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.

† 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).

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 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 *moderate burnup fuel in* 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. *Allowable fuel cladding temperatures for high burnup fuel assemblies are determined using a creep-strain model, developed by Holtec, and described in further detail in Appendix 4.A.* 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 heat emission rates may be stored and Region 2 is the outer region where fuel assemblies with lower heat emission rates are stored. Regionalized loading allows for storage of fuel assemblies with higher heat emission rates (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 limits for regionalized loading are provided in Appendix B to the CoC. The two fuel loading regions are defined by fuel storage location number 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 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~~ *occupational* dose*s* ~~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 and close reflection, including all biases, uncertainties, and MPC manufacturing tolerances.

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 design 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 *Chapter 8,* site-specific requirements that comply with the 10CFR50 Technical Specifications for the plant, and the ~~10CFR72 Technical Specifications for the~~ HI-STORM 100 System *CoC.* ~~contained in *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*s on* ~~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 *Chapter 8,* 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 *CoC.* ~~contained in *Chapter 12*~~.

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 *to the maximum extent practicable*, 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 *side* 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 *normally* 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~~*other site-specific considerations*. As with other dose reduction-based plant *activities* ~~modifications~~, individual users who cannot accommodate the 125 ton HI-TRAC ~~due to plant design limitations must~~ *should* perform a cost-benefit analysis of the *actions (e.g.,* modifications*)* which would be necessary to use the 125 ton HI-TRAC. The cost of the ~~modification(s)~~ *action(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 *Chapter 8,* plant-specific requirements *including the Part 50 Technical Specifications,* and ~~in accordance with site and~~ *the* HI-STORM 100 System *CoC.* ~~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.

2.0.4 Principal Design Criteria for the ISFSI Pad

2.0.4.1 Design and Construction Criteria

In compliance with 10CFR72, Subpart F, "General Design Criteria", the HI-STORM 100 cask system is classified as "important-to-safety" (ITS). This topical safety analysis report (TSAR) explicitly recognizes the HI-STORM 100 System as an assemblage of equipment containing numerous ITS components. The reinforced concrete pad on which the cask is situated, however, is designated as a non-ITS structure [redacted]

[redacted]

[redacted] *The regulatory position with respect to such structures is specified in 10CFR72.122(b):*

"(2) Structures, systems, and components important to safety must be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, lightning, hurricanes, floods, tsunami, and seiches, without impairing their capability to perform safety functions. The design bases for these structures, systems, and components must reflect:

(i) Appropriate consideration of the most severe of the natural phenomena reported for the site and surrounding area, with appropriate margins to take into account the limitations of the data and the period of time in which the data have accumulated, and

(ii) Appropriate combinations of the effects of normal and accident conditions and the effects of natural phenomena."

[redacted]

- *The pad is designed and constructed in accordance with a Part 72, Subpart G-compliant QA program.*

- *Evaluations are performed (e.g., per 72.212) to demonstrate that the seismic and other inertial loadings at the site are enveloped by the respective bounding loadings defined in this report.*

2.0.4.2 Applicable Codes

Factored load combinations for ISFSI pad design are provided in the design code ACI-349-85 [2.0.2] and NUREG-1536 [2.1.5]. The factored loads applicable to the pad design consist of dead weight of the cask, thermal gradient loads, impact loads arising from handling and accident events, external missiles, and bounding environmental phenomena (such as earthquakes, wind, tornado, and flood).

The factored load combinations presented in Table 3-1 of NUREG 1536 are reduced in the following to a bounding set of load combinations that are applied to demonstrate adherence to its acceptance criteria.

[redacted]

[redacted]

[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

[redacted]

[redacted]

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~~ *200* 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

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Neutron Poison:			
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 *(Moderate/High Burnup Fuel)*:			
5-year cooled	*691° / 680° F* ~~692° F~~	PNL-6189/*Appendix 4.A*	Section 4.3/*Appendix 4.A*
6-year cooled	*676° / 660° F* ~~677° F~~	PNL-6189/*Appendix 4.A*	Section 4.3/*Appendix 4.A*
7-year cooled	*635° / 635° F* ~~636° F~~	PNL-6189/*Appendix 4.A*	Section 4.3/*Appendix 4.A*
10-year cooled	*625° / 621° F* ~~626° F~~	PNL-6189/*Appendix 4.A*	Section 4.3/*Appendix 4.A*
15-year cooled	*614° / 611° F* ~~615° F~~	PNL-6189/*Appendix 4.A*	Section 4.3/*Appendix 4.A*
BWR Fuel Cladding *(Moderate and High Burnup Fuel)*:			
5-year cooled	*740* ~~742~~° F	PNL-6189	Section 4.3/*Appendix 4.A*
6-year cooled	*712* ~~714~~° F	PNL-6189	Section 4.3/*Appendix 4.A*
7-year cooled	*669* ~~671~~° F	PNL-6189	Section 4. /*Appendix 4.A* 3
10-year cooled	*658* ~~660~~° F	PNL-6189	Section 4.3/*Appendix 4.A*
15-year cooled	*646* ~~648~~° F	PNL-6189	Section 4.3/*Appendix 4.A*

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Canister Backfill Gas	Helium	-	Section 12.3.3
Canister Backfill ~~*Mass*~~ *Pressure*	~~Varies by MPC~~ *29.3 – 33.3 psig*	-	~~*Section 12.3.3*~~ *(Ch. 12 - TS)*
Short-Term Allowable Fuel Cladding Temperature	1058° F	PNL-4835	Sections 2.0.1 and 4.3
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

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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
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	5×10^{-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

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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			
Criticality:		10CFR72.124 & 10CFR72.236(c)	
Method of Control	Fixed Borated Neutron Absorber, ~~&~~ Geometry, *and Soluble Boron*	-	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,MPC-24EF, 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

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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
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

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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*~~ *68,200 MWD*/MTU ~~*(MPC-24)*~~	-	~~*Figure 2.1.6*~~ *CoC, Appendix B*
Max. Enrichment	Varies by fuel design	-	Table 2.1.3
Max. Decay Heat/Assembly[†]: *(Regionalized fuel loading)*			
5-year cooled	~~*870*~~ *1470* W (MPC-24) *1540 W (MPC-24E)* *1312 W (MPC-32)*	-	Tables ~~*4.4.20 and 2.2.3*~~ *4.4.31*
6-year cooled	~~*840.4*~~ *1470* W (MPC-24) *1540 W (MPC-24E)* *1073 W (MPC-32)*	-	Tables ~~*4.4.20 and 2.2.3*~~ *4.4.31*
7-year cooled	~~*757.5*~~ *1335* W (MPC-24) *1395 (MPC-24E)* *993 (MPC-32)*	-	Tables ~~*4.4.20 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
10-year cooled	~~738.3~~ *1235* W (MPC-24) *1290 W (MPC-24E)* *950 W (MPC-32)*	-	Table~~s~~ ~~4.4.20 and 2.2.3~~ *4.4.31*
15-year cooled	~~715.4~~ *1165* W (MPC-24) *1215 W (MPC-24E)* *918 W (MPC-32)*	-	Table~~s~~ ~~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
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~~ *59,900* MWD/MTU	-	~~Figure 2.1.6~~ *CoC, Appendix B*

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Max. Enrichment	Varies by fuel design	-	Section 6.1, ~~and Chapter 12~~ *Table 2.1.4*
Max. Decay Heat/Assy†. *(Regionalized Fuel Loading)*:			
5-year cooled	~~314.7~~ *501* W (MPC-68)	-	Table~~s~~ ~~4.4.21 and 2.2.3~~ *4.4.31*
6-year cooled	~~298.7~~ *468* W (MPC-68)	-	Table~~s~~ ~~4.4.21 and 2.2.3~~ *4.4.31*
7-year cooled	~~270.7~~ *419* W (MPC-68)	-	Table~~s~~ ~~4.4.21 and 2.2.3~~ *4.4.31*
10-year cooled	~~264.0~~ *406* W (MPC-68)	-	Table~~s~~ ~~4.4.21 and 2.2.3~~ *4.4.31*
15-year cooled	~~256.6~~ *592* W (MPC-68)	-	Table~~s~~ ~~4.4.21 and 2.2.3~~ *4.4.31*
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~~ *176.5*in.	-	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 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
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:			

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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
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

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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*
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

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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 2.0.2
HI-STORM 100 OVERPACK 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. *(Add 2000 lb. for 100A)*	R.G. 3.61	Table 3.2.1
Max. MPC/Overpack *(100/100S)*	~~354,431~~ *354,001/340,472* lb. *(Add 2000 lb. for 100A)*	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

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Local Maximum (Accident)	350° F	ACI 349 Appendix A	Table 2.2.3
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

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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
~~*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)* $\leq$ *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

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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
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			

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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 *(Not applicable for HI-STORM 100A)*	Assumed (Non-mechanistic)	-	Section 2.2.3.2
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 Differential Pressure	*10 psid instantaneous, 5 psid steady state*	*10 CFR 72.128(a)(4)*	*Table 2.2.1*

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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)	*Free Standing:* $G_H + 0.53G_V = 0.53$ *Anchored:* $G_H \leq 2.12$, $G_V \leq 1.5$	10CFR72.102(f)	Section 3.4.7.1 *Section 3.4.7.3*
Tornado			
Wind			
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

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK 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
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

TABLE 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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
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)	

TABLE 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
Thermal:			
Maximum Design Temperature			
Structural Materials	400° F	ASME Code Section II, Part D	Table 2.2.3
Shielding Materials			
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

TABLE 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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
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

TABLE 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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:			
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

TABLE 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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
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

TABLE 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	TSAR Reference
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

TABLE 2.0.4
LIMITING DESIGN PARAMETERS FOR ISFSI PADS AND ANCHOR STUDS FOR HI-STORM 100A

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]		
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

[redacted]

TABLE 2.0.5
ISFSI PAD REQUIREMENTS FOR FREE-STANDING AND ANCHORED HI-STORM INSTALLATION

[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

TABLE 2.0.5 (continued)
ISFSI PAD REQUIREMENTS FOR FREE-STANDING AND ANCHORED HI-STORM INSTALLATION

[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	

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* exceptions *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~~ *empty* fuel rod *locations* 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 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~~ *for storage* 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-24EF is designed to accommodate PWR damaged fuel and fuel debris. 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-designed 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).*

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 specifies the allowable decay heat per assembly for each MPC model. For both uniform and regionalized loading of moderate and high burnup 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, 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, an 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~~ *limits* for intact zircaloy clad fuel to meet the thermal requirements for the *various* MPC's. ~~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 heat emitting fuel assemblies to be stored in the central core basket storage locations with lower heat emitting fuel assemblies in the peripheral fuel storage locations. Regionalized loading allows storage of higher heat emitting 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 conservatively high burnups, low cooling times, and low enrichments, as discussed in Chapter 5.* ~~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 has been evaluated and is authorized for storage in the PWR MPCs 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* features a basket without flux traps. In the *aforementioned* ~~MPC-68~~ baskets, there is one panel of neutron absorber between two adjacent fuel assemblies. The MPC-24, *MPC-24E, and MPC-24EF*

employs 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, MPC-24EF, 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, MPC-24E and MPC-24EF (all 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. Minimum 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 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 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™*
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/ 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~~*3*)	~~≤ 402~~ *≤ 407*	~~≤ 402~~ *≤ 407*	~~≤ 410~~ *≤ 425*	≤ 400	*≤ 206*
Initial Enrichment *(MPC-24, 24E, and 24EF without soluble boron credit)* (wt % ^{235}U) *(Note 7)*	≤ 4.6 *(24)* *≤ 5.0 (24E/24EF)*	≤ 4.6 *(24)* *≤ 5.0 (24E/24EF)*	≤ 4.6 *(24)* *≤ 5.0 (24E/24EF)*	≤ 4.0 *(24)* *≤ 5.0 (24E/24EF)*	*≤ 5.0 (24)* *≤ 5.0 (24E/24EF)*
Initial Enrichment (MPC-24, 24E, 24EF, 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 Rod *Locations*	179	179	176	180	*173*
Fuel Clad O.D. (in.)	≥ 0.400	≥ 0.417	≥ 0.440	≥ 0.422	*≥ 0.3415*
Fuel Clad I.D. (in.)	≤ 0.3514	≤ 0.3734	~~≤ 0.3840~~ *≤ 0.3880*	≤ 0.3890	*≤ 0.3175*
Fuel 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 *and/or Instrument* Tubes	17	17	5 (see Note ~~3~~ *4*)	16	*0*
Guide/*Instrument* Tube Thickness (in.)	≥ 0.017	≥ 0.017	~~≥ 0.040~~ *≥ 0.038*	≥ 0.0145	*N/A*

Table 2.1.3 (continued)
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/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, 24E, and 24EF without soluble boron credit)* (wt % ^{235}U) *(See Note 7)*	≤ 4.1 *(24)* *≤ 4.5 (24E/24EF)*	≤ 4.1 *(24)* *≤ 4.5 (24E/24EF)*	≤ 4.1 *(24)* *≤ 4.5 (24E/24EF)*	≤ 4.1 *(24)* *≤ 4.5 (24E/24EF)*	≤ 4.1 *(24)* *≤ 4.5 (24E/24EF)*	≤ 4.1 *(24)* *≤ 4.5 (24E/24EF)*
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 Rod *Locations*	204	204	204	208	208	208
Fuel Clad O.D. (in.)	≥ 0.418	≥ 0.420	≥ 0.417	≥ 0.430	≥ 0.428	≥ 0.428
Fuel Clad I.D. (in.)	≤ 0.3660	≤ 0.3736	≤ 0.3640	≤ 0.3800	≤ 0.3790	≤ 0.3820
Fuel 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 *and/or Instrument* Tubes	21	21	21	17	17	17
Guide/*Instrument* Tube Thickness (in.)	≥ 0.0165	≥ 0.015	≥ 0.0165	≥ 0.0150	≥ 0.0140	≥ 0.0140

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~~*3*)	≤ 420	≤ *475*	~~≤ 430~~ ≤ *443*	~~≤ 450~~ ≤ *467*	~~≤ 464~~ ≤ *467*	~~≤ 460~~ ≤ *474*
Initial Enrichment *(MPC-24, 24E, and 24EF without soluble boron credit)* (wt % ^{235}U) *(Note 7)*	≤ 4.0 *(24)* ≤ *4.5 (24E/24EF)*	≤ *3.8 (24)* ≤ *4.2 (24E/24EF)*	≤ 4.6 *(24)* ≤ *5.0 (24E/24EF)*	≤ 4.0 *(24)* ≤ *4.4 (24E/24EF)*	≤ 4.0 *(24)* ≤ *4.4 (24E/24EF)*	≤ 4.0 *(24)* ≤ *4.4 (24E/24EF)*
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 Rod *Locations*	204	*208*	236	264	264	264
Fuel Clad O.D. (in.)	≥ 0.422	≥ *0.414*	≥ 0.382	≥ 0.360	≥ 0.372	≥ 0.377
Fuel Clad I.D. (in.)	≤ 0.3890	≤ *0.3700*	≤ 0.3320	≤ 0.3150	≤ 0.3310	≤ 0.3330
Fuel 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 *and/or Instrument* Tubes	21	*17*	5 (see note ~~3~~ *4*)	25	25	25
Guide/*Instrument* Tube Thickness (in.)	≥ 0.0145	≥ *0.140*	≥ 0.0400	≥ 0.016	≥ 0.014	≥ 0.020

Table 2.1.3 (continued)
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 Technical Specification 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 or fuel debris, the maximum initial enrichment of the intact fuel assemblies is limited to the maximum initial enrichment of the damaged fuel assemblies and fuel debris (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~~ *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 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 Rod *Locations*	*35 or* 36	*35 or* 36 (up to 9 MOX rods)	36	49	49	*63 or* 64
Fuel Clad O.D. (in.)	≥ 0.5550	≥ 0.5625	≥ 0.5630	≥ 0.4860	≥ 0.5630	≥ 0.4120
Fuel Clad I.D. (in.)	~~≤ 0.4945~~ *≤ 0.5105*	≤ 0.4945	≤ 0.4990	~~≤ 0.4200~~ *≤ 0.4204*	≤ 0.4990	≤ 0.3620
Fuel 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 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 2.1.4 (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~~ *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*	*≤ 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 Rod *Locations*	63 *or 64*	62	60 *or 61*	59	*64*	74/66 (Note ~~3~~ *5*)
Fuel Clad O.D. (in.)	≥ 0.4840	≥ 0.4830	≥ 0.4830	≥ 0.4930	*≥ 0.4576*	≥ 0.4400
Fuel Clad I.D. (in.)	~~≤ 0.4250~~ *≤ 0.4295*	≤ 0.4250	~~≤ 0.4190~~ *≤ 0.4230*	≤ 0.4250	*≤ 0.3996*	≤ 0.3840
Fuel 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 11)*	1 *or 0*	2	1 - 4 (see note ~~5~~ *7*)	5	*N/A (see 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	*≤ 0.100*	≤ 0.120

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 13)*	**9x9 F** *(Note 13)*	***9x9 G***
Clad Material (Note 2)	Zr	Zr	Zr	Zr	Zr	*Zr*
Design Initial U (kg/assy.) (Note ~~4~~ *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 Rod *Locations*	72	80	79	76	76	*72*
Fuel Clad O.D. (in.)	≥ 0.4330	≥ 0.4230	≥ 0.4240	≥ 0.4170	≥ 0.4430	*≥ 0.4240*
Fuel Clad I.D. (in.)	≤ 0.3810	≤ 0.3640	≤ 0.3640	~~≤ 0.3590~~ *≤ 0.3640*	~~≤ 0.3810~~ *≤ 0.3860*	*≤ 0.3640*
Fuel 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 11)*	1 (see note ~~4~~ *6*)	1	2	5	5	*1 (see note 6)*
Water Rod Thickness (in.)	> 0.00	≥ 0.020	~~≥ 0.0305~~ *≥ 0.0300*	~~≥ 0.0305~~ *≥ 0.0120*	~~≥ 0.0305~~ *≥ 0.0120*	*≥ 0.0320*
Channel Thickness (in.)	≤ 0.120	≤ 0.100	≤ 0.100	~~≤ 0.100~~ ≤ 0.120	~~≤ 0.100~~ ≤ 0.120	*≤ 0.120*

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~~ *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*
Initial Maximum Rod Enrichment (wt.% ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rod *Locations*	92/78 (Note ~~3~~ *8*)	91/83 (Note ~~3~~ *9*)	96	100	96
Fuel Clad O.D. (in.)	≥ 0.4040	≥ 0.3957	~~≥ 0.3790~~ *≥ 0.3780*	≥ 0.3960	≥ 0.3940
Fuel Clad I.D. (in.)	≤ 0.3520	≤ 0.3480	≤ 0.3294	≤ 0.3560	≤ 0.3500
Fuel 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 11)*	2	1 (Note ~~4~~ *6*)	5 (Note ~~5~~ *10*)	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

Table 2.1.4 (continued)
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 2.1.5

DESIGN BASIS FUEL ASSEMBLY FOR EACH DESIGN CRITERION

Criterion	**MPC-68/*68F/68FF***	**MPC-24**	***MPC-24E/24EF***	***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

DESIGN CHARACTERISTICS FOR ~~DESIGN BASIS~~ INTACT ZIRCALOY CLAD FUEL ASSEMBLIES[1]

	MPC-68/68FF	*MPC-68F*	MPC-24	*MPC-24E/24EF*	*MPC-32*
PHYSICAL PARAMETERS:					
Max. assembly width (in.)	5.85	*4.70*	8.54	*8.54*	*8.54*
Max. assembly length (in.)	~~176.2~~ *176.5*	*135.0*	176.8	*176.8*	*176.8*
Max. assembly weight[2] (lb.)	700	*550*	1680	*1680*	*1680*
Max. active fuel length (in.)	150	*120*	150	*150*	*150*
~~Fuel rod clad material~~	~~zircaloy~~		~~zircaloy~~		
RADIOLOGICAL AND THERMAL CHARACTERISTICS:					
	MPC-68/68FF	*MPC-68F*	MPC-24	*MPC-24E/24EF*	*MPC-32*
Max. initial enrichment (wt% ^{235}U)	See Table 2.1.4	*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*	*Table 2.0.1*
Max. average burnup (MWD/MTU)	~~See Figure 2.1.6~~ ~~30,000 (Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, 8x8A)~~ *59,900*	*30,000*	~~See Figure 2.1.6~~ *66,200*	*68,200*	*54,700*
Min. cooling time (years)	~~See Figure 2.1.6~~ ~~18 (Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, 8x8A)~~ *5*	*18*	~~See Figure 2.1.6~~ *5*	*5*	*5*

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].

Table 2.1.7
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/24EF (Damaged Fuel and Fuel Debris)*
PHYSICAL PARAMETERS:			
Max. assembly width (in.)	~~4.7~~ *5.5*	4.7	*8.54*
Max. assembly length (in.)	~~135~~ *176.5*	135.0	*176.8*
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~~ *58,800*	30,000	*68,200*

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 and fuel debris authorized for loading in the HI-STORM 100 System.*

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/24EF*	*PWR MPC-32*
PHYSICAL PARAMETERS:			
Max. assembly width[2] (in.)	5.62	~~8.42~~ *8.54*	*8.54*
Max. assembly length[2] (in.)	102.5	~~138.8~~ *176.8*	*176.8*
Max. assembly weight[3] (lb.)	~~400~~ *700*	~~1421~~ *1680*	*1680*
Max. active fuel length[2] (in.)	83	~~122~~ *144*	*144*
RADIOLOGICAL AND THERMAL CHARACTERISTICS :			
Max. heat generation (W)	95	710	*500*
Min. cooling time (yr)	10	8	*9/20*
Max. initial enrichment *without soluble boron credit* (wt.% ^{235}U)	4.0	~~4.0~~ *See Table 2.1.3*	*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	*30,000/40,000*

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.

[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.

[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

[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, 24E and 24EF	*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*

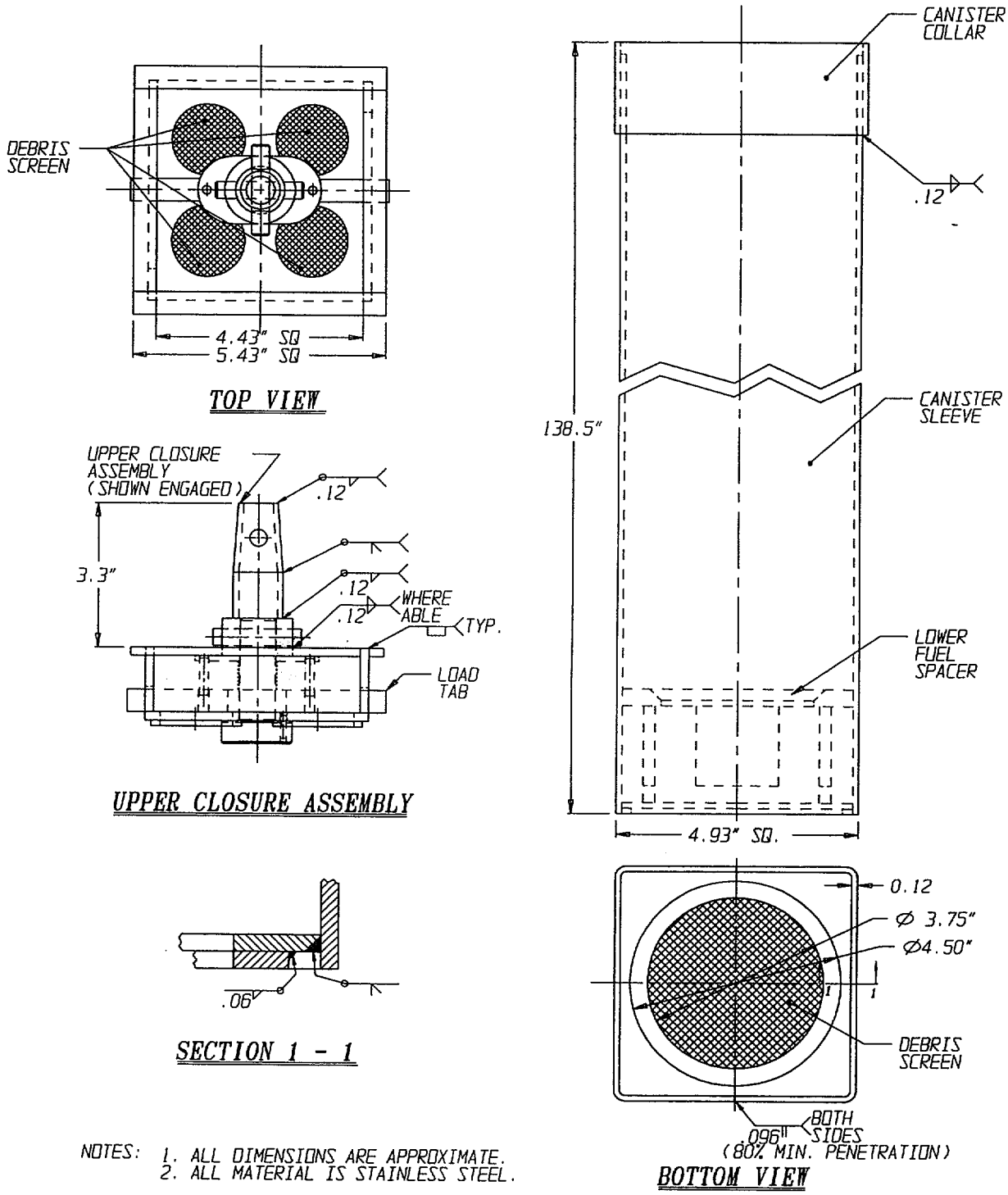
Note: Refer to Figures 1.2.2 through 1.2.4A

Table 2.1.14

Soluble Boron Requirements for PWR Fuel Wet Loading and Unloading Operations

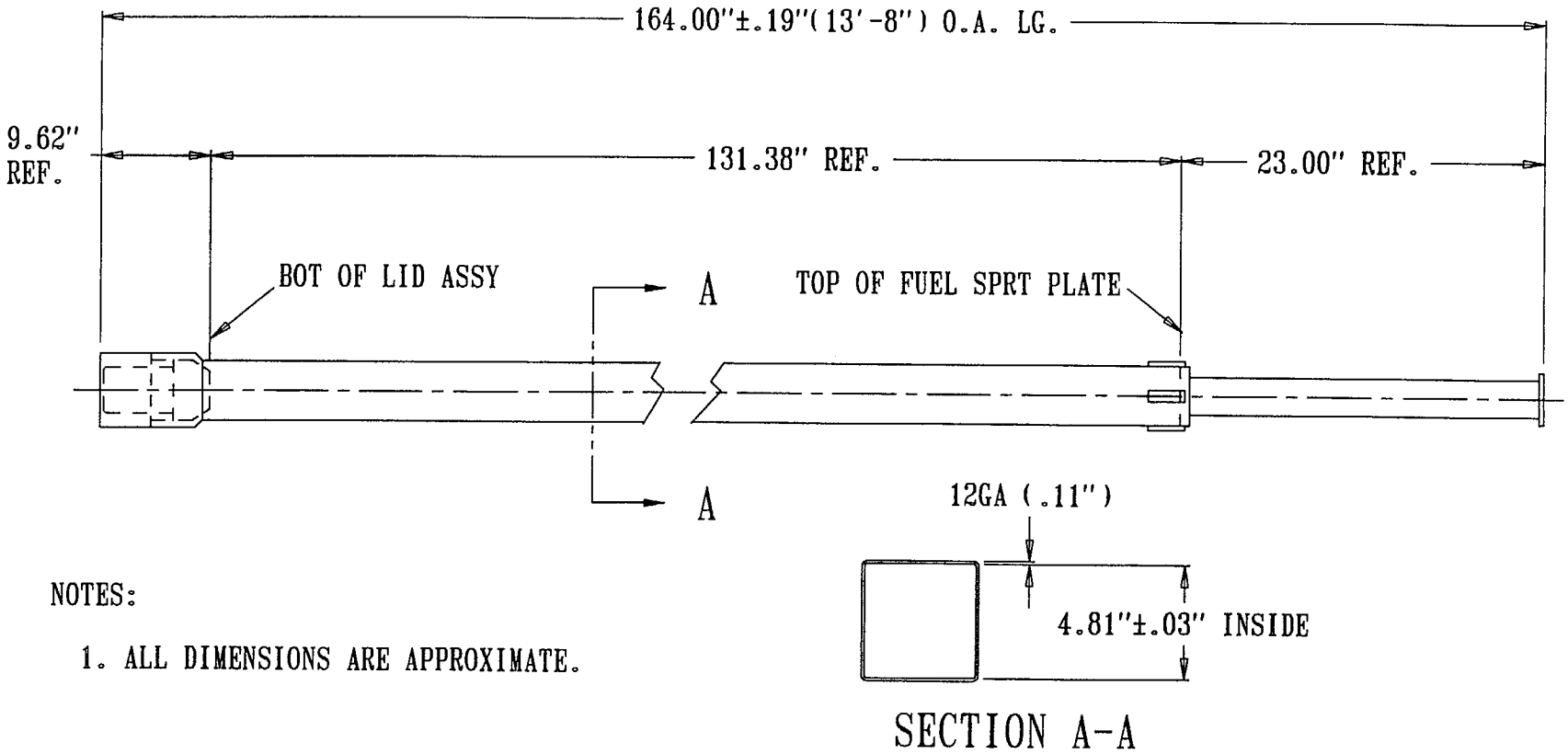
MPC MODEL	***FUEL ASSEMBLY MAXIMUM AVERAGE ENRICHMENT (wt % ^{235}U)***	***MINIMUM SOLUBLE BORON CONCENTRATION (ppmb)***
MPC-24	*All fuel assemblies with initial enrichment[1] less than the prescribed value for soluble boron credit*	*0*
MPC-24	*One or more fuel assemblies with an initial enrichment[1] greater than or equal to the prescribed value for no soluble boron credit AND ≤ 5.0 wt. %*	*≥ 400*
MPC-24E/24EF	*All fuel assemblies with initial enrichment[1] less than the prescribed value for soluble boron credit*	*0*
MPC-24E/24EF	*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 ≤ 4.1 wt. %*	*≥ 1900*
MPC-32	*One or more fuel assemblies with an initial enrichment > 4.1 and ≤ 5.0 wt. %*	*≥ 2600*

[1]*Refer to Table 2.1.3 for these enrichments.*



NOTES:
1. ALL DIMENSIONS ARE APPROXIMATE.
2. ALL MATERIAL IS STAINLESS STEEL.

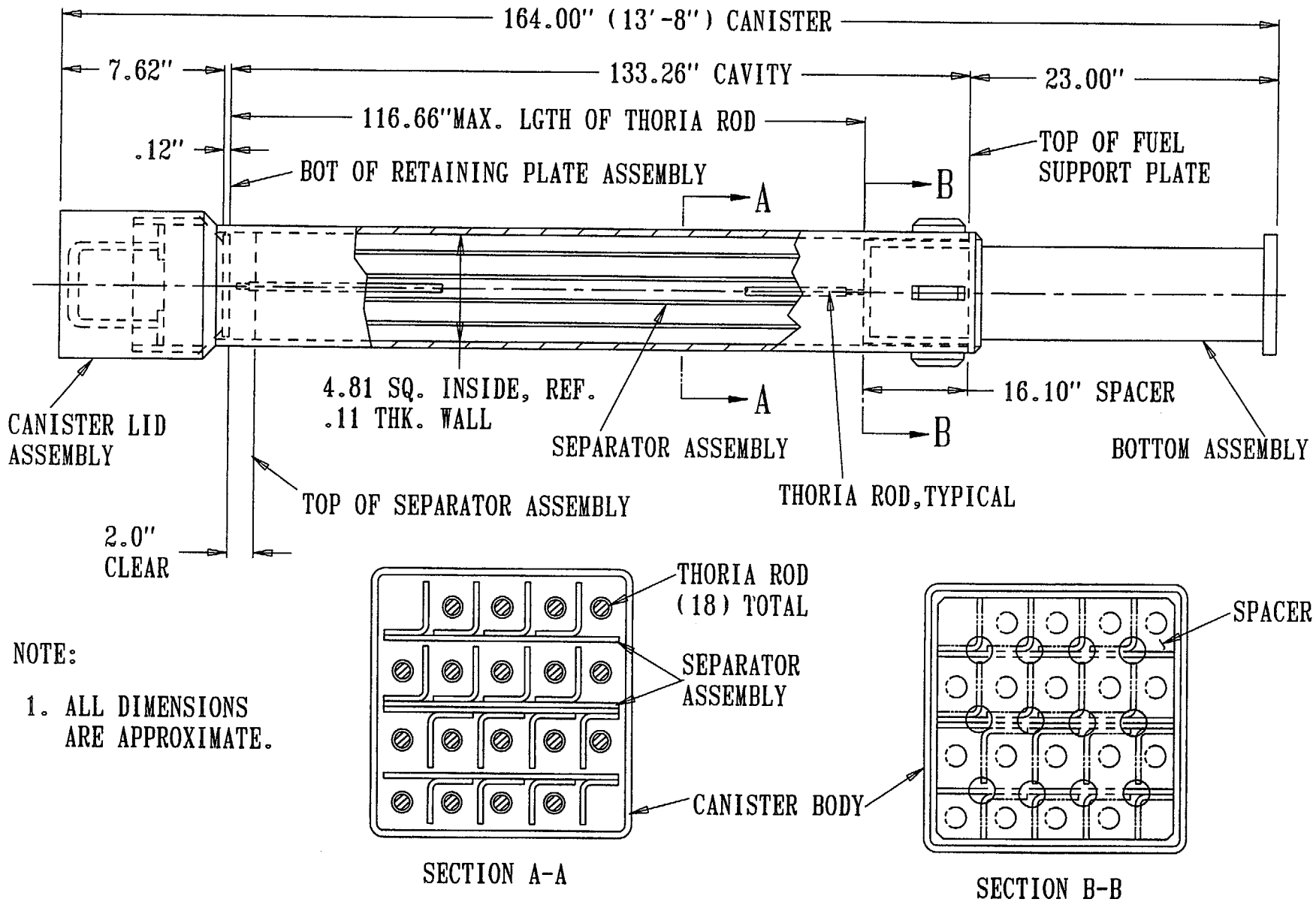
FIGURE 2.1.1; HOLTEC DAMAGED FUEL CONTAINER FOR DRESDEN UNIT-1/ HUMBOLDT BAY SNF



NOTES:

1. ALL DIMENSIONS ARE APPROXIMATE.

FIGURE 2.1.2; TN DAMAGED FUEL CANISTER FOR DRESDEN UNIT-1

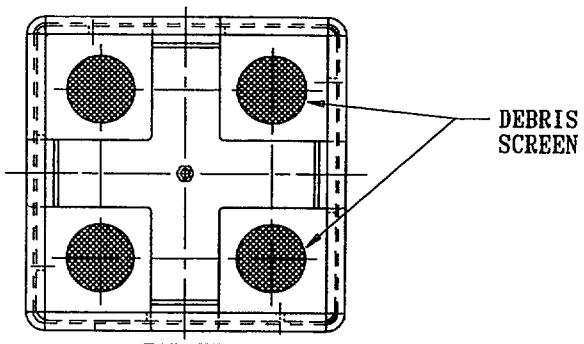


NOTE:

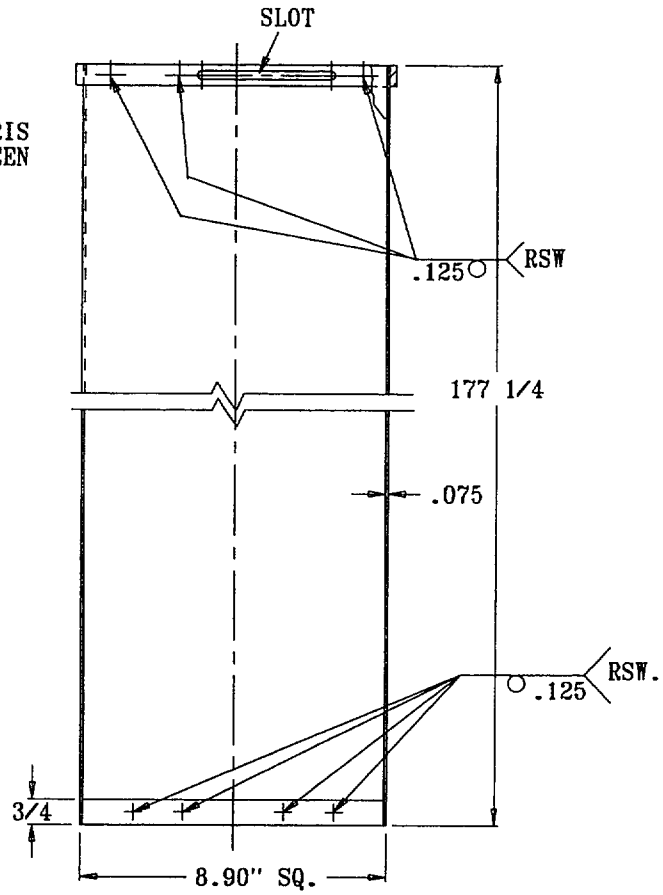
1. ALL DIMENSIONS ARE APPROXIMATE.

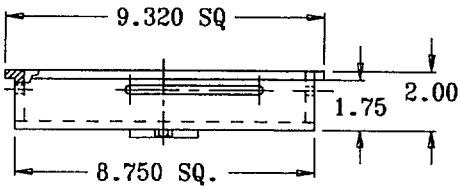
FIGURE 2.1.2A; TN THORIA ROD CANISTER FOR DRESDEN UNIT-1

NOTES:
1. ALL DIMENSIONS ARE APPROXIMATE.
2. ALL MATERIAL IS STAINLESS STEEL.

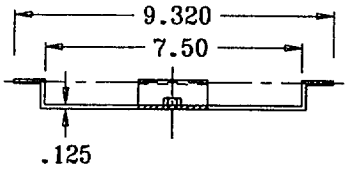


TOP VIEW

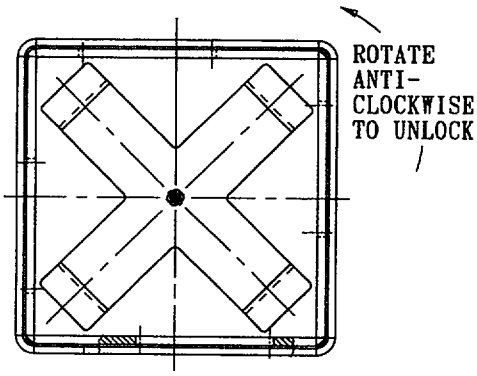




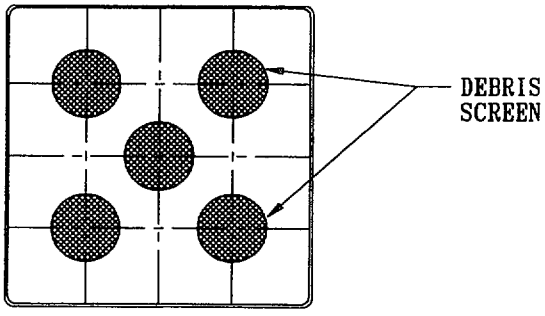
TUBE CLOSURE



LOCK BAR



UNLOCKED POSITION



BOTTOM VIEW

FIGURE 2.1.2B; HOLTEC DAMAGED FUEL CONTAINER FOR PWR SNF IN MPC-24E/24EF

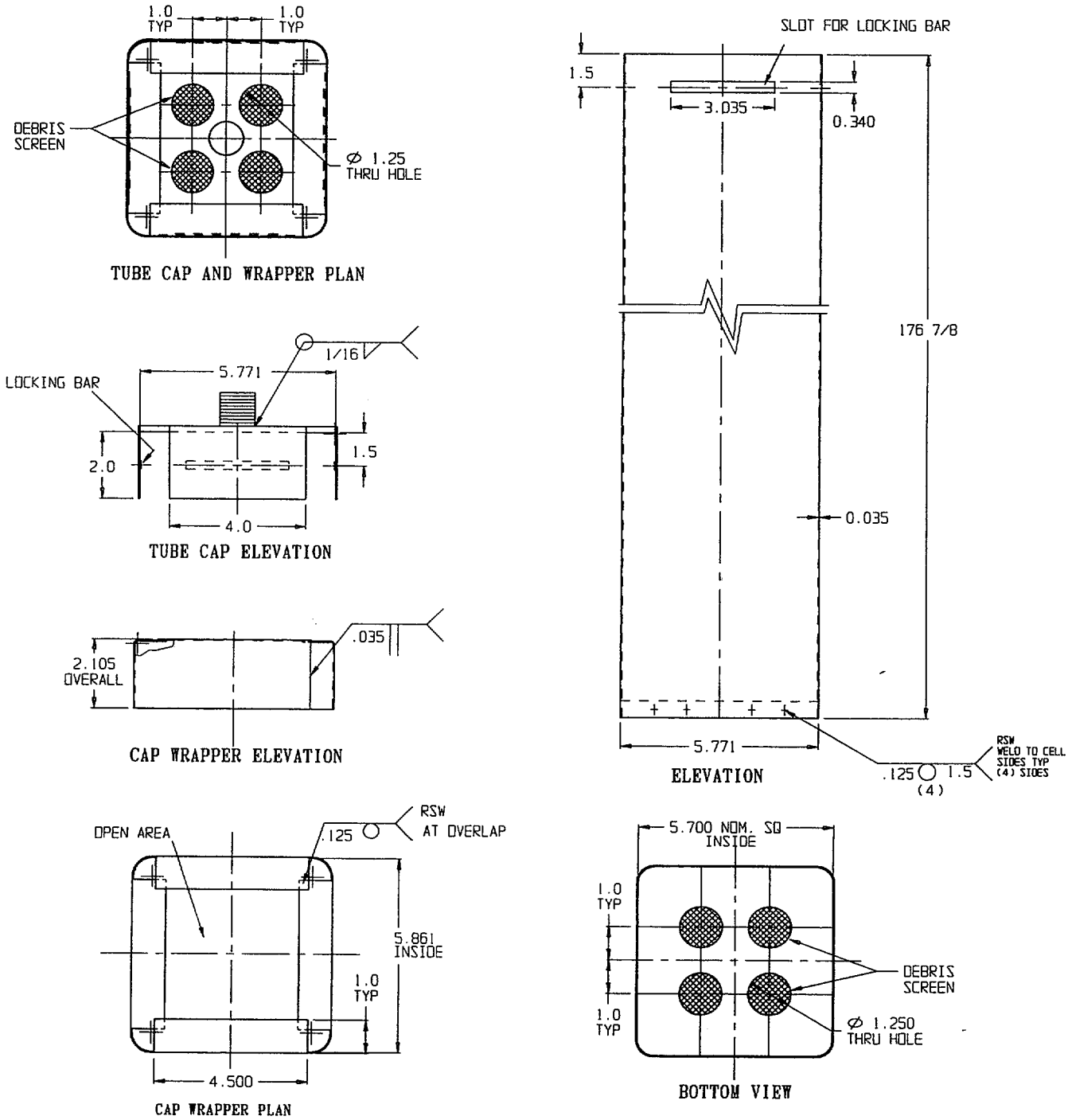


FIGURE 2.1.2C; HOLTEC DAMAGED FUEL CONTAINER FOR BWR SNF IN MPC-68/68FF

DELETED

Figure 2.1.6

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~~ *accident* 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~~ *accident* 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

design pressure in Table 2.2.1 can be withstood by the water jacket and Chapter 4 demonstrates by analysis that the water jacket design pressure will not be exceeded. To provide an additional layer of safety, a pressure relief device set at the design pressure is provided, which ensures the pressure will not be exceeded.

2.2.1.4 Environmental Temperatures

To evaluate the long-term effects of ambient temperatures on the HI-STORM 100 System, an upper bound value on the annual average ambient temperatures for the continental United States is used. The normal temperature specified in Table 2.2.2 is bounding for all reactor sites in the contiguous United States. The "normal" temperature set forth in Table 2.2.2 is intended to ensure that it is greater than the annual average of ambient temperatures at any location in the continental United States. In the northern region of the U.S., the design basis "normal" temperature used in this TSAR will be exceeded only for brief periods, whereas in the southern U.S, it may be straddled daily in summer months. Inasmuch as the sole effect of the "normal" temperature is on the computed fuel cladding temperature to establish long-term fuel integrity, it should not lie below the time averaged yearly mean for the ISFSI site. Previously licensed cask systems have employed lower "normal" temperatures (viz. 75° F in Docket 72-1007) by utilizing national meteorological data.

Likewise, within the thermal analysis, a conservatively assumed soil temperature of the value specified in Table 2.2.2 is utilized to bound the annual average soil temperatures for the continental United States. The 1987 ASHRAE Handbook (HVAC Systems and Applications) reports average earth temperatures, from 0 to 10 feet below grade, throughout the continental United States. The highest reported annual average value for the continental United States is 77° F for Key West, Florida. Therefore, this value is specified in Table 2.2.2 as the bounding soil temperature.

Confirmation of the site-specific annual average ambient temperature and soil temperature is to be performed by the licensee, in accordance with 10CFR72.212. The annual average temperature is combined with insolation in accordance with 10CFR71.71 averaged over 24 hours to establish the normal condition temperatures in the HI-STORM 100 System.

2.2.1.5 Design Temperatures

The ASME Boiler and Pressure Vessel Code (ASME Code) requires that the value of the vessel design temperature be established with appropriate consideration for the effect of heat generation internal or external to the vessel. The decay heat load from the spent nuclear fuel is the internal heat generation source for the HI-STORM 100 System. The ASME Code (Section III, Paragraph NCA-2142) requires the design temperature to be set at or above the maximum through thickness mean metal temperature of the pressure part under normal service (Level A) condition.

Consistent with the terminology of NUREG-1536, we refer to this temperature as the "Design Temperature for Normal Conditions". Conservative calculations of the steady-state temperature field in the HI-STORM 100 System, under assumed environmental normal temperatures with the maximum decay heat load, result in HI-STORM component temperatures at or below the normal condition design temperatures for the HI-STORM 100 System defined in Table 2.2.3.

Maintaining fuel rod cladding integrity is also a design consideration. The maximum fuel rod cladding temperature limits for normal conditions are calculated by the DCCG (Diffusion Controlled Cavity Growth) methodology outlined in the LLNL report [2.2.14] in accordance with NUREG-1536. However, for conservatism, the PNL methodology outlined in PNL report [2.0.3] produces a lower fuel cladding temperature, which is used to establish the *permissible* fuel cladding temperature limits, which are used to determine the allowable fuel decay heat load. Maximum fuel rod stainless steel cladding temperature limits recommended in EPRI report [2.2.13] are greater than the long-term allowable zircaloy fuel cladding temperature limits. However, in this TSAR the long-term zircaloy fuel cladding temperature limits are conservatively applied to the stainless steel clad fuel. The short term temperature limits for zircaloy and stainless steel cladding are taken from references [2.2.15] and [2.2.13], respectively. A detailed description of the maximum fuel rod cladding temperature limits determination is provided in Section 4.3.

2.2.1.6 Snow and Ice

The HI-STORM 100 System must be capable of withstanding pressure loads due to snow and ice. ASCE 7-88 (formerly ANSI A58.1) [2.2.2] provides empirical formulas and tables to compute the effective design pressure on the overpack due to the accumulation of snow for the contiguous U.S. and Alaska. Typical calculated values for heated structures such as the HI-STORM 100 System range from 50 to 70 pounds per square foot. For conservatism, the snow pressure loading is set at a level in Table 2.2.8 which bounds the ASCE 7-88 recommendation.

2.2.2 Off-Normal Conditions Design Criteria

As the HI-STORM 100 System is passive, loss of power and instrumentation failures are not defined as off-normal conditions. The off-normal condition design criteria are defined in the following subsections.

A discussion of the effects of each off-normal condition is provided in Section 11.1. Section 11.1 also provides the corrective action for each off-normal condition. The location of the detailed analysis for each event is referenced in Section 11.1.

2.2.2.1 Pressure

The HI-STORM 100 System must withstand loads due to off-normal pressure. The off-normal condition MPC internal design pressure bounds the cumulative effects of the maximum fill gas volume, off-normal environmental ambient temperatures, the maximum MPC heat load, and an assumed 10% 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. For conservatism, the MPC normal internal design pressure bounds both normal and off-normal conditions. Therefore, the normal and off-normal condition MPC internal pressures are set equal for analysis purposes.

2.2.2.2 Environmental Temperatures

The HI-STORM 100 System must withstand off-normal environmental temperatures. The off-normal environmental temperatures are specified in Table 2.2.2. The lower bound temperature occurs with no solar loads and the upper bound temperature occurs with steady- state insolation. Each bounding temperature is assumed to persist for a duration sufficient to allow the system to reach steady-state temperatures.

Limits on the peaks in the time-varying ambient temperature at an ISFSI site is recognized in the TSAR in the specification of the off-normal temperatures. The lower bound off-normal temperature is defined as the minimum of the 72-hour average of the ambient temperature at an ISFSI site. Likewise, the upper bound off-normal temperature is defined by the maximum of 72-hour average of the ambient temperature. The lower and upper bound off-normal temperatures listed in Table 2.2.2 are intended to cover all ISFSI sites in the continent U.S. The 72-hour average of temperature used in the definition of the off-normal temperature recognizes the considerable thermal inertia of the HI-STORM 100 storage system which reduces the effect of undulations in instantaneous temperature on the internals of the multi-purpose canister.

2.2.2.3 Design Temperatures

In addition to the normal design temperature, we also define an "off-normal/accident condition temperature" pursuant to the provisions of NUREG-1536 and Regulatory Guide 3.61. This is, in effect, the short-term temperature which may exist during a transition state or a transient event (examples of such instances are short-term temperature excursion during canister vacuum drying and backfilling operations (transition state) and fire (transient event)). The off-normal/accident design temperatures of Table 2.2.3 are set down to bound the maximax (maximum in time and

space) value of the thru-thickness average temperature of the structural or non-structural part, as applicable, during a short-term event. These enveloping values, therefore, will bound the maximum temperature reached anywhere in the part, excluding skin effects during or immediately after, a short-term event.

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~~ *may* 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 ~~O~~*o*verpack 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 ~~O~~*o*verpack falls freely from the vertical lift limit height before impacting a thick reinforced concrete pad. The deceleration of the ~~MPC~~ *cask* must be maintained below ~~60~~ *45* g'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~~ *devices designed in accordance with ANSI N14.6 having redundant drop protection features* 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~~ *hinder* 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 *of lifting devices designed in accordance with ANSI N14.6 having redundant drop protection features*~~,~~ 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~~ *Part 50* facility shall be lifted ~~by lifting equipment with redundant drop protection features and~~ *with* ~~lifting~~ devices designed in accordance with ANSI N14.6 *and having redundant drop protection features unless a site-specific analysis has been performed to determine a lift height limit.* ~~Therefore,~~ *For vertical lifts of HI-TRAC with suitably designed lift devices,* 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~~ *required to be established.* Likewise, while the loaded HI-TRAC is positioned atop the HI-STORM 100 ~~O~~*o*verpack for transfer of the MPC into the overpack *(outside the Part 50 facility)*, 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 ~~O~~*o*verpack is not a credible accident for the HI-TRAC transfer cask. ~~This~~ *These* conditions of use for MPC transfer operations from the HI-TRAC transfer cask to the HI-STORM 100 ~~O~~*o*verpack ~~is~~ *are* specified in *the HI-STORM 100 CoC,* ~~*the Technical Specifications in Chapter 12 and*~~ Subsection 2.3.3.1, and ~~is~~ *are* included in the operating procedures of Chapter 8.

The loaded MPC is lowered into the HI-STORM or HI-STAR ~~O~~*o*verpack 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 *and having redundant*

drop protection features. 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 ~~O~~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~~ *Two "pre-approved"* concrete pad design*s* for storing the HI-STORM 100 System ~~shall comply with~~ *are presented in* Table 2.2.9. *Other ISFSI pad designs may be used provided the designs are* ~~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~~ *the design basis limits when analyzed using the methodologies established in this TSAR.* ~~calculated by the dynamic models used in the structural qualifications.~~

2.2.3.2 Tip-Over

The free-standing HI-STORM 100 System is demonstrated by analysis to remain kinematically stable under the design basis environmental phenomena (tornado, earthquake, etc.). However, the HI-STORM 100 Overpack and MPC shall also withstand impacts due to a hypothetical tip-over event. The structural integrity of a loaded HI-STORM 100 System after a tip-over onto a reinforced concrete pad is demonstrated by analysis. The cask tip-over is not postulated as an outcome of any environmental phenomenon or accident condition. The cask tip-over is a non-mechanistic event.

The ISFSI pad for deploying a free-standing HI-STORM 100 overpack must possess sufficient structural stiffness to meet the strength limits set-forth in the ACI Code selected by the ISFSI owner. At the same time, the pad must be sufficiently compliant-such that the maximum deceleration under a tip-over event is below the limit set forth in Table 3.1.2 of this TSAR.

During original licensing for the HI-STAR 100 System, a single set of ISFSI pad and subgrade design parameters (now labeled Set A) was established. Experience has shown that achieving a maximum concrete compressive strength (at 28 days) of 4,200 psi can be difficult. Therefore, a second set of ISFSI pad and subgrade design parameters (labeled Set B) has been developed. The Set B ISFSI parameters include a thinner concrete pad and less stiff subgrade, which allow for a higher concrete compressive strength. Cask deceleration values for all design basis drop and tipover events with the HI-STORM 100 have been verified to be less than or equal to the design limit of 45 g's for both sets of ISFSI pad parameters.

The original set and the new set (Set B) of acceptable ISFSI pad *and subgrade design parameters* are specified in Table 2.2.9. *Users may design their ISFSI pads and subgrade in compliance with either parameter Set A or Set B. Alternatively, users may design their site-specific ISFSI pads and subgrade using any combination of design parameters resulting in a structurally competent pad that meets the provisions of ACI-318 and also limits the deceleration of the cask to less than or equal to*

45 g's for the design basis drop and tip-over events for the HI-STORM 100. The structural analyses for site-specific ISFSI pad design shall be performed using methodologies consistent with those described in this TSAR, as applicable.

[redacted]

2.2.3.3 Fire

The possibility of a fire accident near an ISFSI site is considered to be extremely remote due to the absence of significant combustible materials. The only credible concern is related to a transport vehicle fuel tank fire engulfing the loaded HI-STORM 100 overpack or HI-TRAC transfer cask while it is being moved to the ISFSI.

The HI-STORM 100 System must withstand temperatures due to a fire event. The HI-STORM 100 overpack and HI-TRAC transfer cask fire accidents for storage are conservatively postulated to be the result of the spillage and ignition of 50 gallons of combustible transporter fuel. The HI-STORM 100 overpack and HI-TRAC transfer cask surfaces are considered to receive an incident radiation and forced convection heat flux from the fire. Table 2.2.8 provides the fire durations for the HI-STORM 100 overpack and HI-TRAC transfer cask based on the amount of flammable materials assumed. The temperature of fire is assumed to be 1475° F in accordance with 10CFR71.73.

The accident condition design temperatures for the HI-STORM 100 System, and the fuel rod cladding limits are specified in Table 2.2.3. The specified fuel cladding temperature limits are based on the short-term temperature limit specified in reports [2.2.13 and 2.2.15].

2.2.3.4 Partial Blockage of MPC Basket Vent Holes

The HI-STORM 100 System is designed to withstand reduction of flow area due to partial blockage of the MPC basket vent holes. As the MPC basket vent holes are internal to the confinement barrier, the only events that could partially block the vents are fuel cladding failure and debris associated with this failure, or the collection of crud at the base of the stored SNF assembly. The HI-STORM 100 System maintains the SNF in an inert environment with fuel rod cladding temperatures below accepted values (Table 2.2.3). Therefore, there is no credible

mechanism for gross fuel cladding degradation during storage in the HI-STORM 100. For the 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 entering the penetration of the top lid is not credible. Therefore, no analyses of these impacts are provided.

2.2.3.6 Flood

The HI-STORM 100 System must withstand pressure and water forces associated with a flood. Resultant loads on the HI-STORM 100 System consist of buoyancy effects, static pressure loads, and velocity pressure due to water velocity. The flood is assumed to deeply submerge the HI-STORM 100 System (see Table 2.2.8). The flood water depth is based on the hydrostatic pressure which is bounded by the MPC external pressure stated in Table 2.2.1.

It must be shown that the MPC does not collapse, buckle, or allow water in-leakage under the hydrostatic pressure from the flood.

The flood water is assumed to be nonstagnant. The maximum allowable flood water velocity is determined by calculating the equivalent pressure loading required to slide or tip over the HI-STORM 100 System. The design basis flood water velocity is stated in Table 2.2.8 and the resultant differential pressure on the overpack is stated in Table 2.2.1. Site-specific safety reviews by the licensee must confirm that flood parameters do not exceed the flood depth, slide, or tip-over forces.

If the flood water depth exceeds the elevation of the top of the HI-STORM 100 Overpack inlet vents, then the cooling air flow would be blocked. The flood water may also carry debris which may act to block the air inlets of the HI-STORM 100 Overpack. Blockage of the air inlets is addressed in Subsection 2.2.3.12.

Most reactor sites are hydrologically characterized as required by Paragraph 100.10(C) of 10CFR100 and further articulated in Reg. Guide 1.59, "Design Basis Floods for Nuclear Power Plants" and Reg. Guide 1.102, "Flood Protection for Nuclear Power Plants." It is assumed that a complete characterization of the ISFSI's hydrosphere including the effects of hurricanes, floods, seiches and tsunamis is available to enable a site-specific evaluation of the HI-STORM 100 System for kinematic stability. An evaluation for tsunamis† for certain coastal sites should also be performed to demonstrate that sliding or tip-over will not occur and that the maximum flood depth will not be exceeded.

Analysis for each site for such transient hydrological loadings must be made for that site. It is

---

† A tsunami is an ocean wave from seismic or volcanic activity or from submarine landslides. A tsunami may be the result of nearby or distant events. A tsunami loading may exist in combination with wave splash and spray, storm surge and tides.

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 *and the vertical component* occur simultaneously. The maximum horizontal ZPA provided in Table 2.2.8 is the vector sum of two horizontal earthquakes.

[redacted]

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.

2.2.3.11 Lightning

The HI-STORM 100 System must withstand loads due to lightning. The effect of lightning on the HI-STORM 100 System is evaluated in Chapter 11.

2.2.3.12 Burial Under Debris

The HI-STORM 100 System must withstand burial under debris. Such debris may result from floods, wind storms, or mud slides. Mud slides, blowing debris from a tornado, or debris in flood water may result in duct blockage, which is addressed in Subsection 2.2.3.13. The thermal effects of burial under debris on the HI-STORM 100 System is evaluated in Chapter 11. Siting of the ISFSI pad shall ensure that the storage location is not located near shifting soil. Burial under debris is a highly unlikely accident, but is analyzed in this TSAR.

2.2.3.13 100% Blockage of Air Inlets

For conservatism, this accident is defined as a complete blockage of all four bottom air inlets. Such a blockage may be postulated to occur during accident events such as a flood or tornado with blowing debris. The HI-STORM 100 System must withstand the temperature rise as a result

of 100% blockage of the air inlets and outlets. The fuel cladding temperature must be shown to remain below the short term temperature limit specified in Table 2.2.3.

2.2.3.14 Extreme Environmental Temperature

The HI-STORM 100 System must withstand extreme environmental temperatures. The extreme accident level temperature is specified in Table 2.2.2. The extreme accident level temperature occurs with steady-state insolation. This temperature is assumed to persist for a duration sufficient to allow the system to reach steady-state temperatures. The HI-STORM 100 Overpack and MPC have a large thermal inertia. Therefore, this temperature is assumed to persist over three days (3-day average).

[redacted]

Table 2.2.1

DESIGN PRESSURES

Pressure Location	Condition	Pressure (psig)
MPC Internal Pressure	Normal	100
	Off-Normal	100
	Accident	~~125~~ *200*
MPC External Pressure	Normal	(0) Ambient
	Off-Normal	(0) Ambient
	Accident	60
Overpack External Pressure	Normal	(0) Ambient
	Off-Normal	(0) Ambient
	Accident	10 Differential Pressure for 1 second maximum or 5 Differential Pressure steady state
HI-TRAC Water Jacket	Normal	60
	Off-normal	60
	Accident	N/A (Under accident conditions, the water jacket is assumed to have lost all water thru the pressure relief valves)

Table 2.2.3 DESIGN TEMPERATURES		
HI-STORM 100 Component	**Normal Condition Design Temp. (Long-Term Events) (° F)**	**Off-Normal and Accident Condition Temp. Limits (Short-Term Events) (° F)**
Zircaloy fuel cladding (5-year cooled)[1]	~~692~~ *641*(PWR) ~~742~~ *741*(BWR)	1058
Zircaloy fuel cladding (6-year cooled)[1]	~~677~~ *676*(PWR) ~~714~~ *712*(BWR)	1058
Zircaloy fuel cladding (7-year cooled)[1]	~~636~~ *635*(PWR) ~~671~~ *664*(BWR)	1058
Zircaloy fuel cladding (10-year cooled)[1]	~~626~~ *625*(PWR) ~~660~~ *658*(BWR)	1058
Zircaloy fuel cladding (15-year cooled)[1]	~~615~~ *614*(PWR)~~648~~ *646*(BWR)	1058
Zircaloy fuel cladding (5-year cooled)[2]	*679 (PWR) 740 (BWR)*	*1058*
Zircaloy fuel cladding (6-year cooled)[2]	*660 (PWR) 712 (BWR)*	*1058*
Zircaloy fuel cladding (7-year cooled)[2]	*635 (PWR) 669 (BWR)*	*1058*
Zircaloy fuel cladding (10-year cooled)[2]	*621 (PWR) 658 (BWR)*	*1058*
Zircaloy fuel cladding (15-year cooled)[2]	*611 (PWR) 648 (BWR)*	*1058*
Overpack outer shell	350	600
Overpack concrete	200	350
Overpack inner shell	350	400
Overpack Lid Top Plate	350	550
Remainder of overpack steel structure	350	400

NOTES: 1. Moderate Burnup Fuel
2. High Burnup Fuel

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~~ *B*	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.

Table 2.2.7

HI-STORM 100 ASME BOILER AND PRESSURE VESSEL CODE APPLICABILITY

HI-STORM 100 Component	Material Procurement	Design	Fabrication	Inspection
Overpack steel structure	Section II, Section III, Subsection NF, NF-2000	Section III, Subsection NF, NF-3200	Section III, Subsection NF, NF-4000	Section III, Subsection NF, NF-5350, NF-5360 and Section V
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
MPC confinement boundary	Section II, Section III, Subsection NB, NB-2000	Section III, Subsection NB, NB-3200	Section III, Subsection NB, NB-4000	Section III, Subsection NB, NB-5000 and Section V
MPC fuel basket	Section II, Section III, Subsection NG, NG-2000	Section III, Subsection NG, NG-3300 and NG-3200	Section III, Subsection NG, NG-4000	Section III, Subsection NG, NG-5000 and Section V
HI-TRAC Trunnions	Section II, Section III, Subsection NF, NF-2000	ANSI 14.6	Section III, Subsection NF, NF-4000	See Chapter 9
MPC basket supports	Section II, Section III, Subsection NG, NG-2000	Section III, Subsection NG, NG-3300 and NG-3200	Section III, Subsection NG, NG-4000	Section III, Subsection NG, NG-5000 and Section V
HI-TRAC steel structure	Section II, Section III, Subsection NF, NF-2000	Section III, Subsection NF, NF-3300	Section III, Subsection NF, NF-4000	Section III, Subsection NF, NF-5360 and Section V
Damaged fuel container	Section II, Section III, Subsection NG, NG-2000	Section III, Subsection NG, NG-3300 and NG-3200	Section III, Subsection NG, NG-4000	Section III, Subsection NG, NG-5000 and Section V
Overpack concrete	ACI 349 as specified by Appendix 1.D	ACI 349 and ACI 318-95 as specified by Appendix 1.D	ACI 349 as specified by Appendix 1.D	ACI 349 as specified by Appendix 1.D

[redacted]

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 (*Deg.* 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 *and 100S*) $G_H = 2.12$; $G_V = 1.5$ (HI-STORM 100A)
Net Overturning Moment at base of HI-STORM 100A (ft-lb)	*Accident*	*$18.7x10^6$*
HI-STORM 100 Overpack Vertical Lift Height Limit (in.)	Accident	11††† (HI-STORM 100 *and 100S*), *OR By Users (HI-STORM 100A)*
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 of 0.53 may be increased based on testing described in Subsection 3.4.7.1

††† *For ISFSI and subgrade design parameter Sets A and B. Users may also develop a site-specific lift height limit.*

Table 2.2.9

EXAMPLES OF ACCEPTABLE ISFSI PAD *DESIGN PARAMETERS*

PARAMETER	***PARAMETER SET "A"*** †	***PARAMETER SET "B"***
Concrete thickness, t_p, *(inches)*	$\leq$ 36	$\leq$ *28*
Concrete Compressive Strength *(at 28 days)*, f_c', *(psi)*	$\leq$ 4,200	$\leq$ *6,000 psi*
Reinforcement Top and Bottom (both directions)	Reinforcing bar shall be 60 ksi Yield Strength ASTM Material	*Reinforcing bar shall be 60 ksi Yield Strength ASTM Material*
Subgrade Effective Modulus of Elasticity†† *(measured prior to ISFSI pad installation), E, (psi)*	$\leq$ 28,000	$\leq$ *16,000*

NOTE: A static coefficient of friction of $\geq$ 0.53 between the ISFSI pad and the bottom of the overpack shall be verified by test. The test procedure shall follow the guidelines included in the Sliding Analysis in Subsection 3.4.7.1.

---

† The characteristics of this pad are identical to the pad considered by Lawrence Livermore Laboratory (see Appendix 3.A).

†† An acceptable method of defining the soil effective modulus of elasticity applicable to the drop and tipover analysis is provided in Table 13 of NUREG/CR-6608 with soil classification in accordance with ASTM-D2487 Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System USCS) and density determination in accordance with ASTM-D1586 Standard Test Method for Penetration Test and Split/Barrel Sampling of Soils.

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.

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. *For HI-STORM 100A, the ISFSI pad is designated ITS, Category C as discussed in Subsection 2.0.4.1.*

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,

- 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 *the various* HI-STORM 100 overpacks.

The criticality safety criteria stipulates that the effective neutron multiplication factor, k_{eff}, including statistical uncertainties and biases, is less than 0.95 for all postulated arrangements of fuel within the cask under all credible conditions.

2.3.4.1 Control Methods for Prevention of Criticality

The control methods and design features used to prevent criticality for all MPC configurations are the following:

a. Incorporation of permanent neutron absorbing material (Boral™) in the MPC fuel basket walls.

b. Favorable geometry provided by the MPC fuel basket

Additional control methods used to prevent criticality for the MPC-24, MPC-24E, and MPC-24EF (all with higher enriched fuel), and the MPC-32 are the following:

a. Loading of PWR fuel assemblies 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.

Table 2.4.1

MPC ACTIVATION

Nuclide	Activity After 40-Year Storage (Ci/m^3)
^{54}Mn	~~6.65e-4~~ *2.20e-3*
^{55}Fe	~~1.07e-3~~ *3.53e-3*
^{59}Ni	~~8.79e-7~~ *2.91e-6*
^{60}Co	~~9.39e-5~~ *3.11e-4*
^{63}Ni	~~2.98e-5~~ *9.87e-5*
Total	~~1.86e-3~~ *6.15e-3*

HI-STORM OVERPACK ACTIVATION

Nuclide	Activity After 40-Year Storage (Ci/m^3)
Overpack Steel	
^{54}Mn	~~1.09e-4~~ *3.62e-4*
^{55}Fe	~~2.06e-3~~ 7.18e-3
Total	~~2.17e-3~~ *7.18e-3*
Overpack Concrete	
^{39}Ar	~~9.11e-7~~ *3.02e-6*
^{41}Ca	~~7.36e-8~~ *2.44e-7*
^{54}Mn	~~4.79e-7~~ *1.59e-7*
^{55}Fe	~~8.90e-6~~ *2.95e-5*
Total	~~1.04e-5~~ *3.43e-5*

2.6 REFERENCES

[2.0.1] American Concrete Institute, "Building Code Requirements for Structural Concrete", ACI 318-95, ACI, Detroit, Michigan.

[2.0.2] American Concrete Institute, "Code Requirements for Nuclear Safety Related Concrete Structures", ACI 349-85, ACI, Detroit, Michigan

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

[2.0.4] NRC Regulatory Guide 7.10, "Establishing Quality Assurance Programs for Packaging Used in the Transport of Radioactive Material," USNRC, Washington, D.C. Rev. 1 (1986).

[2.0.5] J.W. McConnell, A.L. Ayers, and M.J. Tyacke, "Classificaation of Transportation Packaging and Dry Spent Fuel Storage Syystem Component According to Important to Safety," Idaho Engineering Laboratory, NUREG/CR-6407, INEL-95-0551, 1996.

[2.0.6] NUREG-1567, Standard Review Plan for Spent Fuel Dry Storage Facilities, March 2000.

[2.0.7] ASME Code, Section III, Subsection NF and Appendix F, and Code Section II, Part D, Materials, 1998.

[2.1.1] ORNL/TM-10902, "Physical Characteristics of GE BWR Fuel Assemblies", by R.S. Moore and K.J. Notz, Martin Marietta (1989).

[2.1.2] U.S. DOE SRC/CNEAF/96-01, Spent Nuclear Fuel Discharges from U.S. Reactors 1994, Feb. 1996.

[2.1.3] Deleted.

[2.1.4] Deleted.

[2.1.5] NUREG-1536, SRP for Dry Cask Storage Systems, USNRC, Washington, DC, January 1997.

[2.1.6] DOE Multi-Purpose Canister Subsystem Design Procurement. Specification.

[2.1.7] S.E. Turner, "Uncertainty Analysis - Axial Burnup Distribution Effects," presented in "Proceedings of a Workshop on the Use of Burnup Credit in Spent Fuel Transport Casks", SAND-89-0018, Sandia National Laboratory, Oct., 1989.

[2.1.8] Commonwealth Edison Company, Letter No. NFS-BND-95-083, Chicago, Illinois.

[2.2.1] ASME Boiler & Pressure Vessel Code, American Society of Mechanical Engineers, 1995 with Addenda through 1997.

[2.2.2] ASCE 7-88 (formerly ANSI A58.1), "Minimum Design Loads for Buildings and Other Structures", American Society of Civil Engineers, New York, NY, 1990.

[2.2.3] ANSI N14.6-1993, "Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 Kg) or More", June 1993.

[2.2.4] Holtec Report HI-941184, "Topical Safety Analysis Report for the HI-STAR 100 Cask System", NRC Docket No. 72-1008, Revision 9, 1998.

[2.2.5] Holtec Report HI-951251, "Safety Analysis Report for the HI-STAR 100 Cask System", NRC Docket No. 71-9261, Revision 7, 1998.

[2.2.6] "Debris Collection System for Boiling Water Reactor Consolidation Equipment", EPRI Project 3100-02 and ESEERCO Project EP91-29, October 1995.

[2.2.7] Design Basis Tornado for Nuclear Power Plants, Regulatory Guide 1.76, U.S. Nuclear Regulatory Commission, April 1974.

[2.2.8] ANSI/ANS 57.9-1992, "Design Criteria for an Independent Spent Fuel Storage Installation (dry type)", American Nuclear Society, LaGrange Park, Illinois.

[2.2.9] NUREG-0800, SRP 3.5.1.4, USNRC, Washington, DC.

[2.2.10] United States Nuclear Regulatory Commission Regulatory Guide 1.59, "Design Basis Floods for Nuclear Power Plants", August 1973 and Rev. 1, April 1976.

[2.2.11] "Estimate of Tsunami Effect at Diablo Canyon Nuclear Generating Station, California." B.W. Wilson, PG&E (September 1985, Revision 1).

[2.2.12] Deleted.

[2.2.13] Cunningham et als., "Evaluation of Expected Behavior of LWR Stainless Clad Fuel in Long-Term Dry Storage", EPRI TR-106440, April 1996.

[2.2.14] M.W. Schwartz and M.C. Witte, Lawrence Livermore National Laboratory, "Spent Fuel Cladding Integrity During Dry Storage", UCID-21181, September 1987.

[2.2.15] PNL-4835, "Technical Basis for Storage of Zircaloy-Clad Spent Fuel in Inert Gases", A.B. Johnson and E.R. Gilbert, Pacific Northwest Laboratories, September 1983.

[2.2.16] Crane Manufacturer's Association of America (CMAA), Specification #70, 1988, Section 3.3.

APPENDIX 2.A

GENERAL DESIGN AND CONSTRUCTION REQUIREMENTS FOR THE ISFSI PAD FOR HI-STORM 100A

[redacted]

[redacted]

CHAPTER 3: STRUCTURAL EVALUATION†

In this chapter, the structural components of the HI-STORM 100 System that are important to safety (ITS) are identified and described. The objective of the structural analyses is to ensure that the integrity of the HI-STORM 100 System is maintained under all credible loads for normal, off-normal, and design basis accident/natural phenomena. The chapter results support the conclusion that the confinement, criticality control, radiation shielding, and retrievability criteria set forth by 10CFR72.236(l), 10CFR72.124(a), 10CFR72.104, 10CFR72.106, and 10CFR72.122(l) are met. In particular, the design basis information contained in the previous two chapters and in this chapter provides sufficient data to permit structural evaluations to demonstrate compliance with the requirements of 10CFR72.24. To facilitate regulatory review, the assumptions and conservatism's inherent in the analyses are identified along with a complete description of the analytical methods, models, and acceptance criteria. A summary of other material considerations, such as corrosion and material fracture toughness is also provided. Design calculations for the HI-TRAC transfer cask are included where appropriate to comply with the guidelines of NUREG-1536.

Detailed numerical computations supporting the conclusions in the main body of this chapter are presented in a series of appendices. Where appropriate, the subsections make reference to results in the appendices. Section 3.6.3 contains the complete list of appendices that support this chapter.

This revision to the HI-STORM Safety Analysis Report, the first since the HI-STORM 100 System was issued a Part 72 Certificate-of-Compliance, incorporates several features into the structural analysis to respond to the changing needs of the U.S. nuclear power generation industry. The most significant changes to this chapter for this revision are:

- *The incorporation of structural results associated with the MPC-32 and the MPC-24E/24EF fuel baskets. In the case of the MPC-32, this revision simply returns results of analyses that were contained in this chapter prior to the initial CoC. In the case of the 24E basket, the new results are based on the same structural analysis model used for all the other baskets evaluated.*

- *The revision of the analyses of free thermal expansion and MPC canister shell to incorporate the changed temperature distribution from the inclusion of the thermosiphon* effect *(convective heat transfer inside the canister)*

† 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).

- *The introduction of new analyses that permit the use of additional damaged fuel canisters in the HI-STORM 100.*

- *The inclusion of a short version of the HI-STORM overpack (designated as HI-STORM 100S) to accommodate plants with reduced clearances. In general, we show that the HI-STORM 100S is bounded by results previously obtained.*

- *Revisions to approved HI-TRAC analyses to accommodate fabrication enhancements.*

- *Enhancement of the handling accident and tipover analyses to provide an additional qualified reference ISFSI pad configuration with higher strength concrete.*

- [redacted]

The organization of technical information in this chapter follows the format and content guidelines of USNRC Regulatory Guide 3.61 (February 1989). The TSAR ensures that the responses to the review requirements listed in NUREG-1536 (January 1997) are complete and comprehensive. The areas of NRC staff technical inquiries, with respect to structural evaluation in NUREG-1536, span a wide array of technical topics within and beyond the material in this chapter. To facilitate the staff's review to ascertain compliance with the stipulations of NUREG-1536, Table 3.0.1 "Matrix of NUREG-1536 Compliance - Structural Evaluation", is included in this chapter. A comprehensive cross-reference of the topical areas set forth in NUREG-1536, and the location of the required compliance information is contained in Table 3.0.1.

Section 3.7 describes in detail HI-STORM 100 System's compliance to NUREG-1536 Structural Evaluation Requirements.

The HI-STORM 100 System matrix of compliance table given in this section is developed with the supposition that the storage overpack is designated as a steel structure that falls within the purview of subsection 3.V.3 "Other Systems Components Important to Safety" (page 3-28 of NUREG-1536), and therefore, does not compel the use of reinforced concrete. (Please refer to Table 1.0.3 for an explicit statement of exception on this matter). The concrete mass installed in the HI-STORM 100 overpack is accordingly equipped with "plain concrete" for which the sole applicable industry code is ACI 318.1 (92). Plain concrete, in contrast to reinforced concrete, is the preferred shielding material HI-STORM 100 because of three key considerations:

(i) Plain concrete is more amenable to a void free pour than reinforced concrete in narrow annular spaces typical of ventilated vertical storage casks.

(ii) The tensile strength bearing capacity of reinforced concrete is not required to buttress the steel weldment of the HI-STORM 100 overpack.

(iii) The compression and bearing strength capacity of plain concrete is unaffected by the absence of rebars. A penalty factor, on the compression strength, pursuant to the provisions of ACI-318.1 is, nevertheless, applied to insure conservatism. However, while plain concrete is the chosen shielding embodiment for the HI-STORM 100 storage overpack, all necessary technical, procedural Q.C., and Q.A. provisions to insure nuclear grade quality will be implemented by utilizing the relevant sections from ACI-349 (85) as specified in Appendix 1.D.

In other words, guidelines of NUREG 1536 pertaining to reinforced concrete are considered to insure that the material specification, construction quality control and quality assurance of the shielding concrete comply with the provisions of ACI 349 (85). These specific compliance items are listed in the compliance matrix.

TABLE 3.0.1 MATRIX OF NUREG-1536 COMPLIANCE ITEMS – STRUCTURAL EVALUATION †

PARAGRAPH IN NUREG-1536	NUREG-1536 COMPLIANCE ITEM	LOCATION IN TSAR CHAPTER 3	LOCATION OUTSIDE OF TSAR CHAPTER 3
IV.1.a	ASME B&PV Compliance		
	NB	3.1.1	Tables 2.2.6,2.2.7
	NG	3.1.1	Tables 2.2.6,2.2.7
IV.2	Concrete Material Specification		Appendix 1.D
IV.4	Lifting Devices	3.1; 3.4;3.D;3.E;3.AC	
V.	Identification of SSC that are ITS		Table 2.2.6
"	Applicable Codes/Standards	3.6.1	Table 2.2.6
"	Loads		Table 2.2.13
"	Load Combinations	3.1.2.1.2; Tables 3.1.1-3.1.5	Table 2.2.14
"	Summary of Safety Factors	3.4.3; 3.4.4.2; 3.4.4.3.1-3 3.4.6-3.4.9; Tables 3.4.3-3.4.9	
"	Design/Analysis Procedures	Chapter 3 plus Appendices	
"	Structural Acceptance Criteria		Tables 2.2.10-2.2.12

Table continued on following page

TABLE 3.0.1 (CONTINUED)

"	Material/QC/Fabrication	Table 3.4.2	Chap. 9; Chap. 13
"	Testing/In-Service Surveillance		Chap. 9; Chap. 12
"	Conditions for Use		Table 1.2.6; Chaps. 8,9,12
V.1.a	Description of SSC	3.1.1	1.2
V.1.b.i.(2)	Identification of Codes & Standards		Tables 2.2.6, 2.2.7
V.1.b.ii	Drawings/Figures		1.5
"	Identification of Confinement Boundary		1.5; 2.3.2; 7.1; Table 7.1.1
"	Boundary Weld Specifications	3.3.1.4	1.5; Table 7.1.2
"	Boundary Bolt Torque	NA	
"	Weights and C.G. Location	Tables 3.2.1-3.2.4	
"	Chemical/Galvanic Reactions	3.4.1; Table 3.4.2	
V.1.c	Material Properties	3.3; Tables 3.3.1-3.3.5	1.A; 1.C; 1.D
"	Allowable Strengths	Tables 3.1.6-3.1.17	Tables 2.2.10-2.2.12; 1.D
"	Suitability of Materials	3.3; Table 3.4.2	1.A; 1.B; 1.D
"	Corrosion	3.3	
"	Material Examination before Fabrication		9.1.1

Table continued on following page

TABLE 3.0.1 (CONTINUED)

"	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

3.1.1

It is quite evident from the geometry of the MPC that a critical loading event pertains to the drop condition when the MPC is postulated to undergo a handling side drop (the longitudinal axis of the 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 un-reinforced (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 that 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* can *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,

- unacceptable risk of criticality
- unacceptable release of radioactive materials
- unacceptable radiation levels
- impairment of ready retrievability of the SNF

The above design objectives for the HI-STORM 100 System can be particularized for individual components as follows:

- The objectives of the structural analysis of the MPC are to demonstrate that:

  1. Confinement of radioactive material is maintained under normal, off-normal, accident conditions, and natural phenomenon events.

  2. The MPC basket does not deform under credible loading conditions such that the subcriticality or retrievability of the SNF is jeopardized.

- The objectives of the structural analysis of the storage overpack are to demonstrate that:

  1. Tornado-generated missiles do not compromise the integrity of the MPC confinement boundary.

  2. The overpack can safely provide for on-site transfer of the loaded MPC and ensure adequate support to the HI-TRAC transfer cask during loading and unloading of the MPC.

  3. The radiation shielding remains properly positioned in the case of any normal, off-normal, or natural phenomenon or accident event.

  4. The flow path for the cooling air flow shall remain available under normal and off-normal conditions of storage and after a natural phenomenon or accident event.

  ~~9.~~5. The loads arising from normal, off-normal, and accident level conditions exerted on the contained MPC do not exceed the structural design criteria of the MPC.

  6. No geometry changes occur under any normal, off-normal, and accident level conditions of storage that may preclude ready retrievability of the contained MPC.

  7. A free-*standing* storage overpack can safely withstand a non-mechanistic tip-over event with a loaded MPC within the overpack.

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 *free-standing* 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 cannot 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.

[redacted]

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.

In contrast to the overpack, the MPC is a closed pressure vessel. Because of the enveloping overpack around it, the explosive pressure wave would manifest as an external pressure on the external surface of the MPC.

The maximum overpressure on the MPC resulting from an explosion is limited by the HI-STORM Technical Specification to be equal to or less than the accident condition design external pressure or external pressure differential specified in Table 2.2.1. The design external pressure differential is applied as a component of the load combinations.

3.1.2.1.1.5 Tornado

The three components of a tornado load are:

1. pressure changes,
2. wind loads, and
3. tornado-generated missiles.

Wind speeds and tornado-induced pressure drop are specified in Table 2.2.4. Tornado missiles are listed in Table 2.2.5. A central functional objective of a storage overpack is to maintain the integrity of the "confinement boundary", namely, the multi-purpose canister stored inside it. This operational imperative requires that the mechanical loadings associated with a tornado at the ISFSI do not jeopardize the physical integrity of the loaded MPC. Potential consequences of a tornado on the cask system are:

- Instability (tip-over) due to tornado missile impact plus either steady wind or impulse from the pressure drop *(only applicable for free-standing cask).*
- Stress in the overpack induced by the lateral force caused by the steady wind or missile impact.
- Loadings applied on the MPC transmitted to the inside of the overpack through its openings or as a secondary effect of loading on the enveloping overpack structure.
- Excessive storage overpack *permanent* deformation *that* ~~which~~ may prevent ready retrievability of the MPC.
- Excessive storage overpack *permanent* deformation *that*~~which~~ may significantly reduce the shielding effectiveness of the storage overpack.

Analyses must be performed to ensure that, due to the tornado-induced loadings:

- The loaded overpack does not become kinematically unstable *(only applicable for free-standing cask).*

- The overpack does not deform plastically such that the retrievability of the stored MPC is threatened.

- The MPC does not sustain an impact from an incident missile.

- The MPC is not subjected to inertia loads (acceleration or deceleration) in excess of its design basis limit set forth in Chapter 2 herein.

- The overpack does not deform sufficiently due to tornado-borne missiles such that the shielding effectiveness of the overpack is significantly affected.

The results obtained for the HI-STORM 100 bound the corresponding results for HI-STORM 100S because of the reduced height [redacted]

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 *of a free-standing cask,* [redacted] and lateral force on the overpack causing excessive stress and deformation of the storage overpack.

[redacted]

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 *that*~~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 *that*~~which~~ are relevant to the stability analyses *of free-standing casks*. 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) that 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 HI-TRAC transfer cask are identical to or bounded by the normal handling loads analyzed in the HI-STAR 100 TSAR Docket Number 72-1008.

Three accident condition scenarios must be considered: (i) drop with the storage overpack axis vertical; (ii) drop with the HI-TRAC axis horizontal; and (iii) storage overpack tipover. The vertical drop scenario is considered in the HI-STAR 100 SAR.

The horizontal drop and tip-over must consider multiple orientation of the fuel basket, as the fuel basket is not radially symmetric. Therefore, two horizontal drop orientations are considered which are referred to as the 0 degree drop and 45 degree drop, respectively. In the 0 degree drop, the basket drops with its panels oriented parallel and normal to the vertical (see Figure 3.1.2). The 45-degree drop implies that the basket's honeycomb section is rotated meridionally by 45 degrees (Figure 3.1.3).

Enclosure Vessel

Table 3.1.4 summarizes all load cases that are applicable to structural analysis of the enclosure vessel to ensure integrity of the confinement boundary.

The enclosure vessel is a pressure vessel consisting of a cylindrical shell, a thick circular baseplate at the bottom, and a thick circular lid at the top. This pressure vessel must be shown to meet the primary stress intensity limits for ASME Section III Class 1 at the design temperature and primary plus secondary stress intensity limits under the combined action of pressure plus thermal loads.

Normal handling of the enclosure vessel is considered in Docket 72-1008; the handling loads are independent of whether the enclosure vessel is within HI-STAR 100, HI-STORM 100, or HI-TRAC.

The off-normal condition handling loads are identical to the normal condition and, therefore, a separate analysis is not required.

Analyses presented in this chapter are intended to demonstrate that the maximum decelerations in drop and tip-over accident events are limited by the bounding values in Table 3.1.2. The vertical drop event is considered in the HI-STAR 100 SAR Docket 72-1008.

The deceleration loadings developed in the enclosure vessel during a horizontal drop event are combined with those due to P_i (internal pressure) acting alone. The accident condition pressure is bounded by P_i^*. The design basis deceleration for the MPC in the HI-STAR 100 System is 60g's, whereas the design basis deceleration for the MPC in the HI-STORM 100 System is 45g's. The design pressures are identical. The fire event (T^* loading) is considered for ensuring absence of interference between the enclosure vessel and the fuel basket and between the enclosure vessel and the overpack.

It is noted that the MPC basket-enclosure vessel thermal expansion and stress analyses are reconsidered in this submittal to reflect the different MPC-to-overpack gaps that exist in the HI-STORM 100 Overpack versus the HI-STAR 100 overpack, coupled with the different design basis decelerations.

Storage Overpack

Table 3.1.5 identifies the load cases to be considered for the overpack. These are in addition to the kinematic criteria listed in Table 3.1.1. Within these load cases and kinematic criteria, the following items must be addressed:

Normal Conditions

- The dead load of the HI-TRAC with the heaviest loaded MPC (dry) on top of the HI-STORM 100 Overpack must be shown to be able to be supported by the metal-concrete (METCON™)

structure consisting of the two concentric steel shells and the steel rib plates, and by the concrete columns away from the vent regions.

- The dead load of the HI-STORM 100 Overpack itself must be supportable by the steel structure with no credit for concrete strength other than self-support in compression.

- Normal handling loads must be accommodated without taking any strength credit from the contained concrete other than self-support in compression.

Accident Conditions

- Maximum flood water velocity for the overpack with an empty MPC must be specified to ensure that no sliding or tip-over occurs.

- Tornado missile plus wind on an overpack with an empty MPC must be specified to demonstrate that no cask tip-over occurs.

- Tornado missile penetration analysis must demonstrate that the postulated large and penetrant missiles cannot contact the MPC. The small missile must be shown not to penetrate the MPC pressure vessel boundary, since it can enter the overpack cavity through the vent ducts.

- Under seismic conditions, a fully loaded, *free-standing* HI-STORM 100 overpack must be demonstrated to not tip over under the maximum ZPA event. The maximum sliding of the overpack must demonstrate that casks will not impact each other.

- Under a non-mechanistic postulated tip-over of a fully loaded, *free-standing* 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; therefore, analyses are not repeated specifically for the HI-STORM 100S unless the specific geometry changes significantly influence the safety factors.

overpack and HI-TRAC cask are made of SA516-70 (with some components having an option for SA203E or SA350-LF3 depending on material availability).

Table 3.1.18 provides a summary of impact testing requirements to satisfy the requirements for prevention of brittle fracture.

3.1.2.4 Fatigue

In storage, the HI-STORM 100 System is not subject to significant cyclic loads. Failure due to fatigue is not a concern for the HI-STORM 100 System.

[redacted]

The system is subject to cyclic temperature fluctuations. These fluctuations result in small changes of thermal expansions and pressures in the MPC. The loads resulting from these changes are small and do not significantly contribute to the "usage factor" of the cask.

Inspection of the HI-TRAC trunnions specified in Chapter 9 will preclude use of a trunnion *that* ~~which~~ exhibits visual damage.

3.1.2.5 Buckling

Certain load combinations subject structural sections with relatively large slenderness ratios (such as the enclosure vessel shell) to compressive stresses that may actuate buckling instability *before* the allowable stress is reached. Tables 3.1.4 and 3.1.5 list load combinations for the enclosure vessel and the HI-STORM 100/HI-TRAC structures; the cases which warrant stability (buckling) check are listed therein (note that a potential buckling load has already been identified as a consequence of a postulated explosion).

3.2 WEIGHTS AND CENTERS OF GRAVITY

Tables 3.2.1 and 3.2.2 provide the calculated weights of the individual HI-STORM 100 components as well as the total system weights. The actual weights will vary within a narrow range of the calculated values due to the tolerances in metal manufacturing and fabrication permitted by the ASME Codes. Contained water mass during fuel loading is not included in this table.

The locations of the calculated centers of gravity (CGs) are presented in Table 3.2.3. All centers of gravity are located on the cask centerline since the non-axisymetric effects of the cask system plus contents are negligible.

Table 3.2.4 provides the lift weight when the HI-TRAC transfer cask with the heaviest fully loaded MPC is being lifted from the fuel pool. The effect of buoyancy is neglected, and the weight of rigging is set at a conservative value.

In all weight tables, bounding values are also listed where necessary for use in structural calculations where their use will provide a conservative result.

Table 3.2.1
HI-STORM 100 OVERPACK WEIGHT DATA

Item	WEIGHT (lb)†		
	Component (lb.)	Assembly (lb.)	Bounding Weight†† (lb.)
HI-STORM 100 Overpack · Overpack top lid	21,638	265,866~~8,334~~	270,000 23,000
HI-STORM 100S Overpack · Overpack top lid	24,771~~498~~	*252,423*	270,000 25,500
HI-STORM 100A		*add 2000 lb. to above weights*	*270,000*
MPC-24 · Without SNF · Fully loaded with SNF		39,667 79,987	90,000
Overpack (100) with fully loaded MPC-24 *(100S) with loaded MPC-24*		345,853~~8,321~~ *332,410*	360,000 *360,000*
MPC-68 · Without SNF · Fully loaded with SNF		39,641 87,241	90,000
Overpack (100) with fully loaded MPC-68 *(100S) with loaded MPC-68*		353,107~~5,575~~ *339,664*	360,000 *360,000*
Overpack (100) with *empty MPC-68*~~*lower bound weight*minimum weight MPC without SNF~~		*304,507*~~307,975~~	303~~03~~,000 (Lower Bound)
MPC-32 · Without SNF · Fully loaded with SNF		34,375 88,135	90,000
Overpack (100) with *fully* loaded MPC-32 *(100S) with loaded MPC-32*		354,001~~6,469~~ *340,558*	360,000 *360,000*
MPC-24E · Without SNF · Fully loaded with SNF		42,069 82,389	90,000
Overpack (100) with *fully* loaded MPC-24E *(100S) with loaded MPC-24E*		*348,255* *334,812*~~350,723~~	360,000 *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. *All bounding weights are applicable to HI-STORM 100A.*

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		142,97~~688~~	143,500
· Pool Lid	12,03~~11~~		12,500
· Top Lid	2,730		2,750
125-Ton HI-TRAC Transfer Cask with Transfer Lid		154,373~~2,636~~	155~~3~~,000
· Transfer Lid	23,428~~1,679~~		24,5~~2,0~~00
· Top Lid	2,730		2,750
MPC-24			
· Without SNF		39,667	
· Fully loaded with SNF		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~~	235~~3~~,000
MPC-68			
· Without SNF		39,641	
· Fully loaded with SNF		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		34,375	
· Fully loaded with SNF		88,135	90,000
125-Ton HI-TRAC with Pool Lid with loaded MPC-32		231,11~~23~~	233,500
125-Ton HI-TRAC with Transfer Lid w/ loaded MPC-32		242,507~~0,771~~	243,000
MPC-24E			
· Without SNF		42,069	
· Fully loaded with SNF		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

† 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†

ITEM	WEIGHT (lb) Component	Assembly	Bounding Weight††
100-Ton HI-TRAC Transfer Cask with Pool Lid • Removable trunnion · Pool Lid · Top Lid	 255 7,915 1,203~~2~~	100,*449*~~960~~	102,000 8,000 *1,*~~52,~~400
100-Ton HI-TRAC Transfer Cask with Transfer Lid • Removable trunnion · Transfer Lid · Top Lid	 255 16,*092*~~425~~ 1,203~~2~~	108,*626*~~267~~	111,000 178,000 *1,*~~52,~~400
MPC-24 · Without SNF · Fully loaded with SNF		 39,667 79,987	 80,000
100-Ton HI-TRAC with Pool Lid with loaded MPC-24		183,*6360*~~,947~~	18~~482~~,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-24		191,*81*~~289,457~~	192~~1~~,000
MPC-68 · Without SNF · Fully loaded with SNF		 39,641 87,241	 90,000
100-Ton HI-TRAC with Pool Lid with loaded MPC-68		190,*89*~~088,201~~	192,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-68		199,*0666*~~,711~~	201,000
MPC-32 · Without SNF · Fully loaded with SNF		 34,375 88,135	 90,000
100-Ton HI-TRAC with Pool Lid with loaded MPC-32		191,*78*~~489,095~~	192,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-32		199,*9606*~~,402~~	201,000
MPC-24E · Without SNF · Fully loaded with SNF		 42,069 82,389	 90,000
100-Ton HI-TRAC with Pool Lid with loaded MPC-24E		186,*0383*~~,349~~	1874,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-24E		194,*2140*~~,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	142,97~~688~~	
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	-1,20*3*~~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

† 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.

3.3.1.3 Bolting Materials

Material properties of the bolting materials used in the HI-STORM 100 System and HI-TRAC lifting trunnions are given in Table 3.3.4[redacted]

3.3.1.4 Weld Material

All weld materials utilized in the welding of the Code components comply with the provisions of the appropriate ASME subsection (e.g., Subsection NB for the MPC enclosure vessel) and Section IX. All non-code welds will be made using weld procedures *that*~~which~~ meet Section IX of the ASME Code. The minimum tensile strength of the weld wire and filler material (where applicable) will be equal to or greater than the tensile strength of the base metal listed in the ASME Code.

3.3.2 Nonstructural Materials

3.3.2.1 Solid Neutron Shield

The solid neutron shielding material in the HI-TRAC top lid and transfer lid doors is not considered as a structural member of the HI-STORM 100 System. Its load carrying capacity is neglected in all structural analyses except where such omission would be non-conservative. The only material property of the solid neutron shield *that*~~which~~ is important to the structural evaluation is weight density (1.63g/cm^3).

3.3.2.2 Boral™ Neutron Absorber

Boral is not a structural member of the HI-STORM 100 System. Its load carrying capacity is neglected in all structural analyses. The only material property of Boral *that*~~which~~ is important to the structural evaluation is weight density. As the MPC fuel baskets can be constructed with Boral panels of variable areal density, the weight that produces the most severe cask load is assumed in each analysis (density 2.644 g/cm^3).

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.,

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*

The table below summarizes the results of the evaluation in Appendix 3.AE.

Safety Factors in HI-TRAC Bottom Flange During a Lift Operation			
Item	Value(ksi)	Allowable(ksi)	Safety Factor
Bottom Flange – Region B	7.798	26.25	3.37
Bottom Flange (3D*)	23.39	33.15	1.42
Outer Shell (3D*)	3.117	33.15	10.63

3.4.3.11 Conclusion

Synopses of lifting device, device/component interface, and component stresses, under all contemplated lifting operations for the HI-STORM 100 System have been presented in the foregoing. The HI-STORM storage overpack and the HI-TRAC transfer cask have been evaluated for limiting stress states. The results show that all factors of safety are greater than 1.

3.4.4 Heat

The thermal evaluation of the HI-STORM 100 System is reported in Chapter 4.

3.4.4.1 Summary of Pressures and Temperatures

Design pressures and design temperatures for all conditions of storage are listed in Tables 2.2.1 and 2.2.3, respectively.

3.4.4.2 Differential Thermal Expansion

Consistent with the requirements of Reg. Guide 3.61, Load Cases F1 (Table 3.1.3) and E4 (Table 3.1.4) are defined to study the effect of differential thermal expansion among the constituent components in the HI-STORM 100 System. Tables 4.4.*9, 4.4.10, 4.4.26, 4.4.27, and 4.4.36*~~15 and 4.5.4~~ provide the temperatures necessary to perform the differential thermal expansion analyses for the MPC in the HI-STORM 100 and HI-TRAC casks, respectively. The material presented in the remainder of this paragraph demonstrates that a physical interference between discrete components of the HI-STORM 100 System (e.g. storage overpack and enclosure vessel) will not develop due to differential thermal expansion during any operating condition.

3.4.4.2.1 Normal Hot Environment

Closed form calculations are performed to demonstrate that initial gaps between the HI-STORM 100 storage overpack or the HI-TRAC transfer cask and the MPC canister, and between the MPC canister and the fuel basket, will not close due to thermal expansion of the system components under loading conditions, defined as F1 and E4 in Tables 3.1.3 and 3.1.4, respectively. To assess this in the most conservative manner, the thermal solutions computed in Chapter 4, *including the thermosiphon effect,* are surveyed for the following information.

- The radial temperature distribution in each of the fuel baskets at the location of peak center metal temperature.

- The highest and lowest mean temperatures of the canister shell for the hot environment condition.

- The inner and outer surface temperature of the HI-STORM 100 storage overpack and the HI-TRAC transfer cask at the location of highest and lowest surface temperature (which will produce the lowest mean temperature).

Table*s 4.4.9, 4.4.10, 4.4.26, 4.4.27, and 4.4.36* ~~4.4.15~~ presents the resulting temperatures used in the evaluation of the MPC expansion in the HI-STORM 100 storage overpack. Table 4.5.24 presents similar results for the MPC in the HI-TRAC transfer cask.

Using the temperature information in the above-mentioned tables, simplified thermoelastic solutions of equivalent axisymmetric problems are used to obtain conservative estimates of gap closures. The following procedure, which conservatively neglects axial variations in temperature distribution, is utilized.

1. Use the surface temperature information for the fuel basket to define a parabolic distribution in the fuel basket that bounds (from above) the actual temperature distribution. –Using this result, generate a conservatively high estimate of the radial and axial growth of the different fuel baskets using classical closed form solutions for thermoelastic deformation in cylindrical bodies.

2. Use the temperatures obtained for the canister to predict an estimate of the radial and axial growth of the canister to check the canister-to-basket gaps.

3. Use the temperatures obtained for the canister to predict an estimate of the radial and axial growth of the canister to check the canister-to-storage overpack and canister-to-HI-TRAC gaps.

4. Use the storage overpack and HI-TRAC surface temperatures to construct a logarithmic temperature distribution (characteristic of a thick walled cylinder) at the location used for canister thermal growth calculations; and use this distribution to predict an estimate of storage overpack or HI-TRAC (as applicable) radial and axial growth.

5. For given initial clearances, compute the operating clearances.

The calculation procedure outlined above is used in Appendix 3.I (HI-TRAC), and in Appendices 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	*0.1040~~.0985~~*	*1.81252~~.0~~*	*1.404~~537~~*
MPC-24E	*0.1875*	*0.104*	*1.8125*	*1.404*
MPC-32	*0.1875*	*0.103*	*1.8125*	*1.398*
MPC-68	0.1875	*0.091~~100~~*	*1.81252~~.0~~*	*1.336~~562~~*
CANISTER – STORAGE OVERPACK				
Unit	Radial Direction (in.)		Axial Direction (in.)	
	Initial Clearance	Final Clearance	Initial Clearance	Final Clearance
MPC-24	*0.54~~0625~~*	*0.435~~348~~*	1.0	*0.63~~374~~*
MPC-24E	*0.5*	*0.434*	*1.0*	*0.628*
MPC-32	*0.5*	*0.433*	*1.0*	*0.621*
MPC-68	*0.54~~0625~~*	*0.434~~349~~*	1.0	*0.628~~48~~*

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	*0.08~~392~~*	*1.81252~~.0~~*	*1.305~~5242~~*
CANISTER - HI-TRAC				
	Radial Direction (in.)		Axial Direction (in.)	
Unit	Initial Clearance	Final Clearance	Initial Clearance	Final Clearance
MPC (worst case)	*0.125~~1875~~*	*0.123~~185~~*	0.75	*0.735~~30~~*

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 mod*el 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 th*e~~i~~se* configuration*s 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 she*ll~~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

deceleration (HI-TRAC and HI-STAR 100 overpacks have the same inside dimensions).

Accelerations

During a side impact event, the stored fuel is directly supported by the cell walls in the fuel basket. Depending on the orientation of the drop, 0 or 45 degrees (see Figures 3.4.8 and 3.4.9), the fuel is supported by either one or two walls. In the finite element model this load is effected by applying a uniformly distributed pressure over the full span of the supporting walls. The magnitude of the pressure is determined by the weight of the fuel assembly (Table 2.1.6), the axial length of the fuel basket support structure, the width of the cell wall, and the impact acceleration. It is assumed that the load is evenly distributed along an axial length of basket equal to the fuel basket support structure. For example, the pressure applied to an impacted cell wall during a 0-degree side drop event is calculated as follows:

$$p = \frac{a_n W}{L c}$$

where:

p = pressure

a_n = ratio of the impact acceleration to the gravitational acceleration

W = weight of a stored fuel assembly

L = axial length of the fuel basket support structure

c = width of a cell wall

For the case of a 45-degree side drop the pressure on any cell wall equals p (defined above) divided by the square root of 2.

It is evident from the above that the effect of deceleration on the fuel basket and canister metal structure is accounted for by amplifying the gravity field in the appropriate direction.

Internal Pressure

Design internal pressure is applied to the MPC model. The inside surface of the enclosure vessel shell is loaded with pressure. The magnitude of the internal pressure applied to the model is taken from Table 2.2.1.

For this load condition, the center node of the fuel basket is fixed in all degrees of freedom to 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 *(conservatively using the outer radius for r)*:

Classical Shell Theory Results for Normal and Accident Internal Pressures				
Item	σ_1 (psi)	σ_2 (psi)	σ_3 (psi)	$\sigma_1 - \sigma_3$ (psi)
P= 100 psi	6838	3419	-100	6938
P= *200*~~125~~ psi	*136758*~~548~~	*68384*~~274~~	*-200*~~125~~	*138758*~~673~~

Finite Element Analysis (Load Case E1.a and E1.c of Table 3.1.4)

The MPC shell, the top lid, and the baseplate together form the confinement boundary (enclosure vessel) for storage of spent nuclear fuel. In this section, we evaluate the operating condition consisting of dead weight, internal pressure, and thermal effects for the hot condition of storage. The top and bottom plates of the MPC enclosure vessel (EV) are modeled using plane axisymmetric elements, while the shell is modeled using the axisymmetric thin shell element. The thickness of the top lid varies in the different MPC types; for conservative results, the minimum thickness top lid is modeled. The temperature distributions for all MPC constructions are nearly identical in magnitude and gradient *and reflect the thermosiphon effect inside the MPC*. Temperature differences across the thickness of both the baseplate and the top lid exist during HI-STORM 100's operations. There is also a thermal gradient from the center of the top lid and baseplate out to the shell wall. The metal temperature profile is essentially parabolic from the centerline of the MPC out to the MPC shell. There is also a parabolic temperature profile along the length of the MPC canister. Figure 3.4.11 shows a sketch of the confinement boundary structure with identifiers A-I locating points where temperature input data is used to represent a continuous temperature distribution for analysis purposes. The overall dimensions of the confinement boundary are also shown in the figure.

~~Table 4.4.19 provides~~ *T*the desired temperatures for confinement thermal stress analysis *are determined from Tables 4.4.9, 4.4.10, 4.4.19, 4.4.26, and 4.4.27 in Chapter 4. The MPC-68 is identified to have the maximum through thickness thermal gradients.* ~~The distribution for the MPC-24 provides the largest temperature gradients in the baseplate and in the shell. It will be shown later that stress intensities are greatest in these components of the confinement vessel.~~ Detailed stress analyses are performed only for the MPC-*68*~~24~~; these results *are representative for all*~~will bound the remaining~~ MPCs.

Figure 3.4.12 shows details of the finite element model of the top lid, canister shell, and baseplate. The top lid is modeled with 40 axisymmetric quadrilateral elements; the weld connecting the lid to the shell is modeled by a single element solely to capture the effect of the top lid attachment to the canister offset from the middle surface of the top lid. The MPC canister is modeled by 50 axisymmetric shell elements, with 20 elements concentrated in a short length of shell appropriate to capture the so-called "bending boundary layer" at both the top and bottom ends of the canister. The remaining 10 shell elements model the MPC canister structure away from the shell ends in the region where stress gradients are expected to be of less importance. The baseplate is modeled by 20

axisymmetric quadrilateral elements. Deformation compatibility at the connections is enforced at the top by the single weld element, and deformation and rotation compatibility at the bottom by additional shell elements between nodes 106-107 and 107-108.

The geometry of the model is listed below (terms are defined in Figure 3.4.12):

$H_t =$	9.5" (the minimum thickness lid is assumed)
$R_L =$	0.5 x 67.25" (Bill of Materials for Top Lid)
$L_{MPC} =$	190.5" (Drawing 1996, Sheet 1)
$t_s =$	0.5"
$t_{BP} =$	0.5 x 68.375"
$\beta =$	$2\sqrt{R_s t_s} \approx 12"$ (the "bending boundary layer")

Stress analysis results are obtained for two cases as follows:

a. internal pressure = 100 psi

b. internal pressure = 100 psi plus applied temperatures ~~for the MPC-24~~

For this configuration, dead weight of the top lid acts to reduce the stresses due to pressure. For example, the equivalent pressure simulating the effect of the weight of the top lid is an external pressure of 3 psi, which reduces the pressure difference across the top lid to 97 psi. The dead weight of the top lid is neglected to provide additional conservatism in the results. The dead weight of the baseplate, however, adds approximately 0.73 psi to the effective internal pressure acting on the base. The effect of dead weight is still insignificant compared to the 100 psi design pressure, and is therefore neglected. The thermal loading in the confinement vessel is obtained by developing a parabolic temperature profile to the entire length of the MPC canister and to the top lid and baseplate. The temperature data provided at locations A-I in Figure 3.4.11 and 3.4.12 are sufficient to establish the profiles. Through-thickness temperatures are assumed linearly interpolated between top and bottom surfaces of the top lid and baseplate.

Finally, in the analysis, all material properties and expansion coefficients are considered to be temperature-dependent in the model.

Results for stress intensity are reported for the case of internal pressure alone and for the combined loading of pressure plus temperature (Load Case E1.c in Table 3.1.4). Tables 3.4.7 and 3.4.8 report results at the inside and outside surfaces of the top lid and baseplate at the centerline and at the extreme radius. Canister results are reported in the "bending boundary layer" and at a location near mid-length of the MPC canister. In the tables, the calculated value is the value from the finite

element analysis, the categories are P_m = primary membrane; $P_L + P_b$ = local membrane plus primary bending; and $P_L + P_b + Q$ = primary plus secondary stress intensity. The allowable strength value is obtained from the appropriate table in Section 3.1 for Level A conditions, and the safety factor SF is defined as the allowable strength divided by the calculated value. Allowable strengths for Alloy X are taken at *300*~~400~~ degrees F *at the bottom of the MPC and 500 degrees F at the top of the MPC. These temperatures reflect actual operating conditions per Table 4.4.19.*~~, which bounds the temperatures anywhere during the normal hot operation.~~ The results given in Tables 3.4.7 and 3.4.8 demonstrate the ruggedness of the MPC as a confinement boundary.

The results in Table 3.4.7 and 3.4.8 also show that the baseplate and the shell connection to the baseplate are the most highly stressed regions under the action of internal pressure. To confirm the finite element results, we perform an alternate closed form solution using classical plate and shell theory equations that are listed in or developed from the reference (Timoshenko and Woinowsky-Krieger, Theory of Plate and Shells, McGraw Hill, Third Edition).

Assuming that the thick baseplate receives little support against rotation from the thin shell, the bending stress at the centerline is evaluated by considering a simply supported plate of radius a and thickness h, subjected to lateral pressure p. The maximum bending stress is given by

$$\sigma = \frac{3(3+\nu)}{8} p \left(\frac{a}{h}\right)^2$$

where:

a = .5 x 68.375"

h = 2.5"

ν = 0.3 (Poisson's Ratio)

p = 100 psi

Calculating the stress in the plate gives σ = 23,142 psi.

Now consider the thin MPC shell (t = 0.5") and first assume that the baseplate provides a clamped support to the shell. Under this condition, the bending stress in the thin shell at the connection to the plate is given as

$$\sigma_{Bp} = 3p\frac{a}{t}\frac{(1-\nu/2)}{\sqrt{3}(1-\nu^2)^{1/2}} = 10{,}553 \text{ psi}$$

In addition to this stress, there is a component of stress in the shell due to the baseplate rotation that causes the shell to rotate. The joint rotation is essentially driven by the behavior of the baseplate as a simply supported plate; the shell offers little resistance because of the disparity in thickness and will essentially follow the rotation of the thick plate.

Using formulas from thin shell theory, the additional axial bending stress in the shell due to this rotation θ can be written in the form

$$\sigma_{B\theta} = 12\ \beta\ D_s \frac{\theta}{t^2}$$

where

$$\theta = pa^3/8D\,(1+\nu) * \left(\frac{1}{1+\alpha}\right)$$

and

$$D = \frac{Eh^3}{12(1-\nu^2)} \qquad E = \text{plate Young's Modulus}$$

$$\alpha = \frac{2\beta a t^3}{h^3(1+\nu)}$$

$$D_s = \frac{Et^3}{12\,(1-\nu^2)}$$

$$\beta^2 = \sqrt{3(1-\nu^2)}\,/at$$

Substituting the numerical values gives

$$\sigma_{B\theta} = 40{,}563 \text{ psi}$$

We note that the approximate solution is independent of the value chosen for Young's Modulus as long as the material properties for the plate and shell are the same.

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.

Under the accident pressure, the MPC baseplate experiences bending. Table NB-3217-1 permits the bending stress at the outer periphery of the baseplate and in the shell wall at the connection to be considered as a secondary bending stress if the primary bending stress at the center of the baseplate can be shown to meet the stress limits without recourse to the restraint provided by the MPC shell. To this end, the bending stress at the center of the baseplate is computed in a conservative manner assuming the baseplate is simply supported at the periphery. The bending stress for a simply supported circular plate is

$$\sigma = (9/8)p\left(r/t\right)^2$$

At the accident pressure, conservatively set at twice the normal operating pressure, the maximum stress is:

Bending stress at center of baseplate = 46,284 psi

Since this occurrence is treated as a Level D event, the stress intensity is compared with the limit from Table 3.1.14 and the safety factor computed as, "SF", where

SF = 69,300 psi/(46,284+200) psi = 1.49

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 1×10^{-1} inch and Figure 3.4.32 is expressed in 1×10^{-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 a*n 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.*27*~~457~~

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} = Weight of HI-TRAC (loaded) = 243,000 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

$$A_o = \frac{\pi}{4}(D_o^2 - (D_o - 2t_o)^2) = \frac{\pi}{4}(132.5^2 - 131^2)$$
$$= 310.43\,in^2$$

The metal area of the radial ribs is

$$A_r = 4t_r(D_o - 2t_o - D_i)/2 = \frac{3}{2}(131 - 76) = 82.5\,in^2$$

The metal area of the inner shell is

$$A_i = \frac{\pi}{4}(D_i^2 - (D_i - 2t_i)^2) = \frac{\pi}{4}(76^2 - 73.5^2)$$
$$= 293.54\,in^2$$

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

$$A_{concrete} = \frac{\pi}{4}((D_o - 2t_o)^2 - (D_i)^2) - A_r$$

$$= \frac{\pi}{4}(131^2 - 76^2) - 82.5\,in^2$$

$$= (8{,}994 - 82.5)\,in^2 = 8{,}859.5\,in^2$$

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:

$A_o = A_o$(no vent) – $4t_o w$ = 260.93 sq. inch

$A_i = A_i$(no vent) – $4t_i w$ = 211.04 sq. inch

$A_{concrete} = A_{concrete}$(no vent) – 4dw = 7044.2 sq. inch

The loading case is a Level A load condition. The load is apportioned to the steel and to the concrete in accordance with the values of EA for the two materials (E(steel) = 28,000,000 psi and E(concrete)=3,605,000 psi).

$$EA(steel) = 28 x 10^6\,psi\, x\,(260.93 + 211.04 + 82.5)in^2$$
$$= 15525.2\,lb\, x\, 10^6\,lbs.$$

$$EA(concrete) = 3.605 \times 10^6 \times (7044.2)\,in^2$$
$$= 25{,}394.3 \times 10^6\,lb.$$

Therefore, the total HI-TRAC load will be apportioned as follows:

F_{STEEL} = (15525.2/40,919.5) x 243,000 = 92,196.2 lb.

$F_{CONCRETE}$ = (25,394.3/40,919.5) x 243,000 = 150,803.8 lb.

Therefore, if the load is apportioned as above, with all load-carrying components in the path acting, the compressive stress in the steel is

$$\sigma_{STEEL} = \frac{F_{STEEL}}{A_o + A_i + A_r} = 134.3 \text{ psi}$$

If we conservatively neglect the compression load bearing capacity of concrete, then

$$\sigma_{STEEL} = \frac{243{,}000}{554.5} = 438 \text{ psi}$$

If we include the concrete, then the maximum compressive stress in the concrete is:

$$\sigma_{CONCRETE} = \frac{F_{CONCRETE}}{A_{CONCRETE}} = 21.4 \text{ psi}$$

It is clear that HI-STORM 100 storage overpack can support the dead load of a fully loaded 125 Ton HI-TRAC placed on top for MPC transfer into or out of the HI-STORM 100 storage overpack cavity. The calculated stresses at a cross-section through the air outlet ducts are small and give rise to large factors of safety. The metal cross-section at the base of the HI-STORM storage overpack will have a 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 100*S* 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:

$A_i = A_i(\text{no vent}) - 4t_iw = 211.04$ sq. inch

Therefore, the additional stress from the HI-STORM 100*S* storage overpack components, at the base of the overpack, is:

$\Delta\sigma = 26\cancel{351}$ psi

and a maximum compressive stress in the inner shell predicted as:

Maximum stress = 438 psi + $26\cancel{351}$ psi = $701\cancel{689}$ psi

The safety factor at the base of the storage overpack inner shell (minimum section) is

SF = 17,500psi/$701\cancel{689}$psi = $24.96\cancel{5.4}$

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 table*s* 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	*6.5298.94*	29.4	*4.5033.292*
Lid Shell-Lid Top Plate Combined Stress	*8.84*	*29.4*	*3.326*
Attachment Bolt Shear Stress	*34.33.62*	60.9	*1.776812*
Attachment Bolt Combined Shear and ~~Tension Interaction~~*Tension Interaction* at interface with Anchor Block	-------	------	1.2791
HI-STORM 100S Top Lid Integrity			
Item	*Value (ksi)*	*Allowable (ksi)*	*Safety Factor*
Inner and Outer Shell Weld to Base	*8.5721*	*29.429.4*	*3.433.43*
Shield Block Shell-to-Lid Weld Shear Stress	*5.9555.96*	*29.429.4*	*4.944.937*

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*——	*1.3254~~5~~*

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	35.25	59.65	1.692

Plate Bending Stress Intensity			
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

HI-TRAC Top Lid Separation Analysis			
Item	Value	Capacity	Safety Factor= Capacity/Value
Attachment Shear Force (lb.)	123,75~~039~~	*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)	35.5~~67.71~~	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

is clear that the instability result for the storage overpack bounds the results for the HI-TRAC transfer cask. This occurs because the R/t ratio (mean radius-to-~~wall thickness~~*wall thickness*) of the HI-TRAC outer shell is less than the corresponding ratio for the HI-STORM storage overpack. Therefore, no HI-TRAC analysis is performed in Appendix 3.AK.

3.4.5 Cold

A discussion of the resistance to failure due to brittle fracture is provided in Subsection 3.1.2.3.

The value of the ambient temperature has two principal effects on the HI-STORM 100 System, namely:

i. The steady-state temperature of all material points in the cask system will go up or down by the amount of change in the ambient temperature.

ii. As the ambient temperature drops, the absolute temperature of the contained helium will drop accordingly, producing a proportional reduction in the internal pressure in accordance with the Ideal Gas Law.

In other words, the temperature gradients in the system under steady-state ~~conditions,~~*conditions* will remain the same regardless of the value of the ambient temperature. The internal pressure, on the other hand, will decline with the lowering of the ambient temperature. Since the stresses under normal storage condition arise principally from pressure and thermal gradients, it follows that the stress field in the MPC under –40 degree F ambient would be smaller than the "heat" condition of storage, treated in the preceding subsection. Additionally, the allowable stress limits tend to increase as the component temperatures decrease.

Therefore, the stress margins computed in Section 3.4.4 can be conservatively assumed to apply to the "cold" condition as well.

Finally, it can be readily shown that the HI-STORM 100 System is engineered to withstand "cold" temperatures (-40 degrees F), as set forth in the Technical Specification, without impairment of its storage function.

Unlike the MPC, the HI-STORM 100 storage overpack is an open structure; it contains no pressure. Its stress field is unaffected by the ambient temperature, unless low temperatures produce brittle fracture due to the small stresses which develop from self-weight of the structure and from the minute difference in the thermal expansion coefficients in the constituent parts of the equipment (steel and concrete). To prevent brittle fracture, all steel material in HI-STORM 100 is qualified by impact testing as set forth in the ASME Code (Table 3.1.18).

The structural material used in the MPC (Alloy X) is recognized to be completely immune from brittle fracture in the ASME Codes.

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 MPC AND 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)	0.54~~530625~~	0.36~~404269~~	1.00~~.75~~	0.24~~163233~~

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:

$$F = Cd\ A\ V^*$$

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, b_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 ~~athe~~ lower bound weight of HI-STORM 100 is used in the above equation.

As stated previously, μ= 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 b_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.*646*" (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 = Cd 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 = *265,86~~670,000~~*	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

$$H_{cg} = \frac{W_o \times 116.8 + W_{MPC} \times H}{W_o + W_{MPC}}$$

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

$$WG_HH$$

where W is the total system weight and G_H is the resultant zero period acceleration seismic loading

† 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.

(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.~~028.98~~"), 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
0.46~~87~~	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 100S (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 3.2.1)) is used. Accordingly,

$$F = (0.47)\ (360{,}000) = 169{,}200 \text{ lbs.}$$

No dynamic amplification is assumed as the overpack, considered as a beam, has a natural frequency

well into the rigid range.

The moment, M, at the base of the HI-STORM 100 due to this lateral force is given by

$$M = \frac{FH}{2}$$

where H = height of HI-STORM 100 (taken conservatively as 235 inches). Note that the loading has now been approximated as a uniform load acting over the full height of the cask.

The flexural stress, σ, is given by the ratio of the moment M to the section modulus of the steel shell structure, z, which is computed to be 12,640 in.^{3} (Structural Calculation Package HI-981928).

Therefore,

$$\sigma = \frac{(169{,}200)\,(235)}{(12{,}640)\,(2)} = 1{,}573 \text{ psi}$$

We note that the strength of concrete has been neglected in the above calculation.

The maximum axial stress in the storage overpack shell will occur on the "compressive" side where the flexural bending stress algebraically sums with the direct compression stress σ_d from vertical compression.

From the representative acceleration table the vertical seismic accelerations corresponding to the net 0.47g horizontal acceleration is below 0.16g.

Therefore, using the maximum storage overpack weight (bounded by 270,000 lbs. from data in Table 3.2.1)

$$\sigma_d = \frac{(270{,}000)\,(1.16)}{554.47} = 565 \text{ psi}$$

where 554.47 sq. inch is the metal area (cross section) of the steel structure in the HI-STORM 100 storage overpack as computed in Subsection 3.4.4.3.2.1. The total axial stress, therefore, is

$$\sigma_T = 1{,}573 + 565 = 2{,}138 \text{ psi}$$

Per Table 3.1.12, the allowable *membrane* stress intensity for a Level D event is 39,750 psi at 350 degrees F.

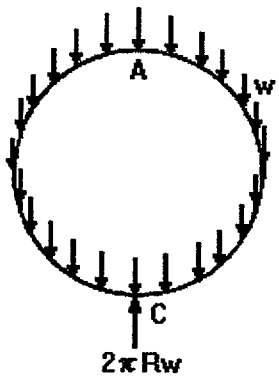
The Factor of Safety, β, is, therefore

$$\beta = \frac{39{,}750}{2{,}138} = 18.59$$

Examination of the results for the stability load case 2 (which considers bounding loads) in Appendix 3.AK demonstrates that no instability will result from this compressive load induced by a seismic or other environmental load leading to bending of the storage overpack as a beam.

The previous calculation has focussed on the axial stress in the members developed assuming that the storage overpack does not overturn but resists the lateral load by remaining in contact with the ground and bending like a beam. Since the lateral loading is only over a portion of the periphery, there is also the potential for this load to develop circumferential stress in the inner and outer shells to resist ovalization of the shells. To demonstrate continued retrievability of the MPC after a seismic event, it must be shown that either the stresses remain in the elastic range or that any permanent deformation that develops due to plasticity doe not intrude into the MPC envelope after the event is ended. In the following subsection, a classical result from Appendix 3.B for the deformation of rings under specified surface loadings is used to provide a conservative solution for the circumferential stresses. Specifically, Appendix 3.B contains a complete solution for a point-supported ring subject to a gravitational induced load around the periphery of the ring. This solution provides a conservative estimate of the circumferential stress and the deformation of the ring that will develop under the actual applied seismic load. Specifically, the following classical ring problem, shown in the sketch below, is applied to obtain the circumferential stress and deformation field under the postulated seismic event:

Ring supported at base and loaded by its own weight, w, given per unit circumferential length.



The solution in Appendix 3.B considers the geometry and load appropriate to a unit length of the inner and outer shells of the HI-STORM 100 storage overpack with a total weight equal to the overpack bounding weight (no MPC) subject to a 45g deceleration inertial loading. The numerical results in Appendix 3.B can be directly applied here by multiplying by the factor "X", where "X" reflects the differences in the deceleration and the weights used for the case considered in Appendix 3.B and for the seismic load case here in this subsection.

X = (0.47g/45g) x (360,000lb./270,000lb.) = 0.0139

Using this factor on the solution in Appendix 3.B, (Attachment B-1, Case 15.16) gives the following bounding results for maximum stresses (without regard for sign and location of the stress) and deformations:

Maximum circumferential stress due to bending moment = (29,310 psi x X) = 407 psi

Maximum circumferential stress due to mean tangential force = (18,900 lb./2 sq.inch) x X = 131.4 psi

Change in diameter in the direction of the load = -0.11" x X = -0.0015"

Change in diameter perpendicular to the direction of the load = +0.06" x X = 0.0008"

From the above results, it is clear that no permanent ovalization of the storage overpack occurs during the seismic event and that circumferential stresses will remain elastic and are bounded by the stresses computed based on considering the storage overpack as a simple beam. Therefore, the safety factors based on maximum values of axial stress are appropriate. The magnitudes of the diameter changes that are suggested by the ring solution clearly demonstrate that ready retrievability of the

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.

$$\zeta = \frac{1{,}321}{28\,\mathrm{E}{+}06} = 47.\mathrm{E}{-}06$$

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

Allowable ConcreteStrain = $(5 \times (0.75) \times (f)^{1/2})/(57{,}000(f)^{1/2}) = 65.8\mathrm{E}{-}06$

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). The

$$m\ddot{x} = R + m\,a \sin \omega t$$

equation of motion for such a "slider block" is given by:

where:

$\ddot{x}$: relative acceleration of the slider block (double dot denotes second derivative of displacement x in time)

a: amplitude of the sinusoidal acceleration input

ω: frequency of the seismic input motion (radians/sec)

t: time coordinate

R is the resistive Coulomb friction force that can reach a maximum value of μ(mg) (μ= coefficient of friction) and which always acts in the direction of opposite to $\dot{x}(t)$.

Solution of the above equation can be obtained by standard numerical integration for specified values of m, a, w and a. The following input values are used.

a = 0.47g

α = 0.84 = 1 - vertical acceleration (vertical acceleration is 0.16g for net horizontal acceleration equal to 0.47 from the acceleration table provided in the foregoing)

m = 360,000 lbs/g

μ = 0.25

For establishing the appropriate value of ω, reference is made to the USAEC publication TID-7024, "Nuclear Reactor and Earthquakes", page 35, 1963, which states that the significant energy of all seismic events in the U.S. essentially lies in the range of 0.4 to 10 Hz. Taking the mid-point value

$$\omega = (6.28)\ (0.5)\ (0.4+10) = 32.7 \text{ rad/sec.}$$

The numerical solution of the above equation yields the maximum excursion of the slider block x_{max} as 0.12 inches, which is negligible compared to the spacing between casks.

Calculations performed at lower values of ω show an increase in x_{max} with reducing ω. At 1 Hz, for example, x_{max} = 3.2 inches. It is apparent from the above that there is a large margin of safety against inter-module collision within the HI-STORM 100 arrays at an ISFSI, where the minimum installed spacing is over 2 feet (Table 1.4.1).

The above dynamic analysis indicates that the HI-STORM 100 System undergoes minimal lateral vibration under a seismic input with net horizontal ZPA g-values as high as 0.47 even under a bounding (from below) low interface surface friction coefficient of 0.25. Data reported in the literature (ACI-349R (85), Commentary on Appendix B) indicates that values of the coefficient of friction, μ, as high as 0.7 are obtained at steel/concrete interfaces.

To ensure against unreasonably low coefficients of friction, the ISFSI pad design may require a "broom finish" at the user's discretion. The bottom surface of the HI-STORM 100 is manufactured from plate stock (i.e. non-machine finish). 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. The coefficient of friction is required to be verified by test (see Table 2.2.9).

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:

$$G_H + \mu G_V \leq \mu$$

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 x (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 lb/(132.5" x 235") = 5.43 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:

$I\omega = (P \times D \times H) \times (0.5 \times H) \times T$

The above formula relates the change in angular motion resulting from an impulsive moment about the base of the overpack. D is the diameter of the outer shell, H is the height of the storage overpack, and I is the mass moment of inertia of the storage overpack about the mass center (assumed to be at half-height). For D=132.5", H=235", P=10 psi, T=1 second, and I=64,277,000 lb.inch sec^2 (calculated in Appendix 3.C), the resulting initial angular velocity is:

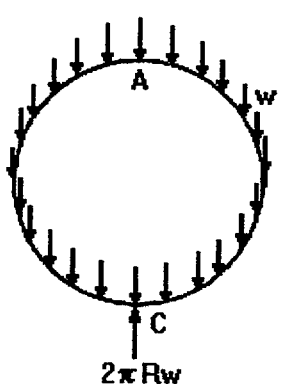
$\omega = 0.569$ radians/second

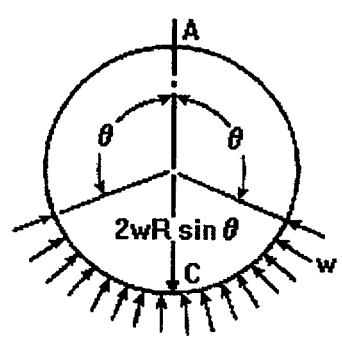
Therefore, an appropriate short time pressure limit is 10 psi with pulse duration less than or equal to 1 second. Table 2.2.1 sets this as the short-time external pressure differential.

The analysis in Subsection 3.4.7.1 evaluates ovalization of the shell by considering the seismically applied load as a line loading along the height of the overpack that is balanced by inertial body forces in the metal ring. The same solutions in Appendix 3.B can be used to examine the circumferential stress state that would be induced to resist an external pressure that developed around one-half of the periphery. Such a pressure distribution may be induced by a pressure wave crossing the cask from a nearby explosion. It is shown here, by reference to solutions in Appendix 3.B, that a uniform pressure load over one-half of the overpack outer shell gives rise to an elastic stress state and deformation state that is bounded by a large margin by the results just presented for the seismic event in Subsection 3.4.7.1.

The case of an external pressure load from an explosion pressure wave (Load Case 05 in Table 3.1.5) is examined by combining the solutions of Case1 and Case 3 in Appendix 3.B. The combined case that results is a balance of pressure load over one-half the perimeter and inertial body forces. The sketch below describes this:

Case 1 + Case 3





In Appendix 3.B, both cases are considered under identical total loads (with the angle in case 3 set to 90 degrees). Therefore, adding the results from the two cases results in the desired combined case; namely, the balance of a peripheral external pressure with internal all around loading simulating an inertia load (since the reactions are identical in magnitude and opposite in direction, there is a complete cancellation of the concentrated loads).

Examination of the results in Appendix 3.B shows that the algebraic sum of the two sets of solutions give results that are smaller in magnitude than the case 1 solution for a line loading balanced by inertially induced body forces. The applied loading used to develop the solution in Appendix 3.B, case 1, is 56,180 lb. per inch of storage overpack axial length. This load is equivalent to an external pressure P = 424 psi applied over one-half of the outer perimeter of the shell as is shown below:

P x D = 56,180 lb./inch D = 132.5"

P = 424 psi

Since this is higher by a large margin than any postulated external pressure load, circumferential stresses induced by the differential pressure specified in Table 2.2.1 are insignificant. Specifically, by adding the results from the two solutions (ring load case 1 for a point support reaction to a body force + ring load case 3 for a point support reaction to a lateral pressure over one-half of the perimeter) considered in Appendix 3.B, it is determined that the circumferential bending stress from case 1 in that appendix is reduced by the factor "R" to obtain the corresponding stress from the combined case. R is computed as the ratio of moment magnitudes from the combined case to the results of case 1 alone.

R = (maximum bending moment from case 1 + case 3)/(maximum bending moment from case 1)
= 0.75/6.197 = 0.12

(results for individual cases are in Appendix 3.B)

Examination of the graphs from the moment distribution from the two solutions in Appendix 3.B shows that the individual terms always subtract and nearly cancel each other at every location.

Therefore, it is concluded that the maximum circumferential stress that develops under a pressure of 424 psi applied over one-half of the perimeter, and conservatively assumed balanced by inertia loading, is

Stress = 29,310 psi x 0.12 = 3517 psi

The stress due to a differential pressure of 10 psi (Table 2.2.1) is only 2.36% of the above value and needs no further evaluation for stress limits or deformation to demonstrate retrievability of the MPC.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]			
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

In the case of a free-standing system, ~~T~~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

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)* ~~undertake~~ a conservative evaluation of the circumferential stress and deformation state due to the missile strike on the outer shell *was performed.* 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 that balances the impact load is conservatively set as the diameter of the impacting missile (8") plus the effect of the "bending boundary layer" length. This boundary layer length is conservatively set as a multiple of twice the square root of the product of mean radius times the average thickness of two shells making up the cylindrical body of the storage overpack. From Appendix 3.B, the mean radius of the composite cylinder and the average thickness of the inner and outer shells, are

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].

The table below provides the values of computed peak decelerations at the top of the fuel basket for the vertical drop and the non-mechanistic tipover scenarios. It is seen that the peak deceleration is below 45 g's.

~~It is shown in Appendix 3.A that the peak deceleration *for the Set "A" pad* 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. *The results for Set B pad show that the limit of 45g's is met under all postulated impact (drop and tipover) scenarios.*~~

Filtered Results for Drop and Tip-Over Scenarios for HI-STORM

Drop Event	*Max. Deceleration at the Top of the Basket (g's)*	
	Set A(36" Thick Pad)	*Set B(28" Thick Pad)*
End Drop for 11 inches	*43.98*	*41.53*
Non-Mechanistic Tip-over	*42.85*	*39.91*

~~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 that the impact kinetic energy is reduced so that the target would absorb the energy with 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 results~~ 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 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 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:

$$A_{HI\text{-}STORM\ 100S}/A_{HI\text{-}STORM\ 100} = 0.946$$

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 overpack*s* 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 requirements for periodic inspection and maintenance of the storage overpack throughout the 40-year design life are defined in Chapter 9. These requirements include provisions for routine inspection of the storage overpack exterior and periodic visual verification that the ventilation flow paths of the storage overpack are free and clear of debris. ISFSIs located in areas subject to atmospheric conditions *that*~~which~~ may degrade the storage cask or canister should be evaluated by the licensee on a site-specific basis to determine the frequency for such inspections to assure long-term performance. In addition, the HI-STORM 100 System is designed for easy retrieval of the MPC from the storage overpack should it become necessary to perform more detailed inspections and repairs on the storage overpack.

The above findings are consistent with those of the NRC's Waste Confidence Decision Review [3.4.11], which concluded that dry storage systems designed, fabricated, inspected, and operate in accordance with such requirements are adequate for a 100-year service life while satisfying the requirements of 10CFR72.

Table 3.4.4
MPC RESULTS - MINIMUM SAFETY FACTOR

Load Case I.D.	Load Combination†,††	Safety Factor	Location in TSAR Where the Analysis is Performed
E1			
	Design internal pressure, P_I	15	E.1.a Lid 3.E.8.1.1 of Docket 72-1008
E1.a		1.326	Baseplate 3.I.8.1 of Docket 72-1008
		1.36	Table 3.4.7
		N/A	Supports
		15	E.1.b Lid P_i bounds
	Design external pressure, P_o	1.326	Baseplate P_i bounds
E1.b		1.17	Shell 3.H (Case 4) (buckling) of Docket 72-1008
		N/A	Supports
	Design internal pressure, P_i, plus Temperature T	~~2.0~~ *1.4*	E1.c Table 3.4.8
E2	D + H + (P_i, P_o)	6.5	Lid 3.E.8.1.2 of Docket 72-1008
		1.088	Baseplate 3.I.8.2 of Docket 72-1008
		2.63(stress),	Shell 3.AA (stress) of Docket 72-1008
		1.17(buckling)	3.H (Case 4) (buckling) of Docket 72-1008
		4.58	Supports 3.AA of Docket 72-1008

† 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*~~42.604~~ (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.A*B*~~D~~ Top Lid *3.AB*~~N/A~~ Pocket Trunnion 3.AA; 3.AI Lifting Calculations 3.4.3
02 02.a	D + H' + (P_o,P_i) (end drop/tip-over)	1.36(weld) 1.08(bolt)	Overpack Shell/Base 3.M;3.4.4.3.2.3 Top Lid 3.K/3.L;3.4.4.3.2.2
02.b	D + H' + (P_o,P_i) (side drop)	2.09 *1.392*~~193~~ *1.651*~~423~~	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)	

† 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 3.4.7
STRESS INTENSITY RESULTS FOR CONFINEMENT BOUNDARY - INTERNAL PRESSURE ONLY

Locations (Per Fig. 3.4.11)	Calculated Value of Stress Intensity (psi)	Category	Table 3.1.13 Allowable Value (psi)†	Safety Factor (Allowable/Calculated)
Top Lid				
A	1641	$P_L + P_b$	*26,300~~30,000~~*	*16.0~~8.3~~*
Neutral Axis	20.2	P_m	*17,500~~20,000~~*	*866.3~~990.1~~*
B	1605	$P_L + P_b$	*26,300~~30,000~~*	*16.3~~18.7~~*
C	687	$P_L + P_b$	*26,300~~30,000~~*	*38.3~~43.7~~*
Neutral Axis	731	P_m	*17,500~~20,000~~*	*23.9~~7.4~~*
D	2960	$P_L + P_b$	*26,300~~30,000~~*	*8.8~~910.1~~*
Baseplate				
E	19,683	$P_L + P_b$	30,000	1.5
Neutral Axis	412	P_m	20,000	48.5
F	20,528	$P_L + P_b$	30,000	1.5
G	9,695	$P_L + P_b$	30,000	3.1
Neutral Axis	2,278	P_m	20,000	8.8
H	8,340	$P_L + P_b$	30,000	3.5

† Allowable stress intensity ~~conservatively taken~~ at 5400 –degrees F *(top) and 300 degrees F (bottom)*

Table 3.4.7 (continued)
STRESS INTENSITY RESULTS FOR CONFINEMENT BOUNDARY - INTERNAL PRESSURE ONLY

Locations (Per Fig. 3.4.11)	Calculated Value of Stress Intensity (psi)	Category	Table 3.1.13 Allowable Value (psi)†	Safety Factor (Allowable/Calculated)
<u>Canister</u>				
I	6,860	P_m	*17,500~~20,000~~*	2.55~~9~~
Upper Bending Boundary Layer Region	7,189 7,044	$P_L + P_b + Q$ $P_L + P_b$	*52,500~~30,000~~* *26,300~~20,000~~*	*7.30~~4.2~~* *3.73~~2.8~~*
Lower Bending Boundary Layer Region	43,986 10,621	$P_L + P_b + Q$ $P_L + P_b$	60,000 30,000	1.36 2.82

† Allowable stress intensity ~~conservatively taken~~ at 5400 degrees F *(top) and 300 degrees F (bottom)*

Table 3.4.8

PRIMARY AND SECONDARY STRESS INTENSITY RESULTS FOR CONFINEMENT BOUNDARY - PRESSURE PLUS THERMAL LOADING

Locations (Per Fig. 3.4.11)	Calculated Value of Stress Intensity (psi)	Category	Allowable Stress Intensity (psi)	Safety Factor (Allowable/Calculated)
Top Lid				
A	1,630	$P_L + P_b + Q$	*52,500~~60,000~~*	32.2
Neutral Axis	22.5	$P_m + P_L$	*26,300~~30,000~~*	1,169.
B	1,604.1	$P_L + P_b + Q$	*52,5~~60,~~000*	32.7
C	696	$P_L + P_b + Q$	*52,5~~60,~~000*	75.5
Neutral Axis	731	$P_m + P_L$	*26,3~~30,~~000*	36.0
D	2,960	$P_L + P_b + Q$	*52,5~~60,~~000*	17.7
Baseplate				
E	19,798	$P_L + P_b + Q$	60,000	3.0
Neutral Axis	410.0	$P_m + P_L$	30,000	73.2
F	20,622	$P_L + P_b + Q$	60,000	2.9
G	4,789.4	$P_m + P_L + Q$	60,000	12.5
Neutral Axis	1,131.8	$P_m + P_L$	30,000	26.5
H	4,139.4	$P_L + P_b + Q$	60,000	14.5

Table 3.4.8

PRIMARY AND SECONDARY STRESS INTENSITY RESULTS FOR CONFINEMENT BOUNDARY - PRESSURE PLUS THERMAL LOADING

Locations (Per Fig. 3.4.11)	Calculated Value of Stress Intensity (psi)	Category	Allowable Stress Intensity (psi)	Safety Factor (Allowable/Calculated)
<u>Canister</u>				
I	6,787.4	$P_m + P_L$	30,000	4.4
Upper Bending Boundary Layer Region	4,200.5 1,729.3	$P_L + P_b + Q$ $P_m + P_L$	*52,500*~~60,000~~ *26,300*~~30,000~~	12.5 15.2
Lower Bending Boundary Layer Region	43,484 10,498	$P_L + P_b + Q$ $P_m + P_L$	60,000 30,000	1.4 2.9

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

TABLE 3.4.10

[redacted]

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

[redacted]

FIGURES 3.4.30 THROUGH 3.4.47 ARE HOLTEC PROPRIETARY

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 ~~Deleted~~ *Detailed Finite Element Listings for MPC-32 Fuel Basket*
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

3.6.4 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 calculation package (Holtec Report No. HI-981928).*

[3.4.6] Deleted.

[3.4.7] NRC Bulletin 96-04: Chemical, Galvanic or Other Reactions in Spent Fuel Storage and Transportation Casks, July 5, 1996.

[3.4.8] Theory of Elastic Stability, S.P. Timoshenko and J. Gere, McGraw Hill, 2nd Edition.

[3.4.9] Marks Standard Handbook for Mechanical Engineering, 9th ed.

[3.4.10] ASME Boiler and Pressure Vessel Code, Section III, Subsection NG, 1995.

[3.4.11] 10CFR71, Waste Confidence Decision Review, USNRC, September 11, 1990.

[3.4.12] "Benchmarking of the Holtec LS-DYNA3D Model for Cask Drop Events", Holtec Report HI-971779, September 1997.

[3.4.13] NUREG/CR-6322, Buckling Analysis of Spent Fuel Basket, Lawrcence Livermore National Laboratory, May, 1995.

[3.4.14] Soler, A, "Calculation Package for High Seismic Support of HI-STORM 100A", Holtec Report HI-2002465, August 2000.

[3.5.1] Chun, Witte, Schwartz, "Dynamic Impact Effects on Spent Fuel Assemblies", UCID-21246, Lawrence Livermore National Laboratory, October 20, 1987.

[3.5.2] Physical and Decay Characteristics of Commercial LWR Spent Fuel, Oak Ridge National Laboratory Report, J. Roddy, H. Claiborne, R. Ashline, P. Johnson, and B. Rhyne, ORNL/TM-9591/V1-R1, 1/86.

APPENDIX 3.A: HI-STORM DECELERATION UNDER POSTULATED VERTICAL DROP EVENT AND TIPOVER

3.A.1 INTRODUCTION

Handling accidents with a HI-STORM overpack containing a loaded MPC are credible events (Section 2.2.3). The stress analyses carried out in Chapter 3 of this safety analysis report assume that the inertial loading on the load bearing members of the MPC, fuel basket, and the overpack due to a handling accident are limited by the Table 3.1.2 decelerations. The maximum deceleration experienced by a structural component is the product of the rigid body deceleration sustained by the structure and the dynamic load factor (DLF) applicable to that structural component. The dynamic load factor (DLF) is a function of the contact impulse and the structural characteristics of the component. A solution for dynamic load factors is provided in Appendix 3.X.

The rigid body deceleration is a strong function of the load-deformation characteristics of the impact interface, weight of the cask, and the drop height or angle of free rotation. For the HI-STORM 100 System, the weight of the structure and its surface compliance characteristics are known. However, the contact stiffness of the ISFSI pad (and other surfaces over which the HI-STORM 100 may be carried during its movement to the ISFSI) is site-dependent. The contact resistance of the collision interface, which is composed of the HI-STORM 100 and the impacted surface compliance, therefore, is not known a priori for a specific site. Analyses for the rigid body decelerations are, therefore, presented here using a reference ISFSI pad (which is the pad used in a recent Lawrence Livermore National Laboratory report and is the same reference pad used in the HI-STAR 100 TSAR). The finite element model (grid size, extent of model, soil properties, etc.) follows the LLNL report.

An in-depth investigation by the Lawrence Livermore Laboratory (LLNL) into the mechanics of impact between a cask-like impactor on a reinforced concrete slab founded on a soil-like subgrade has identified three key parameters, namely, the thickness of the concrete slab, t_p, compressive strength of the concrete f_c'~~N~~ and equivalent Young's Modulus of the subgrade E. These three parameters are key variables in establishing the stiffness of the pad under impact scenarios. The LLNL reference pad parameters, which we hereafter denote as Set A, provide one set of values of t_p, f_c~~N~~', and E that~~which~~ are found to satisfy the deceleration criteria applicable to the HI-STORM 100 cask. Another set of parameters, referred to as Set B herein, is ~~are~~ also shown to satisfy the g-load limit requirements. In fact, an infinite number of combinations- of t_p, f_c'~~N~~, and E can be compiled that~~which~~ would meet the g-load limit qualification. However, in addition to satisfying the g-limit criterion, the pad must be demonstrated to possess sufficient flexural and shear stiffness to meet the ACI 318 strength limits under factored load combinations. The minimum strength requirement to comply with ACI 318 provisions places a restriction on the lower bound values of t_p, f_c~~N~~', and E that~~which~~ must be met in an ISFSI pad design.

Our focus in this appendix, however, is to quantify the peak decelerations that would be experienced by a loaded HI-STORM 100 cask under the postulated impact scenarios for the two pad designs defined by parameter Sets A and B, respectively. The information presented in this appendix also serves to further authenticate the veracity of the Holtec DYNA3D model described in the 1997 benchmark report [3.A.4.]

3.A.2 Purpose

The purpose of this appendix is to demonstrate that the rigid body deceleration experienced by the HI-STORM 100 System during a handling accident or non-mechanistic tip-over are below the design basis deceleration of 45g's (Table 3.1.2). Two accidental drop scenarios of a loaded HI-STORM 100 cask on the ISFSI pad are considered in this appendix. They are:

i. Tipover: A loaded HI-STORM 100 is assumed to undergo a non-mechanistic tipover event and impacting the ISFSI pad with an incipient impact angular velocity, which is readily calculated from elementary dynamics.

ii. End drop: The loaded HI-STORM 100 is assumed to drop from a specified height h, with its longitudinal axis in the vertical orientation, such that its bottom plate *impacts*~~hits first~~ the ISFSI pad.

It is shown in Appendix 3.X that dynamic load factors are a function of the predominate natural frequency of vibration of the component for a given input load pulse shape. Dynamic load factors are applied, as necessary, to the results of specific component analyses performed using the loading from the design basis rigid body decelerations. Therefore, for the purposes of this Appendix 3.A, it is desired to demonstrate that the rigid body deceleration experienced in each of the drop scenarios is below the HI-STORM 100 45g design basis.

3.A.3 Background and Methodology

In 1997 Lawrence Livermore National Laboratory (LLNL) published the experimental*ly* obtained results of the so-called fourth series billet tests [3.A.1] together with a companion report [3.A.2] documenting a numerical solution *that*~~which~~ simulated the drop test results with reasonable accuracy. Subsequently, USNRC personnel published a paper [3.A.3] affirming the NRC's endorsement of the LLNL methodology. The LLNL simulation used modeling and simulation algorithms contained within the commercial computer code DYNA3D [3.A.6].

The LLNL cask drop model is not completely set forth in the above-mentioned LLNL reports. Using the essential information provided by the LLNL [3.A.2] report, however, Holtec is able to develop a finite element model for implementation on LS-DYNA3D [3.A.5] which is fully consistent with LLNL's (including the use of the Butterworth filter for discerning rigid body deceleration from "noisy" impact data). The details of the LS-DYNA3D dynamic model, henceforth referred to as the

Holtec model, are contained in the proprietary benchmark report [3.A.4] wherein it is shown that the peak deceleration in *every* case of billet drop analyzed by LLNL is replicated within a small tolerance by the Holtec model. The case of the so-called "generic" cask, for which LLNL provided predicted response under side drop and tipover events, is also bounded by the Holtec model. In summary, the benchmarking effort documented in [3.A.4] is in full compliance with the guidance of the Commission [3.A.3].

Having developed and benchmarked an LLNL-consistent cask impact model, a very similar model is developed and used to prognosticate the HI-STORM drop scenarios. The reference elasto-plastic-damage characteristics of the target concrete continuum used by LLNL, and used in the HI-STAR 100 TSAR- *are*~~is~~ replicated herein. The HI-STORM 100 target model is identical in all aspects to the reference pad approved for the HI-STAR 100 TSAR.

In the tipover scenario the cask surface structure must be sufficiently pliable to cushion the impact and limit the rigid body deceleration. The angular velocity at the contact time is readily calculated using planar rigid body dynamics and is used as an initial condition in the LS-DYNA3D simulation.

The end drop event produces a circular impact patch equal to the diameter of the overpack baseplate. The elasto-plastic-damage characteristics of the concrete target and the drop height determine the maximum deceleration. A maximum allowable height "h" is determined to limit the deceleration to a value below the design basis.

A description of the work effort and a summary of the results are presented in the following sections. In all cases, the reported decelerations are below the design basis of 45g's *at the top of the MPC fuel basket*.

3.A.4 Assumptions and Input Data

3.A.4.1 Assumptions

The assumptions used to create the model are completely described in Reference [3.A.4] and are shown there to be consistent with the LLNL simulation. There are ~~two~~ key aspects, *however, that*~~which~~ are restated here:

~~The cask pad is assumed to be identical to the pad defined by LLNL [3.A.2] for the generic full size cask. It is also identical to the pad utilized in the benchmark report [3.A.4]. For a specific ISFSI site, the reinforced concrete section, as well as the underlying soil, may be different; in that case, the site-specific conditions must be shown to perform in a manner to ensure compliance with the design limits of the HI-STORM system (e.g., maximum rigid body g-load less than specified limits). The essential data, which define the full-scale reference pad used to qualify the HI-STORM 100, is provided in Table 3.A.1.~~

The maximum deceleration experienced by the cask during a collision event is a direct function of the structural rigidity (or conversely, compliance) of the impact surface. The compliance of the ISFSI pad is quite obviously dependent on the thickness of the pad, t_p, the compressive strength of the concrete, f_c' and stiffness of the sub-grade (expressed by its effective Young's modulus, E). The structural rigidity of the ISFSI pad will increase if any of the three above-mentioned parameters (t_p, f_c' or E) is increased. For the reference pad, the governing parameters (i.e., t_p, f_c' and E) are assumed to be identical to the pad defined by LLNL [3.A.2], which is also the same as the pad utilized in the benchmark report [3.A.4]. We refer to the LLNL ISFSI pad parameters as Set A. (Table 3.A.1).

As can be seen from Table 3.A.1, the nominal compressive strength f_c' in Set A is limited to 4200 psi. -However, experience has shown that ISFSI owners have considerable practical difficulty in limiting the 28 day strength of poured concrete to 4200 psi, chiefly because a principal element of progress in reinforced concrete materials technology has been in realizing ever increasing concrete nominal strength. Inasmuch as a key objective of the ISFSI pad is to limit its structural rigidity (and not f_c' per se), and limiting f_c' to 4200 psi may be problematic in certain cases, an alternative set of reference pad parameters is defined (Set B in Table 3.A.1), which permits a higher value of f_c' but much smaller values of pad thickness, t_p and sub-grade Young's modulus, E.

The ISFSI owner has the option of constructing the pad to comply with the limits of Set A or Set B without performing site-specific cask impact analyses. It is recognized that, for a specific ISFSI site, the reinforced concrete, as well as the underlying engineered fill properties, may be different at different locations on the pad or may be uniform, but non-compliant with either Set A or Set B. In that case, the site-specific conditions must be performed to demonstrate compliance with the design limits of the HI-STORM system (e.g., maximum rigid body g-load less than 45 g's). The essential data which define the pad (Set A and Set B) used to qualify the HI-STORM 100 are provided in Table 3.A.1.

The HI-STORM 100 steel structural elements (outer shell, inner shell, radial plates, lid, etc.), are fabricated from SA-516 Grade 70. The steel is described as a bi-linear elastic-plastic materials with limited strain failure by five material parameters (E, S_y, S_u, ϵ_u, and ν). The numerical values used in the finite element model are shown in Table 3.A.2. The concrete located inside of the overpack for this dynamic analysis is defined to be identical with the concrete pad. This is conservative since the concrete assumed in the reference pad is reinforced. Therefore, the strength of the concrete inside the HI-STORM 100 absorbs less energy if it is also assumed to be reinforced.

3.A.4.2 Input Data

Table 3.A.1 characterizes the properties of the full-scale reference target pad used in the analysis of the full size HI-STORM 100 System. ~~The inputs are taken from References [3.A.2] and [3.A.4].~~ *The*

principal strength parameters that define the stiffness of the pad, namely, t_p, E and f_c' are input in the manner described in [3.A.2] and [3.A.4].

Table 3.A.2 contains the material description parameters for the steel types; SA-516-70 used in the numerical investigation.

Table 3.A.3 details the geometry of the HI-STORM 100 used in the drop simulations. This data is taken from applicable HI-STORM 100 drawings.

3.A.5 Finite Element Model

The finite-element model of the Holtec HI-STORM 100 overpack (baseplate, shells, radial plates, lid, concrete, etc.), concrete pad and a portion of the subgrade soil is constructed using the pre-processor integrated with the LS-DYNA3D software [3.A.5]. The deformation field for all postulated drop events~~,~~ (the end-drop and the tipover)~~,~~ exhibits symmetry with the vertical plane passing through the cask diameter and the concrete pad length. Using this symmetry condition of the deformation field only a half finite-element model is constructed. The finite-element model is organized into nineteen independent parts (the baseplate components, the outer shell, the inner shell, the radial plates, the channels, the lid components, the basket steel plates, the basket fuel zone, the concrete pad and the soil). The final model contains 30351 nodes, 24288 solid type finite-elements, 1531 shell type finite-elements, seven (7) materials, ten (10) properties and twenty-four (24) interfaces. The finite-element model used for the tipover-drop event is depicted in Figures 3.A.1 through 3.A.4. Figures 3.A.5 through 3.A.8 show the end-drop finite-element model.

The soil grid, shown in Figure 3.A.9, is a rectangular prism (800 inches long, 375 inches wide and 470 inches deep), is constructed from 13294 solid type finite-elements. The material defining this part is an elastic isotropic material. The central portion of the soil (400 inches long, 150 inches wide and 170 inches deep) where the stress concentration is expected to appear is discretized with a finer mesh.

The concrete pad is 320 inches long, 100 inches wide and is 36 inches thick. This part contains 8208 solid finite-elements. A uniform sized finite-element mesh, shown in Figure 3.A.10, is used to model the concrete pad. The concrete behavior is described using a special constitutive law and yielding surface (MAT_PSEUDO_TENSOR) contained within LS-DYNA3D. The geometry, the material properties, and the material behavior are identical to the LLNL reference pad (Material 16 IIB).

The half portion of the steel cylindrical overpack contains 1531 shell finite-elements. The steel material description (SA-516-70) is realized using a bi-linear elasto-plastic constitutive model (MAT_PIECEWISE_LINEAR_PLASTICITY). Figure 3.A.11 depicts details of the steel components of the cask finite-element mesh, with the exception of the inner shell, channels and lid components, which are shown in Figures 3.A.12 and 3.A.13. The ~~existing 4000 psi compressive~~

~~strength~~ concrete filled between the inner and the outer shells, *and contained in* the baseplate and lid components is modeled using 1664 solid finite-elements and is depicted in Figure 3.A.14. The concrete material is defined identical to the pad concrete.

The MPC and the contained fuel are modeled in two parts that represent the lid and baseplate, and the fuel area. An elastic material is used for both parts. The finite-element mesh pertinent to the MPC contains 1122 solid finite-elements and is shown in Figure 3.A.15. The mass density is appropriate to match a representative weight of 356,521 lb. that is approximately mid-way between the upper and lower weight estimates for a loaded HI-STORM 100.

The total weight used in the analysis is approximately 2,000 lb. lighter than the HI-STORM 100 containing the lightest weight MPC.

Analysis of a single mass impacting a spring with a given initial velocity shows that both the maximum deceleration "a_M" of the mass and the time duration of contact with the spring "t_c" are related to the dropped weight "w" and drop height "h" as follows:

$$a_M \sim \frac{\sqrt{h}}{\sqrt{w}}; t_c \sim \sqrt{w}$$

Therefore, the most conservatism is introduced into the results by using the minimum weight. It is emphasized that the finite element model described in the foregoing is identical in its approach to the "Holtec model" described in the benchmark report [3.A.4]. Gaps between the MPC and the overpack are included in the model.

3.A.6 Impact Velocity

a. Linear Velocity: Vertical Drops

For the vertical drop event, the impact velocity, v, is readily calculated from the Newtonian formula:

$$v = \sqrt{(2gh)}$$

where

g = acceleration due to gravity
h = free-fall height

b. Angular Velocity: Tip-Over

The tipover event is an artificial construct wherein the HI-STORM 100 overpack is assumed to be perched on its edge with its C.G. directly over the pivot point A (Figure 3.A.16). In this orientation, the overpack begins its downward rotation with zero initial velocity. Towards the end of the tip-over, the overpack is horizontal with its downward velocity ranging from zero at the pivot point (point A) to a maximum at the farthest point of impact (point E in Figure 3.A.17). The angular velocity at the instant of impact defines the downward velocity distribution along the contact line.

In the following, an explicit expression for calculating the angular velocity of the cask at the instant when it impacts on the ISFSI pad is derived. Referring to Figure 3.A.16, let r be the length AC where C is the cask centroid. Therefore,

$$r = \left(\frac{d^2}{4} + h^2 \right)^{1/2}$$

The mass moment of inertia of the HI-STORM 100 System, considered as a rigid body, can be written about an axis through point A, as

$$I_A = I_c + \frac{W}{g} r^2$$

where I_c is the mass moment of inertia about a parallel axis through the cask centroid C and W is the weight of the cask (W = Mg).

Let $\theta_1(t)$ be the rotation angle between a vertical line and the line AC. The equation of motion for rotation of the cask around point A, during the time interval prior to contact with the ISFSI pad, is

$$I_A \frac{d^2\theta_1}{dt^2} = Mgr \sin\theta_1$$

This equation can be rewritten in the form

$$\frac{I_A}{2}\frac{d(\dot{\theta}_1)^2}{d\theta_1} = Mgr\sin\theta_1$$

which can be integrated over the limits $\theta_1 = 0$ to $\theta_1 = \theta_{2f}$ (See Figure 3.A.17).

The final angular velocity θ_1 at the time instant just prior to contact with the ISFSI pad is given by the expression

$$\dot{\theta}_1(t_B) = \sqrt{\frac{2\,Mgr}{I_A}(1-\cos\theta_{2f})}$$

where, from Figure 3.A.17

$$\theta_{2f} = \cos^{-1}\left(\frac{d}{2r_1}\right)$$

This equation establishes the initial conditions for the final phase of the tip-over analysis; namely, the portion of the motion when the cask is decelerated by the resistive force at the ISFSI pad interface.

Using the data germane to HI-STORM 100 (Table 3.A.3), and the above equations, the angular velocity of impact is calculated as 1.49 rad/sec.

3.A.7 Results

3.A.7.1 Set A Pad Parameters

It has been previously demonstrated in the benchmark report [3.A.4] that bounding rigid body decelerations are achieved if the cask is assumed to be rigid with only the target (ISFSI pad) considered as an energy absorbing media. Therefore, for the determination of the bounding decelerations reported in this appendix, the HI-STORM storage overpack was conservatively made rigid except for the radial channels that position the MPC inside of the overpack. The MPC material behavior was characterized in the identical manner used in the Livermore Laboratory analysis as was the target ISFSI pad and underlying soil. The LS-DYNA3D time-history results are processed using the Butterworth filter (in conformance with the LLNL methodology) to establish the rigid body motion time-history of the cask. The material points on the cask where the acceleration displacement and velocity are computed for each of the drop scenarios are shown in Figure 3.A.18.

Node 82533 (Channel A1), which is located at the center of the outer surface of the baseplate, serves as the reference point for end-drop scenarios.

Node 84392 (Channel A2), which is located at the center of the cask top lid outer surface, serves as the reference point for the tipover scenario with the pivot point indicated as Point 0 in Figure 3.A.18.

The final results are shown in Table 3.A.4.

i. Tipover:

~~Figures 3.A.19-3.A.22, respectively, show t~~*T*he time-histories of the impact force, the displacement and velocity time-histories of Channel A2, and the average vertical deceleration of the overpack lid top plate *have been determined* for this event *[3.A.7]*. ~~Nodes on both top lid surfaces are reported.~~

The deceleration at the top of the fuel basket is obtained by ratioing the average deceleration of the overpack lid top plate. The maximum filtered deceleration at the top of the fuel basket is ~~found from Figure 3.A.22 to be 48.48 x 0.8908 =~~ *42.853*~~.19~~g's, which is below the design basis limit. ~~The 0.891 attenuation is based on the geometry of the loaded HI-STORM 100. The maximum contact force in this event is 4.2 E+06 lbs. and the contact duration associated with the initial peak is approximately 6 milli-seconds.~~

~~The duration of the initial deceleration pulse is obtained from Figure 3.A.24 as 9.4milli-seconds.~~

~~To evaluate the sensitivity of the solution to the initial gap between the MPC and the overpack channels, a second tipover simulation has been performed with initial clearance increased by 0.25". The results from this second simulation were essentially identical to the first simulation. Figures 3.A.27 to 3.A.30 (which correspond to the first simulation reported in Figures 3.A.19-3.A.22) provide the results of the sensitivity study.~~

ii. End Drop:

The drop height h = 11" is considered in the numerical analysis. This is considered as an acceptable maximum carry height for the HI-STORM 100 System *if lifted above a surface with design values of* t_p, f_c'~~N~~, *and E equal to those presented in Table 3.A.1 for Parameter Set "A". The maximum filtered deceleration at the top of the fuel basket is 43.98g's, which is below the design basis limit.*
~~The numerical investigation results, depicted in Figures 3.A.23-3.A.26 show the contact force, the displacement and velocity time-histories at Channel A1 and the average deceleration of the overpack baseplate for the 11" end drop. The duration of the contact force~~

~~initial pulse is approximately 2 milli-seconds, and the filtered average deceleration pulse of the overpack baseplate is 3 milli-seconds.~~

The computer code utilized in this analysis is LS-DYNA3D [3.A.5] validated under Holtec's QA system. *Table 3.A.4 summarizes the key results from all impact simulations for the Set A parameters discussed in the foregoing.*

The filter frequencies (to remove unwanted high-frequency contributions) for the Holtec cask analyses analyzed in this TSAR is the same as used for the corresponding problem analyzed in [3.A.2] and [3.A.4]. To verify the Butterworth- filter parameters (350 Hz cutoff frequency, etc.) used in processing the numerical data, a Fourier power decomposition was generated.

3.A.7.2 Set B Parameters

As stated previously, Set B parameters produce a much more compliant pad than the LLNL reference pad (Set A). This fact is borne out by the ~~side drop,~~ tipover and end analyse~~is~~ performed on the pad defined by the Set B parameters. Table 3.A.4 provides the filtered results for the two~~hree~~ impact scenarios. In every case, the peak decelerations corresponding to Set B parameters are less than those for Set A (also provided in Table 3.A.4).

Impact force and acceleration time history curves for Set B have the same general shape as those for Set A and are contained in the calculation package [3.A.7]. A~~a~~ll significant results are summarized in Table 3.A.4.

3.A.8 Computer Codes and Archival Information

The input and output files created to perform the analyses reported in this appendix are archived in Holtec International calculation package [3.A.7].

~~The input and output files created to perform the analyses reported in this appendix are listed for future retrievability.~~

~~The computer code utilized in this analysis is LS-DYNA3D [3.A.5] validated under Holtec's QA system.~~

~~LS-DYNA3D computer code has an extensive finite-element and material description library and can account for various time-dependent contact conditions that normally arise between the various structural components during the impact analysis.~~

~~The input and the output files created are stored on Holtec's server disk and tape archived as required by Holtec's QA procedures.~~

~~F:\USER\ISIMULES\LSDYNA3D\HISTORM\....~~

~~....\END12\... end-drop height 11 inches;~~
~~....\TIPOVER\... tipover-drop from CG-over-corner position;~~

~~Each one of the subdirectories contain specific data related to the analyzed drop scenarios and are organized in five files: LS-DYNA3D input file (XXX.DYN), corresponding to the analyzed drop event, and four time-history files (MATSUM- the impactor velocity time-history, RCFORC- the impact force time-history, NODOUT- displacement, velocity and acceleration and PLOT- the model deformation time-history) generated during the numerical analysis.~~

~~All LS-DYNA3D simulations were performed on a PC environment, using a Dell Corporation Pentium II - 266 MHz computer.~~

~~The Appendix 3.A document, itself, is located on the server in the directory~~

~~F:\PROJECTS\5014\HISTORM\AIS\HI951312\REV6.~~

3.A.~~10~~ *9* Conclusion

The DYNA3D analysis of HI-STORM 100 reported in this appendix leads to the following conclusion:

a. If a loaded HI-STORM undergoes a free fall for a height of 11 inches in a vertical orientation on to a reference pad defined by Table 3.A.1, the maximum rigid body deceleration *is less than 45g's for both Set A and Set B pad parameters.* ~~is limited to 44.13g's.~~

b. If a loaded HI-STORM 100 overpack pivots about its bottom edge and tips over on to a reference pad defined by Table 3.A.1, then the maximum rigid body deceleration of the cask centerline at the plane of the top of the *MPC* fuel basket cellular region is *less than 45g's for both Set A and Set B parameters.* ~~43.2g's~~.

Table 3.A.4 provides key results for all drop cases studied herein for both pad parameter sets (A and B). If the pad designer maintains each of the three significant parameters (t_p, f_c', and E) below the limit for the specific set selected (Set A or Set B), then the stiffness of the pad at any ISFSI site will be lower and the computed decelerations at the ISFSI site will also be lower. Furthermore, it is recognized that a refinement of the cask dynamic model will accrue further reduction in the computed peak deceleration. For example, incorporation of the structural flexibility in the MPC enclosure vessel, fuel basket, etc., would lead to additional reductions in the computed values of the peak deceleration. These refinements, however, add to the computational complexity. Because g-limits are met without the above-mentioned and other refinements in the cask dynamic model, the

simplified dynamic model described in this appendix was retained to reduce the overall computational effort.

3.A.~~11~~ *10* References

[3.A.1] Witte, M., et al., "Evaluation of Low-Velocity Impacts Tests of Solid Steel Billet onto Concrete Pads.", Lawrence Livermore National Laboratory, UCRL-ID-126274, Livermore, California, March 1997.

[3.A.2] Witte, M., et al., "Evaluation of Low-Velocity Impacts Tests of Solid Steel Billet onto Concrete Pads, and Application to Generic ISFSI Storage Cask for Tipover and Side Drop.", Lawrence Livermore National Laboratory, UCRL-ID-126295, Livermore, California, March 1997.

[3.A.3] Tang, D.T., Raddatz, M.G., and Sturz, F.C., "NRC Staff Technical Approach for Spent Fuel Cask Drop and Tipover Accident Analysis", SFPO, USNRC (1997).

[3.A.4] Simulescu, I., "Benchmarking of the Holtec LS-DYNA3D Model for Cask Drop Events", Holtec Report HI-971779, September 1997.

[3.A.5] LS-DYNA3D, Version 936-03, Livermore Software Technology Corporation, September 1996.

[3.A.6] Whirley, R.G., "DYNA3D, A Nonlinear, Explicit, Three-Dimensional Finite element Code for Solid and Structural Mechanics - User Manual.", Lawrence Livermore National Laboratory, UCRL-MA-107254, Revision 1, 1993.

[3.A.7] Zhai, J. "Analysis of the Loaded HI-STORM 100 System Under Drop and Tip-Over Scenarios", Holtec Report HI-2002474, July 2000.

Table 3.A.1: Essential Variables to Characterize the ISFSI Pad *(Set A and Set B)*

Item	*Parameter Set A*	*Parameter Set B*
Thickness of concrete, (inches)	*36*	*28*
Nominal compressive strength of concrete at 28 days, (psi)	4,200	*6,000*
Max. modulus of elasticity of the subgrade (psi)	28,000	*16,000*

Notes: 1. The concrete Young's Modulus is derived from the American Concrete Institute recommended formula 57,000√f where f is the nominal compressive strength of the concrete (psi).

2. *Thee effective modulus of elasticity of the subgrade will be measured by the classical "plate test" or other appropriate means before pouring of the concrete to construct the ISFSI pad.*

3. The pad thickness ~~of 36"~~, concrete compressive strength ~~of 4,200 psi (nom.) at 28 days of curing~~, and the subgrade soil effective modulus ~~of 28,000 psi~~ are the upper bound values to ensure that the deceleration limits under the postulated events set forth in Table 3.1.2 are satisfied.

Table 3.A.2: Essential Steel Material Properties for HI-STORM 100 Overpack

Steel Type	Parameter	Value
SA-516-70 at T = 350 deg. F	E	2.800E + 07
	S_y	3.315E+04 psi
	S_u	7.000E+04 psi
	ϵ_u	0.21
	ν	0.30

Note that the properties of the steel components, except for the radial channels used to position the MPC, do not affect the results reported herein since the HI-STORM 100 is eventually assumed to behave as a rigid body (by internal constraint equations automatically computed by DYNA3D upon issue of a "make rigid" command). In Section 3.4, however, stress and strain results for an additional tip-over analysis, performed using the actual material behavior ascribed to the storage overpack, are presented for the sole purpose of demonstrating ready retrievability of the MPC after the tip-over.

Table 3.A.3: Key Input Data in Drop Analyses

Overpack weight	267,664 lb
Radial Concrete weight	163,673 lb
Length of the cask	231.25 inches
Diameter of the bottom plate	132.50 inches
Inside diameter of the cask shell	72.50 inches
Outside diameter of the cask shells	132.50 inches
MPC weight (including fuel)	88,857 lb
MPC height	190.5 inches
MPC diameter	68.375 inches
MPC bottom plate thickness	2.5 inches
MPC top plate thickness	9.5 inches

Table 3.A.4: Filtered Results for Drop and Tip-Over Scenarios for HI-STORM 100†

Drop Event	*Max. Displacement (inch)*		*Impact Velocity (in/sec)*	*Maex. Deceleration†† aet the Top of the (g's) Basket*		*Duration of Deceleration Pulse (msec)*	
	Set A	*Set B*		*Set A*	*Set B*	*Set A*	*Set B*
End Drop for 11 -inches	*0.65*	*0.81*	*92.2*	*43.98*	*41.53*	*3.3*	*3.0*
Non-Mechanistic -Tip-over	*4.25*	*5.61*	*304.03*	*42.85*	*39.91*	*2.3*	*2.0*

† *The passband frequency of the Butterworth filter is 350 Hz.*

†† *The distance of the top of the fuel basket is 206" from the pivot point. The distance of the top of the cask is 231.25" from the pivot point. Therefore, all displacements, velocities, and accelerations at the top of the fuel basket are 89.08% of those at the cask top (206"/231.25").*

FIGURES 3.A.19 THROUGH 3.A.30 INTENTIONALLY DELETED

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/**10,670**~~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 = **43,7339**~~,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/**43,7339**~~,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 axial location 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 hottest location 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, $\Delta T_{1h} := 322 - 70$

The temperature change at the inside of the water jacket, $\Delta T_{2h} := 314 - 70$

The temperature change at the mean radius of the MPC shell, $\Delta T_{3h} := 455 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (600 - 70) \cdot 1.1$

The temperature change at the center of the basket, $\Delta T_{5h} := 852 - 70$

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, $R_{mpc} := \frac{68.375 \cdot in - 0.5 \cdot in}{2}$ $\quad R_{mpc} = 33.938\,in$

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, $AC_{bm} := 1.8125 \cdot in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875 \cdot in$

The outer radius of the basket, $R_b := R_{mpc} - \frac{0.5}{2} \cdot in - RC_{bm}$ $\quad R_b = 33.5\,in$

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:

$$C_a + C_b \cdot \ln\left(\frac{r}{a}\right)$$

where,

$$C_a := \Delta T_{1h} \qquad C_a = 252$$

$$C_b := \frac{\Delta T_{2h} - \Delta T_{1h}}{\ln\left(\frac{b}{a}\right)} \qquad C_b = -47.889$$

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, $Int = 5.807 \times 10^4\,in^2$

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:

$$Int_s := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\,dr$$

$$Int_s := \frac{1}{2} \cdot C_b \cdot \ln\left(\frac{b}{a}\right) \cdot b^2 + \frac{1}{2} \cdot C_a \cdot b^2 - \frac{1}{4} \cdot C_b \cdot b^2 + \frac{1}{4} \cdot C_b \cdot a^2 - \frac{1}{2} \cdot C_a \cdot a^2 \qquad Int_s = 5.807 \times 10^4\,in^2$$

We note that the values of Int and Ints are identical. The average temperature in the overpack cylinder (T_{bar}) is therefore determined as:

$$T_{bar} := \frac{2}{\left(b^2 - a^2\right)} \cdot Int$$

$$T_{bar} = 247.778$$

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_1 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:

$$\alpha_{avg} := \frac{r_1 \cdot t_1 \cdot \alpha_1 + r_2 \cdot t_2 \cdot \alpha_2 + r_3 \cdot t_3 \cdot \alpha_3}{\frac{a+b}{2} \cdot (t_1 + t_2 + t_3)}$$

$$\alpha_{avg} = 1.413 \times 10^{-5}$$

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:

$$\Delta R_{ah} := \alpha_{avg} \cdot a \cdot T_{bar} \qquad \Delta R_{ah} = 0.12\,\text{in}$$

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:

$$\Delta L_{ovph} := L_{ovp} \cdot \alpha_{avg} \cdot T_{bar}$$

$$\Delta L_{ovph} = 0.669\,\text{in}$$

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, $E := 28600000 \cdot \text{psi}$

$$\sigma_{ca} := \alpha_{avg} \cdot \frac{E}{a^2} \cdot \left[2 \cdot \frac{a^2}{\left(b^2 - a^2\right)} \cdot \text{Int} - \left(C_a\right) \cdot a^2 \right] \qquad \sigma_{ca} = -1706\,\text{psi}$$

$$\sigma_{cb} := \alpha_{avg} \cdot \frac{E}{b^2} \cdot \left[2 \cdot \frac{b^2}{\left(b^2 - a^2\right)} \cdot Int - \left[C_a + C_b \cdot \left(\ln\left(\frac{b}{a}\right)\right)\right] \cdot b^2 \right] \qquad \sigma_{cb} = 1526\,psi$$

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:

$$N := 0.47$$

$$r := a \cdot (1 - N) + N \cdot b$$

$$r = 37.313\,in$$

$$\sigma_r := \alpha_{avg} \cdot \frac{E}{r^2} \cdot \left[\frac{r^2 - a^2}{2} \cdot T_{bar} - \int_a^r \left[C_a + C_b \cdot \left(\ln\left(\frac{y}{a}\right)\right)\right] \cdot y\,dy \right]$$

$$\sigma_r = -67.389\,psi$$

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:

$$\Delta R_{mpch} := \alpha_{mpc} \cdot R_{mpc} \cdot \Delta T_{3h}$$

$$\Delta R_{mpch} = 0.122\,in$$

$$\Delta L_{mpch} := \alpha_{mpc} \cdot L_{mpc} \cdot \Delta T_{3h}$$

$$\Delta L_{mpch} = 0.685\,in$$

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:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch}$$

$$RG_{moh} = 0.123\,in$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch}$$

$$AG_{moh} = 0.735\,in$$

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 $\Delta T_{bas} := \Delta T_{5h} - \Delta T_{4h}$

$$\Delta T_{bas} = 199$$

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:

$$T_{bar} := \frac{2}{R_b^2} \cdot \left(\frac{-1}{4} \cdot \Delta T_{bas} \cdot R_b^2 + \frac{1}{2} \cdot \Delta T_{5h} \cdot R_b^2 \right)$$

$$T_{bar} = 682.5$$

The corresponding radial growth at the periphery (ΔR_{bh}) is therefore determined as:

$$\Delta R_{bh} := \alpha_{bas} \cdot R_b \cdot T_{bar} \qquad \Delta R_{bh} = 0.226\,in$$

and the corresponding axial growth (ΔL_{bas}) is determined from [3.I.2] as:

$$\Delta L_{bh} := \Delta R_{bh} \cdot \frac{L_{bas}}{R_b} \qquad \Delta L_{bh} = 1.193\,in$$

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:

$$RG_{bmh} := RC_{bm} - \Delta R_{bh} + \Delta R_{mpch}$$

$$RG_{bmh} = 0.083\,\text{in}$$

$$AG_{bmh} := AC_{bm} - \Delta L_{bh} + \Delta L_{mpch}$$

$$AG_{bmh} = 1.305\,\text{in}$$

3.I.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-HI-TRAC	Fuel Basket-to-MPC Shell
$RG_{moh} = 0.123$ in	$RG_{bmh} = 0.083$ in
$AG_{moh} = 0.735$ in	$AG_{bmh} = 1.305$ 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.

$$\tau_1 := \frac{Vo}{.7071 \cdot t_w} \qquad \tau_1 = 1.138 \times 10^3 \text{ psi}$$

The weld capacity over the same unit width is

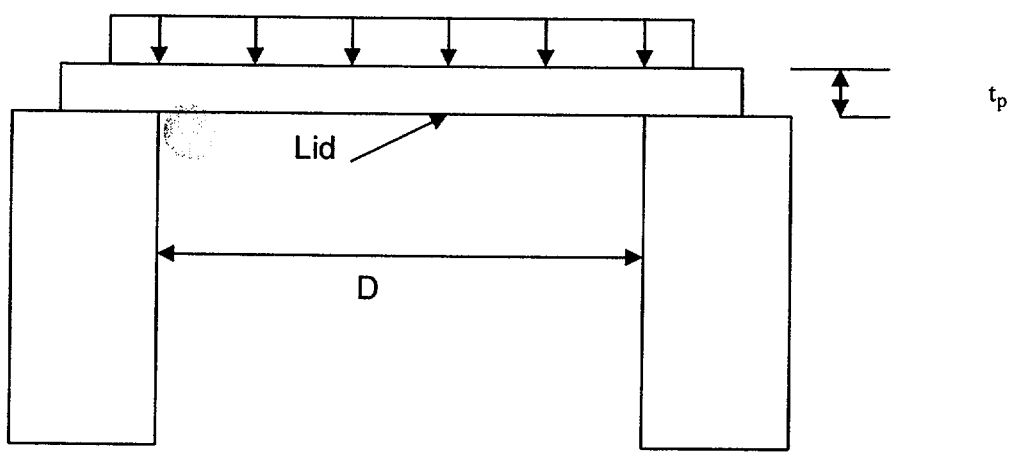
$$Weld\_Capacity := \tau_{allow} \cdot .7071 \cdot t_w \qquad Weld\_Capacity = 5.197 \times 10^3 \frac{lbf}{in}$$

Therefore the safety factor on the pedestal shell-to-baseplate weld is

$$SF_{weld} := \frac{Weld\_Capacity}{Vo} \qquad SF_{weld} = 25.828$$

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

$t_{tp} = 2 \text{ in}$

$D := 73.5 \cdot in$ 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

$$\sigma := \frac{3 \cdot (3 + \nu)}{8} \cdot q \cdot \left(\frac{D}{2 \cdot t_{tp}}\right)^2 \qquad \sigma = 3.597 \times 10^4\,\text{psi}$$

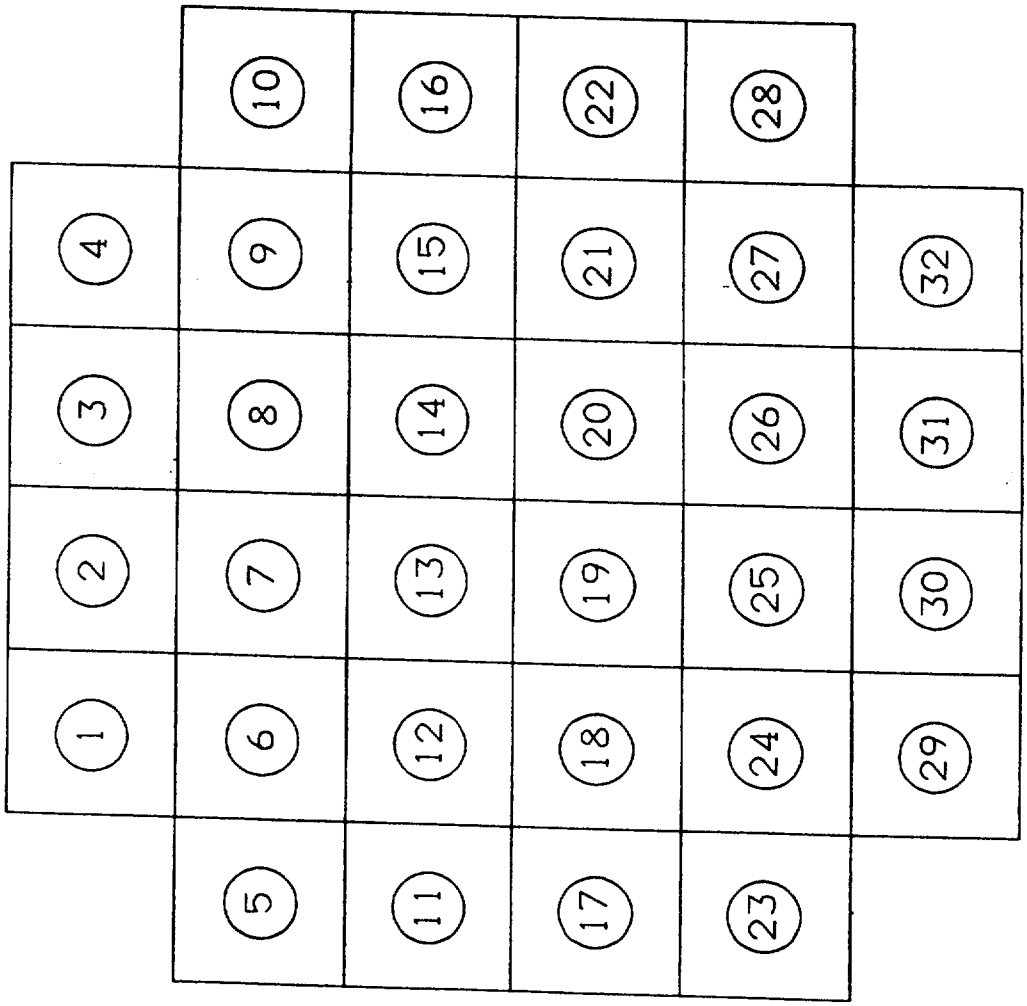
$$SF_{lid\_top\_plate} := \frac{S_a}{\sigma} \qquad SF_{lid\_top\_plate} = 1.658$$

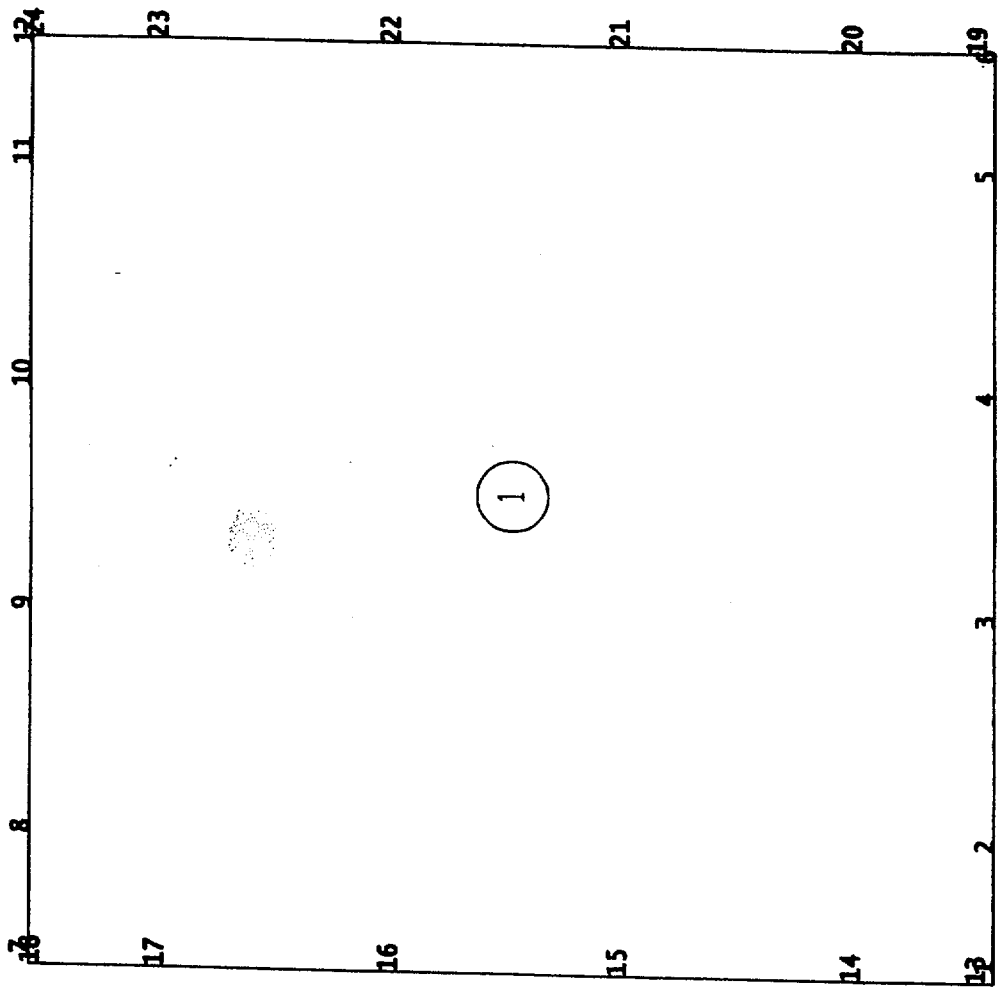
3.M.4 Conclusion

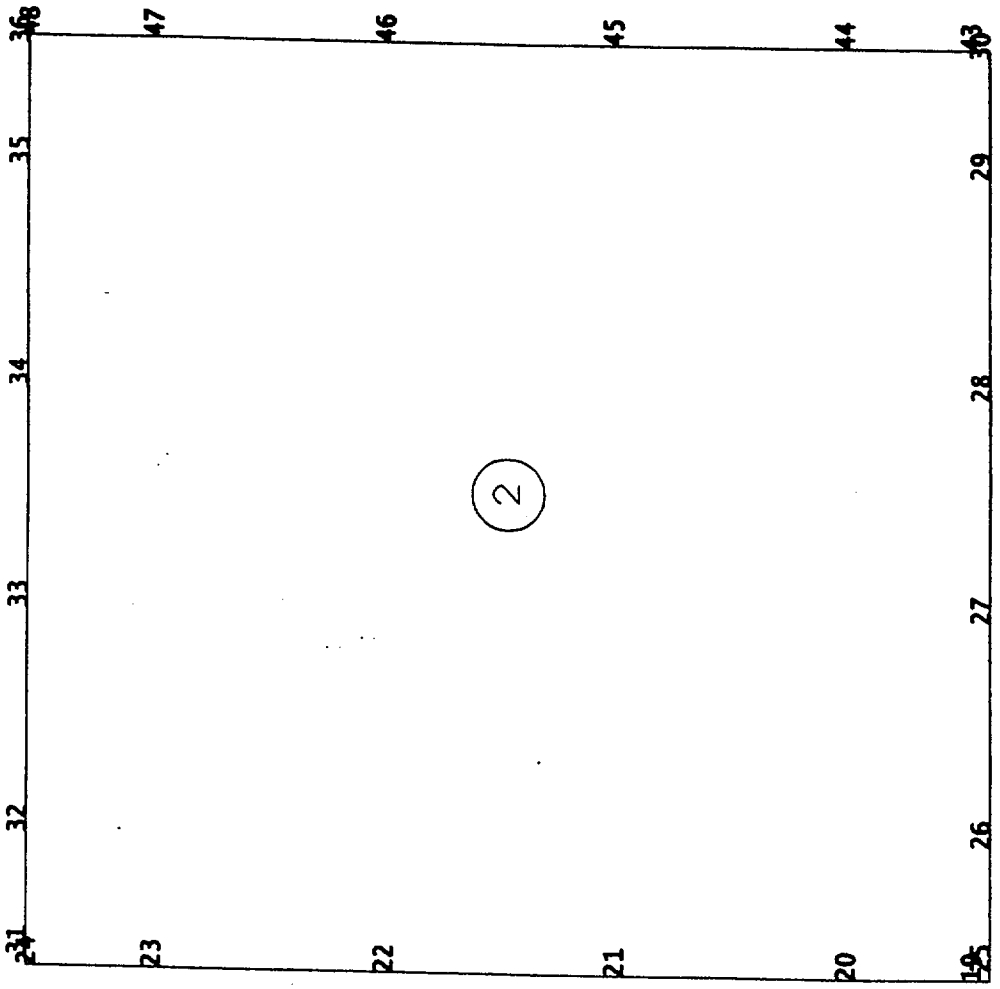
The HI-STORM 100 storage overpack meets Level D requirements for Load Case 02.a in Table 3.1.5. Even under the postulated accident condition loads, the calculated stress levels do not imply that any significant deformations occur that would preclude removal of a loaded MPC. Thus ready retrievability of fuel is maintained after such an event. The results for the HI-STORM 100 will bound the results for the HI-STORM 100S.

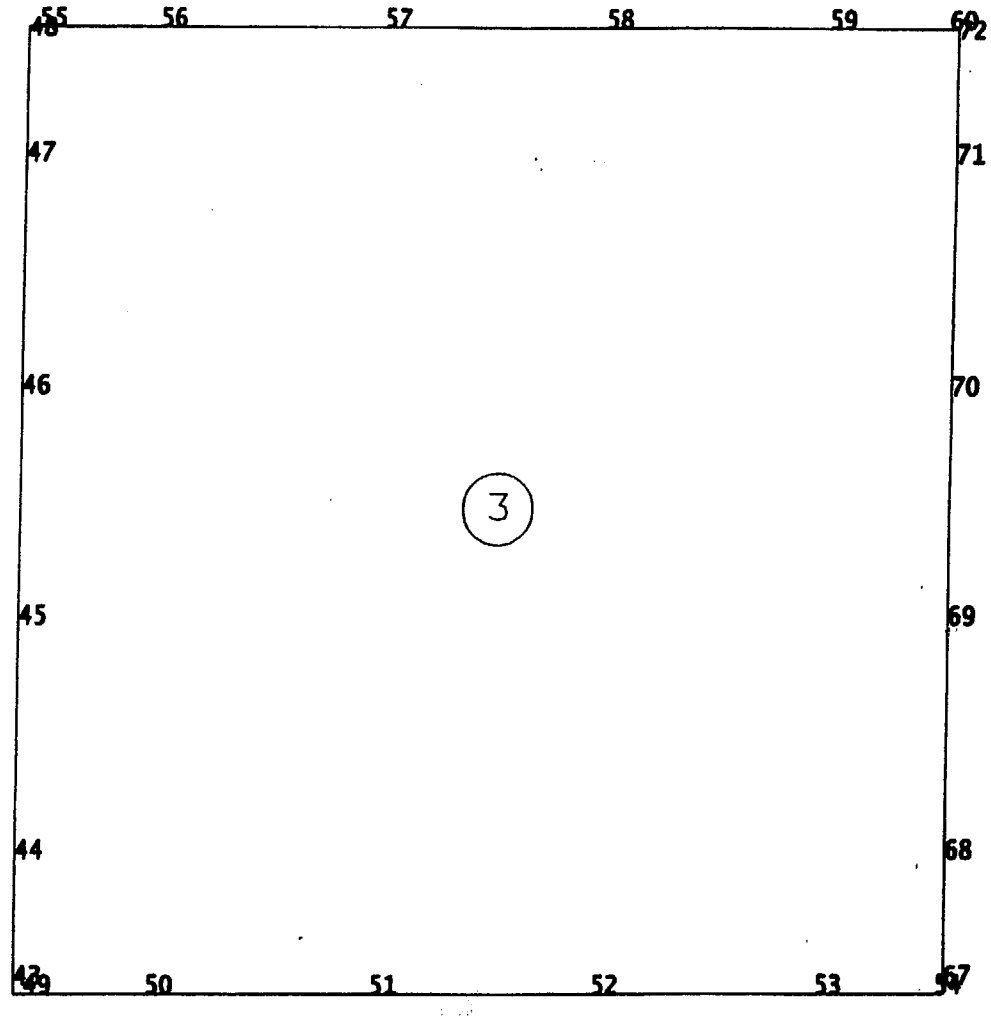
Appendix 3.P - Detailed Finite Element Listings for the MPC-32 Fuel Basket

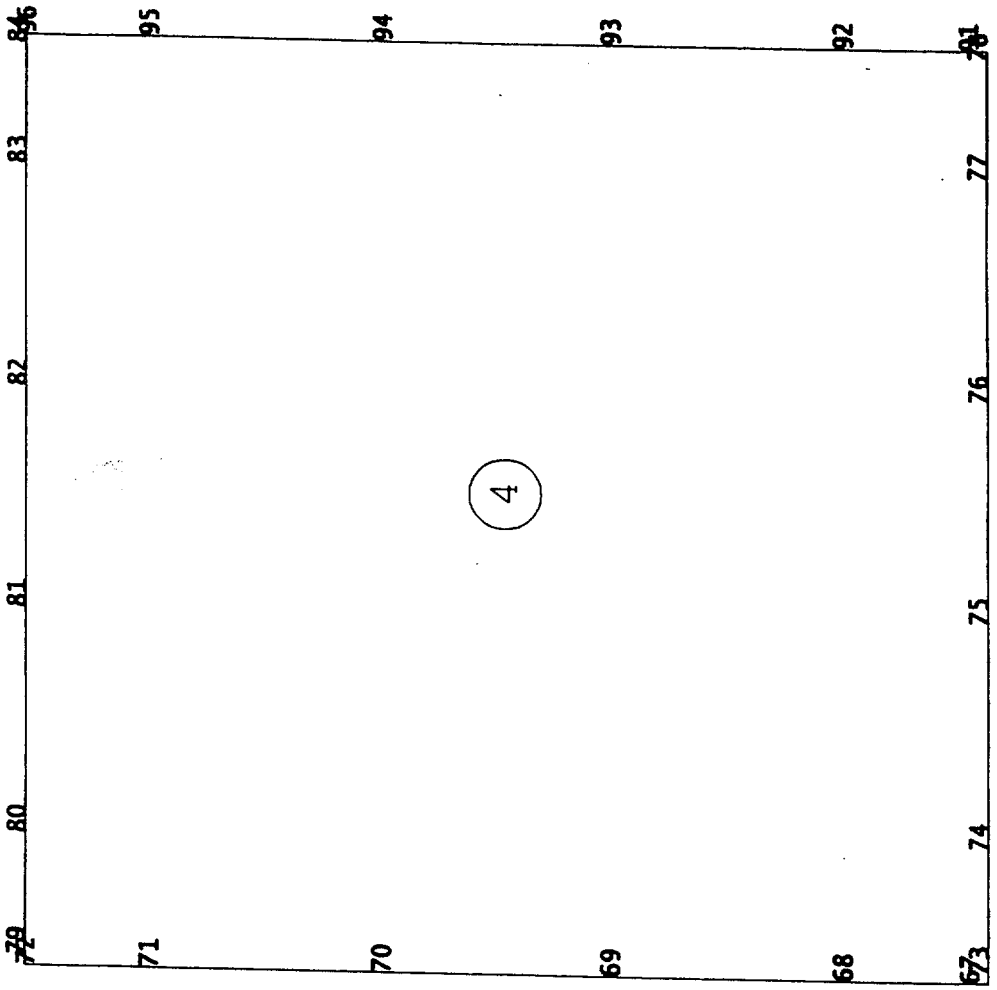
Thirty-four (34) pages total including cover page

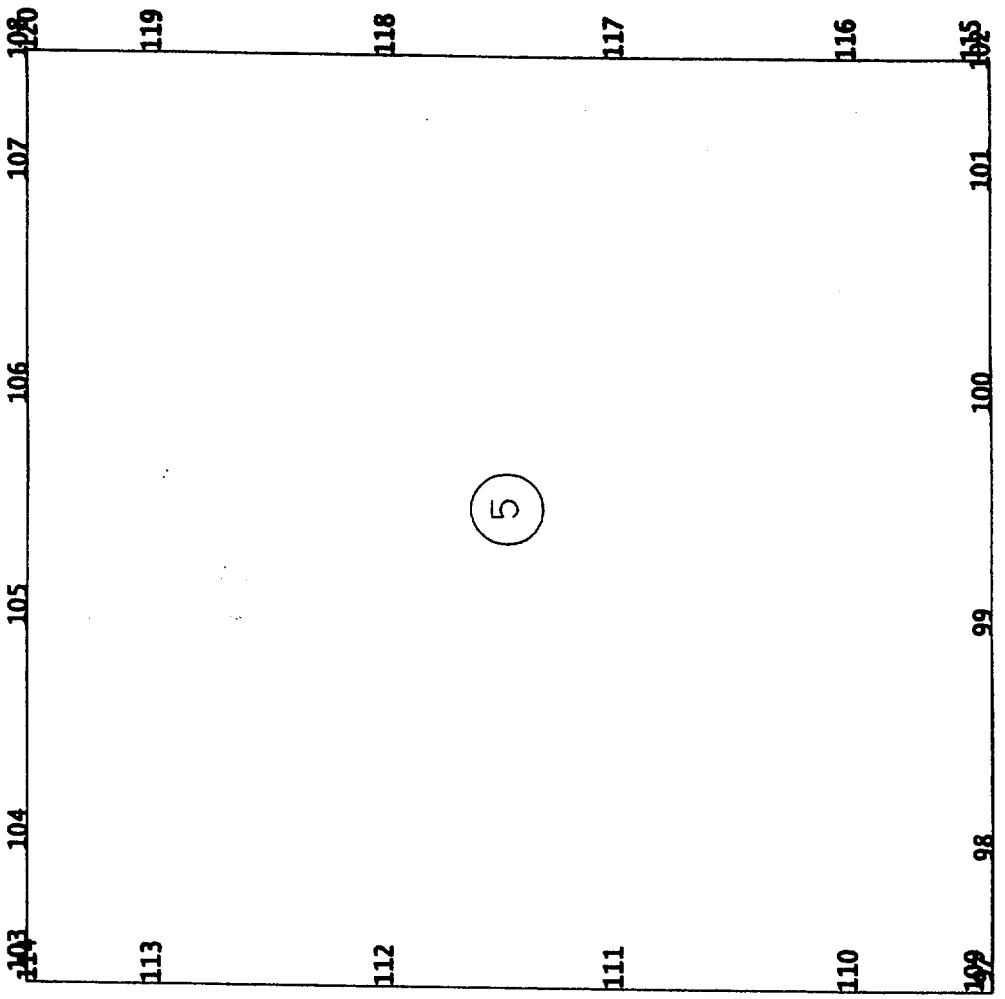

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32

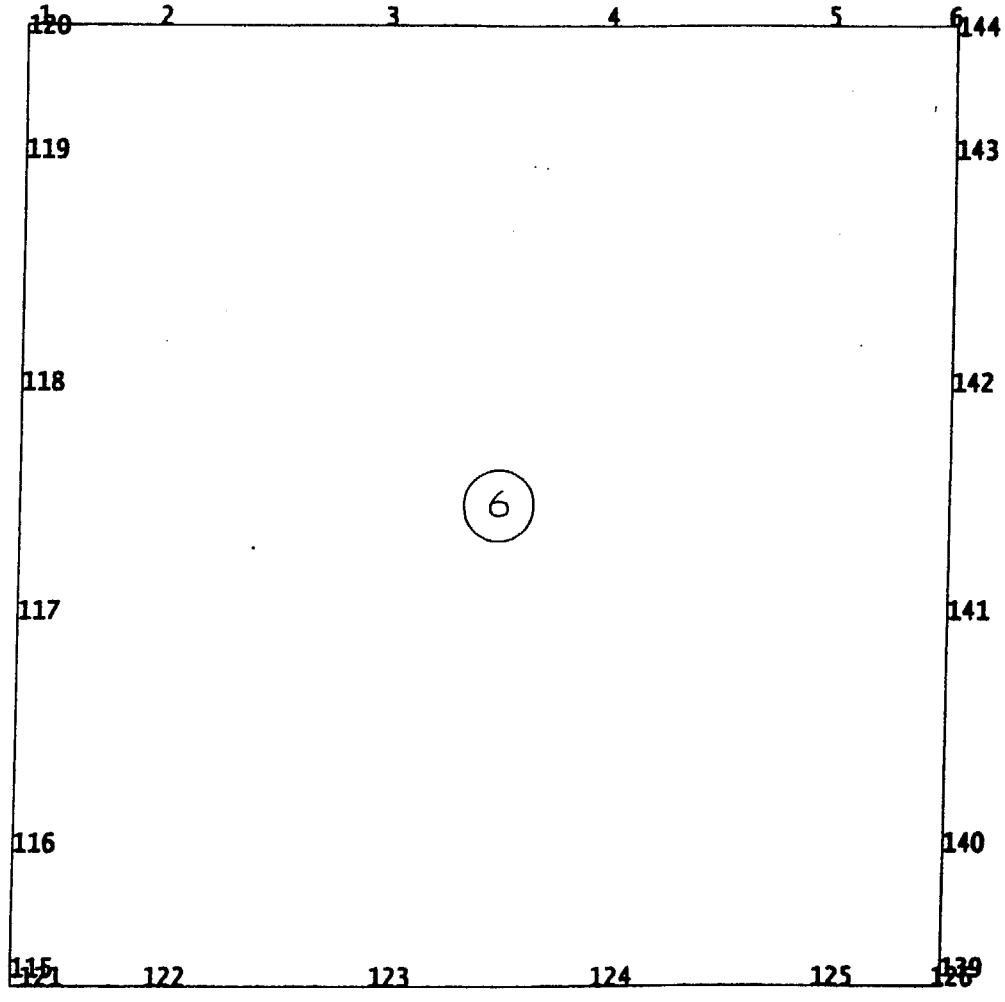

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

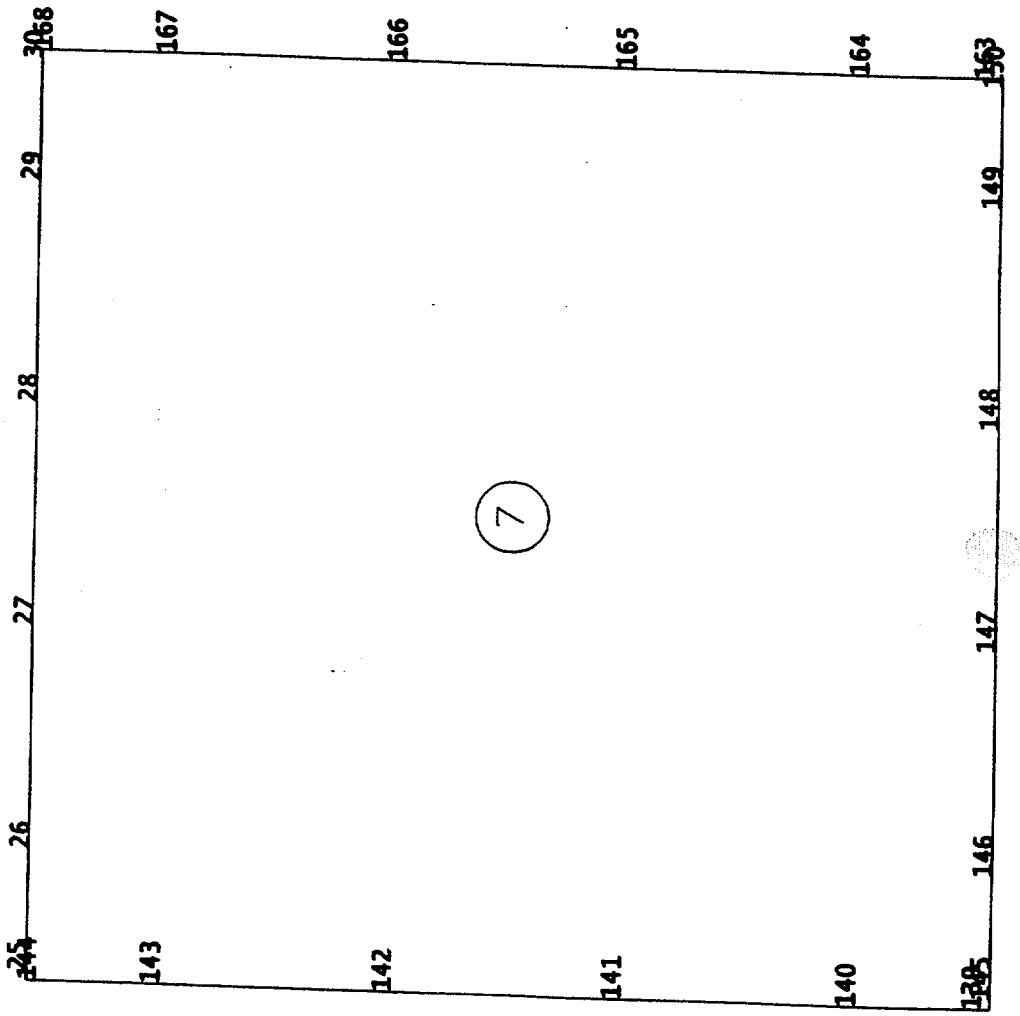

36
35
34
33
32
31
48
47
46
45
44
43
30
29
28
27
26
25
24
23
22
21
20
19
2

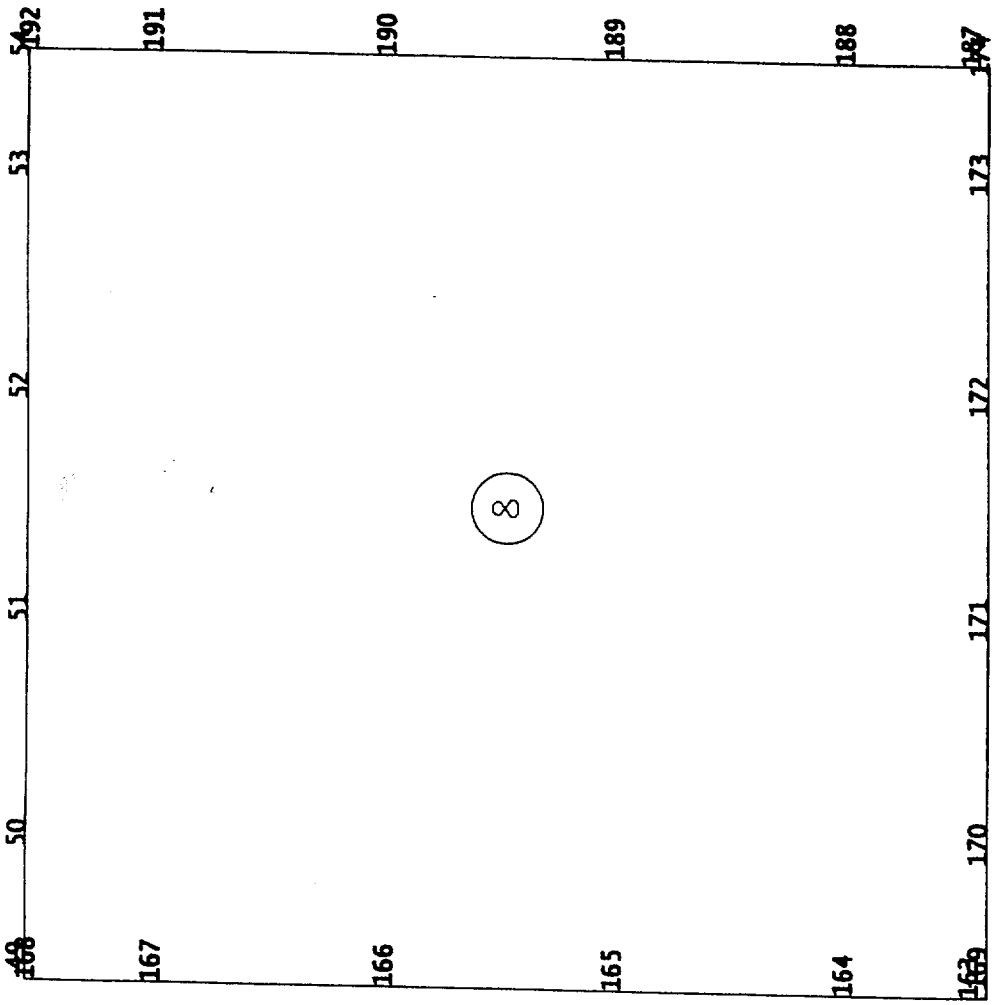

55
56
57
58
59
60
48
72
47
71
46
70
3
45
69
44
68
43
49
50
51
52
53
54
67

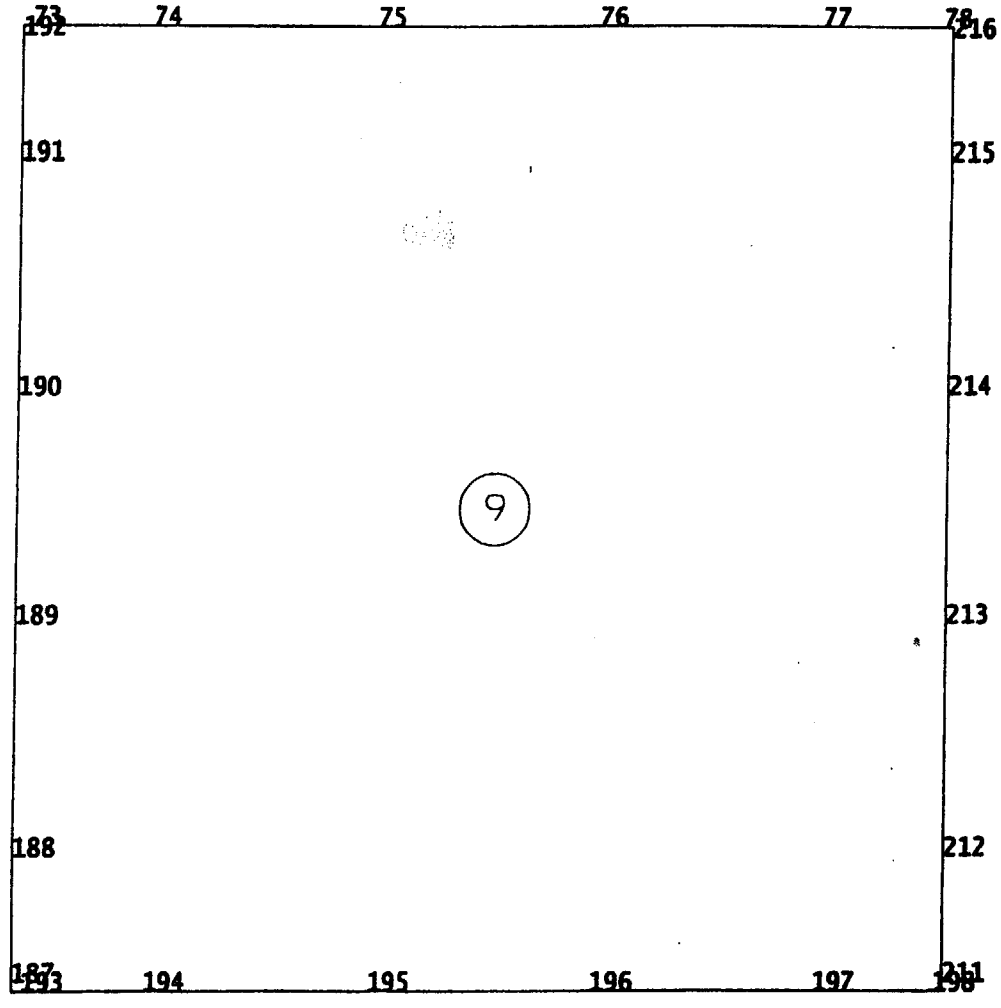

84
96
83
82
81
80
79
72
95
94
93
92
91
78
77
76
75
74
73
67
4
71
70
69
68

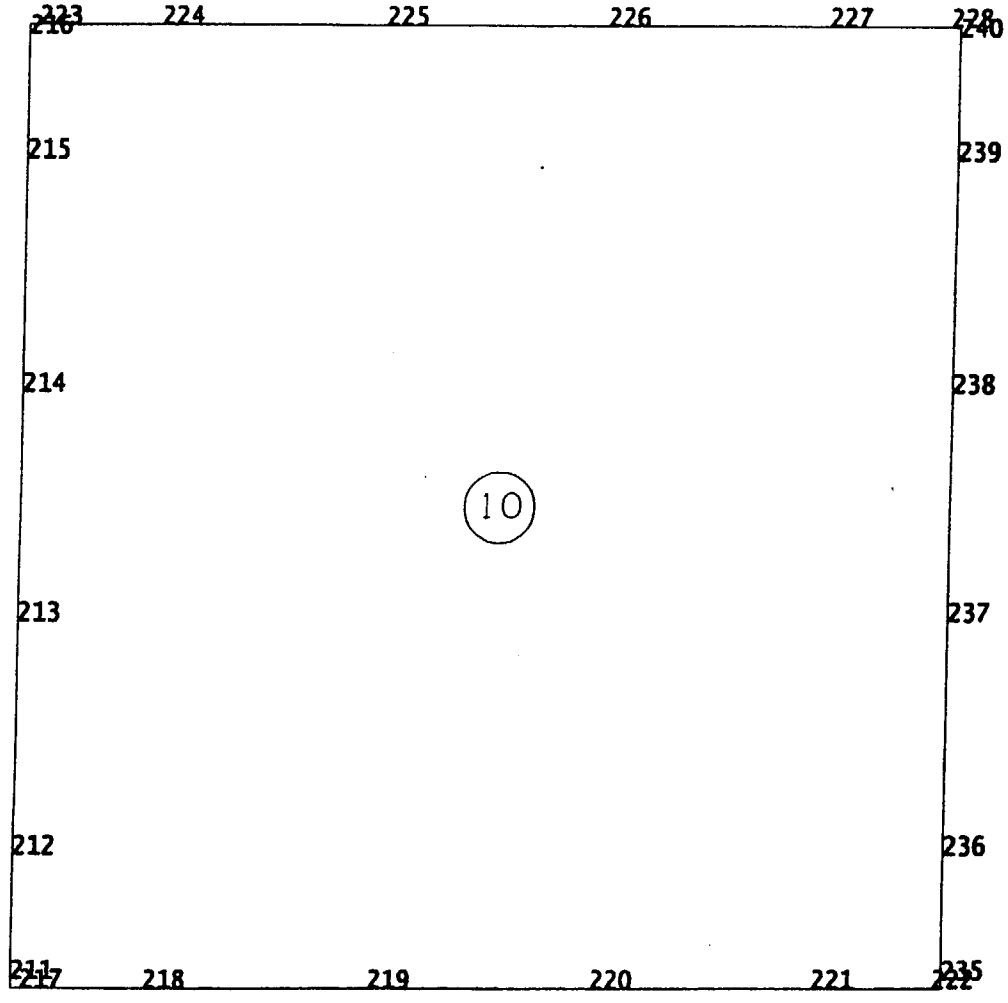

108
120
107
106
105
104
103
114
119
118
117
116
115
102
101
100
99
98
97
109
113
112
111
110
5

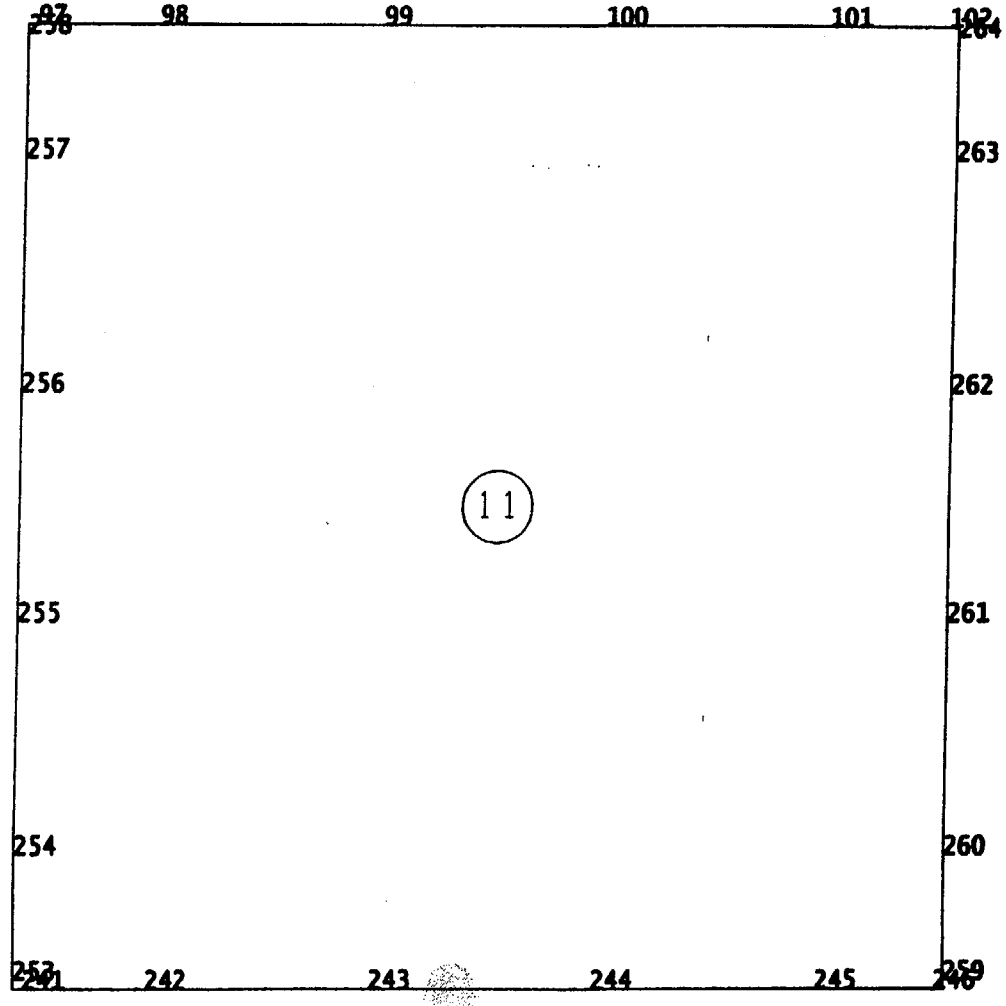

1
2
3
4
5
6
120
144
119
143
118
142
6
117
141
116
140
115
139
121
122
123
124
125
126

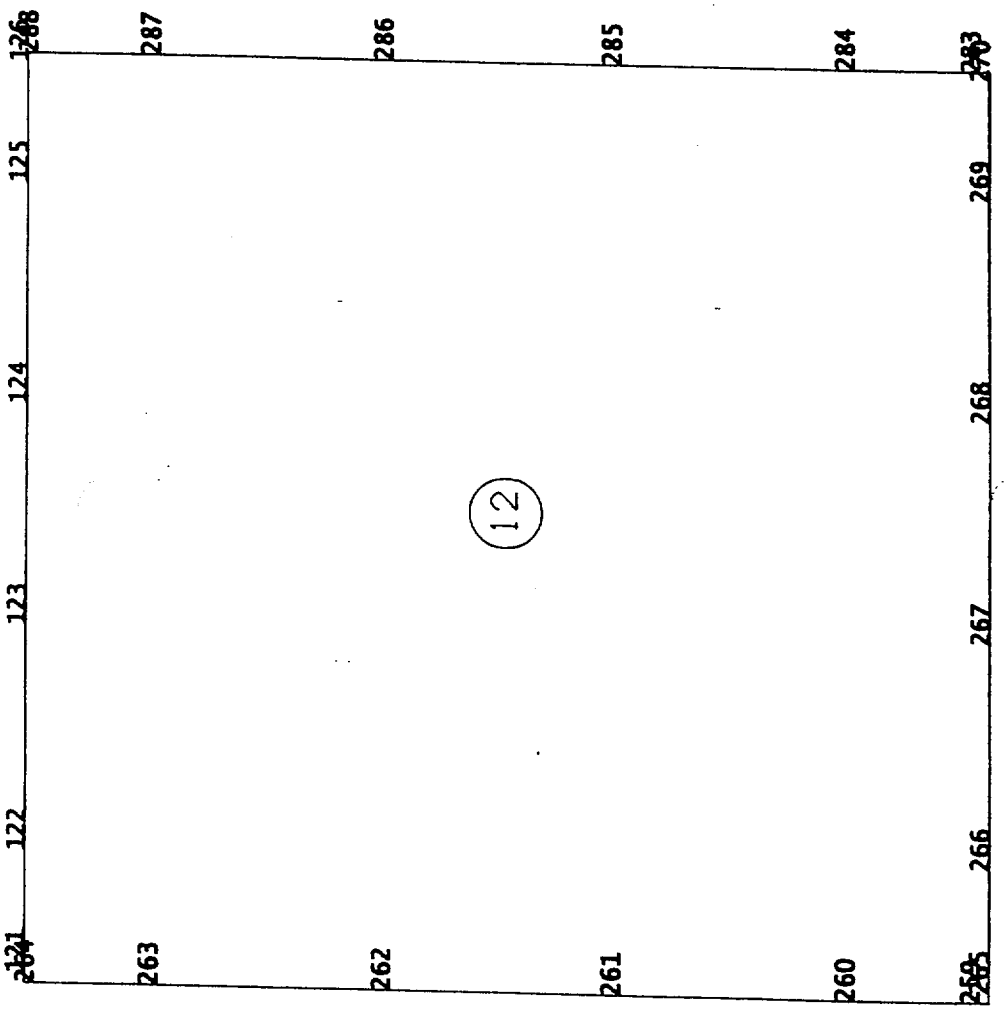

30
168
29
28
27
26
25
244
143
142
141
140
139
138
146
147
148
149
150
163
164
165
166
167
7

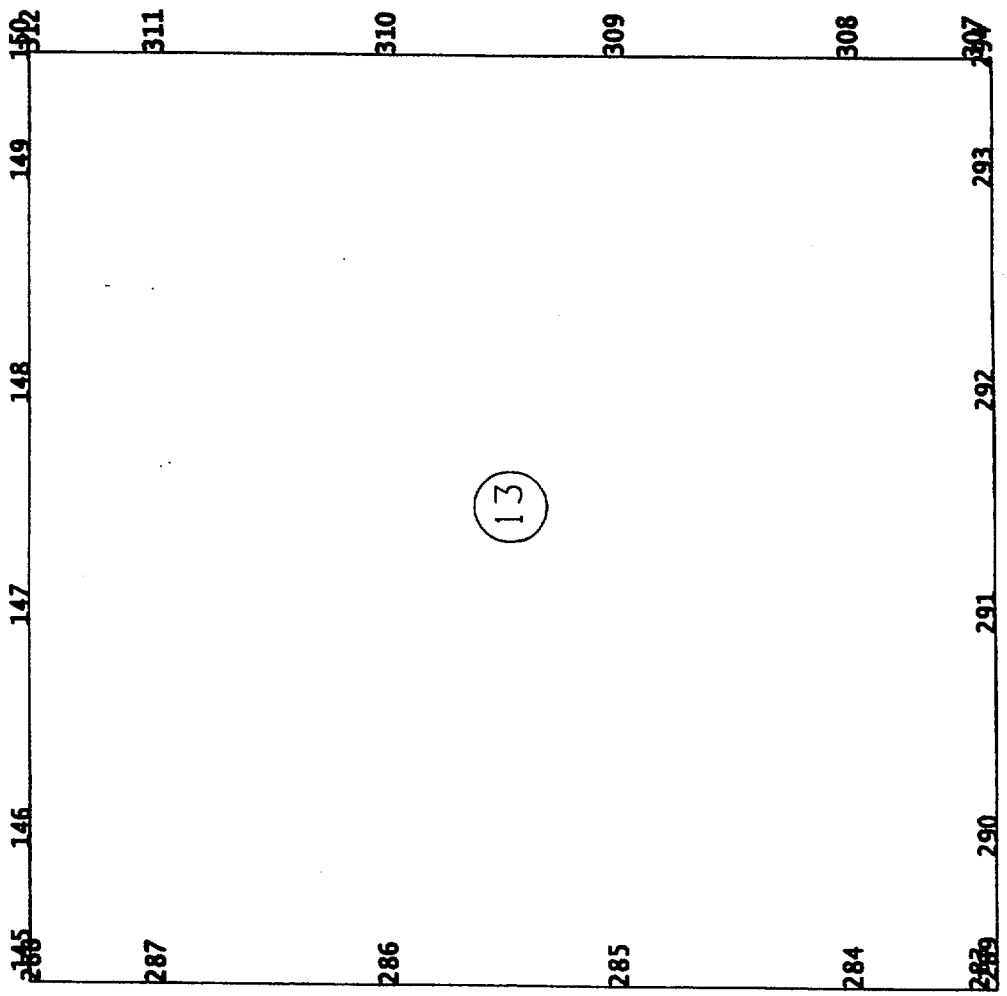

54
53
52
51
50
49
168
167
166
165
164
163
169
170
171
172
173
174
187
188
189
190
191
192
8

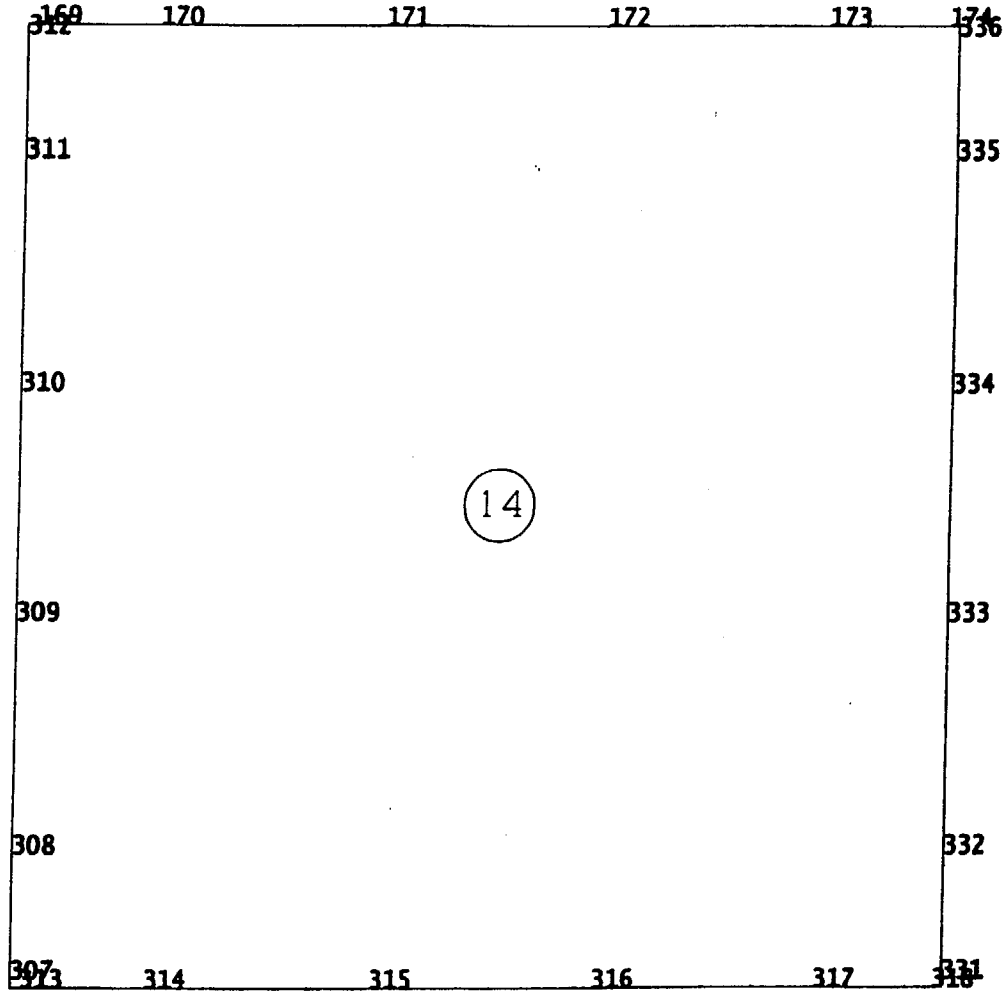

73
74
75
76
77
78
192
216
191
215
190
214
9
189
213
188
212
187
211
193
194
195
196
197
198

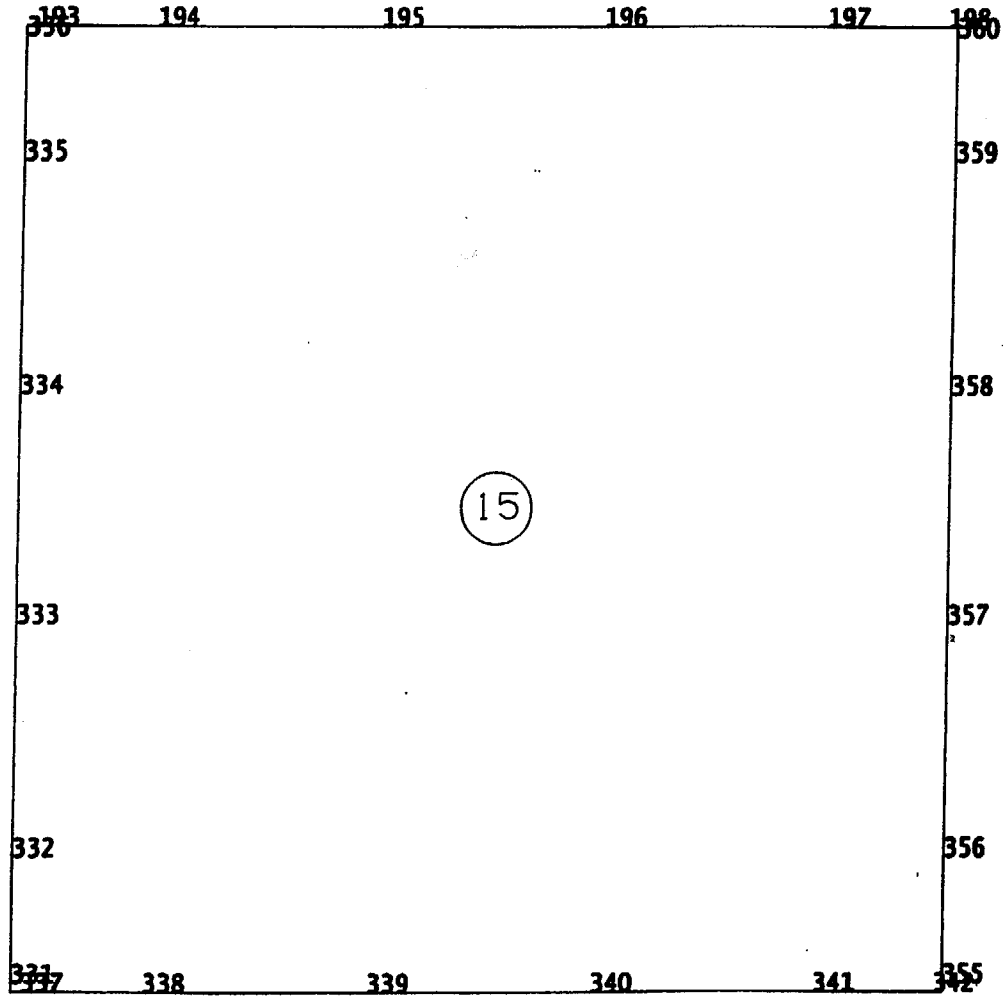

223
224
225
226
227
228
216
240
215
239
214
238
10
213
237
212
236
211
217
218
219
220
221
222
235

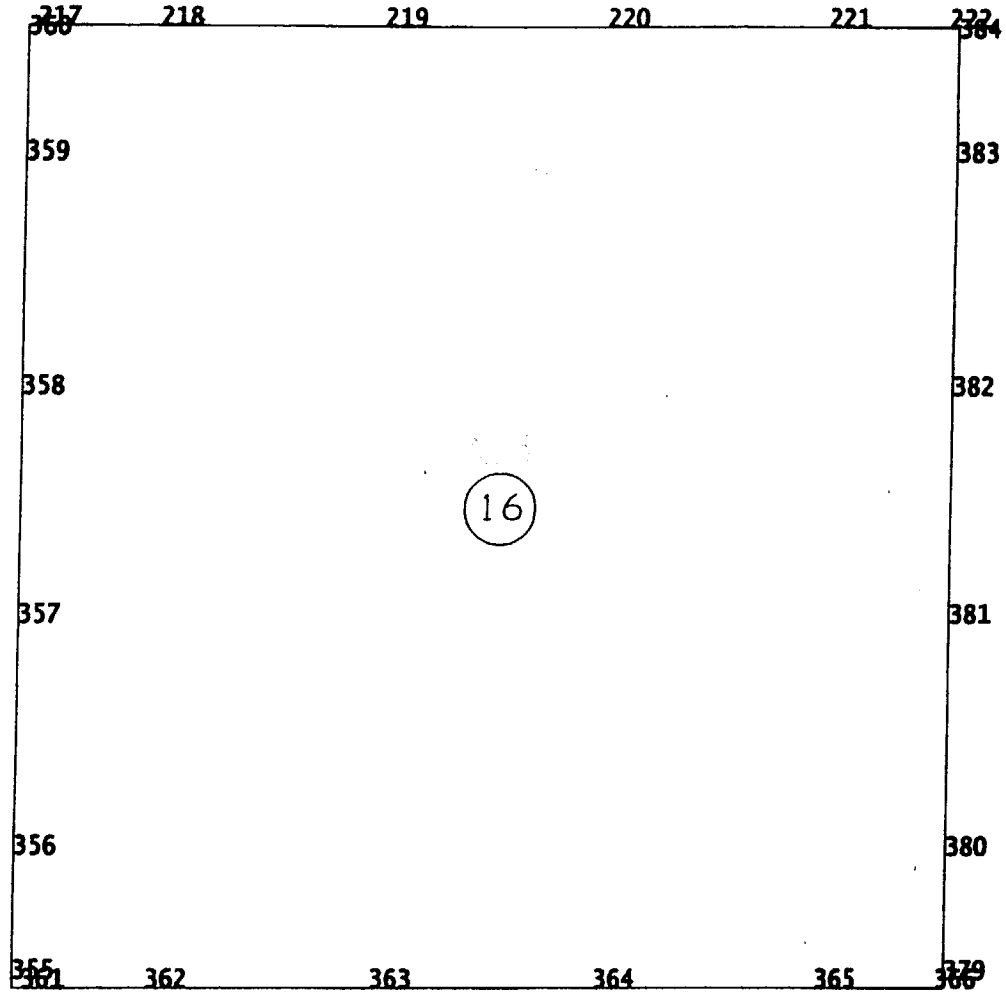

97
98
99
100
101
102
258
264
257
263
256
262
11
255
261
254
260
253
259
241
242
243
244
245
246

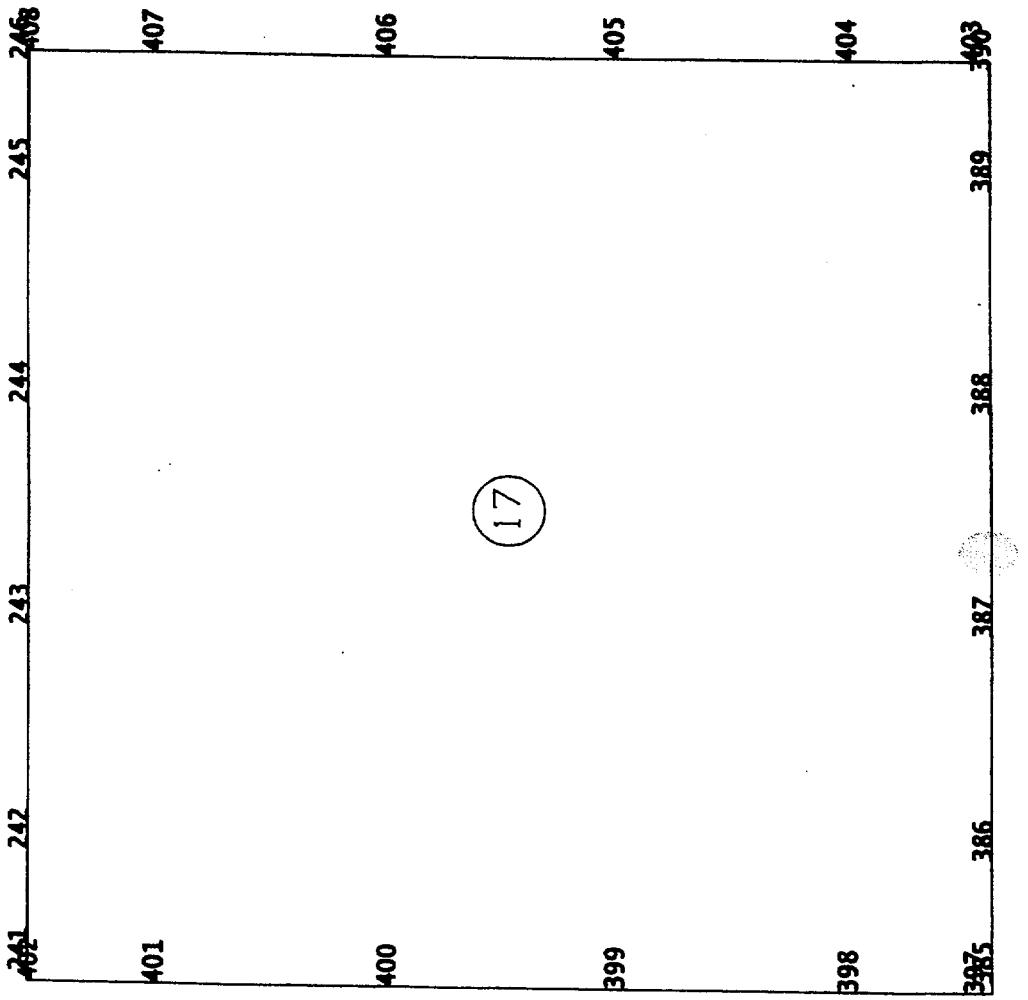

126
288
287
286
285
284
283
270
125
269
124
268
12
123
267
122
266
121
264
263
262
261
260
265
259

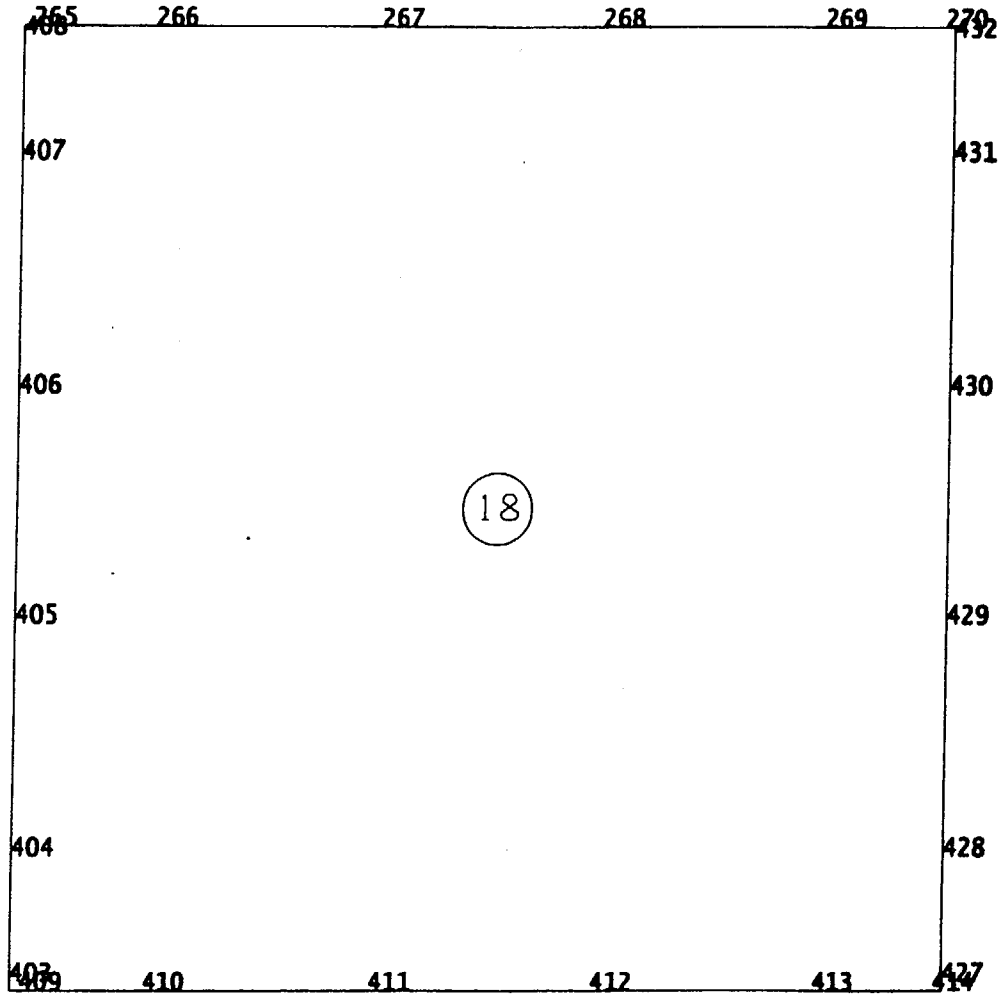

150
312
311
310
309
308
307
306
149
293
148
292
13
147
291
146
290
145
288
287
286
285
284
283
282
281

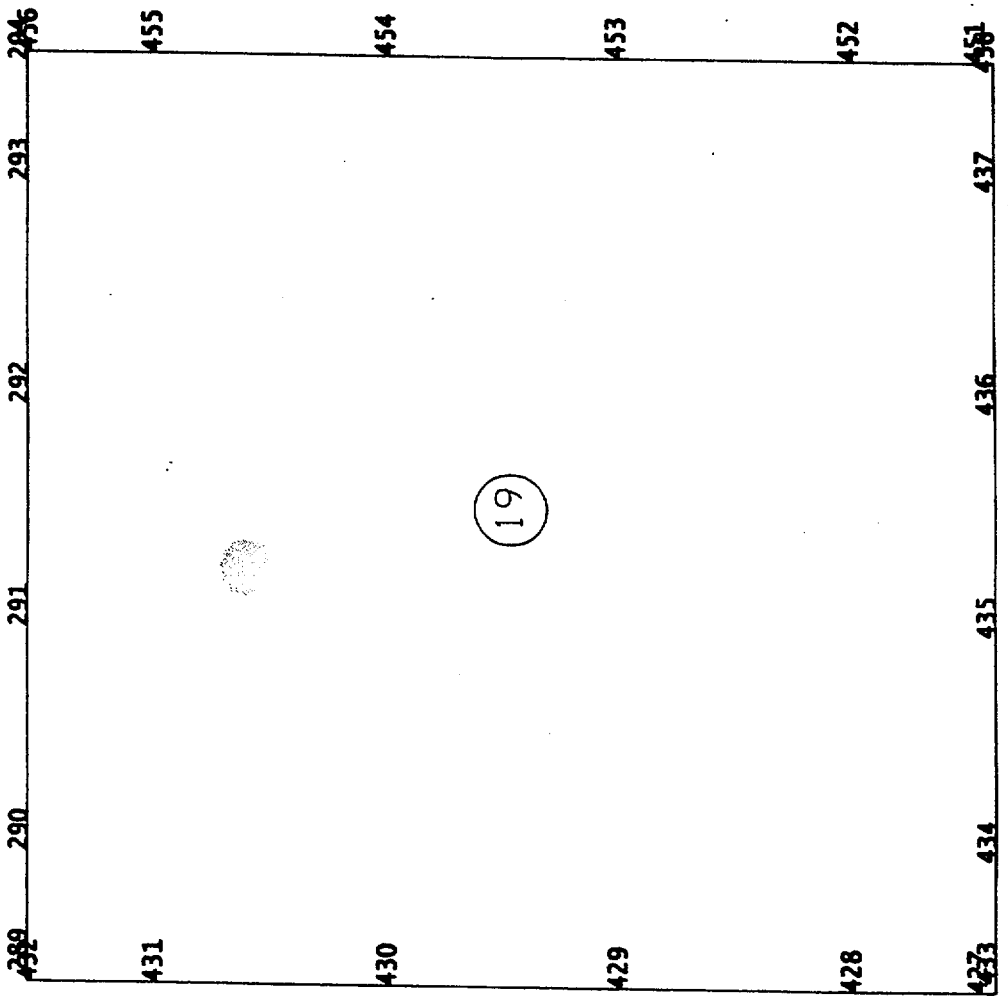

169
170
171
172
173
174
312
336
311
335
310
334
14
309
333
308
332
307
331
313
314
315
316
317
318

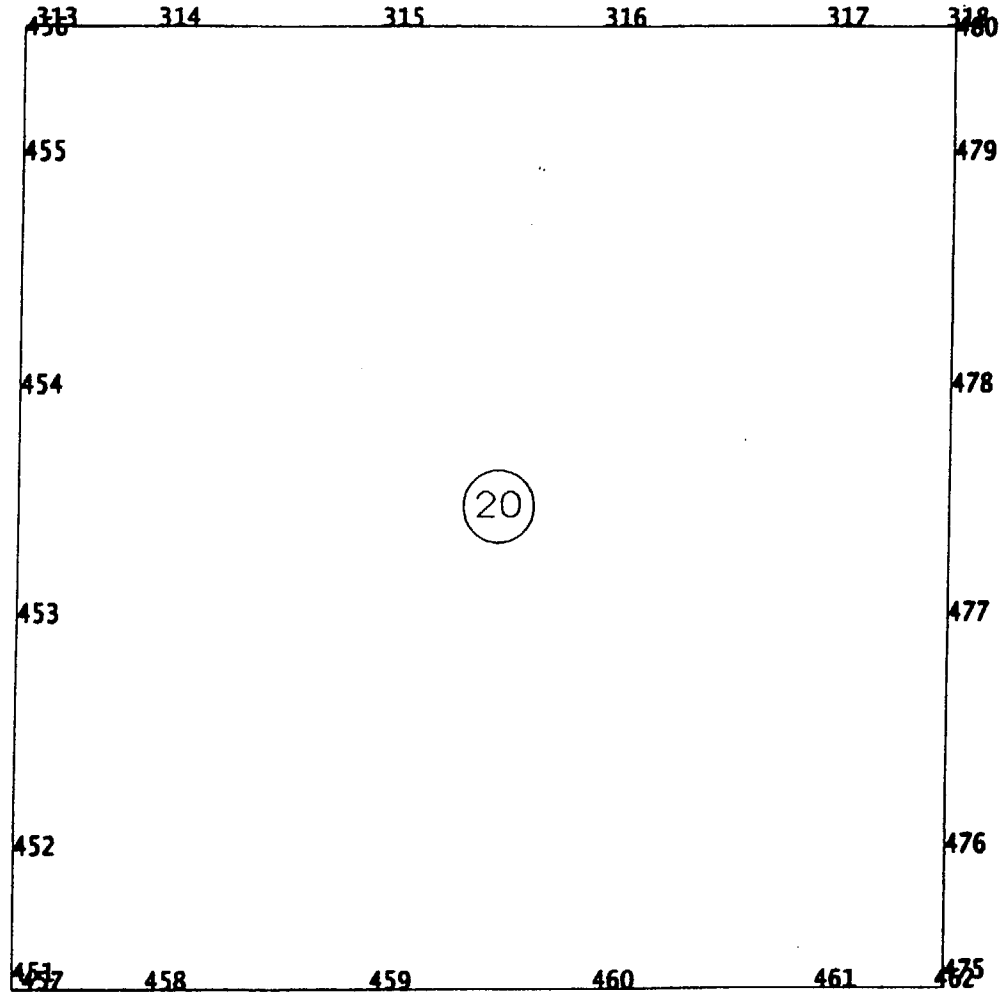

193
194
195
196
197
198
335
359
334
358
15
333
357
332
356
337
338
339
340
341
342
355

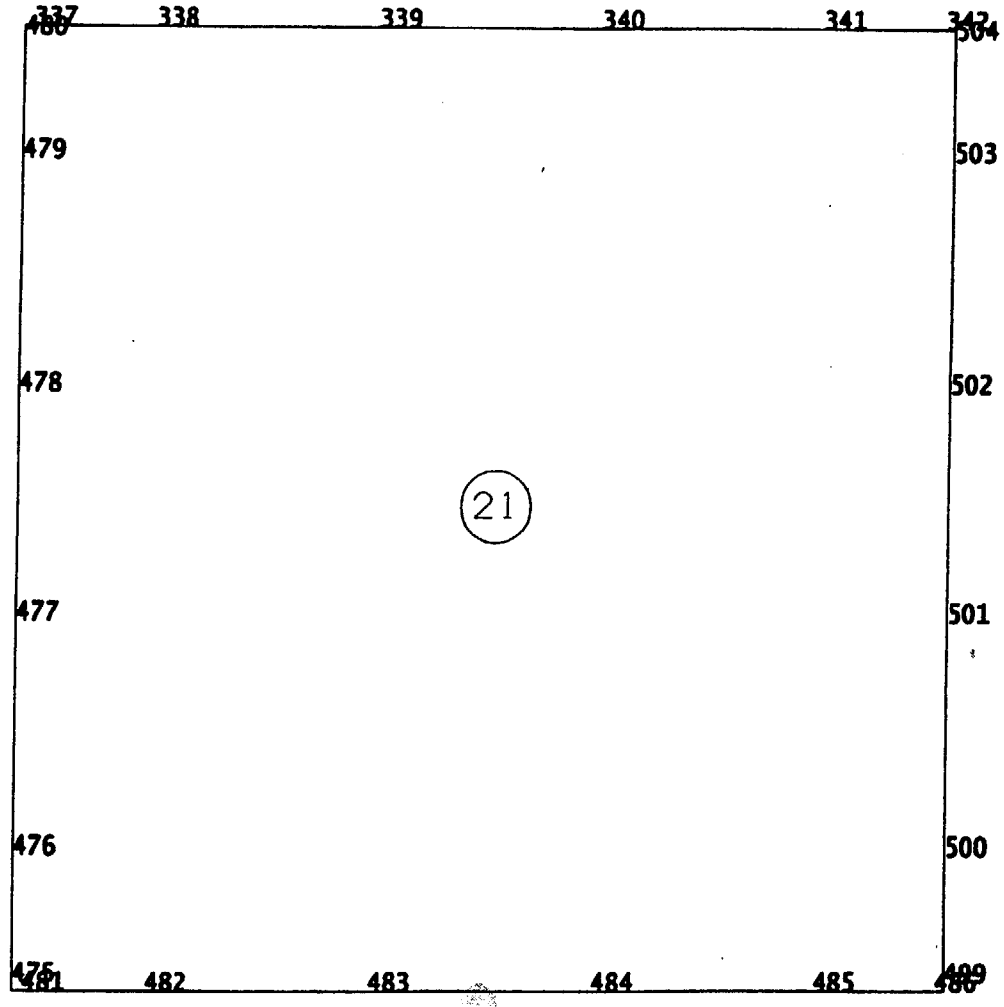

217
218
219
220
221
222
360
384
359
383
358
382
16
357
381
356
380
355
379
361
362
363
364
365
366

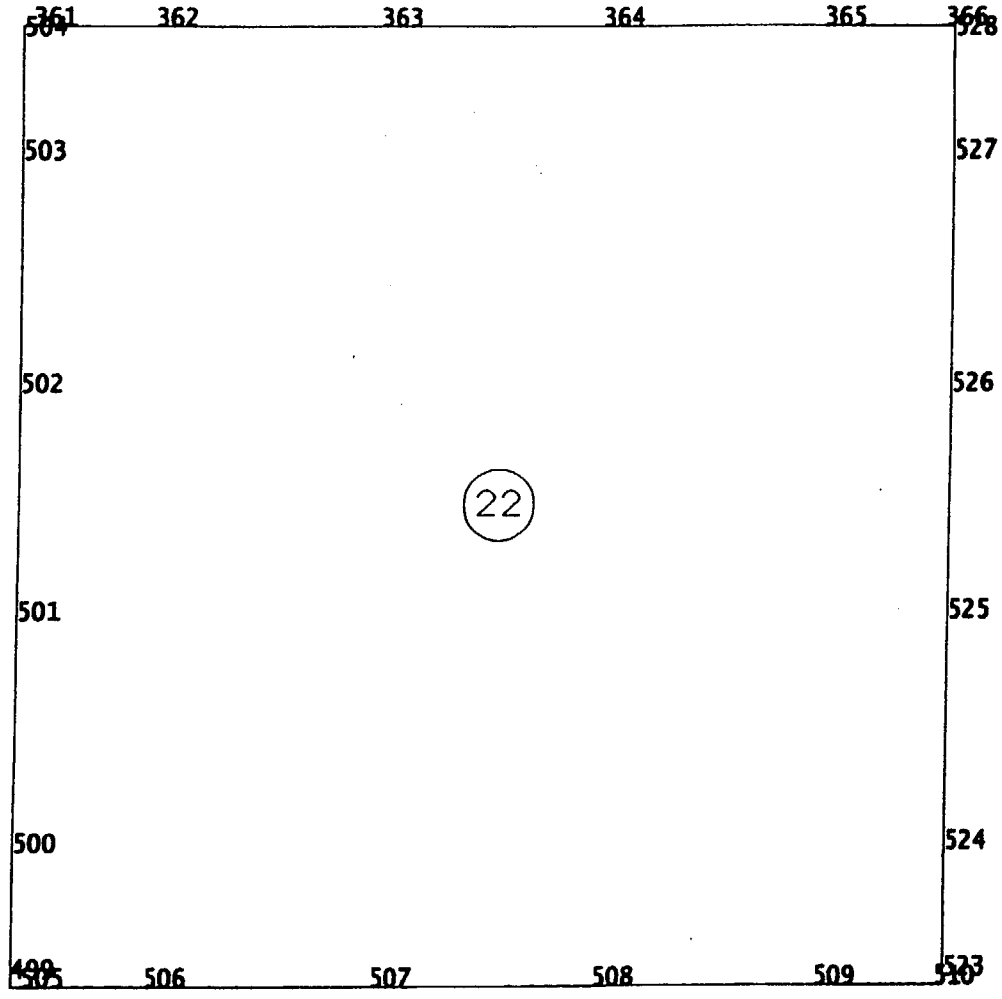

241
242
243
244
245
246
408
407
406
405
404
403
390
389
388
387
386
385
387
398
399
400
401
402
17

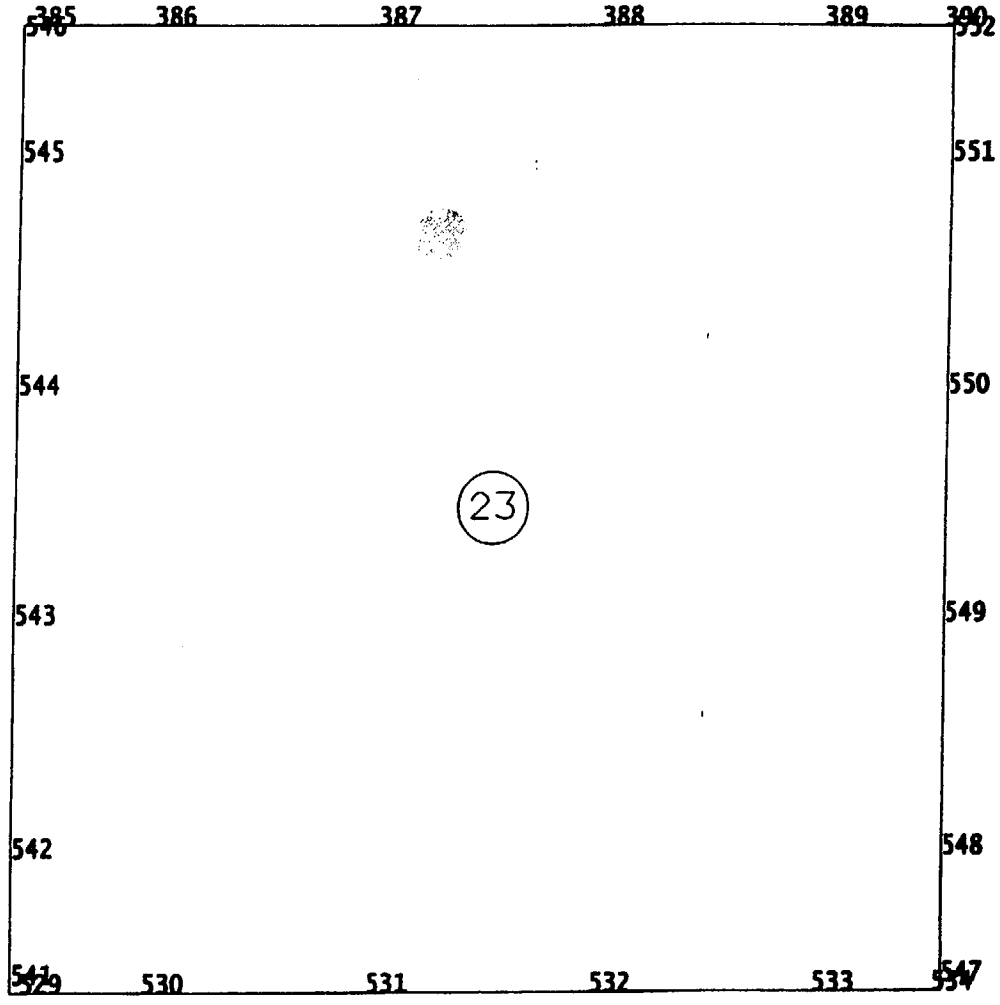

265
266
267
268
269
270
408
432
407
431
406
430
18
405
429
404
428
403
427
409
410
411
412
413
414

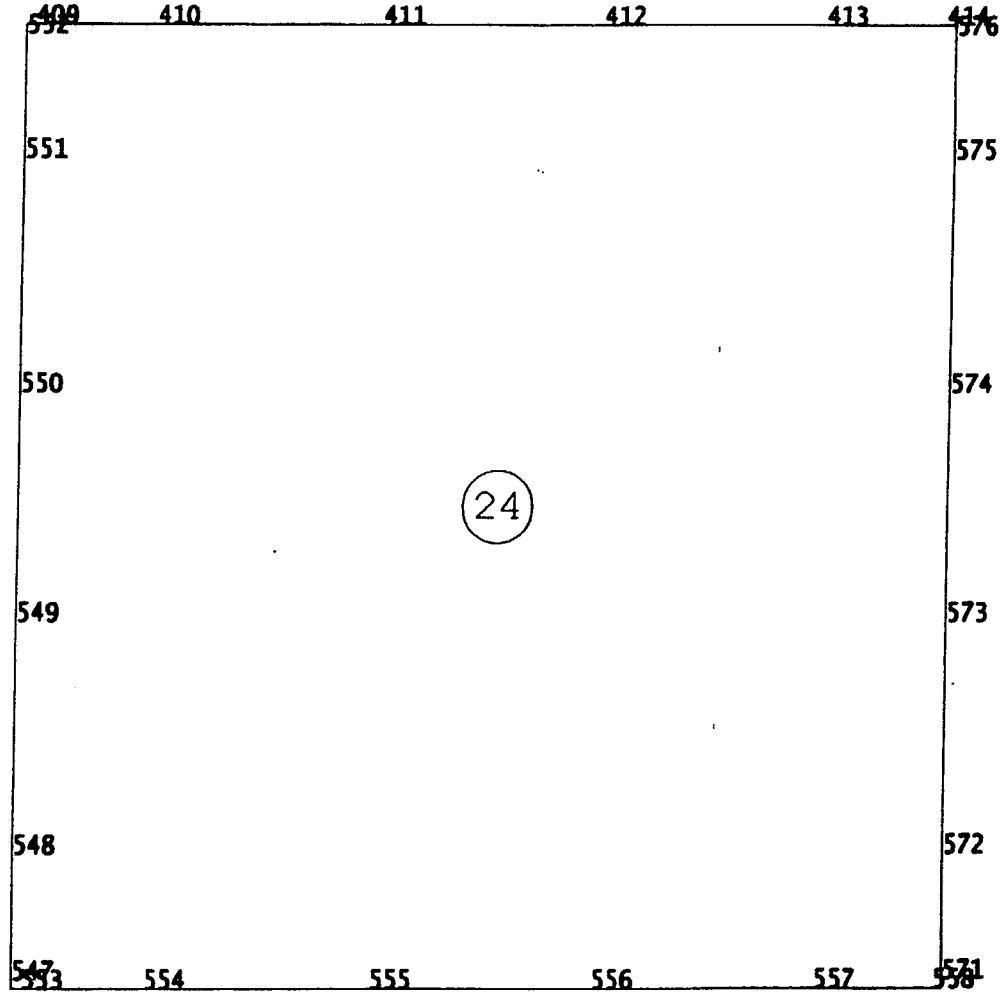

289
290
291
292
293
294
431
430
429
428
427
433
434
435
436
437
438
451
452
453
454
455
456
19

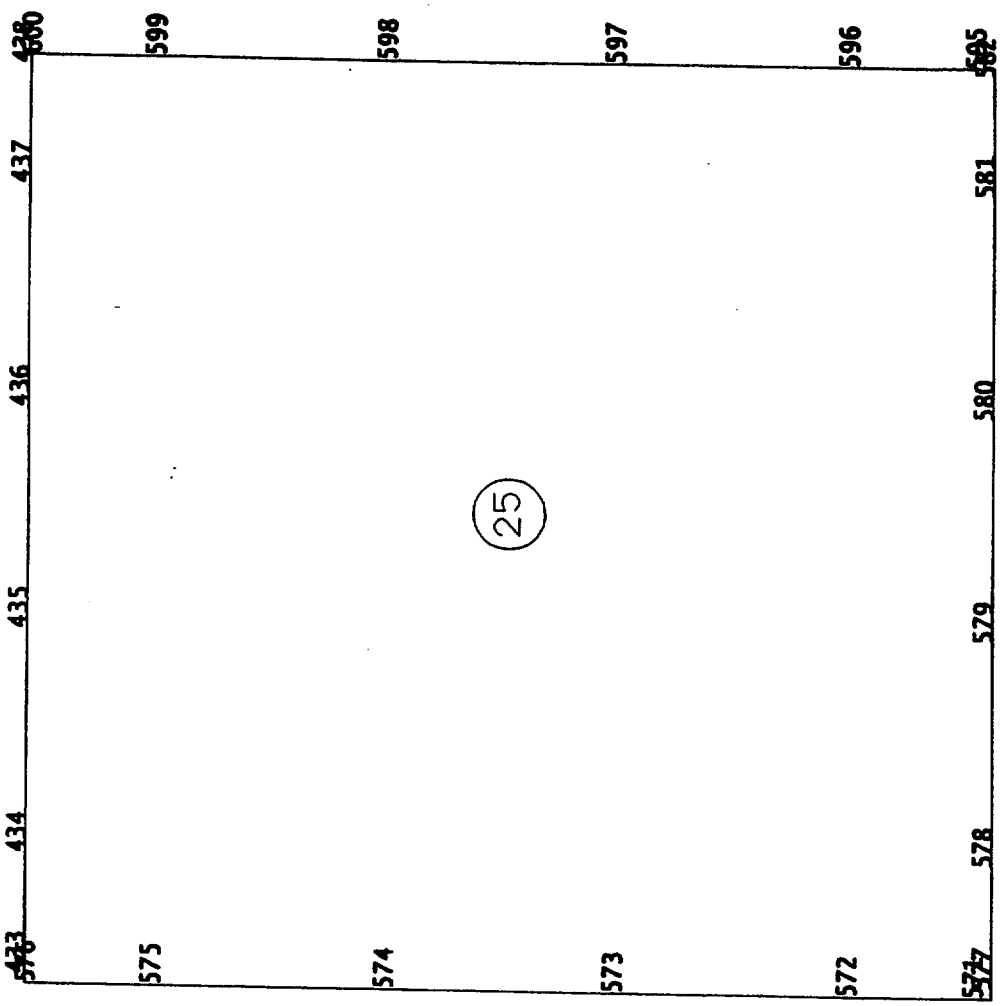

313
314
315
316
317
318
456
480
455
479
454
478
20
453
477
452
476
457
458
459
460
461
462
475

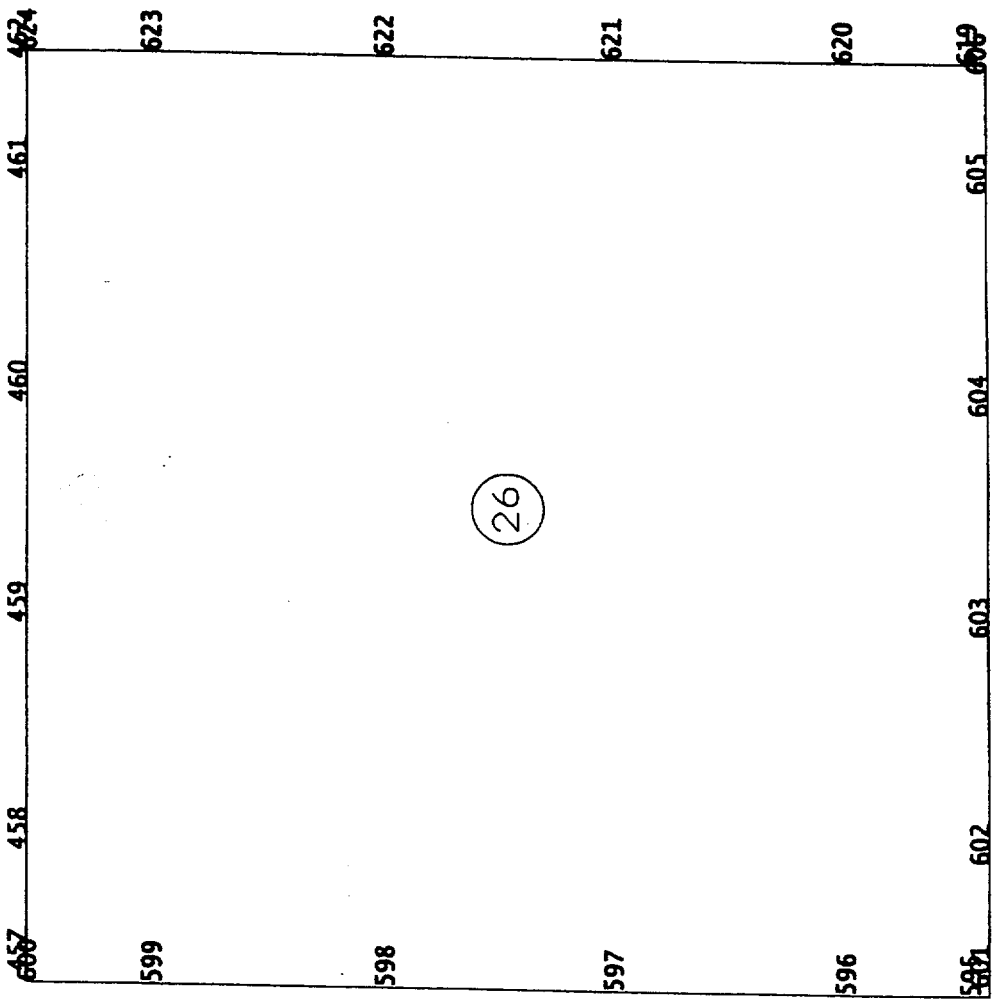

337
338
339
340
341
342
480
504
479
503
478
502
21
477
501
476
500
475
481
482
483
484
485
486
509

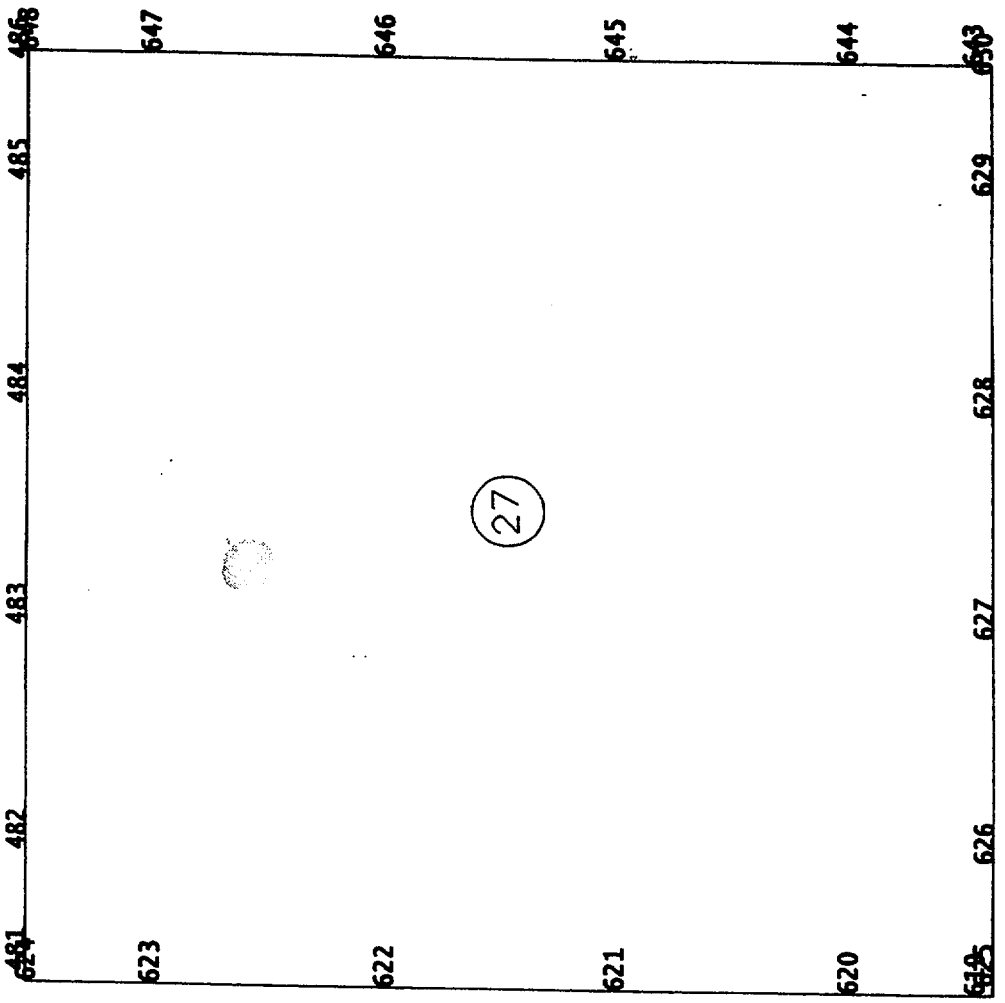

361
362
363
364
365
366
504
528
503
527
502
526
22
501
525
500
524
499
505
506
507
508
509
510
523

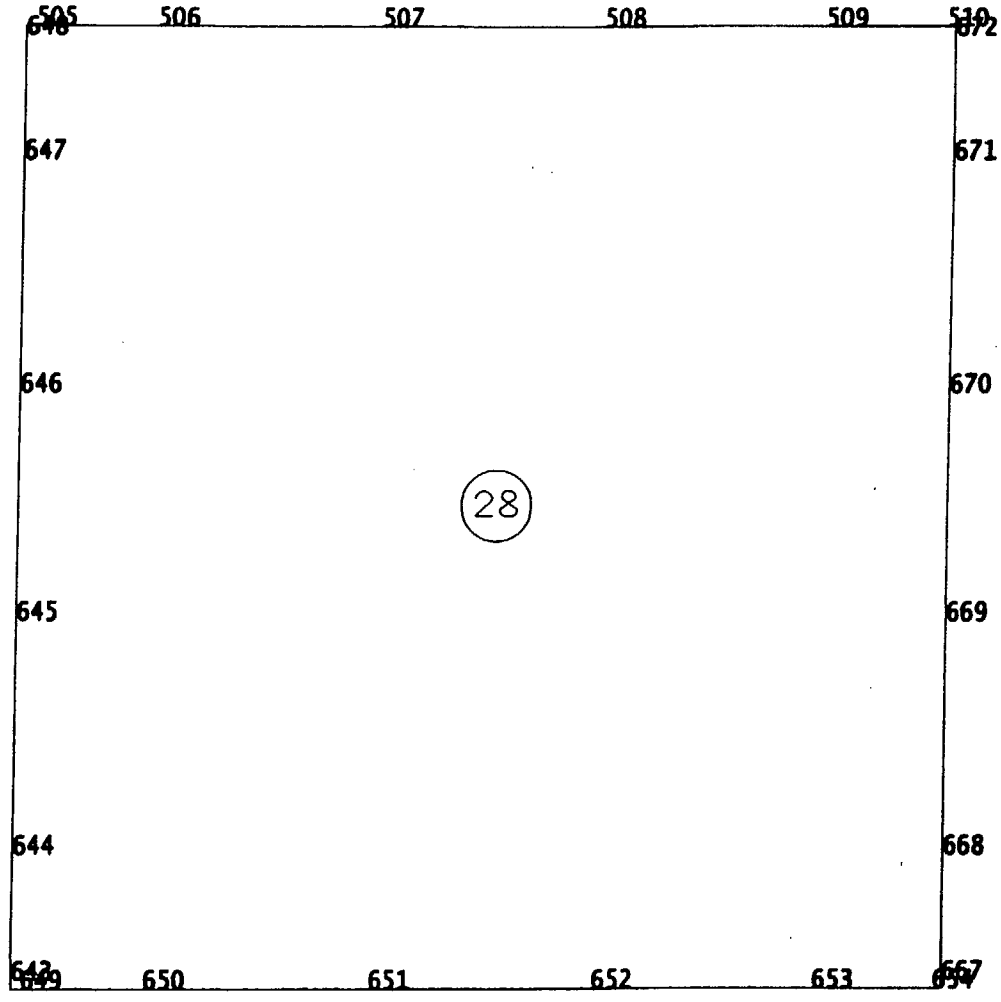

385
386
387
388
389
390
540
552
545
551
544
550
23
543
549
542
548
541
547
529
530
531
532
533
534

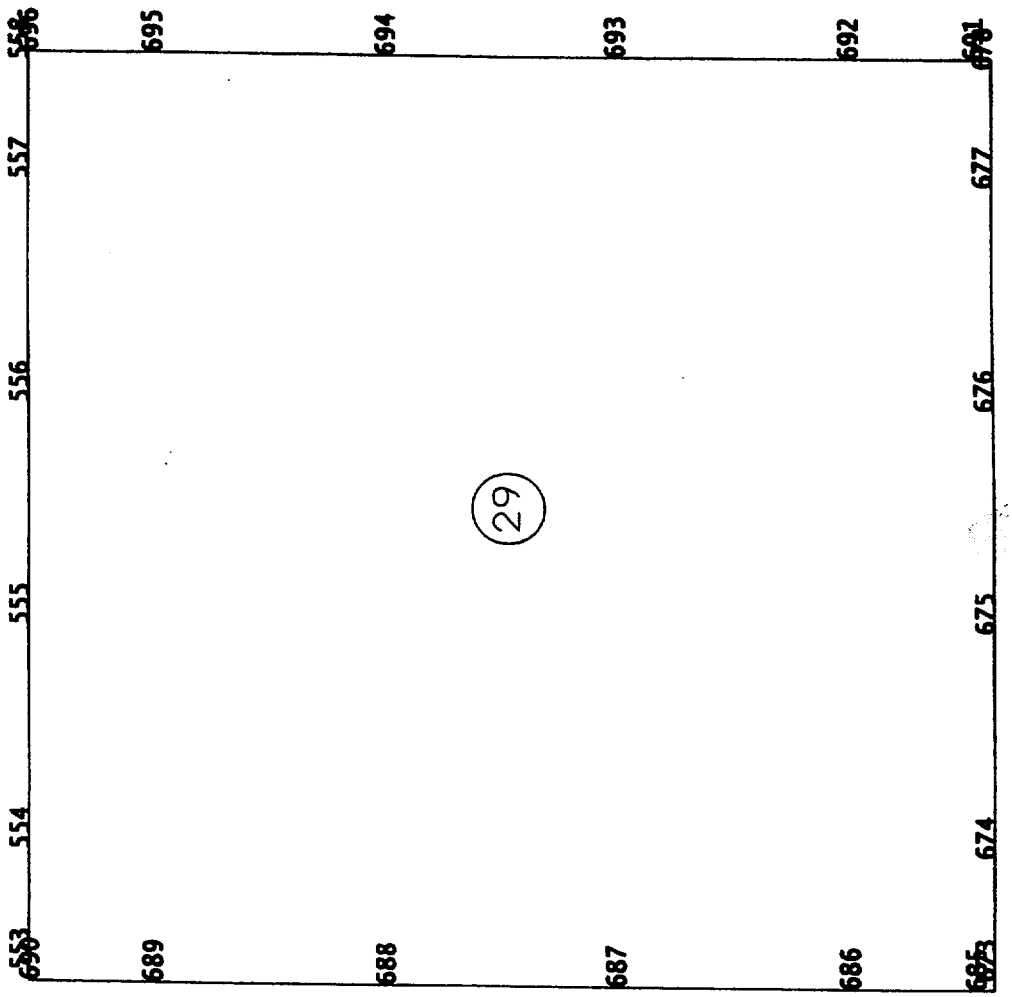

409
410
411
412
413
414
552
576
551
575
550
574
24
549
573
548
572
547
571
553
554
555
556
557
570

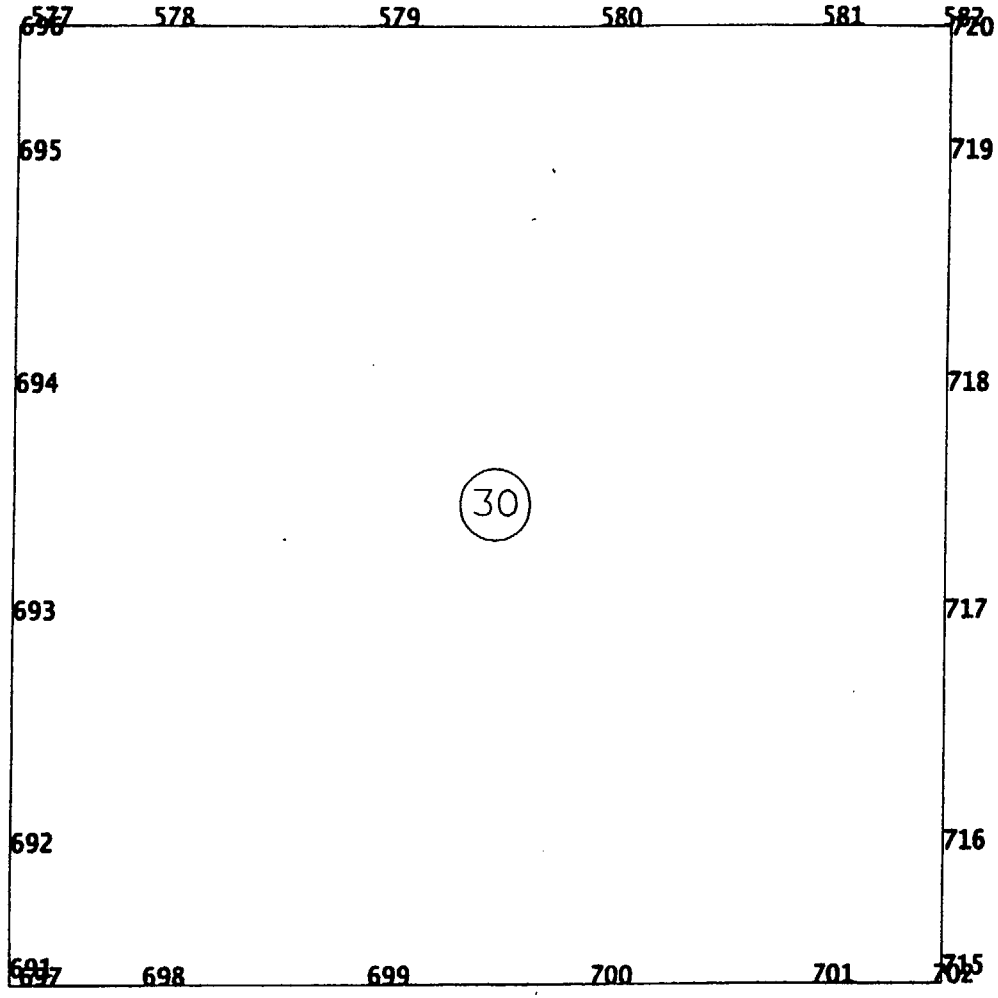

433
434
435
436
437
438
600
599
598
597
596
595
582
581
580
579
578
577
571
572
573
574
575
576
25

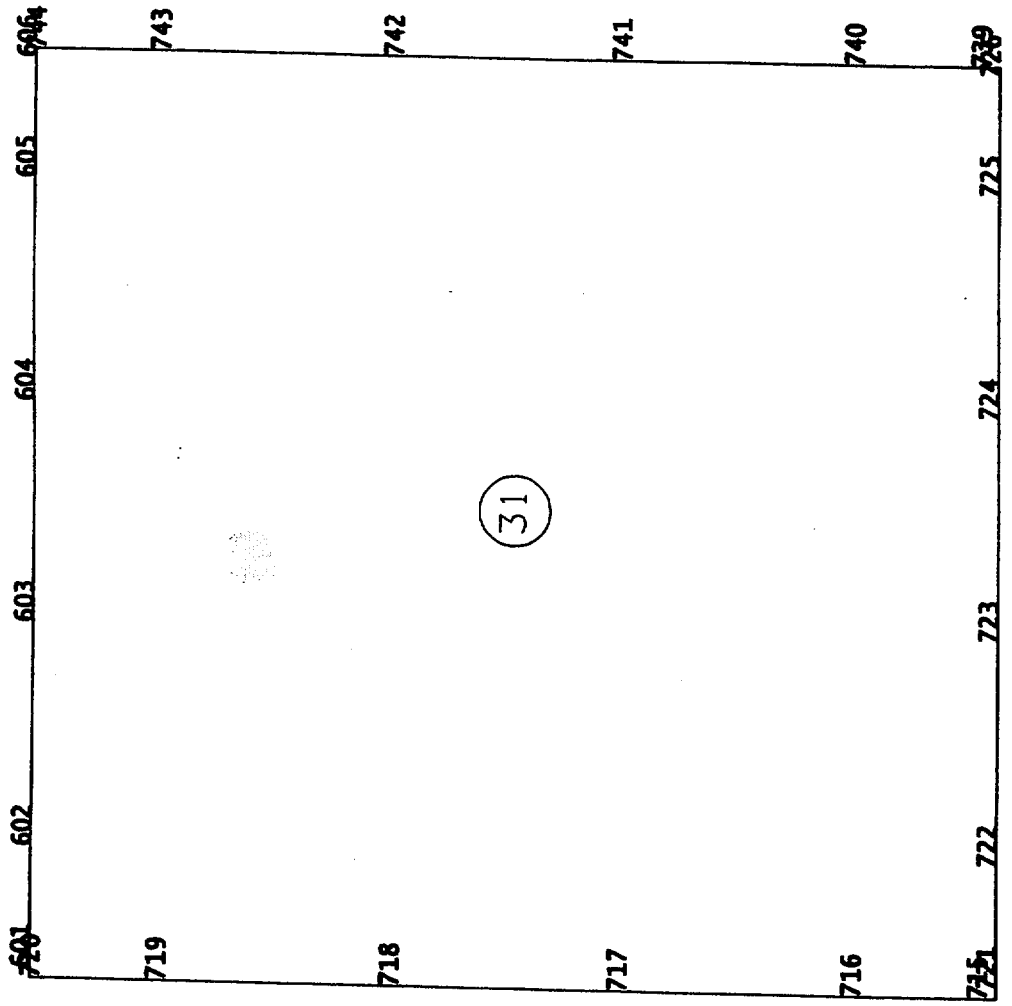

26
457
458
459
460
461
462
624
623
622
621
620
619
609
605
604
603
602
601
596
597
598
599
600

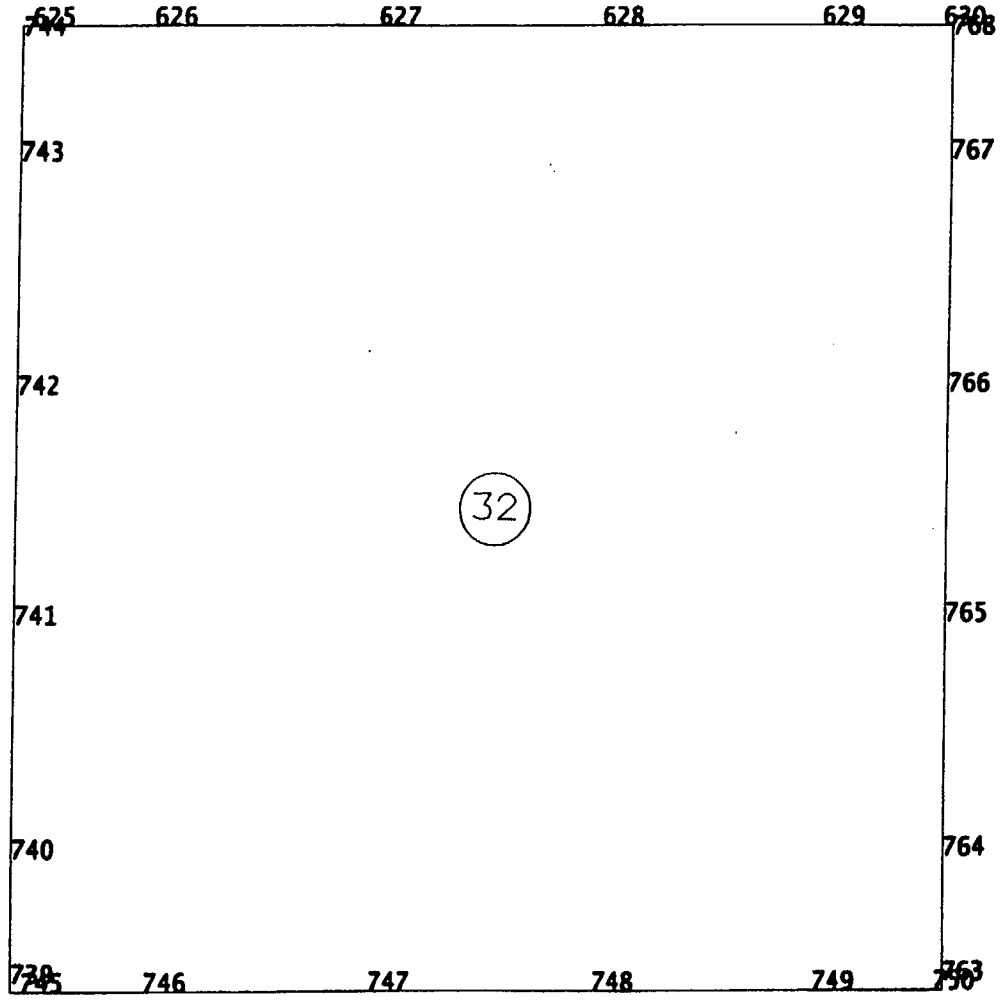

486
648
485
484
483
482
481
624
623
622
621
620
619
625
626
627
628
629
630
643
644
645
646
647
27


505
506
507
508
509
510
648
672
647
671
646
670
28
645
669
644
668
642
649
650
651
652
653
667
654


553
554
555
556
557
558
696
689
688
687
686
685
675
674
676
677
678
679
680
681
692
693
694
695
29

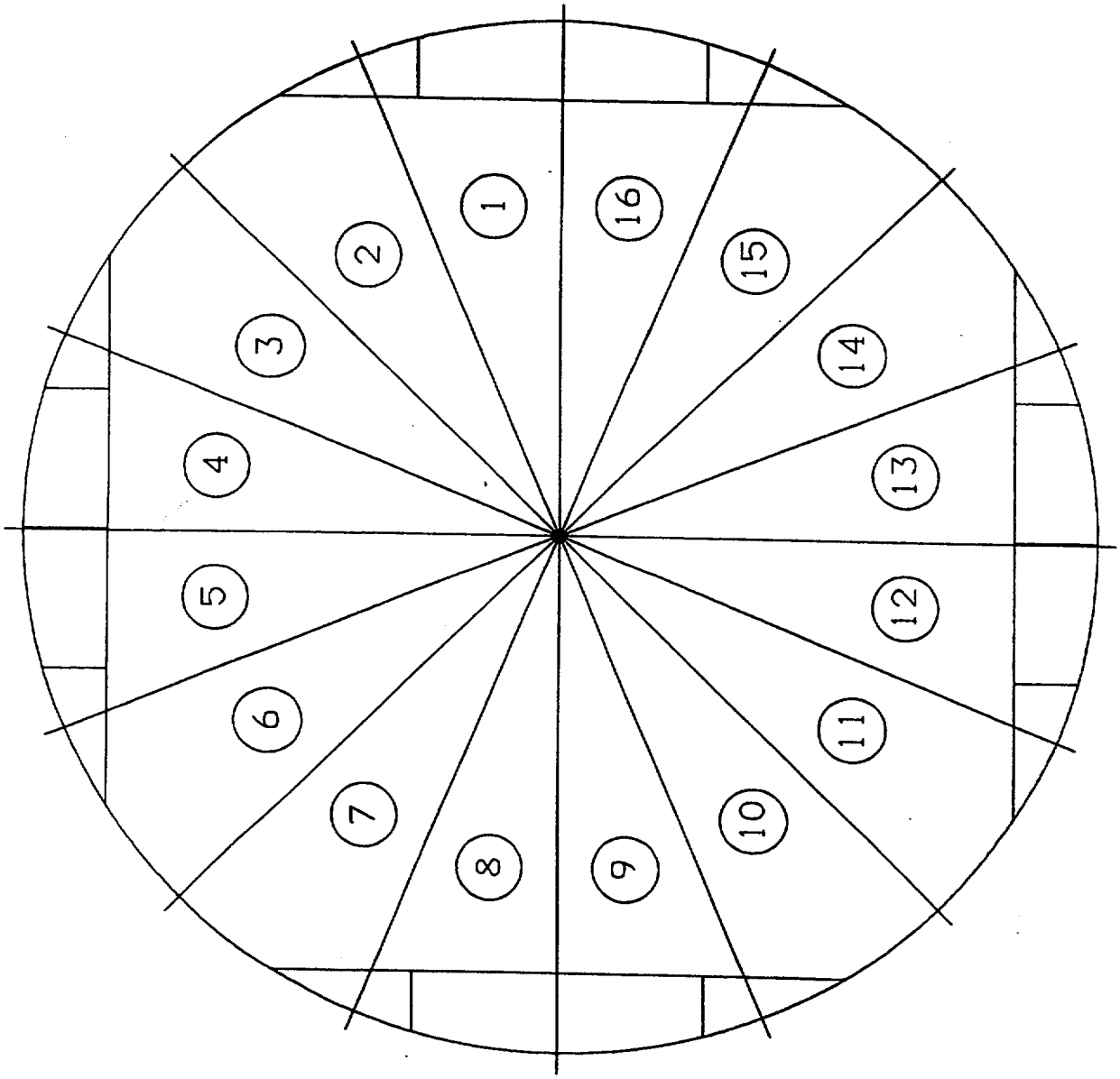

577
578
579
580
581
582
696
720
695
719
694
718
30
693
717
692
716
691
697
698
699
700
701
702
715

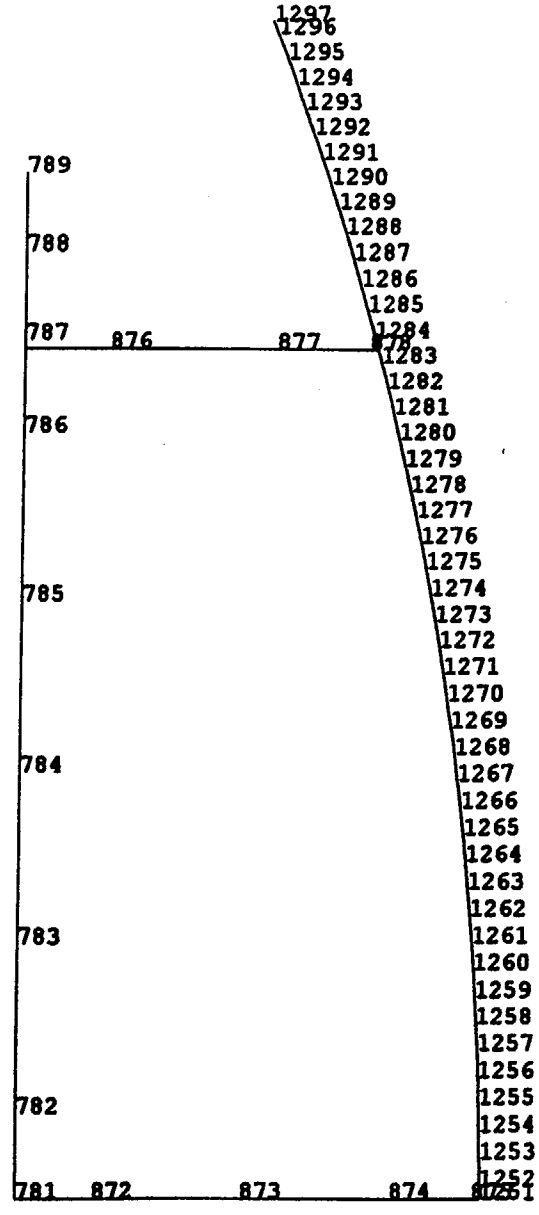

743
742
741
740
605
604
603
602
725
724
723
722
31
719
718
717
716

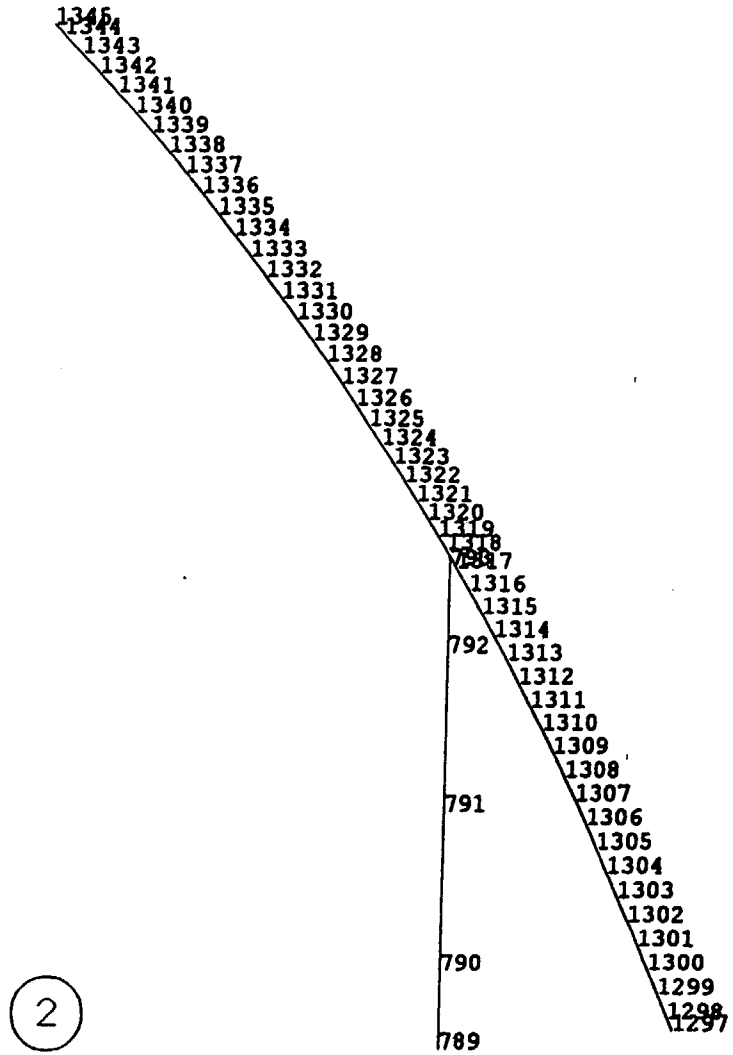

625
626
627
628
629
630
744
768
743
767
742
766
32
741
765
740
764
739
763
745
746
747
748
749
750

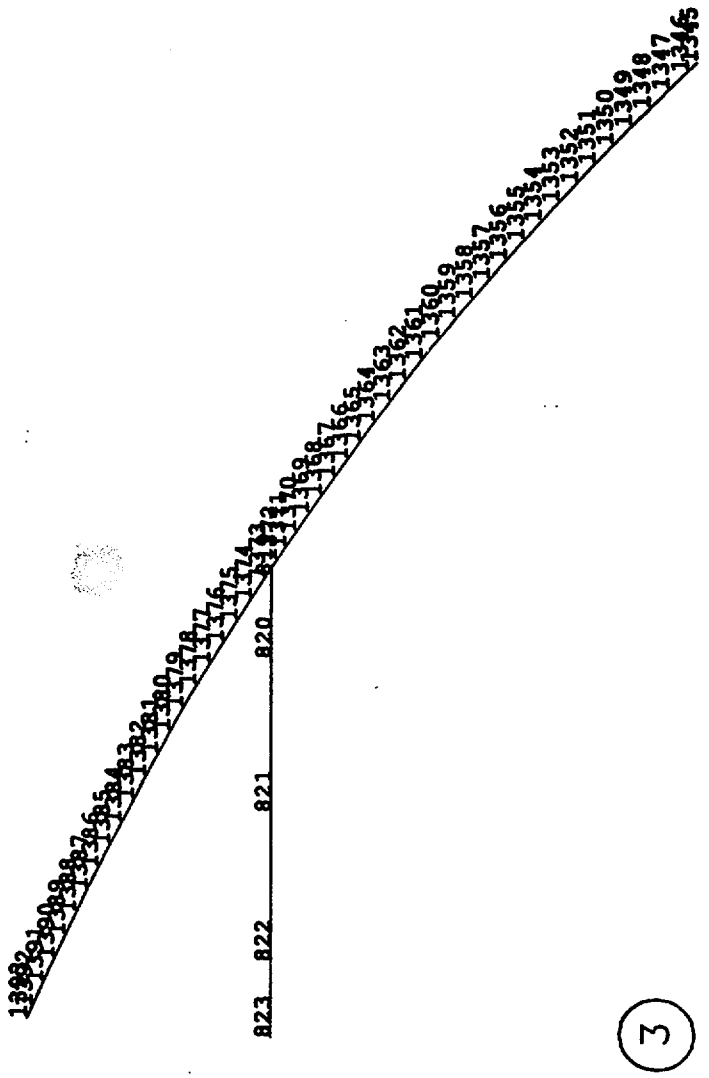
Appendix 3.Q - Detailed Finite Element Listings for the MPC-32 Enclosure Vessel

Eighteen (18) pages total including cover page

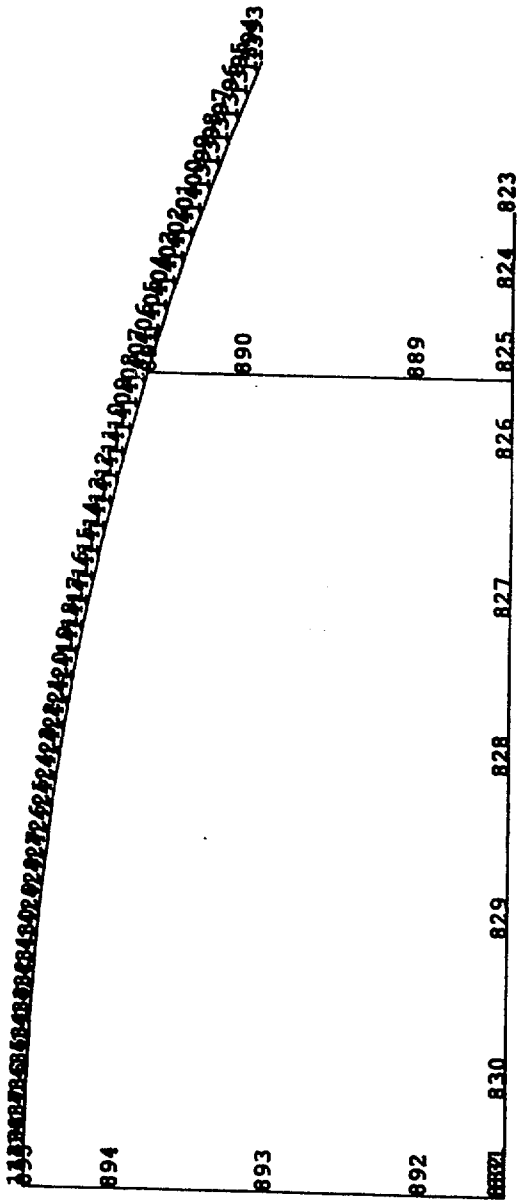

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16


1297
1296
1295
1294
1293
1292
1291
1290
1289
1288
1287
1286
1285
1284
1283
1282
1281
1280
1279
1278
1277
1276
1275
1274
1273
1272
1271
1270
1269
1268
1267
1266
1265
1264
1263
1262
1261
1260
1259
1258
1257
1256
1255
1254
1253
1252
1251
789
788
787
786
785
784
783
782
781
876
877
872
873
874
1

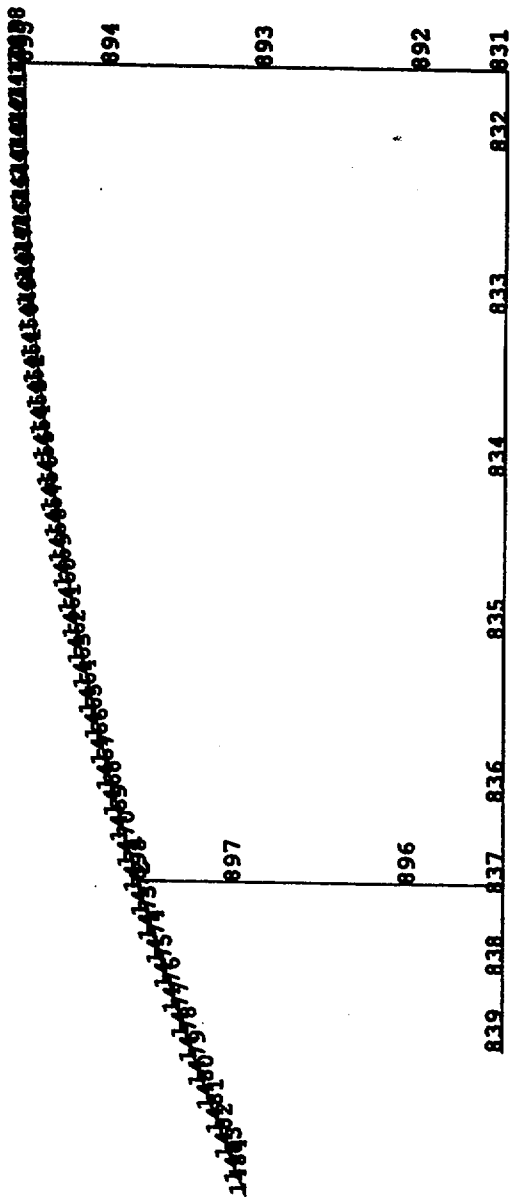

1345
1344
1343
1342
1341
1340
1339
1338
1337
1336
1335
1334
1333
1332
1331
1330
1329
1328
1327
1326
1325
1324
1323
1322
1321
1320
1319
1318
1317
1316
1315
1314
1313
1312
1311
1310
1309
1308
1307
1306
1305
1304
1303
1302
1301
1300
1299
1298
1297
792
791
790
789
2


13345
13346
13347
13348
13349
13350
13351
13352
13353
13354
13355
13356
13357
13358
13359
13360
13361
13362
13363
13364
13365
13366
13367
13368
13369
13370
13371
13372
13373
13374
13375
13376
13377
13378
13379
13380
13381
13382
13383
13384
13385
13386
13387
13388
13389
13390
13391
13392
820
821
822
823

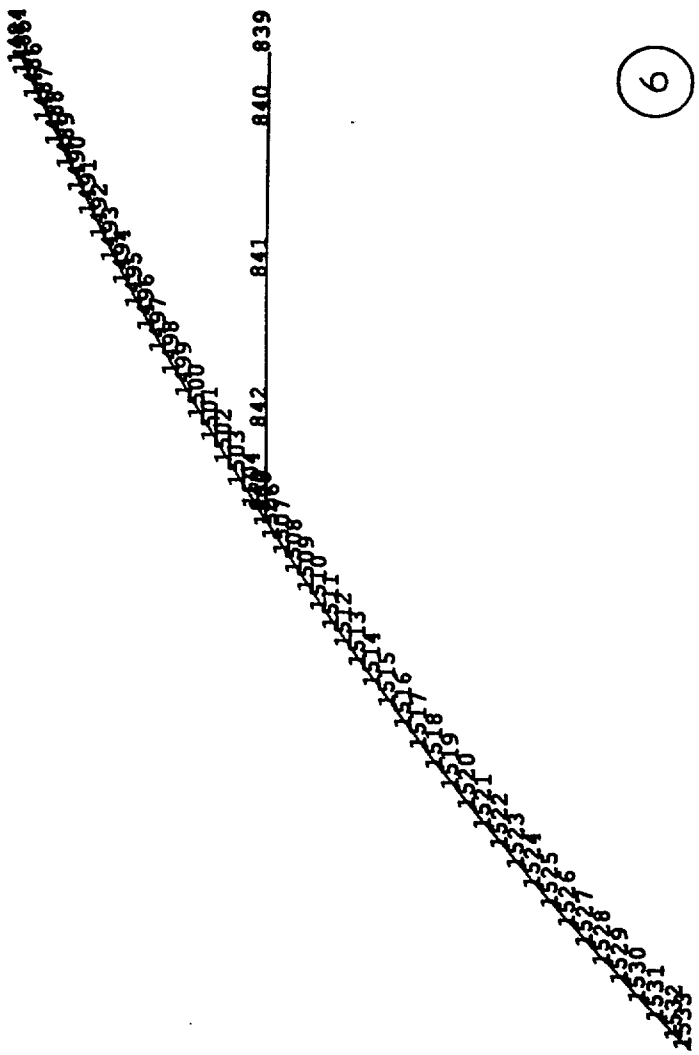
3



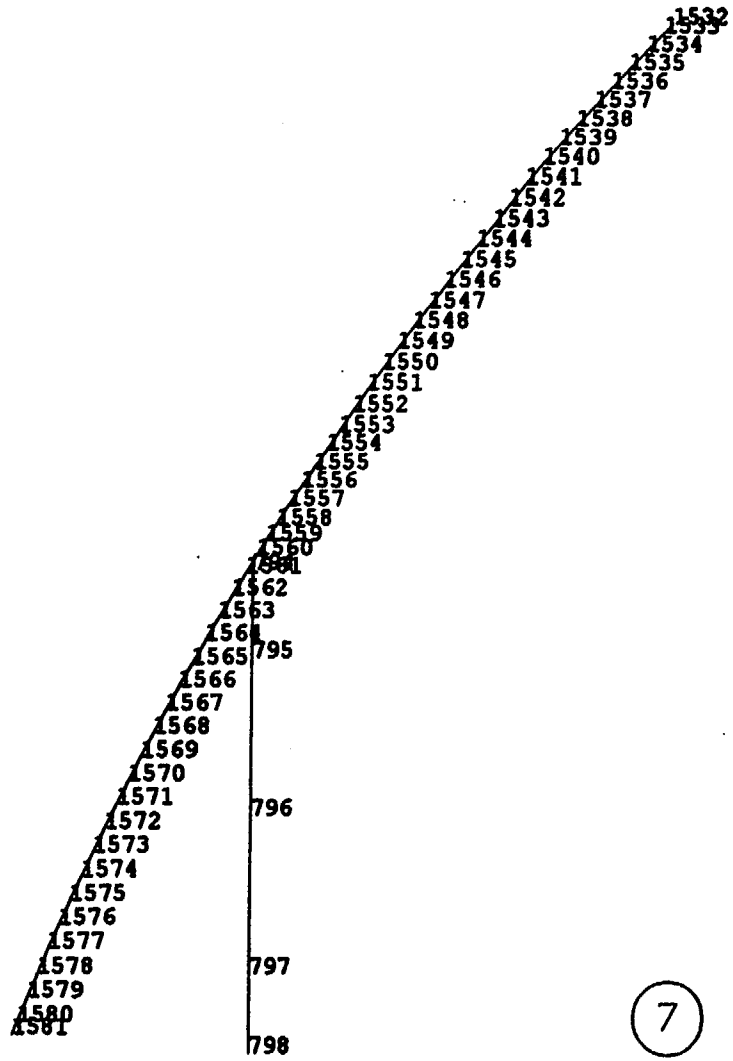
4

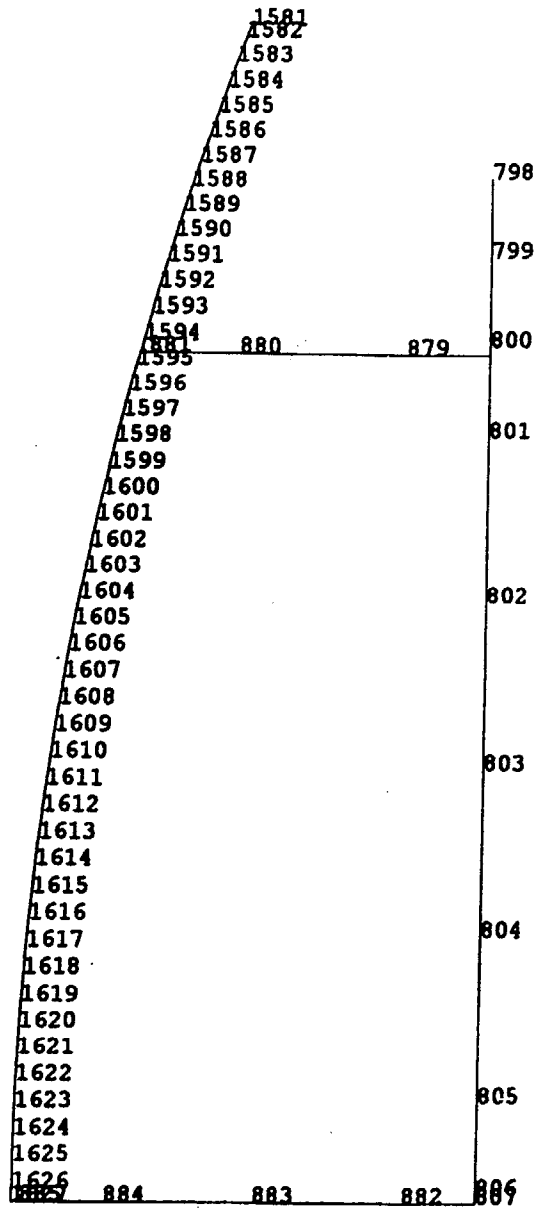


5

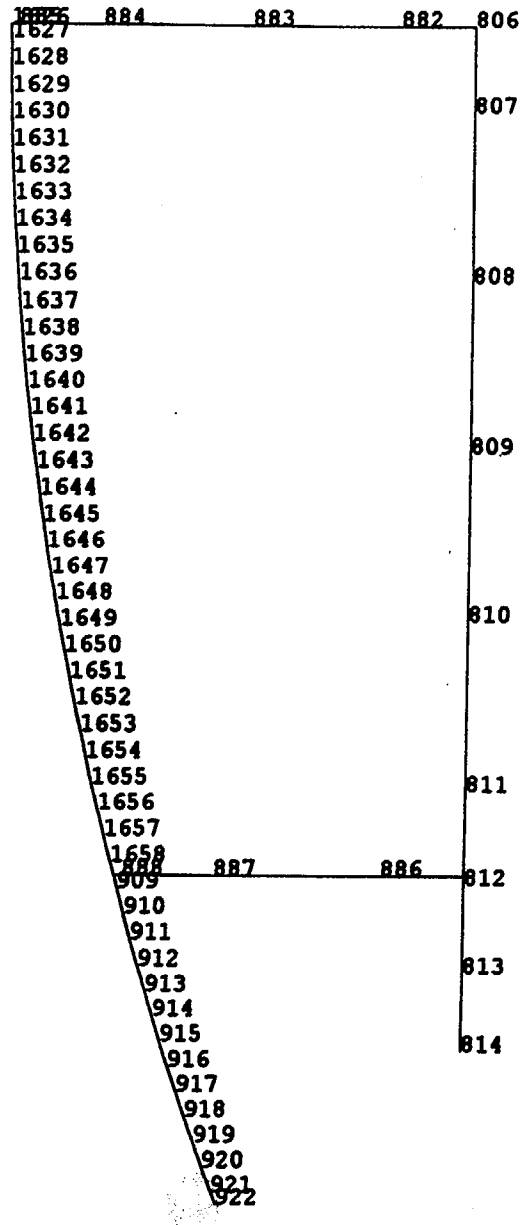


6

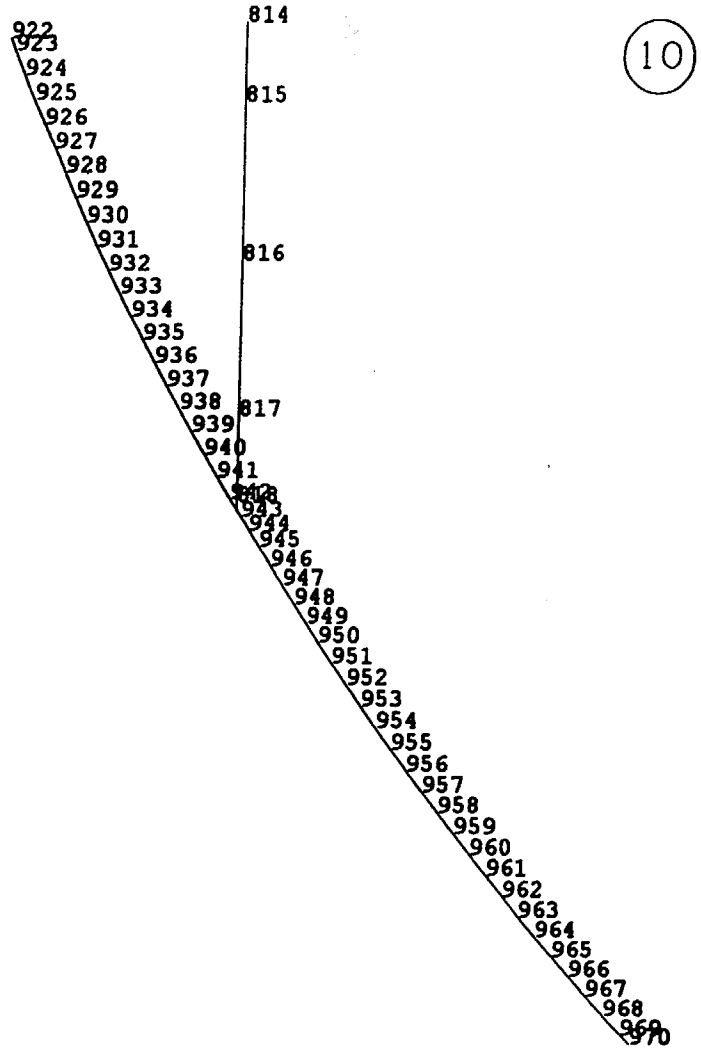

1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
795
796
797
798
7


1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
880
879
798
799
800
801
802
803
804
805
884
883
882

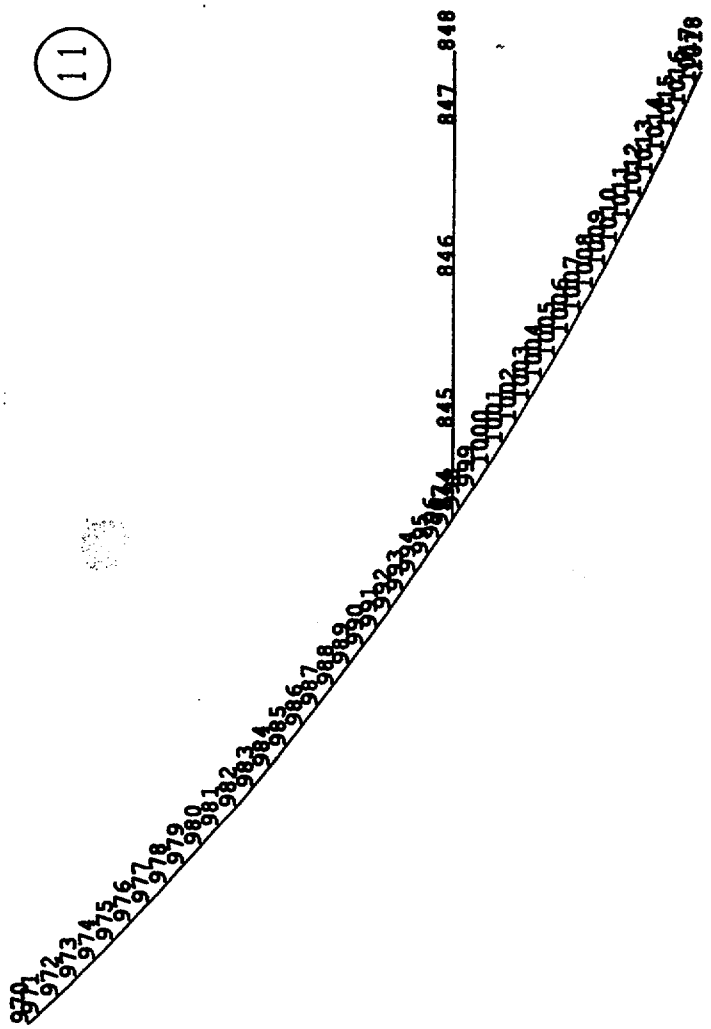
8


884
883
882
806
807
808
809
810
811
812
813
814
887
886
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
909
910
911
912
913
914
915
916
917
918
919
920
921
922

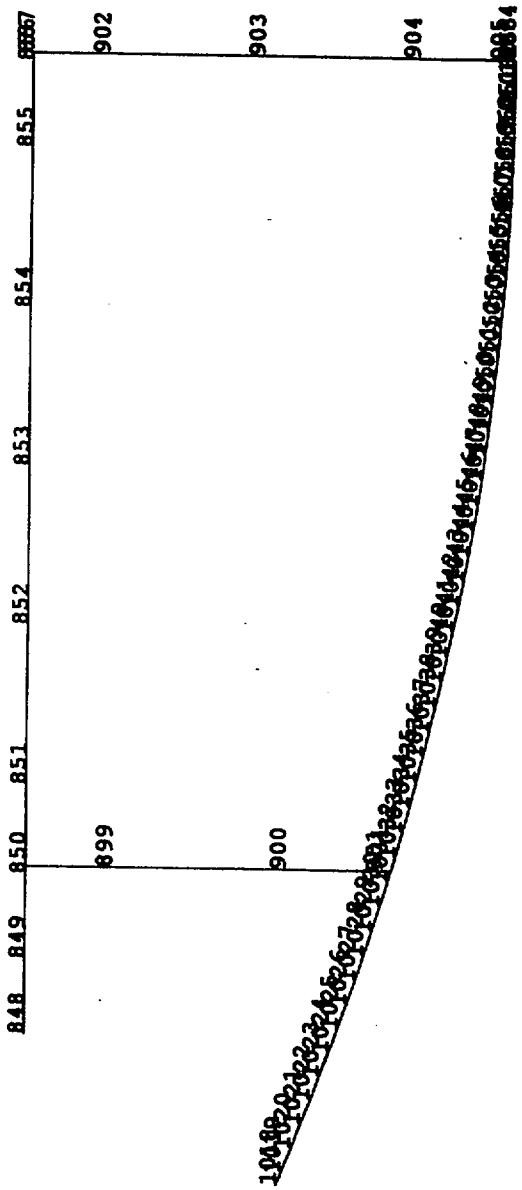
9

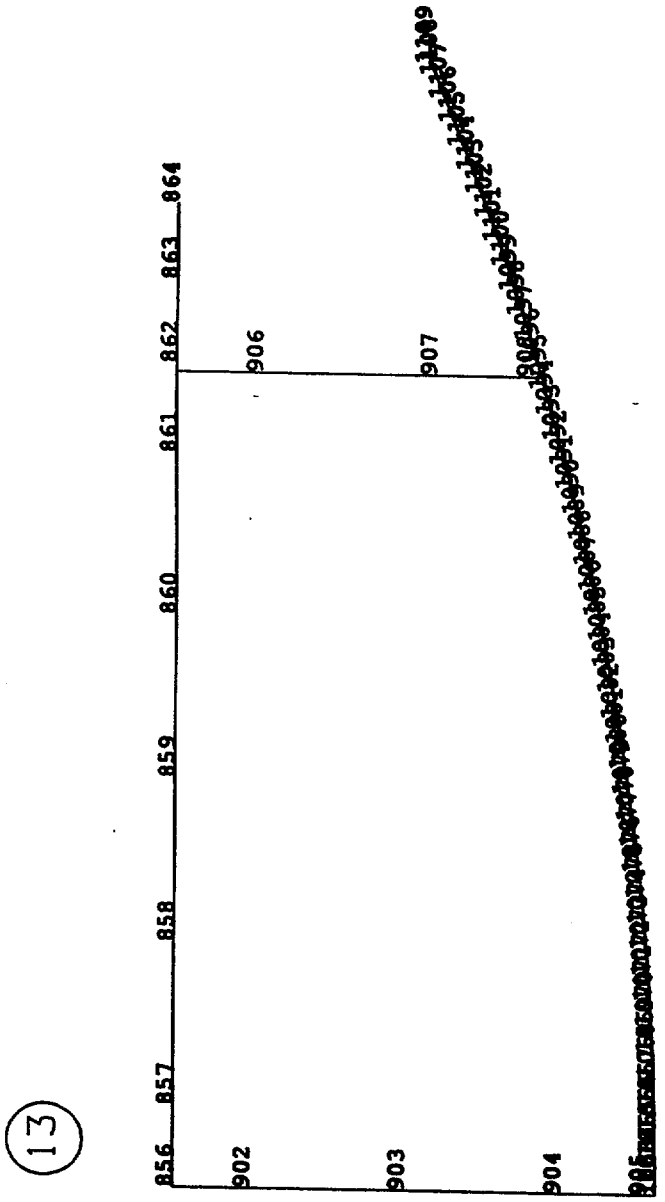

814
815
816
817
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970

10

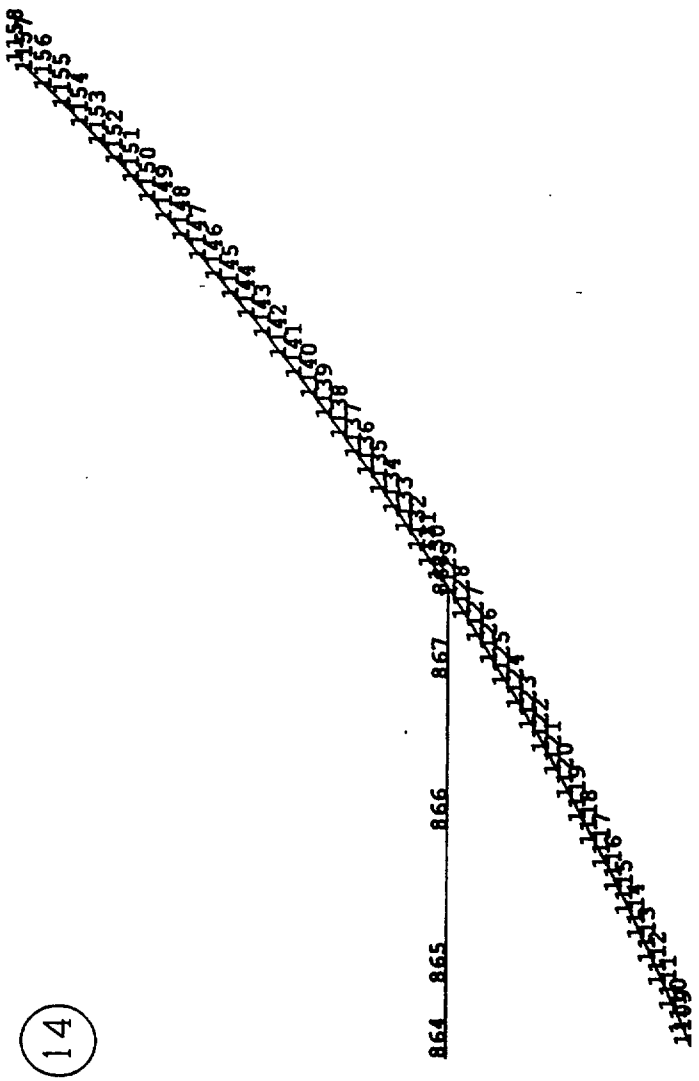

11
845
846
847
848

12

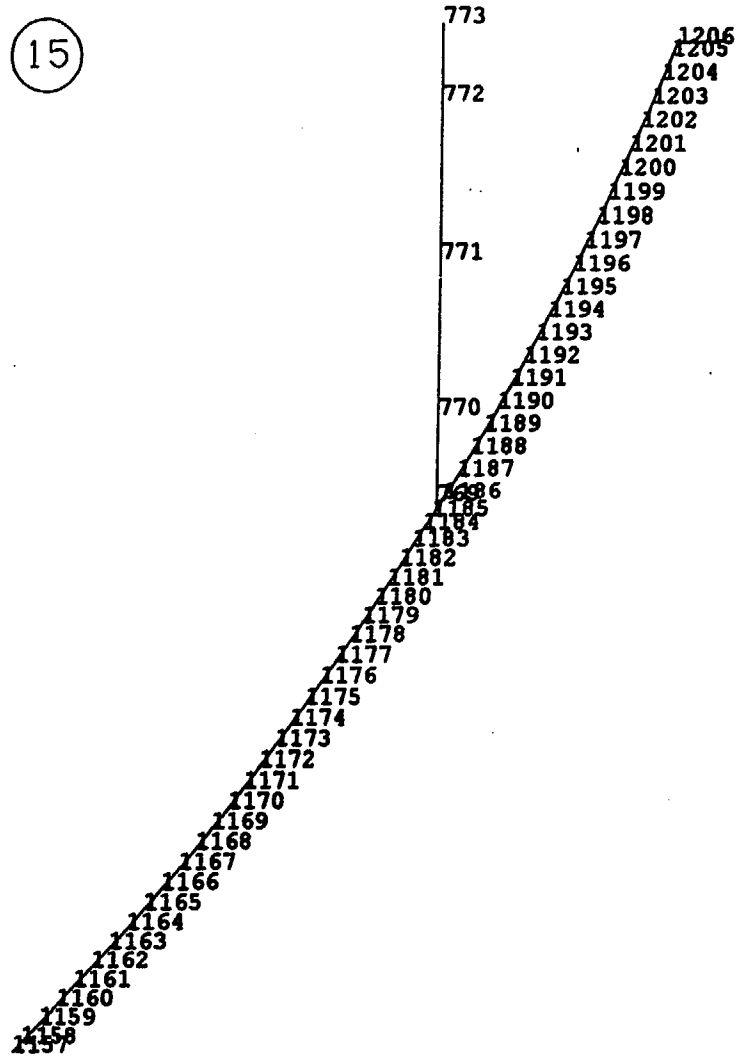




13


14
.864
.865
.866
.867

15


773
772
771
770
1206
1205
1204
1203
1202
1201
1200
1199
1198
1197
1196
1195
1194
1193
1192
1191
1190
1189
1188
1187
1186
1185
1184
1183
1182
1181
1180
1179
1178
1177
1176
1175
1174
1173
1172
1171
1170
1169
1168
1167
1166
1165
1164
1163
1162
1161
1160
1159
1158
1157

16

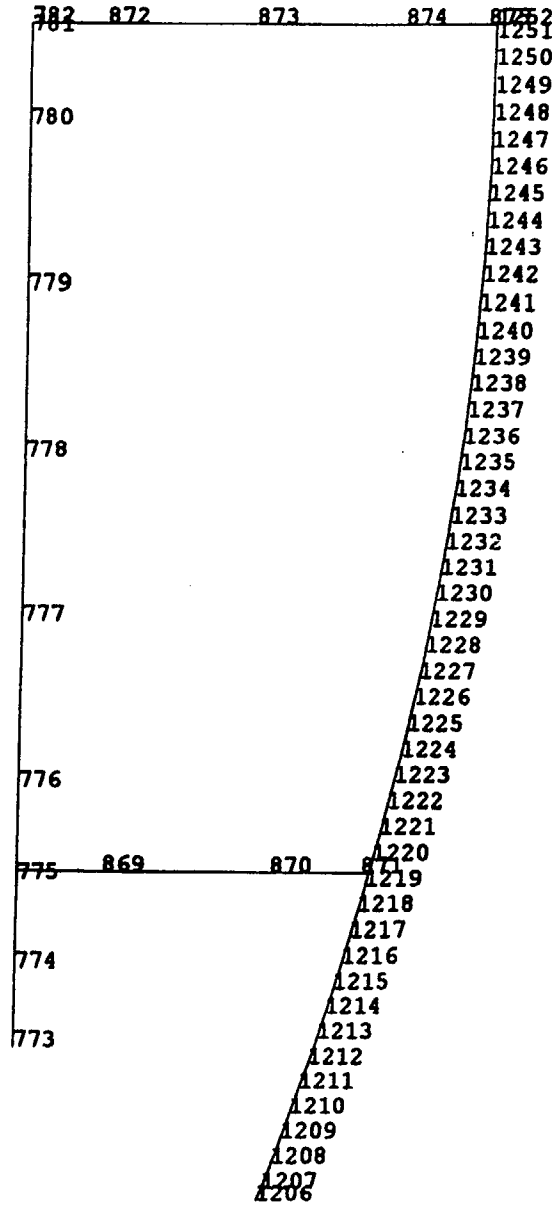

782
872
873
874
781
1251
1250
1249
1248
1247
1246
1245
1244
1243
1242
1241
1240
1239
1238
1237
1236
1235
1234
1233
1232
1231
1230
1229
1228
1227
1226
1225
1224
1223
1222
1221
1220
1219
1218
1217
1216
1215
1214
1213
1212
1211
1210
1209
1208
1207
1206
780
779
778
777
776
775
869
870
774
773

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 ELEM	CURRENT REF TEMP	CURRENT PM	PREVIOUS ALLOW	PREVIOUS 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

Table 3.T.13 (continued)

620	725.00	-7858.5	36950.	4.7019
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
453	725.00	-6420.6	36950.	5.7550
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
479	725.00	-5859.8	36950.	6.3056
432	725.00	-5823.9	36950.	6.3445
480	725.00	-5821.7	36950.	6.3469
499	725.00	-5356.8	36950.	6.8978
403	725.00	-5355.2	36950.	6.8998
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)

309	725.00	-4398.7	36950.	8.4002
310	725.00	-4360.6	36950.	8.4737
311	725.00	-4322.4	36950.	8.5484
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 ELEM	CURRENT REF TEMP	CURRENT PL+PB	PREVIOUS ALLOW	PREVIOUS 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 ELEM	CURRENT REF TEMP	MIXED PM	PREVIOUS ALLOW	PREVIOUS 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

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 ELEM	CURRENT REF TEMP	MIXED PL+PB	PREVIOUS ALLOW	PREVIOUS 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 ELEM	CURRENT REF TEMP	MIXED PM	PREVIOUS ALLOW	PREVIOUS 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 ELEM	CURRENT REF TEMP	MIXED PL+PB	PREVIOUS ALLOW	PREVIOUS 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 ELEM	CURRENT REF TEMP	CURRENT PM	PREVIOUS ALLOW	PREVIOUS 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

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)

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

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 ELEM	CURRENT REF TEMP	CURRENT PL+PB	PREVIOUS ALLOW	PREVIOUS 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 ELEM	CURRENT REF TEMP	MIXED PM	PREVIOUS ALLOW	PREVIOUS 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 ELEM	CURRENT REF TEMP	MIXED PL+PB	PREVIOUS ALLOW	PREVIOUS 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 ELEM	CURRENT REF TEMP	MIXED PM	PREVIOUS ALLOW	PREVIOUS 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 ELEM	CURRENT REF TEMP	MIXED PL+PB	PREVIOUS ALLOW	PREVIOUS 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 hottest cross section of the HI-STORM 100. 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 hottest location of the cask (see Figure 3.U.1 and Tables 4.4.9 and 4.4.36).

The temperature change at the overpack inner shell, $\Delta T_{1h} := 199 - 70$

The temperature change at the overpack outer shell, $\Delta T_{2h} := 145 - 70$

The temperature change at the mean radius of the MPC shell, $\Delta T_{3h} := 344 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (486 - 70) \cdot 1.1$

The temperature change at the center of the basket (helium gas), $\Delta T_{5h} := 650 - 70$

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, $R_{mpc} := \frac{68.375 \cdot in - 0.5 \cdot in}{2}$ $\quad R_{mpc} = 33.938\,in$

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, $AC_{bm} := 1.8125 \cdot in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875 \cdot in$

The outer radius of the basket, $R_b := R_{mpc} - \frac{0.5}{2} \cdot in - RC_{bm}$ $\quad R_b = 33.5\,in$

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

$$C_a := \Delta T_{1h} \qquad C_a = 129$$

$$C_b := \frac{\Delta T_{2h} - \Delta T_{1h}}{\ln\left(\frac{b}{a}\right)} \qquad C_b = -83.688$$

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, $Int = 1.533 \times 10^5\ in^2$

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:

$$Int_s := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\,dr$$

$$Int_s := \frac{1}{2} \cdot C_b \cdot \ln\left(\frac{b}{a}\right) \cdot b^2 + \frac{1}{2} \cdot C_a \cdot b^2 - \frac{1}{4} \cdot C_b \cdot b^2 + \frac{1}{4} \cdot C_b \cdot a^2 - \frac{1}{2} \cdot C_a \cdot a^2$$

$$Int_s = 1.533 \times 10^5\ in^2$$

We note that the values of Int and Ints are identical. The average temperature in the overpack cylinder (T_{bar}) is therefore determined as:

$$T_{bar} := \frac{2}{\left(b^2 - a^2\right)} \cdot Int \qquad T_{bar} = 96.348$$

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).

$$b_1 := r_4 + 0.5 \cdot t_4$$

$$b_1 = 66.25\,in$$

$$b = 66.25\,in$$

We note that the calculated value b_1 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:

$$\alpha_{avg} := \frac{r_1 \cdot t_1 \cdot \alpha_1 + r_2 \cdot t_2 \cdot \alpha_2 + r_3 \cdot t_3 \cdot \alpha_3 + r_4 \cdot t_4 \cdot \alpha_4}{\frac{a+b}{2} \cdot (t_1 + t_2 + t_3 + t_4)}$$

$$\alpha_{avg} = 5.628 \times 10^{-6}$$

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:

$$\Delta R_{ah} := \alpha_{avg} \cdot a \cdot T_{bar}$$

$$\Delta R_{ah} = 0.019\,in$$

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:

$$\Delta L_{ovph} := L_{ovp} \cdot \alpha_{avg} \cdot T_{bar}$$

$$\Delta L_{ovph} = 0.104\,in$$

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, $E := 28300000 \cdot psi$

$$\sigma_{ca} := \alpha_{avg} \cdot \frac{E}{a^2} \cdot \left[2 \cdot \frac{a^2}{\left(b^2 - a^2\right)} \cdot Int - \left(C_a\right) \cdot a^2 \right]$$

$$\sigma_{ca} = -5200\,psi$$

$$\sigma_{cb} := \alpha_{avg} \cdot \frac{E}{b^2} \cdot \left[2 \cdot \frac{b^2}{\left(b^2 - a^2\right)} \cdot Int - \left[C_a + C_b \cdot \left(\ln\left(\frac{b}{a}\right)\right)\right] \cdot b^2 \right]$$

$$\sigma_{cb} = 3400\,psi$$

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:

$$N := 0.37$$

$$r := a \cdot (1 - N) + N \cdot b$$

$$r = 46.405\,in$$

$$\sigma_r := \alpha_{avg} \cdot \frac{E}{r^2} \cdot \left[\frac{r^2 - a^2}{2} \cdot T_{bar} - \int_a^r \left[C_a + C_b \cdot \left(\ln\left(\frac{y}{a}\right)\right)\right] \cdot y\,dy \right]$$

$$\sigma_r = -678.201\,psi$$

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:

$$\Delta R_{mpch} := \alpha_{mpc} \cdot R_{mpc} \cdot \Delta T_{3h} \qquad \Delta R_{mpch} = 0.084\,in$$

$$\Delta L_{mpch} := \alpha_{mpc} \cdot L_{mpc} \cdot \Delta T_{3h} \qquad \Delta L_{mpch} = 0.471\,in$$

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:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch}$$

$$RG_{moh} = 0.435\,in$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch}$$

$$AG_{moh} = 0.633\,in$$

Note that this axial clearance (AG_{moh}) is based on the temperature distribution at the hottest cross section.

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 $\Delta T_{bas} := \Delta T_{5h} - \Delta T_{4h}$ $\qquad \Delta T_{bas} = 122.4$

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:

$$T_{bar} := \frac{2}{R_b^2} \cdot \left(\frac{-1}{4} \cdot \Delta T_{bas} \cdot R_b^2 + \frac{1}{2} \cdot \Delta T_{5h} \cdot R_b^2 \right)$$

$$T_{bar} = 518.8$$

The corresponding radial growth at the periphery (ΔR_{bh}) is therefore determined as:

$$\Delta R_{bh} := \alpha_{bas} \cdot R_b \cdot T_{bar}$$

$$\Delta R_{bh} = 0.167\,in$$

and the corresponding axial growth (ΔL_{bas}) is determined from [3.U.2] as:

$$\Delta L_{bh} := \Delta R_{bh} \cdot \frac{L_{bas}}{R_b}$$

$$\Delta L_{bh} = 0.879\,\text{in}$$

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:

$$RG_{bmh} := RC_{bm} - \Delta R_{bh} + \Delta R_{mpch}$$

$$RG_{bmh} = 0.104\,\text{in}$$

$$AG_{bmh} := AC_{bm} - \Delta L_{bh} + \Delta L_{mpch}$$

$$AG_{bmh} = 1.404\,\text{in}$$

3.U.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-Overpack	Fuel Basket-to-MPC Shell
$RG_{moh} = 0.435\,\text{in}$	$RG_{bmh} = 0.104\,\text{in}$
$AG_{moh} = 0.633\,\text{in}$	$AG_{bmh} = 1.404\,\text{in}$

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 axial location 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 calculations in Chapter 4, the following temperatures are appropriate at the hottest axial location of the cask (see Figure 3.V.1 and Tables 4.4.26 and 4.4.36).

The temperature change at the overpack inner shell, $\Delta T_{1h} := 199 - 70$

The temperature change at the overpack outer shell, $\Delta T_{2h} := 145 - 70$

The temperature change at the mean radius of the MPC shell, $\Delta T_{3h} := 351 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (496 - 70) \cdot 1.1$

The temperature change at the center of the basket (helium gas), $\Delta T_{5h} := 660 - 70$

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, $R_{mpc} := \frac{68.375 \cdot in - 0.5 \cdot in}{2}$ $\quad R_{mpc} = 33.938\,in$

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, $AC_{bm} := 1.8125 \cdot in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875 \cdot in$

The outer radius of the basket, $R_b := R_{mpc} - \frac{0.5}{2} \cdot in - RC_{bm}$ $\quad R_b = 33.5\,in$

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.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:

$$C_a + C_b \cdot \ln\left(\frac{r}{a}\right)$$

where

$$C_a := \Delta T_{1h} \qquad C_a = 129$$

$$C_b := \frac{\Delta T_{2h} - \Delta T_{1h}}{\ln\left(\frac{b}{a}\right)} \qquad C_b = -83.688$$

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, $Int = 1.533 \times 10^5\ in^2$

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:

$$Int_s := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\,dr$$

$$Int_s := \frac{1}{2} \cdot C_b \cdot \ln\left(\frac{b}{a}\right) \cdot b^2 + \frac{1}{2} \cdot C_a \cdot b^2 - \frac{1}{4} \cdot C_b \cdot b^2 + \frac{1}{4} \cdot C_b \cdot a^2 - \frac{1}{2} \cdot C_a \cdot a^2$$

$$Int_s = 1.533 \times 10^5\ in^2$$

We note that the values of Int and Ints are identical. The average temperature in the overpack cylinder (T_{bar}) is therefore determined as:

$$T_{bar} := \frac{2}{\left(b^2 - a^2\right)} \cdot Int \qquad T_{bar} = 96.348$$

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).

$$b_1 := r_4 + 0.5 \cdot t_4$$

$$b_1 = 66.25\,in$$

$$b = 66.25\,in$$

We note that the calculated value b_1 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:

$$\alpha_{avg} := \frac{r_1 \cdot t_1 \cdot \alpha_1 + r_2 \cdot t_2 \cdot \alpha_2 + r_3 \cdot t_3 \cdot \alpha_3 + r_4 \cdot t_4 \cdot \alpha_4}{\frac{a+b}{2} \cdot (t_1 + t_2 + t_3 + t_4)}$$

$$\alpha_{avg} = 5.628 \times 10^{-6}$$

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:

$$\Delta R_{ah} := \alpha_{avg} \cdot a \cdot T_{bar}$$

$$\Delta R_{ah} = 0.019\,in$$

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:

$$\Delta L_{ovph} := L_{ovp} \cdot \alpha_{avg} \cdot T_{bar}$$

$$\Delta L_{ovph} = 0.104\,in$$

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, $E := 28300000 \cdot psi$

$$\sigma_{ca} := \alpha_{avg} \cdot \frac{E}{a^2} \cdot \left[2 \cdot \frac{a^2}{\left(b^2 - a^2\right)} \cdot Int - \left(C_a\right) \cdot a^2 \right]$$

$$\sigma_{ca} = -5200\,psi$$

$$\sigma_{cb} := \alpha_{avg} \cdot \frac{E}{b^2} \cdot \left[2 \cdot \frac{b^2}{\left(b^2 - a^2\right)} \cdot Int - \left[C_a + C_b \cdot \left(\ln\left(\frac{b}{a}\right)\right)\right] \cdot b^2 \right]$$

$$\sigma_{cb} = 3400\,psi$$

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:

$$N := 0.37$$

$$r := a \cdot (1 - N) + N \cdot b$$

$$r = 46.405\,in$$

$$\sigma_r := \alpha_{avg} \cdot \frac{E}{r^2} \cdot \left[\frac{r^2 - a^2}{2} \cdot T_{bar} - \int_a^r \left[C_a + C_b \cdot \left(\ln\left(\frac{y}{a}\right)\right)\right] \cdot y\,dy \right]$$

$$\sigma_r = -678.201\,psi$$

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:

$$\Delta R_{mpch} := \alpha_{mpc} \cdot R_{mpc} \cdot \Delta T_{3h} \qquad \Delta R_{mpch} = 0.086\,in$$

$$\Delta L_{mpch} := \alpha_{mpc} \cdot L_{mpc} \cdot \Delta T_{3h} \qquad \Delta L_{mpch} = 0.483\,in$$

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:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch}$$

$$RG_{moh} = 0.433\,in$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch}$$

$$AG_{moh} = 0.621\,in$$

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 $\Delta T_{bas} := \Delta T_{5h} - \Delta T_{4h}$ $\qquad \Delta T_{bas} = 121.4$

Then the mean temperature can be defined as $T_{bar} := \dfrac{2}{R_b^{\,2}} \cdot \displaystyle\int_0^{R_b} \left(\Delta T_{5h} - \Delta T_{bas} \cdot \frac{r^2}{R_b^{\,2}} \right) \cdot r\,dr$

Using the Maple symbolic engine again, the closed form solution of the integral is:

$$T_{bar} := \frac{2}{R_b^{\,2}} \cdot \left(\frac{-1}{4} \cdot \Delta T_{bas} \cdot R_b^{\,2} + \frac{1}{2} \cdot \Delta T_{5h} \cdot R_b^{\,2} \right)$$

$$T_{bar} = 529.3$$

The corresponding radial growth at the periphery (ΔR_{bh}) is therefore determined as:

$$\Delta R_{bh} := \alpha_{bas} \cdot R_b \cdot T_{bar}$$

$$\Delta R_{bh} = 0.17\,in$$

and the corresponding axial growth (ΔL_{bas}) is determined from [3.V.2] as:

$$\Delta L_{bh} := \Delta R_{bh} \cdot \frac{L_{bas}}{R_b}$$

$$\Delta L_{bh} = 0.897\,\text{in}$$

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:

$$RG_{bmh} := RC_{bm} - \Delta R_{bh} + \Delta R_{mpch}$$

$$RG_{bmh} = 0.103\,\text{in}$$

$$AG_{bmh} := AC_{bm} - \Delta L_{bh} + \Delta L_{mpch}$$

$$AG_{bmh} = 1.398\,\text{in}$$

3.V.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-Overpack	Fuel Basket-to-MPC Shell
$RG_{moh} = 0.433\,\text{in}$	$RG_{bmh} = 0.103\,\text{in}$
$AG_{moh} = 0.621\,\text{in}$	$AG_{bmh} = 1.398\,\text{in}$

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 location 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 hottest location of the cask (see Figure 3.W.1 and Tables 4.4.10 and 4.4.36).

The temperature change at the overpack inner shell, $\Delta T_{1h} := 199 - 70$

The temperature change at the overpack outer shell, $\Delta T_{2h} := 145 - 70$

The temperature change at the mean radius of the MPC shell, $\Delta T_{3h} := 347 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (501 - 70) \cdot 1.1$

The temperature change at the center of the basket (helium gas), $\Delta T_{5h} := 720 - 70$

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, $b := 66.25\,in$

The inner radius of the overpack, $a := 34.75\,in$

The mean radius of the MPC shell, $R_{mpc} := \frac{68.375\,in - 0.5 \cdot in}{2}$ $\quad R_{mpc} = 33.938\,in$

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, $L_{ovp} := 191.5\,in$

The axial length of the MPC, $L_{mpc} := 190.5\,in$

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, $L_{bas} := 176.5\,in$

The initial basket-to-MPC lid nominal axial clearance, $AC_{bm} := 1.8125\,in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875\,in$

The outer radius of the basket, $R_b := R_{mpc} - \frac{0.5}{2} \cdot in - RC_{bm}$ $\quad R_b = 33.5\,in$

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.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

$$C_a := \Delta T_{1h} \qquad C_a = 129$$

$$C_b := \frac{\Delta T_{2h} - \Delta T_{1h}}{\ln\left(\frac{b}{a}\right)} \qquad C_b = -83.688$$

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, $Int = 1.533 \times 10^5\ in^2$

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:

$$Int_s := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\,dr$$

$$Int_s := \frac{1}{2} \cdot C_b \cdot \ln\left(\frac{b}{a}\right) \cdot b^2 + \frac{1}{2} \cdot C_a \cdot b^2 - \frac{1}{4} \cdot C_b \cdot b^2 + \frac{1}{4} \cdot C_b \cdot a^2 - \frac{1}{2} \cdot C_a \cdot a^2$$

$$Int_s = 1.533 \times 10^5\ in^2$$

We note that the values of Int and Ints are identical. The average temperature in the overpack cylinder (T_{bar}) is therefore determined as:

$$T_{bar} := \frac{2}{\left(b^2 - a^2\right)} \cdot Int \qquad T_{bar} = 96.348$$

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).

$$b_1 := r_4 + 0.5 \cdot t_4$$

$$b_1 = 66.25\,in$$

$$b = 66.25\,in$$

We note that the calculated value b_1 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:

$$\alpha_{avg} := \frac{r_1 \cdot t_1 \cdot \alpha_1 + r_2 \cdot t_2 \cdot \alpha_2 + r_3 \cdot t_3 \cdot \alpha_3 + r_4 \cdot t_4 \cdot \alpha_4}{\frac{a+b}{2} \cdot (t_1 + t_2 + t_3 + t_4)}$$

$$\alpha_{avg} = 5.628 \times 10^{-6}$$

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:

$$\Delta R_{ah} := \alpha_{avg} \cdot a \cdot T_{bar}$$

$$\Delta R_{ah} = 0.019\,in$$

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:

$$\Delta L_{ovph} := L_{ovp} \cdot \alpha_{avg} \cdot T_{bar}$$

$$\Delta L_{ovph} = 0.104\,in$$

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, $E := 28300000\,psi$

$$\sigma_{ca} := \alpha_{avg} \cdot \frac{E}{a^2} \cdot \left[2 \cdot \frac{a^2}{\left(b^2 - a^2\right)} \cdot Int - \left(C_a\right) \cdot a^2 \right]$$

$$\sigma_{ca} = -5200\,psi$$

$$\sigma_{cb} := \alpha_{avg} \cdot \frac{E}{b^2} \cdot \left[2 \cdot \frac{b^2}{\left(b^2 - a^2\right)} \cdot Int - \left[C_a + C_b \cdot \left(\ln\left(\frac{b}{a}\right)\right)\right] \cdot b^2 \right]$$

$$\sigma_{cb} = 3400\,psi$$

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:

$$N := 0.38$$

$$r := a \cdot (1 - N) + N \cdot b$$

$$r = 46.72\,in$$

$$\sigma_r := \alpha_{avg} \cdot \frac{E}{r^2} \cdot \left[\frac{r^2 - a^2}{2} \cdot T_{bar} - \int_a^r \left[C_a + C_b \cdot \left(\ln\left(\frac{y}{a}\right)\right)\right] \cdot y\,dy \right]$$

$$\sigma_r = -677.823\,psi$$

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:

$$\Delta R_{mpch} := \alpha_{mpc} \cdot R_{mpc} \cdot \Delta T_{3h} \qquad \Delta R_{mpch} = 0.085\,in$$

$$\Delta L_{mpch} := \alpha_{mpc} \cdot L_{mpc} \cdot \Delta T_{3h} \qquad \Delta L_{mpch} = 0.476\,in$$

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:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch}$$

$$RG_{moh} = 0.434\,in$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch}$$

$$AG_{moh} = 0.628\,in$$

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 $\Delta T_{bas} := \Delta T_{5h} - \Delta T_{4h}$ $\qquad \Delta T_{bas} = 175.9$

Then the mean temperature can be defined as $T_{bar} := \dfrac{2}{R_b^{\,2}} \cdot \displaystyle\int_0^{R_b} \left(\Delta T_{5h} - \Delta T_{bas} \cdot \frac{r^2}{R_b^{\,2}} \right) \cdot r\,dr$

Using the Maple symbolic engine again, the closed form solution of the integral is:

$$T_{bar} := \frac{2}{R_b^{\,2}} \cdot \left(\frac{-1}{4} \cdot \Delta T_{bas} \cdot R_b^{\,2} + \frac{1}{2} \cdot \Delta T_{5h} \cdot R_b^{\,2} \right)$$

$$T_{bar} = 562.05$$

The corresponding radial growth at the periphery (ΔR_{bh}) is therefore determined as:

$$\Delta R_{bh} := \alpha_{bas} \cdot R_b \cdot T_{bar}$$

$$\Delta R_{bh} = 0.181\,in$$

and the corresponding axial growth (ΔL_{bas}) is determined from [3.W.2] as:

$$\Delta L_{bh} := \Delta R_{bh} \cdot \frac{L_{bas}}{R_b}$$

$$\Delta L_{bh} = 0.952\,\text{in}$$

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:

$$RG_{bmh} := RC_{bm} - \Delta R_{bh} + \Delta R_{mpch}$$

$$RG_{bmh} = 0.091\,\text{in}$$

$$AG_{bmh} := AC_{bm} - \Delta L_{bh} + \Delta L_{mpch}$$

$$AG_{bmh} = 1.336\,\text{in}$$

3.W.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-Overpack	Fuel Basket-to-MPC Shell
$RG_{moh} = 0.434\,\text{in}$	$RG_{bmh} = 0.091\,\text{in}$
$AG_{moh} = 0.628\,\text{in}$	$AG_{bmh} = 1.336\,\text{in}$

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.

$$S_p = 55{,}450 \text{ psi at } 725°\text{F}$$

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	**1.40~~828~~**	**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)

$$S_W = \frac{45\,x\,(7.56+17.48)\,x\,1.732}{1.414\,x0.3\,x\,(1/16\,\text{in.})\,(139\,\text{in.})} = 530\ \text{psi}$$

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:

$NC_{32} := 6$ $\qquad NC_{68} := 8$ $\qquad NC_{24} := 7$

The total normal load per unit length on the fuel basket support for each MPC type is therefore computed as:

$$P_{32} := Q_{32} \cdot \frac{NC_{32}}{32} \qquad P_{32} = 3.287 \times 10^3 \frac{lbf}{in}$$

$$P_{68} := Q_{68} \cdot \frac{NC_{68}}{68} \qquad P_{68} = 1.975 \times 10^3 \frac{lbf}{in}$$

$$P_{24} := Q_{24} \cdot \frac{NC_{24}}{24} \qquad P_{24} = 4.829 \times 10^3 \frac{lbf}{in}$$

$$P_{24e} := Q_{24e} \cdot \frac{NC_{24}}{24} \qquad P_{24e} = 4.829 \times 10^3 \frac{lbf}{in}$$

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.

$$M_o := \frac{9}{16} \cdot \frac{Pw^2}{(S + 3 \cdot w)}$$

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

$$\tau_{weld} := \frac{R_{32}}{t_w} \qquad \tau_{weld} = 3.09 \times 10^3 \text{ psi}$$

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

$$\sigma_{bending} := 6 \cdot \frac{M_o}{t_{wall}^2} \qquad \sigma_{bending} = 4.413 \times 10^3 \text{ psi}$$

The direct stress in the basket support angled section is

$$\sigma_{direct} := \frac{\left(R_{32} \cdot \sin(\theta_{32}) + .5 \cdot P_{32} \cdot \cos(\theta_{32})\right)}{t_{wall}} \qquad \sigma_{direct} = 5.331 \times 10^3 \text{ psi}$$

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

$$H_{24} := L_{24} \cdot \tan(\theta_{24}) \qquad H_{24} = 0.634 \, in \qquad w_{24} = 0.531 \, in$$

$$S := \sqrt{L_{24}^2 + H_{24}^2} \qquad S = 4.05 \, in$$

$$M_o := \frac{9}{16} \cdot \frac{\left(P_{24} \cdot w_{24}^2\right)}{\left(S + 3 \cdot w_{24}\right)} * \qquad M_o = 135.848\,\text{lbf} \cdot \frac{\text{in}}{\text{in}}$$

$$R_{24} := \frac{P_{24} \cdot H_{24}}{2 \cdot L_{24}} + \frac{M_o}{L_{24}} * \qquad R_{24} = 416.411\,\frac{\text{lbf}}{\text{in}}$$

$$M_p := \frac{P_{24}}{2} \cdot \frac{w_{24}}{2} - M_o * \qquad M_p = 505.553\,\text{lbf} \cdot \frac{\text{in}}{\text{in}}$$

The weld stress is

$$\tau_{weld} := \frac{R_{24}}{t_w} \qquad \tau_{weld} = 4.711 \times 10^3\,\text{psi}$$

For this event, the safety factor on the weld is

$$SF_{weld} := \frac{\tau_{all}}{\tau_{weld}} \qquad SF_{weld} = 1.997$$

The maximum bending stress in the angled member is

$$\sigma_{bending} := 6 \cdot \frac{M_o}{t_{wall}^2} \qquad \sigma_{bending} = 8.347 \times 10^3\,\text{psi}$$

The direct stress in the basket support angled section is

$$\sigma_{direct} := \frac{\left(R_{24} \cdot \sin\left(\theta_{24}\right) + .5 \cdot P_{24} \cdot \cos\left(\theta_{24}\right)\right)}{t_{wall}} \qquad \sigma_{direct} = 7.84 \times 10^3\,\text{psi}$$

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

$H := 4 \cdot 0.21651 \cdot p$ $H = 0.144\,in$

$Depth_{ext} := \frac{17}{24} \cdot H$ $Depth_{ext} = 0.102\,in$

$Depth_{int} := \frac{5}{8} \cdot H$ $Depth_{int} = 0.09\,in$

$dmaj_{ext} := dm_{ext} + 2 \cdot Depth_{ext}$ $dmaj_{ext} = 1.5\,in$

Using page 103 of reference 3.AC.2,

$$Bolt\_thrd\_shr\_A := \pi \cdot N \cdot L_{eng} \cdot dm_{int} \cdot \left[\frac{1}{2 \cdot N} + .57735 \cdot \left(d_{pitch} - dm_{int} \right) \right]$$

$$Bolt\_thrd\_shr\_A = 4.662\,in^2$$

$$Ext\_thrd\_shr\_A := \pi \cdot N \cdot L_{eng} \cdot dmaj_{ext} \cdot \left[\frac{1}{2 \cdot N} + 0.57735 \cdot \left(dmaj_{ext} - d_{pitch} \right) \right]$$

$$Ext\_thrd\_shr\_A = 6.186\,in^2$$

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):

$Load\_Capacity_{bolt} := 21400 \cdot lbf$ $Load\_Capacity_{bolt} = 2.14 \times 10^4\,lbf$

$$Load\_Capacity_{lid} := \left(0.577 \cdot S_{ylid}\right) \cdot Ext\_thrd\_shr\_A$$

$$Load\_Capacity_{lid} = 3.944 \times 10^4\ lbf$$

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.

$$Max\_Lift\_Load := NB \cdot Load\_Capacity_{lid} \qquad Max\_Lift\_Load = 1.578 \times 10^5\ lbf$$

$$SF := \frac{Max\_Lift\_Load}{W_{lift}} \qquad SF = 5.38 \qquad > 1$$

Even though a vertical lift is required, the safety factor is consistently and conservatively computed based on the assumed lift angle:

or

$$SF := \frac{NB \cdot Load\_Capacity_{bolt} \cdot 0.844}{W_{lift}} \qquad SF = 2.464 \qquad > 1$$

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,

$$\frac{(90 \cdot deg - ang)}{45 \cdot deg} \cdot 0.70 = 0.156 \qquad 1 - .156 = 0.844$$

3.AC.8 <u>Input Data for Lifting of HI-TRAC Pool Lid</u>

Lifted Weight: (the HI-TRAC 125 pool lid bounds all other lids - this is the only load)

$Weight := 12500 \cdot lbf$ Table 3.2.2. This load bounds all other lids that may be lifted.

$ang := 45 \cdot deg$ Minimum Lift Angle from Horizontal (to bound all lifts other than the HI-STORM 100 top lid)

$inertia\_load\_factor := .15$

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

$W_{td} := W_{tp} + W_{lead} + W_{bp} + W_{ha} + W_{mp}$ $W_{td} = 9.949 \times 10^3 lbf$

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:

$$Moment := \frac{(W_{mpc} + W_{td})}{2} \cdot \frac{L}{8} \qquad Moment = 4.545 \times 10^5 \, lbf \cdot in$$

The bending stress is

$$\sigma := \frac{Moment \cdot (h - yc) \cdot (1 + DLF)}{Inertia} \qquad \sigma = 3.127 \times 10^3 \, psi$$

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,

$$Sy := S_y$$

$$SF_{3.61} := \frac{Sy}{3 \cdot \sigma} \qquad SF_{3.61} = 3.486$$

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

$$span := 12.5 \cdot in$$

Calculate the pressure on each half of lid door due to MPC.

$$p := \frac{.5 \cdot W_{mpc} \cdot (1 + DLF)}{L \cdot w} \qquad p = 28.454 \, psi$$

Calculate the pressure due to self weight

$$p_d := .5 \cdot (W_{tp}) \cdot \frac{1 + DLF}{L \cdot w} \qquad p_d = 1.189 \, psi$$

Bending moment due to pressure

$$Moment := \frac{(p + p_d) \cdot L \cdot span^2}{8} \qquad Moment = 4.212 \times 10^4 \, lbf \cdot in$$

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

$$Load := (p + p_d) \cdot L \cdot w \qquad Load = 5.391 \times 10^4\,lbf$$

The shear stress at the weld connection is (conservatively neglect stiffener welds)

$$\tau := \frac{Load}{2 \cdot w \cdot t_{tp}} \qquad \tau = 479.227\,psi \qquad \text{Low!}$$

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

$x := (.5 \cdot 93) \cdot in - 36.375 \cdot in$ $\qquad x = 10.125\,in$

dimension "b" $\qquad b := x - t_1 - t_{21} - .5 \cdot t_1$ $\qquad b = 4.375\,in$

dimension "a" $\qquad a := x - b$ $\qquad a = 5.75\,in$

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

$$\sigma_1 := \frac{F_1}{L_H \cdot t_1} \qquad \sigma_1 = 1.377 \times 10^3 \, psi$$

$$\sigma_2 := \frac{F_2}{L_H \cdot t_2} \qquad \sigma_2 = 892.822 \, psi$$

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

$$A_b := 0.605 \cdot in^2 \qquad d_{bolt} := 1 \cdot in$$

The bolt circle radius is

$$R_b := 45 \cdot in$$

The bolt angular spacing is $\theta := 10 \cdot deg$

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:

$$A_{total} := 9 \cdot A_b \qquad A_{total} = 5.445 \, in^2$$

Compute the following sum:

$$Sum := 2 \cdot A_b \cdot R_b \cdot (1 - \cos(4 \cdot \theta)) + 2 \cdot A_b \cdot R_b \cdot (1 - \cos(3 \cdot \theta)) \ldots$$
$$+ 2 \cdot A_b \cdot R_b \cdot (1 - \cos(2 \cdot \theta)) + 2 \cdot A_b \cdot R_b \cdot (1 - \cos(\theta))$$

$$Sum = 24.145\,in^3$$

Then the centroid of the bolts is $X_{bar} := \frac{Sum}{A_{total}}$ $\quad X_{bar} = 4.434\,in$

Compute the bolt moment of inertia about the centroid by first locating each bolt relative to the centroid. First compute some distances "z":

$z_1 := R_b \cdot (1 - \cos(4 \cdot \theta)) - X_{bar}$ $\quad z_1 = 6.094\,in$

$z_2 := R_b \cdot (1 - \cos(3 \cdot \theta)) - X_{bar}$ $\quad z_2 = 1.595\,in$

$z_3 := R_b \cdot (1 - \cos(2 \cdot \theta)) - X_{bar}$ $\quad z_3 = -1.72\,in$

$z_4 := R_b \cdot (1 - \cos(\theta)) - X_{bar}$ $\quad z_4 = -3.751\,in$

Then the bolt group moment of inertia about the centroid is,

$$I_{bolts} := 2 \cdot A_b \cdot z_1^2 + 2 \cdot A_b \cdot z_2^2 + 2 \cdot A_b \cdot z_3^2 + 2 \cdot A_b \cdot z_4^2 + A_b \cdot X_{bar}^2$$

$$I_{bolts} = 80.507\,in^4$$

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

$moment\_arm := R_b - X_{bar} - 36.375 \cdot in$ $\quad moment\_arm = 4.191\,in$

Therefore, the bolt array must resist the following moment

$Moment_{bolts} := 6 \cdot Load_{wheel} \cdot moment\_arm$ $\quad Moment_{bolts} = 2.459 \times 10^5\,in \cdot lbf$

The bolt stress due to the direct load is:

$$stress_{direct} := 6 \cdot \frac{Load_{wheel}}{A_{total}} \qquad stress_{direct} = 1.078 \times 10^4 psi$$

Compute $y_1 := R_b \cdot (1 - \cos(4 \cdot \theta)) - X_{bar}$ $\qquad y_1 = 6.094 in$ > Xbar

Therefore, the highest bolt stress due to the bending moment is,

$$stress_{moment} := \frac{Moment_{bolts} \cdot y_1}{I_{bolts}} \qquad stress_{moment} = 1.861 \times 10^4 psi$$

Therefore, the total bolt stress to support lifting, on the heaviest loaded bolt, is

$$\sigma_{bolt} := stress_{direct} + stress_{moment}$$

$$\sigma_{bolt} = 2.939 \times 10^4 psi$$

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

$$W_{tl} = 2.45 \times 10^4 lbf$$

The total door load already accounted for in the bolt analysis is

$$W_{td} := 4 \cdot W_{door} \qquad W_{td} = 1.204 \times 10^4 lbf$$

Therefore the additional average stress component in the 36 bolts is

$$\sigma_{avg} := \frac{(W_{tl} - W_{td})}{36 \cdot A_b} \qquad \sigma_{avg} = 572.221 psi$$

Therefore the absolute maximum bolt stress is

$$\sigma_{bolt\_max} := \sigma_{bolt} + \sigma_{avg} \qquad \sigma_{bolt\_max} = 2.996 \times 10^4 psi$$

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)

$S_{ylid} := 38000 \cdot psi$ $Su_{lid} := 70000 \cdot psi$ $Su_{bolt} := S_{ubolt}$

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

$$\sigma_{bolt} := Su_{bolt} \cdot 0.5 \qquad \sigma_{bolt} = 5.75 \times 10^4 \text{psi}$$

The allowable shear stress in the bolt is:

$$\tau_{bolt} := \frac{.62 \cdot Su_{bolt}}{3} \qquad \tau_{bolt} = 2.377 \times 10^4 \text{psi}$$

The allowable shear stress in the lid (or flange) is

$$\tau_{lid} := 0.4 \cdot S_{ylid} \qquad \tau_{lid} = 1.52 \times 10^4 \text{psi}$$

$$F_{shear\_lid} := \tau_{lid} \cdot A_{int} \qquad F_{shear\_lid} = 3.36 \times 10^4 \text{lbf}$$

For the bolt, the allowable strength is the yield strength

$$F_{tensile\_bolt} := \sigma_{bolt} \cdot A_t \qquad F_{tensile\_bolt} = 3.414 \times 10^4 \text{lbf}$$

$$F_{shear\_bolt} := \tau_{bolt} \cdot A_{ext} \qquad F_{shear\_bolt} = 3.936 \times 10^4 \text{lbf}$$

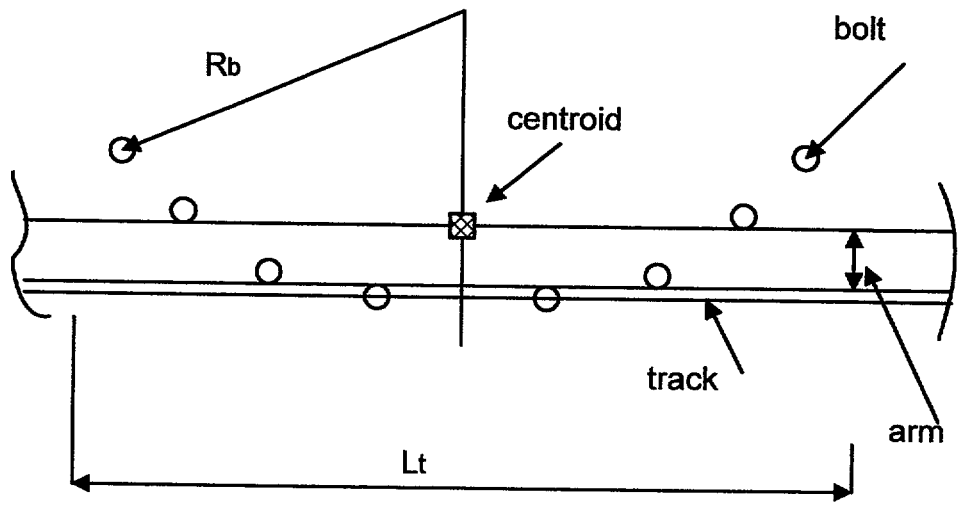
Therefore, thread shear in lid governs the design. The safety factors computed above should by multiplied by the ratio

$$\frac{F_{shear\_lid}}{F_{tensile\_bolt}} = 0.984$$

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;

$arm := moment\_arm$ $\qquad arm = 4.191\,in$

$Moment := Moment_{bolts}$ $\qquad Moment = 2.459 \times 10^5\,in \cdot lbf$

$L_t := R_b \cdot 2 \cdot \sin(45 \cdot deg)$ $\qquad L_t = 63.64\,in$

The thickness of the lid top plate is

$t_p := 1.5 \cdot in$ $\qquad$ 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.

$$I_p := \frac{L_t \cdot t_p^3}{12} \qquad I_p = 17.899\,in^4$$

The primary bending stress is

$$\sigma_{tp} := \frac{Moment \cdot t_p}{2 \cdot I_p} \qquad \sigma_{tp} = 1.03 \times 10^4\,psi$$

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 $\quad nb := 36$

$S_{ubolt} = 1.15 \times 10^5 \text{psi}$ $\qquad A_b := A_t$

$Bolt\_Capacity := nb \cdot .6 \cdot S_{ubolt} \cdot A_b$ $\qquad Bolt\_Capacity = 1.475 \times 10^6 \text{lbf}$

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 $\qquad T_{act} := 270 \cdot ft \cdot lbf$

The calculated bolt torque requirement is $\qquad T = 181.246 ft \cdot lbf$

Therefore the actual clamping force per bolt is:

$$T_{clamp} := \frac{T_{act}}{T} \cdot \sigma_{bolt\_max} \cdot A_b \qquad T_{clamp} = 2.649 \times 10^4 \text{lbf}$$

Following ASME, Section III, Subsection NF, NF-3324.6(4) for a blast cleaned joint, the frictional resistance for the assemblage of bolts is:

$$P_s := nb \cdot T_{clamp} \cdot 0.31 \qquad P_s = 2.957 \times 10^5 \text{lbf}$$

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

$$Shear\_Capacity := Bolt\_Capacity + P_s$$

$$Shear\_Capacity = 1.77 \times 10^6 \text{lbf}$$

The safety factor for lid separation is defined as

$$SF := \frac{Shear\_Capacity}{Interface\_Force} \qquad SF = 1.392$$

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.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 hottest location of the HI-TRAC (see Figure 3.I.1 and Table 4.5.2).

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, $\Delta T_{3h} := 455 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (600 - 70) \cdot 1.1$

The temperature change at the center of the basket (helium gas), $\Delta T_{5h} := 852 - 70$

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, $b := 66.25\,in$ The inner radius of the overpack, $a := 34.75\,in$

The mean radius of the MPC shell, $R_{mpc} := \frac{68.375\,in - 0.5 \cdot in}{2}$ $R_{mpc} = 33.938\,in$

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, $L_{ovp} := 191.5\,in$

The axial length of the MPC, $L_{mpc} := 190.5\,in$

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, $L_{bas} := 176.5\,in$

The initial basket-to-MPC lid nominal axial clearance, $AC_{bm} := 1.8125\,in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875\,in$

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:

$$r_1 := a + .5 \cdot t_1 + 2.0 \cdot in \qquad \text{(add the channel depth)}$$

$$r_2 := r_1 + .5 \cdot t_1 + .5 \cdot t_2$$

$$r_3 := r_2 + .5 \cdot t_2 + .5 \cdot t_3$$

$$r_4 := r_3 + .5 \cdot t_3 + .5 \cdot t_4$$

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).

$$b_1 := r_4 + 0.5 \cdot t_4$$

$$b_1 = 66.25\,\text{in}$$

$$b = 66.25\,\text{in}$$

We note that the calculated value b_1 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:

$$\Delta R_{mpch} := \alpha_{mpc} \cdot R_{mpc} \cdot \Delta T_{3h} \qquad \Delta R_{mpch} = 0.122\,in$$

$$\Delta L_{mpch} := \alpha_{mpc} \cdot L_{mpc} \cdot \Delta T_{3h} \qquad \Delta L_{mpch} = 0.685\,in$$

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:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch} \qquad RG_{moh} = 0.364\,in$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch} \qquad AG_{moh} = 0.24\,in$$

Note that this axial clearance (AG_{moh}) is based on the temperature distribution at the hottest axial location of the system.

3.AF.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-Overpack

Radial clearance $RG_{moh} = 0.364\,in$ Axial clearance $AG_{moh} = 0.24\,in$

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.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

$$W_{lid} := \gamma_s \cdot t_{lid} \cdot \pi \cdot \frac{d_{lid}^2}{4} \qquad W_{lid} = 1.411 \times 10^4 \, lbf$$

Weight of shield block top plate

$$W_{bot} := \gamma_s \cdot t_{ring} \cdot \pi \cdot \frac{d_{ob}^2}{4} \qquad W_{bot} = 410.973 \, lbf$$

Weight of shield block shell

$$W_{shell} := \gamma_s \cdot t_{block} \cdot L_{shieldblock} \cdot \pi \cdot (d_{ob}) \qquad W_{shell} = 382.3 \, lbf$$

Weight of Shield Block Concrete

$$W_{shield} := \gamma_c \cdot \pi \cdot \frac{(d_{ob} - 2 \cdot t_{block})^2}{4} \cdot L_{shieldblock} \qquad W_{shield} = 4.926 \times 10^3 \, lbf$$

The total weight of the assemblage calculated so far is

$$W_{total} := W_{lid} + W_{bot} + W_{shell} + W_{shield}$$

$$W_{total} = 1.983 \times 10^4 \, lbf$$

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.

$$W_{lid} := 25500 \cdot lbf$$

Compute the bearing stress in the bottom plate of the lid at each of the four bolt holes due to the accident load.

$$Area_{bearing} := 4 \cdot d_{bolt} \cdot (t_{lidbottom}) \qquad Area_{bearing} = 6.5 \, in^2$$

$$\sigma_{bearing} := \frac{W_{lid} \cdot G}{Area_{bearing}} \qquad \sigma_{bearing} = 1.903 \times 10^5 \, psi$$

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.

$F_t := W_{lid} \cdot G$ $\qquad F_t = 1.237 \times 10^6 \, lbf$

From Table 3.3.2, the ultimate strength of the steel material (@ 350 degrees F) is

$$S_u := 70000 \cdot psi$$

The weld stress limit for the shear bars, under failure conditions, is taken as 60% of the ultimate strength.

$\tau_{allowable} := .6 \cdot S_u$ $\qquad \tau_{allowable} = 4.2 \times 10^4 \, psi$

The allowable bearing strength is taken as 90% of the ultimate strength at failure.

$A_{bear} := L_{bar} \cdot t_{bar}$ $\qquad A_{weld} := L_{bar} \cdot (t_{wbar} + 0.7071 \cdot t_{wbar})$

Note that we have a groove and a fillet weld holding the shear bar in place.

$\sigma_{bearing} := \dfrac{F_t}{A_{bear}}$ $\qquad \sigma_{bearing} = 4.667 \times 10^4 \, psi$

$\tau_{weld} := \dfrac{F_t}{A_{weld}}$ $\qquad \tau_{weld} = 3.17 \times 10^4 \, psi$

The safety factors are:

$SF_{bear} := \dfrac{.9 \cdot S_u}{\sigma_{bearing}}$ $\qquad SF_{bear} = 1.35$

$SF_{shear} := \dfrac{.6 \cdot S_u}{\tau_{weld}}$ $\qquad SF_{shear} = 1.325$

3.AO.4.2 Inner and Outer Shell Analysis

The total load to be transferred is $\qquad W_1 := G \cdot W_{total}$ $\qquad W_1 = 9.619 \times 10^5 \, lbf$

The shell base metal area available to resist this load is

$$Area := \pi \cdot (D_{OD} - t_{outer}) \cdot t_{outer} + \pi \cdot (d_{ID} + t_{inner}) \cdot t_{inner} - 100 \cdot in \cdot (t_{outer} + t_{inner})$$

$$Area = 388.656 \, in^2$$

The shear stress in the base metal is

$$\tau_{base} := \frac{W_l}{Area} \qquad \tau_{base} = 2.475 \times 10^3 \text{ psi}$$

The weld metal area to transfer the load to the shell is $t_{sweld} = 0.313 \text{ in}$

$$Area_{weld} := \pi \cdot (D_{OD}) \cdot t_{sweld} + \pi \cdot (d_{ID}) \cdot 0.7071 t_{sweld} - 2 \cdot 100 \cdot in \cdot t_{sweld} \qquad Area_{weld} = 112.223 \text{ in}^2$$

The shear stress in the weld group is

$$\tau_{weld2} := \frac{W_l}{Area_{weld}} \qquad \tau_{weld2} = 8.572 \times 10^3 \text{ psi}$$

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)

$$\tau_{allowable} := 0.42 \cdot S_u \qquad SF_2 := \frac{\tau_{allowable}}{\tau_{weld2}} \qquad SF_2 = 3.43$$

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 $t_{weld} = 0.25 \text{ in}$ $d_{ob} = 86 \text{ in}$

$$Area_{weld} := \pi \cdot (d_{ob} + .333 \cdot t_{weld}) \cdot (0.7071 \cdot t_{weld}) \qquad Area_{weld} = 47.807 \text{ in}^2$$

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.

$$W_{lw} := (W_{bot} + W_{shell} + W_{shield}) \qquad W_{lw} = 5.719 \times 10^3 \text{ lbf}$$

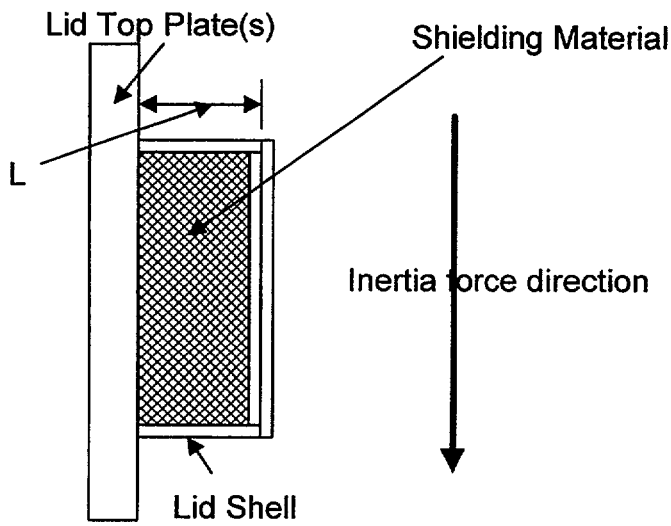
The shear stress in the weld is

$$\tau_{weld} := \frac{W_{lw} \cdot G}{Area_{weld}} \qquad \tau_{weld} = 5.802 \times 10^3 \text{ psi}$$

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:

$$T := 300 \cdot ft \cdot lbf$$

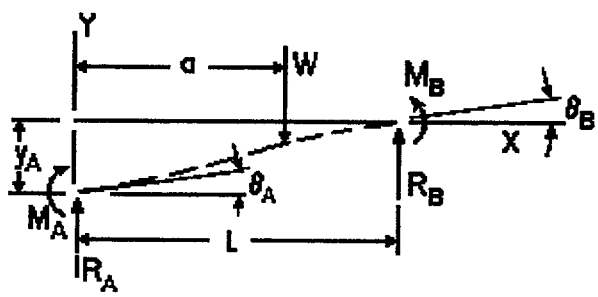
$$\sigma_{initial} := \frac{T}{.12 \cdot A_b \cdot d_{min}} \qquad \sigma_{initial} = 1.147 \times 10^3 psi$$

(see Shigley and Mischke, Mechanical Engineering Design, McGraw Hill, 5th Edition, pp346-347)

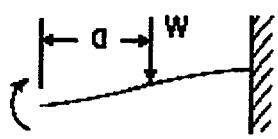
In addition to the mean stress, during a side drop, if the stud contacts the hole and experiences a shear load, the stud can also experience a bending moment developed as the stud resists the shear by guided cantilever action.

$$I := \frac{\pi}{64} \cdot d_{min}^{\ 4} \qquad I = 5.261\, in^4 \qquad Load_{shear} = 2.806 \times 10^4 lbf$$

Concentrated intermediate load



Left end guided, right end fixed



Area moment of inertia:	$I \equiv 5.261 \cdot in^4$
Length of beam:	$L \equiv 11 \cdot in$
Distance from left edge to load:	$a \equiv 0 \cdot ft$
Modulus of elasticity:	$E \equiv 28 \cdot 10^6 \cdot \frac{lbf}{in^2}$
Load:	$W \equiv 28060 \cdot lbf$

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):

$R_A := 0 \cdot lbf$

$M_A := \frac{W \cdot (L-a)^2}{2 \cdot L}$ $\quad M_A = 1.286 \times 10^4 lbf \cdot ft$

$\theta_A := 0 \cdot deg$

$y_A := \frac{-W}{12 \cdot E \cdot I} \cdot (L-a)^2 \cdot (L+2 \cdot a)$ $\quad y_A = -0.021 in$

At the right end of the beam (fixed):

$R_B := W$ $\quad R_B = 2.806 \times 10^4 lbf$

$M_B := \frac{-W \cdot \left(L^2 - a^2\right)}{2 \cdot L}$ $\quad M_B = -1.286 \times 10^4 lbf \cdot ft$

$\theta_B := 0 \cdot deg$

$y_B := 0 \cdot in$

The stress induced by bending of the stud during a side drop is

$\sigma_{pl} := \frac{M_A \cdot d_{min}}{2 \cdot I}$ $\quad \sigma_{pl} = 4.719 \times 10^4 psi$

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

$SF_t := 1. \cdot \frac{S_u}{\sigma_{pl} + \sigma_{initial}}$ $\quad SF_t = 3$

$$Interaction\_factor := \left(\frac{1}{SF_s}\right)^2 + \left(\frac{1}{SF_t}\right)^2 \qquad Interaction\_factor = 0.114$$

Therefore the safety factor for combined tension and shear is

$$SF_{ts} := \frac{1}{Interaction\_factor} \qquad SF_{ts} = 8.745$$

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 location 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 hottest axial location of the cask (Table 4.4.27 and 4.4.36).

The temperature change at the overpack inner shell, $\Delta T_{1h} := 199 - 70$

The temperature change at the overpack outer shell, $\Delta T_{2h} := 145 - 70$

The temperature change at the mean radius of the MPC shell, $\Delta T_{3h} := 347 - 70$

The temperature change at the outside of the MPC basket, $\Delta T_{4h} := (492 - 70) \cdot 1.1$

The temperature change at the center of the basket (helium gas), $\Delta T_{5h} := 650 - 70$

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, $b := 66.25\,in$

The minimum inner radius of the overpack, $a := 34.75\,in$

The mean radius of the MPC shell, $R_{mpc} := \frac{68.375\,in - 0.5 \cdot in}{2}$ $\quad R_{mpc} = 33.938\,in$

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, $L_{ovp} := 191.5\,in$

The axial length of the MPC, $L_{mpc} := 190.5\,in$

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, $L_{bas} := 176.5\,in$

The initial basket-to-MPC lid nominal axial clearance, $AC_{bm} := 1.8125\,in$

The initial basket-to-MPC shell nominal radial clearance, $RC_{bm} := 0.1875\,in$

The outer radius of the basket, $R_b := R_{mpc} - \frac{0.5}{2} \cdot in - RC_{bm}$ $\quad R_b = 33.5\,in$

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

$$C_a := \Delta T_{1h} \qquad C_a = 129$$

$$C_b := \frac{\Delta T_{2h} - \Delta T_{1h}}{\ln\left(\frac{b}{a}\right)} \qquad C_b = -83.688$$

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, $Int = 1.533 \times 10^5\ in^2$

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:

$$Int_s := \int_a^b \left[C_a + C_b \cdot \left(\ln\left(\frac{r}{a}\right)\right)\right] \cdot r\,dr$$

$$Int_s := \frac{1}{2} \cdot C_b \cdot \ln\left(\frac{b}{a}\right) \cdot b^2 + \frac{1}{2} \cdot C_a \cdot b^2 - \frac{1}{4} \cdot C_b \cdot b^2 + \frac{1}{4} \cdot C_b \cdot a^2 - \frac{1}{2} \cdot C_a \cdot a^2$$

$$Int_s = 1.533 \times 10^5\ in^2$$

We note that the values of Int and Ints are identical. The average temperature in the overpack cylinder (T_{bar}) is therefore determined as:

$$T_{bar} := \frac{2}{\left(b^2 - a^2\right)} \cdot Int \qquad T_{bar} = 96.348$$

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).

$$b_1 := r_4 + 0.5 \cdot t_4$$

$$b_1 = 66.25\,in$$

$$b = 66.25\,in$$

We note that the calculated value b_1 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:

$$\alpha_{avg} := \frac{r_1 \cdot t_1 \cdot \alpha_1 + r_2 \cdot t_2 \cdot \alpha_2 + r_3 \cdot t_3 \cdot \alpha_3 + r_4 \cdot t_4 \cdot \alpha_4}{\frac{a+b}{2} \cdot (t_1 + t_2 + t_3 + t_4)}$$

$$\alpha_{avg} = 5.628 \times 10^{-6}$$

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:

$$\Delta R_{ah} := \alpha_{avg} \cdot a \cdot T_{bar}$$

$$\Delta R_{ah} = 0.019\,in$$

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:

$$\Delta L_{ovph} := L_{ovp} \cdot \alpha_{avg} \cdot T_{bar}$$

$$\Delta L_{ovph} = 0.104\,in$$

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, $E := 28300000\,psi$

$$\sigma_{ca} := \alpha_{avg} \cdot \frac{E}{a^2} \cdot \left[2 \cdot \frac{a^2}{\left(b^2 - a^2\right)} \cdot Int - \left(C_a\right) \cdot a^2 \right]$$

$$\sigma_{ca} = -5200\,psi$$

$$\sigma_{cb} := \alpha_{avg} \cdot \frac{E}{b^2} \cdot \left[2 \cdot \frac{b^2}{\left(b^2 - a^2\right)} \cdot Int - \left[C_a + C_b \cdot \left(\ln\left(\frac{b}{a}\right)\right)\right] \cdot b^2 \right]$$

$$\sigma_{cb} = 3400\,psi$$

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:

$$N := 0.37$$

$$r := a \cdot (1 - N) + N \cdot b$$

$$r = 46.405\,in$$

$$\sigma_r := \alpha_{avg} \cdot \frac{E}{r^2} \cdot \left[\frac{r^2 - a^2}{2} \cdot T_{bar} - \int_a^r \left[C_a + C_b \cdot \left(\ln\left(\frac{y}{a}\right)\right)\right] \cdot y\,dy \right]$$

$$\sigma_r = -678.201\,psi$$

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:

$$\Delta R_{mpch} := \alpha_{mpc} \cdot R_{mpc} \cdot \Delta T_{3h} \qquad \Delta R_{mpch} = 0.085\,in$$

$$\Delta L_{mpch} := \alpha_{mpc} \cdot L_{mpc} \cdot \Delta T_{3h} \qquad \Delta L_{mpch} = 0.476\,in$$

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:

$$RG_{moh} := RC_{mo} + \Delta R_{ah} - \Delta R_{mpch}$$

$$RG_{moh} = 0.434\,in$$

$$AG_{moh} := AC_{mo} + \Delta L_{ovph} - \Delta L_{mpch}$$

$$AG_{moh} = 0.628\,in$$

Note that this axial clearance (AG_{moh}) is based on the temperature distribution at the hottest axial location in 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 $\Delta T_{bas} := \Delta T_{5h} - \Delta T_{4h}$ $\qquad \Delta T_{bas} = 115.8$

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:

$$T_{bar} := \frac{2}{R_b^2} \cdot \left(\frac{-1}{4} \cdot \Delta T_{bas} \cdot R_b^2 + \frac{1}{2} \cdot \Delta T_{5h} \cdot R_b^2 \right)$$

$$T_{bar} = 522.1$$

The corresponding radial growth at the periphery (ΔR_{bh}) is therefore determined as:

$$\Delta R_{bh} := \alpha_{bas} \cdot R_b \cdot T_{bar}$$

$$\Delta R_{bh} = 0.168\,in$$

and the corresponding axial growth (ΔL_{bas}) is determined from [3.AQ.2] as:

$$\Delta L_{bh} := \Delta R_{bh} \cdot \frac{L_{bas}}{R_b}$$

$$\Delta L_{bh} = 0.885\,\text{in}$$

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:

$$RG_{bmh} := RC_{bm} - \Delta R_{bh} + \Delta R_{mpch}$$

$$RG_{bmh} = 0.104\,\text{in}$$

$$AG_{bmh} := AC_{bm} - \Delta L_{bh} + \Delta L_{mpch}$$

$$AG_{bmh} = 1.404\,\text{in}$$

3.AQ.5 Summary of Results

The previous results are summarized here.

MPC Shell-to-Overpack	Fuel Basket-to-MPC Shell
$RG_{moh} = 0.434\,\text{in}$	$RG_{bmh} = 0.104\,\text{in}$
$AG_{moh} = 0.628\,\text{in}$	$AG_{bmh} = 1.404\,\text{in}$

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) $Su_{wacc} := Su_w - (S_{u1} - S_{u2})$

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

$$F := DLF \cdot (W_{container} + W_{fuel}) \qquad F = 632\ lbf$$

From TN drawing 9317.1-120-4, the canister sleeve geometry is

$id_{sleeve} := 4.81 \cdot in \qquad t_{sleeve} := 0.11 \cdot in$

The cross sectional area of the sleeve is

$$A_{sleeve} := (id_{sleeve} + 2 \cdot t_{sleeve})^2 - id_{sleeve}^2 \qquad A_{sleeve} = 2.16\ in^2$$

Therefore, the tensile stress in the sleeve is $\sigma := \frac{F}{A_{sleeve}}$ $\sigma = 292\,psi$

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.

$$F = 632\,lbf$$

The weld thickness is $t_{base} := 0.09 \cdot in$

The area of the weld, with proper consideration of quality factors, is

$$A_{weld} := n \cdot 4 \cdot \left(id_{sleeve} + 2 \cdot t_{sleeve}\right) \cdot .7071 \cdot t_{base} \qquad A_{weld} = 0.64\,in^2$$

Therefore, the shear stress in the weld is $\tau := \frac{F}{A_{weld}}$ $\tau = 988\,psi$

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.

$$\sigma_1 := \frac{S_{yl}}{6} \qquad \sigma_2 := \frac{S_{ul}}{10}$$

$$\sigma_1 = 4583\,psi \qquad \sigma_2 = 7300\,psi$$

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

$$\sigma := \frac{F}{A_{frame}} \qquad \sigma = 77\,psi$$

The safety margin is

$$SM := \frac{\sigma_{allowable}}{\sigma} - 1 \qquad SM = 58.59$$

The bearing stress at the four lift locations is computed from the same drawing

$A_{bearing} := 4 \cdot t_{frame} \cdot (2 \cdot 0.38 \cdot in)$ $A_{bearing} = 1.201\,in^2$

$$\sigma_{bearing} := \frac{F}{A_{bearing}} \qquad \sigma_{bearing} = 526.732\,psi \qquad SM := \frac{\sigma_{allowable}}{\sigma_{bearing}} - 1 \qquad SM = 7.7$$

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

$$od := 4 \cdot in \qquad id := 3.548 \cdot in \qquad t_{pipe} := \frac{(od - id)}{2} \qquad t_{pipe} = 0.226\,in$$

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

$F := DLF \cdot (W_{rodcan} + W_{thoria})$ $\qquad F = 449\ lbf$

From TN drawing 9317.1-182-1, the canister sleeve geometry is

$id_{sleeve} := 4.81 \cdot in$ $\qquad t_{sleeve} := 0.11 \cdot in$

The cross sectional area of the sleeve is

$A_{sleeve} := (id_{sleeve} + 2 \cdot t_{sleeve})^2 - id_{sleeve}^2$ $\qquad A_{sleeve} = 2.16\ in^2$

Therefore, the tensile stress in the sleeve is $\sigma := \frac{F}{A_{sleeve}}$ $\qquad \sigma = 207\ psi$

The allowable stress intensity for the primary membrane category is S_m per Subsection NG of the ASME Code. The corresponding safety margin is

$SM := \frac{S_{m1}}{\sigma} - 1$ $\qquad SM = 95.5$

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.

$F = 449\ lbf$

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

$A_{weld} := n \cdot 4 \cdot (id_{sleeve} + 2 \cdot t_{sleeve}) \cdot .7071 \cdot t_{base}$ $\qquad A_{weld} = 0.64\ in^2$

Therefore, the shear stress in the weld is $\tau := \frac{F}{A_{weld}}$. $\qquad \tau = 701\ psi$

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

$SM := \frac{0.3 \cdot S_{u1}}{\tau} - 1$ $\qquad SM = 30.3$

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 $F := DLF \cdot (W_{rodcan} + W_{thoria})$ $\quad F = 449\,\text{lbf}$

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.

$$t_{frame} := 0.395 \cdot \text{in}$$

The inside span is the same as the canister sleeve $\quad id_{sleeve} = 4.81\,\text{in}$

The area available for direct load is

$$A_{frame} := (id_{sleeve} + 2 \cdot t_{frame})^2 - id_{sleeve}^2 \qquad A_{frame} = 8.224\,\text{in}^2$$

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

$$A_{bearing} := 4 \cdot t_{frame} \cdot (2 \cdot 0.38 \cdot \text{in}) \qquad A_{bearing} = 1.201\,\text{in}^2$$

$$\sigma_{bearing} := \frac{F}{A_{bearing}} \qquad \sigma_{bearing} = 373.501\,\text{psi} \qquad SM := \frac{\sigma_{allowable}}{\sigma_{bearing}} - 1 \qquad SM = 11.27$$

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.

$F := 60 \cdot (W_{thoria} + W_{rodcan})$ $\qquad F = 23400\,lbf$

The properties of the pipe are obtained from the Ryerson Stock Catalog as

$od := 4 \cdot in \qquad id := 3.548 \cdot in \qquad t_{pipe} := \frac{(od - id)}{2} \qquad t_{pipe} = 0.226\,in$

The pipe area is

$A_{pipe} := \frac{\pi}{4} \cdot (od^2 - id^2) \qquad A_{pipe} = 2.68\,in^2$

The stress in the member is

$\sigma := \frac{F}{A_{pipe}} \qquad \sigma = 8733\,psi$

The allowable primary membrane stress from Subsection NG of the ASME Code, for accident conditions (Level D), is

$\sigma_{allowable} := 2.4 \cdot S_{m2} \qquad \sigma_{allowable} = 37920\,psi$

The safety margin is

$SM := \frac{\sigma_{allowable}}{\sigma} - 1 \qquad SM = 3.3$

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

$I := \frac{\pi}{64} \cdot (od^4 - id^4) \qquad I = 4.788\,in^4$

$L := 22 \cdot in$

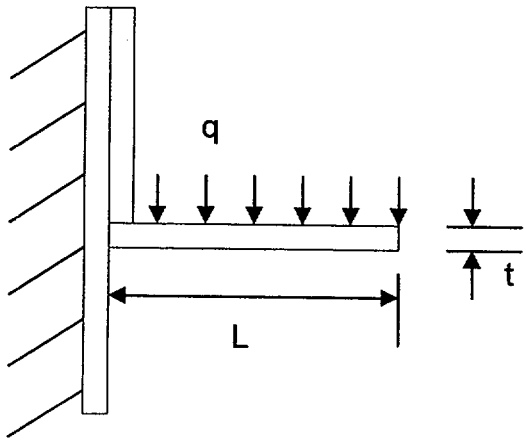
$P_{crit} := \pi^2 \cdot \frac{E \cdot I}{L^2} \qquad P_{crit} = 2.695 \times 10^6\,lbf$

The safety margin is

$SM := \frac{P_{crit}}{F} - 1 \qquad SM = 114.153$

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

$length := 113.16 \cdot in$

$w_{rod} := 90 \cdot \frac{lbf}{18} \cdot \frac{1}{length}$ $\qquad w_{rod} = 0.044 \frac{lbf}{in}$

Weight of support per unit length (per drawing 9317.1-182-3

$L := 1.06 \cdot in \qquad t := 0.11 \cdot in$

$w_{sup} := .29 \cdot \frac{lbf}{in^3} \cdot L \cdot t$ $\qquad w_{sup} = 0.034 \frac{lbf}{in}$

Amplified load (assumed as a uniform distribution)

$q := 60 \cdot (w_{rod} + w_{sup})$ $\qquad q = 4.68 \frac{lbf}{in}$

$Moment := \frac{q \cdot L^2}{2}$ $\qquad Moment = 2.629\, in \cdot lbf$

Bending stress at the root of the cantilever beam is

$\sigma := 6 \cdot \frac{Moment}{1 \cdot in \cdot t^2}$ $\qquad \sigma = 1.304 \times 10^3\, psi$

Shear stress at the root of the cantilever $\qquad \tau := q \cdot \frac{L}{t \cdot 1 \cdot in}$ $\qquad \tau = 45.098\, psi$

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

$$F := DLF \cdot (W_{container} + W_{fuel}) \qquad F = 1932\,lbf$$

The cross sectional area of the sleeve is

$$A_{sleeve} := (id_{sleeve} + 2 \cdot t_{sleeve})^2 - id_{sleeve}^{\ 2} \qquad A_{sleeve} = 2.65\,in^2$$

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

$$A_{tab} := t_{tab} \cdot w_{tab} \qquad A_{tab} = 0.25\ in^2$$

The shear stress in the tab is

$$\tau_{tab} := \frac{F}{A_{tab}} \qquad \tau_{tab} = 1.932 \times 10^3\ psi$$

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

$$\sigma_{max\_c} := \frac{3 \cdot (W_{container} + W_{fuel}) \cdot DLF}{2 \cdot \pi \cdot t_{cp}^2} \cdot \left[(1 + 0.3) \cdot \ln\left(\frac{2 \cdot id_{sleeve}}{\pi \cdot r_{bolt}} \right) + \beta \right]$$

$$\sigma_{max\_c} = 1.787 \times 10^4\ psi$$

The allowable primary stress for the plate, per Subsection NG of ASME code, is

$$\sigma_{allowable\_cp} := 1.5 S_{m1} \qquad \sigma_{allowable\_cp} = 3 \times 10^4\ psi$$

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

$F_{drop} := 60 \cdot W_{bplate}$ $\qquad$ $F_{drop} = 774.983\ lbf$

$$\sigma := \frac{F_{drop}}{A_{weld}} \qquad \sigma = 3949\ psi$$

$$\sigma_{allowable} := 0.42 \cdot S_{u2}$$

$$\sigma_{allowable} = 26586\ psi$$

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)	$S_{m1} := 20000 \cdot psi$	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)	$S_{u2} := 63300 \cdot psi$	
Total weight of the loaded container	$W_{load} := 700 \cdot lbf$	
Wall thickness of the container sleeve	$t_{sleeve} := 0.035 \cdot in$	
Dimension of the square baseplate	$d_{bplate} := 5.7 \cdot in$	
Thickness of the baseplate	$t_{bplate} := 0.5 \cdot in$	

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

$$F := DLF \cdot W_{load} \qquad F = 805\ lbf$$

The minimum cross sectional area, located at the locking slot elevation, of the sleeve is

$$A_{sleeve} := \left(id_{sleeve} + 2 \cdot t_{sleeve}\right)^2 - id_{sleeve}^{\ 2} - 4 \cdot L_{slot} \cdot t_{sleeve} \qquad A_{sleeve} = 0.38\ in^2$$

Therefore, the tensile stress in the sleeve is

$$\sigma := \frac{F}{A_{sleeve}} \qquad \sigma = 2 \times 10^3\ psi$$

The allowable stress intensity for the primary membrane category is S_m per Subsection NG of the ASME Code. The corresponding safety factor is

$$SF := \frac{S_{m1}}{\sigma} \qquad SF = 9.3$$

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

$$d_{slot} := \frac{F}{0.6 \cdot S_{m1} \cdot 8 \cdot t_{sleeve}} + \frac{w_{slot}}{2} \qquad d_{slot} = 0.41\ in$$

The tube won't tearout since the center line of the slot is located below the top edge at a distance of

$L_{l\_bar} = 1.5\ in$

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

$$\sigma_{max\_c} := \frac{3 \cdot W_{load} \cdot DLF}{2 \cdot \pi \cdot t_{cap\_tp}^{2}} \cdot \left[(1 + 0.3) \cdot \ln\left(\frac{2 \cdot id_{sleeve}}{\pi \cdot r_{bolt}} \right) + \beta \right]$$

$\sigma_{max\_c} = 4.631 \times 10^3 \text{ psi}$

Safety factor $\quad SF := \dfrac{\sigma_{allowable\_cp}}{\sigma_{max\_c}} \qquad SF = 6.479$

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 $\quad d_{sp} := t_{bar} \qquad d_{sp} = 0.1 \text{ in}$

The bending stress of the side plate is calculated by assuming that the side plate behaves as a cantilever beam.

$E_{sp} := 2.7 \cdot 10^7 \cdot \text{psi} \qquad L_{bend\_sp} := L_{l\_bar} + \dfrac{w_{l\_bar}}{2}$

$\sigma_{sp} := \dfrac{1.5 E_{sp} \cdot d_{sp} \cdot t_{cap\_sp}}{L_{bend\_sp}^{\ 2}} \qquad \sigma_{sp} = 5.368 \times 10^4 \text{ psi}$

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 $\quad A_{bolt} = 0.605 \text{ in}^2$

The tensile stress in the bolt $\quad \sigma_{t\_bolt} := \dfrac{W_{load} \cdot DLF}{A_{bolt}} \qquad \sigma_{t\_bolt} = 1.33 \times 10^3 \text{ psi}$

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.

$\sigma_1 := \dfrac{S_{y1}}{3} \qquad \sigma_1 = 9167 \text{ psi} \qquad \sigma_2 := \dfrac{S_{u1}}{5} \qquad \sigma_2 = 14600 \text{ psi}$

For SA240-304 material the yield stress governs at the lifting temperature.

$$\sigma_{allowable} := \sigma_1$$

Safety factor $\quad SF := \dfrac{\sigma_{allowable}}{\sigma_{t\_bolt}} \qquad SF = 6.89$

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

$$SF := \frac{\sigma_{allowable}}{\sigma} \qquad SF = 16.7$$

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.