6.7233
1603	450.00	6462.2	43450.	6.7237
1421	450.00	6461.9	43450.	6.7240
1645	450.00	6461.1	43450.	6.7249
1462	450.00	6460.2	43450.	6.7258
1604	450.00	6459.8	43450.	6.7262
1420	450.00	6458.0	43450.	6.7281
1461	450.00	6457.7	43450.	6.7284
1605	450.00	6457.4	43450.	6.7288
1646	450.00	6457.2	43450.	6.7289
1460	450.00	6455.2	43450.	6.7310
1606	450.00	6454.9	43450.	6.7314
1419	450.00	6454.1	43450.	6.7321
1647	450.00	6453.3	43450.	6.7330
1459	450.00	6452.7	43450.	6.7336
1607	450.00	6452.3	43450.	6.7340
1418	450.00	6450.2	43450.	6.7362
1458	450.00	6450.2	43450.	6.7363
1608	450.00	6449.8	43450.	6.7367
1648	450.00	6449.4	43450.	6.7371
1457	450.00	6447.6	43450.	6.7390
1609	450.00	6447.2	43450.	6.7394
1417	450.00	6446.3	43450.	6.7403
1649	450.00	6445.5	43450.	6.7412
1456	450.00	6445.0	43450.	6.7417
1610	450.00	6444.6	43450.	6.7421
1455	450.00	6442.3	43450.	6.7444
1416	450.00	6442.3	43450.	6.7444
1611	450.00	6442.0	43450.	6.7448
1650	450.00	6441.6	43450.	6.7453
1454	450.00	6439.7	43450.	6.7472
1612	450.00	6439.3	43450.	6.7476
1415	450.00	6438.4	43450.	6.7486
1651	450.00	6437.6	43450.	6.7494
1453	450.00	6437.0	43450.	6.7500
1613	450.00	6436.6	43450.	6.7504
1414	450.00	6434.4	43450.	6.7527
1452	450.00	6434.3	43450.	6.7529
1614	450.00	6433.9	43450.	6.7533
1652	450.00	6433.6	43450.	6.7536
1451	450.00	6431.5	43450.	6.7558
1615	450.00	6431.2	43450.	6.7562
1413	450.00	6430.5	43450.	6.7569

Table 3.T.21 (continued)

1653	450.00	6429.7	43450.	6.7577
1450	450.00	6428.8	43450.	6.7587
1616	450.00	6428.4	43450.	6.7591
1412	450.00	6426.5	43450.	6.7611
1449	450.00	6426.0	43450.	6.7616
1654	450.00	6425.7	43450.	6.7619
1617	450.00	6425.6	43450.	6.7620
1284	450.00	-6424.4	43450.	6.7633
1448	450.00	6423.2	43450.	6.7646
1618	450.00	6422.8	43450.	6.7650
1411	450.00	6422.5	43450.	6.7653
1561	450.00	6421.8	43450.	6.7660
1655	450.00	6421.7	43450.	6.7661
1031	450.00	-6421.1	43450.	6.7668
1504	450.00	6420.9	43450.	6.7669
1562	450.00	6420.9	43450.	6.7670
1447	450.00	6420.3	43450.	6.7676
1503	450.00	6420.0	43450.	6.7679
1563	450.00	6420.0	43450.	6.7680
1619	450.00	6419.9	43450.	6.7680
1502	450.00	6419.1	43450.	6.7689
1564	450.00	6419.0	43450.	6.7690
1410	450.00	6418.5	43450.	6.7695
1501	450.00	6418.1	43450.	6.7699
1565	450.00	6418.0	43450.	6.7700
1656	450.00	6417.7	43450.	6.7703
1446	450.00	6417.5	43450.	6.7706
1620	450.00	6417.1	43450.	6.7710
1500	450.00	6417.1	43450.	6.7710
1566	450.00	6417.0	43450.	6.7711
1499	450.00	6416.0	43450.	6.7721
1567	450.00	6415.9	43450.	6.7722
1498	450.00	6414.9	43450.	6.7733
1568	450.00	6414.8	43450.	6.7734
1445	450.00	6414.6	43450.	6.7736
1409	450.00	6414.5	43450.	6.7738
1621	450.00	6414.2	43450.	6.7740
1497	450.00	6413.8	43450.	6.7745
1657	450.00	6413.7	43450.	6.7745
1569	450.00	6413.7	43450.	6.7746
1496	450.00	6412.6	43450.	6.7757
1570	450.00	6412.5	43450.	6.7758
1444	450.00	6411.7	43450.	6.7767
1495	450.00	6411.4	43450.	6.7770
1571	450.00	6411.3	43450.	6.7771
1622	450.00	6411.3	43450.	6.7771
1408	450.00	6410.4	43450.	6.7780
1494	450.00	6410.2	43450.	6.7783
1572	450.00	6410.1	43450.	6.7784
1658	450.00	6409.7	43450.	6.7788
1493	450.00	6408.9	43450.	6.7796
1573	450.00	6408.8	43450.	6.7797
1443	450.00	6408.7	43450.	6.7798

Table 3.T.21 (continued)

1623	450.00	6408.4	43450.	6.7802
1492	450.00	6407.6	43450.	6.7810
1574	450.00	6407.5	43450.	6.7811
1407	450.00	6406.4	43450.	6.7823
1491	450.00	6406.3	43450.	6.7824
1575	450.00	6406.2	43450.	6.7825
1442	450.00	6405.8	43450.	6.7829
1624	450.00	6405.4	43450.	6.7833
1490	450.00	6405.0	43450.	6.7838
1576	450.00	6404.8	43450.	6.7839
1489	450.00	6403.6	43450.	6.7853
1577	450.00	6403.4	43450.	6.7854
1533	450.00	6403.3	43450.	6.7855
1532	450.00	6403.3	43450.	6.7855
1534	450.00	6403.3	43450.	6.7855
1531	450.00	6403.3	43450.	6.7856
1535	450.00	6403.3	43450.	6.7856
1530	450.00	6403.2	43450.	6.7857
1536	450.00	6403.2	43450.	6.7857
1529	450.00	6403.1	43450.	6.7858
1537	450.00	6403.0	43450.	6.7858
1528	450.00	6402.9	43450.	6.7860
1538	450.00	6402.9	43450.	6.7860
1441	450.00	6402.8	43450.	6.7861
1527	450.00	6402.7	43450.	6.7862
1539	450.00	6402.7	43450.	6.7862
1526	450.00	6402.5	43450.	6.7864
1540	450.00	6402.5	43450.	6.7864
1625	450.00	6402.5	43450.	6.7865
1525	450.00	6402.2	43450.	6.7867
1541	450.00	6402.2	43450.	6.7867
1488	450.00	6402.1	43450.	6.7868
1578	450.00	6402.0	43450.	6.7869
1524	450.00	6401.9	43450.	6.7870
1542	450.00	6401.9	43450.	6.7870
1523	450.00	6401.6	43450.	6.7873
1543	450.00	6401.6	43450.	6.7874
1522	450.00	6401.3	43450.	6.7877
1544	450.00	6401.2	43450.	6.7878
1521	450.00	6400.9	43450.	6.7882
1545	450.00	6400.8	43450.	6.7882
1487	450.00	6400.7	43450.	6.7884
1579	450.00	6400.5	43450.	6.7885
1520	450.00	6400.4	43450.	6.7886
1546	450.00	6400.4	43450.	6.7887
1519	450.00	6400.0	43450.	6.7891
1547	450.00	6399.9	43450.	6.7892
1440	450.00	6399.8	43450.	6.7892
1626	450.00	6399.5	43450.	6.7896
1518	450.00	6399.5	43450.	6.7896
1548	450.00	6399.4	43450.	6.7897
1486	450.00	6399.2	43450.	6.7899
1580	450.00	6399.1	43450.	6.7901

Table 3.T.21 (continued)

1517	450.00	6398.9	43450.	6.7902
1549	450.00	6398.9	43450.	6.7903
1516	450.00	6398.4	43450.	6.7908
1550	450.00	6398.3	43450.	6.7909
1515	450.00	6397.8	43450.	6.7914
1551	450.00	6397.7	43450.	6.7915
1485	450.00	6397.7	43450.	6.7916
1581	450.00	6397.5	43450.	6.7917
1514	450.00	6397.1	43450.	6.7921
1552	450.00	6397.0	43450.	6.7922
1439	450.00	6396.8	43450.	6.7924
1513	450.00	6396.5	43450.	6.7928
1553	450.00	6396.4	43450.	6.7929
1484	450.00	6396.1	43450.	6.7932
1582	450.00	6396.0	43450.	6.7933
1512	450.00	6395.8	43450.	6.7935
1554	450.00	6395.7	43450.	6.7936
1511	450.00	6395.2	43450.	6.7942
1555	450.00	6395.1	43450.	6.7943
1510	450.00	6394.5	43450.	6.7949
1483	450.00	6394.5	43450.	6.7949
1556	450.00	6394.4	43450.	6.7950
1583	450.00	6394.4	43450.	6.7950
1509	450.00	6393.8	43450.	6.7956
1557	450.00	6393.7	43450.	6.7957
1508	450.00	6393.1	43450.	6.7964
1558	450.00	6393.0	43450.	6.7965
1482	450.00	6392.9	43450.	6.7966
1584	450.00	6392.8	43450.	6.7967
1507	450.00	6392.4	43450.	6.7972
1559	450.00	6392.3	43450.	6.7973
1506	450.00	6391.8	43450.	6.7978
1560	450.00	6391.7	43450.	6.7978
1481	450.00	6391.3	43450.	6.7984
1505	450.00	6391.2	43450.	6.7984
1585	450.00	6391.1	43450.	6.7985
1480	450.00	6389.6	43450.	6.8001
1586	450.00	6389.4	43450.	6.8003
1479	450.00	6387.9	43450.	6.8020
1587	450.00	6387.7	43450.	6.8021
1478	450.00	6386.1	43450.	6.8038
1588	450.00	6386.0	43450.	6.8039
1477	450.00	6384.4	43450.	6.8057
1589	450.00	6384.2	43450.	6.8058
1476	450.00	6382.6	43450.	6.8076
1590	450.00	6382.4	43450.	6.8077
1475	450.00	6380.8	43450.	6.8095
1591	450.00	6380.6	43450.	6.8097
1474	450.00	6378.9	43450.	6.8115
1592	450.00	6378.8	43450.	6.8117
1473	450.00	6377.0	43450.	6.8135
1593	450.00	6376.9	43450.	6.8137
1472	450.00	6375.1	43450.	6.8155

Table 3.T.21 (continued)

1594	450.00	6375.0	43450.	6.8157
1285	450.00	-6374.4	43450.	6.8163
1471	450.00	6373.2	43450.	6.8176
1030	450.00	-6371.1	43450.	6.8199
1299	450.00	-6348.3	43450.	6.8443
1298	450.00	-6348.2	43450.	6.8445
1300	450.00	-6347.9	43450.	6.8448
1297	450.00	-6347.4	43450.	6.8454
1301	450.00	-6346.8	43450.	6.8460
1296	450.00	-6346.0	43450.	6.8469
1302	450.00	-6345.0	43450.	6.8480
1016	450.00	-6344.8	43450.	6.8481
1017	450.00	-6344.7	43450.	6.8483
1015	450.00	-6344.4	43450.	6.8486
1295	450.00	-6344.0	43450.	6.8490
1018	450.00	-6343.9	43450.	6.8491
1014	450.00	-6343.2	43450.	6.8498
1019	450.00	-6342.5	43450.	6.8506
1303	450.00	-6342.5	43450.	6.8507
1294	450.00	-6341.5	43450.	6.8517
1013	450.00	-6341.4	43450.	6.8518
1020	450.00	-6340.5	43450.	6.8527
1304	450.00	-6339.3	43450.	6.8541
1012	450.00	-6338.9	43450.	6.8545
1293	450.00	-6338.5	43450.	6.8550
1021	450.00	-6338.0	43450.	6.8554
1011	450.00	-6335.7	43450.	6.8579
1305	450.00	-6335.4	43450.	6.8583
1022	450.00	-6335.0	43450.	6.8587
1292	450.00	-6335.0	43450.	6.8587
1010	450.00	-6331.8	43450.	6.8622
1023	450.00	-6331.6	43450.	6.8624
1291	450.00	-6331.1	43450.	6.8629
1306	450.00	-6330.8	43450.	6.8632
1024	450.00	-6327.7	43450.	6.8666
1286	450.00	-6327.7	43450.	6.8667
1009	450.00	-6327.3	43450.	6.8671
1290	450.00	-6326.8	43450.	6.8676
1307	450.00	-6325.6	43450.	6.8689
1029	450.00	-6324.3	43450.	6.8703
1025	450.00	-6323.5	43450.	6.8712
1311	450.00	-6323.2	43450.	6.8715
1310	450.00	-6323.1	43450.	6.8716
1312	450.00	-6322.6	43450.	6.8722
1309	450.00	-6322.4	43450.	6.8724
1289	450.00	-6322.2	43450.	6.8726
1008	450.00	-6322.0	43450.	6.8728
1313	450.00	-6321.3	43450.	6.8736
1308	450.00	-6320.9	43450.	6.8740
1004	450.00	-6319.6	43450.	6.8754
1005	450.00	-6319.5	43450.	6.8755
1314	450.00	-6319.2	43450.	6.8758
1003	450.00	-6319.0	43450.	6.8761

Table 3.T.21 (continued)

1026	450.00	-6318.9	43450.	6.8762
1006	450.00	-6318.8	43450.	6.8764
1002	450.00	-6317.6	43450.	6.8776
1007	450.00	-6317.3	43450.	6.8779
1315	450.00	-6316.4	43450.	6.8789
1001	450.00	-6315.6	43450.	6.8798
1288	450.00	-6313.5	43450.	6.8820
1316	450.00	-6312.9	43450.	6.8827
1000	450.00	-6312.8	43450.	6.8829
1027	450.00	-6310.2	43450.	6.8857
999	450.00	-6309.2	43450.	6.8867
1317	450.00	-6308.6	43450.	6.8874
998	450.00	-6304.9	43450.	6.8914
1287	450.00	-6284.4	43450.	6.9140
1028	450.00	-6281.0	43450.	6.9176
943	450.00	5766.3	43450.	7.5352
944	450.00	5765.1	43450.	7.5368
945	450.00	5764.0	43450.	7.5381
1372	450.00	5764.0	43450.	7.5381
1371	450.00	5762.8	43450.	7.5398
946	450.00	5762.4	43450.	7.5403
1370	450.00	5760.9	43450.	7.5423
947	450.00	5760.8	43450.	7.5423
948	450.00	5759.3	43450.	7.5443
1369	450.00	5759.2	43450.	7.5444
949	450.00	5757.8	43450.	7.5463
1368	450.00	5757.6	43450.	7.5465
950	450.00	5756.4	43450.	7.5481
1367	450.00	5756.1	43450.	7.5485
1366	450.00	5754.6	43450.	7.5504
1365	450.00	5753.2	43450.	7.5523
1132	450.00	5705.3	43450.	7.6157
1183	450.00	5704.7	43450.	7.6166
1133	450.00	5702.3	43450.	7.6197
1182	450.00	5701.7	43450.	7.6206
1134	450.00	5699.5	43450.	7.6235
1181	450.00	5698.8	43450.	7.6244
1135	450.00	5696.7	43450.	7.6272
1180	450.00	5696.1	43450.	7.6280
1136	450.00	5694.1	43450.	7.6308
1179	450.00	5693.5	43450.	7.6315
1137	450.00	5691.5	43450.	7.6341
1178	450.00	5691.0	43450.	7.6349
960	450.00	4898.3	43450.	8.8703
1355	450.00	4894.6	43450.	8.8772
961	450.00	4894.1	43450.	8.8780
959	450.00	4893.6	43450.	8.8789
1354	450.00	4890.3	43450.	8.8849
1356	450.00	4889.8	43450.	8.8858
958	450.00	4888.9	43450.	8.8875
962	450.00	4888.8	43450.	8.8876
1357	450.00	4885.1	43450.	8.8944
1353	450.00	4885.0	43450.	8.8945

Table 3.T.21 (continued)

957	450.00	4884.1	43450.	8.8962
963	450.00	4883.6	43450.	8.8971
1358	450.00	4880.3	43450.	8.9031
1352	450.00	4879.8	43450.	8.9040
956	450.00	4879.3	43450.	8.9049
964	450.00	4878.6	43450.	8.9063
1359	450.00	4875.5	43450.	8.9118
1351	450.00	4874.8	43450.	8.9132
955	450.00	4874.5	43450.	8.9137
965	450.00	4873.6	43450.	8.9153
1360	450.00	4870.7	43450.	8.9206
1350	450.00	4869.9	43450.	8.9222
954	450.00	4869.7	43450.	8.9225
966	450.00	4868.8	43450.	8.9241
1361	450.00	4866.0	43450.	8.9294
1349	450.00	4865.0	43450.	8.9311
953	450.00	4864.9	43450.	8.9313
967	450.00	4864.2	43450.	8.9327
1362	450.00	4861.2	43450.	8.9382
1348	450.00	4860.4	43450.	8.9397
952	450.00	4860.2	43450.	8.9400
968	450.00	4859.6	43450.	8.9411
1363	450.00	4856.4	43450.	8.9469
1347	450.00	4855.8	43450.	8.9481
951	450.00	4855.4	43450.	8.9487
969	450.00	4855.2	43450.	8.9492
1364	450.00	4851.7	43450.	8.9557
1346	450.00	4851.4	43450.	8.9562
970	450.00	4850.9	43450.	8.9572
1345	450.00	4847.1	43450.	8.9642
971	450.00	4846.7	43450.	8.9649
1344	450.00	4842.9	43450.	8.9719
972	450.00	4842.7	43450.	8.9723
1343	450.00	4838.9	43450.	8.9794
973	450.00	4838.8	43450.	8.9795
974	450.00	4835.0	43450.	8.9865
1342	450.00	4835.0	43450.	8.9866
975	450.00	4831.4	43450.	8.9933
1341	450.00	4831.2	43450.	8.9936
976	450.00	4827.9	43450.	8.9998
1340	450.00	4827.6	43450.	9.0003
977	450.00	4824.6	43450.	9.0060
1339	450.00	4824.1	43450.	9.0068
978	450.00	4821.3	43450.	9.0120
1338	450.00	4820.8	43450.	9.0131
979	450.00	4818.3	43450.	9.0178
1337	450.00	4817.6	43450.	9.0191
1336	450.00	4814.5	43450.	9.0249
980	450.00	4814.3	43450.	9.0252
1335	450.00	4810.5	43450.	9.0323
981	450.00	4806.1	43450.	9.0407
1334	450.00	4802.3	43450.	9.0478
982	450.00	4797.9	43450.	9.0560

Table 3.T.21 (continued)

1333	450.00	4794.2	43450.	9.0631
983	450.00	4789.9	43450.	9.0711
1332	450.00	4786.2	43450.	9.0783
984	450.00	4782.0	43450.	9.0861
1331	450.00	4778.3	43450.	9.0933
985	450.00	4774.2	43450.	9.1009
1330	450.00	4770.5	43450.	9.1081
986	450.00	4766.6	43450.	9.1155
1329	450.00	4762.8	43450.	9.1227
987	450.00	4759.1	43450.	9.1299
1328	450.00	4755.3	43450.	9.1371
988	450.00	4751.7	43450.	9.1441
1327	450.00	4748.0	43450.	9.1513
989	450.00	4744.5	43450.	9.1580
1326	450.00	4740.7	43450.	9.1652
990	450.00	4737.6	43450.	9.1712
1325	450.00	4734.4	43450.	9.1774
991	450.00	4731.7	43450.	9.1827
1324	450.00	4728.5	43450.	9.1889
992	450.00	4725.9	43450.	9.1941
1323	450.00	4722.7	43450.	9.2003
993	450.00	4720.2	43450.	9.2052
1322	450.00	4717.0	43450.	9.2114
994	450.00	4714.6	43450.	9.2161
1321	450.00	4711.4	43450.	9.2223
995	450.00	4709.1	43450.	9.2267
1320	450.00	4706.0	43450.	9.2329
1147	450.00	2927.7	43450.	14.841
1168	450.00	2927.4	43450.	14.843
1148	450.00	2921.3	43450.	14.873
1167	450.00	2921.0	43450.	14.875
1149	450.00	2918.7	43450.	14.887
1166	450.00	2918.5	43450.	14.888
1146	450.00	2916.6	43450.	14.898
1150	450.00	2916.4	43450.	14.898
1169	450.00	2916.2	43450.	14.899
1165	450.00	2916.2	43450.	14.900
1151	450.00	2914.4	43450.	14.909
1164	450.00	2914.2	43450.	14.910
1152	450.00	2912.6	43450.	14.918
1163	450.00	2912.5	43450.	14.919
1153	450.00	2911.2	43450.	14.925
1162	450.00	2911.0	43450.	14.926
1154	450.00	2910.0	43450.	14.931
1161	450.00	2909.9	43450.	14.932
1155	450.00	2909.1	43450.	14.936
1160	450.00	2909.0	43450.	14.936
1156	450.00	2908.5	43450.	14.939
1159	450.00	2908.4	43450.	14.939
1157	450.00	2908.2	43450.	14.941
1158	450.00	2908.1	43450.	14.941
1145	450.00	2905.4	43450.	14.955
1170	450.00	2905.1	43450.	14.957

Table 3.T.21 (continued)

1144	450.00	2894.3	43450.	15.012
1171	450.00	2893.9	43450.	15.014
1143	450.00	2883.3	43450.	15.070
1172	450.00	2882.8	43450.	15.072
1142	450.00	2872.3	43450.	15.127
1173	450.00	2871.8	43450.	15.130
1141	450.00	2861.4	43450.	15.185
1174	450.00	2860.9	43450.	15.187
1140	450.00	2850.7	43450.	15.242
1175	450.00	2850.2	43450.	15.245
1139	450.00	2840.1	43450.	15.299
1176	450.00	2839.6	43450.	15.302
1138	450.00	2829.7	43450.	15.355
1177	450.00	2829.2	43450.	15.358
997	450.00	2557.1	43450.	16.992
1318	450.00	2554.8	43450.	17.007
996	450.00	2542.0	43450.	17.093
1319	450.00	2539.7	43450.	17.108
1130	450.00	2046.7	43450.	21.229
1185	450.00	2046.2	43450.	21.235
1131	450.00	2026.2	43450.	21.444
1184	450.00	2025.7	43450.	21.450

Table 3.T.22

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Enclosure Vessel
SUBTITLE  2 =
Load Combination: E3.c (See Table 3.1.4)
SUBTITLE  3 =
Stress Result: Local Membrane Plus Primary Bending (PL+PB)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT    CURRENT       MIXED        PREVIOUS      PREVIOUS
   ELEM    REF TEMP      PL+PB         ALLOW         SF
   1288   450.00       44478.       65200.       1.4659
   1027   450.00       44478.       65200.       1.4659
   1287   450.00       44445.       65200.       1.4670
   1028   450.00       44445.       65200.       1.4670
   1289   450.00       43520.       65200.       1.4982
   1026   450.00       43520.       65200.       1.4982
   1100   450.00       43330.       65200.       1.5047
   1215   450.00       43330.       65200.       1.5047
   1099   450.00       43295.       65200.       1.5060
   1216   450.00       43295.       65200.       1.5060
   1101   450.00       42210.       65200.       1.5447
   1214   450.00       42210.       65200.       1.5447
   1096   450.00       41865.       65200.       1.5574
   1219   450.00       41865.       65200.       1.5574
   1284   450.00       39693.       65200.       1.6426
   1031   450.00       39692.       65200.       1.6426
   1290   450.00       39483.       65200.       1.6514
   1025   450.00       39483.       65200.       1.6514
   1073   450.00       38788.       65200.       1.6809
   1242   450.00       38788.       65200.       1.6809
   1074   450.00       38781.       65200.       1.6812
   1241   450.00       38781.       65200.       1.6812
   1102   450.00       38588.       65200.       1.6896
   1213   450.00       38588.       65200.       1.6896
   1261   450.00       38134.       65200.       1.7098
   1054   450.00       38134.       65200.       1.7098
   1262   450.00       38127.       65200.       1.7101
   1053   450.00       38127.       65200.       1.7101
   1091   450.00       36928.       65200.       1.7656
   1224   450.00       36928.       65200.       1.7656
   1092   450.00       36928.       65200.       1.7656
   1223   450.00       36928.       65200.       1.7656
   1090   450.00       36778.       65200.       1.7728
   1225   450.00       36778.       65200.       1.7728
   1093   450.00       36678.       65200.       1.7776
   1222   450.00       36678.       65200.       1.7776
   1279   450.00       36282.       65200.       1.7970
   1280   450.00       36282.       65200.       1.7970
   1036   450.00       36282.       65200.       1.7970
```

Table 3.T.22 (continued)

1035	450.00	36282.	65200.	1.7970
1089	450.00	36230.	65200.	1.7996
1226	450.00	36230.	65200.	1.7996
1278	450.00	36123.	65200.	1.8049
1037	450.00	36123.	65200.	1.8049
1281	450.00	36053.	65200.	1.8084
1034	450.00	36053.	65200.	1.8084
1094	450.00	36029.	65200.	1.8097
1221	450.00	36029.	65200.	1.8097
1072	450.00	35987.	65200.	1.8118
1243	450.00	35987.	65200.	1.8118
1291	450.00	35687.	65200.	1.8270
1024	450.00	35687.	65200.	1.8270
1277	450.00	35576.	65200.	1.8327
1038	450.00	35576.	65200.	1.8327
1282	450.00	35437.	65200.	1.8399
1033	450.00	35437.	65200.	1.8399
1260	450.00	35397.	65200.	1.8420
1055	450.00	35397.	65200.	1.8420
1088	450.00	35284.	65200.	1.8479
1227	450.00	35284.	65200.	1.8479
1103	450.00	35223.	65200.	1.8510
1212	450.00	35223.	65200.	1.8510
1095	450.00	34983.	65200.	1.8638
1220	450.00	34983.	65200.	1.8638
1276	450.00	34642.	65200.	1.8821
1039	450.00	34642.	65200.	1.8821
1283	450.00	34435.	65200.	1.8934
1032	450.00	34435.	65200.	1.8934
1087	450.00	33943.	65200.	1.9209
1228	450.00	33943.	65200.	1.9209
1275	450.00	33324.	65200.	1.9566
1040	450.00	33324.	65200.	1.9566
943	450.00	32748.	65200.	1.9909
1372	450.00	32748.	65200.	1.9909
1178	450.00	32637.	65200.	1.9978
1137	450.00	32636.	65200.	1.9978
1075	450.00	32520.	65200.	2.0049
1240	450.00	32520.	65200.	2.0049
944	450.00	32383.	65200.	2.0134
1371	450.00	32383.	65200.	2.0134
1086	450.00	32208.	65200.	2.0243
1229	450.00	32208.	65200.	2.0243
1292	450.00	32139.	65200.	2.0287
1023	450.00	32139.	65200.	2.0287
1104	450.00	32120.	65200.	2.0299
1211	450.00	32120.	65200.	2.0299
945	450.00	32005.	65200.	2.0372
1370	450.00	32005.	65200.	2.0372
1263	450.00	31969.	65200.	2.0395
1052	450.00	31969.	65200.	2.0395
1179	450.00	31958.	65200.	2.0402
1136	450.00	31958.	65200.	2.0402

Table 3.T.22 (continued)

1274	450.00	31622.	65200.	2.0619
1041	450.00	31622.	65200.	2.0619
946	450.00	31461.	65200.	2.0724
1369	450.00	31461.	65200.	2.0724
1180	450.00	31242.	65200.	2.0869
1135	450.00	31242.	65200.	2.0869
947	450.00	30893.	65200.	2.1105
1368	450.00	30893.	65200.	2.1105
1071	450.00	30755.	65200.	2.1200
1244	450.00	30755.	65200.	2.1200
1181	450.00	30490.	65200.	2.1384
1134	450.00	30490.	65200.	2.1384
948	450.00	30301.	65200.	2.1517
1367	450.00	30301.	65200.	2.1518
1259	450.00	30284.	65200.	2.1529
1056	450.00	30284.	65200.	2.1529
1085	450.00	30085.	65200.	2.1672
1230	450.00	30085.	65200.	2.1672
1177	450.00	29775.	65200.	2.1897
1138	450.00	29775.	65200.	2.1897
1182	450.00	29702.	65200.	2.1951
1133	450.00	29702.	65200.	2.1951
949	450.00	29686.	65200.	2.1963
1366	450.00	29686.	65200.	2.1963
1273	450.00	29540.	65200.	2.2072
1042	450.00	29540.	65200.	2.2072
1105	450.00	29283.	65200.	2.2265
1210	450.00	29283.	65200.	2.2265
950	450.00	29047.	65200.	2.2447
1365	450.00	29047.	65200.	2.2447
1183	450.00	28878.	65200.	2.2578
1132	450.00	28878.	65200.	2.2578
1293	450.00	28843.	65200.	2.2605
1022	450.00	28842.	65200.	2.2606
942	450.00	27868.	65200.	2.3396
1373	450.00	27868.	65200.	2.3396
1084	450.00	27576.	65200.	2.3644
1231	450.00	27576.	65200.	2.3644
951	450.00	27485.	65200.	2.3722
1364	450.00	27485.	65200.	2.3722
941	450.00	27263.	65200.	2.3915
1374	450.00	27263.	65200.	2.3915
1272	450.00	27081.	65200.	2.4076
1043	450.00	27081.	65200.	2.4076
1106	450.00	26717.	65200.	2.4404
1209	450.00	26717.	65200.	2.4404
940	450.00	26652.	65200.	2.4464
1375	450.00	26651.	65200.	2.4464
1076	450.00	26557.	65200.	2.4551
1239	450.00	26557.	65200.	2.4551
1286	450.00	26211.	65200.	2.4875
1029	450.00	26211.	65200.	2.4875
1264	450.00	26106.	65200.	2.4975

Table 3.T.22 (continued)

1051	450.00	26106.	65200.	2.4975
939	450.00	26033.	65200.	2.5046
1376	450.00	26033.	65200.	2.5046
1176	450.00	25870.	65200.	2.5203
1139	450.00	25870.	65200.	2.5203
1070	450.00	25823.	65200.	2.5249
1245	450.00	25823.	65200.	2.5249
1294	450.00	25804.	65200.	2.5268
1021	450.00	25804.	65200.	2.5268
1258	450.00	25471.	65200.	2.5598
1057	450.00	25471.	65200.	2.5598
938	450.00	25407.	65200.	2.5662
1377	450.00	25407.	65200.	2.5662
1098	450.00	24912.	65200.	2.6172
1217	450.00	24912.	65200.	2.6172
937	450.00	24775.	65200.	2.6317
1378	450.00	24775.	65200.	2.6317
1083	450.00	24686.	65200.	2.6412
1232	450.00	24686.	65200.	2.6412
1107	450.00	24427.	65200.	2.6692
1208	450.00	24427.	65200.	2.6692
952	450.00	24381.	65200.	2.6742
1363	450.00	24381.	65200.	2.6742
1184	450.00	24335.	65200.	2.6792
1131	450.00	24335.	65200.	2.6792
1097	450.00	24313.	65200.	2.6817
1218	450.00	24313.	65200.	2.6817
1271	450.00	24251.	65200.	2.6886
1044	450.00	24251.	65200.	2.6886
936	450.00	24137.	65200.	2.7013
1379	450.00	24137.	65200.	2.7013
935	450.00	23493.	65200.	2.7754
1380	450.00	23492.	65200.	2.7754
1295	450.00	23027.	65200.	2.8315
1020	450.00	23026.	65200.	2.8315
934	450.00	22843.	65200.	2.8543
1381	450.00	22843.	65200.	2.8543
1108	450.00	22415.	65200.	2.9088
1207	450.00	22415.	65200.	2.9088
1285	450.00	22233.	65200.	2.9326
1030	450.00	22232.	65200.	2.9327
933	450.00	22188.	65200.	2.9385
1382	450.00	22188.	65200.	2.9385
1175	450.00	21827.	65200.	2.9872
1140	450.00	21827.	65200.	2.9872
932	450.00	21529.	65200.	3.0285
1383	450.00	21529.	65200.	3.0285
1082	450.00	21421.	65200.	3.0438
1233	450.00	21421.	65200.	3.0438
953	450.00	21216.	65200.	3.0731
1362	450.00	21216.	65200.	3.0732
1069	450.00	21201.	65200.	3.0754
1246	450.00	21201.	65200.	3.0754

Table 3.T.22 (continued)

1270	450.00	21053.	65200.	3.0970
1045	450.00	21053.	65200.	3.0970
1168	450.00	21024.	65200.	3.1012
1147	450.00	21024.	65200.	3.1012
1167	450.00	21018.	65200.	3.1021
1148	450.00	21018.	65200.	3.1021
1257	450.00	20964.	65200.	3.1101
1058	450.00	20964.	65200.	3.1101
1077	450.00	20903.	65200.	3.1192
1238	450.00	20903.	65200.	3.1192
1064	450.00	20877.	65200.	3.1231
1251	450.00	20877.	65200.	3.1231
1384	450.00	20865.	65200.	3.1249
931	450.00	20865.	65200.	3.1249
1196	450.00	20769.	65200.	3.1393
1119	450.00	20769.	65200.	3.1393
1195	450.00	20764.	65200.	3.1401
1120	450.00	20764.	65200.	3.1401
1109	450.00	20686.	65200.	3.1519
1206	450.00	20686.	65200.	3.1520
1265	450.00	20548.	65200.	3.1731
1050	450.00	20548.	65200.	3.1731
1296	450.00	20515.	65200.	3.1781
1019	450.00	20515.	65200.	3.1782
1252	450.00	20266.	65200.	3.2172
1063	450.00	20266.	65200.	3.2173
1385	450.00	20196.	65200.	3.2283
930	450.00	20196.	65200.	3.2283
1166	450.00	19926.	65200.	3.2721
1149	450.00	19926.	65200.	3.2721
1386	450.00	19524.	65200.	3.3395
929	450.00	19524.	65200.	3.3395
1197	450.00	19308.	65200.	3.3768
1118	450.00	19308.	65200.	3.3768
1110	450.00	19241.	65200.	3.3886
1205	450.00	19241.	65200.	3.3886
995	450.00	18975.	65200.	3.4361
1320	450.00	18975.	65200.	3.4361
1165	450.00	18947.	65200.	3.4413
1150	450.00	18946.	65200.	3.4413
1387	450.00	18848.	65200.	3.4592
928	450.00	18848.	65200.	3.4592
1297	450.00	18273.	65200.	3.5681
1018	450.00	18273.	65200.	3.5681
1388	450.00	18169.	65200.	3.5885
927	450.00	18169.	65200.	3.5885
994	450.00	18141.	65200.	3.5941
1321	450.00	18141.	65200.	3.5941
1198	450.00	18136.	65200.	3.5951
1117	450.00	18136.	65200.	3.5951
1204	450.00	18084.	65200.	3.6054
1111	450.00	18084.	65200.	3.6054
1164	450.00	18081.	65200.	3.6060

Table 3.T.22 (continued)

1151	450.00	18081.	65200.	3.6060
954	450.00	17990.	65200.	3.6242
1361	450.00	17990.	65200.	3.6242
1234	450.00	17787.	65200.	3.6657
1081	450.00	17787.	65200.	3.6657
1174	450.00	17648.	65200.	3.6945
1141	450.00	17648.	65200.	3.6945
1186	450.00	17608.	65200.	3.7029
1129	450.00	17607.	65200.	3.7030
1269	450.00	17493.	65200.	3.7272
1046	450.00	17493.	65200.	3.7272
1389	450.00	17487.	65200.	3.7285
926	450.00	17487.	65200.	3.7285
1163	450.00	17330.	65200.	3.7623
1152	450.00	17330.	65200.	3.7623
993	450.00	17256.	65200.	3.7783
1322	450.00	17256.	65200.	3.7783
1199	450.00	17253.	65200.	3.7791
1116	450.00	17253.	65200.	3.7791
1203	450.00	17216.	65200.	3.7871
1112	450.00	17216.	65200.	3.7871
1194	450.00	16903.	65200.	3.8574
1121	450.00	16903.	65200.	3.8574
1247	450.00	16896.	65200.	3.8590
1068	450.00	16896.	65200.	3.8590
996	450.00	16811.	65200.	3.8784
1319	450.00	16811.	65200.	3.8784
1185	450.00	16809.	65200.	3.8788
1130	450.00	16809.	65200.	3.8789
1390	450.00	16802.	65200.	3.8805
925	450.00	16802.	65200.	3.8806
1256	450.00	16772.	65200.	3.8874
1059	450.00	16772.	65200.	3.8874
1162	450.00	16693.	65200.	3.9058
1153	450.00	16693.	65200.	3.9058
1200	450.00	16661.	65200.	3.9133
1115	450.00	16661.	65200.	3.9133
1202	450.00	16639.	65200.	3.9185
1113	450.00	16639.	65200.	3.9185
1187	450.00	16532.	65200.	3.9439
1128	450.00	16532.	65200.	3.9440
1201	450.00	16361.	65200.	3.9851
1114	450.00	16361.	65200.	3.9851
992	450.00	16322.	65200.	3.9947
1323	450.00	16322.	65200.	3.9947
1298	450.00	16304.	65200.	3.9991
1017	450.00	16304.	65200.	3.9991
1161	450.00	16172.	65200.	4.0317
1154	450.00	16172.	65200.	4.0317
1391	450.00	16114.	65200.	4.0461
924	450.00	16114.	65200.	4.0461
1355	450.00	16002.	65200.	4.0745
960	450.00	16002.	65200.	4.0745

Table 3.T.22 (continued)

1354	450.00	16002.	65200.	4.0746
961	450.00	16002.	65200.	4.0746
1169	450.00	15955.	65200.	4.0865
1146	450.00	15955.	65200.	4.0865
1160	450.00	15766.	65200.	4.1354
1155	450.00	15766.	65200.	4.1354
1078	450.00	15567.	65200.	4.1884
1237	450.00	15567.	65200.	4.1884
1159	450.00	15476.	65200.	4.2129
1156	450.00	15476.	65200.	4.2129
1392	450.00	15425.	65200.	4.2270
923	450.00	15425.	65200.	4.2270
991	450.00	15337.	65200.	4.2511
1324	450.00	15337.	65200.	4.2512
1353	450.00	15323.	65200.	4.2551
962	450.00	15323.	65200.	4.2551
1266	450.00	15304.	65200.	4.2603
1049	450.00	15304.	65200.	4.2603
1157	450.00	15302.	65200.	4.2609
1158	450.00	15302.	65200.	4.2609
1188	450.00	15130.	65200.	4.3093
1127	450.00	15130.	65200.	4.3094
1393	450.00	14733.	65200.	4.4253
922	450.00	14733.	65200.	4.4253
955	450.00	14705.	65200.	4.4339
1360	450.00	14705.	65200.	4.4340
1352	450.00	14697.	65200.	4.4362
963	450.00	14697.	65200.	4.4362
1299	450.00	14610.	65200.	4.4627
1016	450.00	14610.	65200.	4.4627
990	450.00	14303.	65200.	4.5584
1325	450.00	14303.	65200.	4.5584
1351	450.00	14125.	65200.	4.6159
964	450.00	14125.	65200.	4.6159
1394	450.00	14040.	65200.	4.6437
921	450.00	14040.	65200.	4.6438
1235	450.00	13790.	65200.	4.7281
1080	450.00	13790.	65200.	4.7281
1065	450.00	13779.	65200.	4.7317
1250	450.00	13779.	65200.	4.7317
1350	450.00	13607.	65200.	4.7918
965	450.00	13607.	65200.	4.7918
1268	450.00	13578.	65200.	4.8020
1047	450.00	13578.	65200.	4.8020
1189	450.00	13405.	65200.	4.8639
1126	450.00	13405.	65200.	4.8640
1253	450.00	13357.	65200.	4.8812
1062	450.00	13357.	65200.	4.8812
1395	450.00	13346.	65200.	4.8853
920	450.00	13346.	65200.	4.8853
1142	450.00	13337.	65200.	4.8888
1173	450.00	13337.	65200.	4.8888
1193	450.00	13334.	65200.	4.8899

Table 3.T.22 (continued)

1122	450.00	13334.	65200.	4.8899
989	450.00	13221.	65200.	4.9316
1326	450.00	13221.	65200.	4.9316
1300	450.00	13194.	65200.	4.9417
1015	450.00	13194.	65200.	4.9417
1349	450.00	13143.	65200.	4.9610
966	450.00	13143.	65200.	4.9610
1248	450.00	12915.	65200.	5.0483
1067	450.00	12915.	65200.	5.0483
1060	450.00	12903.	65200.	5.0532
1255	450.00	12903.	65200.	5.0532
1348	450.00	12733.	65200.	5.1205
967	450.00	12733.	65200.	5.1205
1396	450.00	12651.	65200.	5.1537
919	450.00	12651.	65200.	5.1538
979	450.00	12524.	65200.	5.2058
1336	450.00	12524.	65200.	5.2059
980	450.00	12524.	65200.	5.2059
1335	450.00	12524.	65200.	5.2059
1347	450.00	12379.	65200.	5.2670
968	450.00	12379.	65200.	5.2670
1356	450.00	12371.	65200.	5.2706
959	450.00	12371.	65200.	5.2706
978	450.00	12197.	65200.	5.3455
1337	450.00	12197.	65200.	5.3455
1407	450.00	12117.	65200.	5.3810
1658	450.00	12117.	65200.	5.3811
1346	450.00	12080.	65200.	5.3974
969	450.00	12080.	65200.	5.3974
1301	450.00	12058.	65200.	5.4072
1014	450.00	12058.	65200.	5.4072
1008	450.00	12020.	65200.	5.4245
1307	450.00	12019.	65200.	5.4245
1007	450.00	12019.	65200.	5.4250
1308	450.00	12018.	65200.	5.4250
1397	450.00	11955.	65200.	5.4537
918	450.00	11955.	65200.	5.4538
977	450.00	11928.	65200.	5.4662
1338	450.00	11928.	65200.	5.4662
988	450.00	11894.	65200.	5.4818
1327	450.00	11894.	65200.	5.4818
1345	450.00	11837.	65200.	5.5083
970	450.00	11837.	65200.	5.5083
1408	450.00	11834.	65200.	5.5096
1657	450.00	11834.	65200.	5.5097
976	450.00	11716.	65200.	5.5649
1339	450.00	11716.	65200.	5.5649
1344	450.00	11649.	65200.	5.5969
971	450.00	11649.	65200.	5.5969
975	450.00	11562.	65200.	5.6390
1340	450.00	11562.	65200.	5.6390
1409	450.00	11546.	65200.	5.6470
1656	450.00	11546.	65200.	5.6471

Table 3.T.22 (continued)

1343	450.00	11518.	65200.	5.6605
972	450.00	11518.	65200.	5.6605
974	450.00	11466.	65200.	5.6865
1341	450.00	11466.	65200.	5.6865
973	450.00	11444.	65200.	5.6973
1342	450.00	11444.	65200.	5.6973
956	450.00	11361.	65200.	5.7391
1359	450.00	11361.	65200.	5.7392
1190	450.00	11359.	65200.	5.7400
1125	450.00	11359.	65200.	5.7400
1438	450.00	11286.	65200.	5.7773
1627	450.00	11285.	65200.	5.7774
1398	450.00	11259.	65200.	5.7910
917	450.00	11259.	65200.	5.7911
1410	450.00	11253.	65200.	5.7939
1655	450.00	11253.	65200.	5.7940
1595	450.00	11235.	65200.	5.8031
1470	450.00	11235.	65200.	5.8031
1532	450.00	11234.	65200.	5.8040
1533	450.00	11234.	65200.	5.8040
1531	450.00	11233.	65200.	5.8045
1534	450.00	11233.	65200.	5.8045
1530	450.00	11230.	65200.	5.8061
1535	450.00	11230.	65200.	5.8061
1529	450.00	11225.	65200.	5.8086
1536	450.00	11225.	65200.	5.8086
1528	450.00	11218.	65200.	5.8122
1537	450.00	11218.	65200.	5.8122
1527	450.00	11209.	65200.	5.8168
1538	450.00	11209.	65200.	5.8168
1013	450.00	11203.	65200.	5.8197
1302	450.00	11203.	65200.	5.8197
1526	450.00	11198.	65200.	5.8225
1539	450.00	11198.	65200.	5.8225
1525	450.00	11185.	65200.	5.8292
1540	450.00	11185.	65200.	5.8292
1009	450.00	11177.	65200.	5.8335
1306	450.00	11177.	65200.	5.8335
1524	450.00	11170.	65200.	5.8369
1541	450.00	11170.	65200.	5.8369
1523	450.00	11154.	65200.	5.8456
1542	450.00	11154.	65200.	5.8456
1522	450.00	11135.	65200.	5.8554
1543	450.00	11135.	65200.	5.8554
1521	450.00	11115.	65200.	5.8662
1544	450.00	11115.	65200.	5.8662
1596	450.00	11099.	65200.	5.8746
1469	450.00	11099.	65200.	5.8746
1520	450.00	11092.	65200.	5.8780
1545	450.00	11092.	65200.	5.8780
1519	450.00	11068.	65200.	5.8908
1546	450.00	11068.	65200.	5.8909
1518	450.00	11042.	65200.	5.9047

Table 3.T.22 (continued)

1547	450.00	11042.	65200.	5.9047
1517	450.00	11014.	65200.	5.9196
1548	450.00	11014.	65200.	5.9197
1170	450.00	11001.	65200.	5.9267
1145	450.00	11001.	65200.	5.9267
1516	450.00	10985.	65200.	5.9356
1549	450.00	10985.	65200.	5.9356
1597	450.00	10959.	65200.	5.9493
1468	450.00	10959.	65200.	5.9493
1411	450.00	10956.	65200.	5.9509
1654	450.00	10956.	65200.	5.9511
1515	450.00	10953.	65200.	5.9526
1550	450.00	10953.	65200.	5.9526
1437	450.00	10949.	65200.	5.9547
1628	450.00	10949.	65200.	5.9548
1514	450.00	10920.	65200.	5.9706
1551	450.00	10920.	65200.	5.9706
1513	450.00	10885.	65200.	5.9896
1552	450.00	10885.	65200.	5.9897
1512	450.00	10849.	65200.	6.0097
1553	450.00	10849.	65200.	6.0097
1598	450.00	10818.	65200.	6.0273
1467	450.00	10817.	65200.	6.0273
1511	450.00	10816.	65200.	6.0282
1554	450.00	10816.	65200.	6.0282
1510	450.00	10781.	65200.	6.0474
1555	450.00	10781.	65200.	6.0475
1509	450.00	10746.	65200.	6.0675
1556	450.00	10746.	65200.	6.0675
1508	450.00	10709.	65200.	6.0883
1557	450.00	10709.	65200.	6.0883
1599	450.00	10673.	65200.	6.1087
1466	450.00	10673.	65200.	6.1087
1507	450.00	10671.	65200.	6.1099
1558	450.00	10671.	65200.	6.1100
1412	450.00	10655.	65200.	6.1192
1653	450.00	10655.	65200.	6.1193
1506	450.00	10632.	65200.	6.1323
1559	450.00	10632.	65200.	6.1324
1012	450.00	10631.	65200.	6.1329
1303	450.00	10631.	65200.	6.1329
981	450.00	10622.	65200.	6.1380
1334	450.00	10622.	65200.	6.1380
1010	450.00	10616.	65200.	6.1418
1305	450.00	10616.	65200.	6.1418
1436	450.00	10611.	65200.	6.1444
1629	450.00	10611.	65200.	6.1445
1505	450.00	10603.	65200.	6.1489
1560	450.00	10603.	65200.	6.1490
1399	450.00	10562.	65200.	6.1729
916	450.00	10562.	65200.	6.1730
1079	450.00	10559.	65200.	6.1748
1236	450.00	10559.	65200.	6.1748

Table 3.T.22 (continued)

1600	450.00	10527.	65200.	6.1936
1465	450.00	10527.	65200.	6.1936
1328	450.00	10502.	65200.	6.2085
987	450.00	10502.	65200.	6.2085
1267	450.00	10384.	65200.	6.2791
1048	450.00	10384.	65200.	6.2791
1601	450.00	10379.	65200.	6.2822
1464	450.00	10378.	65200.	6.2822
1413	450.00	10350.	65200.	6.2997
1652	450.00	10350.	65200.	6.2998
1011	450.00	10342.	65200.	6.3042
1304	450.00	10342.	65200.	6.3042
999	450.00	10282.	65200.	6.3414
1000	450.00	10282.	65200.	6.3414
1316	450.00	10282.	65200.	6.3414
1315	450.00	10281.	65200.	6.3415
1435	450.00	10272.	65200.	6.3476
1630	450.00	10271.	65200.	6.3477
1602	450.00	10228.	65200.	6.3746
1463	450.00	10228.	65200.	6.3746
998	450.00	10171.	65200.	6.4103
1317	450.00	10171.	65200.	6.4104
1001	450.00	10097.	65200.	6.4575
1314	450.00	10097.	65200.	6.4576
1603	450.00	10076.	65200.	6.4709
1462	450.00	10076.	65200.	6.4709
1192	450.00	10062.	65200.	6.4799
1123	450.00	10062.	65200.	6.4799
1414	450.00	10041.	65200.	6.4935
1651	450.00	10041.	65200.	6.4936
997	450.00	10020.	65200.	6.5070
1318	450.00	10020.	65200.	6.5071
1504	450.00	9957.1	65200.	6.5481
1561	450.00	9957.0	65200.	6.5482
1503	450.00	9931.2	65200.	6.5651
1562	450.00	9931.2	65200.	6.5652
1434	450.00	9930.6	65200.	6.5655
1631	450.00	9930.5	65200.	6.5656
1604	450.00	9922.0	65200.	6.5713
1461	450.00	9922.0	65200.	6.5713
1502	450.00	9903.3	65200.	6.5837
1563	450.00	9903.2	65200.	6.5837
1501	450.00	9873.2	65200.	6.6037
1564	450.00	9873.1	65200.	6.6038
1400	450.00	9866.0	65200.	6.6086
915	450.00	9865.8	65200.	6.6087
1500	450.00	9841.1	65200.	6.6253
1565	450.00	9841.0	65200.	6.6253
1499	450.00	9807.0	65200.	6.6483
1566	450.00	9806.9	65200.	6.6484
1006	450.00	9802.6	65200.	6.6513
1309	450.00	9802.6	65200.	6.6513
1498	450.00	9770.9	65200.	6.6729

Table 3.T.22 (continued)

1567	450.00	9770.9	65200.	6.6729
1605	450.00	9766.6	65200.	6.6758
1460	450.00	9766.5	65200.	6.6758
1497	450.00	9733.0	65200.	6.6989
1568	450.00	9733.0	65200.	6.6989
1415	450.00	9728.4	65200.	6.7021
1650	450.00	9728.2	65200.	6.7021
1496	450.00	9693.3	65200.	6.7263
1569	450.00	9693.3	65200.	6.7263
1495	450.00	9651.8	65200.	6.7552
1570	450.00	9651.8	65200.	6.7552
1002	450.00	9617.4	65200.	6.7794
1313	450.00	9617.4	65200.	6.7794
1459	450.00	9609.7	65200.	6.7848
1606	450.00	9609.7	65200.	6.7848
1494	450.00	9608.7	65200.	6.7855
1571	450.00	9608.7	65200.	6.7855
1433	450.00	9588.5	65200.	6.7998
1632	450.00	9588.4	65200.	6.7999
1493	450.00	9564.0	65200.	6.8172
1572	450.00	9564.0	65200.	6.8173
1492	450.00	9517.7	65200.	6.8504
1573	450.00	9517.7	65200.	6.8504
1491	450.00	9470.0	65200.	6.8849
1574	450.00	9470.0	65200.	6.8849
1458	450.00	9451.7	65200.	6.8982
1607	450.00	9451.7	65200.	6.8983
1490	450.00	9420.9	65200.	6.9208
1575	450.00	9420.9	65200.	6.9208
1416	450.00	9412.7	65200.	6.9268
1649	450.00	9412.5	65200.	6.9269
1576	450.00	9370.5	65200.	6.9580
1489	450.00	9370.5	65200.	6.9580
1061	450.00	9363.2	65200.	6.9634
1254	450.00	9363.2	65200.	6.9634
1066	450.00	9327.1	65200.	6.9904
1249	450.00	9327.1	65200.	6.9904
1577	450.00	9318.8	65200.	6.9966
1488	450.00	9318.8	65200.	6.9966
1457	450.00	9292.5	65200.	7.0164
1608	450.00	9292.5	65200.	7.0164
1578	450.00	9266.0	65200.	7.0365
1487	450.00	9266.0	65200.	7.0365
1432	450.00	9245.4	65200.	7.0522
1633	450.00	9245.3	65200.	7.0523
1579	450.00	9212.1	65200.	7.0776
1486	450.00	9212.1	65200.	7.0776
1401	450.00	9170.0	65200.	7.1101
914	450.00	9169.9	65200.	7.1102
1580	450.00	9157.3	65200.	7.1200
1485	450.00	9157.3	65200.	7.1200
1456	450.00	9132.4	65200.	7.1394
1609	450.00	9132.4	65200.	7.1394

Table 3.T.22 (continued)

1581	450.00	9101.5	65200.	7.1636
1484	450.00	9101.5	65200.	7.1636
1417	450.00	9093.9	65200.	7.1696
1648	450.00	9093.8	65200.	7.1697
1582	450.00	9045.0	65200.	7.2084
1483	450.00	9044.9	65200.	7.2084
1329	450.00	9044.9	65200.	7.2085
986	450.00	9044.9	65200.	7.2085
1191	450.00	8995.7	65200.	7.2479
1124	450.00	8995.7	65200.	7.2479
1583	450.00	8987.7	65200.	7.2544
1482	450.00	8987.7	65200.	7.2544
1455	450.00	8971.5	65200.	7.2674
1610	450.00	8971.5	65200.	7.2675
1584	450.00	8929.8	65200.	7.3014
1481	450.00	8929.7	65200.	7.3014
1431	450.00	8901.5	65200.	7.3246
1634	450.00	8901.4	65200.	7.3247
1143	450.00	8895.2	65200.	7.3298
1172	450.00	8895.2	65200.	7.3298
1585	450.00	8871.3	65200.	7.3495
1480	450.00	8871.3	65200.	7.3496
1003	450.00	8844.0	65200.	7.3722
1312	450.00	8844.0	65200.	7.3722
1586	450.00	8812.4	65200.	7.3986
1479	450.00	8812.4	65200.	7.3987
1454	450.00	8810.0	65200.	7.4007
1611	450.00	8809.9	65200.	7.4008
1357	450.00	8792.6	65200.	7.4154
958	450.00	8792.5	65200.	7.4154
982	450.00	8779.2	65200.	7.4266
1333	450.00	8779.2	65200.	7.4266
1418	450.00	8772.4	65200.	7.4324
1647	450.00	8772.3	65200.	7.4325
1587	450.00	8753.2	65200.	7.4487
1478	450.00	8753.1	65200.	7.4488
1588	450.00	8693.7	65200.	7.4997
1477	450.00	8693.7	65200.	7.4997
1453	450.00	8647.9	65200.	7.5394
1612	450.00	8647.9	65200.	7.5394
1589	450.00	8634.1	65200.	7.5515
1476	450.00	8634.0	65200.	7.5515
1590	450.00	8574.4	65200.	7.6040
1475	450.00	8574.4	65200.	7.6041
1430	450.00	8557.1	65200.	7.6194
1635	450.00	8557.0	65200.	7.6195
1591	450.00	8514.8	65200.	7.6572
1474	450.00	8514.8	65200.	7.6573
1452	450.00	8485.5	65200.	7.6837
1613	450.00	8485.5	65200.	7.6837
1402	450.00	8474.7	65200.	7.6934
913	450.00	8474.6	65200.	7.6936
1592	450.00	8455.4	65200.	7.7111

Table 3.T.22 (continued)

1473	450.00	8455.3	65200.	7.7111
1419	450.00	8448.3	65200.	7.7175
1646	450.00	8448.2	65200.	7.7176
1593	450.00	8396.2	65200.	7.7654
1472	450.00	8396.1	65200.	7.7655
1594	450.00	8337.4	65200.	7.8201
1471	450.00	8337.4	65200.	7.8202
1451	450.00	8323.0	65200.	7.8337
1614	450.00	8322.9	65200.	7.8338
909	450.00	8267.4	65200.	7.8864
1406	450.00	8267.2	65200.	7.8865
1429	450.00	8212.4	65200.	7.9393
1636	450.00	8212.3	65200.	7.9393
1450	450.00	8160.4	65200.	7.9898
1615	450.00	8160.3	65200.	7.9899
1420	450.00	8121.9	65200.	8.0277
1645	450.00	8121.8	65200.	8.0278
1449	450.00	7998.0	65200.	8.1521
1616	450.00	7997.9	65200.	8.1522
957	450.00	7958.8	65200.	8.1922
1358	450.00	7958.7	65200.	8.1923
1005	450.00	7869.9	65200.	8.2847
1310	450.00	7869.9	65200.	8.2848
1428	450.00	7867.5	65200.	8.2873
1637	450.00	7867.4	65200.	8.2873
1448	450.00	7835.8	65200.	8.3208
1617	450.00	7835.7	65200.	8.3209
1421	450.00	7793.4	65200.	8.3661
1644	450.00	7793.3	65200.	8.3662
1403	450.00	7780.4	65200.	8.3800
912	450.00	7780.3	65200.	8.3802
1311	450.00	7777.6	65200.	8.3830
1004	450.00	7777.6	65200.	8.3830
1447	450.00	7674.1	65200.	8.4961
1618	450.00	7674.0	65200.	8.4962
910	450.00	7569.6	65200.	8.6134
1405	450.00	7569.4	65200.	8.6136
1330	450.00	7524.3	65200.	8.6652
985	450.00	7524.3	65200.	8.6653
1427	450.00	7522.7	65200.	8.6671
1638	450.00	7522.6	65200.	8.6672
1446	450.00	7513.1	65200.	8.6782
1619	450.00	7513.0	65200.	8.6783
1422	450.00	7463.0	65200.	8.7365
1643	450.00	7462.9	65200.	8.7365
1445	450.00	7352.9	65200.	8.8673
1620	450.00	7352.8	65200.	8.8674
1444	450.00	7193.6	65200.	9.0636
1621	450.00	7193.5	65200.	9.0638
1426	450.00	7178.2	65200.	9.0831
1639	450.00	7178.2	65200.	9.0831
1423	450.00	7130.9	65200.	9.1433
1642	450.00	7130.9	65200.	9.1433

Table 3.T.22 (continued)

1404	450.00	7087.3	65200.	9.1996
911	450.00	7087.1	65200.	9.1998
1443	450.00	7035.5	65200.	9.2673
1622	450.00	7035.4	65200.	9.2675
983	450.00	6995.8	65200.	9.3198
1332	450.00	6995.8	65200.	9.3199
1442	450.00	6878.7	65200.	9.4785
1623	450.00	6878.6	65200.	9.4787
1425	450.00	6834.2	65200.	9.5403
1640	450.00	6834.2	65200.	9.5403
1424	450.00	6797.4	65200.	9.5919
1641	450.00	6797.4	65200.	9.5919
1441	450.00	6723.4	65200.	9.6974
1624	450.00	6723.2	65200.	9.6977
1440	450.00	6569.8	65200.	9.9242
1625	450.00	6569.6	65200.	9.9245
1626	450.00	6525.3	65200.	9.9919
1439	450.00	6525.1	65200.	9.9922
1171	450.00	6165.1	65200.	10.576
1144	450.00	6165.1	65200.	10.576
1331	450.00	5940.8	65200.	10.975
984	450.00	5940.8	65200.	10.975

Table 3.T.23

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Basket Supports
SUBTITLE  2 =
Load Combination: E3.c (See Table 3.1.4)
SUBTITLE  3 =
Stress Result: Primary Membrane (PM)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT     CURRENT      MIXED        PREVIOUS     PREVIOUS
   ELEM     REF TEMP     PM           ALLOW        SF
    905   450.00      -8944.6       43450.       4.8577
    875   450.00      -8944.6       43450.       4.8577
    904   450.00      -8942.9       43450.       4.8586
    874   450.00      -8942.9       43450.       4.8586
    903   450.00      -8927.2       43450.       4.8671
    873   450.00      -8927.2       43450.       4.8671
    902   450.00      -8911.6       43450.       4.8757
    872   450.00      -8911.5       43450.       4.8757
    878   450.00      -8306.3       43450.       5.2310
    901   450.00      -8306.2       43450.       5.2310
    877   450.00      -8303.1       43450.       5.2330
    900   450.00      -8303.1       43450.       5.2330
    908   450.00      -8284.1       43450.       5.2450
    871   450.00      -8284.0       43450.       5.2450
    876   450.00      -8283.7       43450.       5.2452
    899   450.00      -8283.7       43450.       5.2453
    907   450.00      -8280.0       43450.       5.2476
    870   450.00      -8279.9       43450.       5.2476
    906   450.00      -8260.0       43450.       5.2603
    869   450.00      -8259.9       43450.       5.2603
    793   450.00       8023.9       43450.       5.4151
    844   450.00       8023.8       43450.       5.4151
    792   450.00       8022.4       43450.       5.4161
    845   450.00       8022.4       43450.       5.4161
    791   450.00       8007.0       43450.       5.4265
    846   450.00       8006.9       43450.       5.4265
    790   450.00       7991.3       43450.       5.4371
    847   450.00       7991.3       43450.       5.4372
    789   450.00       7975.6       43450.       5.4479
    848   450.00       7975.6       43450.       5.4479
    788   450.00       7959.8       43450.       5.4587
    849   450.00       7959.8       43450.       5.4587
    787   450.00       7944.1       43450.       5.4695
    850   450.00       7944.1       43450.       5.4695
    862   450.00       7935.2       43450.       5.4756
    775   450.00       7935.1       43450.       5.4757
    863   450.00       7933.6       43450.       5.4767
    774   450.00       7933.5       43450.       5.4768
    864   450.00       7917.9       43450.       5.4876
```

Table 3.T.23 (continued)

773	450.00	7917.8	43450.	5.4876
865	450.00	7902.2	43450.	5.4985
772	450.00	7902.1	43450.	5.4985
866	450.00	7886.3	43450.	5.5095
771	450.00	7886.3	43450.	5.5096
867	450.00	7870.2	43450.	5.5208
770	450.00	7870.2	43450.	5.5208
868	450.00	7854.1	43450.	5.5322
769	450.00	7854.0	43450.	5.5322
786	450.00	7603.9	43450.	5.7142
851	450.00	7603.9	43450.	5.7142
852	450.00	7587.3	43450.	5.7266
785	450.00	7587.0	43450.	5.7269
853	450.00	7570.8	43450.	5.7392
784	450.00	7570.1	43450.	5.7397
857	450.00	7557.3	43450.	5.7494
781	450.00	7557.2	43450.	5.7495
780	450.00	7555.6	43450.	5.7507
854	450.00	7554.2	43450.	5.7518
783	450.00	7553.2	43450.	5.7525
858	450.00	7540.4	43450.	5.7623
779	450.00	7539.0	43450.	5.7634
855	450.00	7537.6	43450.	5.7644
782	450.00	7536.2	43450.	5.7655
859	450.00	7523.4	43450.	5.7753
778	450.00	7522.4	43450.	5.7761
856	450.00	7520.9	43450.	5.7772
860	450.00	7506.4	43450.	5.7884
777	450.00	7505.7	43450.	5.7889
861	450.00	7489.4	43450.	5.8015
776	450.00	7489.0	43450.	5.8018
882	450.00	-3347.2	43450.	12.981
892	450.00	-3347.2	43450.	12.981
896	450.00	-3341.1	43450.	13.005
879	450.00	-3341.1	43450.	13.005
889	450.00	-3339.1	43450.	13.012
886	450.00	-3339.1	43450.	13.012
883	450.00	-3331.0	43450.	13.044
893	450.00	-3331.0	43450.	13.044
897	450.00	-3323.5	43450.	13.074
880	450.00	-3323.5	43450.	13.074
890	450.00	-3322.1	43450.	13.079
887	450.00	-3322.1	43450.	13.079
884	450.00	-3316.0	43450.	13.103
894	450.00	-3315.9	43450.	13.103
898	450.00	-3306.1	43450.	13.142
881	450.00	-3306.1	43450.	13.142
891	450.00	-3306.1	43450.	13.142
888	450.00	-3306.1	43450.	13.142
885	450.00	-3300.8	43450.	13.163
895	450.00	-3300.8	43450.	13.163
818	450.00	-1374.6	43450.	31.610
819	450.00	-1374.6	43450.	31.610

Table 3.T.23 (continued)

817	450.00	-1372.3	43450.	31.662
820	450.00	-1372.3	43450.	31.662
816	450.00	-1355.8	43450.	32.048
821	450.00	-1355.8	43450.	32.049
815	450.00	-1339.7	43450.	32.434
822	450.00	-1339.6	43450.	32.434
814	450.00	-1323.9	43450.	32.820
823	450.00	-1323.9	43450.	32.820
813	450.00	-1308.4	43450.	33.210
824	450.00	-1308.3	43450.	33.210
812	450.00	-1292.8	43450.	33.609
825	450.00	-1292.8	43450.	33.609
811	450.00	-792.79	43450.	54.807
826	450.00	-792.78	43450.	54.807
827	450.00	-775.86	43450.	56.002
810	450.00	-775.53	43450.	56.026
828	450.00	-759.29	43450.	57.225
809	450.00	-758.63	43450.	57.274
829	450.00	-742.93	43450.	58.485
808	450.00	-741.95	43450.	58.562
830	450.00	-726.66	43450.	59.794
807	450.00	-725.36	43450.	59.902
831	450.00	-710.28	43450.	61.173
806	450.00	-427.83	43450.	101.56
832	450.00	-427.73	43450.	101.58
805	450.00	-426.06	43450.	101.98
833	450.00	-410.81	43450.	105.77
804	450.00	-409.48	43450.	106.11
834	450.00	-394.02	43450.	110.27
803	450.00	-393.03	43450.	110.55
835	450.00	-377.28	43450.	115.17
802	450.00	-376.62	43450.	115.37
836	450.00	-360.51	43450.	120.52
801	450.00	-360.19	43450.	120.63
800	450.00	-133.92	43450.	324.46
837	450.00	-133.91	43450.	324.48
799	450.00	-132.23	43450.	328.59
838	450.00	-132.22	43450.	328.62
798	450.00	-116.57	43450.	372.73
839	450.00	-116.56	43450.	372.76
797	450.00	-100.93	43450.	430.48
840	450.00	-100.93	43450.	430.51
796	450.00	-85.284	43450.	509.47
841	450.00	-85.275	43450.	509.53
795	450.00	-69.601	43450.	624.27
842	450.00	-69.592	43450.	624.35
794	450.00	-53.892	43450.	806.25
843	450.00	-53.883	43450.	806.38

Table 3.T.24

```
TITLE=
MPC-32 Structural Analysis

SUBTITLE  1 =
Component: Basket Supports
SUBTITLE  2 =
Load Combination: E3.c (See Table 3.1.4)
SUBTITLE  3 =
Stress Result: Local Membrane Plus Primary Bending (PL+PB)

PRINT ELEMENT TABLE ITEMS PER ELEMENT
   STAT     CURRENT      MIXED        PREVIOUS     PREVIOUS
   ELEM     REF TEMP     PL+PB         ALLOW         SF
    908   450.00       37983.       65200.       1.7166
    871   450.00       37982.       65200.       1.7166
    907   450.00       36411.       65200.       1.7907
    870   450.00       36410.       65200.       1.7907
    878   450.00       32902.       65200.       1.9816
    901   450.00       32901.       65200.       1.9817
    877   450.00       31789.       65200.       2.0510
    900   450.00       31788.       65200.       2.0511
    891   450.00       23096.       65200.       2.8230
    888   450.00       23096.       65200.       2.8230
    890   450.00       21296.       65200.       3.0616
    887   450.00       21296.       65200.       3.0616
    769   450.00       19595.       65200.       3.3273
    868   450.00       19595.       65200.       3.3273
    819   450.00       19009.       65200.       3.4300
    818   450.00       19009.       65200.       3.4300
    770   450.00       18889.       65200.       3.4518
    867   450.00       18889.       65200.       3.4518
    869   450.00       18567.       65200.       3.5116
    906   450.00       18567.       65200.       3.5116
    820   450.00       18425.       65200.       3.5388
    817   450.00       18424.       65200.       3.5388
    899   450.00       18177.       65200.       3.5870
    876   450.00       18176.       65200.       3.5871
    886   450.00       17450.       65200.       3.7363
    889   450.00       17450.       65200.       3.7363
    844   450.00       17055.       65200.       3.8230
    793   450.00       17054.       65200.       3.8231
    845   450.00       16478.       65200.       3.9568
    792   450.00       16478.       65200.       3.9569
    885   450.00       15349.       65200.       4.2478
    895   450.00       15349.       65200.       4.2478
    884   450.00       14441.       65200.       4.5150
    894   450.00       14441.       65200.       4.5150
    775   450.00       13633.       65200.       4.7825
    862   450.00       13632.       65200.       4.7827
    771   450.00       13478.       65200.       4.8374
    866   450.00       13478.       65200.       4.8374
    774   450.00       13368.       65200.       4.8774
```

Table 3.T.24 (continued)

863	450.00	13367.	65200.	4.8776
882	450.00	13264.	65200.	4.9154
892	450.00	13264.	65200.	4.9155
821	450.00	13079.	65200.	4.9850
816	450.00	13079.	65200.	4.9850
856	450.00	12739.	65200.	5.1183
782	450.00	12737.	65200.	5.1189
811	450.00	12582.	65200.	5.1819
826	450.00	12582.	65200.	5.1820
850	450.00	12575.	65200.	5.1850
787	450.00	12574.	65200.	5.1854
855	450.00	12400.	65200.	5.2579
849	450.00	12388.	65200.	5.2632
788	450.00	12387.	65200.	5.2636
846	450.00	12079.	65200.	5.3979
791	450.00	12079.	65200.	5.3979
781	450.00	11943.	65200.	5.4593
857	450.00	11942.	65200.	5.4595
780	450.00	11652.	65200.	5.5954
773	450.00	11030.	65200.	5.9111
864	450.00	11030.	65200.	5.9113
905	450.00	10797.	65200.	6.0385
875	450.00	10796.	65200.	6.0390
848	450.00	10710.	65200.	6.0878
789	450.00	10710.	65200.	6.0880
904	450.00	10622.	65200.	6.1382
874	450.00	10621.	65200.	6.1387
861	450.00	10308.	65200.	6.3255
776	450.00	10306.	65200.	6.3266
783	450.00	9973.7	65200.	6.5372
854	450.00	9820.2	65200.	6.6394
865	450.00	9789.8	65200.	6.6600
772	450.00	9789.7	65200.	6.6601
902	450.00	9729.9	65200.	6.7010
872	450.00	9728.0	65200.	6.7023
858	450.00	9604.5	65200.	6.7885
903	450.00	9496.1	65200.	6.8660
873	450.00	9494.9	65200.	6.8668
779	450.00	9478.8	65200.	6.8785
790	450.00	9107.5	65200.	7.1590
847	450.00	9107.3	65200.	7.1591
786	450.00	8997.2	65200.	7.2467
851	450.00	8994.4	65200.	7.2489
898	450.00	8914.2	65200.	7.3141
881	450.00	8914.2	65200.	7.3141
777	450.00	8768.0	65200.	7.4361
860	450.00	8746.9	65200.	7.4541
784	450.00	8464.2	65200.	7.7030
859	450.00	8433.7	65200.	7.7309
853	450.00	8409.2	65200.	7.7534
778	450.00	8397.5	65200.	7.7642
880	450.00	8237.9	65200.	7.9146
897	450.00	8237.9	65200.	7.9146

Table 3.T.24 (continued)

807	450.00	8079.4	65200.	8.0699
831	450.00	8079.1	65200.	8.0702
815	450.00	8042.5	65200.	8.1069
822	450.00	8042.5	65200.	8.1069
852	450.00	8040.1	65200.	8.1093
785	450.00	8029.2	65200.	8.1203
830	450.00	7873.6	65200.	8.2809
827	450.00	7550.9	65200.	8.6347
810	450.00	7454.9	65200.	8.7459
896	450.00	7186.9	65200.	9.0720
879	450.00	7186.8	65200.	9.0722
825	450.00	7006.9	65200.	9.3051
812	450.00	7006.8	65200.	9.3052
824	450.00	6681.5	65200.	9.7583
813	450.00	6681.4	65200.	9.7585
832	450.00	6368.0	65200.	10.239
806	450.00	6368.0	65200.	10.239
805	450.00	5986.8	65200.	10.891
893	450.00	5728.2	65200.	11.382
883	450.00	5728.2	65200.	11.382
808	450.00	5657.0	65200.	11.525
829	450.00	5432.7	65200.	12.001
836	450.00	5362.2	65200.	12.159
801	450.00	5361.9	65200.	12.160
802	450.00	4596.2	65200.	14.186
835	450.00	4573.8	65200.	14.255
814	450.00	3433.4	65200.	18.990
823	450.00	3433.3	65200.	18.991
803	450.00	3152.2	65200.	20.684
834	450.00	3079.8	65200.	21.171
828	450.00	3070.8	65200.	21.232
809	450.00	2902.6	65200.	22.463
833	450.00	2804.8	65200.	23.246
804	450.00	2550.3	65200.	25.565
796	450.00	2535.3	65200.	25.717
795	450.00	2535.3	65200.	25.717
841	450.00	2535.2	65200.	25.717
842	450.00	2535.2	65200.	25.717
800	450.00	2355.1	65200.	27.685
837	450.00	2355.0	65200.	27.686
840	450.00	2315.3	65200.	28.161
797	450.00	2315.3	65200.	28.161
794	450.00	2172.4	65200.	30.013
843	450.00	2172.4	65200.	30.013
799	450.00	2107.8	65200.	30.932
838	450.00	2107.7	65200.	30.933
798	450.00	2084.0	65200.	31.286
839	450.00	2083.9	65200.	31.287

APPENDIX 3.U: HI-STORM 100 COMPONENT THERMAL EXPANSIONS; MPC-24

3.U.1 Scope

In this calculation, estimates of operating gaps, both radially and axially, are computed for the fuel basket-to-MPC shell, and for the MPC shell-to-overpack. This calculation is in support of the results presented in Section 3.4.4.2.

3.U.2 Methodology

Bounding temperatures are used to construct temperature distributions that will permit calculation of differential thermal expansions both radially and axially for the basket-to-MPC gaps, and for the MPC-to-overpack gaps. Reference temperatures are set at 70°F for all components. Temperature distributions are computed at the middle of the HI-STORM 100 System where the temperatures are highest. A comprehensive nomenclature listing is provided in Section 3.U.6.

3.U.3 References

[3.U.1] Boley and Weiner, Theory of Thermal Stresses, John Wiley, 1960, Sec. 9.10, pp. 288-291.

[3.U.2] Burgreen, Elements of Thermal Stress Analysis, Arcturus Publishers, Cherry Hill NJ, 1988.

3.U.4 Calculations for Hot Components (Middle of System)

3.U.4.1 Input Data

Based on thermal calculations in Chapter 4, the following temperatures are appropriate at the middle of the cask (see Figure 3.U.1 and Tables 4.4.9).

The temperature change at the overpack inner shell, $\Delta T_{1h} := 169 - 70$

The temperature change at the overpack outer shell, $\Delta T_{2h} := 135 - 70$

The temperature change at the mean radius of the MPC shell, $\Delta T_{3h} := 299 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (439 - 70)\cdot 1.1$

The temperature change at the center of the basket (helium gas), $\Delta T_{5h} := 657 - 70$

Note that the outer basket temperature is conservatively amplified by 10% to insure a bounding parabolic distribution. This conservatism serves to maximize the growth of the basket.

The geometry of the components are as follows (referring to Figure 3.U.1)

The outer radius of the overpack, $b := 66.25 \cdot in$

The minimum inner radius of the overpack, $a := 34.75 \cdot in$

The mean radius of the MPC shell, $R_{mpc} := \dfrac{68.375 \cdot in - 0.5 \cdot in}{2}$ $\quad R_{mpc} = 33.938\,in$

The initial MPC-to-overpack radial clearance, $RC_{mo} := .5 \cdot (69.5 - 68.5) \cdot in$

$RC_{mo} = 0.5\,in$

This initial radial clearance value, used to perform a radial growth check, is conservatively based on the channel radius (see Dwg. 1495, Sh. 5) and the maximum MPC diameter. For axial growth calculations for the MPC-to-overpack lid clearance, the axial length of the overpack is defined as the distance from the top of the pedestal platform to the bottom of the lid bottom plate, and the axial length of the MPC is defined as the overall MPC height.

The axial length of the overpack, $L_{ovp} := 191.5 \cdot in$

The axial length of the MPC, $L_{mpc} := 190.5 \cdot in$

The initial MPC-to-overpack nominal axial clearance, $AC_{mo} := L_{ovp} - L_{mpc}$

$AC_{mo} = 1\,in$

For growth calculations for the fuel basket-to-MPC shell clearances, the axial length of the basket is defined as the total length of the basket and the outer radius of the basket is defined as the mean radius of the MPC shell minus one-half of the shell thickness minus the initial basket-to-shell radial clearance.

The axial length of the basket, $L_{bas} := 176.5 \cdot in$

The initial basket-to-MPC lid nominal axial clearance, $AC_{bm} := 2 \cdot in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875 \cdot in$

The outer radius of the basket, $R_b := R_{mpc} - \dfrac{0.5}{2} \cdot in - RC_{bm}$ $\quad R_b = 33.5\,in$

The coefficients of thermal expansion used in the subsequent calculations are based on the mean temperatures of the MPC shell and the basket (conservatively estimated high).

The coefficient of thermal expansion for the MPC shell, $\alpha_{mpc} := 9.015 \cdot 10^{-6}$

The coefficient of thermal expansion for the basket, $\alpha_{bas} := 9.60 \cdot 10^{-6}$ 600 deg. F

3.U.4.2 Thermal Growth of the Overpack

Results for thermal expansion deformation and stress in the overpack are obtained here. The system is replaced by a equivalent uniform hollow cylinder with approximated average properties.

Based on the given inside and outside surface temperatures, the temperature solution in the cylinder is given in the form:

$$C_a + C_b \cdot \ln\left(\frac{r}{a}\right)$$

where

$$C_a := \Delta T_{1h} \qquad C_a = 99$$

$$C_b := \frac{\Delta T_{2h} - \Delta T_{1h}}{\ln\left(\frac{b}{a}\right)} \qquad C_b = -52.692$$

Next, form the integral relationship:

$$\mathrm{Int} := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\, dr$$

The Mathcad program, which was used to create this appendix, is capable of evaluating the integral "Int" either numerically or symbolically. To demonstrate that the results are equivalent, the integral is evaluated both ways in order to qualify the accuracy of any additional integrations that are needed.

The result obtained through numerical integration, $\mathrm{Int} = 1.248 \times 10^5\, \mathrm{in}^2$

To perform a symbolic evaluation of the solution the integral "Ints" is defined. This integral is then evaluated using the Maple symbolic math engine built into the Mathcad program as:

$$\mathrm{Int}_s := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\, dr$$

$$\mathrm{Int}_s := \frac{1}{2} \cdot C_b \cdot \ln\left(\frac{b}{a}\right) \cdot b^2 + \frac{1}{2} \cdot C_a \cdot b^2 - \frac{1}{4} \cdot C_b \cdot b^2 + \frac{1}{4} \cdot C_b \cdot a^2 - \frac{1}{2} \cdot C_a \cdot a^2$$

$$\mathrm{Int}_s = 1.248 \times 10^5\, \mathrm{in}^2$$

We note that the values of Int and Ints are identical. The average temperature in the overpack cylinder (T_{bar}) is therefore determined as:

$$T_{bar} := \frac{2}{\left(b^2 - a^2\right)} \cdot Int \qquad T_{bar} = 78.441$$

We estimate the average coefficient of thermal expansion for the overpack by weighting the volume of the various layers. A total of four layers are identified for this calculation. They are:

1) the inner shell
2) the shield shell
3) the radial shield
4) the outer shell

Thermal properties are based on estimated temperatures in the component and coefficient of thermal expansion values taken from the tables in Chapter 3. The following averaging calculation involves the thicknesses (t) of the various components, and the estimated coefficients of thermal expansion at the components' mean radial positions. The results of the weighted average process yields an effective coefficient of linear thermal expansion for use in computing radial growth of a solid cylinder (the overpack).

The thicknesses of each component are defined as:

$$t_1 := 1.25 \cdot in$$

$$t_2 := 0.75 \cdot in$$

$$t_3 := 26.75 \cdot in$$

$$t_4 := 0.75 \cdot in$$

and the corresponding mean radii can therefore be defined as:

$$r_1 := a + .5 \cdot t_1 + 2.0 \cdot in \qquad \text{(add the channel depth)}$$

$$r_2 := r_1 + .5 \cdot t_1 + .5 \cdot t_2$$

$$r_3 := r_2 + .5 \cdot t_2 + .5 \cdot t_3$$

$$r_4 := r_3 + .5 \cdot t_3 + .5 \cdot t_4$$

To check the accuracy of these calculations, the outer radius of the overpack is calculated from r_4 and t_4, and the result is compared with the previously defined value (b).

$$b_l := r_4 + 0.5 \cdot t_4$$

$$b_l = 66.25\,\text{in}$$

$$b = 66.25\,\text{in}$$

We note that the calculated value b_l is identical to the previously defined value b. The coefficients of thermal expansion for each component, estimated based on the temperature gradient, are defined as:

$$\alpha_l := 5.782 \cdot 10^{-6}$$

$$\alpha_2 := 5.782 \cdot 10^{-6}$$

$$\alpha_3 := 5.5 \cdot 10^{-6}$$

$$\alpha_4 := 5.638 \cdot 10^{-6}$$

Thus, the average coefficient of thermal expansion of the overpack is determined as:

$$\alpha_{avg} := \frac{r_l \cdot t_l \cdot \alpha_l + r_2 \cdot t_2 \cdot \alpha_2 + r_3 \cdot t_3 \cdot \alpha_3 + r_4 \cdot t_4 \cdot \alpha_4}{\frac{a+b}{2} \cdot \left(t_l + t_2 + t_3 + t_4\right)}$$

$$\alpha_{avg} = 5.628 \times 10^{-6}$$

Reference 3.U.1 gives an expression for the radial deformation due to thermal growth. At the inner radius of the overpack (r = a), the radial growth is determined as:

$$\Delta R_{ah} := \alpha_{avg} \cdot a \cdot T_{bar}$$

$$\Delta R_{ah} = 0.015\,\text{in}$$

Similarly, an overestimate of the axial growth of the overpack can be determined by applying the average temperature (T_{bar}) over the entire length of the overpack as:

$$\Delta L_{ovph} := L_{ovp} \cdot \alpha_{avg} \cdot T_{bar}$$

$$\Delta L_{ovph} = 0.085\,\text{in}$$

Estimates of the secondary thermal stresses that develop in the overpack due to the radial temperature variation are determined using a conservatively high value of E as based on the temperature of the steel. The circumferential stress at the inner and outer surfaces (σ_{ca} and σ_{cb}, respectively) are determined as:

The Young's Modulus of the material, $E := 28300000 \cdot \text{psi}$

$$\sigma_{ca} := \alpha_{avg} \cdot \frac{E}{a^2} \cdot \left[2 \cdot \frac{a^2}{\left(b^2 - a^2\right)} \cdot \text{Int} - \left(C_a\right) \cdot a^2 \right]$$

$$\sigma_{ca} = -3274\,\text{psi}$$

$$\sigma_{cb} := \alpha_{avg} \cdot \frac{E}{b^2} \cdot \left[2 \cdot \frac{b^2}{\left(b^2 - a^2\right)} \cdot \text{Int} - \left[C_a + C_b \cdot \left(\ln\left(\frac{b}{a}\right)\right)\right] \cdot b^2 \right]$$

$$\sigma_{cb} = 2141\,\text{psi}$$

The radial stress due to the temperature gradient is zero at both the inner and outer surfaces of the overpack. The radius where a maximum radial stress is expected, and the corresponding radial stress, are determined by trial and error as:

$$N := 0.37$$

$$r := a \cdot (1 - N) + N \cdot b$$

$$r = 46.405\,\text{in}$$

$$\sigma_r := \alpha_{avg} \cdot \frac{E}{r^2} \cdot \left[\frac{r^2 - a^2}{2} \cdot T_{bar} - \int_a^r \left[C_a + C_b \cdot \left(\ln\left(\frac{y}{a}\right)\right)\right] \cdot y\,dy \right]$$

$$\sigma_r = -427.015\,\text{psi}$$

The axial stress developed due to the temperature gradient is equal to the sum of the radial and tangential stresses at any radial location. (see eq. 9.10.7) of [3.U.1]. Therefore, the axial stresses are available from the above calculations. The stress intensities in the overpack due to the temperature distribution are below the Level A membrane stress.

3.U.4.3 Thermal Growth of the MPC Shell

The radial and axial growth of the MPC shell (ΔR_{mpch} and ΔL_{mpch}, respectively) are determined as:

$$\Delta R_{mpch} := \alpha_{mpc} \cdot R_{mpc} \cdot \Delta T_{3h} \qquad \Delta R_{mpch} = 0.07\,\text{in}$$

$$\Delta L_{mpch} := \alpha_{mpc} \cdot L_{mpc} \cdot \Delta T_{3h} \qquad \Delta L_{mpch} = 0.393\,\text{in}$$

3.U.4.4 Clearances Between the MPC Shell and Overpack

The final radial and axial MPC shell-to-overpack clearances (RG_{moh} and AG_{moh}, respectively) are determined as:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch}$$

$$RG_{moh} = 0.445\,\text{in}$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch}$$

$$AG_{moh} = 0.691\,\text{in}$$

Note that this axial clearance (AG_{moh}) is based on the temperature distribution at the middle of the system.

3.U.4.5 Thermal Growth of the MPC-24 Basket

Using formulas given in [3.U.2] for a solid body of revolution, and assuming a parabolic temperature distribution in the radial direction with the center and outer temperatures given previously, the following relationships can be developed for free thermal growth.

Define $\Delta T_{bas} := \Delta T_{5h} - \Delta T_{4h}$ $\Delta T_{bas} = 181.1$

Then the mean temperature can be defined as $T_{bar} := \frac{2}{R_b^2} \cdot \int_0^{R_b} \left(\Delta T_{5h} - \Delta T_{bas} \cdot \frac{r^2}{R_b^2} \right) \cdot r\,dr$

Using the Maple symbolic engine again, the closed form solution of the integral is:

$$T_{bar} := \frac{2}{R_b^2} \cdot \left(\frac{-1}{4} \cdot \Delta T_{bas} \cdot R_b^2 + \frac{1}{2} \cdot \Delta T_{5h} \cdot R_b^2 \right)$$

$$T_{bar} = 496.45$$

The corresponding radial growth at the periphery (ΔR_{bh}) is therefore determined as:

$$\Delta R_{bh} := \alpha_{bas} \cdot R_b \cdot T_{bar}$$

$$\Delta R_{bh} = 0.16\,\text{in}$$

and the corresponding axial growth (ΔL_{bas}) is determined from [3.U.2] as:

$$\Delta L_{bh} := \Delta R_{bh} \cdot \frac{L_{bas}}{R_b}$$

$$\Delta L_{bh} = 0.841\,\text{in}$$

Note that the coefficient of thermal expansion for the hottest basket temperature has been used, and the results are therefore conservative.

3.U.4.6 Clearances Between the Fuel Basket and MPC Shell

The final radial and axial fuel basket-to-MPC shell and lid clearances (RG_{bmh} and AG_{bmh}, respectively) are determined as:

$$RG_{bmh} := RC_{bm} - \Delta R_{bh} + \Delta R_{mpch}$$

$$RG_{bmh} = 0.098\,\text{in}$$

$$AG_{bmh} := AC_{bm} - \Delta L_{bh} + \Delta L_{mpch}$$

$$AG_{bmh} = 1.552\,\text{in}$$

3.U.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-Overpack	Fuel Basket-to-MPC Shell
$RG_{moh} = 0.445\,\text{in}$	$RG_{bmh} = 0.098\,\text{in}$
$AG_{moh} = 0.691\,\text{in}$	$AG_{bmh} = 1.552\,\text{in}$

3.U.6 Nomenclature

a is the inner radius of the overpack

AC_{bm} is the initial fuel basket-to-MPC axial clearance.

AC_{mo} is the initial MPC-to-overpack axial clearance.

AG_{bmh} is the final fuel basket-to-MPC shell axial gap for the hot components.

AG_{moh} is the final MPC shell-to-overpack axial gap for the hot components.

b is the outer radius of the overpack.

L_{bas} is the axial length of the fuel basket.

L_{mpc} is the axial length of the MPC.

L_{ovp} is the axial length of the overpack.

r_1 (r_2,r_3,r_4) is mean radius of the overpack inner shell (shield shell, concrete, outer shell).

R_b is the outer radius of the fuel basket.

R_{mpc} is the mean radius of the MPC shell.

RC_{bm} is the initial fuel basket-to-MPC radial clearance.

RC_{mo} is the initial MPC shell-to-overpack radial clearance.

RG_{bmh} is the final fuel basket-to-MPC shell radial gap for the hot components.

RG_{moh} is the final MPC shell-to-overpack radial gap for the hot components.

t_1 (t_2,t_3,t_4) is the thickness of the overpack inner shell (shield shell, concrete, outer shell).

T_{bar} is the average temperature of the overpack cylinder.

α_1 (α_2,α_3,α_4) is the coefficient of thermal expansion of the overpack inner shell (shield shell, concrete, outer shell).

α_{avg} is the average coefficient of thermal expansion of the overpack.

α_{bas} is the coefficient of thermal expansion of the overpack.

α_{mpc} is the coefficient of thermal expansion of the MPC.

ΔL_{bh} is the axial growth of the fuel basket for the hot components.

ΔL_{mpch} the the axial growth of the MPC for the hot components.

ΔL_{ovph} is the axial growth of the overpack for the hot components.

ΔR_{ah} is the radial growth of the overpack inner radius for the hot components.

ΔR_{bh} is the radial growth of the fuel basket for the hot components.

ΔR_{mpch} is the radial growth of the MPC shell for the hot components.

ΔT_{1h} is the temperature change at the overpack inner shell for hot components.

ΔT_{2h} is the temperature change at the overpack outer shell for hot components.

ΔT_{3h} is the temperature change at the MPC shell mean radius for hot components.

ΔT_{4h} is the temperature change at the MPC basket periphery for hot components.

ΔT_{5h} is the temperature change at the MPC basket centerline for hot components.

ΔT_{bas} is the fuel basket centerline-to-periphery temperature gradient.

σ_{ca} is the circumferential stress at the overpack inner surface.

σ_{cb} is the circumferential stress at the overpack outer surface.

σ_r is the maximum radial stress of the overpack.

σ_{zi} is the axial stress at the fuel basket centerline.

σ_{zo} is the axial stress at the fuel basket periphery.

APPENDIX 3.V: HI-STORM 100 COMPONENT THERMAL EXPANSIONS; MPC-32

3.V.1 Scope

In this calculation, estimates of operating gaps, both radially and axially, are computed for the fuel basket-to-MPC shell, and for the MPC shell-to-overpack. This calculation is in support of the results presented in Section 3.4.4.2.

3.V.2 Methodology

Bounding temperatures are used to construct temperature distributions that will permit calculation of differential thermal expansions both radially and axially for the basket-to-MPC gaps, and for the MPC-to-overpack gaps. Reference temperatures are set at 70°F for all components. Temperature distributions are computed at the middle of the HI-STORM 100 System where the temperatures are highest. A comprehensive nomenclature listing is provided in Section 3.V.6.

3.V.3 References

[3.V.1] Boley and Weiner, Theory of Thermal Stresses, John Wiley, 1960, Sec. 9.10, pp. 288-291.

[3.V.2] Burgreen, Elements of Thermal Stress Analysis, Arcturus Publishers, Cherry Hill NJ, 1988.

3.V.4 Calculations for Hot Components (Middle of System)

3.V.4.1 Input Data

Based on thermal calculations in Chapter 4, the following temperatures are appropriate at the middle of the cask (see Figure 3.V.1 and Tables 4.4.26).

The temperature change at the overpack inner shell, $\Delta T_{1h} := 169 - 70$

The temperature change at the overpack outer shell, $\Delta T_{2h} := 135 - 70$

The temperature change at the mean radius of the MPC shell, $\Delta T_{3h} := 297 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (379 - 70) \cdot 1.1$

The temperature change at the center of the basket (helium gas), $\Delta T_{5h} := 667 - 70$

Note that the outer basket temperature is conservatively amplified by 10% to insure a bounding parabolic distribution. This conservatism serves to maximize the growth of the basket.

The geometry of the components are as follows (refering to Figure 3.V.1)

The outer radius of the overpack, $b := 66.25 \cdot in$

The inner radius of the overpack, $a := 34.75 \cdot in$

The mean radius of the MPC shell, $R_{mpc} := \dfrac{68.375 \cdot in - 0.5 \cdot in}{2}$ $R_{mpc} = 33.938\,in$

The initial MPC-to-overpack nominal radial clearance, $RC_{mo} := .5 \cdot (69.5 - 68.5) \cdot in$

$RC_{mo} = 0.5\,in$

This initial radial clearance value, used to perform a radial growth check, is conservatively based on the channel radius and the maximum MPC diameter. For axial growth calculations for the MPC-to-overpack lid clearance, the axial length of the overpack is defined as the distance from the top of the pedestal platform to the bottom of the lid bottom plate, and the axial length of the MPC is defined as the overall MPC height.

The axial length of the overpack, $L_{ovp} := 191.5 \cdot in$

The axial length of the MPC, $L_{mpc} := 190.5 \cdot in$

The initial MPC-to-overpack nominal axial clearance, $AC_{mo} := L_{ovp} - L_{mpc}$

$AC_{mo} = 1\,in$

For growth calculations for the fuel basket-to-MPC shell clearances, the axial length of the basket is defined as the total length of the basket and the outer radius of the basket is defined as the mean radius of the MPC shell minus one-half of the shell thickness minus the initial basket-to-shell radial clearance.

The axial length of the basket, $L_{bas} := 176.5 \cdot in$

The initial basket-to-MPC lid nominal axial clearance, $AC_{bm} := 2 \cdot in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875 \cdot in$

The outer radius of the basket, $R_b := R_{mpc} - \dfrac{0.5}{2} \cdot in - RC_{bm}$ $R_b = 33.5\,in$

The coefficients of thermal expansion used in the subsequent calculations are based on the mean temperatures of the MPC shell and the basket (conservatively estimated high).

The coefficient of thermal expansion for the MPC shell, $\alpha_{mpc} := 9.015 \cdot 10^{-6}$

The coefficient of thermal expansion for the basket, $\alpha_{bas} := 9.60 \cdot 10^{-6}$ 600 deg. F

3.V.4.2 Thermal Growth of the Overpack

Results for thermal expansion deformation and stress in the overpack are obtained here. The system is replaced by a equivalent uniform hollow cylinder with approximated average properties.

Based on the given inside and outside surface temperatures, the temperature solution in the cylinder is given in the form:

$$C_a + C_b \cdot \ln\left(\frac{r}{a}\right)$$

wher-
e

$$C_a := \Delta T_{1h} \qquad C_a = 99$$

$$C_b := \frac{\Delta T_{2h} - \Delta T_{1h}}{\ln\left(\frac{b}{a}\right)} \qquad C_b = -52.692$$

Next, form the integral relationship:

$$\mathrm{Int} := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\, dr$$

The Mathcad program, which was used to create this appendix, is capable of evaluating the integral "Int" either numerically or symbolically. To demonstrate that the results are equivalent, the integral is evaluated both ways in order to qualify the accuracy of any additional integrations that are needed.

The result obtained through numerical integration, $\mathrm{Int} = 1.248 \times 10^5\,\mathrm{in}^2$

To perform a symbolic evaluation of the solution the integral "Ints" is defined. This integral is then evaluated using the Maple symbolic math engine built into the Mathcad program as:

$$\mathrm{Int}_s := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\, dr$$

$$\mathrm{Int}_s := \frac{1}{2} \cdot C_b \cdot \ln\left(\frac{b}{a}\right) \cdot b^2 + \frac{1}{2} \cdot C_a \cdot b^2 - \frac{1}{4} \cdot C_b \cdot b^2 + \frac{1}{4} \cdot C_b \cdot a^2 - \frac{1}{2} \cdot C_a \cdot a^2$$

$$\mathrm{Int}_s = 1.248 \times 10^5\,\mathrm{in}^2$$

We note that the values of Int and Ints are identical. The average temperature in the overpack cylinder (T_{bar}) is therefore determined as:

$$T_{bar} := \frac{2}{\left(b^2 - a^2\right)} \cdot Int \qquad T_{bar} = 78.441$$

We estimate the average coefficient of thermal expansion for the overpack by weighting the volume of the various layers. A total of four layers are identified for this calculation. They are:

1) the inner shell
2) the shield shell
3) the radial shield
4) the outer shell

Thermal properties are based on estimated temperatures in the component and coefficient of thermal expansion values taken from the tables in Chapter 3. The following averaging calculation involves the thicknesses (t) of the various components, and the estimated coefficients of thermal expansion at the components' mean radial positions. The results of the weighted average process yields an effective coefficient of linear thermal expansion for use in computing radial growth of a solid cylinder (the overpack).

The thicknesses of each component are defined as:

$$t_1 := 1.25 \cdot in$$

$$t_2 := 0.75 \cdot in$$

$$t_3 := 26.75 \cdot in$$

$$t_4 := 0.75 \cdot in$$

and the corresponding mean radii can therefore be defined as:

$$r_1 := a + .5 \cdot t_1 + 2 \cdot in$$

$$r_2 := r_1 + .5 \cdot t_1 + .5 \cdot t_2$$

$$r_3 := r_2 + .5 \cdot t_2 + .5 \cdot t_3$$

$$r_4 := r_3 + .5 \cdot t_3 + .5 \cdot t_4$$

To check the accuracy of these calculations, the outer radius of the overpack is calculated from r_4 and t_4, and the result is compared with the previously defined value (b).

$$b_l := r_4 + 0.5 \cdot t_4$$

$$b_l = 66.25\,\text{in}$$

$$b = 66.25\,\text{in}$$

We note that the calculated value b_l is identical to the previously defined value b. The coefficient thermal expansion for each component, estimated based on the temperature gradient, are defined

$$\alpha_1 := 5.782 \cdot 10^{-6}$$

$$\alpha_2 := 5.782 \cdot 10^{-6}$$

$$\alpha_3 := 5.5 \cdot 10^{-6}$$

$$\alpha_4 := 5.638 \cdot 10^{-6}$$

Thus, the average coefficient of thermal expansion of the overpack is determined as:

$$\alpha_{avg} := \frac{r_1 \cdot t_1 \cdot \alpha_1 + r_2 \cdot t_2 \cdot \alpha_2 + r_3 \cdot t_3 \cdot \alpha_3 + r_4 \cdot t_4 \cdot \alpha_4}{\frac{a+b}{2} \cdot \left(t_1 + t_2 + t_3 + t_4\right)}$$

$$\alpha_{avg} = 5.628 \times 10^{-6}$$

Reference 3.V.1 gives an expression for the radial deformation due to thermal growth. At the inner radius of the overpack (r = a), the radial growth is determined as:

$$\Delta R_{ah} := \alpha_{avg} \cdot a \cdot T_{bar}$$

$$\Delta R_{ah} = 0.015\,\text{in}$$

Similarly, an overestimate of the axial growth of the overpack can be determined by applying the average temperature (T_{bar}) over the entire length of the overpack as:

$$\Delta L_{ovph} := L_{ovp} \cdot \alpha_{avg} \cdot T_{bar}$$

$$\Delta L_{ovph} = 0.085\,\text{in}$$

Estimates of the secondary thermal stresses that develop in the overpack due to the radial temperature variation are determined using a conservatively high value of E as based on the temperature of the steel. The circumferential stress at the inner and outer surfaces (σ_{ca} and σ_{cb}, respectively) are determined as:

The Young's Modulus of the material, $E := 28300000 \cdot \text{psi}$

$$\sigma_{ca} := \alpha_{avg} \cdot \frac{E}{a^2} \cdot \left[2 \cdot \frac{a^2}{\left(b^2 - a^2\right)} \cdot Int - \left(C_a\right) \cdot a^2 \right]$$

$$\sigma_{ca} = -3274\,psi$$

$$\sigma_{cb} := \alpha_{avg} \cdot \frac{E}{b^2} \cdot \left[2 \cdot \frac{b^2}{\left(b^2 - a^2\right)} \cdot Int - \left[C_a + C_b \cdot \left(\ln\left(\frac{b}{a}\right)\right) \right] \cdot b^2 \right]$$

$$\sigma_{cb} = 2141\,psi$$

The radial stress due to the temperature gradient is zero at both the inner and outer surfaces of the overpack. The radius where a maximum radial stress is expected, and the corresponding radial stress, are determined by trial and error as:

$$N := 0.37$$

$$r := a \cdot (1 - N) + N \cdot b$$

$$r = 46.405\,in$$

$$\sigma_r := \alpha_{avg} \cdot \frac{E}{r^2} \cdot \left[\frac{r^2 - a^2}{2} \cdot T_{bar} - \int_a^r \left[C_a + C_b \cdot \left(\ln\left(\frac{y}{a}\right)\right) \right] \cdot y \, dy \right]$$

$$\sigma_r = -427.015\,psi$$

The axial stress developed due to the temperature gradient is equal to the sum of the radial and tangential stresses at any radial location. (see eq. 9.10.7) of [3.V.1]. Therefore, the axial stresses are available from the above calculations. The stress intensities in the overpack due to the temperature distribution are below the Level A membrane stress.

3.V.4.3 Thermal Growth of the MPC Shell

The radial and axial growth of the MPC shell (ΔR_{mpch} and ΔL_{mpch}, respectively) are determined as:

$$\Delta R_{mpch} := \alpha_{mpc} \cdot R_{mpc} \cdot \Delta T_{3h} \qquad \Delta R_{mpch} = 0.069\,in$$

$$\Delta L_{mpch} := \alpha_{mpc} \cdot L_{mpc} \cdot \Delta T_{3h} \qquad \Delta L_{mpch} = 0.39\,in$$

3.V.4.4 Clearances Between the MPC Shell and Overpack

The final radial and axial MPC shell-to-overpack clearances (RG_{moh} and AG_{moh}, respectively) are determined as:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch}$$

$$RG_{moh} = 0.446\,\text{in}$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch}$$

$$AG_{moh} = 0.695\,\text{in}$$

Note that this axial clearance (AG_{moh}) is based on the temperature distribution at the middle of the system.

3.V.4.5 Thermal Growth of the MPC-32 Basket

Using formulas given in [3.V.2] for a solid body of revolution, and assuming a parabolic temperature distribution in the radial direction with the center and outer temperatures given previously, the following relationships can be developed for free thermal growth.

Define $\Delta T_{bas} := \Delta T_{5h} - \Delta T_{4h}$ $\quad \Delta T_{bas} = 257.1$

Then the mean temperature can be defined as $T_{bar} := \frac{2}{R_b^2} \cdot \int_0^{R_b} \left(\Delta T_{5h} - \Delta T_{bas} \cdot \frac{r^2}{R_b^2} \right) \cdot r\,dr$

Using the Maple symbolic engine again, the closed form solution of the integral is:

$$T_{bar} := \frac{2}{R_b^2} \cdot \left(\frac{-1}{4} \cdot \Delta T_{bas} \cdot R_b^2 + \frac{1}{2} \cdot \Delta T_{5h} \cdot R_b^2 \right)$$

$$T_{bar} = 468.45$$

The corresponding radial growth at the periphery (ΔR_{bh}) is therefore determined as:

$$\Delta R_{bh} := \alpha_{bas} \cdot R_b \cdot T_{bar}$$

$$\Delta R_{bh} = 0.151\,\text{in}$$

and the corresponding axial growth (ΔL_{bas}) is determined from [3.V.2] as:

$$\Delta L_{bh} := \Delta R_{bh} \cdot \frac{L_{bas}}{R_b}$$

$$\Delta L_{bh} = 0.794\,\text{in}$$

Note that the coefficient of thermal expansion for the hottest basket temperature has been used, and the results are therefore conservative.

3.V.4.6 Clearances Between the Fuel Basket and MPC Shell

The final radial and axial fuel basket-to-MPC shell and lid clearances (RG_{bmh} and AG_{bmh}, respectively) are determined as:

$$RG_{bmh} := RC_{bm} - \Delta R_{bh} + \Delta R_{mpch}$$

$$RG_{bmh} = 0.106\,\text{in}$$

$$AG_{bmh} := AC_{bm} - \Delta L_{bh} + \Delta L_{mpch}$$

$$AG_{bmh} = 1.596\,\text{in}$$

3.V.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-Overpack	Fuel Basket-to-MPC Shell
$RG_{moh} = 0.446\,\text{in}$	$RG_{bmh} = 0.106\,\text{in}$
$AG_{moh} = 0.695\,\text{in}$	$AG_{bmh} = 1.596\,\text{in}$

3.V.6 Nomenclature

a is the inner radius of the overpack
AC_{bm} is the initial fuel basket-to-MPC axial clearance.
AC_{mo} is the initial MPC-to-overpack axial clearance.
AG_{bmh} is the final fuel basket-to-MPC shell axial gap for the hot components.
AG_{moh} is the final MPC shell-to-overpack axial gap for the hot components.
b is the outer radius of the overpack.
L_{bas} is the axial length of the fuel basket.
L_{mpc} is the axial length of the MPC.
L_{ovp} is the axial length of the overpack.
r_1 (r_2,r_3,r_4) is mean radius of the overpack inner shell (shield shell, concrete, outer shell).
R_b is the outer radius of the fuel basket.
R_{mpc} is the mean radius of the MPC shell.
RC_{bm} is the initial fuel basket-to-MPC radial clearance.
RC_{mo} is the initial MPC shell-to-overpack radial clearance.
RG_{bmh} is the final fuel basket-to-MPC shell radial gap for the hot components.
RG_{moh} is the final MPC shell-to-overpack radial gap for the hot components.
t_1 (t_2,t_3,t_4) is the thickness of the overpack inner shell (shield shell, concrete, outer shell).
T_{bar} is the average temperature of the overpack cylinder.
α_1 (α_2,α_3,α_4) is the coefficient of thermal expansion of the overpack inner shell (shield shell, concrete, outer shell).
α_{avg} is the average coefficient of thermal expansion of the overpack.
α_{bas} is the coefficient of thermal expansion of the overpack.
α_{mpc} is the coefficient of thermal expansion of the MPC.
ΔL_{bh} is the axial growth of the fuel basket for the hot components.

ΔL_{mpch} the the axial growth of the MPC for the hot components.

ΔL_{ovph} is the axial growth of the overpack for the hot components.

ΔR_{ah} is the radial growth of the overpack inner radius for the hot components.

ΔR_{bh} is the radial growth of the fuel basket for the hot components.

ΔR_{mpch} is the radial growth of the MPC shell for the hot components.

ΔT_{1h} is the temperature change at the overpack inner shell for hot components.

ΔT_{2h} is the temperature change at the overpack outer shell for hot components.

ΔT_{3h} is the temperature change at the MPC shell mean radius for hot components.

ΔT_{4h} is the temperature change at the MPC basket periphery for hot components.

ΔT_{5h} is the temperature change at the MPC basket centerline for hot components.

ΔT_{bas} is the fuel basket centerline-to-periphery temperature gradient.

σ_{ca} is the circumferential stress at the overpack inner surface.

σ_{cb} is the circumferential stress at the overpack outer surface.

σ_r is the maximum radial stress of the overpack.

σ_{zi} is the axial stress at the fuel basket centerline.

σ_{zo} is the axial stress at the fuel basket periphery.

APPENDIX 3.W: HI-STORM 100 COMPONENT THERMAL EXPANSIONS; MPC-68

3.W.1 Scope

In this calculation, estimates of operating gaps, both radially and axially, are computed for the fuel basket-to-MPC shell, and for the MPC shell-to-overpack. This calculation is in support of the results presented in Section 3.4.4.2.

3.W.2 Methodology

Bounding temperatures are used to construct temperature distributions that will permit calculation of differential thermal expansions both radially and axially for the basket-to-MPC gaps, and for the MPC-to-overpack gaps. Reference temperatures are set at 70°F for all components. Temperature distributions are computed at the middle of the HI-STORM 100 System where the temperatures are highest. A comprehensive nomenclature listing is provided in Section 3.W.6.

3.W.3 References

[3.W.1] Boley and Weiner, Theory of Thermal Stresses, John Wiley, 1960, Sec. 9.10, pp. 288-291.

[3.W.2] Burgreen, Elements of Thermal Stress Analysis, Arcturus Publishers, Cherry Hill NJ, 1988.

3.W.4 Calculations for Hot Components (Middle of System)

3.W.4.1 Input Data

Based on thermal calculations in Chapter 4, the following temperatures are appropriate at the middle of the cask (see Figure 3.W.1 and Tables 4.4.10).

The temperature change at the overpack inner shell, $\Delta T_{1h} := 184 - 70$

The temperature change at the overpack outer shell, $\Delta T_{2h} := 139 - 70$

The temperature change at the mean radius of the MPC shell, $\Delta T_{3h} := 326 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (404 - 70)\cdot 1.1$

The temperature change at the center of the basket (helium gas), $\Delta T_{5h} := 722 - 70$

Note that the outer basket temperature is conservatively amplified by 10% to insure a bounding parabolic distribution. This conservatism serves to maximize the growth of the basket.
The geometry of the components are as follows (referring to Figure 3.W.1)

The outer radius of the overpack, $b := 66.25 \cdot in$

The inner radius of the overpack, $a := 34.75 \cdot in$

The mean radius of the MPC shell, $R_{mpc} := \dfrac{68.375 \cdot in - 0.5 \cdot in}{2}$ $\qquad R_{mpc} = 33.938\,in$

The initial MPC-to-overpack nominal radial clearance, $RC_{mo} := .5 \cdot (69.5 - 68.5) \cdot in$

$RC_{mo} = 0.5\,in$

This initial radial clearance value, used to perform a radial growth check, is conservatively based on the channel radius (see Dwg. 1495, Sh. 5) and the maximum MPC diameter. For axial growth calculations for the MPC-to-overpack lid clearance, the axial length of the overpack is defined as the distance from the top of the pedestal platform to the bottom of the lid bottom plate, and the axial length of the MPC is defined as the overall MPC height.

The axial length of the overpack, $L_{ovp} := 191.5 \cdot in$

The axial length of the MPC, $L_{mpc} := 190.5 \cdot in$

The initial MPC-to-overpack nominal axial clearance, $AC_{mo} := L_{ovp} - L_{mpc}$

$AC_{mo} = 1\,in$

For growth calculations for the fuel basket-to-MPC shell clearances, the axial length of the basket is defined as the total length of the basket and the outer radius of the basket is defined as the mean radius of the MPC shell minus one-half of the shell thickness minus the initial basket-to-shell radial clearance.

The axial length of the basket, $L_{bas} := 176.5 \cdot in$

The initial basket-to-MPC lid nominal axial clearance, $AC_{bm} := 2 \cdot in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875 \cdot in$

The outer radius of the basket, $R_b := R_{mpc} - \dfrac{0.5}{2} \cdot in - RC_{bm}$ $\qquad R_b = 33.5\,in$

The coefficients of thermal expansion used in the subsequent calculations are based on the mean temperatures of the MPC shell and the basket (conservatively estimated high).

The coefficient of thermal expansion for the MPC shell, $\alpha_{mpc} := 9.015 \cdot 10^{-6}$

The coefficient of thermal expansion for the basket, $\alpha_{bas} := 9.60 \cdot 10^{-6}$ 600 deg. F

3.W.4.2 Thermal Growth of the Overpack

Results for thermal expansion deformation and stress in the overpack are obtained here. The system is replaced by a equivalent uniform hollow cylinder with approximated average properties.

Based on the given inside and outside surface temperatures, the temperature solution in the cylinder is given in the form:

$$C_a + C_b \cdot \ln\left(\frac{r}{a}\right)$$

where

$$C_a := \Delta T_{1h} \qquad C_a = 114$$

$$C_b := \frac{\Delta T_{2h} - \Delta T_{1h}}{\ln\left(\frac{b}{a}\right)} \qquad C_b = -69.74$$

Next, form the integral relationship:

$$\mathrm{Int} := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\,dr$$

The Mathcad program, which was used to create this appendix, is capable of evaluating the integral "Int" either numerically or symbolically. To demonstrate that the results are equivalent, the integral is evaluated both ways in order to qualify the accuracy of any additional integrations that are needed.

The result obtained through numerical integration, $\mathrm{Int} = 1.381 \times 10^5\,\mathrm{in}^2$

To perform a symbolic evaluation of the solution the integral "Ints" is defined. This integral is then evaluated using the Maple symbolic math engine built into the Mathcad program as:

$$\mathrm{Int_s} := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\,dr$$

$$\mathrm{Int_s} := \frac{1}{2} \cdot C_b \cdot \ln\left(\frac{b}{a}\right) \cdot b^2 + \frac{1}{2} \cdot C_a \cdot b^2 - \frac{1}{4} \cdot C_b \cdot b^2 + \frac{1}{4} \cdot C_b \cdot a^2 - \frac{1}{2} \cdot C_a \cdot a^2$$

$$\mathrm{Int_s} = 1.381 \times 10^5\,\mathrm{in}^2$$

We note that the values of Int and Ints are identical. The average temperature in the overpack cylinder (T_{bar}) is therefore determined as:

$$T_{bar} := \frac{2}{\left(b^2 - a^2\right)} \cdot Int \qquad T_{bar} = 86.79$$

We estimate the average coefficient of thermal expansion for the overpack by weighting the volume of the various layers. A total of four layers are identified for this calculation. They are:

1) the inner shell
2) the shield shell
3) the radial shield
4) the outer shell

Thermal properties are based on estimated temperatures in the component and coefficient of thermal expansion values taken from the tables in Chapter 3. The following averaging calculation involves the thicknesses (t) of the various components, and the estimated coefficients of thermal expansion at the components' mean radial positions. The results of the weighted average process yields an effective coefficient of linear thermal expansion for use in computing radial growth of a solid cylinder (the overpack).

The thicknesses of each component are defined as:

$$t_1 := 1.25 \cdot in$$

$$t_2 := 0.75 \cdot in$$

$$t_3 := 26.75 \cdot in$$

$$t_4 := 0.75 \cdot in$$

and the corresponding mean radii can therefore be defined as:

$$r_1 := a + .5 \cdot t_1 + 2.0 \cdot in \qquad \text{(add the channel depth)}$$

$$r_2 := r_1 + .5 \cdot t_1 + .5 \cdot t_2$$

$$r_3 := r_2 + .5 \cdot t_2 + .5 \cdot t_3$$

$$r_4 := r_3 + .5 \cdot t_3 + .5 \cdot t_4$$

To check the accuracy of these calculations, the outer radius of the overpack is calculated from r_4 and t_4, and the result is compared with the previously defined value (b).

$$b_l := r_4 + 0.5 \cdot t_4$$

$$b_l = 66.25\,\text{in}$$

$$b = 66.25\,\text{in}$$

We note that the calculated value b_l is identical to the previously defined value b. The coefficients of thermal expansion for each component, estimated based on the temperature gradient, are defined as:

$$\alpha_l := 5.782 \cdot 10^{-6}$$

$$\alpha_2 := 5.782 \cdot 10^{-6}$$

$$\alpha_3 := 5.5 \cdot 10^{-6}$$

$$\alpha_4 := 5.638 \cdot 10^{-6}$$

Thus, the average coefficient of thermal expansion of the overpack is determined as:

$$\alpha_{avg} := \frac{r_l \cdot t_l \cdot \alpha_l + r_2 \cdot t_2 \cdot \alpha_2 + r_3 \cdot t_3 \cdot \alpha_3 + r_4 \cdot t_4 \cdot \alpha_4}{\frac{a+b}{2} \cdot \left(t_l + t_2 + t_3 + t_4\right)}$$

$$\alpha_{avg} = 5.628 \times 10^{-6}$$

Reference 3.W.1 gives an expression for the radial deformation due to thermal growth. At the inner radius of the overpack (r = a), the radial growth is determined as:

$$\Delta R_{ah} := \alpha_{avg} \cdot a \cdot T_{bar}$$

$$\Delta R_{ah} = 0.017\,\text{in}$$

Similarly, an overestimate of the axial growth of the overpack can be determined by applying the average temperature (T_{bar}) over the entire length of the overpack as:

$$\Delta L_{ovph} := L_{ovp} \cdot \alpha_{avg} \cdot T_{bar}$$

$$\Delta L_{ovph} = 0.094\,\text{in}$$

Estimates of the secondary thermal stresses that develop in the overpack due to the radial temperature variation are determined using a conservatively high value of E as based on the temperature of the steel. The circumferential stress at the inner and outer surfaces (σ_{ca} and σ_{cb}, respectively) are determined as:

The Young's Modulus of the material, $E := 28300000 \cdot \text{psi}$

$$\sigma_{ca} := \alpha_{avg}\cdot\frac{E}{a^2}\cdot\left[2\cdot\frac{a^2}{\left(b^2-a^2\right)}\cdot \mathrm{Int} - \left(C_a\right)\cdot a^2\right]$$

$$\sigma_{ca} = -4334\,\mathrm{psi}$$

$$\sigma_{cb} := \alpha_{avg}\cdot\frac{E}{b^2}\cdot\left[2\cdot\frac{b^2}{\left(b^2-a^2\right)}\cdot \mathrm{Int} - \left[C_a + C_b\cdot\left(\ln\left(\frac{b}{a}\right)\right)\right]\cdot b^2\right]$$

$$\sigma_{cb} = 2833\,\mathrm{psi}$$

The radial stress due to the temperature gradient is zero at both the inner and outer surfaces of the overpack. The radius where a maximum radial stress is expected, and the corresponding radial stress, are determined by trial and error as:

$$N := 0.38$$

$$r := a\cdot(1-N) + N\cdot b$$

$$r = 46.72\,\mathrm{in}$$

$$\sigma_r := \alpha_{avg}\cdot\frac{E}{r^2}\cdot\left[\frac{r^2-a^2}{2}\cdot T_{bar} - \int_a^r \left[C_a + C_b\cdot\left(\ln\left(\frac{y}{a}\right)\right)\right]\cdot y\,dy\right]$$

$$\sigma_r = -564.853\,\mathrm{psi}$$

The axial stress developed due to the temperature gradient is equal to the sum of the radial and tangential stresses at any radial location. (see eq. 9.10.7) of [3.W.1]. Therefore, the axial stresses are available from the above calculations. The stress intensities in the overpack due to the temperature distribution are below the Level A membrane stress.

3.W.4.3 Thermal Growth of the MPC Shell

The radial and axial growth of the MPC shell (ΔR_{mpch} and ΔL_{mpch}, respectively) are determined as:

$$\Delta R_{mpch} := \alpha_{mpc}\cdot R_{mpc}\cdot \Delta T_{3h} \qquad \Delta R_{mpch} = 0.078\,\mathrm{in}$$

$$\Delta L_{mpch} := \alpha_{mpc}\cdot L_{mpc}\cdot \Delta T_{3h} \qquad \Delta L_{mpch} = 0.44\,\mathrm{in}$$

3.W.4.4 Clearances Between the MPC Shell and Overpack

The final radial and axial MPC shell-to-overpack clearances (RG_{moh} and AG_{moh}, respectively) are determined as:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch}$$

$$RG_{moh} = 0.439\,\text{in}$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch}$$

$$AG_{moh} = 0.654\,\text{in}$$

Note that this axial clearance (AG_{moh}) is based on the temperature distribution at the middle of the system.

3.W.4.5 Thermal Growth of the MPC-68 Basket

Using formulas given in [3.W.2] for a solid body of revolution, and assuming a parabolic temperature distribution in the radial direction with the center and outer temperatures given previously, the following relationships can be developed for free thermal growth.

Define $\Delta T_{bas} := \Delta T_{5h} - \Delta T_{4h}$ $\quad \Delta T_{bas} = 284.6$

Then the mean temperature can be defined as $T_{bar} := \frac{2}{R_b^2} \cdot \int_0^{R_b} \left(\Delta T_{5h} - \Delta T_{bas} \cdot \frac{r^2}{R_b^2} \right) \cdot r\,dr$

Using the Maple symbolic engine again, the closed form solution of the integral is:

$$T_{bar} := \frac{2}{R_b^2} \cdot \left(\frac{-1}{4} \cdot \Delta T_{bas} \cdot R_b^2 + \frac{1}{2} \cdot \Delta T_{5h} \cdot R_b^2 \right)$$

$$T_{bar} = 509.7$$

The corresponding radial growth at the periphery (ΔR_{bh}) is therefore determined as:

$$\Delta R_{bh} := \alpha_{bas} \cdot R_b \cdot T_{bar}$$

$$\Delta R_{bh} = 0.164\,\text{in}$$

and the corresponding axial growth (ΔL_{bas}) is determined from [3.W.2] as:

$$\Delta L_{bh} := \Delta R_{bh} \cdot \frac{L_{bas}}{R_b}$$

$$\Delta L_{bh} = 0.864\,\text{in}$$

Note that the coefficient of thermal expansion for the hottest basket temperature has been used, and the results are therefore conservative.

3.W.4.6 Clearances Between the Fuel Basket and MPC Shell

The final radial and axial fuel basket-to-MPC shell and lid clearances (RG_{bmh} and AG_{bmh}, respectively) are determined as:

$$RG_{bmh} := RC_{bm} - \Delta R_{bh} + \Delta R_{mpch}$$

$$RG_{bmh} = 0.102\,\text{in}$$

$$AG_{bmh} := AC_{bm} - \Delta L_{bh} + \Delta L_{mpch}$$

$$AG_{bmh} = 1.576\,\text{in}$$

3.W.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-Overpack	Fuel Basket-to-MPC Shell
$RG_{moh} = 0.439\,\text{in}$	$RG_{bmh} = 0.102\,\text{in}$
$AG_{moh} = 0.654\,\text{in}$	$AG_{bmh} = 1.576\,\text{in}$

3.W.6 Nomenclature

a is the inner radius of the overpack

AC_{bm} is the initial fuel basket-to-MPC axial clearance.

AC_{mo} is the initial MPC-to-overpack axial clearance.

AG_{bmh} is the final fuel basket-to-MPC shell axial gap for the hot components.

AG_{moh} is the final MPC shell-to-overpack axial gap for the hot components.

b is the outer radius of the overpack.

L_{bas} is the axial length of the fuel basket.

L_{mpc} is the axial length of the MPC.

L_{ovp} is the axial length of the overpack.

r_1 (r_2,r_3,r_4) is mean radius of the overpack inner shell (shield shell, concrete, outer shell).

R_b is the outer radius of the fuel basket.

R_{mpc} is the mean radius of the MPC shell.

RC_{bm} is the initial fuel basket-to-MPC radial clearance.

RC_{mo} is the initial MPC shell-to-overpack radial clearance.

RG_{bmh} is the final fuel basket-to-MPC shell radial gap for the hot components.

RG_{moh} is the final MPC shell-to-overpack radial gap for the hot components.

t_1 (t_2,t_3,t_4) is the thickness of the overpack inner shell (shield shell, concrete, outer shell).

T_{bar} is the average temperature of the overpack cylinder.

α_1 (α_2,α_3,α_4) is the coefficient of thermal expansion of the overpack inner shell (shield shell, concrete, outer shell).

α_{avg} is the average coefficient of thermal expansion of the overpack.

α_{bas} is the coefficient of thermal expansion of the overpack.

α_{mpc} is the coefficient of thermal expansion of the MPC.

ΔL_{bh} is the axial growth of the fuel basket for the hot components.

ΔL_{mpch} the the axial growth of the MPC for the hot components.

ΔL_{ovph} is the axial growth of the overpack for the hot components.

ΔR_{ah} is the radial growth of the overpack inner radius for the hot components.

ΔR_{bh} is the radial growth of the fuel basket for the hot components.

ΔR_{mpch} is the radial growth of the MPC shell for the hot components.

ΔT_{1h} is the temperature change at the overpack inner shell for hot components.

ΔT_{2h} is the temperature change at the overpack outer shell for hot components.

ΔT_{3h} is the temperature change at the MPC shell mean radius for hot components.

ΔT_{4h} is the temperature change at the MPC basket periphery for hot components.

ΔT_{5h} is the temperature change at the MPC basket centerline for hot components.

ΔT_{bas} is the fuel basket centerline-to-periphery temperature gradient.

σ_{ca} is the circumferential stress at the overpack inner surface.

σ_{cb} is the circumferential stress at the overpack outer surface.

σ_r is the maximum radial stress of the overpack.

σ_{zi} is the axial stress at the fuel basket centerline.

σ_{zo} is the axial stress at the fuel basket periphery.

$$S_p = 55{,}450 \text{ psi at } 725^\circ \text{F}$$

The appropriate limit for the weld stress is set as

$$S_w = 0.42\, S_u$$

Table 3.3.1 gives a value for the ultimate strength of the base metal as 62,350 psi at 725degreesF. The weld metal used at the panel connections is one grade higher in ultimate tensile stress than the adjacent base metal (80,000 psi at room temperature compared with 75,000 for the base metal at room temperature).

The strength of the weld is assumed to decrease with temperature the same as the base metal.

$$S_W = .42x80{,}000\left(\frac{62{,}350}{75{,}000}\right) = 27{,}930 \text{ psi}$$

Therefore, the corresponding limit stress on the weld throat is

$$h^2 = (0.283)\,(6)\,\frac{S_w}{S_p}\,(ht + t^2)$$

$$h^2 = 1.698\,\frac{S_w}{S_p}(ht + t^2)$$

The equation given above establishes the relationship between the weld size "t", the fuel basket panel wall thickness "h", and the ratio of allowable weld strength "S_W" to base metal allowable strength "S_p". We now apply this formula to establish the minimum fillet weld size to be specified on the design drawings to insure a factor of safety of 1.0 subsequent to incorporation of the appropriate dynamic load amplifier. Table 3.4.6 gives fuel basket safety factors "SF" for primary membrane plus bending stress intensities corresponding to the base metal allowable strength S_p at 725 degrees F. As noted in Subsection 3.4.4.4.1, the reported safety factors are conservatively low because of the conservative assumptions in modeling. Appendix 3.X provides dynamic amplification factors "DAF" for **typical**~~each~~ fuel basket types. To establish the minimum permissible weld size, Sp is replaced in the above formula by (S_px(DAF/SFx1.1)), and t/h computed for each basket. The additional 10%

increase in safety factor is a conservative accounting that factors in the known conservatism in the finite element solution and the results from the simplified evaluation in Subsection 3.4.4.4.1. The following results are obtained:

MINIMUM WELD SIZE FOR FUEL BASKETS					
Item	SF (Table 3.4.6) x 1.1	DAF (**Bounding Values**)	t/h	h (inch)	t (inch)
MPC-24	1.41	1.077	0.57	10/32	0.178
MPC-68	1.58	1.06	0.516	8/32	0.129
MPC-32	**1.408~~28~~**	**1.08**	**0.57**	**9/32**	**0.160**
MPC-24E	**1.903**	**1.08**	**0.455**	**10/32**	**0.142**

Sheathing Weld Capacity

Theory:

Simple Force equilibrium relationships are used to demonstrate that the sheathing weld is adequate to support a 45g deceleration load applied vertically and horizontally to the sheathing and to the confined Boral. We perform the analysis assuming the weld is continuous and then modify the results to reflect the amplification due to intermittent welding.

Definitions

h = length of weld line (in.) (long side of sheathing)

w = width of weld line (in.) (short edge of sheathing)

t_w = weld size

e = 0.3 = quality factor for single fillet weld (from subsection NG, Table NG-3352-1)

W_b = weight of a Boral panel (lbf)

W_s = weight of sheathing confining a Boral panel (lbf)

G = 45

S_w = weld shear stress (psi)

$$S_W = \frac{45\,x\,(7.56 + 17.48)\,x\,1.732}{1.414\,x\,0.3\,x\,(1/16\,\text{in.})\,(139\,\text{in.})} = 530\text{ psi}$$

The actual welding specified along the length of a sheathing panel is 2" weld on 8" pitch. The effect of the intermittent weld is to raise the average weld shear stress by a factor of 4. From the above results, it is concluded that the sheathing weld stress is negligible during the most severe drop accident condition. **This conclusion is valid for any and all fuel baskets.**

3.Y.2 Calculation for MPC Cover Plates in MPC Lid

The MPC cover plates are welded to the MPC lid during loading operations. The cover plates are part of the confinement boundary for the MPC. No credit is taken for the pressure retaining abilities of the quick disconnect couplings for the MPC vent and drain. Therefore, the MPC cover plates must meet ASME Code, Section III, Subsection NB limits for normal, off-normal, and accident conditions.

The normal and off-normal condition design basis MPC internal pressure is 100 psi. The accident condition design basis MPC internal pressure is 125 psi. Conservatively, the accident condition pressure loading is applied and it is demonstrated that the Level A limits for Subsection NB are met.

The MPC cover plate is depicted in the Design Drawings. The cover plate is stepped and has a maximum and minimum thickness of 0.38 inches and 0.1875 inches, respectively. Conservatively, the minimum thickness is utilized for these calculations.

To verify the MPC cover plate maintains the MPC internal pressure while meeting the ASME Code, Subsection NB limits, the cover plate bending stress and shear stress, and weld stress are calculated and compared to allowables.

Definitions

P = accident condition MPC internal pressure (psi) = 125 psi

r = cover plate radius (in.) = 2 in.

t = cover plate minimum thickness (in.) = 0.1875 in.

We first establish as input data common to all MPC's, the allowable weld shear stress. In section 3.Y.1, the allowable weld stress for a Level D accident event defined. We further reduce this allowable stress by an appropriate weld efficiency obtained from the ASME Code, Section III, Subsection NG, Table NG-3352-1.

Weld efficiency $e := 0.35$ (single fillet weld, visual inspection only)

The fuel support brackets are constructed from Alloy "X". At the canister interface,

Ultimate Strength $S_u := 64000 \cdot psi$ Alloy X @ 450 degrees F (Table 3.3.1)

Note that here we use the design temperature for the MPC shell under normal conditions (Table 2.2.3) since the fire accident temperature is not applicable during the tip-over. The allowable weld shear stress, incorporating the weld efficiency is (use the base metal ultimate strength for additional conservatism) determined as:

$\tau_{all} := .42 \cdot S_u \cdot e$ $\tau_{all} = 9.408 \times 10^3 \, psi$

For the non-mechanistic tip-over, the design basis deceleration in "g's" is

$G := 45$ (Table 3.1.2)

The total load to be resisted by the fuel basket supports is obtained by first computing the moving weight, relative to the MPC canister, for each MPC. The fuel basket weight is obtained from the weight calculation (dated 11/11/97) in HI-971656, HI-STAR 100 Structural Calculation Package.

The weights of the fuel baskets and total fuel load are (the notation "lbf" = "pound force")

Fuel Basket	Fuel	
$W_{mpc32} := 11875 \cdot lbf$	$W_{f32} := 53760 \cdot lbf$	MPC-32
$W_{mpc68} := 15263 \cdot lbf$	$W_{f68} := 47600 \cdot lbf$	MPC-68
$W_{mpc24} := 17045 \cdot lbf$	$W_{f24} := 40320 \cdot lbf$	MPC-24
$W_{mpc24e} := 21496 \cdot lbf$	$W_{f24} := 40320 \cdot lbf$	MPC-24E

Since the MPC24E is heavier, we assign a bounding weight to the MPC24 basket equal to that of the MPC24E in the following calculation.

$W_{mpc24} := W_{mpc24e}$

The minimum length of the fuel basket support is $L := 168 \cdot in$

Dwg. 1396, sheet 1 Note that for the MPC-68, the support length is increased by 1/2"

Therefore, the load per unit length that acts along the line of action of the deceleration, and is resisted by the total of all supports, is computed as

$$Q_{32} := \frac{(W_{mpc32} + W_{f32}) \cdot G}{(L + 0.5 \cdot in)} \qquad Q_{32} = 1.753 \times 10^4 \frac{lbf}{in}$$

$$Q_{68} := \frac{(W_{mpc68} + W_{f68}) \cdot G}{(L + 0.5 \cdot in)} \qquad Q_{68} = 1.679 \times 10^4 \frac{lbf}{in}$$

$$Q_{24} := \frac{(W_{mpc24} + W_{f24}) \cdot G}{L} \qquad Q_{24} = 1.656 \times 10^4 \frac{lbf}{in}$$

$$Q_{24e} := \frac{(W_{mpc24e} + W_{f24}) \cdot G}{L} \qquad Q_{24e} = 1.656 \times 10^4 \frac{lbf}{in}$$

The subscript associated with the above items is used as the identifier for the particular MPC.

An examination of the MPC construction drawings 1392, 1395, 1401, (sheet 1 of each drawing) indicates that the deceleration load is supported by shims and by fuel basket angle supports. By inspection of the relevant drawing, we can determine that the most highly loaded fuel basket angle support will resist the deceleration load from "NC" cells where NC for each basket type is obtained by counting the cells and portions of cells "above" the support in the direction of the deceleration. The following values for NC are used in the subsequent computation of fuel basket angle support stress:

$NC_{32} := 6$ $NC_{68} := 8$ $NC_{24} := 7$

The total normal load per unit length on the fuel basket support for each MPC type is therefore computed as:

$P_{32} := Q_{32} \cdot \frac{NC_{32}}{32}$ $\quad P_{32} = 3.287 \times 10^3 \frac{lbf}{in}$

$P_{68} := Q_{68} \cdot \frac{NC_{68}}{68}$ $\quad P_{68} = 1.975 \times 10^3 \frac{lbf}{in}$

$P_{24} := Q_{24} \cdot \frac{NC_{24}}{24}$ $\quad P_{24} = 4.829 \times 10^3 \frac{lbf}{in}$

$P_{24e} := Q_{24e} \cdot \frac{NC_{24}}{24}$ $\quad P_{24e} = 4.829 \times 10^3 \frac{lbf}{in}$

Here again, the subscript notation identifies the particular MPC.

Figure 3.Y.2 shows a typical fuel basket support with the support reactions at the base of the leg. The applied load and the loads necessary to put the support in equilibrium is not subscripted since the figure is meant to be typical of any MPC fuel basket angle support. The free body is drawn in a conservative manner by assuming that the load P is applied at the quarter point of the top flat portion. In reality, as the load is applied, the top flat portion deforms and the load shifts completely to the outer edges of the top flat section of the support. From the design drawings, we use the appropriate dimensions and perform the following analyses (subscripts are introduced as necessary as MPC identifiers):

The free body diagram shows the bending moment that will arise at the location where the idealized top flat section and the angled support are assumed to meet. Compatibility of joint rotation at the connection between the top flat and the angled portion of the support plus force and moment equilibrium equations from classical beam theory provide sufficient equations to solve for the bending moment at the connection (point O in Figure 3.Y.2), the load R at the weld, and the bending moment under the load P/2.

$$M_o := \frac{9}{16} \cdot \frac{Pw^2}{(S + 3 \cdot w)} \blacksquare$$

Note that the small block after the equation indicates that this is a text equation rather than an evaluated equation. This is a Mathcad identifier.

The load in the weld, R, is expressed in the form

$$R := \frac{P \cdot H}{2 \cdot L} + \frac{M_o}{L}$$

Finally, the bending moment under the load, on the top flat portion, is given as

$$M_p := \frac{P}{2} \cdot \frac{w}{2} - M_o$$

The throat thickness of the fillet weld used between the supports and the MPC shell is

$t_w := 0.125 \cdot in \cdot .7071$

The wall thickness for computation of member stresses is: $t_{wall} := \frac{5}{16} \cdot in$

Performing the indicated computations and evaluations for each of the MPC's gives:

MPC-32 (Dwg.1392 sheet 4)

$\theta_{32} := 9 \cdot deg$ $\quad L_{32} := 5.6 \cdot in$ $\quad w_{32} := \left(0.25 + .125 + .5 \cdot \frac{5}{16}\right) \cdot in$

Therefore

$H_{32} := L_{32} \cdot \tan(\theta_{32})$ $\quad H_{32} = 0.887\,in$ $\quad w_{32} = 0.531\,in$

$S := \sqrt{L_{32}{}^2 + H_{32}{}^2}$ $\quad S = 5.67\,in$

$M_o := \frac{9}{16} \cdot \frac{\left(P_{32} \cdot w_{32}{}^2\right)}{\left(S + 3 \cdot w_{32}\right)} *$ $\quad M_o = 71.832\,lbf \cdot \frac{in}{in}$

$R_{32} := \frac{P_{32} \cdot H_{32}}{2 \cdot L_{32}} + \frac{M_o}{L_{32}} *$ $\quad R_{32} = 273.102 \frac{lbf}{in}$

$M_p := \frac{P_{32}}{2} \cdot \frac{w_{32}}{2} - M_{o*}$ $\quad M_p = 364.672\,lbf \cdot \frac{in}{in}$

The weld stress is

$$\tau_{weld} := \frac{R_{32}}{t_w} \qquad \tau_{weld} = 3.09 \times 10^3 \, psi$$

For this event, the safety factor on the weld is

$$SF_{weld} := \frac{\tau_{all}}{\tau_{weld}} \qquad SF_{weld} = 3.045$$

The maximum bending stress in the angled member is

$$\sigma_{bending} := 6 \cdot \frac{M_o}{t_{wall}^2} \qquad \sigma_{bending} = 4.413 \times 10^3 \, psi$$

The direct stress in the basket support angled section is

$$\sigma_{direct} := \frac{\left(R_{32} \cdot \sin\left(\theta_{32}\right) + .5 \cdot P_{32} \cdot \cos\left(\theta_{32}\right)\right)}{t_{wall}} \qquad \sigma_{direct} = 5.331 \times 10^3 \, psi$$

From Table 3.1.16, the allowable membrane stress intensity for this condition is

$S_{membrane} := 39400 \cdot psi$ (use the value at 600 degree F to conservatively bound the Safety Factor)

$$SF_{membrane} := \frac{S_{membrane}}{\sigma_{direct}} \qquad SF_{membrane} = 7.391$$

From Table 3.1.16, the allowable combined stress intensity for this accident condition is

$S_{combined} := 59100 \cdot psi$ (use the value at 600 degree F to conservatively bound the Safety Factor)

$$SF_{combined} := \frac{S_{combined}}{\sigma_{direct} + \sigma_{bending}} \qquad SF_{combined} = 6.065$$

Note that for this model, it is appropriate to compare the computed stress with allowable stress intensities since we are dealing with beams and there are no surface pressure stresses.

The maximum bending stress in the top flat section is

$$\sigma_{bending} := 6 \cdot \frac{M_p}{t_{wall}^2} \qquad \sigma_{bending} = 2.241 \times 10^4 \, psi$$

The direct stress in the basket support top flat section is

$$\sigma_{direct} := \frac{R_{32}}{t_{wall}} \qquad \sigma_{direct} = 873.926 \, psi$$

Computing the safety factors gives:

$$SF_{membrane} := \frac{S_{membrane}}{\sigma_{direct}} \qquad SF_{membrane} = 45.084$$

$$SF_{combined} := \frac{S_{combined}}{\sigma_{direct} + \sigma_{bending}} \qquad SF_{combined} = 2.539$$

All safety factors are greater than 1.0; therefore, the design is acceptable

MPC-24 (Dwg.1395 sheet 4)

$$\theta_{24} := 9 \cdot deg \qquad L_{24} := 4 \cdot in \qquad w_{24} := \left(0.25 + .125 + .5 \cdot \frac{5}{16}\right) \cdot in$$

Therefore

$$H_{24} := L_{24} \cdot \tan\left(\theta_{24}\right) \qquad H_{24} = 0.634 \, in \qquad w_{24} = 0.531 \, in$$

$$S := \sqrt{L_{24}^2 + H_{24}^2} \qquad S = 4.05 \, in$$

$$M_o := \frac{9}{16}\cdot\frac{\left(P_{24}\cdot w_{24}^{2}\right)}{\left(S+3\cdot w_{24}\right)}*$$ $$M_o = 135.848\,\text{lbf}\cdot\frac{\text{in}}{\text{in}}$$

$$R_{24} := \frac{P_{24}\cdot H_{24}}{2\cdot L_{24}} + \frac{M_o}{L_{24}}*$$ $$R_{24} = 416.411\,\frac{\text{lbf}}{\text{in}}$$

$$M_p := \frac{P_{24}}{2}\cdot\frac{w_{24}}{2} - M_{o*}$$ $$M_p = 505.553\,\text{lbf}\cdot\frac{\text{in}}{\text{in}}$$

The weld stress is

$$\tau_{weld} := \frac{R_{24}}{t_w}$$ $$\tau_{weld} = 4.711\times10^{3}\,\text{psi}$$

For this event, the safety factor on the weld is

$$SF_{weld} := \frac{\tau_{all}}{\tau_{weld}}$$ $$SF_{weld} = 1.997$$

The maximum bending stress in the angled member is

$$\sigma_{bending} := 6\cdot\frac{M_o}{t_{wall}^{2}}$$ $$\sigma_{bending} = 8.347\times10^{3}\,\text{psi}$$

The direct stress in the basket support angled section is

$$\sigma_{direct} := \frac{\left(R_{24}\cdot\sin\left(\theta_{24}\right) + .5\cdot P_{24}\cdot\cos\left(\theta_{24}\right)\right)}{t_{wall}}$$ $$\sigma_{direct} = 7.84\times10^{3}\,\text{psi}$$

From Table 3.1.16, the allowable membrane stress intensity for this condition is

$S_{membrane} := 39400\cdot\text{psi}$ (use the value at 600 degree F to conservatively bound the Safety Factor)

$$SF_{membrane} := \frac{S_{membrane}}{\sigma_{direct}} \qquad SF_{membrane} = 5.025$$

From Table 3.1.16, the allowable combined stress intensity for this accident condition is

$S_{combined} := 59100 \cdot psi$ (use the value at 600 degree F to conservatively bound the Safety Factor)

$$SF_{combined} := \frac{S_{combined}}{\sigma_{direct} + \sigma_{bending}} \qquad SF_{combined} = 3.651$$

Note that for this model, it is appropriate to compare the computed stress with allowable stress intensities since we are dealing with beams and there are no surface pressure stresses.

$$SF_{membrane} := \frac{S_{membrane}}{\sigma_{direct}} \qquad SF_{membrane} = 5.025$$

$$SF_{combined} := \frac{S_{combined}}{\sigma_{direct} + \sigma_{bending}} \qquad SF_{combined} = 3.651$$

The maximum bending stress in the top flat section is

$$\sigma_{bending} := 6 \cdot \frac{M_p}{t_{wall}^2} \qquad \sigma_{bending} = 3.106 \times 10^4 \, psi$$

The direct stress in the basket support top flat section is

$$\sigma_{direct} := \frac{R_{24}}{t_{wall}} \qquad \sigma_{direct} = 1.333 \times 10^3 \, psi$$

Computing the safety factors gives:

$$SF_{membrane} := \frac{S_{membrane}}{\sigma_{direct}} \qquad SF_{membrane} = 29.568$$

$$SF_{combined} := \frac{S_{combined}}{\sigma_{direct} + \sigma_{bending}} \qquad SF_{combined} = 1.824$$

All safety factors are greater than 1.0; therefore, the design is acceptable

MPC-68 (Dwg 1401 sheet 4)

$\theta_{68} := 12.5 \cdot deg$ $\quad L_{68} := 4.75 \cdot in$ (estimated) $\quad w_{68} := \left(0.75 - .5 \cdot \frac{5}{16}\right) \cdot in$

Note that in the MPC-68, there is no real top flat portion to the angle support. "w" is computed as the radius of the bend less 50% of the wall thickness. However, in the remaining calculations, the applied load is assumed a distance w/2 from the center on each side of the support centerline in Figure 3.Y.2.

Therefore

$$H_{68} := L_{68} \cdot \tan(\theta_{68}) \qquad H_{68} = 1.053\,in \qquad w_{68} = 0.594\,in$$

$$S := \sqrt{L_{68}^2 + H_{68}^2} \qquad S = 4.865\,in$$

$$M_o := \frac{9}{16} \cdot \frac{P_{68} \cdot w_{68}^2}{(S + 3 \cdot w_{68})} \qquad M_o = 58.928\,lbf \cdot \frac{in}{in}$$

$$R_{68} := \frac{P_{68} \cdot H_{68}}{2 \cdot L_{68}} + \frac{M_o}{L_{68}}* \qquad R_{68} = 231.34 \frac{lbf}{in}$$

$$M_p := \frac{P_{68}}{2} \cdot \frac{w_{68}}{2} - M_{o*} \qquad M_p = 234.251\,lbf \cdot \frac{in}{in}$$

The weld stress is

$$\tau_{weld} := \frac{R_{68}}{t_w} \qquad \tau_{weld} = 2.617 \times 10^3\,psi$$

$$SF_{combined} := \frac{S_{combined}}{\sigma_{direct} + \sigma_{bending}} \qquad SF_{combined} = 3.905$$

All safety factors are greater than 1.0; therefore, the design is acceptable

SUMMARY OF RESULTS

The above calculations demonstrate that for all MPC fuel basket angle supports, the minimum safety margin is 1.82 (MPC-24 combined membrane plus bending in the top flat section). This is a larger safety factor than predicted from the finite element solution. The reason for this increase is attributed to the fact that the finite element analysis used a less robust structural model of the supports for stress analysis purposes since the emphasis there was on analysis of the fuel basket itself and the MPC canister.. Therefore, in reporting safety factors, or safety margins, the minimum safety factor of 1.82 should be used for this component in any summary table.

APPENDIX 3.AC - LIFTING CALCULATIONS

3.AC.1 Scope of Appendix

In this Appendix, the attachment locations that are used for lifting various lids are analyzed for strength and engagement length. The mating lifting device is not a part of this submittal but representative catalog items are chosen for analysis to demonstrate that commercially available lifting devices suffice to meet the required safety margins.

3.AC.2 Configuration

The required data for analysis is 1) the number of bolts NB; 2) the bolt diameter db; 3) the lifted weight; and 4), the details of the individual bolts.

3.AC.3 Acceptance Criteria

The lifting bolts are considered as part of a special lifting device; therefore, NUREG-0612 applies. The acceptance criteria is that the bolts and the adjacent lid threads must have stresses less than 1/3 x material yield strength and 1/5 x material ultimate strength. These reduced requirements are acceptable since the outer diameters of the lifted parts are larger than the inside diameter of the cavity under the lifted parts; therefore, the lifted parts cannot impact stored fuel directly as long as sufficient controls are maintained on carry heights to preclude inordinant lid rotations in the event of a handling accident.

3.AC.4 Composition of Appendix

This appendix is created using the Mathcad (version 2000) software package. Mathcad uses the symbol ':=' as an assignment operator, and the equals symbol '=' retrieves values for constants or variables.

3.AC.5 References

[3.AC.1] E. Oberg and F.D. Jones, *Machinery's Handbook*, Fifteenth Edition, Industrial Press, 1957, pp987-990.

[3.AC.2] FED-STD-H28/2A, *Federal Standard Screw-Thread Standards for Federal Services*, United States Government Printing Office, April, 1984.

3.AC.6 Input Data for Lifting of Overpack Top Lid (HI-STORM 100S bounds)

Lifted Weight (Table 3.2.1): $W_{lift} := (25500 \cdot 1.15) \cdot lbf$ includes 15% inertia load factor

The following input parameters are taken from Holtec Dwgs. for 100S lid.

Bolt diameter $db := 1.5 \cdot in$ Dwg. 3072)

$N := 6 \cdot \frac{1}{in}$ is the number of threads per inch (UNC)

$L_{eng} := 1.5 \cdot in$ is the length of engagement (lower of two 2" top plates, Dwg. 1561).

Number of Bolts $NB := 4$

Lifting of the HI-STORM 100 lid is limited to a straight (90 deg) lift. For conservatism the minimum lift angle (from the horizontal) is assumed to be:

$$ang := 80 \cdot deg$$

$A_d := \pi \cdot \frac{db^2}{4}$ $A_d = 1.767\,in^2$ is the area of the unthreaded portion of the bolt

$A_{stress} := 1.405 \cdot in^2$ is the stress area of the bolt

$d_{pitch} := 1.3917 \cdot in$ is the pitch diameter of the bolt

$dm_{ext} := 1.2955 \cdot in$ is the minor diameter of the bolt

$dm_{int} := 1.3196 \cdot in$ is the minor diameter of the hole

The design temperature of the top lid, located atop the overpack, is 350 deg. F. The lid lifting bolts, will not see this temperature under normal circumstances. For conservatism, the material properties and allowable stresses for the lid used in the qualification are taken at 350 deg F.
The yield and ultimate strengths of the overpack top lid are reduced by factors of 3 and 5, respectively. The eyebolt working load limit(not part of the HI-STORM 100 System) will have a safety factor of 5.

$S_{ulid} := \frac{70000}{5} \cdot psi$ (Table 3.3.2) $S_{ylid} := \frac{33150}{3} \cdot psi$ (Table 3.3.2)

The yield stress criteria governs the analysis.

3.AC.7 Calculations

3.AC.7.1 Length of Engagement/Strength Calculations

In this section, it is shown that the length of thread engagement is adequate The method and terminology of Reference 3.AC.2 is followed.

$p := \frac{1}{N}$ is the thread pitch

$H := 4 \cdot 0.21651 \cdot p$ $\quad H = 0.144\,\text{in}$

$Depth_{ext} := \frac{17}{24} \cdot H$ $\quad Depth_{ext} = 0.102\,\text{in}$

$Depth_{int} := \frac{5}{8} \cdot H$ $\quad Depth_{int} = 0.09\,\text{in}$

$dmaj_{ext} := dm_{ext} + 2 \cdot Depth_{ext}$ $\quad dmaj_{ext} = 1.5\,\text{in}$

Using page 103 of reference 3.AC.2,

$$Bolt\_thrd\_shr\_A := \pi \cdot N \cdot L_{eng} \cdot dm_{int} \cdot \left[\frac{1}{2 \cdot N} + .57735 \cdot \left(d_{pitch} - dm_{int} \right) \right]$$

$$Bolt\_thrd\_shr\_A = 4.662\,\text{in}^2$$

$$Ext\_thrd\_shr\_A := \pi \cdot N \cdot L_{eng} \cdot dmaj_{ext} \cdot \left[\frac{1}{2 \cdot N} + 0.57735 \cdot \left(dmaj_{ext} - d_{pitch} \right) \right]$$

$$Ext\_thrd\_shr\_A = 6.186\,\text{in}^2$$

The normal stress capacities of the bolt, and load capacity of the top lid material, based on yield strength, are (the shear area is taken as the stress area here since the lifting bolt that also fits into this hole is not part of the HI-STORM 100 System. The representative lid lifting bolt specification for the analysis is assumed as equivalent to Crosby S-279, Part Number 9900271):

$Load\_Capacity_{bolt} := 21400 \cdot \text{lbf}$ $\quad Load\_Capacity_{bolt} = 2.14 \times 10^4\,\text{lbf}$

$\text{Load\_Capacity}_{\text{lid}} := (0.577 \cdot S_{\text{ylid}}) \cdot \text{Ext\_thrd\_shr\_A}$

$$\text{Load\_Capacity}_{\text{lid}} = 3.944 \times 10^4 \,\text{lbf}$$

Therefore, the lifting capacity of the configuration is based on bolt shear due to lid thread capacity or the actual catalog rated capacity of the bolt adjusted for the angled lift.

$\text{Max\_Lift\_Load} := \text{NB} \cdot \text{Load\_Capacity}_{\text{lid}}$ $\qquad \text{Max\_Lift\_Load} = 1.578 \times 10^5 \,\text{lbf}$

$$SF := \frac{\text{Max\_Lift\_Load}}{W_{\text{lift}}} \qquad SF = 5.38 \qquad > 1$$

Even though a vertical lift is required, the safety factor is consistently and conservatively computed based on the assumed lift angle:

or

$$SF := \frac{\text{NB} \cdot \text{Load\_Capacity}_{\text{bolt}} \cdot 0.844}{W_{\text{lift}}} \qquad SF = 2.464 \qquad > 1$$

Note that the minimum safety factor based on bolt rated capacity does not include the built-in catalog rated safety factor of 5. The factor of 0.844 is based on an interpolation of the reduction factor stated in the Crosby Catalog (p. 72) for off angle lifts as computed below:

For a 45 degree off-angle, the reduction factor is 0.70; therefore for the assumed 10 degree off-angle,

$$\frac{(90 \cdot \text{deg} - \text{ang})}{45 \cdot \text{deg}} \cdot 0.70 = 0.156 \qquad 1 - .156 = 0.844$$

3.AC.8 Input Data for Lifting of HI-TRAC Pool Lid

Lifted Weight: (the HI-TRAC 125 pool lid bounds all other lids - this is the only load)

$\text{Weight} := 12500 \cdot \text{lbf}$ Table 3.2.2. This load bounds all other lids that may be lifted.

$\text{ang} := 45 \cdot \text{deg}$ Minimum Lift Angle from Horizontal (to bound all lifts other than the HI-STORM 100 top lid)

$\text{inertia\_load\_factor} := .15$

APPENDIX 3.AD 125 TON HI-TRAC TRANSFER LID STRESS ANALYSES

3.AD.1 Introduction

This appendix considers the structural analysis of the HI-TRAC transfer lid under the following limiting conditions:

Lifting of fully loaded MPC - Normal Condition
Horizontal Drop of HI-TRAC - Accident Condition

In the first case, it is shown that the sliding doors adequately support a loaded MPC plus the door weight, both being amplified by a dynamic load factor associated with a low speed lifting operation, and that the loads are transferred to the transfer cask body without overstress.

In the second case, analysis is performed to show that the transfer lid and the transfer cask body do not separate during a HI-TRAC horizontal drop which imposes a deceleration load on the connection. In this case, because of the geometry of the transfer lid housing, the force of separation is from the HI-TRAC since the housing impacts the ground before the HI-TRAC body; i.e., the connection needs to withstand an amplified load from the HI-TRAC loaded weight, amplified by the deceleration. Analysis is also performed to show that the bolts that act as "door stops" will keep the doors from opening due to deceleration from a side drop.

3.AD.2 References

[3.AD.2.1] Young, Warren C., *Roark's Formulas for Stress and Strain*, 6th Edition, McGraw-Hill,1989.

[3.AD.2.2] Holtec Drawing 1928 (two sheets)

[3.AD.2.3] J.Shigley and C. Mischke, *Mechanical Engineering Design*, McGraw Hill, 1989.

[3.AD.2.4] McMaster-Carr Supply Company, Catalog No. 101, 1995.

[3.AD.2.5] Machinery's Handbook, 23rd Edition, Industrial Press

3.AD.3 Composition

This appendix was created using the Mathcad (version 8.0) software package. Mathcad uses the symbol ':=' as an assignment operator, and the equals symbol '=' retrieves values for constants or variables.

3.AD.4 General Assumptions

1. Formulas taken from Reference [3.AD.2.1] are based on assumptions that are delineated in that reference.

2. During lifting operation, the MPC is supported on a narrow rectangular section of the door. The width of the section in each of two doors is set at the span of the three wheels. Beam theory is used to calculate stresses.

3. The loading from the MPC on the door is simulated by a uniform pressure acting on the total surface area of the postulated beam section of the door.

3.AD.5 Methodology and Assumptions

Strength of Materials analysis are performed to establish structural integrity. Stresses in the transfer lid door are computed based on simplified beam analysis, where the width of the top plate beam is taken as the span of the door support wheels (see drawing 1928).
For all lifting analyses, the acceptance criteria is the more severe of ASME Section III, Subsection NF (allowable stresses per tables in Chapter 3),or USNRC Regulatory Guide 3.61 (33.3% of yield strength at temperature).

3.AD.6 Input Data (per BM-1928 and drawing 1928; weights are from Table 3.2.2, with detailed door component weights from the calculation package HI-981928)

Unsupported door top plate length	$L := 72.75 \cdot in$
Half Door top plate width	$w := 25 \cdot in$
Door top plate thickness	$t_{tp} := 2.25 \cdot in$
Thickness of middle plate	$t_{mp} := .5 \cdot in$
Thickness of bottom plate	$t_{bp} := 0.75 \cdot in$
HI-TRAC bounding dry weight	$W := 243000 \cdot lbf$
MPC bounding weight	$W_{mpc} := 90000 \cdot lbf$
Transfer Lid Bounding Weight (with door)	$W_{tl} := 24500 \cdot lbf$
Weight of door top plate (2 items)	$W_{tp} := 3762 \cdot lbf$
Door Lead shield weight (2 items)	$W_{lead} := 3839 \cdot lbf$

Weight of door bottom plate (2 items) $W_{bp} := 994 \cdot lbf$

Weight of Holtite A (2 items) $W_{ha} := 691 \cdot lbf$

Weight of door middle plate (2 items) $W_{mp} := 663 \cdot lbf$

Total door weight (2 components) excluding wheels and trucks

$$W_{td} := W_{tp} + W_{lead} + W_{bp} + W_{ha} + W_{mp} \qquad W_{td} = 9.949 \times 10^3 lbf$$

Weight of wheels, trucks and miscellaneous pieces $W_{misc} := 2088 \cdot lbf$

Total Load transferred by 1 set of 3 wheels including wheels, trucks, and miscellaneous items

$$W_{door} := \frac{.5 \cdot (W_{td} + W_{misc})}{2} \qquad W_{door} = 3.009 \times 10^3 lbf$$

Dynamic Load Factor for low speed lift $DLF := 0.15$

Young's Modulus SA-516-Gr70 @ 350 deg. F $E := 28 \cdot 10^6 \cdot psi$

Allowable membrane stress
for Level A condition @ 350 deg. F(Table 3.3.2)
(Use allowable of SA-516-Gr 70 to be conservative) $S_a := 17500 \cdot psi$

Yield strength of SA-350-LF3 @ 350 deg. F
to be conservative (Table 3.3.3) $S_y := 32700 \cdot psi$

Maximum Deceleration g level per design basis $G_{max} := 45$

3.AD.7 Analysis of Door plates Under Lift of MPC - Level A Event

The transfer lid door has a top and bottom plate connected by side plates that act as stiffeners in the loaded section. The top plate is 2.25" thick and the total span between wheel centers is 73". The bottom plate is 0.75" thick and spans 73". The side plates that connect the plates are 1" thick.

The lid door acts as a composite beam between wheel sets. To ensure conservatism, the effective width of the composite beam is taken as the distance between the outermost stiffeners. Beam theory is valid up to 1/8 of the span [Ref. 3.AD.2.1]. Beyond this value, a beam begins to act as a stronger two-way plate. Therefore, a one-way beam approximation for the dimensions of this lid underestimates the capacity of the lid. The load acting on the beam is taken as the bounding weight from a fully loaded MPC plus the bounding weight of the transfer lid door assembly. The load is applied as a uniform pressure and the beam is assumed simply supported.

The geometric parameters of the system are (drawing 1928, sheet 2):

$b := w$

$h := 8 \cdot in$ overall beam height

$htp := t_{tp}$ thickness of top plate $htp = 2.25\,in$

$hg := 5.75 \cdot in$ height of side plate

$hbp := t_{bp}$ thickness of bottom plate $hbp = 0.75\,in$

$tg := 1 \cdot in$ thickness of each side plate

The centroid (measured from the top surface) and area moment of inertia of the composite beam are:

$$yc := \frac{3 \cdot hg \cdot tg \cdot \left(htp + \frac{hg}{2}\right) + htp \cdot b \cdot \frac{htp}{2} + hbp \cdot (b - 3 \cdot tg) \cdot \left(h - \frac{hbp}{2}\right)}{htp \cdot b + 3 \cdot hg \cdot tg + hbp \cdot (b - 3 \cdot tg)}$$

$$yc = 3.083\,in$$

$$Inertia := \frac{b \cdot htp^3}{12} + htp \cdot b \cdot \left(yc - \frac{htp}{2}\right)^2 + \frac{tg \cdot hg^3}{4} + 3 \cdot hg \cdot tg \cdot \left(yc - htp - \frac{hg}{2}\right)^2 \ldots$$
$$+ \frac{(b - 3 \cdot tg) \cdot hbp^3}{12} + hbp \cdot (b - 3 \cdot tg) \cdot \left(yc - htp - hg - \frac{hbp}{2}\right)^2$$

$$Inertia = 821.688\,in^4$$

The maximum stress is due to the moment:

$$\text{Moment} := \frac{(W_{mpc} + W_{td})}{2} \cdot \frac{L}{8} \qquad \text{Moment} = 4.545 \times 10^{5}\,\text{lbf}\cdot\text{in}$$

The bending stress is

$$\sigma := \frac{\text{Moment}\cdot(h - yc)\cdot(1 + DLF)}{\text{Inertia}} \qquad \sigma = 3.127 \times 10^{3}\,\text{psi}$$

The stress must be less than the 33.3% of the yield strength of the material. This acceptance criteria comes from Reg. Guide 3.61. The safety factor is,

$$Sy := S_y$$

$$SF_{3.61} := \frac{Sy}{3\cdot\sigma} \qquad SF_{3.61} = 3.486$$

The safety factor as defined by ASME Section III, Subsection NF for Class 3 components is

$$SF_{nf} := \frac{1.5\cdot S_a}{\sigma} \qquad SF_{nf} = 8.394$$

Now consider the plate section between stiffeners and check to see if plate stress is acceptable. The span of the plate between stiffeners is

$$\text{span} := 12.5\cdot\text{in}$$

Calculate the pressure on each half of lid door due to MPC.

$$p := \frac{.5\cdot W_{mpc}\cdot(1 + DLF)}{L\cdot w} \qquad p = 28.454\,\text{psi}$$

Calculate the pressure due to self weight

$$p_d := .5\cdot(W_{tp})\cdot\frac{1 + DLF}{L\cdot w} \qquad p_d = 1.189\,\text{psi}$$

Bending moment due to pressure

$$\text{Moment} := \frac{(p + p_d)\cdot L\cdot \text{span}^2}{8} \qquad \text{Moment} = 4.212 \times 10^{4}\,\text{lbf}\cdot\text{in}$$

Maximum bending stress

$$\sigma_{bending} := \frac{6 \cdot Moment}{L \cdot t_{tp}^2} \qquad \sigma_{bending} = 686.179\,psi$$

(Small!!!)

Now perform a Weld Check

$$Load := (p + p_d) \cdot L \cdot w \qquad Load = 5.391 \times 10^4\,lbf$$

The shear stress at the weld connection is (conservatively neglect stiffener welds)

$$\tau := \frac{Load}{2 \cdot w \cdot t_{tp}} \qquad \tau = 479.227\,psi$$

Low!

It is concluded that the significant stresses arise only by the action of the member as a composite beam composed of plates and stiffeners. Local bending stresses in the plate are small and can be neglected

3.AD.8 Wheel Loads on Housing

$W_{door} = 3.009 \times 10^3\,lbf$ From weight calculation - 50% of 1 half-door

Load per wheel

$$Load_{wheel} := \frac{(W_{door} + .25 \cdot W_{mpc}) \cdot (1 + DLF)}{3}$$

$$Load_{wheel} = 9.779 \times 10^3\,lbf$$

Note that working capacities of wheels are 10000 lb per McMaster Carr Catalog [3.AD.2.4].

The wheel rides on an angle track (item 7 in dwg. 1928). The thickness of the angle is

$$t_a := 0.125 \cdot in$$

The wheel span (three wheels) is (see sheet 2, side view of Dwg. 1928)

$$s := 18.5 \cdot in$$

Therefore the direct stress in the leg of the angle is

$$\sigma_a := \frac{1}{2 \cdot \cos(45 \cdot deg) \cdot s \cdot t_a} \cdot 3 \cdot Load_{wheel}$$

$$\sigma_a = 8.97 \times 10^3 psi$$

Overstress in this track does not impede ready retrievability of the fuel. Nevertheless, for conservatism, the safety factor in accordance with Regulatory Guide 3.61 is evaluated for the material specified for the angle.

$$SF_{angle} := \frac{36000 \cdot psi}{3 \cdot \sigma_a} \qquad SF_{angle} = 1.338$$

3.AD.9 Housing Stress Analysis

The most limiting section that sets the minimum safety factor for the door housing under a lifting condition is the box structure adjacent to the track that serves as the direct load path to the bolts. In this section, a conservative estimate of the stress levels in this region is obtained and the safety factor established. The door load is transferred to the bottom plate by the wheels running on an angle track. The load is then transferred to two vertical stiffeners that form the side of the box. The top plate, forming the top of the box, serves as the structure that moves the load to the bolts.

The lid bottom plate of the housing (item 2 of Dwg. 1928) that directly supports the wheel loading can be conservatively considered as a wide plate supporting the load from one of the sliding doors. The applied load is transferred to the two vertical plates (items 3 and 4 of Dwg. 1928). Figure 3.AD.2 shows the configuration for analysis. The following dimensions are obtained from the drawing:

Length of analyzed section	$L_H := 25 \cdot in$	
Thickness of item 2	$t_{bottom} := 2 \cdot in$	From BM-1928
Thickness of item 3	$t_1 := 1.5 \cdot in$	
Thickness of item 4	$t_2 := 1 \cdot in$	
Width of item 21	$t_{21} := 3.5 \cdot in$	

With respect to Figure 3.AD.2, referring to the drawing, the length x is defined as a+b

$x := (.5 \cdot 93) \cdot in - 36.375 \cdot in$ $\quad x = 10.125\, in$

dimension "b" $\quad b := x - t_1 - t_{21} - .5 \cdot t_1$ $\quad b = 4.375\, in$

dimension "a" $\quad a := x - b$ $\quad a = 5.75\, in$

Compute the moment of inertia of item 2 at the root assuming a wide beam

$$I := L_H \cdot \frac{t_{bottom}^3}{12} \qquad I = 16.667\, in^4$$

The maximum bending moment in the bottom plate is given as,

$$Moment := 3 \cdot Load_{wheel} \cdot b \qquad Moment = 1.283 \times 10^5\, lbf \cdot in$$

The maximum bending stress is

$$\sigma_{bending} := \frac{Moment \cdot t_{bottom}}{2 \cdot I} \qquad \sigma_{bending} = 7.701 \times 10^3\, psi$$

The safety factor, based on primary bending stress (ASME Code evaluation), is

$$1.5 \cdot \frac{S_a}{\sigma_{bending}} = 3.409$$

It is concluded that this region is not limiting.

The safety factor based on Reg. Guide 3.61 (compare to 33% of yield strength) is

$$\frac{S_y}{3 \cdot \sigma_{bending}} = 1.415$$

The reactions at the two support points for the section are

$$F_1 := 3 \cdot Load_{wheel} \cdot \left(1 + \frac{b}{a}\right) \qquad F_1 = 5.166 \times 10^4\, lbf$$

$$F_2 := 3 \cdot Load_{wheel} \cdot \frac{b}{a} \qquad F_2 = 2.232 \times 10^4\, lbf$$

Therefore, consistent with the support assumptions, the direct stress in the two stiffeners is

$$\sigma_1 := \frac{F_1}{L_H \cdot t_1} \qquad \sigma_1 = 1.377 \times 10^3 \, \text{psi}$$

$$\sigma_2 := \frac{F_2}{L_H \cdot t_2} \qquad \sigma_2 = 892.822 \, \text{psi}$$

Safety factors, using the more conservative Reg. Guide 3.61 criteria, are

$$SF_1 := \frac{S_y}{3 \cdot \sigma_1} \qquad SF_1 = 7.913$$

$$SF_2 := \frac{S_y}{3 \cdot \sigma_2} \qquad SF_2 = 12.208$$

3.AD.10 Bolt Stress

Figure 3.AD.3 shows the bolt array assumed to resist the lifted load when the doors are closed and when the fully loaded MPC is being supported by the doors.

The bolt tensile stress area is, for the 1" diameter bolts

$$A_b := 0.605 \cdot \text{in}^2 \qquad d_{bolt} := 1 \cdot \text{in}$$

The bolt circle radius is

$$R_b := 45 \cdot \text{in}$$

The bolt angular spacing is $\theta := 10 \cdot \text{deg}$

The centroid of the nine bolts point P* in Figure 3.AD.3, assumed to carry 100% of the wheel load, is computed as follows:

$$A_{total} := 9 \cdot A_b \qquad A_{total} = 5.445 \, \text{in}^2$$

Compute the following sum:

$$\text{Sum} := 2 \cdot A_b \cdot R_b \cdot (1 - \cos(4 \cdot \theta)) + 2 \cdot A_b \cdot R_b \cdot (1 - \cos(3 \cdot \theta)) \ldots$$
$$+ 2 \cdot A_b \cdot R_b \cdot (1 - \cos(2 \cdot \theta)) + 2 \cdot A_b \cdot R_b \cdot (1 - \cos(\theta))$$

$\text{Sum} = 24.145\,\text{in}^3$

Then the centroid of the bolts is $X_{bar} := \dfrac{\text{Sum}}{A_{total}}$ $X_{bar} = 4.434\,\text{in}$

Compute the bolt moment of inertia about the centroid by first locating each bolt relative to the centroid. First compute some distances "z":

$z_1 := R_b \cdot (1 - \cos(4 \cdot \theta)) - X_{bar}$ $z_1 = 6.094\,\text{in}$

$z_2 := R_b \cdot (1 - \cos(3 \cdot \theta)) - X_{bar}$ $z_2 = 1.595\,\text{in}$

$z_3 := R_b \cdot (1 - \cos(2 \cdot \theta)) - X_{bar}$ $z_3 = -1.72\,\text{in}$

$z_4 := R_b \cdot (1 - \cos(\theta)) - X_{bar}$ $z_4 = -3.751\,\text{in}$

Then the bolt group moment of inertia about the centroid is,

$$I_{bolts} := 2 \cdot A_b \cdot z_1^2 + 2 \cdot A_b \cdot z_2^2 + 2 \cdot A_b \cdot z_3^2 + 2 \cdot A_b \cdot z_4^2 + A_b \cdot X_{bar}^2$$

$I_{bolts} = 80.507\,\text{in}^4$

The bolts must support the total wheel load acting on one rail, plus the additional load necessary to resist the moment induced about the bolt group centroid.

The moment arm is the distance from the bolt centroid to the angle guide rail

$\text{moment\_arm} := R_b - X_{bar} - 36.375 \cdot \text{in}$ $\text{moment\_arm} = 4.191\,\text{in}$

Therefore, the bolt array must resist the following moment

$\text{Moment}_{bolts} := 6 \cdot \text{Load}_{wheel} \cdot \text{moment\_arm}$ $\text{Moment}_{bolts} = 2.459 \times 10^5\,\text{in} \cdot \text{lbf}$ |

The bolt stress due to the direct load is:

$$\text{stress}_{\text{direct}} := 6 \cdot \frac{\text{Load}_{\text{wheel}}}{A_{\text{total}}} \qquad \text{stress}_{\text{direct}} = 1.078 \times 10^{4}\,\text{psi}$$

Compute $y_1 := R_b \cdot (1 - \cos(4 \cdot \theta)) - X_{\text{bar}}$ $\qquad y_1 = 6.094\,\text{in}$ $\quad$ > Xbar

Therefore, the highest bolt stress due to the bending moment is,

$$\text{stress}_{\text{moment}} := \frac{\text{Moment}_{\text{bolts}} \cdot y_1}{I_{\text{bolts}}} \qquad \text{stress}_{\text{moment}} = 1.861 \times 10^{4}\,\text{psi}$$

Therefore, the total bolt stress to support lifting, on the heaviest loaded bolt, is

$$\sigma_{\text{bolt}} := \text{stress}_{\text{direct}} + \text{stress}_{\text{moment}} \qquad \sigma_{\text{bolt}} = 2.939 \times 10^{4}\,\text{psi}$$

The above calculation has considered only the stress induced by the MPC and the door; that is, the stress induced in the bolts by the load transmitted through the wheels. The entire set of bolts acts to support the door housing and this induces an additional component of stress in the bolts. This is computed below:

The total bounding weight of the transfer lid is

$$W_{\text{tl}} = 2.45 \times 10^{4}\,\text{lbf}$$

The total door load already accounted for in the bolt analysis is

$$W_{\text{td}} := 4 \cdot W_{\text{door}} \qquad W_{\text{td}} = 1.204 \times 10^{4}\,\text{lbf}$$

Therefore the additional average stress component in the 36 bolts is

$$\sigma_{\text{avg}} := \frac{(W_{\text{tl}} - W_{\text{td}})}{36 \cdot A_b} \qquad \sigma_{\text{avg}} = 572.221\,\text{psi}$$

Therefore the absolute maximum bolt stress is

$$\sigma_{\text{bolt\_max}} := \sigma_{\text{bolt}} + \sigma_{\text{avg}} \qquad \sigma_{\text{bolt\_max}} = 2.996 \times 10^{4}\,\text{psi}$$

The allowable bolt load is obtained from the ASME Code, Subsection NF, NF-3324.6 as 50% of the ultimate strength of the bolts. The bolts are assumed to be at a temperature below 200 degrees F because of their location.

$S_{ubolt} := 115000 \cdot psi$ @200 deg. F Table 3.3.4

$S_{ybolt} := 95000 \cdot psi$

Therefore, the bolt safety factor is

$$SF_{bolts} := \frac{.5 \cdot S_{ubolt}}{\sigma_{bolt\_max}} \qquad SF_{bolts} = 1.919$$

The transfer lid bolt preload required is

$T := .12 \cdot \sigma_{bolt\_max} \cdot A_b \cdot d_{bolt}$ [3.AD.3] $T = 181.246 ft \cdot lbf$

Note that this exceeds the value calculated for the pool lid.

The safety factor using the Reg. Guide 3.61 criteria is

$$SF_{3.61} := \frac{S_{ybolt}}{3 \cdot \sigma_{bolt\_max}} \qquad SF_{3.61} = 1.057$$

Calculation of Thread Capacity

The following calculations are taken from Machinery's Handbook, 23rd Edition, pp. 1278-1279 plus associated screw thread Table 4, p 1514.

Input Geometry Data - 1" UNC, 8 threads/inch, 2A class

$L_e := 1.0 \cdot in$ Thread engagement length

$N := \frac{8}{in}$ Threads per inch

$D_m := 1 \cdot in$ Basic Major Diameter of threads

$D := .9755 \cdot in$ Minimum Major Diameter of External Threads

$E_{min} := .91 \cdot in$ Minimum Pitch Diameter of External Threads

$E_{max} := .9276in$ Maximum Pitch Diameter of Internal Threads

$K_n := .89 \cdot in$ Maximum Minor Diameter of Internal Threads

Input Yield Strength-Internal Threads (lid or forging); External Threads (bolts)

Values are obtained from ASME Code,Section II)

$Sy_{lid} := 38000 \cdot psi$ $Su_{lid} := 70000 \cdot psi$ $Su_{bolt} := S_{ubolt}$

Calculation of Tensile stress area (high-strength bolt, ultimate strength exceeding 100,000 psi)

$$A_{th} := \pi \cdot \left(.5 \cdot E_{min} - \frac{0.16238}{N}\right)^2 \qquad A_{tl} := .7854 \cdot \left(D_m - \frac{.9743}{N}\right)^2$$

$$A_{th} = 0.594\,in^2 \qquad A_{tl} = 0.606\,in^2$$

$$A_t := if\left(Su_{bolt} > 100000 \cdot psi, A_{th}, A_{tl}\right) \qquad A_t = 0.594\,in^2$$

Calculation of Shear Stress Area per the Handbook

$$A_{ext} := \pi \cdot N \cdot L_e \cdot K_n \cdot \left[\frac{0.5}{N} + 0.57735 \cdot \left(E_{min} - K_n\right)\right] \qquad A_{ext} = 1.656\,in^2$$

$$A_{int} := \pi \cdot N \cdot L_e \cdot D \cdot \left[\frac{0.5}{N} + 0.57735 \cdot \left(D - E_{max}\right)\right] \qquad A_{int} = 2.21\,in^2$$

Required Length of Engagement per Machinery's Handbook

$$L_{req} := 2 \cdot \frac{A_t}{\frac{A_{ext}}{L_e}} \qquad L_{req} = 0.717\,in$$

Capacity Calculation Using Actual Engagement Length

For the specified condition, the allowable tensile stress in the bolt is per ASME NF

$\sigma_{bolt} := Su_{bolt} \cdot 0.5$ $\qquad \sigma_{bolt} = 5.75 \times 10^4 psi$

The allowable shear stress in the bolt is:

$$\tau_{bolt} := \frac{.62 \cdot Su_{bolt}}{3} \qquad \tau_{bolt} = 2.377 \times 10^4 psi$$

The allowable shear stress in the lid (or flange) is

$$\tau_{lid} := 0.4 \cdot Sy_{lid} \qquad \tau_{lid} = 1.52 \times 10^4 psi$$

$$F_{shear\_lid} := \tau_{lid} \cdot A_{int} \qquad F_{shear\_lid} = 3.36 \times 10^4 lbf$$

For the bolt, the allowable strength is the yield strength

$$F_{tensile\_bolt} := \sigma_{bolt} \cdot A_t \qquad F_{tensile\_bolt} = 3.414 \times 10^4 lbf$$

$$F_{shear\_bolt} := \tau_{bolt} \cdot A_{ext} \qquad F_{shear\_bolt} = 3.936 \times 10^4 lbf$$

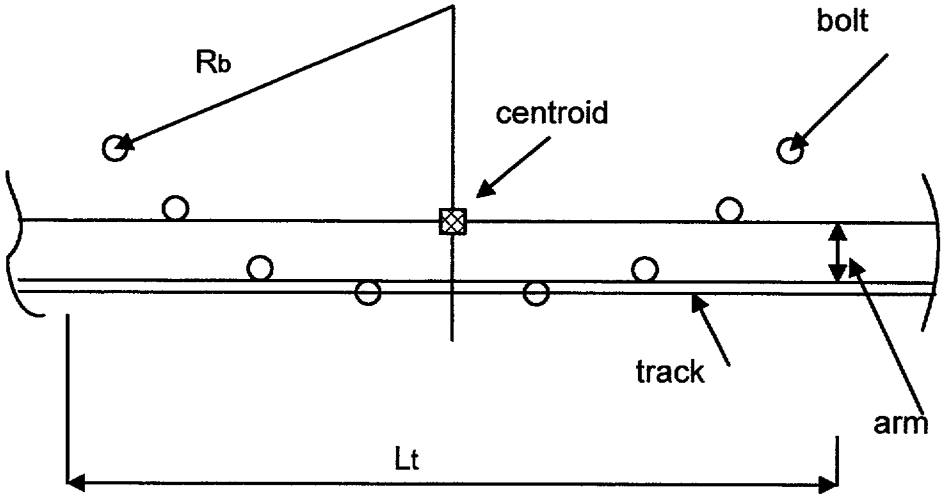
Therefore, thread shear in lid governs the design. The safety factors computed above should by multiplied by the ratio

$$\frac{F_{shear\_lid}}{F_{tensile\_bolt}} = 0.984$$

3.AD.11 Estimate of Primary Bending Stress in Lid Top Plate

The lid top plate maximum primary stresses develop due to the structural requirement of transferring the wheel loads to the bolt array. Based on the assumptions above as to the number of bolts participating in the support of the load, a total direct load and a bending moment is reacted by the bolt array. The active bolts have been assumed to be only those bolts in an 80 degree arc (see Figure 3.AD.3). To estimate the minimum safety factor inherent in the top plate, it is assumed that the same bending moment must also be reacted by the the lid top plate. The sketch below aids in the analysis:

The analysis is conservative as it neglects any support from either plate or bolts outside of the section identified.



The view shown is similar to the view in Figure 3.AD.3 with identification of terms for use in the following analysis;

$\text{arm} := \text{moment\_arm}$ $\quad$ $\text{arm} = 4.191\,\text{in}$

$\text{Moment} := \text{Moment}_{\text{bolts}}$ $\quad$ $\text{Moment} = 2.459 \times 10^{5}\,\text{in}\cdot\text{lbf}$

$L_t := R_b \cdot 2 \cdot \sin(45 \cdot \text{deg})$ $\quad$ $L_t = 63.64\,\text{in}$

The thickness of the lid top plate is

$t_p := 1.5 \cdot \text{in}$ $\quad$ item 1 in BM-1928

The safety factor is established by considering the bending moment in the section of top plate a distance "arm" away from the track.

$$I_p := \frac{L_t \cdot t_p^{\,3}}{12} \qquad I_p = 17.899\,\text{in}^4$$

The primary bending stress is

$$\sigma_{tp} := \frac{\text{Moment} \cdot t_p}{2 \cdot I_p} \qquad \sigma_{tp} = 1.03 \times 10^{4}\,\text{psi}$$

The limiting safety factor is obtained by consideration of the Regulatory Guide 3.61 criteria. Therefore,

$$SF_{tp} := \frac{S_y}{3 \cdot \sigma_{tp}} \qquad SF_{tp} = 1.058$$

Similarly, the average shear stress developed across the section is

$$\tau_{tp} := 6 \cdot \frac{Load_{wheel}}{t_p \cdot L_t} \qquad \tau_{tp} = 614.619\,psi$$

The safety factor against primary shear overstress is large.

$$SF_{shear} := .6 \cdot \frac{S_y}{3 \cdot \tau_{tp}} \qquad SF_{shear} = 10.641$$

In the above safety factor calculation, the yield strength in shear is assumed as 60% of the yield strength in tension for the Reg. Guide 3.61 evaluation.

The validity of the approximate strength of materials calculation has been independently verified by a finite element analysis (see calculation package HI-981928).

3.AD.11 Separation of Transfer Lid from HI-TRAC

In the event of a side drop while HI-TRAC is in a horizontal position, the transfer lid housing will impact the ground, and the HI-TRAC body, including the MPC, will attempt to separate from the lid. Appendix 3.AN provides a detailed dynamic analysis of the handling accident and provides the interface load that must be transferred by the bolts.

From Appendix 3.AN, Section 3.AN.2.7, we find the following results for the 125- ton HI-TRAC:

$$Interface\_Force := 1272000 \cdot lbf$$

We now demonstrate that this load can be transferred by a combination of bolt shear and interface friction.

3.AD.11.1 Shear Capacity of 36 SA 193 B7 bolts

Number of bolts $nb := 36$

$S_{ubolt} = 1.15 \times 10^{5} psi$ $A_b := A_t$

$Bolt\_Capacity := nb \cdot .6 \cdot S_{ubolt} \cdot A_b$ $Bolt\_Capacity = 1.475 \times 10^{6} lbf$

Note that here we are performing a failure analysis

3.AD.11.2 Shear Capacity due to Friction - 125 Ton HI-TRAC

Table 8.1.5 lists the actual preload torque as $T_{act} := 270 \cdot ft \cdot lbf$

The calculated bolt torque requirement is $T = 181.246 ft \cdot lbf$

Therefore the actual clamping force per bolt is:

$T_{clamp} := \frac{T_{act}}{T} \cdot \sigma_{bolt\_max} \cdot A_b$ $T_{clamp} = 2.649 \times 10^{4} lbf$

Following ASME, Section III, Subsection NF, NF-3324.6(4) for a blast cleaned joint, the frictional resistance for the assemblage of bolts is:

$P_s := nb \cdot T_{clamp} \cdot 0.31$ $P_s = 2.957 \times 10^{5} lbf$

Note that since we are evaluating a side drop, the actual value of the clamping force may be used since there is no other tensile load acting on the bolts.

Therefore, the total shear capacity, based on ultimate strength in shear, is

$Shear\_Capacity := Bolt\_Capacity + P_s$

$Shear\_Capacity = 1.77 \times 10^{6} lbf$

The safety factor for lid separation is defined as

$SF := \frac{Shear\_Capacity}{Interface\_Force}$ $SF = 1.392$

It is concluded that there will be no separation of the HI-TRAC 125 from the transfer lid.

3.AD.12 Analysis of Door Lock Bolts (Item 22 of Dwg. 1928, Sheet 1)

Under the design basis side drop handling accident, the transfer lid doors (both) are restrained only by the two door lock bolts. Since the doors must remain closed to maintain shielding, these bolts need to have sufficient shear capacity to resist the door deceleration loading. The following calculation demonstrates that the door lock bolts have the desired shear capacity. The following input data is required to obtain a result:

$G_{max} = 45$

$D_{bolt} := 3.0 \cdot in$ Door lock bolt diameter per 125 ton transfer cask bill of materials.

$S_{abolt} := .42 \cdot S_{ubolt}$ Level D event per Appendix F of ASME Code

$Total\_Load := 4 \cdot W_{door}$ $Total\_Load = 1.204 \times 10^4 \, lbf$

Recall that W_{door} has been defined in 3.AD.8 as 50% of the weight of one(of two) doors. The door bolt area is

$D_{bolt} = 3 \, in$ $n := 4$ Threads/inch

The stress area is computed from the following formula (Machinery's Handbook, Industrial Press, NYC, 23rd Edition, p. 1279,)

$$A_{bolt} := \pi \cdot \left(\frac{D_{bolt}}{2} - \frac{0.16238}{n} \cdot in \right)^2 \qquad A_{bolt} = 6.691 \, in^2$$

There are two bolts which support load and there are two shear faces per bolt (see section B-B on Dwg. 1928). The shear stress in the bolt section is

$$\tau_{bolt} := Total\_Load \cdot \frac{G_{max}}{2 \cdot 2 \cdot A_{bolt}} \qquad \tau_{bolt} = 2.024 \times 10^4 \, psi$$

Therefore, the safety factor on bolt shear stress is

$$SF_{bolt\_shear} := \frac{S_{abolt}}{\tau_{bolt}} \qquad SF_{bolt\_shear} = 2.387$$

and no loss of shielding will occur since the doors will be retained in place.

APPENDIX 3.AE: GLOBAL ANALYSIS OF HI-TRAC LIFT

3.AE.1 Introduction

The global analysis of the 125 ton HI-TRAC lift is performed in this Appendix to show that the general primary stresses in the top flange, the inner shell, and the outer shell in the vicinity of the trunnion attachment do not exceed 17,500 psi and 1.5 x 17,500 psi = 26,250 psi for membrane and membrane plus bending stress, respectively, in accordance with requirements of the ASME Code, Section III, Subsection NF, for Level A conditions. In addition, we show in this ~~appendix that~~**appendix that** the **primary membrane stress, conservatively averaged over the width of the interface between the base of the trunnion block and the outer shell,** ~~average stress across the highest loaded section modeled~~ does not exceed one-third of the material yield stress at temperature; this is in keeping with the requirements of USNRC Regulatory Guide 3.61. The trunnion and the trunnion block are modeled only to the extent necessary to insure that the proper moment arm is present. The analysis of the threaded lifting trunnions and the trunnion weldments at the top end of the 125 ton HI-TRAC are documented in Appendix 3.E.

A separate analysis is also performed in this appendix to evaluate the stress state in the lower part of the HI-TRAC flange when the bounding lid is in place. Specifically, it is shown that the bottom flange of HI-TRAC and the inner and outer shells meet the allowable stress limits of ASME Section III, Subsection NF, for Class 3 plate and shell structures. It is also demonstrated that the allowable stress limits imposed by Regulatory Guide 3.61 for a lifting operation are met. The imposed loading on the flange is the limiting bolt loading obtained from the analyses of the HI-TRAC pool lid (Appendix 3.AB) and the HI-TRAC transfer lid analyses (Appendices 3.AD and 3.AJ).

3.AE.2 Assumptions for Analysis of Upper Portion of HI-TRAC-125

The analysis in this appendix is based on the following conservative assumptions:

1. The analysis does not take any structural credit for the lead shielding annulus between the inner shell and the outer shell.

2. The analysis does not take any structural credit for the steel water jacket **on**~~at~~ the outer surface of the outer shell **that is in close proximity to the trunnion.**

3. The cask component temperature during lifting operation is taken as 2~~3~~00~~50~~ degrees F. **This is based on an evaluation of actual MPC temperatures at the top of the cask.**

4. The weight of the loaded HI-TRAC **is the bounding weight amplified by 15%**

to account for dynamic effects, ~~taken as 376,296 pounds in this evaluation, is conservatively 151% higher than the documented maximum loaded wet weight listed in Table 3.2.4.~~

~~9.~~5. The load on the upper trunnion is ~~conservatively~~ **positioned at the midpoint of a 2.5" wide contact interface located at the outermost position of** ~~located at the outer tip of~~ the trunnion barrel. **This is conservative since during a heavy lift, the load will shift towards the inner edge of the initial contact interface area.**

3.AE.3 Finite Element Model

A 3-D, 1/4-symmetry model of the HI-TRAC structure near the lifting trunnion is constructed using **the** ANSYS [1] 3-D isoparametric element SOLID45 as shown in Figures 3.AE.1a, ~~3.AE.1b,~~ and 3.AE.**2**~~1c~~. The finite element plots ~~(Figures 3.AE.1a-3AE.1c)~~ are coded according to the particular properties of each HI-TRAC component modeled, i.e., shades of blue for the shells and the top flange, red for the threaded trunnion, and purple for the trunnion block. **The Young' Moduli for the three structural components are assigned values commensurate with the assumed operating temperature.**~~The Poisson's ratio is taken as 0.29 for all components. The Young's modulus for the inner and outer shells taken as 28.3E+06 psi.~~ The ~~Young's modulus for the threaded trunnion is taken as 27.8E+06 psi (Table 3.3.4). The~~ base of the finite element model is restrained from vertical movement while a concentrated vertical force equal to 1/4 of the assumed loaded weight is applied to a node point located on the trunnion axis at the **appropriate position near the**~~outermost~~ end of the trunnion elements. **Note that t**~~T~~he trunnion stress analysis is performed in Appendix 3.E, consistent with NRC accepted methodology, so a detailed local stress analysis **of the trunnion barrel** is not required here.

3.AE.4 Stress Evaluation From Finite Element Analysis

The applied load is 0.25 x 250,000 lb. x 1.15 = 71,875 lb. The load is positioned at a node point on the trunnion centerline that is a radial distance of 45.0 inch – 1.25 inch = 43.75 inch from the longitudinal (vertical) centerline of the HI-TRAC. The subtraction of 1.25 inch reflects the geometry of the lift yoke arm that attaches to the trunnion during a lifting operation. The full width and longitudinal dimension of the trunnion block in the model are 10 inches. A static stress analysis is performed and the stress ~~intensity~~ distributions evaluated. For this loading scenario, **the largest stress (a normal stress parallel to the cask longitudinal axis) occurs at the interface between the base of the trunnion block and the interface with the edge of the outer shell (1 inch thick). The interface contact stress results show the local character of this stress with a significant variation occurring both through the thickness of the outer shell and along the circumferential length of the interface (10 inch).** ~~stress-~~ ~~intensities~~ ~~at surface locations will be equal to or bound the maximum stresses. The stress intensities calculated for the load of 376,296 lbs in the inner and outer shells are plotted in~~

~~Figure 3.AE.2.~~ In the following, the evaluation of the safety factors existing in the structure is consistent with ASME, Section III, Subsection NF for a Class 3 plate and shell structure. **As this analysis involves a non-axisymetric geometry and loading, a comparison of the primary stress state with NF allowable values can only be performed once a characteristic width of section is defined (In a pressure vessel, such a definition is not required as the stresses are independent of peripheral position). To this end, we note that ASME Code Section III, NB-3213.10 provides guidance on the extent of the region over which local stresses are categorized. Specifically, a characteristic length L in the circumferential direction no smaller than**

$$L = 2\sqrt{Rt}$$

need be considered in the calculation of primary stresses for comparison with NF allowable stress levels. In the above equation, R is the radius of curvature of the mid-surface of the outer shell and t is the outer shell thickness. For the HI-TRAC 125,

R = (.5 x 81.25"-0.5") = 40.125" and t=1.0"

Therefore the characteristic circumferential length, over which the stress state is averaged, prior to comparing with Code allowable stress values, is:

L = 12.67"

Noting that this characteristic circumferential length exceeds the actual interface circumferential length, we conservatively evaluate the stress state by averaging over the entire 10" interface width along the base of the trunnion block and the outer shell. By virtue of the rapid decay in the stress magnitude as we move away from the centerline of the trunnion, the use of a lower characteristic length leads to a conservatively larger stress value.

We seek safety factors on ~~maximum normal~~ primary membrane stress and ~~maximum normal~~ surface~~primary~~ membrane stress plus ~~primary~~ bending stress **associated with the above section**~~across the heavily stressed sections~~ as defined by the ASME Code.

The interface nodes are identified and the normal stresses in the global "Z" direction identified and averaged to obtain the longitudinal primary membrane stress for the outer shell section. Since moment equilibrium is primarily provided by the force associated with this stress component (and an opposing force on the inner shell), the stress variation through the thickness of the individual shells at the interface is most properly characterized as a secondary in the Code nomenclature. Nevertheless, in the evaluation of safety factors associated with satisfaction of ASME Code NF stress levels for a single shell

acting as a pressure vessel, we conservatively include this local through thickness variation in the safety factor calculation. To this end, the subset of nodes associated with the outer surface of the outer shell at the interface is separately identified and the normal stresses in the global "Z" direction identified and averaged to obtain the membrane plus bending stress for the section. The following results are obtained:

Membrane stress (averaged over the characteristic circumferential width) = 6,185.9 psi
Surface stress (averaged over the characteristic circumferential width) = 8,191.9 psi

~~The maximum primary membrane stress intensity in the shells can be conservatively taken as 15,800 psi (a bounding average of 14,689 psi and 16,782 psi). The maximum primary membrane plus primary bending stress intensity is 18,875 psi. These values are obtained from the results plotted in Figure 3.AE.2. As can be seen from Figure 3.AE.2, regions of high stress are very localized in a small region at the trunnion block weldment.~~ An evaluation of safety factors at this location provides the lower bound to safety factors at all other sections of the region modeled.

Comparison with Level A allowables **(Table 3.1.10) is provided below:**~~ using stress rather than stress intensities gives conservative safety factors for membrane and for membrane plus bending as (allowable stresses taken from Table 3.1.10):~~

SF(primary membrane) = 17,500 psi ~~x 1.51~~/**6,185.9**~~15,800~~ psi = **2.83**~~1.67~~

SF(primary membrane plus primary bending) = 26,250 psi~~ x 1.51~~/**8,191.9**~~18,875~~ psi = **3.2**~~2.10~~

~~Note that we have introduced the factor 1.51 to produce safety factors that reflect the actual lifted load.~~ Consistent with the definition of safety factors in other sections of this TSAR, the safety factor is defined as the allowable value divided by the calculated value.

~~These are results at the highest loaded point. To insure that the Regulatory Guide requirement that the stress at any point in the HI-TRAC body be less than the material yield strength under three times the lifted load, four stiffeners have been added under the trunnion block to increase the metal area and the local metal moment of inertia (see Figure 3.AE.4). The effect of the addition of these stiffeners (not included in the finite element analysis) is to replace the plate section under the trunnion block (10 inch x 1 inch thick) by four "Tee" sections. (See Drawing 1880, sheet 8 for HI-TRAC 125) The revised stress at the most heavily loaded point is conservatively computed by multiplying the stress result from the finite element analysis by the maximum of the following two ratios:~~

~~Ra = Metal Area without stiffeners/Metal Area with stiffeners = 0.769~~

~~Rb = (I/c) without stiffeners/ (I/c) with stiffeners = 0.635~~

~~In the calculation of "Rb", I is the metal moment of inertia of either the plate or four T-sections, and "c" is the respective maximum distance to an extreme fiber from the neutral axis.~~

~~Therefore, the maximum stress intensity, reflecting the presence of stiffeners, is:~~

~~SI = (3 x 18,875 psi / 1.51) x 0.769 = 28,838 psi~~
Consistent with the intent of Regulatory Guide 3.61, we compare the primary membrane stress in the outer shell with 1/3 of the material yield strength of the shell material. Yield strength data for SA-516 at 200 degrees F is used in the calculation.
~~This result is less than the material yield strength of 33,150 psi at 350 degrees F (Table 3.3.2). Therefore, we conclude that at the most limiting section, the average stress intensity is below 1/3 of the material yield strength at temperature. The corresponding safety factor is 33,150/28,838 = 1.15~~
SF(Reg. Guide 3.61) = 34,600 psi/(3 x 6185.9) = 1.86

We conclude that the construction satisfies the intent of Regulatory Guide 3.61, Section 3.4.3.

3.AE.5 Analysis of HI-TRAC 125 Bottom Flange

Appendix 3.AD contains an analysis of the transfer lid for HI-TRAC 125 to demonstrate structural integrity during the postulated lifting operation. The bounding lifted load at that location is the bounding weight of the loaded MPC together with the bounding weight of the transfer lid. The results from Appendix 3.AD bound the results for the smaller HI-TRAC in Appendix 3.AJ. The transfer lid establishes the bolt preload for the transfer cask application. Appendix 3.AB examines the pool lid under the same conditions. Since there is water in the cask during this operation, the lifted weight, including the water, exceeds the lifted weight -when the transfer lid is in place. Therefore, a bounding flange analysis is undertaken that uses the results from the pool lid evaluation as the input to the calculation.

From Appendix 3.AB, for the 125 Ton HI-TRAC, the total bolt load, including a 15% amplification factor, is

T = 137,400 lb. (Appendix. 3.AB, subsection 3.AB.8)

Conservatively assuming that all of the bolt preload is removed when the lift commences, the flange is modeled as an annular plate subjected to a total peripheral load applied at the outer diameter (bolt circle diameter = 90") and clamped by the HI-TRAC inner and outer shells at a ~~diameter equal~~**diameter equal** to 72". Figure 3.AE.3 shows a free body of a section of the flange with the total load from the bolts "T" and the reaction loads "T1" and "T2" in the inner and outer shells, respectively. This annular plate solution giving maximum bending stress, due to the load "T", is available in the classical plate literature [2]. It is conservatively assumed that the outer periphery of the flange is free to rotate. In the actual loaded configuration, there is some restraint to flange rotation provided by the flange of the fastened lid. Specifically, Case 8 in Figure 38 of [2] (Table 3) gives the maximum bending stress in the form

Stress = k x T/h^2

where k is a constant depending on the flange inner and outer diameters, T is the total bolt load, and "h" is the flange thickness. For the diameter ratio 90"/72" = 1.25, the constant k = 0.227. The bottom flange thickness "h" is

h = 2" (Bill-of-Materials -1880)

Therefore, under the amplified lifted load, the maximum bending stress in the flange is

Stress = 0.227 x 137,400 lb./4 sq.inch = 7797.5 psi

The allowable stress permitted by the governing ASME "NF" subsection is 1.5 x 17,500 psi = 26,250 psi. Therefore, the safety factor, considering this flange as an NF plate component, is

Safety Factor = 26,250psi/7798psi = 3.37

Alternately, applying the Regulatory Guide 3.61 criteria (a comparison with 33.3% of tensile yield strength at temperature **(here we use 350 degrees F as the operating temperature)** to establish the safety factor gives

Safety Factor = 33,150 psi/(3 x 7797.5psi) = 1.42

This result for the HI-TRAC 125 bounds the similar result that would be obtained for the HI-TRAC 100 since the lifted load is lower and the bolt circle diameter is smaller.

The peripheral loading from the bolts is resisted by direct loads in the inner and outer shells to maintain equilibrium. These loads develop primary membrane stress in the respective shells. The connecting welds are full penetration so consideration need only be given to the direct stress in the two shells. Conservatively neglecting any reduction in the moment due to circumferential bending stresses induced in the narrow plate, the loads and stresses in the shells can be determined using the free body sketch shown in Figure 3.AE.3.

Let r_1, r_2, and r_o be the mean radius of the inner shell, outer shell, and bolt circle, respectively.

From BM-1880 and the associated drawings, the values are:

r_1 = .5 x (68.75" + 0.75") = 34.75"

$r_2 = .5 \times (81.25'' - 1.00'') = 40.125''$
$r_o = 45''$

Then if T1 and T2 are the total tensile forces in the inner and outer shells, respectively, force and moment equilibrium equations applied to a unit peripheral section of the annular ring, yield:

$T1 + T2 = T$

$T(r_o - r_1) - T2(r_2 - r_1) = 0$

The solution for T1 and T2 are

$T1 = -(r_o - r_2)T/(r_2 - r_1)$ $\quad\quad$ $T2 = (r_o - r_1)T/(r_2 - r_1)$

or

T1 = -124,619 lb.

T2 = +262,019 lb.

Therefore, the average stresses in the shells are
Inner shell Stress = T1/(3.14159 x 69.5" x 0.75") = -761 psi

Outer shell Stress = T2/(3.14159 x 80.25" x 1") = +1039 psi

Large factors of safety exist in the shells under this lifting condition. Under the more limiting Regulatory Guide 3.61 limit, the safety factor is:

Safety Factor = 33,150psi/(3 x 1,039psi) = 10.63

3.AE.6 Conclusion

The analysis in this appendix shows that the design of the 125 ton HI-TRAC is adequate for lifting and meets the requirements imposed by ASME Section III, Subsection NF for Class 3 plate and shell structures. Further, the intent of Regulatory Guide 3.61 to limit stresses under a lift to 33.3% of tensile yield strength is also satisfied. The safety factors calculated in this appendix provide a lower bound to the safety factors existing at all sections of the HI-TRAC subject to primary stresses during the lifting operation.

3.AE.7 Reference

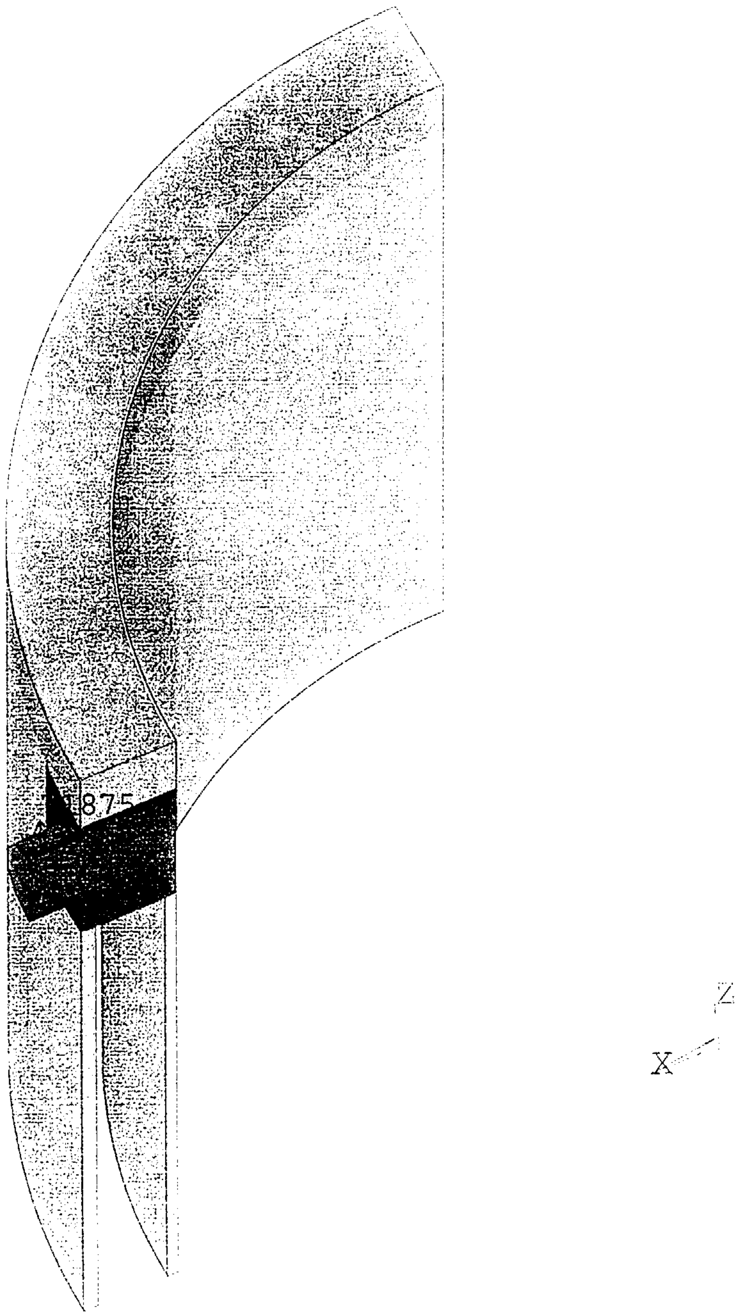
1. ANSYS, General Purpose Finite Element Code, Revisions 5.3, 5.4, ANSYS Inc.

2. Timoshenko and Woinowsky-Kreiger, Theory of Plates and Shells, 2nd Edition, McGraw-Hill, 1959, Chapter 3, Table 3.

~~FIGURE 3.AE.3; FREE-BODY OF HI-TRAC 125 BOTTOM FLANGE SHOWING LOAD FROM LID BOLTS "T" AND EQUILIBRIUM LOADS "T1" AND "T2" IN THE INNER AND OUTER SHELLS~~

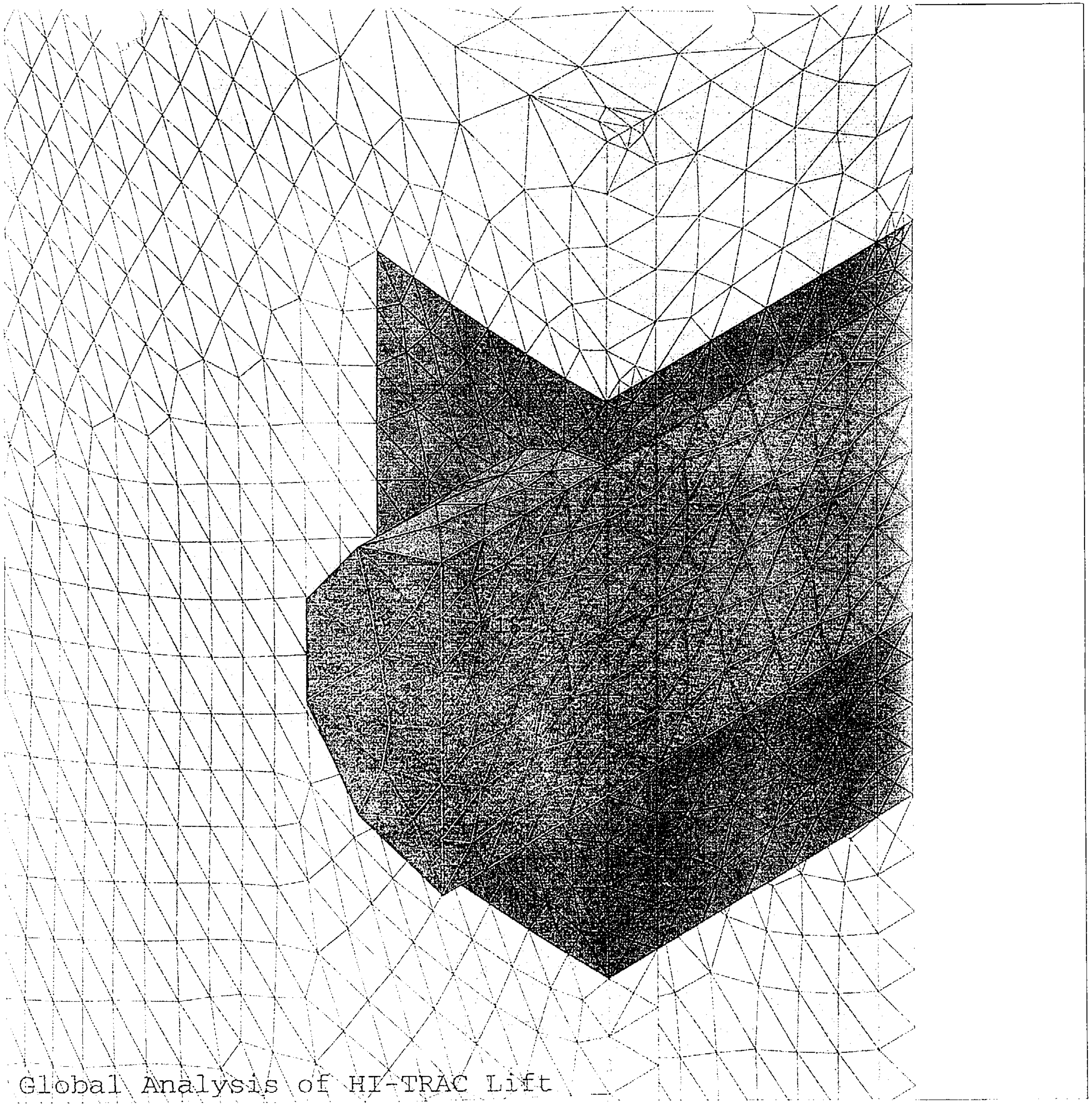
ANSYS 5.4
MAR 29 2000
15:13:21
ELEMENTS
MAT NUM
F

XV =1
YV =2
ZV =3
DIST=41.595
XF =22.25
YF =-20.563
ZF =25.25
VUP =Z
CENTROID HIDDEN
EDGE



Global Analysis of HI-TRAC Lift

FIGURE 3.AE.1



Global Analysis of HI-TRAC Lift

FIGURE 3.AE.2

APPENDIX 3.AF: MPC TRANSFER FROM HI-TRAC TO HI-STORM 100 UNDER COLD CONDITIONS OF STORAGE

3.AF.1 Scope

In this calculation, estimates of operating gaps, both radially and axially, are computed for the fuel basket-to-MPC shell, and for the MPC shell-to-overpack. This calculation is in support of the results presented in Section 3.4.5. A hot MPC is lowered from a HI-TRAC transfer cask into a storage overpack assumed to be at steady state temperatures appropriate to cold conditions of storage.

3.AF.2 Methodology

Bounding temperatures are used to construct temperature distributions that will permit calculation of differential thermal expansions both radially and axially for the basket-to-MPC gaps, and for the MPC-to-overpack gaps. Reference temperatures are set at 70°F for all components. A comprehensive nomenclature listing is provided in Section 3.AF.6.

3.AF.3 References

[3.AF.1] Boley and Weiner, Theory of Thermal Stresses, John Wiley, 1960, Sec. 9.10, pp. 288-291.

[3.AF.2] Burgreen, Elements of Thermal Stress Analysis, Arcturus Publishers, Cherry Hill NJ, 1988.

3.AF.4 Calculations

3.AF.4.1 Input Data

Based on thermal calculations in Chapter 4 and results from Appendix 3.I, the following temperatures are appropriate at the middle of the cask (see Figure 3.I.1 and Table 4.4.9).

The temperature change at the overpack inner shell, $\Delta T_{1h} := 0 - 70$

The temperature change at the overpack outer shell, $\Delta T_{2h} := 0 - 70$

The temperature change at the mean radius of the MPC shell, $\Delta T_{3h} := 498 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (576 - 70)\cdot 1.1$

The temperature change at the center of the basket (helium gas), $\Delta T_{5h} := 934 - 70$

Note that the outer basket temperature is conservatively amplified by 10% to insure a bounding parabolic distribution. This conservatism serves to maximize the growth of the basket.

The geometry of the components are as follows (referring to Figure 3.AF.1)

The outer radius of the overpack, $b := 66.25 \cdot in$ The inner radius of the overpack, $a := 34.75 \cdot in$

The mean radius of the MPC shell, $R_{mpc} := \frac{68.375 \cdot in - 0.5 \cdot in}{2}$ $R_{mpc} = 33.938\,in$

The initial MPC-to-storage overpack radial clearance, $RC_{mo} := .5 \cdot (69.5 - 68.5) \cdot in$

$RC_{mo} = 0.5\,in$

This initial radial clearance value, used to perform a radial growth check, is conservatively based on the channel radius (see Dwg. 1495, Sh. 5) and the maximum diameter of the MPC. For axial growth calculations for the MPC-to-overpack lid clearance, the axial length of the overpack is defined as the distance from the top of the pedestal platform to the bottom of the lid bottom plate, and the axial length of the MPC is defined as the overall MPC height.

The axial length of the overpack, $L_{ovp} := 191.5 \cdot in$

The axial length of the MPC, $L_{mpc} := 190.5 \cdot in$

The initial MPC-to-overpack nominal axial clearance, $AC_{mo} := L_{ovp} - L_{mpc}$

$AC_{mo} = 1\,in$

For growth calculations for the fuel basket-to-MPC shell clearances, the axial length of the basket is defined as the total length of the basket and the outer radius of the basket is defined as the mean radius of the MPC shell minus one-half of the shell thickness minus the initial basket-to-shell radial clearance.

The axial length of the basket, $L_{bas} := 176.5 \cdot in$

The initial basket-to-MPC lid nominal axial clearance, $AC_{bm} := 2 \cdot in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875 \cdot in$

The outer radius of the basket, $R_b := R_{mpc} - \frac{0.5}{2} \cdot in - RC_{bm}$ $R_b = 33.5\,in$

The coefficients of thermal expansion used in the subsequent calculations are based on the mean temperatures of the MPC shell and the basket (conservatively estimated high).

The coefficient of thermal expansion for the MPC shell, $\alpha_{mpc} := 9.338 \cdot 10^{-6}$

The coefficient of thermal expansion for the basket, $\alpha_{bas} := 9.90 \cdot 10^{-6}$ 600 deg. F

3.AF.4.2 Thermal Growth of the Overpack

Results for thermal expansion deformation and stress in the overpack are obtained here. The system is replaced by a equivalent uniform hollow cylinder with approximated average properties.

Based on the given inside and outside surface temperatures, the temperature solution in the cylinder is given in the form:

$$C_a + C_b \cdot \ln\left(\frac{r}{a}\right)$$

where

$$C_a := \Delta T_{1h} \qquad C_a = -70$$

$$C_b := \frac{\Delta T_{2h} - \Delta T_{1h}}{\ln\left(\frac{b}{a}\right)} \qquad C_b = 0$$

Next, form the integral relationship:

$$Int := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\,dr$$

The Mathcad program, which was used to create this appendix, is capable of evaluating the integral "Int" either numerically or symbolically. To demonstrate that the results are equivalent, the integral is evaluated both ways in order to qualify the accuracy of any additional integrations that are needed.

The result obtained through numerical integration, $Int = -1.114 \times 10^5\,in^2$

To perform a symbolic evaluation of the solution the integral "Ints" is defined. This integral is then evaluated using the Maple symbolic math engine built into the Mathcad program as:

$$Int_s := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\,dr$$

$$Int_s := \frac{1}{2} \cdot C_b \cdot \ln\left(\frac{b}{a}\right) \cdot b^2 + \frac{1}{2} \cdot C_a \cdot b^2 - \frac{1}{4} \cdot C_b \cdot b^2 + \frac{1}{4} \cdot C_b \cdot a^2 - \frac{1}{2} \cdot C_a \cdot a^2$$

$$Int_s = -1.114 \times 10^5\,in^2$$

We note that the values of Int and Ints are identical. The average temperature change in the overpack cylinder (T_{bar}) is therefore determined as:

$$T_{bar} := \frac{2}{\left(b^2 - a^2\right)} \cdot Int \qquad T_{bar} = -70$$

In this case, the result of the calculation is obvious and simply affords an independent check!!

We estimate the average coefficient of thermal expansion for the overpack by weighting the volume of the various layers. A total of four layers are identified for this calculation. They are:

1) the inner shell
2) the shield shell
3) the radial shield
4) the outer shell

Thermal properties are based on estimated temperatures in the component and coefficient of thermal expansion values taken from the tables in Chapter 3. The following averaging calculation involves the thicknesses (t) of the various components, and the estimated coefficients of thermal expansion at the components' mean radial positions. The results of the weighted average process yields an effective coefficient of linear thermal expansion for use in computing radial growth of a solid cylinder (the overpack).

The thicknesses of each component are defined as:

$$t_1 := 1.25 \cdot in$$

$$t_2 := 0.75 \cdot in$$

$$t_3 := 26.75 \cdot in$$

$$t_4 := 0.75 \cdot in$$

and the corresponding mean radii can therefore be defined as:

$$r_1 := a + .5 \cdot t_1 + 2.0 \cdot in$$ (add the channel depth)

$$r_2 := r_1 + .5 \cdot t_1 + .5 \cdot t_2$$

$$r_3 := r_2 + .5 \cdot t_2 + .5 \cdot t_3$$

$$r_4 := r_3 + .5 \cdot t_3 + .5 \cdot t_4$$

To check the accuracy of these calculations, the outer radius of the overpack is calculated from r_4 and t_4, and the result is compared with the previously defined value (b).

$$b_l := r_4 + 0.5 \cdot t_4$$

$$b_l = 66.25\,\text{in}$$

$$b = 66.25\,\text{in}$$

We note that the calculated value b_l is identical to the previously defined value b. The coefficients of thermal expansion for each component, estimated based on the temperature gradient, are defined as:

$$\alpha_1 := 5.53 \cdot 10^{-6}$$

$$\alpha_2 := 5.53 \cdot 10^{-6}$$

$$\alpha_3 := 5.5 \cdot 10^{-6}$$

$$\alpha_4 := 5.53 \cdot 10^{-6}$$

Thus, the average coefficient of thermal expansion of the overpack is determined as:

$$\alpha_{avg} := \frac{r_1 \cdot t_1 \cdot \alpha_1 + r_2 \cdot t_2 \cdot \alpha_2 + r_3 \cdot t_3 \cdot \alpha_3 + r_4 \cdot t_4 \cdot \alpha_4}{\frac{a + b}{2} \cdot (t_1 + t_2 + t_3 + t_4)}$$

$$\alpha_{avg} = 5.611 \times 10^{-6}$$

Reference 3.AF.1 gives an expression for the radial deformation due to thermal growth. At the inner radius of the overpack (r = a), the radial growth is determined as:

$$\Delta R_{ah} := \alpha_{avg} \cdot a \cdot T_{bar}$$

$$\Delta R_{ah} = -0.014\,\text{in}$$

Similarly, an overestimate of the axial growth of the overpack can be determined by applying the average temperature (T_{bar}) over the entire length of the overpack as:

$$\Delta L_{ovph} := L_{ovp} \cdot \alpha_{avg} \cdot T_{bar}$$

$$\Delta L_{ovph} = -0.075\,\text{in}$$

As expected, the drop in temperature causes a decrease in the inner radius and the axial length of the storage overpack.

3.AF.4.3 Thermal Growth of the MPC Shell

The radial and axial growth of the MPC shell (ΔR_{mpch} and ΔL_{mpch}, respectively) are determined as:

$$\Delta R_{mpch} := \alpha_{mpc} \cdot R_{mpc} \cdot \Delta T_{3h} \qquad \Delta R_{mpch} = 0.136\,\text{in}$$

$$\Delta L_{mpch} := \alpha_{mpc} \cdot L_{mpc} \cdot \Delta T_{3h} \qquad \Delta L_{mpch} = 0.761\,\text{in}$$

3.AF.4.4 Clearances Between the MPC Shell and Overpack

The final radial and axial MPC shell-to-overpack clearances (RG_{moh} and AG_{moh}, respectively) are determined as:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch} \qquad RG_{moh} = 0.351\,\text{in}$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch} \qquad AG_{moh} = 0.163\,\text{in}$$

Note that this axial clearance (AG_{moh}) is based on the temperature distribution at the middle of the system.

3.AF.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-Overpack

Radial clearance $RG_{moh} = 0.351\,\text{in}$ Axial clearance $AG_{moh} = 0.163\,\text{in}$

3.AF.6 Nomenclature

a is the inner radius of the overpack
AC_{bm} is the initial fuel basket-to-MPC axial clearance.
AC_{mo} is the initial MPC-to-overpack axial clearance.
AG_{bmh} is the final fuel basket-to-MPC shell axial gap for the hot components.
AG_{moh} is the final MPC shell-to-overpack axial gap for the hot components.
b is the outer radius of the overpack.
L_{bas} is the axial length of the fuel basket.
L_{mpc} is the axial length of the MPC.

L_{ovp} is the axial length of the overpack.
r_1 (r_2,r_3,r_4) is mean radius of the overpack inner shell (shield shell, concrete, outer shell).
R_b is the outer radius of the fuel basket.
R_{mpc} is the mean radius of the MPC shell.
RC_{bm} is the initial fuel basket-to-MPC radial clearance.
RC_{mo} is the initial MPC shell-to-overpack radial clearance.
RG_{bmh} is the final fuel basket-to-MPC shell radial gap for the hot components.
RG_{moh} is the final MPC shell-to-overpack radial gap for the hot components.
t_1 (t_2,t_3,t_4) is the thickness of the overpack inner shell (shield shell, concrete, outer shell).

T_{bar} is the average temperature of the overpack cylinder.
α_1 (α_2,α_3,α_4) is the coefficient of thermal expansion of the overpack inner shell (shield shell, concrete, outer shell).
α_{avg} is the average coefficient of thermal expansion of the overpack.
α_{bas} is the coefficient of thermal expansion of the overpack.
α_{mpc} is the coefficient of thermal expansion of the MPC.
ΔL_{bh} is the axial growth of the fuel basket for the hot components.

ΔL_{mpch} the the axial growth of the MPC for the hot components.

ΔL_{ovph} is the axial growth of the overpack for the hot components.

ΔR_{ah} is the radial growth of the overpack inner radius for the hot components.

ΔR_{bh} is the radial growth of the fuel basket for the hot components.

ΔR_{mpch} is the radial growth of the MPC shell for the hot components.

ΔT_{1h} is the temperature change at the overpack inner shell for hot components.

ΔT_{2h} is the temperature change at the overpack outer shell for hot components.

ΔT_{3h} is the temperature change at the MPC shell mean radius for hot components.

ΔT_{4h} is the temperature change at the MPC basket periphery for hot components.

ΔT_{5h} is the temperature change at the MPC basket centerline for hot components.

ΔT_{bas} is the fuel basket centerline-to-periphery temperature gradient.

σ_{ca} is the circumferential stress at the overpack inner surface.

σ_{cb} is the circumferential stress at the overpack outer surface.

σ_r is the maximum radial stress of the overpack.

σ_{zi} is the axial stress at the fuel basket centerline.

σ_{zo} is the axial stress at the fuel basket periphery.

APPENDIX 3.AH HI-TRAC TOP LID SEPARATION ANALYSES

3.AH.1 Introduction

This appendix considers the separation analysis of the 125 ton HI-TRAC top lid under the following condition:

Horizontal Drop of HI-TRAC - Accident Condition

In this case, analysis is limited to showing that the top lid and the transfer cask body do not separate during a HI-TRAC horizontal drop which imposes the design basis G load on the top lid. Results from analysis of the 125 ton unit analysis will bound the 100 ton HI-TRAC top lid results. We also show that under a drop, the top lid and the top lid stud array are sufficiently robust to insure that the MPC is not ejected from the HI-TRAC during the secondary impact.

3.AH.2 References

[3.AH.2.1] J.Shigley and C. Mischke, *Mechanical Engineering Design*, McGraw Hill, 1989.

[3.AH.2.2] Roark's Handbook for Stress and Strain, 6th Edition, Electronic Version

3.AH.3 Composition

This appendix was created using the Mathcad (version 8.0) software package. Mathcad uses the symbol ':=' as an assignment operator, and the equals symbol '=' retrieves values for constants or variables.

3.AH.4 Input Data for Top Lid

Number of studs $nb := 24$ (Holtec drawing no. 1880)

Top Lid Weight $W := 2750 \cdot lbf$ (Table 3.2.2 for 125 ton HI TRAC)

Design Basis Deceleration $G := 45$

3.AH.5 Separation of Top Lid from HI-TRAC

In the event of a side drop while HI-TRAC is in a horizontal position, the top lid will attempt to separate from the body of the cask. Here, the ultimate shear load capacity of the top lid is computed and compared with the expected G load.

3.AH.5.1 Shear and Tensile Capacity of SA 193 B7 studs and stud Holes

Because of the location of the studs in the top flange (near the outer surface), 300 degrees F is assumed as an appropriate temperature to assess material properties for the studs and for the flange material surrounding the stud holes

$S_{ubolt} := 112140 \cdot psi$ @300 deg. F Table 3.3.4

$S_{ybolt} := 94200 \cdot psi$

Calculation of Thread Capacity

The following calculations are taken from Machinery's Handbook, 23rd Edition, pp. 1278-1279 plus associated screw thread Table 4, p 1514.

Input Geometry Data - 1" UNC, 8 threads/inch, 2A class

$L_e := 1.5 \cdot in$ Thread engagement length

$N := \frac{8}{in}$ Threads per inch

$D_m := 1 \cdot in$ Basic Major Diameter of threads

$D := .9755 \cdot in$ Minimum Major Diameter of External Threads

$E_{min} := .91 \cdot in$ Minimum Pitch Diameter of External Threads

$E_{max} := .9276in$ Maximum Pitch Diameter of Internal Threads

$K_n := .89 \cdot in$ Maximum Minor Diameter of Internal Threads

Input Strength-Internal Threads (lid or forging); External Threads (bolts)

$Su_{bolt} := S_{ubolt}$

The ultimate strength of the top flange material, SA350 LF3 @ 300 degrees F. is

$Su_{lid} := 66700 \cdot psi$

Calculation of Tensile stress area (high-strength bolt, ultimate strength exceeding 100,000 psi)

$$A_{th} := \pi \cdot \left(.5 \cdot E_{min} - \frac{0.16238}{N} \right)^2 \qquad A_{tl} := .7854 \cdot \left(D_m - \frac{.9743}{N} \right)^2$$

$$A_{th} = 0.594\,in^2 \qquad A_{tl} = 0.606\,in^2$$

$$A_t := if\left(Su_{bolt} > 100000 \cdot psi, A_{th}, A_{tl} \right) \qquad A_t = 0.594\,in^2$$

Calculation of Shear Stress Area per the Handbook

$$A_{ext} := \pi \cdot N \cdot L_e \cdot K_n \cdot \left[\frac{0.5}{N} + 0.57735 \cdot \left(E_{min} - K_n \right) \right] \qquad A_{ext} = 2.484\,in^2$$

$$A_{int} := \pi \cdot N \cdot L_e \cdot D \cdot \left[\frac{0.5}{N} + 0.57735 \cdot \left(D - E_{max} \right) \right] \qquad A_{int} = 3.315\,in^2$$

Required Length of Engagement per Machinery's Handbook

$$L_{req} := 2 \cdot \frac{A_t}{\frac{A_{ext}}{L_e}} \qquad L_{req} = 0.717\,in$$

Capacity Calculation Using Actual Engagement Length

For the specified (limit) condition, the allowable tensile stress in the bolt is per ASME III, Appendix F

$$\sigma_{bolt} := Su_{bolt} \cdot 0.7 \qquad \sigma_{bolt} = 7.85 \times 10^4\,psi$$

The allowable shear stress in the bolt is (use 60% of ultimate since we are performing failure analysis:

$$\tau_{bolt} := .6 \cdot Su_{bolt} \qquad \tau_{bolt} = 6.728 \times 10^4\,psi$$

The allowable shear stress in the lid (or flange) is taken as (here we are examining for safety against failure; hence we use ultimate shear strength of lid material.

$\tau_{lid} := 0.6 \cdot Su_{lid}$ $\tau_{lid} = 4.002 \times 10^{4}\,psi$

$F_{shear\_lid} := \tau_{lid} \cdot A_{int}$ $F_{shear\_lid} = 1.327 \times 10^{5}\,lbf$

For the bolt, the allowable strength is the yield strength

$F_{tensile\_bolt} := \sigma_{bolt} \cdot A_{t}$ $F_{tensile\_bolt} = 4.66 \times 10^{4}\,lbf$

$F_{shear\_bolt} := \tau_{bolt} \cdot A_{ext}$ $F_{shear\_bolt} = 1.672 \times 10^{5}\,lbf$

Therefore, bolt tension governs the design.

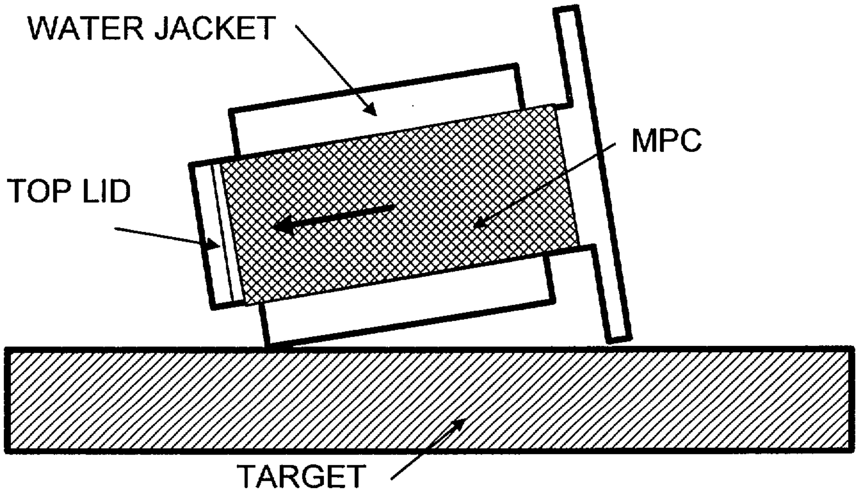
$Bolt\_Capacity\_in\_Tension := F_{tensile\_bolt}$

3.AH.6 CONTAINMENT OF THE MPC - Stud and Lid Evaluation

Appendix 3.AN contains results of the side drop of the HI-TRAC transfer cask from an initial orientation with the trunnions horizontal. This drop accident has been postulated as a bounding drop accident during handling of the HI-TRAC in a horizontal orientation. The results of the analysis have shown that the maximum interface longitudinal load that develops between the MPC and the HI-TRAC top lid is

$$\text{Load} := 132000 \cdot \text{lbf}$$

The interface load develops because their is a difference in the centrifugal accelerations values for transfer cask and the MPC that results in the MPC moving towards and impacting with the top lid. The sketch below describes the scenario:



The MPC/Top Lid interface force tends to stretch the studs and bend the lid. In the following section, we investigate:

1. The ability of the studs to resist the tensile interface load and the stud shear force due to the impact with the target.

2. The ability of the top lid (an annular plate) to resist the ring loading at the interface developed by the impact.

The safety factor on stud tensile load is

$$SF_{bolt\_tension} := \frac{nb \cdot Bolt\_Capacity\_in\_Tension}{Load} \qquad SF_{bolt\_tension} = 8.473$$

The total shear load that must be resisted by the bolts is

$$Load_{shear} := W \cdot G \qquad Load_{shear} = 1.238 \times 10^{5} \, lbf$$

$$SF_{shear} := \frac{nb \cdot \left(\tau_{bolt} \cdot A_t\right)}{Load_{shear}} \qquad SF_{shear} = 7.747$$

The interaction equation for combined shear and tension is

$$I := \left(\frac{1}{SF_{bolt\_tension}}\right)^2 + \left(\frac{1}{SF_{shear}}\right)^2 \qquad I = 0.031$$

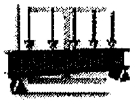
< 1.0 OK

It is clear that sufficient margin exists in the bolts to prevent lid separation even without consideration of any interface friction due to preload.

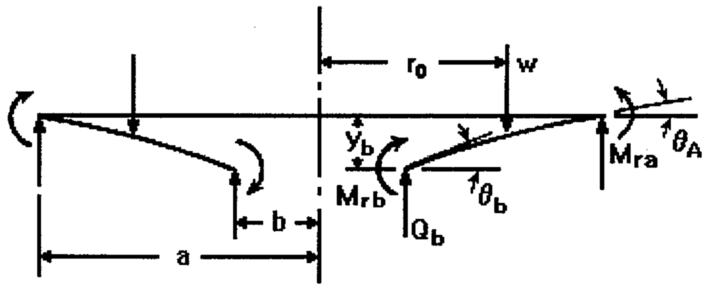
Lid Stress Evaluation

To evaluate the bending capacity of the lid, we assume a simply supported annular plate subject to the impact load from the MPC. The load is applied as a ring load at the location of the outer diameter of the MPC. This is appropriate since the top lid of the HI-TRAC is considerably more flexible in bending then the MPC lid. The appropriate plate solution is given in [3.AH.2.2, Table 24] and the calculations detailed in the Calculation Package for HI-STORM 100 (HI-981928). The summary of calculations is given below:

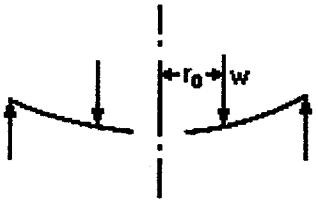
Table 24 Formulas for shear, moment and deflection of flat circular plates of constant thickness



Cases 1a - 1d Annular Plate With Uniform Annular Line Load w at Radius r_0; Outer Edge Simply Supported



Outer edge simply supported, inner edge free



For this analysis, only Case 1a is of interest

$$a \equiv 39.375 \cdot in \qquad w := \frac{Load}{2 \cdot \pi \cdot a} \qquad w = 533.548 \frac{lbf}{in}$$

Enter dimensions, properties and loading

Plate dimensions:

thickness: $t \equiv 1.0 \cdot in$

outer radius: $a \equiv 39.375 \cdot in$

inner radius: $b \equiv 13.5 \cdot in$

Applied unit load: $w \equiv 533.548 \cdot \frac{lbf}{in}$

Modulus of elasticity: $E \equiv 28.5 \cdot 10^6 \cdot \frac{lbf}{in^2}$

Poisson's ratio: $\nu \equiv 0.3$

Radial location of applied load: $r_o \equiv 33.8125 \cdot in$

The following results are obtained from the detailed calculation following Roark's handbook:

Maximum lateral deflection at edge of opening = 0.908"

Maximum radial bending stress (at point of application of impact load) = 14,930 psi

Maximum tangential bending stress (at edge of opening) = 35,560 psi.

The maximum stress intensity, away from the impact circle is equal to the maximum of either the radial or tangential stresses since both stresses always have the same sign. Therefore, based on Level D stress allowable for Subsection NF, (Table 3.1.12), The safety factor on the lid bending stress is

$$SF_{lid\_bending} := \frac{58700 \cdot psi}{35560 \cdot psi} \qquad SF_{lid\_bending} = 1.651$$

The allowable shear load around the periphery of the lid us computed as:

$$Q_{all} := (.42 \cdot 70000 \cdot psi) \cdot 1 \cdot in \qquad Q_{all} = 2.94 \times 10^4 \frac{lbf}{in}$$

The safety factor on a failure due to peripheral shear is

$$SF_{shear} := \frac{Q_{all}}{w} \qquad SF_{shear} = 55.103$$

3.AH.7 CONCLUSIONS

The lid will not separate from the top flange of HI-TRAC due to the design basis deceleration.

The lid bolts are adequate to maintain the MPC inside of the HI-TRAC.

The top lid meets Level D allowable when subject to the impact load from a side drop that induces maximum slapdown angle.

APPENDIX 3.AJ 100 TON HI-TRAC TRANSFER LID STRESS ANALYSES

3.AJ.1 Introduction

This appendix considers the structural analysis of the HI-TRAC transfer lid under the following limiting conditions:

Lifting of fully loaded MPC - Normal Condition
Horizontal Drop of HI-TRAC - Accident Condition

In the first case, it is shown that the sliding doors adequately support a loaded MPC plus the door weight, both being amplified by a dynamic load factor associated with a low speed lifting operation, and that the loads are transferred to the transfer cask body without overstress.

In the second case, analysis is performed to show that the transfer lid and the transfer cask body do not separate during a HI-TRAC horizontal drop which imposes the design basis 45G load (Table 3.1.2) on the connection. In this case, because of the geometry of the transfer lid housing, the force of separation is from the HI-TRAC since the housing impacts the ground before the HI-TRAC body; i.e., the connection needs to withstand an amplified load from the HI-TRAC loaded weight, amplified by the deceleration. Analysis is also performed to show that the bolts that act as "door stops" will keep the doors from opening due to deceleration from a side drop.

3.AJ.2 References

[3.AJ.2.1] Young, Warren C., *Roark's Formulas for Stress and Strain*, 6th Edition, McGraw-Hill,1989.

[3.AJ.2.2] Holtec Drawing 2152 (two sheets)

[3.AJ.2.3] J.Shigley and C. Mischke, *Mechanical Engineering Design*, McGraw Hill, 1989.

[3.AJ.2.4] McMaster-Carr Supply Company, Catalog No. 101, 1995.

3.AJ.3 Composition

This appendix was created using the Mathcad (version 8.0) software package. Mathcad uses the symbol ':=' as an assignment operator, and the equals symbol '=' retrieves values for constants or variables.

3.AJ.4 General Assumptions

1. Formulas taken from Reference [3.AJ.2.1] are based on assumptions that are delineated in that reference.

2. During lifting operation, the MPC is supported on a narrow rectangular section of the door. The width of the section in each of two doors is set at the span of the three wheels. Beam theory is used to calculate stresses.

3. The loading from the MPC on the door is simulated by a uniform pressure acting on the total surface area of the postulated beam section of the door.

3.AJ.5 Methodology and Assumptions

Strength of Materials analysis are performed to establish structural integrity. Stresses in the transfer lid door are computed based on simplified beam analysis, where the width of the top plate beam is taken as the span of the door support wheels.
For all lifting analyses, the acceptance criteria is the more severe of ASME Section III, Subsection NF (allowable stresses per tables in Chapter 3),or USNRC Regulatory Guide 3.61 (33.3% of yield strength at temperature).

3.AJ.6 Input Data(BM-2152 and drawing 2152, Table 3.2.2 for weights)

Unsupported door top plate length	$L := 72.75 \cdot in$
Half Door top plate width	$w := 25 \cdot in$
Door top plate thickness	$t_{tp} := 2.25 \cdot in$
Thickness of bottom plate	$t_{bp} := 0.5 \cdot in$
HI-TRAC bounding dry weight	$W := 201000 \cdot lbf$
MPC bounding weight	$W_{mpc} := 90000 \cdot lbf$
Transfer Lid Bounding Weight (with door)	$W_{tl} := 17000 \cdot lbf$
Weight of door top plate	$W_{tp} := 3762 \cdot lbf$
Door Lead shield weight	$W_{lead} := 2879.2 \cdot lbf$
Weight of door bottom plate	$W_{bp} := 663 \cdot lbf$

Weight of Holtite A $W_{ha} := 0 \cdot lbf$

Note that above weights calculated from data in HI-981928 (Calc. Package for HI-STORM). The total door weight excluding wheels and trucks is:

$W_{td} := W_{tp} + W_{lead} + W_{bp} + W_{ha}$ $W_{td} = 7.304 \times 10^{3} lbf$

Total Door Weight transferred by 1 set of 3 wheels +trucks and wheels $W_{door} := \dfrac{4339.4 \cdot lbf}{2}$

Dynamic Load Factor for low speed lift $DLF := 0.15$

Young's Modulus SA-516-Gr70 @ 350 deg. F $E := 28 \cdot 10^{6} \cdot psi$

Allowable membrane stress
for Level A condition @ 350 deg. F(Table 3.3.2)
Use allowable stress for SA-516 Gr 70 $S_a := 17500 \cdot psi$

Yield strength @ 350 deg. F - Use minimum value for SA-350 LF3(Table 3.3.3) $S_y := 32700 \cdot psi$

Maximum Deceleration (design basis) g level $G_{max} := 45$

3.AJ.7 Analysis of Door plates Under Lift of MPC - Level A Event

The transfer lid door has a top and bottom plate connected by side plates that act as stiffeners in the loaded section. The top plate is 2.25 inches thick and the total span between wheel centers is 73 inches. The bottom plate is 0.5 inches thick and spans 73 inches. The side plates that connect the two plates are 1 inch thick. There is one side plate on each end of the beam and one down the middle. The side plates extend below the bottom plate (Drg.and BM 2152).

The lid door acts as a composite beam between wheel sets. It supports the load of the MPC along its span. To ensure conservatism, the effective width of the composite beam is taken as the distance between the outermost stiffeners. Beam theory is valid up to 1/8 of the span [Ref. 3.AJ.2.1]. Beyond this value, a beam begins to act as a stronger two-way plate. Therefore, a one-way beam approximation for the dimensions of this lid underestimates the capacity of the lid.

The load acting on the beam is taken as the bounding weight from a fully loaded MPC plus the bounding weight of the transfer lid door assembly. The load is applied as a uniform pressure and the beam is assumed simply supported.

The geometric parameters of the system are (drawing 2152, sheet 2:

$b := w$

$h := 8 \cdot in$ overall beam height

$htp := t_{tp}$ thickness of top plate $htp = 2.25 in$

$hg := 6 \cdot in$ height of side plate (extends below bottom plate)

$hbp := t_{bp}$ thickness of bottom plate $hbp = 0.5 in$

$hs := 5.25 \cdot in$ position of bottom plate below top surface

$tg := 1 \cdot in$ thickness of each side plate

The centroid (measured from the top surface) and area moment of inertia of the composite beam are:

$$yc := \frac{3 \cdot hg \cdot tg \cdot \left(htp + \frac{hg}{2} \right) + htp \cdot b \cdot \frac{htp}{2} + hbp \cdot (b - 3 \cdot tg) \cdot (hs)}{htp \cdot b + 3 \cdot hg \cdot tg + hbp \cdot (b - 3 \cdot tg)}$$

$$yc = 2.528 in$$

$$Inertia := \frac{b \cdot htp^3}{12} + htp \cdot b \cdot \left(yc - \frac{htp}{2} \right)^2 + \frac{tg \cdot hg^3}{4} + 3 \cdot hg \cdot tg \cdot \left(yc - htp - \frac{hg}{2} \right)^2 \ldots + \frac{(b - 3 \cdot tg) \cdot hbp^3}{12} + hbp \cdot (b - 3 \cdot tg) \cdot (yc - hs)^2$$

$$Inertia = 403.552 in^4$$

The maximum stress is due to the moment:

$$Moment := \frac{\left(W_{mpc} + W_{td} \right)}{2} \cdot \frac{L}{8} \qquad Moment = 4.424 \times 10^5 lbf \cdot in$$

The bending stress is $$\sigma := \frac{Moment \cdot (h - yc) \cdot (1 + DLF)}{Inertia}$$

$$\sigma = 6.899 \times 10^3 psi$$

The stress must be less than the 33.3% of the yield strength of the material. This acceptance criteria comes from Reg. Guide 3.61. The safety factor is,

$$Sy := S_y \qquad SF_{3.61} := \frac{Sy}{3 \cdot \sigma} \qquad SF_{3.61} = 1.58$$

The safety factor as defined by ASME Section III, Subsection NF for Class 3 components is

$$SF_{nf} := \frac{1.5 \cdot S_a}{\sigma} \qquad SF_{nf} = 3.805$$

Now consider the plate section between stiffeners and check to see if plate stress is acceptable. The span of the plate between stiffeners is

$span := 12.5 \cdot in$ Drg. 2152)

Calculate the pressure on each half of lid door due to MPC.

$$p := \frac{.5 \cdot W_{mpc} \cdot (1 + DLF)}{L \cdot w} \qquad p = 28.454\,psi$$

Calculate the pressure due to self weight

$$p_d := .5 \cdot \left(W_{tp}\right) \cdot \frac{1 + DLF}{L \cdot w} \qquad p_d = 1.189\,psi$$

Bending moment due to pressure

$$Moment := \frac{\left(p + p_d\right) \cdot L \cdot span^2}{8} \qquad Moment = 4.212 \times 10^4\,lbf \cdot in$$

Maximum bending stress

$$\sigma_{bending} := \frac{6 \cdot Moment}{L \cdot t_{tp}{}^2} \qquad \sigma_{bending} = 686.179\,psi$$

(Small!!!)

Now perform a Weld Check

$$Load := \left(p + p_d\right) \cdot L \cdot w \qquad Load = 5.391 \times 10^4\,lbf$$

The shear stress at the weld connection is (conservatively neglect stiffener welds)

$\tau := \frac{Load}{2 \cdot w \cdot t_{tp}}$ $\tau = 479.227\,psi$ Low!

It is concluded that the significant stresses arise only by the action of the member as a composite beam composed of plates and stiffeners. Local bending stresses in the plate are small and can be neglected

3.AJ.8 Wheel Loads on Housing

$W_{door} = 2.17 \times 10^{3}\,lbf$ From weight calculation - 50% of 1 half-door

Load per wheel $Load_{wheel} := \frac{\left(W_{door} + .25 \cdot W_{mpc}\right) \cdot (1 + DLF)}{3}$

$Load_{wheel} = 9.457 \times 10^{3}\,lbf$

Note that working capacities of wheels are 10000 lb per McMaster Carr Catalog [3.AJ.2.4].

The wheel rides on an angle track (item 7 in dwg. 2152). The thickness of the angle is

$t_a := 0.125 \cdot in$

The wheel span (three wheels) is (see sheet 2, side view of Dwg. 2152)

$s := 18.5 \cdot in$

Therefore the direct stress in the leg of the angle is

$\sigma_a := \frac{1}{2 \cdot \cos(45 \cdot deg) \cdot s \cdot t_a} \cdot 3 \cdot Load_{wheel}$ $\sigma_a = 8.675 \times 10^{3}\,psi$

Overstress in this track does not impede ready retrievability of the fuel. Nevertheless, for conservatism, the safety factor in accordance with Regulatory Guide 3.61 is evaluated for the material specified for the angle.

$SF_{angle} := \frac{36000 \cdot psi}{3 \cdot \sigma_a}$ $SF_{angle} = 1.383$

3.AJ.9 Housing Stress Analysis

The most limiting section that sets the minimum safety factor for the door housing under a lifting condition is the box structure adjacent to the track that serves as the direct load path to the bolts. In this section, a conservative estimate of the stress levels in this region is obtained and the safety factor established. The door load is transferred to the bottom plate by the wheels running on an angle track. The load is then transferred to two vertical stiffeners that form the side of the box. The top plate, forming the top of the box, serves as the structure that moves the load to the bolts.

The lid bottom plate of the housing (item 2 of Dwg. 2152) that directly supports the wheel loading can be conservatively considered as a wide plate supporting the load from one of the sliding doors. The applied load is transferred to the two vertical plates (items 3 and 4 of Dwg. 1928). Figure 3.AJ.2 shows the configuration for analysis. The following dimensions are obtained from the drawing.

Length of analyzed section	$L_H := 25 \cdot in$	
Thickness of item 2	$t_{bottom} := 2 \cdot in$	From BM-1928
Thickness of item 3	$t_1 := 1.5 \cdot in$	
Thickness of item 4	$t_2 := 1 \cdot in$	
Width of item 21	$t_{21} := 1.5 \cdot in$	

With respect to Figure 3.AJ.2, referring to the drawing, the length x is defined as a+b

$x := (.5 \cdot 89) \cdot in - 36.375 \cdot in$ $\qquad x = 8.125\,in$

dimension "b" $\quad b := x - t_1 - t_{21} - .5 \cdot t_1$ $\qquad b = 4.375\,in$

dimension "a" $\quad a := x - b$ $\qquad a = 3.75\,in$

Compute the moment of inertia of item 2 at the root assuming a wide beam

$$I := L_H \cdot \frac{t_{bottom}^{\ 3}}{12} \qquad I = 16.667\,in^4$$

The maximum bending moment in the bottom plate is given as,

$$Moment := 3 \cdot Load_{wheel} \cdot b \qquad Moment = 1.241 \times 10^5\,lbf \cdot in$$

The maximum bending stress is

$$\sigma_{bending} := \frac{Moment \cdot t_{bottom}}{2 \cdot I} \qquad \sigma_{bending} = 7.447 \times 10^{3}\,psi$$

The safety factor, based on primary bending stress (ASME Code evaluation), is

$$1.5 \cdot \frac{S_a}{\sigma_{bending}} = 3.525$$

It is concluded that this region is not limiting.

The safety factor based on Reg. Guide 3.61 (compare to 33% of yield strength) is

$$\frac{S_y}{3 \cdot \sigma_{bending}} = 1.464$$

The reactions at the two support points for the section are

$$F_1 := 3 \cdot Load_{wheel} \cdot \left(1 + \frac{b}{a}\right) \qquad F_1 = 6.147 \times 10^{4}\,lbf$$

$$F_2 := 3 \cdot Load_{wheel} \cdot \frac{b}{a} \qquad F_2 = 3.31 \times 10^{4}\,lbf$$

Therefore, consistent with the support assumptions, the direct stress in the two stiffeners is

$$\sigma_1 := \frac{F_1}{L_H \cdot t_1} \qquad \sigma_1 = 1.639 \times 10^{3}\,psi$$

$$\sigma_2 := \frac{F_2}{L_H \cdot t_2} \qquad \sigma_2 = 1.324 \times 10^{3}\,psi$$

Safety factors, using the more conservative Reg. Guide 3.61 criteria, are

$$SF_1 := \frac{S_y}{3 \cdot \sigma_1} \qquad SF_1 = 6.65$$

$$SF_2 := \frac{S_y}{3 \cdot \sigma_2} \qquad SF_2 = 8.233$$

3.AJ.10 Bolt Stress

Figure 3.AJ.3 shows the bolt array assumed to resist the lifted load when the doors are closed and when the fully loaded MPC is being supported by the doors.

The bolt tensile stress area is, for the 1" diameter bolts (use standard area)

$A_b := 0.605 \cdot in^2$ $\quad d_{bolt} := 1 \cdot in$ $\quad Nb := 36$ |

The bolt circle radius is

$$R_b := \frac{86.5}{2} \cdot in$$

The bolt angular spacing is $\theta := 10 \cdot deg$

The centroid of the nine bolts point P* in Figure 3.AJ.3, assumed to carry 100% of the wheel load, is computed as follows:

$A_{total} := 9 \cdot A_b$ $\quad A_{total} = 5.445\,in^2$

Compute the following sum

$$Sum := 2 \cdot A_b \cdot R_b \cdot (1 - \cos(4 \cdot \theta)) + 2 \cdot A_b \cdot R_b \cdot (1 - \cos(3 \cdot \theta)) \; ... \\ + 2 \cdot A_b \cdot R_b \cdot (1 - \cos(2 \cdot \theta)) + 2 \cdot A_b \cdot R_b \cdot (1 - \cos(\theta))$$

$Sum = 23.206\,in^3$

Then the centroid of the bolts is $X_{bar} := \frac{Sum}{A_{total}}$ $\quad X_{bar} = 4.262\,in$

Compute the bolt moment of inertia about the centroid by first locating each bolt relative to the centroid. First compute some distances "z":

$z_1 := R_b \cdot (1 - \cos(4 \cdot \theta)) - X_{bar}$ $\quad z_1 = 5.857\,in$

$z_2 := R_b \cdot (1 - \cos(3 \cdot \theta)) - X_{bar}$ $\quad z_2 = 1.533\,in$

$z_3 := R_b \cdot (1 - \cos(2 \cdot \theta)) - X_{bar}$ $\quad z_3 = -1.654\,in$

$z_4 := R_b \cdot (1 - \cos(\theta)) - X_{bar}$ $\quad z_4 = -3.605\,in$

Then the bolt group moment of inertia about the centroid is,

$$I_{bolts} := 2 \cdot A_b \cdot {z_1}^2 + 2 \cdot A_b \cdot {z_2}^2 + 2 \cdot A_b \cdot {z_3}^2 + 2 \cdot A_b \cdot {z_4}^2 + A_b \cdot {X_{bar}}^2$$

$I_{bolts} = 74.367\,in^4$

The bolts must support the total wheel load acting on one rail, plus the additional load necessary to resist the moment induced about the bolt group centroid.

The moment arm is the distance from the bolt centroid to the angle guide rail

$moment\_arm := R_b - X_{bar} - 36.375 \cdot in \qquad moment\_arm = 2.613\,in$

Therefore, the bolt array must resist the following moment

$Moment_{bolts} := 6 \cdot Load_{wheel} \cdot moment\_arm \qquad Moment_{bolts} = 1.483 \times 10^5\,in \cdot lbf$

The bolt stress due to the direct load is

$$stress_{direct} := 6 \cdot \frac{Load_{wheel}}{A_{total}} \qquad stress_{direct} = 1.042 \times 10^4\,psi$$

Compute $\quad y_1 := R_b \cdot (1 - \cos(4 \cdot \theta)) - X_{bar} \qquad y_1 = 5.857\,in \qquad > Xbar$

Therefore, the highest bolt stress due to the bending moment is,

$$stress_{moment} := \frac{Moment_{bolts} \cdot y_1}{I_{bolts}} \qquad stress_{moment} = 1.168 \times 10^4\,psi$$

Therefore, the total bolt stress to support lifting, on the heaviest loaded bolt, is

$\sigma_{bolt} := stress_{direct} + stress_{moment} \qquad \sigma_{bolt} = 2.21 \times 10^4\,psi$

The above calculation has considered only the stress induced by the MPC and the door; that is, the stress induced in the bolts by the load transmitted through the wheels. The entire set of bolts acts to support the door housing and this induces an additional component of stress in the bolts. This is computed below:

The total bounding weight of the transfer lid is

$W_{tl} = 1.7 \times 10^4\,lbf$

The total door load already accounted for in the bolt analysis is

$W_{td} := 4 \cdot W_{door}$ $\qquad$ $W_{td} = 8.679 \times 10^{3}\,\text{lbf}$

Therefore the additional average stress component in the 36 bolts is

$$\sigma_{avg} := \frac{(W_{tl} - W_{td})}{36 \cdot A_b} \qquad \sigma_{avg} = 382.056\,\text{psi}$$

Therefore the absolute maximum bolt stress is

$$\sigma_{bolt\_max} := \sigma_{bolt} + \sigma_{avg} \qquad \sigma_{bolt\_max} = 2.248 \times 10^{4}\,\text{psi}$$

The allowable bolt load is obtained from the ASME Code, Subsection NF, NF-3324.6 as 50% of the ultimate strength of the bolts. The bolts are assumed to be at a temperature below 200 degrees F because of their location.

$S_{ubolt} := 115000 \cdot \text{psi}$ $\qquad$ @200 deg. F $\qquad$ Table 3.3.4

$S_{ybolt} := 95000 \cdot \text{psi}$

Therefore, the bolt safety factor based on tensile capacity is (NF-3324.6)

$$SF_{bolts} := \frac{.5 \cdot S_{ubolt}}{\sigma_{bolt\_max}} \qquad SF_{bolts} = 2.558$$

The transfer lid bolt preload required is

$$T := .12 \cdot \sigma_{bolt\_max} \cdot A_b \cdot d_{bolt} \qquad [3.AJ.3] \qquad T = 136.002\,\text{ft} \cdot \text{lbf}$$

Note that this exceeds the value calculated for the pool lid.

The maximum load in any bolt, based on the above calculations, is:

$$P_{tension} := \sigma_{bolt\_max} \cdot A_b \qquad P_{tension} = 1.36 \times 10^{4}\,\text{lbf}$$

The safety factor using the Reg. Guide 3.61 criteria is

$$SF_{3.61} := \frac{S_{ybolt}}{3 \cdot \sigma_{bolt\_max}} \qquad SF_{3.61} = 1.409$$

Calculation of Thread Capacity

The following calculations are taken from Machinery's Handbook, 23rd Edition, pp. 1278-1279 plus associated screw thread Table 4, p 1514.

Input Geometry Data - 1" UNC, 8 threads/inch, 2A class

$L_e := 1.\cdot in$ Thread engagement length

$N := \frac{8}{in}$ Threads per inch

$D_m := 1\cdot in$ Basic Major Diameter of threads

$D := .9755\cdot in$ Minimum Major Diameter of External Threads

$E_{min} := .91\cdot in$ Minimum Pitch Diameter of External Threads

$E_{max} := .9276 in$ Maximum Pitch Diameter of Internal Threads

$K_n := .89\cdot in$ Maximum Minor Diameter of Internal Threads

Input Yield Strength-Internal Threads (lid or forging); External Threads (bolts)

Values are obtained from ASME Code,Section II)

$Sy_{lid} := 38000\cdot psi$ $Su_{lid} := 70000\cdot psi$ $Su_{bolt} := S_{ubolt}$

Calculation of Tensile stress area (high-strength bolt, ultimate strength exceeding 100,000 psi)

$$A_{th} := \pi\cdot\left(.5\cdot E_{min} - \frac{0.16238}{N}\right)^2 \qquad A_{tl} := .7854\cdot\left(D_m - \frac{.9743}{N}\right)^2$$

$$A_{th} = 0.594 in^2 \qquad A_{tl} = 0.606 in^2$$

$$A_t := if\left(Su_{bolt} > 100000\cdot psi, A_{th}, A_{tl}\right) \qquad A_t = 0.594 in^2$$

Calculation of Shear Stress Area per the Handbook

$$A_{ext} := \pi\cdot N\cdot L_e\cdot K_n\cdot\left[\frac{0.5}{N} + 0.57735\cdot\left(E_{min} - K_n\right)\right] \qquad A_{ext} = 1.656 in^2$$

$$A_{int} := \pi \cdot N \cdot L_e \cdot D \cdot \left[\frac{0.5}{N} + 0.57735 \cdot (D - E_{max}) \right] \qquad A_{int} = 2.21\,in^2$$

Required Length of Engagement per Machinery's Handbook

$$L_{req} := 2 \cdot \frac{A_t}{\frac{A_{ext}}{L_e}} \qquad L_{req} = 0.717\,in$$

Capacity Calculation Using Actual Engagement Length

For the specified condition, the allowable tensile stress in the bolt is per ASME NF

$$\sigma_{bolt} := Su_{bolt} \cdot 0.5 \qquad \sigma_{bolt} = 5.75 \times 10^4\,psi$$

The allowable shear stress in the bolt is:

$$\tau_{bolt} := \frac{.62 \cdot Su_{bolt}}{3} \qquad \tau_{bolt} = 2.377 \times 10^4\,psi$$

The allowable shear stress in the lid (or flange) is

$$\tau_{lid} := 0.4 \cdot Sy_{lid} \qquad \tau_{lid} = 1.52 \times 10^4\,psi$$

$$F_{shear\_lid} := \tau_{lid} \cdot A_{int} \qquad F_{shear\_lid} = 3.36 \times 10^4\,lbf$$

For the bolt, the allowable strength is the yield strength

$$F_{tensile\_bolt} := \sigma_{bolt} \cdot A_t \qquad F_{tensile\_bolt} = 3.414 \times 10^4\,lbf$$

$$F_{shear\_bolt} := \tau_{bolt} \cdot A_{ext} \qquad F_{shear\_bolt} = 3.936 \times 10^4\,lbf$$

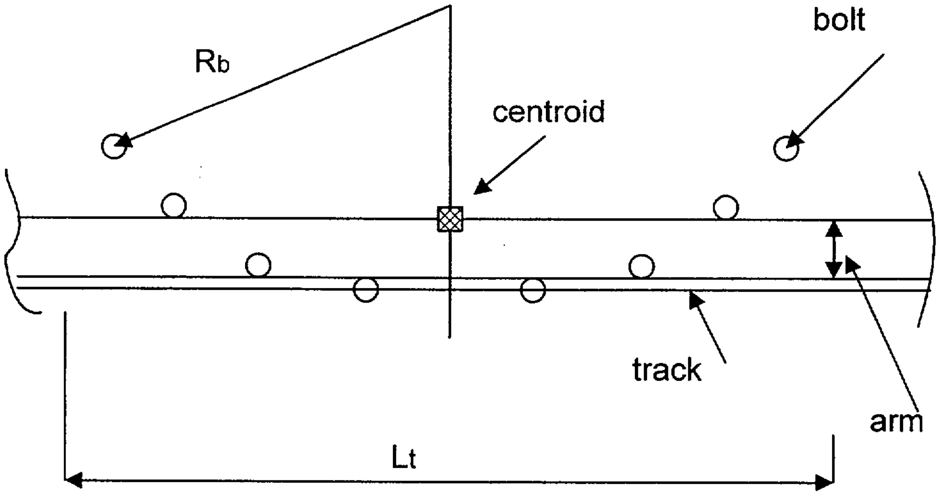
Therefore, thread shear in lid governs the design. The safety factors computed above should by multiplied by the ratio

$$\frac{F_{shear\_lid}}{F_{tensile\_bolt}} = 0.984$$

3.AJ.11 Estimate of Primary Bending Stress in Lid Top Plate

The lid top plate maximum primary stresses develop due to the structural requirement of transferring the wheel loads to the bolt array. Based on the assumptions above as to the number of bolts participating in the support of the load, a total direct load and a bending moment is reacted by the bolt array. The active bolts have been assumed to be only those bolts in an 80 degree arc (see Figure 3.AJ.3). To estimate the minimum safety factor inherent in the top plate, it is assumed that the same bending moment must also be reacted by the the lid top plate. The sketch below aids in the analysis:

The analysis is conservative as it neglects any support from either plate or bolts outside of the section identified.



The view shown is similar to the view in Figure 3.AJ.3 with identification of terms for use in the following analysis;

$arm := moment\_arm$ $\quad arm = 2.613\,in$

$Moment := Moment_{bolts}$ $\quad Moment = 1.483 \times 10^{5}\,in \cdot lbf$

$L_t := R_b \cdot 2 \cdot \sin(45 \cdot deg)$ $\quad L_t = 61.165\,in$

The thickness of the lid top plate is

$t_p := 1.5 \cdot in$ $\quad$ item 1 in BM-2152

The safety factor is established by considering the bending moment in the section of top plate a distance "arm" away from the track.

$$I_p := \frac{L_t \cdot t_p^{\,3}}{12} \qquad I_p = 17.203\,\text{in}^4$$

The primary bending stress is

$$\sigma_{tp} := \frac{\text{Moment} \cdot t_p}{2 \cdot I_p} \qquad \sigma_{tp} = 6.464 \times 10^3\,\text{psi}$$

The limiting safety factor is obtained by consideration of the Regulatory Guide 3.61 criteria. Therefore,

$$SF_{tp} := \frac{S_y}{3 \cdot \sigma_{tp}} \qquad SF_{tp} = 1.686$$

Similarly, the average shear stress developed across the section is

$$\tau_{tp} := 6 \cdot \frac{\text{Load}_{\text{wheel}}}{t_p \cdot L_t} \qquad \tau_{tp} = 618.442\,\text{psi}$$

The safety factor against primary shear overstress is large.

$$SF_{\text{shear}} := .6 \cdot \frac{S_y}{3 \cdot \tau_{tp}} \qquad SF_{\text{shear}} = 10.575$$

In the above safety factor calculation, the yield strength in shear is assumed as 60% of the yield strength in tension for the Reg. Guide 3.61 evaluation.

3.AJ.12 Separation of Transfer Lid from HI-TRAC

In the event of a side drop while HI-TRAC is in a horizontal position, the transfer lid housing will impact the ground, and the HI-TRAC body, including the MPC, will attempt to separate from the lid. Appendix 3.AN provides a detailed dynamic analysis of the handling accident and provides the interface load that must be transferred by the bolts.

From Appendix 3.AN, Section 3.AN.2.7, we find the following results for the 100- ton HI-TRAC:

$$\text{Interface\_Force} := 1129000 \cdot \text{lbf}$$

We now demonstrate that this load can be transferred by a combination of bolt shear and interface friction.

3.AD.12.1 Shear Capacity of 36 SA 193 B7 bolts

Number of bolts $nb := 36$

$S_{ubolt} = 1.15 \times 10^{5}\,\text{psi}$

$A_b = 0.605\,\text{in}^2$

$$\text{Bolt\_Capacity} := nb \cdot .6 \cdot S_{ubolt} \cdot A_b$$

$$\text{Bolt\_Capacity} = 1.503 \times 10^{6}\,\text{lbf}$$

3.AD.12.2 Shear Capacity due to Friction - 100 Ton HI-TRAC

Table 8.1.5 lists the actual preload torque as

$$T_{act} := 203 \cdot ft \cdot lbf$$

The calculated bolt torque requirement is $T = 136.002\, ft \cdot lbf$

Therefore the actual clamping force per bolt is:

$$T_{clamp} := \frac{T_{act}}{T} \cdot \sigma_{bolt\_max} \cdot A_b \qquad T_{clamp} = 2.03 \times 10^4\, lbf$$

Following ASME, Section III, Subsection NF, NF-3324.6(4) for a blast cleaned joint, the frictional resistance for the assemblage of bolts is:

$$P_s := nb \cdot T_{clamp} \cdot 0.31 \qquad P_s = 2.265 \times 10^5\, lbf$$

Note that since we are evaluating a side drop, the actual value of the clamping force may be used since there is no other tensile load acting on the bolts.

Therefore, the total shear capacity, based on ultimate strength in shear, is

$$Shear\_Capacity := Bolt\_Capacity + P_s$$

$$Shear\_Capacity = 1.729 \times 10^6\, lbf$$

The safety factor for lid separation is defined as

$$SF := \frac{Shear\_Capacity}{Interface\_Force} \qquad SF = 1.532$$

It is concluded that there will be no separation of the HI-TRAC from the transfer lid

3.AJ.13 Analysis of Door Lock Bolts (Item 22 of Dwg. 2152, Sheet 1)

Under the design basis side drop handling accident, the transfer lid doors (both) are restrained only by the two door lock bolts. Since the doors must remain closed to maintain shielding, these bolts need to have sufficient shear capacity to resist the door deceleration loading. The following calculation demonstrates that the door lock bolts have the desired shear capacity. The following input data is required to obtain a result

$G_{max} = 45$

$D_{bolt} := 3.0 \cdot in$ Door lock bolt diameter per 100 ton transfer cask bill of materials.

$S_{abolt} := 48300 \cdot psi$ Level D event per Appendix F of ASME Code

$Total\_Load := 4 \cdot W_{door}$ $Total\_Load = 8.679 \times 10^3 \, lbf$

Recall that Wdoor represents 50% of one (of two) doors.

$A_{bolt} := \frac{\pi}{4} \cdot D_{bolt}^2$ $A_{bolt} = 7.069 \, in^2$

There are two bolts which support load and there are two shear faces per bolt (see section B-B on Dwg. 2152). Assuming a reduction factor of .8 to account for shear across the threads, the shear stress in the bolt section is

$\tau_{bolt} := Total\_Load \cdot \frac{G_{max}}{2 \cdot 2 \cdot A_{bolt}}$ $\tau_{bolt} = 1.381 \times 10^4 \, psi$

Therefore, the safety factor on bolt shear stress is

$SF_{bolt\_shear} := \frac{S_{abolt}}{\tau_{bolt}}$ $SF_{bolt\_shear} = 3.497$

and no loss of shielding will occur since the doors will be retained in place.

APPENDIX 3.AO HI-STORM TIPOVER - 100S LID ANALYSIS

3.AO.1 Introduction

The fully loaded HI-STORM 100S, with the top lid in place, hypothetically tips over onto the ISFSI pad generating a resultant deceleration load that is bounded by 45 G's at the top of the fuel basket and 49 G's at the top of the storage overpack lid, per Appendix 3.A. In this appendix, the necessary stress analyses are performed to insure that the concrete shielding maintains its position after a non-mechanistic tipover event. Of particular interest is the concrete shield on the outside of the lid of the HI-STORM 100S. It is required that the shielding remain in place subsequent to any accident condition of storage. Appendix 3.K addresses the top lid of the longer HI-STORM 100 that has a different lid configuration. We note that using the G levels from Appendix 3.A is conservative since a corresponding tipover of a shorter HI-STORM will yield reduced decelerations since the initial impact velocity at the top end will be reduced.

3.AO.2 Methodology

Strength of materials formulations are used to estimate weld stress and shell stresses in the enclosing metal shells surrounding the concrete shielding.

3.AO.3 Input Data - HI-STORM 100S (from BOM and Chap. 1 Dwgs.)

3.AO.3.1 Geometry

Lid bolt diameter $d_{bolt} := 3.25 \cdot in$ Number of bolts $NB := 4$

Lid top plate thickness $t_{lid} := 4 \cdot in$ Lid top plate diameter $d_{lid} := 126 \cdot in$

Note that the top lid is really two 2" thick plates

Shield block shell thickness $t_{block} := 0.5 \cdot in$

Shield block height $L_{shieldblock} := 10.0 \cdot in$ Shield Block outer shell OD $d_{ob} := 86 \cdot in$

Shield Block Top Plate Thickness $t_{ring} := 0.25 \cdot in$

Fillet weld size $t_{weld} := 0.25 \cdot in$

Lid bottom plate thickness $t_{lidbottom} := 0.5 \cdot in$

Outer shell thickness $t_{outer} := 0.75 \cdot in$

Inner shell thickness $t_{inner} := 1.25 \cdot in$

Inner and Outer Shell weld size $t_{sweld} := 0.3125 \cdot in$

Outer shell OD $D_{OD} := 126 \cdot in$

Inner shell ID $d_{ID} := 73.5 \cdot in$

Shear bar dimensions

$L_{bar} := 53 \cdot in$ $t_{bar} := 0.5 \cdot in$ (contact area)

weld size $t_{wbar} := 0.43125 \cdot in$

Note that the outer plate and inner shell thicknesses are identical to the outer and inner shell thicknesses of the HI-STORM barrel.

shell length $L_{shell} := 6 \cdot in$

Barrel top cover plate thickness $t_{cover} := 0.75 \cdot in$

3.AO.3.2 Weight Densities

Concrete $\gamma_c := 150 \cdot \frac{lbf}{ft^3}$ Steel $\gamma_s := 0.283 \cdot \frac{lbf}{in^3}$

3.AO.4 Analyses

3.AO.4.1 Lid bottom plate stress analysis

First compute the total load resisted by the four lid bolts when the lid is decelerated by

$G := 48.5$ Design basis deceleration per Table 3.A.4 of Appendix 3.A (conservative since HI-STORM 100S is shorter, so impact velocity less)

Note that the load path is developed in the following manner:

The bolts have a clearance hole in the 4" thick top lid. Therefore, the deceleration load is transferred to the lid bottom plate by the inner and outer shells.

The four lid bolts act in direct shear to transfer the load from the lid bottom plate (actually a four segment annular plate) into the body of the HI-STORM 100S.

We first compute the total deceleration load transferred to the inner and outer shells

Weight of top plate

$$W_{lid} := \gamma_s \cdot t_{lid} \cdot \pi \cdot \frac{{d_{lid}}^2}{4} \qquad W_{lid} = 1.411 \times 10^4\ \mathrm{lbf}$$

Weight of shield block top plate

$$W_{bot} := \gamma_s \cdot t_{ring} \cdot \pi \cdot \frac{{d_{ob}}^2}{4} \qquad W_{bot} = 410.973\ \mathrm{lbf}$$

Weight of shield block shell

$$W_{shell} := \gamma_s \cdot t_{block} \cdot L_{shieldblock} \cdot \pi \cdot (d_{ob}) \qquad W_{shell} = 382.3\ \mathrm{lbf}$$

Weight of Shield Block Concrete

$$W_{shield} := \gamma_c \cdot \pi \cdot \frac{(d_{ob} - 2 \cdot t_{block})^2}{4} \cdot L_{shieldblock} \qquad W_{shield} = 4.926 \times 10^3\ \mathrm{lbf}$$

The total weight of the assemblage calculated so far is

$$W_{total} := W_{lid} + W_{bot} + W_{shell} + W_{shield}$$

$$W_{total} = 1.983 \times 10^4\ \mathrm{lbf}$$

The remaining weight is associated with the inner and outer shells, the duct plates, the concrete surrounding the ducts, and the lid bottom plate. This computes to approximately 4700 lb. For the total weight of the lid, we use the bounding weight assigned in Table 3.2.1

For subsequent calculations where the total weight is required, use the bounding weight from Table 3.2.1 for the HI-STORM 100S lid.

$$W_{lid} := 25500 \cdot \mathrm{lbf}$$

Compute the bearing stress in the bottom plate of the lid at each of the four bolt holes due to the accident load.

$$Area_{bearing} := 4 \cdot d_{bolt} \cdot (t_{lidbottom}) \qquad Area_{bearing} = 6.5\ \mathrm{in}^2$$

$$\sigma_{bearing} := \frac{W_{lid} \cdot G}{Area_{bearing}} \qquad \sigma_{bearing} = 1.903 \times 10^5\ \mathrm{psi}$$

This demonstrates that the bolts cannot support the shear load. We demonstrate that we have full shear capacity in each of the shear bars to withstand the load.

$F_t := W_{lid} \cdot G$ $\qquad$ $F_t = 1.237 \times 10^6\,\mathrm{lbf}$

From Table 3.3.2, the ultimate strength of the steel material (@ 350 degrees F) is

$S_u := 70000 \cdot \mathrm{psi}$

The weld stress limit for the shear bars, under failure conditions, is taken as 60% of the ultimate strength.

$\tau_{allowable} := .6 \cdot S_u$ $\qquad$ $\tau_{allowable} = 4.2 \times 10^4\,\mathrm{psi}$

The allowable bearing strength is taken as 90% of the ultimate strength at failure.

$A_{bear} := L_{bar} \cdot t_{bar}$ $\qquad$ $A_{weld} := L_{bar} \cdot (t_{wbar} + 0.7071 \cdot t_{wbar})$ $\qquad$ Note that we have a groove and a fillet weld holding the shear bar in place.

$\sigma_{bearing} := \dfrac{F_t}{A_{bear}}$ $\qquad$ $\sigma_{bearing} = 4.667 \times 10^4\,\mathrm{psi}$

$\tau_{weld} := \dfrac{F_t}{A_{weld}}$ $\qquad$ $\tau_{weld} = 3.17 \times 10^4\,\mathrm{psi}$

The safety factors are: $\qquad$ $SF_{bear} := \dfrac{.9 \cdot S_u}{\sigma_{bearing}}$ $\qquad$ $SF_{bear} = 1.35$

$SF_{shear} := \dfrac{.6 \cdot S_u}{\tau_{weld}}$ $\qquad$ $SF_{shear} = 1.325$

3.AO.4.2 Inner and Outer Shell Analysis

The total load to be transferred is $\qquad$ $W_l := G \cdot W_{total}$ $\qquad$ $W_l = 9.619 \times 10^5\,\mathrm{lbf}$

The shell base metal area available to resist this load is

$$Area := \pi \cdot (D_{OD} - t_{outer}) \cdot t_{outer} + \pi \cdot (d_{ID} + t_{inner}) \cdot t_{inner} - 100 \cdot in \cdot (t_{outer} + t_{inner})$$

$Area = 388.656\,\mathrm{in}^2$

The shear stress in the base metal is

$\tau_{base} := \frac{W_l}{Area}$ $\tau_{base} = 2.475 \times 10^3 \text{ psi}$

The weld metal area to transfer the load to the shell is $t_{sweld} = 0.313 \text{ in}$

$Area_{weld} := \pi \cdot (D_{OD}) \cdot t_{sweld} + \pi \cdot (d_{ID}) \cdot 0.7071 t_{sweld} - 2 \cdot 100 \cdot in \cdot t_{sweld}$ $Area_{weld} = 112.223 \text{ in}^2$

The shear stress in the weld group is

$\tau_{weld2} := \frac{W_l}{Area_{weld}}$ $\tau_{weld2} = 8.572 \times 10^3 \text{ psi}$

Therefore, the safety factor for this weld, under the postulated accident, is (for the actual lid components, we use 42% of the ultimate as the allowable weld stress)

$\tau_{allowable} := 0.42 \cdot S_u$ $SF_2 := \frac{\tau_{allowable}}{\tau_{weld2}}$ $SF_2 = 3.43$

We conclude that the amplified load can be transferred to the inner and outer shells without weld failure.

3.AO.4.3 Shield Block Shell-to-Lid Top Plate Weld

The weld is an all around fillet weld of thickness $t_{weld} = 0.25 \text{ in}$ $d_{ob} = 86 \text{ in}$

$Area_{weld} := \pi \cdot (d_{ob} + .333 \cdot t_{weld}) \cdot (0.7071 \cdot t_{weld})$ $Area_{weld} = 47.807 \text{ in}^2$

The load to be resisted by this weld is the weight of the shield block, the shield block shell, and the shield block top plate.

$W_{lw} := (W_{bot} + W_{shell} + W_{shield})$ $W_{lw} = 5.719 \times 10^3 \text{ lbf}$

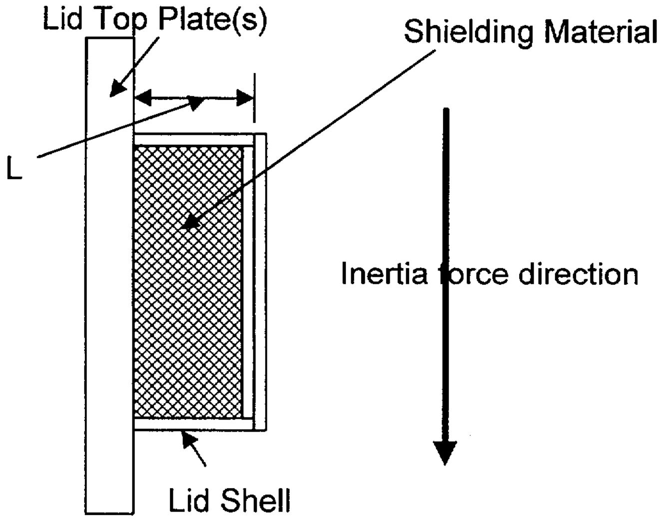
The shear stress in the weld is

$\tau_{weld} := \frac{W_{lw} \cdot G}{Area_{weld}}$ $\tau_{weld} = 5.802 \times 10^3 \text{ psi}$

3.AO.5 Shield Block Shell Stress Evaluation

3.AO.5.1 Consideration of the shield block shell as a short beam cantilevered from the lid top plate and subject to the amplified weight of the shielding material plus its own amplified weight.

We consider the following sketch that shows a "side" view of the lid top plate, the shield block top plate and the shield shell:



The following analysis computes the "axial" stress in the shield shell due to bending as a short beam.

$L := L_{shieldblock}$ $\quad L = 10\,in$

$t := t_{block}$ $\quad t = 0.5\,in$ $\quad t_{weld} = 0.25\,in$

$d := d_{ob}$ $\quad d = 86\,in$

The load applied to the "beam" is

$Load := \left(W_{bot} + W_{shell} + W_{shield}\right)\cdot G$ $\quad Load = 2.774 \times 10^{5}\,lbf$

The area moment of inertia of the weld metal is (base calculation on 2 times throat)

$I := \frac{\pi}{64}\cdot\left[\left(d + 2.0\cdot.7071\cdot t_{weld}\right)^{4} - (d)^{4}\right]$ $\quad I = 4.443 \times 10^{4}\,in^{4}$

The stress induced by the bending moment is

$$\sigma_{bending} := \frac{Load\cdot(0.5\cdot L)\cdot d}{2\cdot I} \qquad \sigma_{bending} = 1.342\times 10^{3}\,psi$$

Accounting for bending and shear stress in the weld, the safety factor on the weld needs to be reevaluated.

$$SF_2 := \frac{\tau_{allowable}}{\sqrt{\tau_{weld}^{2} + \sigma_{bending}^{2}}} \qquad SF_2 = 4.937 \qquad \sqrt{\tau_{weld}^{2} + \sigma_{bending}^{2}} = 5.955\times 10^{3}\,psi$$

3.AO.5.2 Consideration of circumferential stress in the shield shell

The shield shell is prevented from departing from a circular shape by the top and bottom plates. The effect of these end restraints is felt through an axial distance equal to the so called "bending boundary layer". The bending boundary layer extends along the shell axis approximately a distance equal to $2(td/2)^{1/2}$.

$$L_{bl} := 2\cdot\sqrt{\frac{d}{2}\cdot t} \qquad L_{bl} = 9.274\,in$$

Since the bending boundary layer extends from each end a distance equal to the shell length, it is concluded that the shell does not experience any peripheral stresses due to ring type deformation modes.

3.AO.6 Conclusions

The analysis has shown that the stress in the lid remains below the Level A allowable value for the lid material for all but bearing action at the bolt holes. Therefore, no gross deformation of the lid occurs during the non-mechanistic tipover event.

Stress in the shells remains below Level A values.

All welds connecting the shield block shells and the shield shell to the lid have stress levels below the Level A limit for welds from ASME Section III, Subsection NF. Therefore, the shield materials remain in place.

It is concluded that the HI-STORM 100S lid will remain in place after a hypothetical tipover event and continue to provide the necessary radiation shielding.

APPENDIX 3.AP HI-STORM 100S LID TOP PLATE BOLTING

3.AP.1 Introduction

This appendix provides a calculation which shows that the 4 studs holding the lid to the overpack top plate have sufficient capacity to resist any shear load that may be imposed by the lid during a non-mechanistic tipover of the cask

3.AP.2 Methodology

Force equilibrium relations are used to calculate the stud shear force resisting movement of the lid top plates, relative to the body of HI-STORM, under the design basis deceleration. This load is shown to be larger than the load causing enlargement of the clearance hole in the lid so the actual bolt load is reduced. The bolt safety factor, in the event that shear is transferred to the bolts, is computed using formulas and allowable strengths from the ASME Code.

3.AP.3 Input Data

From the tipover analysis (Table 3.A.4), the deceleration on the lid at the top of the storage overpack is

$Glevel := 48.5$ Conservative for HI-STORM 100S

From Table 3.2.1, the bounding weight for the top lid (HI-STORM 100S) is:

$Weight := 25500 \cdot lbf$

Stud material: SA564-630 (Age Hardened at 1075 degrees F)

Stud Material Ultimate Tensile and yield Strengths

@ 300 deg. F, Table 3.3.4 $S_u := 145000 \cdot psi$ $S_y := 110700 \cdot psi$

The allowable shear stress in the stud during this failure analysis is conservatively limited to the Code Level D limit of 42% of the ultimate strength even though 60% of ultimate defines the failure stress of the bolt.

$.42 \cdot S_u = 6.09 \times 10^4 psi$

Stud unsupported length $L_{stud} := 12 \cdot in$

Stud diameter (excluding threads) (see BOM No. 3065) $d_{bolt} := 3.25 \cdot in$

Minimum diameter (including threads) $d_{min} := .99 \cdot d_{bolt}$

This minimum diameter is estimated from Table 3 of Machinery's Handbook, 23rd Edition, Industrial Press, p. 1283.

Therefore the bolt area in the threaded region at the nut and at the overpack interface is obtained from the equation in the above cited reference (p. 1279).

$$A_{min} := \pi \cdot \left(.5 \cdot d_{min} - \frac{0.16238 \cdot in}{4} \right)^2 \qquad A_{min} = 7.726\,in^2$$

This is based on 4-UNC threads

Thickness of lid bottom plate $L := 0.5 \cdot in$

3.AP.4 Calculations

The four studs holding the top lid to the overpack are sized to enable a top lift of a fully loaded HI-STORM to be accomplished. The bolting is not subject to any significant pre-torque so in the event of a side drop (non-mechanistic tipover), the lid will experience a lateral movement relative to the top of the overpack. Four shear bars have been conservatively sized to insure that the lid will not separate from the body of the overpack. Since the bolts pass through clearance holes, there will be no shear load transferred to the bolts in the event of a lateral inertia load transmitted to the bolts. Nevertheless, for conservatism, we compute the safety factor in the bolts assuming that shear load is transferred to the stud by bearing action. The maximum force that could be transmitted occurs if the clearance holes close prior to the shear bar coming in contact with the bottom plate of the lid. The total force is

$$Force := Weight \cdot Glevel$$

$$Force = 1.237 \times 10^6\,lbf \qquad Number\_of\_bolts := 4$$

$$Force\_per\_bolt := \frac{Force}{Number\_of\_bolts} \qquad Force\_per\_bolt = 3.092 \times 10^5\,lbf$$

Calculate the lid plate area resisting shear. define db as the contact width that defines the contact area when the hole enlarges. Since we have a line contact, there will be an immediate local yielding and hole enlargement. Conformance of the bolt and the hole cannot occur prior to the shear bars becoming effective. Therefore a realistic estimate of the contact width is assumed to be 1/3 of the bolt diameter (engineering judgment)

$db := 0.333 \cdot d_{bolt}$ $\qquad A_{plate} := L \cdot db$

The bolt hole will begin to substantially open up at the "flow stress" that is assumed to be the average of yield and ultimate stress. At 300 degrees F, the yield and ultimate stress are:

$\sigma_{y516} := 33700 \cdot psi$ $\qquad \sigma_{u516} := 70000 \cdot psi$ $\qquad$ Table 3.3.2

Therefore the shear load that can be transmitted to a bolt is estimated as

$$Load_{shear} := \frac{(\sigma_{y516} + \sigma_{u516})}{2} \cdot A_{plate} \qquad Load_{shear} = 2.806 \times 10^{4}\, lbf$$

It is clear that the bolts cannot resist the entire load because the bolt holes will simply open due to the high stress in the lid material. Thus, our result is consistent with our assumption.

The shear capacity of one stud is $\qquad A_b := \pi \cdot \frac{d_{min}^{\ 2}}{4}$

$$Shear\_capacity := .42 \cdot S_u \cdot A_b \qquad Shear\_capacity = 4.952 \times 10^{5}\, lbf$$

Stud shear stress at interface

$$\tau_{bolt} := \frac{Load_{shear}}{A_b} \qquad \tau_{bolt} = 3.451 \times 10^{3}\, psi$$

The safety factor for direct shear at the interface, based on the defined failure criteria and the maximum load that can be transferred, is

$$SF_s := .42 \cdot \frac{S_u}{\tau_{bolt}} \qquad SF_s = 17.648 \qquad S_u = 1.45 \times 10^{5}\, psi$$

There is no requirement that the stud be other than "hand-tight" for storage. We specify 300 ft-lb. as the initial torque to be applied for the lid studs during storage (not lifting). Assuming a lubricated surface, this imposes an initial average stud stress conservatively computed below:

$$T := 300\cdot\mathrm{ft}\cdot\mathrm{lbf}$$

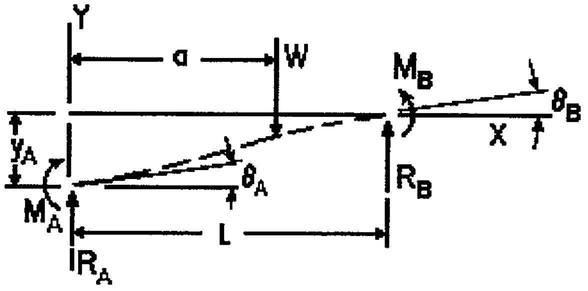
$$\sigma_{\mathrm{initial}} := \frac{T}{.12\cdot A_b\cdot d_{\mathrm{min}}} \qquad \sigma_{\mathrm{initial}} = 1.147\times 10^{3}\,\mathrm{psi}$$

(see Shigley and Mischke, Mechanical Engineering Design, McGraw Hill, 5th Edition, pp346-347)

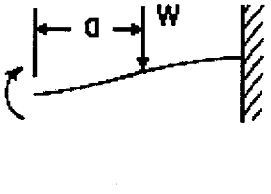
In addition to the mean stress, during a side drop, if the stud contacts the hole and experiences a shear load, the stud can also experience a bending moment developed as the stud resists the shear by guided cantilever action.

$$I := \frac{\pi}{64}\cdot d_{\mathrm{min}}{}^{4} \qquad I = 5.261\,\mathrm{in}^{4} \qquad \mathrm{Load}_{\mathrm{shear}} = 2.806\times 10^{4}\,\mathrm{lbf}$$

Concentrated intermediate load



Left end guided, right end fixed



Area moment of inertia: $I \equiv 5.261 \cdot \mathrm{in}^4$

Length of beam: $L \equiv 11 \cdot \mathrm{in}$

Distance from
left edge to load: $a \equiv 0 \cdot \mathrm{ft}$

Modulus of elasticity: $E \equiv 28 \cdot 10^6 \cdot \frac{\mathrm{lbf}}{\mathrm{in}^2}$

Load: $W \equiv 28060 \cdot \mathrm{lbf}$

Boundary values The following specify the reaction forces (R), moments (M), slopes (θ) and deflections (y) at the left and right ends of the beam (denoted as A and B, respectively).

At the left end of the beam (guided):

$$R_A := 0 \cdot \mathrm{lbf}$$

$$M_A := \frac{W \cdot (L-a)^2}{2 \cdot L} \qquad M_A = 1.286 \times 10^4 \,\mathrm{lbf \cdot ft}$$

$$\theta_A := 0 \cdot \mathrm{deg}$$

$$y_A := \frac{-W}{12 \cdot E \cdot I} \cdot (L-a)^2 \cdot (L + 2 \cdot a) \qquad y_A = -0.021 \,\mathrm{in}$$

At the right end of the beam (fixed):

$$R_B := W \qquad R_B = 2.806 \times 10^4 \,\mathrm{lbf}$$

$$M_B := \frac{-W \cdot \left(L^2 - a^2\right)}{2 \cdot L} \qquad M_B = -1.286 \times 10^4 \,\mathrm{lbf \cdot ft}$$

$$\theta_B := 0 \cdot \mathrm{deg}$$

$$y_B := 0 \cdot \mathrm{in}$$

The stress induced by bending of the stud during a side drop is

$$\sigma_{pl} := \frac{M_A \cdot d_{min}}{2 \cdot I} \qquad \sigma_{pl} = 4.719 \times 10^4 \,\mathrm{psi}$$

We apply the formulas of ASME Code Section III, Appendix F for bolts assuming Level D conditions apply. Under the accident condition, the outer fiber tensile stress in the stud cannot exceed the material ultimate strength (F-1335.1) Assuming that a combined state of tension and shear is present in the stud at the interface with the anchor block, then F-1335.3 imposes an interaction criteria that must be satisfied

$$SF_t := 1. \cdot \frac{S_u}{\sigma_{pl} + \sigma_{initial}} \qquad SF_t = 3$$

$$\text{Interaction\_factor} := \left(\frac{1}{SF_s}\right)^2 + \left(\frac{1}{SF_t}\right)^2 \qquad \text{Interaction\_factor} = 0.114$$

Therefore the safety factor for combined tension and shear is

$$SF_{ts} := \frac{1}{\text{Interaction\_factor}} \qquad SF_{ts} = 8.745$$

3.AP.5 Conclusion

For the Level D tip over condition, the HI-STORM 100S lid top plate will be held in place by the shear bars. If tolerances cause initial loading of bolt, then it is shown that hole enlargement occurs and limits the bolt load. The limit bolt load is computed and safety factors computed. In Appendix AO, the shear bar is demonstrated to have sufficient load capacity to resist all of the load from the lid; Any shear load from the bolts provides additional margin against lid separation.

APPENDIX 3.AQ: HI-STORM 100 COMPONENT THERMAL EXPANSIONS; MPC-24E

3.AQ.1 Scope

In this calculation, estimates of operating gaps, both radially and axially, are computed for the fuel basket-to-MPC shell, and for the MPC shell-to-overpack. This calculation is in support of the results presented in Section 3.4.4.2.

3.AQ.2 Methodology

Bounding temperatures are used to construct temperature distributions that will permit calculation of differential thermal expansions both radially and axially for the basket-to-MPC gaps, and for the MPC-to-overpack gaps. Reference temperatures are set at 70°F for all components. Temperature distributions are computed at the middle of the HI-STORM 100 System where the temperatures are highest. A comprehensive nomenclature listing is provided in Section 3.AQ.6.

3.AQ.3 References

[3.AQ.1] Boley and Weiner, Theory of Thermal Stresses, John Wiley, 1960, Sec. 9.10, pp. 288-291.

[3.AQ.2] Burgreen, Elements of Thermal Stress Analysis, Arcturus Publishers, Cherry Hill NJ, 1988.

3.AQ.4 Calculations for Hot Components (Middle of System)

3.AQ.4.1 Input Data

Based on thermal calculations in Chapter 4, the following temperatures are appropriate at the middle of the cask (Table 4.4.27).

The temperature change at the overpack inner shell, $\Delta T_{1h} := 175 - 70$

The temperature change at the overpack outer shell, $\Delta T_{2h} := 137 - 70$

The temperature change at the mean radius of the MPC shell, $\Delta T_{3h} := 309 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (454 - 70) \cdot 1.1$

The temperature change at the center of the basket (helium gas), $\Delta T_{5h} := 657 - 70$

Note that the outer basket temperature is conservatively amplified by 10% to insure a bounding parabolic distribution. This conservatism serves to maximize the growth of the basket.

The geometry of the components are as follows:

The outer radius of the overpack, $b := 66.25 \cdot in$

The minimum inner radius of the overpack, $a := 34.75 \cdot in$

The mean radius of the MPC shell, $R_{mpc} := \dfrac{68.375 \cdot in - 0.5 \cdot in}{2}$ $\quad R_{mpc} = 33.938\,in$

The initial MPC-to-overpack radial clearance, $RC_{mo} := .5 \cdot (69.5 - 68.5) \cdot in$

$RC_{mo} = 0.5\,in$

This initial radial clearance value, used to perform a radial growth check, is conservatively based on the channel radius (see Dwg. 1495, Sh. 5) and the maximum MPC diameter. For axial growth calculations for the MPC-to-overpack lid clearance, the axial length of the overpack is defined as the distance from the top of the pedestal platform to the bottom of the lid bottom plate, and the axial length of the MPC is defined as the overall MPC height.

The axial length of the overpack, $L_{ovp} := 191.5 \cdot in$

The axial length of the MPC, $L_{mpc} := 190.5 \cdot in$

The initial MPC-to-overpack nominal axial clearance, $AC_{mo} := L_{ovp} - L_{mpc}$

$AC_{mo} = 1\,in$

For growth calculations for the fuel basket-to-MPC shell clearances, the axial length of the basket is defined as the total length of the basket and the outer radius of the basket is defined as the mean radius of the MPC shell minus one-half of the shell thickness minus the initial basket-to-shell radial clearance.

The axial length of the basket, $L_{bas} := 176.5 \cdot in$

The initial basket-to-MPC lid nominal axial clearance, $AC_{bm} := 2 \cdot in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875 \cdot in$

The outer radius of the basket, $R_b := R_{mpc} - \dfrac{0.5}{2} \cdot in - RC_{bm}$ $\quad R_b = 33.5\,in$

The coefficients of thermal expansion used in the subsequent calculations are based on the mean temperatures of the MPC shell and the basket (conservatively estimated high).

The coefficient of thermal expansion for the MPC shell, $\alpha_{mpc} := 9.015 \cdot 10^{-6}$

The coefficient of thermal expansion for the basket, $\alpha_{bas} := 9.60 \cdot 10^{-6}$ 600 deg. F

3.AQ.4.2 Thermal Growth of the Overpack

Results for thermal expansion deformation and stress in the overpack are obtained here. The system is replaced by a equivalent uniform hollow cylinder with approximated average properties.

Based on the given inside and outside surface temperatures, the temperature solution in the cylinder is given in the form:

$$C_a + C_b \cdot \ln\left(\frac{r}{a}\right)$$

where

$$C_a := \Delta T_{1h} \qquad C_a = 105$$

$$C_b := \frac{\Delta T_{2h} - \Delta T_{1h}}{\ln\left(\frac{b}{a}\right)} \qquad C_b = -58.891$$

Next, form the integral relationship:

$$\mathrm{Int} := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\, dr$$

The Mathcad program, which was used to create this appendix, is capable of evaluating the integral "Int" either numerically or symbolically. To demonstrate that the results are equivalent, the integral is evaluated both ways in order to qualify the accuracy of any additional integrations that are needed.

The result obtained through numerical integration, $\mathrm{Int} = 1.305 \times 10^5\, \mathrm{in}^2$

To perform a symbolic evaluation of the solution the integral "Ints" is defined. This integral is then evaluated using the Maple symbolic math engine built into the Mathcad program as:

$$\mathrm{Int}_s := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\, dr$$

$$\mathrm{Int}_s := \frac{1}{2} \cdot C_b \cdot \ln\left(\frac{b}{a}\right) \cdot b^2 + \frac{1}{2} \cdot C_a \cdot b^2 - \frac{1}{4} \cdot C_b \cdot b^2 + \frac{1}{4} \cdot C_b \cdot a^2 - \frac{1}{2} \cdot C_a \cdot a^2$$

$$\mathrm{Int}_s = 1.305 \times 10^5\, \mathrm{in}^2$$

We note that the values of Int and Ints are identical. The average temperature in the overpack cylinder (T_{bar}) is therefore determined as:

$$T_{bar} := \frac{2}{\left(b^2 - a^2\right)} \cdot Int \qquad T_{bar} = 82.022$$

We estimate the average coefficient of thermal expansion for the overpack by weighting the volume of the various layers. A total of four layers are identified for this calculation. They are:

1) the inner shell
2) the shield shell
3) the radial shield
4) the outer shell

Thermal properties are based on estimated temperatures in the component and coefficient of thermal expansion values taken from the tables in Chapter 3. The following averaging calculation involves the thicknesses (t) of the various components, and the estimated coefficients of thermal expansion at the components' mean radial positions. The results of the weighted average process yields an effective coefficient of linear thermal expansion for use in computing radial growth of a solid cylinder (the overpack).

The thicknesses of each component are defined as:

$$t_1 := 1.25 \cdot in$$

$$t_2 := 0.75 \cdot in$$

$$t_3 := 26.75 \cdot in$$

$$t_4 := 0.75 \cdot in$$

and the corresponding mean radii can therefore be defined as:

$$r_1 := a + .5 \cdot t_1 + 2.0 \cdot in \qquad \text{(add the channel depth)}$$

$$r_2 := r_1 + .5 \cdot t_1 + .5 \cdot t_2$$

$$r_3 := r_2 + .5 \cdot t_2 + .5 \cdot t_3$$

$$r_4 := r_3 + .5 \cdot t_3 + .5 \cdot t_4$$

To check the accuracy of these calculations, the outer radius of the overpack is calculated from r_4 and t_4, and the result is compared with the previously defined value (b).

$$b_l := r_4 + 0.5 \cdot t_4$$

$$b_l = 66.25\,\text{in}$$

$$b = 66.25\,\text{in}$$

We note that the calculated value b_l is identical to the previously defined value b. The coefficients of thermal expansion for each component, estimated based on the temperature gradient, are defined as:

$$\alpha_1 := 5.782 \cdot 10^{-6}$$

$$\alpha_2 := 5.782 \cdot 10^{-6}$$

$$\alpha_3 := 5.5 \cdot 10^{-6}$$

$$\alpha_4 := 5.638 \cdot 10^{-6}$$

Thus, the average coefficient of thermal expansion of the overpack is determined as:

$$\alpha_{avg} := \frac{r_1 \cdot t_1 \cdot \alpha_1 + r_2 \cdot t_2 \cdot \alpha_2 + r_3 \cdot t_3 \cdot \alpha_3 + r_4 \cdot t_4 \cdot \alpha_4}{\frac{a+b}{2} \cdot \left(t_1 + t_2 + t_3 + t_4\right)}$$

$$\alpha_{avg} = 5.628 \times 10^{-6}$$

Reference 3.AQ.1 gives an expression for the radial deformation due to thermal growth. At the inner radius of the overpack (r = a), the radial growth is determined as:

$$\Delta R_{ah} := \alpha_{avg} \cdot a \cdot T_{bar}$$

$$\Delta R_{ah} = 0.016\,\text{in}$$

Similarly, an overestimate of the axial growth of the overpack can be determined by applying the average temperature (T_{bar}) over the entire length of the overpack as:

$$\Delta L_{ovph} := L_{ovp} \cdot \alpha_{avg} \cdot T_{bar}$$

$$\Delta L_{ovph} = 0.088\,\text{in}$$

Estimates of the secondary thermal stresses that develop in the overpack due to the radial temperature variation are determined using a conservatively high value of E as based on the temperature of the steel. The circumferential stress at the inner and outer surfaces (σ_{ca} and σ_{cb}, respectively) are determined as:

The Young's Modulus of the material, $E := 28300000 \cdot \text{psi}$

$$\sigma_{ca} := \alpha_{avg}\cdot\frac{E}{a^2}\cdot\left[2\cdot\frac{a^2}{\left(b^2-a^2\right)}\cdot Int - \left(C_a\right)\cdot a^2\right]$$

$$\sigma_{ca} = -3660\,psi$$

$$\sigma_{cb} := \alpha_{avg}\cdot\frac{E}{b^2}\cdot\left[2\cdot\frac{b^2}{\left(b^2-a^2\right)}\cdot Int - \left[C_a + C_b\cdot\left(\ln\left(\frac{b}{a}\right)\right)\right]\cdot b^2\right]$$

$$\sigma_{cb} = 2393\,psi$$

The radial stress due to the temperature gradient is zero at both the inner and outer surfaces of the overpack. The radius where a maximum radial stress is expected, and the corresponding radial stress, are determined by trial and error as:

$$N := 0.37$$

$$r := a\cdot(1-N) + N\cdot b$$

$$r = 46.405\,in$$

$$\sigma_r := \alpha_{avg}\cdot\frac{E}{r^2}\cdot\left[\frac{r^2-a^2}{2}\cdot T_{bar} - \int_a^r \left[C_a + C_b\cdot\left(\ln\left(\frac{y}{a}\right)\right)\right]\cdot y\,dy\right]$$

$$\sigma_r = -477.253\,psi$$

The axial stress developed due to the temperature gradient is equal to the sum of the radial and tangential stresses at any radial location. (see eq. 9.10.7) of [3.AQ.1]. Therefore, the axial stresses are available from the above calculations. The stress intensities in the overpack due to the temperature distribution are below the Level A membrane stress.

3.AQ.4.3 Thermal Growth of the MPC Shell

The radial and axial growth of the MPC shell (ΔR_{mpch} and ΔL_{mpch}, respectively) are determined as:

$$\Delta R_{mpch} := \alpha_{mpc}\cdot R_{mpc}\cdot \Delta T_{3h} \qquad \Delta R_{mpch} = 0.073\,in$$

$$\Delta L_{mpch} := \alpha_{mpc}\cdot L_{mpc}\cdot \Delta T_{3h} \qquad \Delta L_{mpch} = 0.41\,in$$

3.AQ.4.4 Clearances Between the MPC Shell and Overpack

The final radial and axial MPC shell-to-overpack clearances (RG_{moh} and AG_{moh}, respectively) are determined as:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch}$$

$$RG_{moh} = 0.443\,\text{in}$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch}$$

$$AG_{moh} = 0.678\,\text{in}$$

Note that this axial clearance (AG_{moh}) is based on the temperature distribution at the middle of the system.

3.AQ.4.5 Thermal Growth of the MPC-24E Basket

Using formulas given in [3.AQ.2] for a solid body of revolution, and assuming a parabolic temperature distribution in the radial direction with the center and outer temperatures given previously, the following relationships can be developed for free thermal growth.

Define $\Delta T_{bas} := \Delta T_{5h} - \Delta T_{4h}$ $\Delta T_{bas} = 164.6$

Then the mean temperature can be defined as $T_{bar} := \frac{2}{R_b^2} \cdot \int_0^{R_b} \left(\Delta T_{5h} - \Delta T_{bas} \cdot \frac{r^2}{R_b^2} \right) \cdot r\,dr$

Using the Maple symbolic engine again, the closed form solution of the integral is:

$$T_{bar} := \frac{2}{R_b^2} \cdot \left(\frac{-1}{4} \cdot \Delta T_{bas} \cdot R_b^2 + \frac{1}{2} \cdot \Delta T_{5h} \cdot R_b^2 \right)$$

$$T_{bar} = 504.7$$

The corresponding radial growth at the periphery (ΔR_{bh}) is therefore determined as:

$$\Delta R_{bh} := \alpha_{bas} \cdot R_b \cdot T_{bar}$$

$$\Delta R_{bh} = 0.162\,\text{in}$$

and the corresponding axial growth (ΔL_{bas}) is determined from [3.AQ.2] as:

$$\Delta L_{bh} := \Delta R_{bh} \cdot \frac{L_{bas}}{R_b}$$

$$\Delta L_{bh} = 0.855\,\mathrm{in}$$

Note that the coefficient of thermal expansion for the hottest basket temperature has been used, and the results are therefore conservative.

3.AQ.4.6 Clearances Between the Fuel Basket and MPC Shell

The final radial and axial fuel basket-to-MPC shell and lid clearances (RG_{bmh} and AG_{bmh}, respectively) are determined as:

$$RG_{bmh} := RC_{bm} - \Delta R_{bh} + \Delta R_{mpch}$$

$$RG_{bmh} = 0.098\,\mathrm{in}$$

$$AG_{bmh} := AC_{bm} - \Delta L_{bh} + \Delta L_{mpch}$$

$$AG_{bmh} = 1.555\,\mathrm{in}$$

3.AQ.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-Overpack	Fuel Basket-to-MPC Shell
$RG_{moh} = 0.443\,\mathrm{in}$	$RG_{bmh} = 0.098\,\mathrm{in}$
$AG_{moh} = 0.678\,\mathrm{in}$	$AG_{bmh} = 1.555\,\mathrm{in}$

3.AQ.6 Nomenclature

a is the inner radius of the overpack

AC_{bm} is the initial fuel basket-to-MPC axial clearance.

AC_{mo} is the initial MPC-to-overpack axial clearance.

AG_{bmh} is the final fuel basket-to-MPC shell axial gap for the hot components.

AG_{moh} is the final MPC shell-to-overpack axial gap for the hot components.

b is the outer radius of the overpack.

L_{bas} is the axial length of the fuel basket.

L_{mpc} is the axial length of the MPC.

L_{ovp} is the axial length of the overpack.

r_1 (r_2,r_3,r_4) is mean radius of the overpack inner shell (shield shell, concrete, outer shell).

R_b is the outer radius of the fuel basket.

R_{mpc} is the mean radius of the MPC shell.

RC_{bm} is the initial fuel basket-to-MPC radial clearance.

RC_{mo} is the initial MPC shell-to-overpack radial clearance.

RG_{bmh} is the final fuel basket-to-MPC shell radial gap for the hot components.

RG_{moh} is the final MPC shell-to-overpack radial gap for the hot components.

t_1 (t_2,t_3,t_4) is the thickness of the overpack inner shell (shield shell, concrete, outer shell).

T_{bar} is the average temperature of the overpack cylinder.

α_1 (α_2,α_3,α_4) is the coefficient of thermal expansion of the overpack inner shell (shield shell, concrete, outer shell).

α_{avg} is the average coefficient of thermal expansion of the overpack.

α_{bas} is the coefficient of thermal expansion of the overpack.

α_{mpc} is the coefficient of thermal expansion of the MPC.

ΔL_{bh} is the axial growth of the fuel basket for the hot components.

ΔL_{mpch} the the axial growth of the MPC for the hot components.

ΔL_{ovph} is the axial growth of the overpack for the hot components.

ΔR_{ah} is the radial growth of the overpack inner radius for the hot components.

ΔR_{bh} is the radial growth of the fuel basket for the hot components.

ΔR_{mpch} is the radial growth of the MPC shell for the hot components.

ΔT_{1h} is the temperature change at the overpack inner shell for hot components.

ΔT_{2h} is the temperature change at the overpack outer shell for hot components.

ΔT_{3h} is the temperature change at the MPC shell mean radius for hot components.

ΔT_{4h} is the temperature change at the MPC basket periphery for hot components.

ΔT_{5h} is the temperature change at the MPC basket centerline for hot components.

ΔT_{bas} is the fuel basket centerline-to-periphery temperature gradient.

σ_{ca} is the circumferential stress at the overpack inner surface.

σ_{cb} is the circumferential stress at the overpack outer surface.

σ_r is the maximum radial stress of the overpack.

σ_{zi} is the axial stress at the fuel basket centerline.

σ_{zo} is the axial stress at the fuel basket periphery.

APPENDIX 3.AR - ANALYSIS OF TRANSNUCLEAR DAMAGED FUEL CANISTER AND THORIA ROD CANISTER

3.AR.1 Introduction

Some of the items at the Dresden Station that have been considered for storage in the HI-STAR 100 System are damaged fuel stored in Transnuclear damaged fuel canisters and Thoria rods that are also stored in a special canister designed by Transnuclear. Both of these canisters have been designed and have been used by ComEd to transport the damaged fuel and the Thoria rods. Despite the previous usage of these canisters, it is prudent and appropriate to provide an independent structural analysis of the major load path of these canisters prior to accepting them for inclusion as permitted items in the HI-STAR and HI-STORM 100 MPC's. This appendix contains the necessary structural analysis of the Transnuclear damaged fuel canister and Thoria rod canister. The objective of the analysis is to demonstrate that the canisters are structurally adequate to support the loads that develop during normal lifting operations and during postulated accident conditions.

The upper closure assembly is designed to meet the requirements of NUREG-0612 [2]. The remaining components of the canisters are governed by ASME Code Section III, Subsection NG [3]. These are the same criteria used in Appendix 3.B of the HI-STAR 100 to analyze the Holtec damaged fuel container for Dresden damaged fuel.

3.AR.2 Composition

This appendix was created using the Mathcad (version 8.02) software package. Mathcad uses the symbol ':=' as an assignment operator, and the equals symbol '=' retrieves values for constants or variables.

3.AR.3 References

1. Crane Manufacture's of America Association, Specifications for Electric Overhead Traveling Cranes #70.

2. NUREG-0612, Control of Heavy Loads at Nuclear Power Plants

3. ASME Boiler and Pressure Vessel Code, Section III, July 1995

3.AR.4 Assumptions

1. Buckling is not a concern during an accident since during a drop the canister will be confined by the fuel basket.

2. The strength of the weld is assumed to decrease the same as the base metal as the temperature increases.

3.AR.5 Method

3.AR.5 Method

Two are considered: 1) normal lifting and handling of canister, and 2) accident drop event.

3.AR.6 Acceptance Criteria

1) Normal Handling -

a) Canister governed by ASME NG allowables:

b)Welds governed by NG and NF allowables;
quality factors taken from NG
stress limit = 0.3 Su

c) Lifting governed by NUREG-0612 allowables.

2) Drop Accident -

a) canister governed by ASME NG allowables:
shear = 0.42 Su (conservative)

b)Welds governed by NG and NF allowables;
quality factors taken from NG
stress limit = 0.42 Su

3.AR.7 Input Stress Data

The canisters is handled while still in the spent fuel pool. Therefore, its design temperature for lifting considerations is the temperature of the fuel pool water (150°F). The design temperature for accident conditions is 725°F. All dimensions are taken from the Transnuclear design drawings listed at the end of this appendix. The basic input parameters used to perform the calculations are:

Design stress intensity of SA240-304 (150°F)	$S_{m1} := 20000 \cdot psi$
Design stress intensity of SA240-304 (775°F)	$S_{m2} := 15800 \cdot psi$
Yield stress of SA240-304 (150°F)	$S_{y1} := 27500 \cdot psi$
Yield stress of SA240-304 (775°F)	$S_{y2} := 17500 \cdot psi$
Ultimate strength of SA240-304 (150°F)	$S_{u1} := 73000 \cdot psi$
Ultimate strength of SA240-304 (775°F)	$S_{u2} := 63300 \cdot psi$

Ultimate strength of weld material (150°F) $Su_w := 70000 \cdot psi$

Ultimate strength of weld material (775°F) $Su_{wacc} := Su_w - \left(S_{u1} - S_{u2}\right)$

Weight of a BWR fuel assembly (D-1) $W_{fuel} := 400 \cdot lbf$

Weight of 18 Thoria Rods (Calculated by Holtec) $W_{thoria} := 90 \cdot lbf$

Bounding Weight of the damaged fuel canister (Estimated by Holtec) $W_{container} := 150 \cdot lbf$

Bounding Weight of the Thoria Rod Canister (Estimated) $W_{rodcan} := 300 \cdot lbf$

Quality factor for full penetration weld (visual inspection) $n := 0.5$

Dynamic load factor for lifting $DLF := 1.15$

The remaining input data is provided as needed in the calculation section

3.AR.8 Calculations for Transnuclear Damaged Fuel Canister

3.AR.8.1 Lifting Operation (Normal Condition)

The critical load case under normal conditions is the lifting operation. The key areas of concern for ASME NG analysis are the canister sleeve, the sleeve to lid frame weld, and the lid frame. All calculations performed for the lifting operation assume a dynamic load factor of 1.15 [1].

3.AR.8.1.1 Canister Sleeve

During a lift, the canister sleeve is loaded axially, and the stress state is pure tensile membrane. For the subsequent stress calculation, it is assumed that the full weight of the damaged fuel canister and the fuel assembly are supported by the sleeve. The magnitude of the load is

$$F := DLF \cdot \left(W_{container} + W_{fuel}\right) \qquad F = 632\,lbf$$

From TN drawing 9317.1-120-4, the canister sleeve geometry is

$id_{sleeve} := 4.81 \cdot in$ $t_{sleeve} := 0.11 \cdot in$

The cross sectional area of the sleeve is

$$A_{sleeve} := \left(id_{sleeve} + 2 \cdot t_{sleeve}\right)^2 - id_{sleeve}^{\ 2} \qquad A_{sleeve} = 2.16\,in^2$$

Therefore, the tensile stress in the sleeve is $\sigma := \frac{F}{A_{sleeve}}$ $\sigma = 292\ \text{psi}$

The allowable stress intensity for the primary membrane category is S_m per Subsection NG of the ASME Code. The corresponding safety margin is

$$SM := \frac{S_{ml}}{\sigma} - 1 \qquad SM = 67.5$$

3.AR.8.1.2 Sleeve Welds

The top of the canister must support the amplified weight. This load is carried directly by the fillet weld that connects the lid frame to the canister sleeve. The magnitude of the load is conservatively taken a the entire amplified weight of canister plus fuel.

$$F = 632\ \text{lbf}$$

The weld thickness is $t_{base} := 0.09 \cdot in$

The area of the weld, with proper consideration of quality factors, is

$$A_{weld} := n \cdot 4 \cdot (id_{sleeve} + 2 \cdot t_{sleeve}) \cdot .7071 \cdot t_{base} \qquad A_{weld} = 0.64\ in^2$$

Therefore, the shear stress in the weld is $\tau := \frac{F}{A_{weld}}$ $\tau = 988\ \text{psi}$

From the ASME Code the allowable weld shear stress, under normal conditions (Level A), is 30% of the ultimate strength of the base metal. The corresponding safety margin is

$$SM := \frac{0.3 \cdot S_{ul}}{\tau} - 1 \qquad SM = 21.2$$

3.AR.8.1.3 Lid Frame Assembly

The Lid Frame assembly is classified as a NUREG-0612 lifting device. As such the allowable stress for design is the lesser of one-sixth of the yield stress and one-tenth of the ultimate strength.

$$\sigma_1 := \frac{S_{yl}}{6} \qquad \sigma_2 := \frac{S_{ul}}{10}$$

$$\sigma_1 = 4583\ \text{psi} \qquad \sigma_2 = 7300\ \text{psi}$$

For SA240-304 material the yield stress governs. $\sigma_{allowable} := \sigma_1$

The total lifted load is $F := DLF \cdot (W_{container} + W_{fuel})$ $F = 632\ lbf$

The frame thickness is obtained from Transnuclear drawing 9317.1-120-11

$t_{frame} := 0.395 \cdot in$

The inside span is the same as the canister sleeve $id_{sleeve} = 4.81\ in$

The area available for direct load is

$A_{frame} := (id_{sleeve} + 2 \cdot t_{frame})^2 - id_{sleeve}^2$ $A_{frame} = 8.224\ in^2$

The direct stress in the frame is $\sigma := \dfrac{F}{A_{frame}}$ $\sigma = 77\ psi$

The safety margin is $SM := \dfrac{\sigma_{allowable}}{\sigma} - 1$ $SM = 58.59$

The bearing stress at the four lift locations is computed from the same drawing

$A_{bearing} := 4 \cdot t_{frame} \cdot (2 \cdot 0.38 \cdot in)$ $A_{bearing} = 1.201\ in^2$

$\sigma_{bearing} := \dfrac{F}{A_{bearing}}$ $\sigma_{bearing} = 526.732\ psi$ $SM := \dfrac{\sigma_{allowable}}{\sigma_{bearing}} - 1$ $SM = 7.7$

3.AR.8.2 60g End Drop of HI-STAR 100 (Bounding Accident Condition since HI-STORM limit is 45g's)

The critical member of the damaged fuel canister during the drop scenario is the bottom assembly (see Transnuclear drawing 9317.1-120-5). It is subjected to direct compression due to the amplified weight of the fuel assembly and the canister. The bottom assembly is a 3.5" Schedule 40S pipe. The load due to the 60g end drop is

$F := 60 \cdot (W_{fuel} + W_{container})$ $F = 33000\ lbf$

The properties of the pipe are obtained from the Ryerson Stock Catalog as

$od := 4 \cdot in$ $id := 3.548 \cdot in$ $t_{pipe} := \dfrac{(od - id)}{2}$ $t_{pipe} = 0.226\ in$

The pipe area is $A_{pipe} := \frac{\pi}{4} \cdot \left(od^2 - id^2\right)$ $\qquad A_{pipe} = 2.68\,in^2$

The stress in the member is $\sigma := \frac{F}{A_{pipe}}$ $\qquad \sigma = 12316\,psi$

The allowable primary membrane stress from Subsection NG of the ASME Code, for accident conditions (Level D), is

$$\sigma_{allowable} := 2.4 \cdot S_{m2} \qquad \sigma_{allowable} = 37920\,psi$$

The safety margin is $SM := \frac{\sigma_{allowable}}{\sigma} - 1$ $\qquad SM = 2.1$

To check the stability of the pipe, we conservatively compute the Euler Buckling load for a simply supported beam.

The Young's Modulus is $E := 27600000 \cdot psi$

Compute the moment of inertia as $I := \frac{\pi}{64} \cdot \left(od^4 - id^4\right)$ $\qquad I = 4.788\,in^4$

$$L := 22 \cdot in \qquad P_{crit} := \pi^2 \cdot \frac{E \cdot I}{L^2} \qquad P_{crit} = 2.695 \times 10^6\,lbf$$

The safety margin is $SM := \frac{P_{crit}}{F} - 1$ $\qquad SM = 80.654$

3.AR.8.3 Conclusion for TN Damaged Fuel Canister

The damaged fuel canister and the upper closure assembly are structurally adequate to withstand the specified normal and accident condition loads. All calculated safety margins are greater than zero.

3.AR.9 Calculations for Transnuclear Thoria Rod Canister

3.AR.9.1 Lifting Operation (Normal Condition)

The critical load case under normal conditions is the lifting operation. The key areas of concern for ASME NG analysis are the canister sleeve, the sleeve to lid frame weld, and the lid frame. All calculations performed for the lifting operation assume a dynamic load factor of 1.15.

3.AR.9.1.1 Canister Sleeve

During a lift, the canister sleeve is loaded axially, and the stress state is pure tensile membrane. For the subsequent stress calculation, it is assumed that the full weight of the Thoria rod canister and the Thoria rods are supported by the sleeve. The magnitude of the load is

$F := DLF \cdot (W_{rodcan} + W_{thoria})$ $\quad F = 449\ \mathrm{lbf}$

From TN drawing 9317.1-182-1, the canister sleeve geometry is

$id_{sleeve} := 4.81 \cdot in$ $\quad t_{sleeve} := 0.11 \cdot in$

The cross sectional area of the sleeve is

$A_{sleeve} := (id_{sleeve} + 2 \cdot t_{sleeve})^2 - id_{sleeve}{}^2$ $\quad A_{sleeve} = 2.16\ in^2$

Therefore, the tensile stress in the sleeve is $\sigma := \dfrac{F}{A_{sleeve}}$ $\quad \sigma = 207\ psi$

The allowable stress intensity for the primary membrane category is S_m per Subsection NG of the ASME Code. The corresponding safety margin is

$SM := \dfrac{S_{m1}}{\sigma} - 1$ $\quad SM = 95.5$

3.AR.9.1.2 Sleeve Welds

The top of the canister must support the amplified weight. This load is carried directly by the fillet weld that connects the lid frame to the canister sleeve. The magnitude of the load is conservatively taken a the entire amplified weight of canister plus Thoria rod.

$F = 449\ \mathrm{lbf}$

The weld thickness is $t_{base} := 0.09 \cdot in$ (assumed equal to the same weld for the damaged fuel canister

The area of the weld, with proper consideration of quality factors, is

$A_{weld} := n \cdot 4 \cdot (id_{sleeve} + 2 \cdot t_{sleeve}) \cdot .7071 \cdot t_{base}$ $\quad A_{weld} = 0.64\ in^2$

Therefore, the shear stress in the weld is $\tau := \dfrac{F}{A_{weld}}$ $\quad \tau = 701\ psi$

From the ASME Code the allowable weld shear stress, under normal conditions (Level A), is 30% of the ultimate strength of the base metal. The corresponding safety margin is

$SM := \dfrac{0.3 \cdot S_{u1}}{\tau} - 1$ $\quad SM = 30.3$

3.AR.9.1.3 Lid Frame Assembly

The Lid Frame assembly is classified as a NUREG-0612 lifting device. As such the allowable stress for design is the lesser of one-sixth of the yield stress and one-tenth of the ultimate strength.

$$\sigma_1 := \frac{S_{yl}}{6} \qquad \sigma_2 := \frac{S_{ul}}{10}$$

$$\sigma_1 = 4583\,\text{psi} \qquad \sigma_2 = 7300\,\text{psi}$$

For SA240-304 material the yield stress governs. $\sigma_{allowable} := \sigma_1$

The total lifted load is $F := DLF\cdot\left(W_{rodcan} + W_{thoria}\right)$ $F = 449\,\text{lbf}$

The frame thickness is obtained from Transnuclear drawing 9317.1-182-8. This drawing was not available, but the TN drawing 9317.1-182-4 that included a view of the lid assembly suggests that it is identical in its structural aspects to the lid frame in the damaged fuel canister.

$t_{frame} := 0.395\cdot in$

The inside span is the same as the canister sleeve $id_{sleeve} = 4.81\,in$

The area available for direct load is

$$A_{frame} := \left(id_{sleeve} + 2\cdot t_{frame}\right)^2 - id_{sleeve}^{\,2} \qquad A_{frame} = 8.224\,in^2$$

The direct stress in the frame is

$$\sigma := \frac{F}{A_{frame}} \qquad \sigma = 55\,\text{psi}$$

The safety margin is

$$SM := \frac{\sigma_{allowable}}{\sigma} - 1 \qquad SM = 83.04$$

The bearing stress at the four lift locations is computed from the same drawing

$$A_{bearing} := 4\cdot t_{frame}\cdot(2\cdot 0.38\cdot in) \qquad A_{bearing} = 1.201\,in^2$$

$$\sigma_{bearing} := \frac{F}{A_{bearing}} \qquad \sigma_{bearing} = 373.501\,\text{psi} \qquad SM := \frac{\sigma_{allowable}}{\sigma_{bearing}} - 1 \qquad SM = 11.27$$

3.AR.9.2 60g HI-STAR End Drop (Bounds Accident Condition in HI-STORM)

The critical member of the damaged fuel canister during the drop scenario is the bottom assembly. Transnuclear drawing 9317.1-120-5). It is subjected to direct compression due to the amplified weight of the Thoria rods and the canister.

$F := 60 \cdot (W_{thoria} + W_{rodcan})$ $\quad F = 23400\,\text{lbf}$

The properties of the pipe are obtained from the Ryerson Stock Catalog as

$od := 4 \cdot in$ $\quad id := 3.548 \cdot in$ $\quad t_{pipe} := \frac{(od - id)}{2}$ $\quad t_{pipe} = 0.226\,in$

The pipe area is $A_{pipe} := \frac{\pi}{4} \cdot (od^2 - id^2)$ $\quad A_{pipe} = 2.68\,in^2$

The stress in the member is $\sigma := \frac{F}{A_{pipe}}$ $\quad \sigma = 8733\,psi$

The allowable primary membrane stress from Subsection NG of the ASME Code, for accident conditions (Level D), is

$\sigma_{allowable} := 2.4 \cdot S_{m2}$ $\quad \sigma_{allowable} = 37920\,psi$

The safety margin is $SM := \frac{\sigma_{allowable}}{\sigma} - 1$ $\quad SM = 3.3$

To check the stability of the pipe, we compute the Euler Buckling load for a simply supported beam.

The Young's Modulus is $E := 27600000 \cdot psi$

Compute the moment of inertia as $I := \frac{\pi}{64} \cdot (od^4 - id^4)$ $\quad I = 4.788\,in^4$

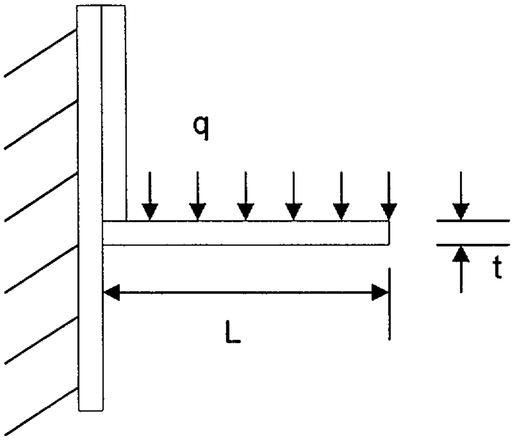
$L := 22 \cdot in$

$P_{crit} := \pi^2 \cdot \frac{E \cdot I}{L^2}$ $\quad P_{crit} = 2.695 \times 10^6\,lbf$

The safety margin is $SM := \frac{P_{crit}}{F} - 1$ $\quad SM = 114.153$

3.AR.9.4 60g HI-STAR Side Drop (Bounds Accident Condition for HI-STORM)

The Thoria Rod Separator Assembly is shown in TN drawings 9317.1-182-1 and 9317.1-182-3. under the design basis side drop or tipover accident, we examine the consequences to one of the rod support strips acting as a cantilever strip acted upon by self-weight and the weight of one Thoria rod.



Weight of 1 rod per unit length

length := 113.16·in

$w_{rod} := 90 \cdot \frac{lbf}{18} \cdot \frac{1}{length}$ $w_{rod} = 0.044 \frac{lbf}{in}$

Weight of support per unit length (per drawing 9317.1-182-3

L := 1.06·in t := 0.11·in

$w_{sup} := .29 \cdot \frac{lbf}{in^3} \cdot L \cdot t$ $w_{sup} = 0.034 \frac{lbf}{in}$

Amplified load (assumed as a uniform distribution)

$q := 60 \cdot (w_{rod} + w_{sup})$ $q = 4.68 \frac{lbf}{in}$

$Moment := \frac{q \cdot L^2}{2}$ $Moment = 2.629\, in \cdot lbf$

Bending stress at the root of the cantilever beam is

$\sigma := 6 \cdot \frac{Moment}{1 \cdot in \cdot t^2}$ $\sigma = 1.304 \times 10^3\, psi$

Shear stress at the root of the cantilever $\tau := q \cdot \frac{L}{t \cdot 1 \cdot in}$ $\tau = 45.098\, psi$

Large margins of safety are indicated by these stress results.

3.AR.9.5 Conclusion for TN Thoria Rod Canister

The Thoria rod canister is structurally adequate to withstand the specified normal and accident condition loads. All calculated safety margins are greater than zero.

3.AR.10 General Conclusion

The analysis of the TN damaged fuel canister and the TN Thoria rod canister have demonstrated that all structural safety margins are large. We have confirmed that the TN canisters have positive safety margins for the HI-STAR 100 governing design basis loads. The HI-STAR design basis handling accident load bounds the corresponding load for HI-STORM. Therefore, the loaded TN canisters from ComEd Dresden Unit#1 can safely be carried in both the HI-STAR and HI-STORM 100 Systems.

3.AR.11 List of Transnuclear Drawing Numbers

9317.1-120 - 2,3,4,5,6,7,8,9,10,11,13,14,15,17,18,19,20,21,22,23

9317.1-182- 1,2,3,4,5,6

APPENDIX 3.AS - ANALYSIS OF GENERIC PWR AND BWR DAMAGED FUEL CONTAINERS

3.AS.1 Introduction

This appendix contains an analysis of the damaged fuel containers that are used for the HI-STAR 100 MPC-24E and MPC-68, respectively. The objective of the analysis is to demonstrate that the two types of storage containers are structurally adequate to support the loads that develop during normal lifting operations and during an end drop.

The lifting bolt of each containers is designed to meet the requirements set forth for Special Lifting Devices in Nuclear Plants [2]. The remaining components of the damaged fuel container are compared to ASME Code Section III, Subsection NG allowable stress levels.

3.AS.2 Composition

This appendix was created using the Mathcad (version 2000) software package. Mathcad uses the symbol ':=' as an assignment operator, and the equals symbol '=' retrieves values for constants or variables.

3.AS.3 References

1. Crane Manufacture's of America Association, Specifications for Electric Overhead Traveling Cranes #70.

2. ANSI N14-6, Special Lifting Devices for Loads Greater than 10000 lbs. in Nuclear Plants.

3. ASME Boiler and Pressure Vessel Code, Section III Subsection NG, July 1995

4. Roark's Formulas for Stress & Strain, 6th Edition, 1989.

5. Kent's Mechanical Engineers' Handbook, Design and Production Volume, 12th Edition, 1965

6. ASME, "Boiler & Pressure Vessel Code," Section II, Part D-Material Properties, July 1, 1995

3.AS.4 Assumptions

1. Buckling is not a concern during an accident since during a drop the canister will be supported by the walls of the fuel basket.

2. The strength of the weld is assumed to decrease the same as the base metal as the temperature is increased.

3.AS.5 Method

Two cases are considered: 1) normal handling of container, and 2) accident drop event.

3.AS.6 Acceptance Criteria

1) Normal Handling -

a) Container governed by ASME NG[3] allowables:
shear stress allowable is 60% of membrane stress intensity

b)Welds are governed by NG Code allowables; stress limit =60% of tensile stress intensity(per Section III, Subsection NG-3227.2).

c) Lifting bolt is governed by ANSI N14-6 criteria

2) Drop Accident -

a) Container governed by ASME Section III, Appendix F allowables:
(allowable shear stress = 0.42 Su)

3.AS.7 Input Data for MPC-24E (PWR) Damaged Fuel Container

The damaged fuel container is only handled while still in the spent fuel pool. Therefore, its design temperature for lifting considerations is the temperature of the fuel pool water (150°F). The design temperature for accident conditions is 725°F. All dimensions are taken from Dwg. 2776. The basic input parameters used to perform the calculations are:

Design stress intensity of SA240-304 (150°F)	$S_{m1} := 20000 \cdot psi$	Table 1.A.1
Design stress intensity of SA240-304 (725°F)	$S_{m2} := 15800 \cdot psi$	
Yield stress of SA240-304 (150°F)	$S_{y1} := 27500 \cdot psi$	Table 1.A.3
Yield stress of SA240-304 (725°F)	$S_{y2} := 17500 \cdot psi$	
Ultimate strength of SA240-304 (150°F)	$S_{u1} := 73000 \cdot psi$	Table 1.A.2
Ultimate strength of SA240-304 (725°F)	$S_{u2} := 63300 \cdot psi$	
Minimum Yield stress of SA564-630 (200°F)	$S_{by} := 97100 \cdot psi$	Table 2.3.5
Minimum Ultimate strength of SA564-630 (200°F)	$S_{bu} := 135000 \cdot psi$	

Weight of a PWR fuel assembly (allowable maximum value)	$W_{fuel} := 1507 \cdot lbf$	
Weight of the damaged fuel container	$W_{container} := 173 \cdot lbf$	
Wall thickness of the container sleeve	$t_{sleeve} := 0.075 \cdot in$	
Dimension of the square baseplate	$d_{bplate} := 8.75 \cdot in$	
Thickness of the baseplate	$t_{bplate} := 0.75 \cdot in$	
Diameter of baseplate through hole	$d_{bph} := 2 \cdot in$	
Number of baseplate through holes	$N_{bph} := 5$	
Diameter of the baseplate spot weld	$dw_{base} := 0.125 \cdot in$	
Inner dimension of the container sleeve	$id_{sleeve} := 8.75 \cdot in$	
Wall thickness of container collar	$t_{collar} := 0.21 \cdot in$	
Distance from end of sleeve to top of engagement slot	$d_{slot} := 0.1875 \cdot in$	
Thickness of the load tab	$t_{tab} := 0.125 \cdot in$	
Width of the load tab	$w_{tab} := 2.0 \cdot in$	
Thickness of the closure plate	$t_{cp} := 0.5 \cdot in$	
Radius of the lifting bolt	$r_{bolt} := 0.1875 \cdot in$	
Weight density of the stainless steel	$\gamma_{ss} := 0.283 \cdot \frac{lbf}{in^3}$	
Thickness of the nut	$t_{nut} := 0.346 \cdot in$	[5]
Length of the bolt	$L_{bolt} := 2.0in$	
Height of the bolt head	$t_{bolt} := 0.268 \cdot in$	[5]
Thickness of the washer	$t_{washer} := 0.125 \cdot in$	
Dynamic load factor for lifting [1]	$DLF := 1.15$	

3.AS.7 Calculations for MPC-24E Damaged Fuel Container

3.AS.7.1 Lifting Operation (Normal Condition)

The critical load case under normal conditions is the lifting operation. The key areas of concern are the container sleeve, the weld between the sleeve and the base of the container, the container upper closure, and the lifting bolt. All calculations performed for the lifting operation assume a dynamic load factor of 1.15.

3.AS.7.1.1 Container Sleeve (Item 1)

During a lift, the container sleeve is loaded axially, and the stress state is pure tensile membrane. For the subsequent stress calculation, it is assumed that the full weight of the damaged fuel container and the fuel assembly are supported by the sleeve. The magnitude of the load is

$$F := DLF \cdot \left(W_{container} + W_{fuel}\right) \qquad F = 1932\,lbf$$

The cross sectional area of the sleeve is

$$A_{sleeve} := \left(id_{sleeve} + 2 \cdot t_{sleeve}\right)^2 - id_{sleeve}^{\ 2} \qquad A_{sleeve} = 2.65\,in^2$$

Therefore, the tensile stress in the sleeve is

$$\sigma := \frac{F}{A_{sleeve}} \qquad \sigma = 730\,psi$$

The allowable stress intensity for the primary membrane category is S_m per Subsection NG of the ASME Code. The corresponding safety factor is

$$SF := \frac{S_{m1}}{\sigma} \qquad SF = 27.4$$

3.AS.7.1.2 Base Weld (Between Item 1 and Item 7)

The base of the container must support the amplified weight of the fuel assembly. This load is carried directly by 16 spot welds (4 on each side) which connect the base to the container sleeve. The weight of the baseplate is

$$W_{bplate} := \left(d_{bplate}^{\ 2} - N_{bph} \cdot \frac{\pi}{4} \cdot d_{bph}^{\ 2}\right) \cdot t_{bplate} \cdot \gamma_{ss} \qquad W_{bplate} = 13\,lbf$$

The total load carried by the spot welds is

$$F := DLF \cdot (W_{fuel} + W_{bplate}) \qquad F = 1748\,lbf$$

The area of the weld is

$$A_{weld} := 4 \cdot 4 \cdot \frac{3.14 \cdot dw_{base}{}^2}{4} \qquad A_{weld} = 0.2\,in^2$$

Therefore, the amplified shear stress in the weld is

$$\sigma := \frac{F}{A_{weld}} \qquad \sigma = 8907\,psi$$

From the ASME Code the allowable weld shear stress, under normal conditions (Level A), is 60% of the membrane strength of the base metal. The corresponding safety factor is

$$SF := \frac{0.6 \cdot S_{m1}}{\sigma} \qquad SF = 1.3$$

3.AS.7.1.3 Container Collar (Items 1 and 2)

The load tabs of the upper lock device engage the container collar during a lift. The load transferred to the engagement slot, by a single tab, is

$$F := \frac{DLF \cdot (W_{container} + W_{fuel})}{4} \qquad F = 483\,lbf$$

The shear area of the container collar is

$$A_{collar} := 2 \cdot d_{slot} \cdot (t_{sleeve} + t_{collar}) \qquad A_{collar} = 0.107\,in^2$$

The shear stress in the collar is

$$\sigma := \frac{F}{A_{collar}} \qquad \sigma = 4519\,psi$$

The allowable shear stress from Subsection NG, under normal conditions, is

$$\sigma_{allowable} := 0.6 \cdot S_{m1} \qquad \sigma_{allowable} = 12000\,psi$$

Therefore, the safety factor is

$$SF := \frac{\sigma_{allowable}}{\sigma} \qquad SF = 2.7$$

3.AS.7.1.4 Load Tabs (Item 3)

The load tabs of the lock device engage the container collar during a lift. The shear area of each tab is

$$A_{tab} := t_{tab} \cdot w_{tab} \qquad A_{tab} = 0.25\,\text{in}^2$$

The shear stress in the tab is

$$\tau_{tab} := \frac{F}{A_{tab}} \qquad \tau_{tab} = 1.932 \times 10^3\,\text{psi}$$

Therefore, the safety factor is

$$SF := \frac{0.6 \cdot S_{m1}}{\tau_{tab}} \qquad SF = 6.211$$

3.AS.7.1.4 Upper Closure (Item 4)

The damaged fuel container is lifted by a bolt at the center of the upper closure plate. Assuming that the square upper closure plate is simply supported at the boundary and loaded by a uniform concentric circle of radius of the bolt, we can use the formula given in Table 26 of Ref. [4] to calculate the maximum bending stress of the plate. For a square plate, the coefficient of the stress formula is:

$$\beta := 0.435$$

The maximum bending stress in the plate is

$$\sigma_{max\_c} := \frac{3 \cdot \left(W_{container} + W_{fuel}\right) \cdot DLF}{2 \cdot \pi \cdot t_{cp}^{\,2}} \cdot \left[(1 + 0.3) \cdot \ln\left(\frac{2 \cdot id_{sleeve}}{\pi \cdot r_{bolt}}\right) + \beta\right]$$

$$\sigma_{max\_c} = 1.787 \times 10^4\,\text{psi}$$

The allowable primary stress for the plate, per Subsection NG of ASME code, is

$$\sigma_{allowable\_cp} := 1.5 S_{m1} \qquad \sigma_{allowable\_cp} = 3 \times 10^4\,\text{psi}$$

Safety factor $SF := \frac{\sigma_{allowable\_cp}}{\sigma_{max\_c}}$ $SF = 1.678$

3.AS.7.1.5 Lifting Bolt (Item 5)

The stress area of the 1/2-12UNC bolt is

$A_{bolt} := 0.0773 \cdot in^2$ [5]

The tensile stress in the bolt $\sigma_{bolt} := \frac{(W_{container} + W_{fuel}) \cdot DLF}{A_{bolt}}$ $\sigma_{bolt} = 2.499 \times 10^4 psi$

The lifting bolt must meet the requirements set forth for Special Devices [2]. As such the allowable tensile stress for design is the lesser of one-third of the yield stress and one-fifth of the ultimate strength.

$\sigma_1 := \frac{S_{by}}{3}$ $\sigma_2 := \frac{S_{bu}}{5}$

$\sigma_1 = 32367 psi$ $\sigma_2 = 27000 psi$

For SA193-B8 material the yield stress governs at the lifting temperature.

$\sigma_{allowable} := \sigma_2$

Safety factor $SF := \frac{\sigma_{allowable}}{\sigma_{bolt}}$ $SF = 1.08$

Now check the thread engagement of the bolt. The minimum required length of the bolt is

$L_{engage} := t_{cp} + t_{washer} + t_{tab} + 2 \cdot t_{nut}$ $L_{engage} = 1.442 in$

The length of the bolt is $L_{bolt} = 2 in$

Therefore, the thread engagement requirement is satisfied.

3.AS.7.2 60g End Drop (Accident Condition)

The critical member of the damaged fuel container, during a postulated upside down end drop scenario, is the 16 spot welds. The total load applied to the welds in a 60g end drop is

$F_{drop} := 60 \cdot W_{bplate}$ $\qquad F_{drop} = 774.983\,\text{lbf}$

$$\sigma := \frac{F_{drop}}{A_{weld}} \qquad \sigma = 3949\,\text{psi}$$

$\sigma_{allowable} := 0.42 \cdot S_{u2}$

$\sigma_{allowable} = 26586\,\text{psi}$

The safety factor is

$$SF := \frac{\sigma_{allowable}}{\sigma}$$

$SF = 6.7$

3.AS.8 Input Data for MPC-68 BWR Damaged Fuel Container

The damaged fuel container is only handled while still in the spent fuel pool. Therefore, its design temperature for lifting considerations is the temperature of the fuel pool water (150°F). The design temperature for accident conditions is 725°F. All dimensions are taken from the Dwg. 2775. The basic input parameters used to perform the calculations are:

Design stress intensity of SA240-304 (150°F)	$S_{m1} := 20000 \cdot \text{psi}$	Table 1.A.1
Design stress intensity of SA240-304 (725°F)	$S_{m2} := 15800 \cdot \text{psi}$	
Yield stress of SA240-304 (150°F)	$S_{y1} := 27500 \cdot \text{psi}$	Table 1.A.3
Yield stress of SA240-304 (725°F)	$S_{y2} := 17500 \cdot \text{psi}$	
Ultimate strength of SA240-304 (150°F)	$S_{u1} := 73000 \cdot \text{psi}$	Table 1.A.2
Ultimate strength of SA240-304 (725°F)	$S_{u2} := 63300 \cdot \text{psi}$	
Total weight of the loaded container	$W_{load} := 700 \cdot \text{lbf}$	
Wall thickness of the container sleeve	$t_{sleeve} := 0.035 \cdot \text{in}$	
Dimension of the square baseplate	$d_{bplate} := 5.7 \cdot \text{in}$	
Thickness of the baseplate	$t_{bplate} := 0.5 \cdot \text{in}$	

Diameter of baseplate through hole	$d_{bph} := 1.25 \cdot in$
Number of baseplate through holes	$N_{bph} := 4$
Diameter of spot welds	$dw_{base} := 0.125 \cdot in$
Inner dimension of the container sleeve	$id_{sleeve} := 5.701 \cdot in$
Thickness of the tube cap top plate	$t_{cap\_tp} := 0.5 \cdot in$
Diameter of the hole on the top plate	$d_{tph} := 1.25 \cdot in$
Thickness of the tube cap side plate	$t_{cap\_sp} := 0.035 \cdot in$
Width of the side plate	$w_{sp} := 4 \cdot in$
Length of the locking slot	$L_{slot} := 3.05 \cdot in$
Width of locking slot	$w_{slot} := 0.34 \cdot in$
Distance between locking bar center to the top plate bottom	$L_{l\_bar} := 1.5 \cdot in$
Thickness of locking bar	$t_{bar} := 0.1 \cdot in$
Width of the locking bar	$w_{l\_bar} := 0.25 \cdot in$
Diameter of the lifting bolt	$d_{bolt} := 1.0 \cdot in$
Length of the lifting bolt	$L_{bolt} := 1.0 \cdot in$
Stress area of the bolt	$A_{bolt} := 0.6051 \cdot in^2$
Weld size at the bolt and top plate connection	$ww_{bolt} := \frac{1}{16} \cdot in$
Weight density of the stainless steel	$\gamma_{ss} := 0.283 \cdot \frac{lbf}{in^3}$
Dynamic load factor for lifting [1]	$DLF := 1.15$

3.AS.9 Calculations for MPC-68 Damaged Fuel Container

3.AS.9.1 Lifting Operation (Normal Condition)

The critical load case under normal conditions is the lifting operation. The key areas of concern are the container sleeve, the spot welds, the tube cap plates, and the lifting bolt. All calculations performed for the lifting operation assume a dynamic load factor of 1.15.

3.AS.9.1.1 Container Sleeve (Item 1)

During a lift, the container sleeve is loaded axially, and the stress state is pure tensile membrane. For the subsequent stress calculation, it is assumed that the full weight of the damaged fuel container and the fuel assembly are supported by the sleeve. The magnitude of the load is

$F := DLF \cdot W_{load}$ $\qquad F = 805\ \text{lbf}$

The minimum cross sectional area, located at the locking slot elevation, of the sleeve is

$A_{sleeve} := \left(id_{sleeve} + 2 \cdot t_{sleeve}\right)^2 - id_{sleeve}^{\ 2} - 4 \cdot L_{slot} \cdot t_{sleeve}$ $\qquad A_{sleeve} = 0.38\ \text{in}^2$

Therefore, the tensile stress in the sleeve is

$\sigma := \dfrac{F}{A_{sleeve}}$ $\qquad \sigma = 2 \times 10^3\ \text{psi}$

The allowable stress intensity for the primary membrane category is S_m per Subsection NG of the ASME Code. The corresponding safety factor is

$SF := \dfrac{S_{m1}}{\sigma}$ $\qquad SF = 9.3$

The tube may tearout at those four slots. From the ASME Code the allowable shear stress, under normal conditions (Level A), is 60% of the membrane strength of the metal. The minimum distance between the slot center line to top edge of the tube is determined as

$d_{slot} := \dfrac{F}{0.6 \cdot S_{m1} \cdot 8 \cdot t_{sleeve}} + \dfrac{w_{slot}}{2}$ $\qquad d_{slot} = 0.41\ \text{in}$

The tube won't tearout since the center line of the slot is located below the top edge at a distance of

$L_{l\_bar} = 1.5\ \text{in}$

3.AS.9.1.2 Spot Weld

Some of the container parts are connected by spot welds at three locations: (1) between base plate of the container and the sleeve (2) between the locking bars and the tube cap side plates, and (3) between the tube cap side plates and the top plate. At each location, there are at least 12 spot welds to carry the load. To evaluate the structural integrity of these spot welds, the load applied to the welds is conservatively assumed to be the weight of the fully loaded container in each case.

The total load carried by the spot welds is

$F := DLF \cdot W_{load}$ $\qquad F = 805\,\text{lbf}$

The minimum total area of the weld connection is

$$A_{weld} := 12 \cdot \frac{3.14 \cdot dw_{base}^{\,2}}{4} \qquad A_{weld} = 0.15\,\text{in}^2$$

Therefore, the amplified shear stress in the weld is

$$\sigma := \frac{F}{A_{weld}} \qquad \sigma = 5469\,\text{psi}$$

From the ASME Code the allowable weld shear stress, under normal conditions (Level A), is 60% of the membrane strength of the base metal. The corresponding safety factor is

$$SF := \frac{0.6 \cdot S_{m1}}{\sigma} \qquad SF = 2.2$$

3.AS.9.1.3 Tube cap top plate (Item 2A)

The damaged fuel container is lifted through a lifting bolt welded to the center of the tube cap top plate. Assuming that the square top plate is simply supported at the boundary and loaded by a uniform concentric circle of radius of the bolt, we can use the formula given in Table 26 of Ref. [4] to calculate the maximum bending stress in the plate. For a square plate, the coefficient in the stress formula is:

$$\beta := 0.435 \qquad r_{bolt} := \frac{d_{bolt}}{2}$$

The maximum bending stress in the plate is

$$\sigma_{max\_c} := \frac{3 \cdot W_{load} \cdot DLF}{2 \cdot \pi \cdot t_{cap\_tp}^{\,2}} \cdot \left[(1 + 0.3) \cdot \ln\left(\frac{2 \cdot id_{sleeve}}{\pi \cdot r_{bolt}} \right) + \beta \right]$$

$\sigma_{max\_c} = 4.631 \times 10^3 psi$

Safety factor $SF := \frac{\sigma_{allowable\_cp}}{\sigma_{max\_c}}$ $SF = 6.479$

3.AS.9.1.4 Tube cap side plate (Item 2B)

Four locking bars are welded to each of the four side plates. These side plates are bent to allow the locking bars to fit into the slots of the tube for lifting the container. Subsequent to bending, the side plates are forced to be vertical by the locking "ring" which pushes the locking bars into the slots in the container walls. While the side plates are deformed into the plastic range during the initial insertion over the canister tube process, the lowering of the locking ring reverses the state of stress in the side plates. It is required that the side plate should not reach the ultimate stress value during this single cycle of loading .

Deflection of the side plate $d_{sp} := t_{bar}$ $d_{sp} = 0.1 in$

The bending stress of the side plate is calculated by assuming that the side plate behaves as a cantilever beam.

$E_{sp} := 2.7 \cdot 10^7 \cdot psi$ $L_{bend\_sp} := L_{l\_bar} + \frac{w_{l\_bar}}{2}$

$\sigma_{sp} := \frac{1.5 E_{sp} \cdot d_{sp} \cdot t_{cap\_sp}}{L_{bend\_sp}^{\;2}}$ $\sigma_{sp} = 5.368 \times 10^4 psi$

The bending stress is less than the ultimate stress of the material (73 ksi) and therefore acceptable.

3.AS.9.1.5 Lifting Bolt (Item 5)

The stress area of the bolt is $A_{bolt} = 0.605 in^2$

The tensile stress in the bolt $\sigma_{t\_bolt} := \frac{W_{load} \cdot DLF}{A_{bolt}}$ $\sigma_{t\_bolt} = 1.33 \times 10^3 psi$

The lifting bolt must meet the requirements set forth for Special Devices [2]. As such the allowable tensile stress for design is the lesser of one-third of the yield stress and one-fifth of the ultimate strength.

$\sigma_1 := \frac{S_{yl}}{3}$ $\sigma_1 = 9167 psi$ $\sigma_2 := \frac{S_{ul}}{5}$ $\sigma_2 = 14600 psi$

For SA240-304 material the yield stress governs at the lifting temperature.

$$\sigma_{allowable} := \sigma_1$$

Safety factor $SF := \dfrac{\sigma_{allowable}}{\sigma_{t\_bolt}}$ $SF = 6.89$

The bolt is welded to the tube cap top plate by the 1/16 fillet weld surrounding the periphery of the bolt. The shear stress in the weld is

$$\tau_{b\_weld} := \frac{DLF \cdot W_{load}}{\pi \cdot d_{bolt} \cdot (0.707 \cdot ww_{bolt})} \qquad \tau_{b\_weld} = 5.799 \times 10^3 \text{ psi}$$

From the ASME code the allowable weld shear stress, under normal condition (level A), is 60% of the membrane strength of the base metal. The corresponding safety factor is

$$SF := \frac{0.6 \cdot S_{m1}}{\tau_{b\_weld}} \qquad SF = 2.069$$

3.AS.9.2 60g End Drop (Accident Condition)

The critical member of the damaged fuel container, under a postulated top down end drop scenario (that would occur only when the MPC is in transit), is the 16 spot welds. The total load applied to the welds in a 60g end drop (while installed in a HI-STAR 100 overpack) is

$$W_{bplate} := \left(d_{bplate}^2 - N_{bph} \cdot \frac{\pi}{4} \cdot d_{bph}^2\right) \cdot t_{bplate} \cdot \gamma_{ss} \qquad W_{bplate} = 4 \text{ lbf}$$

$$F_{drop} := 60 \cdot W_{bplate} \qquad F_{drop} = 234.165 \text{ lbf}$$

$$\sigma := \frac{F_{drop}}{A_{weld}} \qquad \sigma = 1591 \text{ psi} \qquad \sigma_{allowable} := 0.42 \cdot S_{u2} \qquad \sigma_{allowable} = 26586 \text{ psi}$$

The safety factor is $SF := \dfrac{\sigma_{allowable}}{\sigma}$ $SF = 16.7$

3.AS.10 Conclusion

Both of the two types of damaged fuel containers are structurally adequate to withstand the specified normal and accident condition loads. All calculated safety factors are greater than one, which demonstrates that all acceptance criteria have been met or exceeded.