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Washington, DC 20555-0001

April 22, 2009

Subject: Response to Request for Additional Information on HI-STORM 100 System – Supplement 2 Additional Calculation (100U License Amendment Request 1014-6), USNRC Docket 72-1014, TAC NO. L24085

Reference: [1] Holtec Letter 5014680, dated April 6, 2009, "Response to Request for Additional Information on HI-STORM 100 System – Supplement 2 (100U License Amendment Request 1014-6), USNRC Docket 72-1014, TAC NO. L24085"

Dear Mr. Goshen:

This submittal provides an additional calculation and proposed FSAR pages in support of the response to request for additional information given in Supplement 2 [1].

This submittal includes updated proposed FSAR pages marked "Proposed Rev. 7.D" (Attachment 1); Holtec Proprietary Report HI-2053389, Revision 8 (Attachment 2); and an affidavit pursuant to 10CFR 2.390 requesting the withholding of the Report HI-2053389 from the public (Attachment 3).

Again, thank you for your continued effort toward timely approval of this amendment, any additional information requested will be promptly provided. Feel free to contact me if you have any questions at 856-797-0900 x687.

Sincerely,

Tammy Morin
Acting Licensing Manager
Holtec International

cc (letter only VIA EMAIL): Mr. Eric Benner, USNRC
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NMSS01

SUPPLEMENT 2.I
PRINCIPAL DESIGN CRITERIA FOR THE HI-STORM 100U SYSTEM

2.I.0 OVERVIEW OF THE PRINCIPAL DESIGN CRITERIA

General

A description of the HI-STORM 100U VVM is provided in Supplement 1.I. Because the HI-STORM 100U System uses the same MPCs, transfer cask, and ancillary equipment as the aboveground systems, the design criteria presented in Table 2.0.1 for the MPC, and Table 2.0.3 for the HI-TRAC provide the basis for setting down the applicable criteria in this supplement with due recognition of the advances in the analysis methodologies over the past decade. The applicable loads, the affected parts under each loading condition, and the applicable structural acceptance criteria are compiled in this supplement to provide a complete framework for the required qualifying analyses in Supplement 3.I. Information consistent with the regulatory requirements related to shielding, thermal performance, confinement, radiological, and operational considerations is also provided. Drawings of the VVM are provided in Section 1.I.5.

Structural

All required information on the design bases and criteria for the VVM are compiled in this supplement to fulfill the requirements of 10CFR72.24(c)(3) and 72.44(d). Table 2.I.1 contains a detailed listing of the information and its location in this FSAR corresponding to each relevant requirement in 10CFR72 with reference to the VVM. The VVM structure described in Supplement 1.I is designed for all applicable normal, off-normal, extreme environmental phenomena, and accident condition loadings pursuant to 10CFR72.24(c), 72.122(b) and 72.122(c).

The surrounding subgrade, the Support Foundation on which the VVM is founded, and the VVM Interface Pad are categorized as "interfacing SSCs", while the Top Surface Pad is categorized as a "proximate structure". These structures are also classified as important-to-safety (ITS) (see Table 2.I.8) and are included in the analyses in Supplement 3.I, and in other supplements as applicable. The current supplement defines the critical characteristics (Table 2.I.2) and design data (Table 2.I.7) for these structures. ~~While a detailed design of the interfacing SSCs* and the proximate structure, of necessity, must be specific for a site, their essential critical characteristics for a typical design germane to the VVM's performance are set down in this FSAR. Accordingly, a typical set of design data for the ISFSI Pad (consisting of the VVM Interface Pad and the Top Surface Pad) (thickness and minimum concrete density) is specified in this supplement. Similarly, the top surface of the Support Foundation (referred to as TOF) provides an interface boundary for the VVM. The vertical stiffness of the Support Foundation and its underlying substrate is also an essential critical characteristic whose reference value is specified in this FSAR.~~ ACI-318 (2005) is specified as the governing code for the design and construction of the Foundation Pad, VVM Interface Pad , and the Top Surface Pad. The methodology to perform the seismic qualification of the storage system is

* ~~In Subsection NF of the ASME Code, Section III, the term "intervening elements" is used.~~

illustrated in Chapter 3 using the reference design data for the ISFSI. A site specific seismic analysis following the method presented in Chapter 3 is required for all sites where the underground storage system will be deployed.

The ~~reference~~ values of the *critical characteristics* data on the interfacing SSCs and the Top Surface Pad, set down in this supplement, help ensure that the structural and shielding performance of the VVM will meet or exceed the requirements of 10CFR72 at all ISFSI sites (criticality, radiological, and thermal performance are unaffected by the interfacing SSCs and the Top Surface Pad).

In addition to defining critical characteristics for interfacing SSCs and proximate structures, critical characteristics are also defined for the materials used in the VVM. Material designations used by ASTM and ASME for various product forms are subject to change as these material certifying organizations publish periodic updates of their standards. Material designations adopted by the International Standards Organization (ISO) also affect the type of steels and steel alloys available from suppliers around the world. Therefore, it is necessary to provide for the ability in this FSAR to substitute materials with equivalent materials in the manufacture of the equipment governed by this FSAR.

As defined in this FSAR, the term "Equivalent Material" has a specific meaning: Equivalent materials are those that can be substituted for each other without adversely affecting the safety function of the SSC (system, structure, and component) in which the substitution is made. Substitution by an equivalent material can be made ~~in the Bill of Materials of an SSC~~ after the equivalence in accordance with the provisions of this FSAR has been established.

The concept of material equivalence explained above has been previously used in this FSAR to qualify four different austenitic stainless steel alloys (ASME SA240 Types 304, 304LN, 316, and 316LN) to serve as candidate MPC basket materials.

The equivalence of materials is directly tied to the notion of *critical characteristics*. A critical characteristic of a material is a material property whose value must be specified and controlled to ensure an SSC will render its intended function. The numerical value of the critical characteristic invariably enters in the safety evaluation of an SSC and therefore its range must be guaranteed. To ensure that the safety calculation is not adversely affected properties such as Yield Strength, Ultimate Strength and Elongation must be specified as *minimum* guaranteed values. However, there are certain properties where both minimum and maximum acceptable values are required (in this category lies specific gravity and thermal expansion coefficient).

Table 2.I.10 lists the array of properties typically required in safety evaluation of an SSC in dry storage and transport applications. The required value of each applicable property, guided by the safety evaluation needs defines the critical characteristics of the material. The subset of applicable properties for a material depends on the role played by the material. The role of a material in the SSC is divided into three categories:

Type	Technical Area of Applicability

S	Those needed to ensure structural compliance
T	Those needed to ensure compliance with thermal (temperature limits)
R	Those needed to ensure radiation (criticality and shielding) compliance

The properties listed in Table 2.I.10 are the ones that may apply in a dry storage or transport application.

To summarize, the following procedure shall be used to establish acceptable equivalent materials for a particular application.

Criterion i: Functional Adequacy:
Evaluate the guaranteed critical characteristics of the equivalent material against h values required to be used in safety evaluations. The required values of each critical characteristic must be met by the minimum (or maximum) guaranteed values (MGVs of the selected material).

Criterion ii: Chemical and Environmental Compliance:
Perform the necessary evaluations and analyses to ensure the candidate material will not excessively corrode or otherwise degrade in the operating environment.

A material from another designation regime that meets Criteria (i) and (ii) above is deemed to be an acceptable material, and hence, equivalent to the candidate material.

Equivalent materials as an alternative to the U.S. national standards materials (e.g., ASME, ASTM, ANSI) shall not be used for the Confinement Boundary materials. For other ITS materials, recourse to equivalent materials shall be made only in the extenuating circumstances where the designated material in this FSAR is not readily available.

As can be ascertained from its definition in the glossary, the *critical characteristics* of the material used in a subcomponent depend on its function. The Closure Lid, for example, serves as a shielding device and as a physical barrier to protect the MPC against loadings under all service conditions, including the Extreme Environmental phenomena. Therefore, the critical characteristics of steel used in the lid are its strength (yield and ultimate), ductility, and fracture resistance.

The appropriate critical characteristics for structural components of the VVM, therefore, are:

i. Material yield strength, σ_y
ii. Material ultimate strength, σ_u
iii. Elongation, ε
iv. Charpy impact strength at the lowest service temperature for the part, C_i

Thus, the carbon steel specified in the drawing package can be substituted with different steel so long as each of the four above properties in the replacement material is equal to or greater than their minimum values used in the qualifying analyses used in this FSAR. The above *critical* *characteristics* apply to all materials used in the primary and secondary structural parts of the CEC. Table 2.I.9 provides guidance for the critical characteristics associated with the steels used in the VVM.

In the event that one or more of the *critical characteristics* of the replacement material is slightly lower than the original material, then the use of the §72.48 process is necessary to ensure that all regulatory predicates for the material substitution are fully satisfied.

Further, recognizing that each ISFSI is apt to have its own unique layout and quantity of VVMs, site-specific seismic inputs, and unique substrates (both around and under a VVM), a site-specific analysis is necessary to quantify the design margins under the limiting extreme environmental phenomena (viz., the site Design Basis Earthquake). To ensure that each site uses a consistent approach to the VVM structural qualification, an acceptable analysis methodology, grounded on a three-dimensional non-linear time-history solution procedure, is set down in Supplement 3.I and is applied to a representative configuration. This methodology is incorporated by reference into the Technical Specification (TS).

To serve their intended functions, the CEC and Closure Lid shall ensure confinement integrity and subcriticality, and allow the retrieval of the MPC under all conditions of storage (72.122(l)). Because the VVM is located under ground, drops and tipover of the VVM are not credible events and, therefore, do not warrant analysis. The load combinations (cases) germane to establishing the structural adequacy of the VVM pursuant to 72.24(c) are compiled in Table 2.I.5. The physical characteristics of the MPCs, which are intended for storage in the VVM, are presented in the main body of Chapter 1.

The design bases and criteria provided in this supplement are intended to demonstrate the large margins inherent in the typical VVM design with respect to all applicable loadings that follow from the provisions of 10CFR72.24(c)(3), §72.122(b) and §72.122(c).

Thermal

The engineered thermal performance of the HI-STORM 100U system is essentially equivalent to its aboveground counterparts under quiescent conditions. Ambient air enters from a circumferential opening provided in the Closure Lid. The intake air flows downward through an annular passage or intake plenum formed between the CEC and the Divider Shell. At the bottom of the intake plenum the air turns inwards through openings or cutouts provided in the Divider Shell bottom and rises up through an annular gap formed between the MPC and the Divider Shell. Heat is dissipated from the MPC to this upward rising column of air. The rising air column enters the curved flow passages engineered in the Closure Lid and exhausts from the top through a large central opening (see Figure 1.I.4). To minimize the heating of the downward flowing inlet air and the upward column of heated air, the divider shell is insulated on its outside surface. The *critical characteristic* of the insulation is specified in Table 2.I.1. This thermal insulation material is required to meet the service conditions (temperature and humidity) for the design life of the VVM. Because the thermal performance of the HI-STORM 100U relies on buoyancy-driven convection of air and because of the relative proximity of the inlet and outlet vents to each other, the effect of wind on its thermal performance is also considered.

The allowable long-term and short term section-average temperature limits for concrete (used in the Closure Lid) are established in Appendix 1.D. Section-average temperature limits for structural steel in the VVM are provided in Table 2.I.8.

The VVM is designed for extreme cold conditions, as discussed in Subsection 2.2.2.2. The safety of structural steel material used for the VVM from brittle fracture is discussed in Subsection 3.1.2.3.

The VVM is designed to reject the maximum allowable heat load as defined below in a reliable and testable manner consistent with its important-to-safety designation (10CFR72.128(a)(4)).

The maximum permissible HI-STORM 100U heat load Q(X) is a function of the parameter "X" defined as the ratio of the maximum permissible inner region assembly heat load q_1, and outer region assembly heat load q_2. The inner and outer fuel storage regions are defined in Table 2.1.27. The functional relationship Q(X) is presented below:

$$Q(X) = 2 \cdot \alpha \cdot Q_d / (1 + X^y) \text{ where } y = 0.23/X^{0.1}$$

Q_d is the maximum heat load where X=1 (34kW) and α is a penalty factor for underground storage discussed in Supplement 4.I.

Shielding

The off-site dose for normal operating conditions to any real individual beyond the controlled area 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 on site-specific conditions (e.g., the ISFSI design and proximity to the controlled area boundary, and the number and arrangement of loaded storage casks at the ISFSI), the determination and comparison of ISFSI doses to these limits are necessarily site-specific. Dose rates from the HI-STORM 100U System are provided in Supplement 5.I. 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 for the specific VVM array in accordance with 10CFR72.212.

The VVM is designed to limit the dose rates for all MPCs to ALARA values. The VVM is also designed to maintain occupational exposures ALARA during MPC transfer operations, in accordance with 10CFR20. The underground location of the VVM significantly reduces the radiation from the ISFSI at the site boundary compared to an aboveground cask. The calculated VVM dose rates are discussed in Supplement 5.I, which also discusses dose rates during site construction next to an operating ISFSI.

The dose rate calculations presented in Chapter 5 conservatively use a much smaller subgrade density than is specified in the system Technical Specification. For dose rate calculation at a particular ISFSI, the spatial average of the actual subgrade density shall be used.

Criticality

The VVM does not perform any criticality control function. The MPCs provide criticality control for all design basis normal, off-normal and postulated accident conditions, as discussed in Chapter 6.

Confinement

The VVM does not perform any confinement function. Confinement during storage is provided by the MPC and is addressed in Chapter 7. The CEC provides physical protection and biological shielding for the MPC confinement boundary during MPC dry storage operations.

Operations

MPC preparation for storage and onsite transport of the MPC in the HI-TRAC transfer cask is the same for the VVM as for the aboveground overpack designs. The cask transporter is used to move the loaded transfer cask to the ISFSI and to transfer the MPC into the VVM. Generic operating instructions for the use of the HI-STORM 100U System that parallel those for the aboveground overpack are provided in Supplement 8.I.

Acceptance Tests and Maintenance

The fabrication acceptance bases and maintenance program to be applied to the VVM are described in Supplement 9.I. Application of these requirements will assure that the VVM is fabricated and maintained in a manner that satisfies the design criteria defined in this FSAR.

Decommissioning

Decommissioning considerations for the HI-STORM 100U System, including the VVM, are addressed in Section 2.I.11.

2.I.1 SPENT FUEL TO BE STORED

There is no difference in the authorized contents of the HI-STORM 100U VVM and the aboveground HI-STORM systems. The information in Section 2.1 is applicable.

2.I.2 HI-STORM 100U VVM SUB-COMPONENTS AND INTERFACING SSCs

The VVM is engineered for outdoor below-grade storage for the duration of its design life, and is designed to withstand normal, off-normal, and extreme environmental phenomena as well as accident conditions of storage with appropriate margins of safety.

As discussed in Supplement 1.I, the principal components of the VVM are (see Figure 1.I.2):

i. The MPC Cavity Enclosure Container (CEC), and
ii. The Closure Lid

The CEC is comprised of the following subcomponents:

1. Container Shell (a cylindrical enclosure shell)
2. Bottom Plate
3. Container Flange (a top ring flange)
4. Divider Shell (and MPC Guides)
5. MPC bearing pads

The Closure Lid consists of:

1. The integral steel weldment (filled with shielding concrete), and
2. The removable vent screen assemblies (inlet and outlet).

The structural limit criteria imposed on the above VVM parts are selected to comply with the provisions of 10CFR72, with an embedded large margin of safety. Table 2.I.1 provides the principal design criteria applicable to the VVM. The specifications of the materials of construction for the load bearing and non-load bearing parts are provided in Table 2.I.8 along with their maximum permissible temperature for different conditions of storage.

The five SSCs that interface with the VVM and the one proximate structure germane to the design of a HI-STORM 100U ISFSI are:

i) The VVM Support Foundation (including the undergirding substrate) that supports the weight of the loaded VVM.

ii) The ISFSI pad consists of the VVM Interface Pad (provides a water seepage barrier against rainwater and melting snow and also acts as a missile barrier) and the Top Surface Pad (the proximate structure) that serves as a water seepage barrier as well as the riding surface for the transporter.

iii) The lateral subgrade (natural or engineered fill) surrounding the CEC.

iv) The impressed current cathodic protection system (ICCPS) that may be used as a corrosion mitigation measure for the CEC in accordance with the Technical Specifications.

v) The concrete encasement that may be used as a corrosion mitigation measure for the CEC in accordance with Technical Specifications. Reference is made to Figure 2.I.3 for typical concrete encasement of the CEC.

Each of these SSCs is discussed below:

i. The VVM Support Foundation

The structural requirements on the VVM Support Foundation are focused on providing a robust support to the CEC structure (for shear and compression), and to limit the long-term settlement of the Support Foundation. The minimum structural requirements on the VVM Support Foundation are provided in Table 2.I.2. The evaluations of the CEC structure that include the VVM Support Foundation utilize these typical foundation strength values as applicable.

To meet the requirements set forth in Table 2.I.2, it may be necessary at "soft soil" sites to utilize a reinforced concrete Support Foundation undergirded by pilings, Soilcrete™ columns, and the like. ACI 318-05 is the prescribed Code for Support Foundation design for the HI-STORM 100U System where a reinforced concrete slab is utilized.

ii. VVM Interface Pad and Top Surface Pad

The VVM Interface Pad portion of the ISFSI Pad serves no structural function in supporting the VVM structure. However, it girdles the Container Shell and underlies the Container Flange to form a leak tight interface, and directs water away from the CEC. The principal functions of the Top Surface Pad are to provide the riding surface for the loaded transporter and also to enable rainwater to be channeled away from the storage arrays and into the site's storm drain system. The Top Surface Pad is isolated from the VVM Interface Pad by appropriately located expansion joints to isolate the CEC from any unbalanced loads imparted by the transporter. Similarly, an expansion joint between the CEC and the VVM Interface Pad is incorporated to permit differential movement between the two. The drawings in Section 1.I.5 provide details for the expansion joint and typical drainage and sealing details. Because the sealing is visible and accessible, re-sealing, when and if necessary, is easily accomplished. Thus, continued sealing is assured. A specific brand of sealant is noted on the expansion joint detail, but there are several equivalent* proven sealant materials commercially available that are ideal for this application and the expected ambient conditions.

Because the VVM Interface Pad and the Top Surface Pad constitute a physical interfacing and proximate structure around the CEC, respectively, their performance mission must be set down in this FSAR. A ~~reference~~ set of design data, derived from Holtec's experience with pad designs, is summarized in Table 2.I.7. The design objective is to ensure that the self-supporting VVM Interface Pad provides a leak tight interface and the Top Surface Pad provides a sufficiently inflexible surface for the loaded transporter.

* The definition of the term "equivalent" is provided in the Glossary.

iii. Lateral Subgrade

The physical characteristics of the subgrade surrounding the Container Shell vary from site-to-site. Further, an ISFSI owner may elect to excavate the natural subgrade and replace it with an engineered fill of an appropriate density and composition to fulfill shielding demand. While the surrounding subgrade may not provide a structural support function to the CEC structure, as an interfacing body, it plays a role in the loading applied to the CEC under certain scenarios, namely:

a. during an earthquake event
b. during movement of the cask along the Top Surface Pad
c. normal storage condition from the natural overburden or under the state of maximum soil saturation (hydraulic buoyancy).

During a seismic event, the surrounding subgrade may exert a time-varying lateral pressure loading on the Container Shell, which, in principle, may ovalize it and possibly bend it like a beam.

During the movement of the cask transporter, loaded with the transfer cask (see Chapter 8 for operational details), the vertical load of the cask transporter results in a lateral pressure on the upper part of the Container Shell. Although the lateral pressure is apt to be quite small due to the physical restriction on how close to the Container Shell the transporter can ride, mandatory limits on the lateral separation and subgrade properties are necessary to ensure a design with adequate safety margins.

The soil overburden pressure on the Container Shell is the third loading category whose limiting value must be established. Also, the condition of maximum soil saturation implies a hydrostatic pressure on the CEC whose maximum value depends on the depth of the MPC storage cavity and the effective density of the saturated soil.

iv. Impressed Current Cathodic Protection System (ICCPS)

If an ICCPS is required by the technical specifications, it shall be implemented in accordance with the requirements in Supplement 3.I, Subsection 3.I.4 and appropriate references. The following general design procedure may be followed:

1. Select the current density to be applied.
2. Compute the total current required to achieve the selected current density.
3. Design the ground bed system or distributed anode system.
4. Select a rectifier of proper voltage and current output.
5. Design all electrical circuits, fittings, and switchgear in accordance with good electrical practice.
6. Locate the cathodic protection test stations.
7. Prepare the necessary drawings and specifications for the project.

An example design is provided in this subsection for illustrative purposes and should not be interpreted as implying to present the best design or the only possible design. Because there are a multitude of ISFSI variables that will bear upon the design of the ICCPS for a particular site including differing ISFSI layouts, certain simplifying assumptions are made throughout the example. The example provides the user with insight on the types of design decisions that will need to be made. For example, because of possible shielding effects between CECs, as well as other SSC obstructions, the design implements a layout with closely distributed anodes to provide more uniform current distribution. Also, the example design implements closed loop electrical connections such that if the wire/cable is severed at any one place, electrical continuity is maintained to all anodes. Another item to be considered during the design phase is whether or not a test station is needed for each and every CEC.

Figure 2.I.1 presents an example ICCPS design layout for a 2x6 Array of VVMs. The ICCPS consists of the following four main subsystems/components:

1) Rectifier
2) Anodes
3) Test Stations
4) Wires and Cables

Figure 2.I.2 presents an example ICCPS test station.

The following is an example computation for determining the required current (approximate dimensions and quantities are used) as applicable to Figure 2.I.1:

Assume a CEC length (determined from "top of grade" to bottom of CEC bottom plate): 219.5 in.
CEC outside diameter: 86 in.
CEC condition: exterior is coated
Coating efficiency: 91.5% (i.e. 8.5% of the coated CEC surface is considered bare metal)
Cathodic Protection: Rectifier and distributed Natural Graphite Anodes with carbonaceous backfill
Soil resistivity: 4,000 ohm/cm^2
Current density: 1 mA/ft^2 exposed metal
Outside area of each CEC: 59,300 in^2 (412 ft^2)
Total area for an array of twelve CECs: 4,944 ft^2
Bare CEC metal exposed: 4,944 ft^2 x 0.085 or 420 ft^2
Current required: 420 ft^2 x 1 mA/ft^2 or 420 mA

The following is additional data applicable to Figure 2.I.1.

Approximate Anode quantity: 11
Approximate Anode size: 5 in dia. x 120 in. long
Approximate Backfill quantity: 6,000 lbs of carbonaceous backfill

The total number of anodes required is determined primarily by the total current requirements of the CEC metal to be protected and the optimum current density of the anode material selected.

Graphite is a semi-consumable anode. Graphite typically has experienced corrosion rates of 1.5 to 2.16 lbs /amp year [2.I.3] or as determined by experiment, 0.08 grams per square meter of anode per amp-hour of current (at 30 C, 40 mA/cm^2 anode current density) [2.I.4]. A computed anode life of less than 40 years is acceptable as long as appropriate measures are taken to facilitate the replacement of anodes during the design phase and appropriate maintenance planning measures are implemented. Use of carbonaceous backfill should be considered since it can substantially lengthen the anode life. Inert (non-consumable) platinized anodes may also be considered.

v. Concrete Encasement

If concrete encasement is used, it shall be implemented in accordance with the requirements in Supplement 3.I, Subsection 3.I.4 and appropriate references.

The following points shall also be taken into consideration:

- The effect of the concrete encasement on the ICCPS, if an ICCPS is also implemented. The concrete encasement should not interfere with the settlement of the concrete pad providing the transporter support surface without appropriate evaluation.

~~vii. Detailed Design Considerations~~

~~The detailed design of the interfacing SSCs for dry storage systems is customarily prepared for each site to best accord with the specific site's conditions. The same approach is followed for the HI-STORM 100U System. For a specific site, *critical characteristics* shall be selected to insure that the site-specific adaptation will not result in the impaction of any of the design criteria applicable to the VVM set forth in this FSAR (the interfacing SSCs do not affect confinement, criticality, or evaluated thermal performance of the system). Thus, any site-specific adaptation of the interfacing SSC design will require only evaluation of the structural and shielding adequacy of the VVM, which is embedded with large margins of safety because of its inherent configuration.~~

~~Thus, for example, the resistance to settlement of the VVM Support Foundation is expressed in terms of the vertical stiffness, and a threshold minimum value of stiffness is prescribed in Table 2.I.2. This minimum admissible value may be obtained using an engineered fill of a specific minimum Young's Modulus undergirding a reinforced concrete pad, as is the case for the reference foundation design data presented in Table 2.I.7. However, at a bedrock subgrade, it may be more appropriate to finish off the top of the VVM Support Foundation with engineered layers of mud mat, concrete, and/or grout. It is the stiffness of the resulting foundation that defines the *critical characteristic* whose minimum prescribed value in Table 2.I.2 must be met at each site, not the physical details that result in meeting the prescribed minimum value. Likewise, the average density of the subgrade material surrounding the Container Shell is set in Table 2.I.2 to accord with the value used in the soil structural interaction analysis. A smaller value of~~

~~subgrade density is used in Supplement 5.I. A denser material may be used; however, its effect on the seismic adequacy of the VVM must be analyzed to ensure that the structural margins remain positive. On the other hand, presence of a less dense subgrade would affect the site-specific site boundary dose computation under 10CFR§72.212 for the ISFSI. Analyses and results presented in Supplements 3.I and 5.I include interaction of the *critical characteristics* of the interfacing SSCs with the VVM. The acceptable range of all critical attributes of the subterranean ISFSI have been set down in the Technical Specification to insure that the ISFSI will be sufficiently robust to serve its intended function during its Design Life.~~

2.I.3 Service Conditions and Applicable Loads

The categories of loads on the HI-STORM 100U VVM are identified below. They parallel those for the aboveground systems.

- Normal Condition: dead weight, handling of the Closure Lid, soil overburden pressure from subgrade, self-weight and from live load due to cask transporter movement, snow loads, and buoyancy effect of water saturation of surrounding subgrade and foundation. Most normal condition loadings occur at an ambient temperature denoted as the "normal storage condition temperature"; however, for calculations involving the Closure Lid, a higher temperature is assumed when the VVM carries a loaded MPC since the Closure Lid outlet ducts will be subject to heated air.

- Off-Normal Condition: elevated ambient temperature and partial blockage of air inlets. .

- Extreme Environmental Phenomena and Accident Condition: handling accidents, fire, tornado, flood, earthquake, explosion, lightning, burial under debris, 100% blockage of air inlets, extreme environmental temperature, 100% fuel rod rupture, and an accident during construction in the vicinity of a loaded ISFSI.

The design basis magnitudes of the above loads, as applicable, are provided in Tables 2.I.1 and 2.I.4, and are discussed further in the following subsections. Applicable loads for an MPC contained in a VVM or for a HI-TRAC that services a VVM are identical to those already identified in the main body of Chapter 2 and, therefore, are not repeated or discussed within this supplement. However, recognizing that the support of an MPC in a VVM is different from the support provided in an above ground HI-STORM, the design basis dynamic analysis model includes the fuel assemblies, the fuel basket, and the enclosure vessel so that the loads described above are properly distributed within the VVM.

2.I.4 Normal Condition Operating Parameters and Loads

i. Dead Weight

The HI-STORM 100U System must withstand the static loads due to the weight of each of its components. If any support provided by the subgrade and the VVM Interface Pad is neglected, then the dead weight of the Closure Lid bears on the Container Flange and the

Container Shell; the load to the VVM Support Foundation is transferred through a direct bearing action.

ii. Handling Loads

The only instance of a handling load occurs during emplacement or removal of the Closure Lid while the CEC contains a loaded MPC. To provide defense-in-depth, Closure Lid lifting attachments shall meet the design requirements of ANSI N14.6 [2.2.3].

Lift locations for the CEC and the Divider Shell are used for lifting only during construction, and possibly during maintenance and decommissioning of the VVM with no loaded MPC present; therefore, these lifting locations are not subject to the defense-in-depth measures of NUREG-0612. They are therefore considered as a part of the site construction safety plan, site-specific maintenance program, or site decommissioning plan, as applicable, and as such are treated as being outside the scope of this FSAR.

iii. Live Load

a. Subgrade Pressure Due to Transporter Movement

The properties of the surrounding subgrade and the presence of a loaded cask transporter affect the state of stress in the subgrade continuum. This stress field may produce a lateral compressive load on the Container Shell, which acts together with the effect from soil overburden.

b. MPC Transfer Operation

The VVM must withstand the weight of the loaded HI-TRAC transfer cask and the mating device during MPC transfer operations. Bounding weights for these components are used in the qualifying analysis.

iv. Ambient Temperature

The HI-STORM 100U System is analyzed for the same maximum yearly average ambient air temperature as that used for the aboveground overpacks. This normal operating condition temperature bounds all locations in the continental United States.

v. Snow

An appropriately conservative snow load on the Closure Lid is considered as a potential bounding case (see Table 2.I.1).

vi. Differential settlement

The effect of long term differential settlement on the Support Foundation pad (mat) shall be considered as a concurrent load with dead weight.

2.I.5 Off-Normal Condition Design Criteria

i. Elevated Ambient Air Temperature

The HI-STORM 100U System must be able to reject the design basis heat load under short-term conditions of elevated ambient air temperature.

ii. Partial Blockage of Inlet Air Ducts

The HI-STORM 100U System must withstand 50% blockage of the inlet air flow area without exceeding allowable temperature and pressure limits.

2.I.6 Environmental Phenomena and Accident Condition Criteria

The extreme environmental phenomena and accident conditions specific to the HI-STORM 100U System are defined in the following discussion. No additional structural load condition is identified on the HI-STORM 100U system.

i. Handling Accidents (Drops and Tipover)

Because the VVM is situated underground and cannot be moved, drop and tipover events are not credible accidents for this design. The Closure Lid, as discussed in Supplement 1.I, cannot strike the MPC lid due to geometry constraints if it were to undergo a free fall. Further, because the load handling device and lifting equipment are required to meet the defense-in-depth criteria set down in this FSAR, the drop of the Closure Lid or transfer cask during handling operation is termed non-credible (as is the case for the aboveground HI-STORM system MPC transfer operations at the ISFSI).

ii. Fire

The VVM must withstand the effects of a fire that consumes the maximum volume of fuel permitted to be in the fuel tank of the cask transporter. The duration of the fire for the VVM is conservatively assumed to be the same as that used for the aboveground overpacks. As is the case for aboveground overpacks, the fuel is assumed to spill, surround one storage system and burn until it is depleted. Because the VVM is configured to have a surrounding built-in step or spill barrier (see Figure 1.I.3), the spilled fuel will collect and burn over the Top Surface Pad, also referred to as Top-of-Grade (see Figure 1.I.2). Therefore, the location of fuel combustion will be somewhat removed from the CEC. Also, the natural grade in the transporter movement surface, engineered to direct the rainwater away from the VVMs, will do the same to the spilled fuel, further ameliorating the thermal consequence of the fire to the stored SNF.

The closed-end geometry of the MPC storage cavity ensures that a sustained combustion of the fuel, even if it were to be hypothesized to enter the VVM cavity, is not possible.

The loss of shielding effectiveness due to heat up of the concrete and the surrounding SSCs is primarily due to vaporization of the small amount of volatiles, including the contained moisture present in the concrete. This reduction in shielding is small and is permitted under the regulations. Therefore, the fire analysis of the VVM is focused on determining safety against a structural collapse due to elevation in the structure's metal temperature.

The sole effect of fire on the VVM structure is to raise the metal temperature of the structural members surrounding the shielding concrete in the Closure Lid. The analysis for the fire event accordingly seeks to establish that the load bearing structure will not be weakened by the rise in its metal temperature (and a consequent reduction in the yield and ultimate strength) and result in its structural collapse.

iii. Tornado

The HI-STORM 100U System is protected from the effects of a tornado and accompanying missiles by virtue of its underground configuration. The only VVM component that warrants evaluation for the effects of a tornado-induced missile strike is the Closure Lid, which is made of a steel weldment with encased concrete.

The HI-STORM 100U System is inherently stable under tornado missile impact. The impact of a large missile (1800kg Automobile) is evaluated to determine whether the Closure Lid continues to maintain its required shielding function. Penetration and perforation issues associated with the Closure Lid due to intermediate missiles that constitute the Extreme Environmental Phenomena loads for the HI-STORM 100U system are also addressed. The Closure Lid is analyzed for penetration of a solid steel cylinder traveling at a high speed consistent with the characteristics of the intermediate missile listed in Table 2.2.5. As there is no direct line of sight to the MPC, small missiles are not considered. Also, since a tornado is a short duration event, the effect of extremely high tornado winds on the thermal performance of the VVM would be negligible due to the system's thermal inertia. Therefore, the effect of tornado wind on the thermal performance of the HI-STORM 100U system is not analyzed.

iv. Flood

As discussed in Subsection 1.I.2, the HI-STORM 100U System is engineered to be flood resistant. However, even though the potential water ingress passages are elevated in the HI-STORM 100U (in contrast to the pad level inlet ducts in typical ventilated overpacks), submersion flooding that fills all or a portion of the ducts could occur at certain ISFSI sites located in flood zones. The MPC is designed to withstand 125 feet of water submergence. The VVM will clearly withstand this static head of water above the surface of the ISFSI because all structural members either are not subject to any pressure differential from the flood or are backed by the subgrade, which resists the flood water directly. Full or partial submergence of the MPC is not a concern from a thermal perspective, as discussed in Supplement 1.I, because heat removal is enhanced by the floodwater.

The most severe flooding event from a thermal perspective would be the partial filling of the intake plenum such that airflow is blocked but the MPC is not submerged in water. To mitigate the consequences of this event, the height of the Divider Shell cutouts is purposely located well above the bottom elevation of the MPC. Therefore, if the flood level is just high enough to block air flow, the lower portion of the MPC will be submerged in water. The wetted MPC bottom region serves as an efficient means of heat rejection to the floodwater. This accident event is described in Supplement 11.I.

v. Earthquake

The MPC Enclosure Vessel and fuel basket have been qualified to a 60g deceleration limit in the HI-STAR 100 (Docket Nos. 72-1008, 71-9261); this deceleration exceeds the expected deceleration from a seismic event. However, to ensure an accurate structural evaluation of the VVM, the evaluation of the response of the VVM to the design basis seismic event shall include a detailed model of the MPC, the fuel basket, and the contained fuel; this model should capture impacts between the fuel and the fuel basket, between the fuel basket and the MPC, and between the MPC and applicable components of the VVM.

There are two criteria that must be considered when establishing that a site can deploy the HI-STORM 100U System. These are: a) the strength of the input seismic event and, b) the stiffness of the surrounding and undergirding subgrade. Each of these is considered below.

a) As required by 10CFR72.102(f), the Design Basis Earthquake for the ISFSI must be specified. The Design Basis Earthquake (DBE) at a plant site is variously stated in terms of the so-called "free field" acceleration or the "top-of-rock" acceleration, etc. The accelerations are typically specified in two orthogonal horizontal directions, and in the vertical direction. While the vertical acceleration is largely unaffected by the presence of a massive underground structure, such as the vertical ventilated module (VVM), the effect on the horizontal acceleration components may be significant.

The underlying premise adopted for deployment of the HI-STORM 100U System is that the user shall perform a site-specific dynamic analysis, using the methodology prescribed in Supplement 3.I and incorporated by reference into the Technical Specification. The dynamic analysis model includes a single isolated VVM, a surrounding substrate of sufficient extent to preclude the free-field behavior from being altered by the presence of a VVM, and the undergirding pad, substrate, and any additional structure below the pad. The ZPA values for the underground VVM in Table 2.I.4 are used solely to demonstrate the robustness of a representative system analyzed in Subsection 3.I.4.7 using the specified methodology. The dynamic model referenced in the Technical Specification is demonstrated to provide a conservative portrayal of the response of the VVM under earthquakes in Section 3.I.4. This model is referred to as the Design Basis Seismic Model (DBSM).

vi. Explosion

The HI-STORM 100U System must withstand the pressure pulse due to a design basis explosion event. The effect of overpressure due to an explosion near the VVM is evaluated. The overpressure design value applied to the Closure Lid outer shell surface is intended to bound all credible explosion events because no combustible material is permitted to be stored near the VVM, and all materials of construction are engineered to be compatible with the operating environment. However, site-specific explosion scenarios that are not evidently bounded by the design basis explosion load considered herein (see Table 2.I.1) shall be evaluated under the provisions of 10CFR72.212.

vii. Lightning

The HI-STORM 100U System must withstand a lightning strike without a significant loss in its shielding capability. The effect of a lightning strike on the VVM is the same as that described for the aboveground overpack design, even though the likelihood of a lightning strike on the VVM is lower due to its low height above grade. Lightning is treated as an Extreme Environmental Phenomena event in Supplement 11.I. Because of its non-significant structural effect on the VVM, it is not considered as a load that warrants analysis in Supplement 3.I.

viii. Burial Under Debris

The burial under debris event for the HI-STORM 100U System is bounded by the evaluation performed for the aboveground overpacks, as discussed in Supplement 4.I.

ix. 100% Blockage of Air Inlets

The blockage of the entire inlet air flow area is analyzed as an accident event and is described in Supplement 11.I and analyzed in Supplement 4.I.

x. Extreme Environmental Temperature

An extremely high ambient air temperature is analyzed as an extreme environmental event and is described in Supplement 11.I and analyzed in Supplement 4.I.

xi. 100% Fuel Rod Rupture

This loading condition is specific to the MPC thermal evaluation and treated in Supplement 11.I.

xii. Construction Accident Proximate to the ISFSI

As shown in the licensing drawings (Section 1.5) a radiation protection space (RPS) around a loaded ISFSI is specified within which any activity that may disturb the substrate lateral to the VVM is forbidden. The extent of the protected region defined in the licensing drawings is set down to ensure, with sufficient margin of safety, that the ISFSI will continue to meet all relevant safety criteria under all applicable conditions of storage including normal, off-normal, extreme environmental phenomena and accident conditions. Thus, for example, the RPS must be sufficiently wide to insure that the design basis projectiles (large, medium, and penetrant missiles) defined in Chapter 2 under extreme environmental phenomena loadings, will not access an MPC stored in a VVM cavity. As explained in Supplement 3.I, the incident missile is assumed to act when a deep cavity has been excavated contiguous to the protected space and the direction of action of the missile is oriented to achieve maximum penetration of the substrate towards the CEC shell. The *minimum* ground buffer requirement around the ISFSI must be evaluated under the provisions of 10CFR72.212 for an ISFSI site for the site-specific conditions for the ISFSI. Because the earth around an operating ISFSI serves a principal shielding function, it is essential that any excavation activity adjacent to the ISFSI (to build an extension of the ISFSI, for example), must not disturb the soil in the Radiation Protection Space (RPS) (see subsection 1.I.4). If the soil column in the RPS is not adequately secured, then (since the soil is not integral to the VVM) it is susceptible to being stripped from the RPS as a result of human error during construction activities involving excavation, or as a result of a coincident seismic event.

2.I.7 Codes, Standards, and Practices to Ensure Regulatory Compliance

There is no U.S. or international code that is sufficiently comprehensive to provide a completely prescriptive set of requirements for the design, manufacturing, and structural qualification of the VVM. The various sections of the ASME Codes, however, contain a broad range of specifications that can be assembled to provide a complete set of requirements for the design, analysis, shop manufacturing, and field erection of the VVM. The portions of the Codes and Standards that are invoked for the various elements of the VVM design, analysis, and manufacturing activities are summarized in Table 2.I.3.

The ASME Boiler and Pressure Vessel Code (ASME Code) Section III, Subsection NF Class 3, 1995 Edition, with Addenda through 1997 [2.2.1], is the applicable code to determine stress limits for the metallic structural components of the VVM when required by the acceptance criteria listed in Table 2.I.5. Table 2.I.3 summarizes considerations for design, fabrication, materials, and inspection. The permitted material types and their permissible temperature limits for long-term use are listed in Table 2.I.8. Manufacturing requirements are set down in licensing and design drawings.

ACI 318-05 [2.1.5] is the applicable reference code to establish applicable limits on unreinforced concrete (in the Closure Lid), which is subject to secondary structural loadings. Appendix 1.D contains the design, construction, and testing criteria applicable to the plain concrete in the VVM's Closure Lid. Applicable sections of [2.1.5] should be used in the design of the interfacing and proximate SSCs.

As mandated by 10CFR72.24(c)(3) and §72.44(d), Holtec International's quality assurance program requires all constituent parts of an SSC subject to NRC's certification under 10CFR72 to be assigned an ITS category appropriate to its function in the control and confinement of radiation. The ITS designations for the constituent parts of the HI-STORM 100U VVM, using the guidelines of NUREG-CR/6407 [2.0.5], are provided in Table 2.1.8.

The aggregate of the citations from the codes, standards, and generally recognized industry publications invoked in this FSAR, supplemented by the commitments in Holtec's quality assurance procedures, provide the necessary technical framework to ensure that the as-installed VVM would meet the intent of §72.24(c), §72.120(a) and §72.236(b). As required by Holtec's QA Program (discussed in Chapter 13), all operations on ITS components must be performed under QA validated written procedures and specifications that are in compliance with the governing citations of codes, standards, and practices set down in this FSAR. For activities that may be performed by others, such as site construction work to install the VVM, Holtec International requires that all activities be formalized in procedures and subject to the CoC holder's as well as the ISFSI owner's review and approval.

An ITS designation is also applied to the interfacing SSCs (such as the Support Foundation), which requires that all quality assurance measures set down in Holtec's Quality Assurance Procedure Manual be complied with by the entity performing the site construction work. In this manner, the compliance of the as-built VVMs with its engineered safety margins under all design basis scenarios of loading is assured.

2.1.8 Service Limits

No new service limits are defined for the HI-STORM 100U System beyond those described in Subsection 2.2.5.

2.1.9 Loads and Acceptance Criteria

Subsections 2.1.4, 2.1.5, and 2.1.6 describe the loadings for normal, off-normal, and extreme environmental phenomena and accident conditions, respectively, for the HI-STORM 100U System. Tables 2.1.1 and 2.1.4, respectively, provide the design loads and representative seismic load parameters in terms of ZPA values for an illustrative analysis using the methodology of Subsection 3.1.4.7.

Bounding load cases that are significant to the structural performance of the VVM and require evaluation are compiled in Table 2.1.5 using information provided in Sections 2.1.4, 2.1.5, and 2.1.6.

Supplement 3.I contains a description of the evaluations, establishes the evaluation methodology, and provides evaluation results that demonstrate compliance of the VVM to the applicable load cases and acceptance criteria described below. The load cases and acceptance criteria are explained in subsequent paragraphs and summarized in Table 2.I.5. Table 2.I.6 summarizes the acceptance criteria for extreme environmental events.

Each loading case in Table 2.I.5 is distinct in respect of the sub-component of the VVM that it affects most significantly. The acceptance criteria consist of demonstrating that (i) radiation shielding does not degrade under normal and off-normal conditions of storage loadings, (ii) the system does not deform under credible loading conditions in a manner that would jeopardize the subcritical condition or retrievability of the fuel, and (iii) the MPC maintains confinement. For accident conditions of storage loadings, any permissible degradation in shielding must be shown to result in dose rates sufficiently low to permit recovery of the MPC from the damaged cask, including unloading if necessary, and loss of function must be readily visible, apparent or detectable.

The above set of criteria, extracted from NUREG-1536, is further particularized below in a more conservative form for each applicable loading case in this subsection.

<u>Load Case 01: Buoyant Force</u>

This loading case pertains to the scenario wherein a VVM has been built, but the Closure Lid and MPC are not yet installed. Strictly speaking, this condition is not important to storage safety because the MPC is not present. However, considerations of long-term service life warrant that a minimum weight CEC, subject to the maximum buoyant force of water under an assumed hypothetical condition of submergence in water with a head equal to the length of the CEC, does not float. This evaluation sets a minimum additional weight (usually on a temporary cover) that will be set in place during construction to protect the CEC from construction debris, to provide for construction worker safety, and to insure that the CEC does not suffer uplift from buoyant forces. In addition, the Bottom Plate of the CEC must have sufficient flexural strength such that under a buoyant uplift pressure, its primary bending stress intensity remains below the ASME Level D allowable stress intensity at the reference metal temperature (assumed to be 125°F (extreme environmental condition temperature) in Table 2.I.5).

<u>Load Case 02: Dead Load plus Design Basis Explosion Pressure</u>

The dead weight loading, explained in Paragraph 2.I.4(i) is accentuated by the design basis explosion loading defined in Paragraph 2.I.6(vi). The explosion load is stated in terms of an equivalent static pressure. The affected sub-components are:

a. The Container Shell, subjected to a compressive state of stress under the combined effect of dead weight of the Closure Lid and surface pressure on the Closure Lid under the explosion event.

b. The Closure Lid, subject to self-weight and the Closure Lid surface pressure under the explosion event.

Other VVM components are not in the direct path of this loading. The explosion pressure envelops other mechanical loads such as snow and flood. Load Case 02, therefore, is a bounding load combination that conservatively subsumes a number of normal and extreme environmental phenomena loads. As this load case is intended to bound any normal condition, Level A stress limits are applicable to this case based on reference metal temperatures that bound all mechanical loading scenarios.

Load Case 03: Tornado Missile Impact

The Closure Lid is the only exposed portion of the VVM. Therefore, the tornado-borne missile strikes must be postulated to occur on the lid. The only other affected VVM part is the Container Flange, which prevents lateral sliding of the lid.

When subject to a tornado missile strike, the Closure Lid must not be dislodged, resulting in a direct line of sight from the top of the MPC to the outside. For the intermediate missile, the Closure Lid must resist full penetration. Finally, any CEC deformation from the compressive axial impulse due to the missile strike must not prevent MPC retrievability.

Load Case 04: Design Basis Seismic Event

The effect of a seismic event on a loaded VVM is influenced by a number of parameters such as the structural characteristics of the surrounding and undergirding substrate, the presence of other VVMs, the properties of the interfacing structures (i.e., the Support Foundation and VVM Interface Pad), the type of MPC stored, and the harmonic content of the earthquake. An array of analyses documented in Section 3.I provides the quantitative information to help define an analysis methodology that has been termed the Design Basis Seismic Model (DBSM) in Section 2.I.6. The details of the DBSM are provided in Subsection 3.I.4.7 and are set down as the prescribed method in the Technical Specification. The array of ISFSI parameters, significant to the seismic behavior of the storage system and used in the qualifying analysis in Chapter 3, are used to define their minimum acceptable reference value in the Technical Specification. All HI-STORM 100U ISFSIs must be analyzed to demonstrate their structural compliance to the criteria set forth in this FSAR under all applicable site specific loads. The Design Basis Seismic Event is classified as an extreme environmental phenomenon, and as such, the Level D service condition limits are applicable to the Code components, such as the MPC Enclosure Vessel.

The CEC shell is subject to performance-based limits, which require that the deformation of the CEC does not prevent MPC retrievability, does not cause loss of confinement, and that the system remains subcritical. This is accomplished by demonstrating that after the seismic event, permanent ovalization of the Container Shell and/or Divider Shell does not result in a geometry that precludes removal of an MPC.

The Divider shell's sole function is to direct the airflow inside the CEC cavity and to hold MPC Guides that serve to restrain the MPC from excessive rattling motion during an earthquake event. The guides are subject to in-plane compressive impacts from the "hard points" on the MPC (the approximately 2.5-inch thick baseplate at the bottom and the 9.5-inch thick lid at the top). The ratio of the buckling load or the ultimate load for the MPC Guides to the calculated maximax (maximum in time and space) in-plane load is the factor of safety for this item.

Finally, because the MPC Enclosure Vessel is designed to meet ASME Section III, Subsection "NB" (Class 1) stress intensity limits, and the earthquake is categorized as a "Level D" event, the primary stress intensities in the MPC Enclosure Vessel must meet Level D limits. The primary stress intensity in the MPC shell is the maximum longitudinal flexural stress intensity, which is compared against the primary membrane stress intensity limit for the material (Alloy X) at the applicable service temperature. The fuel basket is a multi-flange 3-D beam structure, designed to meet the stress limits of Subsection "NG" of the Code. The maximum longitudinal primary stress intensity in the basket, calculated from the 3-D fuel basket/fuel assembly model, must be less than the corresponding Level D condition limit at the service temperature. In addition to the primary stress based limits it is also necessary to demonstrate that the transverse bending stress in any panel normalized over the length of the fuel basket is less than the Level D primary stress limit.

The limits on the primary stresses in the MPC components, stated above for the DBE condition, are also applicable to other Level D (faulted) events consistent with the dynamic analysis using a 3-D detailed model of the MPC, the internal fuel basket, and the fuel assemblies inside the basket. In particular, the local strain in the Confinement Boundary due to the impact between the MPC and the MPC guides under the Design Basis Earthquake for the site requires evaluation.

Table 2.I.6 summarizes the above discussion in tabular form.

Load Case 05: Closure Lid Handling

The Closure Lid lifting attachments shall meet the strength limits of ANSI N14.6 for heavy load handling. The metal load bearing parts shall satisfy the requirements of Reg. Guide 3.61 for primary stresses near the lifting locations and shall satisfy ASME NF Level A limits away from the lifting locations.

Yield and ultimate strength values used in the stress compliance demonstration per ANSI N14.6 shall utilize confirmed material test data through either independent coupon testing or material suppliers' CMTR or COC, as appropriate.

Load Case 06: Design Basis Fire Event

The exposed portion of the VVM, namely the Closure Lid, will experience the heat input and temperature rise under the fire event. The balance of the VVM, because of its underground location, will be subject to only a secondary temperature increase.

It is required to demonstrate that the structural collapse of the Closure Lid cannot occur due to the reduction of its structural material's (low carbon steel) strength at the elevated temperatures from the fire.

Load Case 07: CEC Loading From Surrounding Subgrade

The CEC is subject to a lateral pressure from the soil in the non-seismic condition. This pressure is affected by the presence of a loaded cask transporter adjacent to the CEC. The CEC must be shown to provide adequate resistance to this loading.

This load case tends to ovalize the CEC; the maximum primary membrane plus bending stress is limited to the material yield strength under normal conditions of storage.

In evaluating the structural safety margins in Supplement 3.I for the load cases described above, ~~reference~~ design data for the interfacing SSCs presented in Table 2.I.7 is used as applicable.

2.I.10 Safety Protection Systems

The HI-STORM 100U System, featuring the VVM, provides for confinement, criticality control, and heat removal for the stored spent nuclear fuel in the manner of the aboveground overpacks. The VVM provides better shielding and protection from environmental events, such as tornado missiles, because of its underground configuration. The information in Section 2.3 also applies to the HI-STORM 100U System, with the recognition that the air ventilation system is modified. Instead of the ambient air entering through inlet ducts at the bottom, the cooling air enters the circumferentially symmetric passage at the top of the VVM and is directed to the bottom of the VVM cavity along a radially symmetric annulus (Figure 1.I.4). However, the mechanism of heat transfer from the MPC to the cooling air is identical to the aboveground overpack designs.

The HI-STORM 100U System is completely passive requiring no active components or instrumentation to perform its design functions. Temperature monitoring or scheduled visual verification of the integrity of the air passages is used to verify continued operability of the VVM heat removal system.

2.I.11 Decommissioning Considerations

The HI-STORM 100U VVM is specifically engineered to facilitate convenient decommissioning. As discussed in Supplement 1.I, the component most proximate to the active fuel and, hence, likely to be the most activated, is the Divider Shell. The Divider Shell is not welded to the CEC structure; therefore, it can be conveniently removed for decommissioning. The CEC structure can be removed by excavating the surrounding subgrade. Alternatively, the cavity can be filled with suitable fill materials and the CEC left in place. While the above discussion is unique to the VVM design, the information in Section 2.4 pertaining to decommissioning of other HI-STORM models is also applicable to the VVM. Even if the decision is made to dispose of all activated material, the VVM, due to differences in its geometry and construction (particularly, use of the native soil as the biological shield to the extent possible) will result in less steel and concrete to be disposed of. In the aggregate, it is estimated that less material will need to be disposed of to decommission a VVM ISFSI in comparison to an ISFSI containing aboveground overpacks.

Finally, the activation estimate in Table 2.4.1 for the aboveground overpack inner shell is conservatively applicable to the VVM steel shell enclosure.

2.I.12 Regulatory Compliance

Pursuant to the guidance provided in NUREG-1536, the foregoing material in this supplement provides:

i. a complete set of principal design criteria for the VVM as mandated by 10CFR72.24I(1), §72.24(c)(2), §72.120(a) and §72.236(b);

ii. a clear identification of VVM structural parts subject to a fully articulated design subject to certification under 10CFR72 and of interfacing SSCs ~~that may need to be customized for a specific ISFSI site~~;

iii. the required set of limiting critical characteristics of the interfacing SSCs to ensure that the VVM will render its intended function under all design basis scenarios of operation;

iv. a complete set of requirements premised on well-recognized codes and standards to govern the design and analysis (to establish safety margins) and manufacturing of the VVM; and

v. a table containing cross-reference between the applicable 10CFR72 requirements and the location in this FSAR where the fulfillment of each specific requirement is demonstrated.

It is noted that the requirements of 10CFR72 do not preclude the use of an underground storage system such as the HI-STORM 100U. The VVM concept, while not specifically mentioned in the regulatory guidance literature associated with implementing the requirements in 10CFR72 (i.e., NUREG-1536), meets and exceeds the intent of the guidance in that it provides an enhanced protection of the stored spent nuclear fuel and a significantly reduced site boundary dose, enables a more convenient handling operation, and presents a much smaller target for missiles/projectiles compared to an aboveground storage system.

2.I.13 References

The references in Section 2.6 apply to the VVM to the extent that they are appropriate for use with an underground system.

[2.I.1] NACE Standard RP0104-2004 "The Use of Coupons for Cathodic Protection Monitoring Applications", NACE International.

[2.I.2] NACE Standard TM0101-2001 "Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Tank Systems", NACE International.

[2.I.3] Federal Construction Council Technical Report No. 32, Cathodic Protection As Applied to Underground Metal Structures", National Academy of Sciences – National Research Council, Publication 741, 1959.

[2.I.4] Rabah, M.A., et al., "Electrochemical Wear of Graphite Anodes during Electrolysis of Brine," *Carbon*, Vol. 29, No. 2, pp. 165-171, 1991.

[2.I.5] ACI-318-05, Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05), Chapter 22, American Concrete Institute, 2005.

Table 2.I.1

LOADS, CRITERIA, APPLICABLE REGULATIONS, REFERENCE CODES, AND STANDARDS FOR THE VVM

Type	Criteria or Value and Reference Location in the FSAR	Basis, Regulation and Reference Code/Standard
Life:		
Design Life	40 yrs, Section 3.I.4	-
License Life	20 yrs, Section 3.I.4	10CFR72.42(a) & 10CFR72.236(g)
Structural:		
Design & Fabrication Codes: Foundation Pad; VVM Interface Pad and Top Surface Pad	ACI 318 (2005)	10CFR 72.24
Unreinforced Concrete Stress Limits (Closure Lid)	Applicable Sections of ACI 318 (2005)	10CFR72.24(c)(4)
Structural Steel	Section 2.I.7, Tables 2.I.5, 2.I.6	10CFR72.24(c)(4)
VVM Closure Lid Dead Weight†:	Table 3.I.1	R.G. 3.61
Design Internal Pressure	Atmospheric, Supplement 1.I	Ventilated Module
Response and Degradation Limits	Section 3.I.4	10CFR72.122(b), (c)
Corrosion Allowance	1/8" on surfaces directly in contact with subgrade	Standard industry practice
Thermal:		
Maximum Design Temperatures:		
Closure Lid Concrete		
Through-Thickness Section Average (Normal)	Table 1.D.1	ACI 349-85, Appendix A, (Paragraph A.4.3)
Through-Thickness Section Average (Off-Normal and Accident)	Table 1.D.1	ACI 349-85, Appendix A, (Paragraph A.4.2)
Structural Steel	Table 2.I.8	ASME Code, Section II, Part D
VVM Divider Shell Thermal Insulation	Heat transfer resistance ≥ 4 hr-ft^2-°F/Btu. Must be stable at temperatures $\leq$ 800°F	N/A
Confinement:	N/A, Provided by MPC; Supplement 7.I	10CFR72.128(a)(3) and 10CFR72.236(d) & (e)
Retrievability: Normal/Off-Normal/Accident	No damage that precludes MPC retrieval or threatens subcriticality of fuel. MPC maintains confinement,	10CFR72.122(f), (h), (1), & (l)

† All weights listed in Table 3.I.1 are bounding weights. Actual weights will be less, and will vary based on as-built dimensions of the components, fuel type, and the presence of fuel spacers and non-fuel hardware, as applicable.

Table 2.I.1 (continued)
LOADS, CRITERIA, APPLICABLE REFERENCE REGULATION/CODES AND STANDARDS FOR HI-STORM 100U VVM

Type	Criteria or Value and Reference Location in the FSAR	Basis, Regulation and Reference Code/Standard
	Supplement 3.I	
Criticality:	N/A; Provided by MPC; Supplement 6.I	10CFR72.124 and 10CFR72.128(a)(2)
Radiation Protection/Shielding:		
Normal/Off-Normal	Provide capability to meet controlled area boundary dose limits under 10CFR72 for all normal and off-normal conditions; Supplement 5.I	10CFR72.104 and 10CFR72.212
	Ensure dose rates on and around the VVM during MPC transfer and lid installation operations are ALARA; Supplement 10.I	10CFR20
Accident or conditions of Extreme Environmental Phenomena	Meet controlled area boundary dose limits in regulations for all accidents; Supplement 5.I	10CFR72.106
Design Bases:		
Spent Fuel Specification	Table 2.0.1; Section 2.I.1	10CFR72.236(a)
Normal Design Event Conditions:		
Ambient Outside Temperature:	-	-
Max. Yearly Average	80°F; Subsection 2.2.1.4	ANSI/ANS 57.9
Live Load†:		
Loaded HI-TRAC 125D and Mating Device	Table 3.I.1, Subsection 2.I.9	R.G. 3.61
Dry Loaded MPC	Table 3.I.1, Subsection 2.I.9	R.G. 3.61
Cask Transporter	Table 3.I.1, Subsection 2.I.9	-
Handling:	Subsection 2.I.4	-
VVM Closure Lid Lift Points	Subsection 3.I.4	NUREG-0612 ANSI N14.6
Minimum Temperature During Closure Lid Handling Operations	0°F; Subsection 2.2.1.2	ANSI/ANS 57.9
Snow and Ice Load	100 lb/ft^2; Subsection 2.I.4	ASCE 7-88
Wet/Dry Loading	Dry; Supplement 1.I, 8.I	-
Storage Orientation	Vertical; Supplement 1.I	-

† Weights listed in Table 3.I.1 are bounding weights. Actual weights will be less, and will vary based on as-built dimensions of the components, fuel type, and the presence of fuel spacers and non-fuel hardware, as applicable.

Table 2.I.1 (continued)
LOADS, CRITERIA, APPLICABLE REFERENCE REGULATION/CODES AND STANDARDS FOR HI-STORM 100U VVM

Type	Criteria or Value and Reference Location in the FSAR	Basis, Regulation and Reference Code/Standard
Off-Normal Design Event Conditions:		
Ambient Temperature:	Subsection 2.I.5	-
Minimum	-40°F; Subsection 2.2.2.2	ANSI/ANS 57.9
Maximum	100°F; Subsection 2.2.2.2	ANSI/ANS 57.9
Partial Blockage of Air Inlets	50% blockage of air inlet flow area; Supplement 4.I	-
Design Basis Accident Events and Conditions:		
Drop Cases:		
End Drop	Not credible; Subsection 2.I.6	In-ground VVM is not lifted
Tipover	Not credible; Subsection 2.I.6	In-ground VVM is constrained by subgrade and foundation
Fire:	-	-
Duration	217 seconds; Supplement 11.I	10CFR72.122(c)
Temperature	1475°F; Supplement 11.I	10CFR72.122(c)
Fuel Rod Rupture	See Table 2.0.1; Subsection 2.2.3.8	-
Air Flow Blockage	100% blockage of air inlet flow area; Subsection 2.I.6	10CFR72.128(a)(4)
Explosive Overpressure External Differential Pressure	10 psi steady state; Subsection 2.I.6 and Table 2.2.1	10CFR72.128(a)(4)
Extreme Environmental Phenomenon Events and Conditions:		
Flood:	Subsection 2.I.6	-
Height	125 ft	R.G. 1.59
Velocity	N/A; Supplement 1.I	In-ground VVM is not subject to tipover or sliding. Loads on the Closure Lid are bounded by missile impact loads.
Max. Earthquake	Table 2.I 4; Subsection 2.I.6 and Supplement 3.I	10CFR72.102(f)
Tornado:	Subsection 2.I.6	-
Tornado-Borne Missiles:		
i. Automobile	Ensure confinement, subcriticality and retrievability Subsection 2.I.6 and Supplement 3.I	NUREG-1536
▪ Weight	Table 2.2.5	NUREG-0800

Table 2.I.1 (continued)
LOADS, CRITERIA, APPLICABLE REFERENCE REGULATION/CODES AND STANDARDS FOR HI-STORM 100U VVM

Type	Criteria or Value and Reference Location in the FSAR	Basis, Regulation and Reference Code/Standard
▪ Velocity	Table 2.2.5	NUREG-0800
ii. Rigid Solid Steel Cylinder (intermediate tornado missile)	Ensure confinement, subcriticality and retrievability	NUREG-1536
▪ Weight	Table 2.2.5	NUREG-0800
▪ Velocity	Table 2.2.5	NUREG-0800
iii. Steel Sphere	Subsection 2.I.6	NUREG-1536 In-ground VVM has no penetrations that provide line-of-sight to MPC
▪ Weight	Table 2.2.5	NUREG-0800
▪ Velocity	Table 2.2.5	NUREG-0800
Burial Under Debris	Maximum decay heat load and adiabatic heat-up; Subsection 2.I.6	-
Lightning	Bounded by aboveground evaluation (resistance heat-up); Subsection 2.I.6	In-ground VVM contains less metal
Extreme Environmental Temp.	125°F; Subsection 2.I.6 and Table 2.2.2	-
Load Cases for Structural Qualification:	Subsection 2.I.9 and Table 2.I.5	ANSI/ANS 57.9 and NUREG-1536

Table 2.I.2
CRITICAL CHARACTERISTICS FOR INTERFACING SSCs, MPC GUIDES, AND VVM SPACING

	Item	Value	Symbol	Comment
1.	Minimum value for nominal vertical stiffness of the Support Foundation Undergirding Subgrade (lb/inch)	97.9E6	K	This stiffness value is equivalent to that of a homogeneous substrate subject to vertical loading from a rigid punch having diameter equal to that of the CEC bottom plate, and homogeneous best estimate properties corresponding to a shear wave speed of 3500 ft./sec., and a Poisson's Ratio of 0.4. (see Note 1)
2.	Minimum thickness of the VVM Interface Pad (inch)	28	T	This thickness is used in shielding analysis in Supplement 5.I; use of a larger value will enhance shielding even further.
3.	Minimum density of the VVM Interface Pad concrete (lb/ft^3)	140	ϒ	This density is used in shielding analysis in Supplement 5.I; use of a different value will results in a change in the computed dose results.
4.	Minimum density of subgrade adjacent to CEC (spatial average) (lb/ft^3)	120	$ϒ_s$	A lower average density value may be used in shielding analysis in Supplement 5.I for conservatism.
5	Minimum Number of Upper/Lower MPC Guides	4 / 6	Ng	The MPC Guides transfer impact loads from the MPC to the Divider Shell.
6	Minimum VVM Pitch (ft.)	See Licensing Drawing in Subsection 1.I.5	-	-

Note 1: The resistance of a homogeneous elastic material to load from a rigid punch of diameter D (see Theory of Elasticity, Timoshenko and Goodier, 3rd Edition, McGraw Hill, Chapter 12) can be written in the form:

$$K = \frac{2G\sqrt{A}}{0.96(1-\nu)}$$

G is the subgrade shear modulus, ν is the subgrade Poisson's Ratio (assumed to be 0.4), and A is the area of the circular punch in contact with the subgrade. Since G is related to subgrade mass density and the wave speed, a direct relation is obtained between subgrade stiffness and subgrade shear wave speed.

Table 2.I.3
REFERENCE ASME CODE PARAGRAPHS FOR VVM PRIMARY LOAD BEARING PARTS

	Item	Code Paragraph†	Explanation and Applicability
1.	Definition of primary and secondary members	NF-1215	-
2.	Jurisdictional boundary	NF-1133	The "intervening elements" are termed interfacing SSCs in this FSAR.
3.	Certification of material	NF-2130(b) and (c)	Materials shall be certified to the applicable Section II of the ASME Code or equivalent ASTM Specification.
4.	Heat treatment of material	NF-2170 and NF-2180	-
5.	Storage of welding material	NF-2400	-
6.	Welding procedure	Section IX	-
7.	Welding material	Section II	-
8.	Loading conditions	NF-3111	-
9.	Allowable stress values	NF-3112.3	-
10.	Rolling and sliding supports	NF-3424	-
11.	Differential thermal expansion	NF-3127	-
12.	Stress analysis	NF-3143 NF-3380 NF-3522 NF-3523	Provisions for stress analysis for Class 3 plate and shell supports and for linear supports are applicable for Closure Lid and Container Shell, respectively.
13.	Cutting of plate stock	NF-4211 NF-4211.1	-
14.	Forming	NF-4212	-
15.	Forming tolerance	NF-4221	Applies to the Divider Shell and Container Shell
16.	Fitting and Aligning Tack Welds	NF-4231 NF-4231.1	-
17.	Alignment	NF-4232	-
18.	Storage of Welding Materials	NF-4411	-
19.	Cleanliness of Weld Surfaces	NF-4412	Applies to structural and non-structural welds
20.	Backing Strips, Peening	NF-4421 NF-4422	Applies to structural and non-structural welds
21.	Pre-heating and Interpass Temperature	NF-4611 NF-4612 NF-4613	Applies to structural and non-structural welds
22.	Non-Destructive Examination	NF-5360	Invokes Section V
23.	NDE Personnel Certification	NF-5522 NF-5523 NF-5530	-

† All references to the ASME Code refer to applicable sections of the 1995 edition with addenda through 1997.

Table 2.I.4

SEISMIC AND SUBSTRATE DATA FOR THE HI-STORM 100U SYSTEM IN THE REPRESENTATIVE SOLUTIONS

Direction	**Value**
Net Horizontal ZPA at specified bedrock depth (g)	0.50
Zero Period Vertical Acceleration at specified bedrock depth (g)	0.33
Substrate Weight Density below Support Foundation Pad (lb/cu.ft.)	140
Substrate Weight Density above Support Foundation Pad (lb/cu.ft.)	120

Note 1: Site-Specific values shall be used for qualification at a specific location.

Note 2: Time histories are derived from Reg. Guide 1.60 spectra set with a 20 second duration. Acceleration time histories developed from the Reg Guide 1.60 spectra meet the enveloping and statistical independence requirements of SRP 3.7.1 of NUREG-0800 (1980).

Note 3: The reference surface for the input spectra used in the sample evaluations is approximately 51' below TOG as shown in the drawings in Section 1.I.5.

Table 2.I.5

BOUNDING LOADINGS, AFFECTED SUB-COMPONENTS, APPLICABLE DATA, ACCEPTANCE CRITERION

Case I.D.	Bounding Loading	Affected Sub-Component	Applicable Data		Acceptance Criterion
			Magnitude of Loading (Ref. Table I.D.)	Value of Coincident Metal Temperature used (Deg. F)	
01	Condition with no MPC or Closure Lid installed; buoyancy from a water head equal to the distance between TOG and TOF.	• Temporary Cover • CEC Bottom Plate	Buoyant Force From CEC Displaced Volume < 8 psi	125 125	The minimum weight of the anti-buoyancy cover is 16,000lb. Maximum primary bending stress intensity in the CEC Bottom Plate must be below Level D limit.
02	Normal operation condition; dead load plus design basis explosion pressure	• Container Shell structure • Closure Lid	2.I.1; 3.I.1 2.I.1	125 350	Primary stresses do not exceed applicable Level A stress limits of ASME Subsection NF (or Level D limits with explosion)
03	Design basis missile	Closure Lid	2.I.1 and 2.2.5	350	Closure Lid does not collapse, is not dislodged from the cavity, and is not perforated by the missile.
04	Design basis earthquake	Container Shell	Site-specific (Table 2.I.4 used for sample evaluation)	125	After the event, MPC retrievability, subcriticality and confinement must not be compromised. Additional criteria for the CEC and its contents are defined in Table 2.I.6.
05	Closure lid handling	Lid Lift Lugs; all metal structure in Lid	1.15 x Closure Lid Weight (From Table 3.I.1)	125	ANSI 14.6 limits based on yield or ultimate strength including magnified inertia loads. Meet Reg. Guide 3.61 and Level A limits as applicable. (See Section 2.I.9)

Table 2.I.5 (continued)

BOUNDING LOADINGS, AFFECTED SUB-COMPONENTS, APPLICABLE DATA, ACCEPTANCE CRITERION

Case I.D.	Bounding Loading	Affected Sub-Component	Applicable Data		Acceptance Criterion
			Magnitude of Loading (Ref. Table I.D.)	Limiting Value of Coincident Metal Temperature (Deg. F)	
06	Design basis fire	Closure Lid	2.I.1	800	The Closure Lid structure does not collapse under its dead weight due to elevated metal temperatures.
07	CEC loading from subgrade	Container Shell	Calculated in 3.I	125	Service A stress limit for NF Class 3 plate and shell structure for the maximum "body extensive" membrane plus bending stress (body extensive defined as the region whose characteristic dimension exceeds 2.5 SQRT (R*T), where R and T are, respectively, the radius and thickness of the CEC shell.

Note 1. Structural loads and acceptance criteria for each load case are further explained in Section 2.I.9.
Note 2: Materials of construction are identified in Table 2.I.8.
Note 3: Design attributes of the VVM are explained in Section 1.I.2 and details are presented in the drawings in Section 1.I.5.
Note 4: The limiting value of coincident metal temperature is used to establish material properties and allowable stress (or stress intensity) when applicable.

Table 2.I.6
Acceptance Criteria for the HI-STORM 100U CEC and Internals under Extreme Environmental Conditions

Component	Calculated Value	Allowable Limit
CEC Container Shell and Divider Shell	Radial gap between CEC Shell and Divider Shell Insulation after the seismic event	Nominal Gap (based on OD of Divider Shell Insulation and ID of CEC Shell) must remain open at end of event.
CEC Container Shell	Change in nominal diameter of shell at location of MPC Guides after seismic event.	Nominal Gap (based on OD of Divider Shell Insulation and ID of CEC Shell + Diametral gap between MPC guides and MPC) must remain open at end of event.
MPC Guides	Maximum compression load	Minimum of limiting buckling load or ultimate load.
MPC Shell	Longitudinal flexural stress intensity in shell wall from bending of the MPC shell as a beam. The local true strain in the MPC shell in the region of MPC guide/MPC impact.	ASME Level D primary membrane stress intensity limit The local strain from impact must be less than 10%, which has been established as a conservative limit in [3.I.31]
MPC Fuel Basket	Longitudinal primary flexural stress intensity in basket panel from bending of the fuel basket as a beam	ASME Level D primary membrane stress intensity limit
MPC Fuel Basket	Maximum transverse bending stress in most heavily loaded basket panel, averaged over the panel length	ASME Level D primary membrane + bending stress intensity limit

Table 2.I.7

MINIMUM DATA FOR THE DESIGN OF INTERFACING SSCs and TOP SURFACE PAD

	Interfacing SSC	Reference Design Data
1.	Support Foundation	30" thick reinforced concrete pad founded on subgrade. Concrete density = 145 lb/ft^3 Minimum concrete compressive strength @ ≤ 28 days = 4,000 psi Grade 60 Rebar - Minimum yield strength of rebar = 60,000 psi; rebar is #10@9" (each face, each direction) Minimum concrete cover on rebar per section 7.7.1 of ACI 318 (2005)
2.	Subgrade Under Support Foundation	Minimum Shear Wave Speed = 3500 fps (see Note 1); Density from Table 2.I.4
3.	Subgrade Surrounding VVMs	Minimum Shear Wave Speed = 800 fps (see Note 1); Density from Table 2.I.2
4.	VVM Interface Pad (See Licensing Dwg. In Section 1.I.5)	Reinforced Concrete Thickness per Table 2.I.2 Concrete density per Table 2.I.2 Minimum concrete compressive strength @ ≤ 28 days = 4,000 psi Grade 60 Rebar - Minimum yield strength of rebar = 60,000 psi; rebar is #10@9" (each face, each direction) Minimum Concrete cover on rebar per section 7.7.1 of ACI 318 (2005)
5.	Top Surface Pad	24" thick reinforced concrete pad; other parameters same as VVM Interface Pad. Minimum width of TSP beams are: 6' (along direction of transporter path); 4' (perpendicular to direction of transporter path)

Note 1: The substrate low strain shear wave speed, corresponding to best estimate elastic properties averaged over the region 30' below the base of the Support Foundation or down to bedrock (whichever is less) and to the substrate surrounding the VVM (averaged over a distance of 5 CEC shell diameters) is specified above. Should these conditions not be satisfied, then substrate remediation is required prior to installation of the HI-STORM 100U facility. Design analyses shall also account for uncertainties in substrate properties in accordance with ASCE 4-98 [3.I.28].

Table 2.I.8

PERMISSIBLE MATERIALS FOR HI-STORM 100U VVM SUB-COMPONENTS

	Primary Function	Part	ITS Category	Material (note6)	Max. Permissible Temperature (°F)		Special Surface Finish/ Coating (note 1)	Interfacing Matl. (if dissimilar)
					Normal Storage (Long-Term Limit)	Off-normal, extreme environmental phenomena, and accident conditions		
1	Shielding	Closure Lid Concrete	C	Shielding Concrete per Appendix 1.D (note 2)	300 (note 3)	350 (note 3)	NA	Steel
2	Shielding	Closure Lid Steel	C	ASTM A516, Gr. 70, A515 Gr. 70 or equivalent	800 (note 4)	800 (note 4)	(note 5)	Concrete/Elastomer
3	Structural	CEC (Container Shell, Bottom Plate and Container Flange)	C	ASTM A516, Gr. 70, A515 Gr. 70 or equivalent	800 (note 4)	800 (note 4)	(note 5)	Subgrade/Concrete
4	Thermal	Insulation	C	Commercial	800	800	NA	Steel
5	Thermal	Inlet/Outlet Vent Screens and associated hardware	NITS	Carbon steel, stainless steel, aluminum, a polymeric fabric capable of 400°F (min.) service temperature or commercial	800 (note 4) if all metallic 400 otherwise	800 (note 4) if all metallic 400 otherwise	(note 5)	variable
6	Thermal	Outlet Vent Cover and associated hardware	NITS	Carbon steel, stainless steel, aluminum or commercial	800 (note 4)	800 (note 4)	(note 5)	variable
7	Thermal	Divider Shell and Divider Shell Restraints	C	ASTM A516, Gr. 70, A515 Gr. 70 or equivalent	800 (note 4)	800 (note 4)	(note 5)	Insulation

Note: Equivalent materials have their critical characteristics defined in Table 2.I.9.

Table 2.I.8 (continued)

PERMISSIBLE MATERIALS FOR HI-STORM 100U VVM SUB-COMPONENTS

	Primary Function	Part	ITS Category	Material (note 6)	Max. Permissible Temperature (°F) Normal Storage (Long-Term Limit)	Max. Permissible Temperature (°F) Off-normal, extreme environmental phenomena, and accident conditions	Special Surface Finish/ Coating (note 1)	Interfacing Matl. (if dissimilar)
9	Structural	Upper and Lower MPC Guides	C	ASTM A516, Gr. 70, A515 Gr. 70 or equivalent	800 (note 4)	800 (note 4)	(note 5)	-
10	Structural	MPC Bearing Pads	C	Carbon Steel (with stainless steel liners)	800 (note 4)	800 (note 4)	(note 5)	Stainless steel
11	Shielding and Physical Protection to the CEC	VVM Interface Pad (VIP)	B	Reinforced Concrete Per ACI-318 (2005)	150	350	N/A	Steel
12	Shielding and Physical Protection	Top Surface Pad (TSP)	B	Reinforced Concrete Per ACI-318 (2005)	150	350	N/A	—
13	Shielding and Physical Protection	Substrate Below VIP and TSP	B	Engineered fill, natural soil, or treated soil	150	350	N/A	Steel or Concrete
14	Structural Support	Foundation Pad	C	Reinforced Concrete per ACI-318 (2005)	150	350	N/A	Soil, rock, mud mat, piling, etc., as appropriate

Note 1 Materials identified by a supplier's trademark may be replaced with an equivalent product after an appropriate evaluation of acceptability.
Note 2 *All requirements are identical to the shielding concrete in aboveground HI-STORMs.*
Note 3 Limit per Appendix 1.D.
Note 4 Permissible temperature limit from ASME Code, Section II, is used as guidance to define all long and short-term loading limits. The metal temperature limits do not apply to the fire event (see Subsection 2.I.6).
Note 5 Surface preservative per Subsection 3.I.4.
Note 6 Materials listed as "or equivalent" may be replaced with "equivalent materials" as defined in Table 1.0.1. The critical characteristics for these materials are given in Table 2.I.9.

Table 2.I.9

CRITICAL CHARACTERISTICS OF EQUIVALENT MATERIALS USED IN THE VVM

Designated Material	Item	Critical Characteristic
ASTM A515 or A516, Gr. 70	Yield Strength	Yield strength vs. Temperature data must exceed values from appropriate tables for 515/516 Gr.70 materials in ASME Code, Section II, Part D at all applicable temperatures. Applicable Code year is the same as used for the above ground HI-STORM.
	Ultimate Strength	Ultimate strength vs. Temperature data must exceed values from appropriate tables for 515/516 Gr.70 materials in ASME Code, Section II, Part D at all applicable temperatures. Applicable Code year is the same as used for the above ground HI-STORM.
	Elongation	Elongation must equal or exceed value(s) for 515/516 Gr. 70
	Charpy Impact	Values that measure resistance to impact must equal or exceed corresponding values for 515/516 Gr. 70.

Table 2.I.10
Critical Characteristics of Materials Required for Safety Evaluation of Storage and Transport Systems

	Property	Type	Purpose	Bounding Acceptable Value
1.	Minimum Yield Strength	S	To ensure adequate elastic strength for normal service conditions	Min.
2.	Minimum Tensile Strength	S	To ensure material integrity under accident conditions	Min.
3.	Young's Modulus	S	For input in structural analysis model	Min.
4.	Minimum elongation of $\delta_{min.}$ %	S	To ensure adequate material ductility	Min.
5.	Impact Resistance at ambient conditions	S	To ensure protection against crack propagation	Min.
6.	Maximum allowable creep rate	S	To prevent excessive deformation under steady state loading at elevated temperatures	Max.
7.	Thermal conductivity (minimum averaged value in the range of ambient to maximum service temperature, t_{max})	T	To ensure that the basket will conduct heat at the rate assumed in its thermal model	Min.
8.	Minimum Emissivity	T	To ensure that the thermal calculations are performed conservatively	Min.
9.	Specific Gravity	S (and R)	To compute weight of the component (and shielding effectiveness)	Max. (and Min.)
10.	Thermal Expansion Coefficient	T (and S)	To compute the change in basket dimension due to temperature (and thermal stresses)	Min. and Max.
11.	Boron-10 Content	R	To control reactivity	Min.

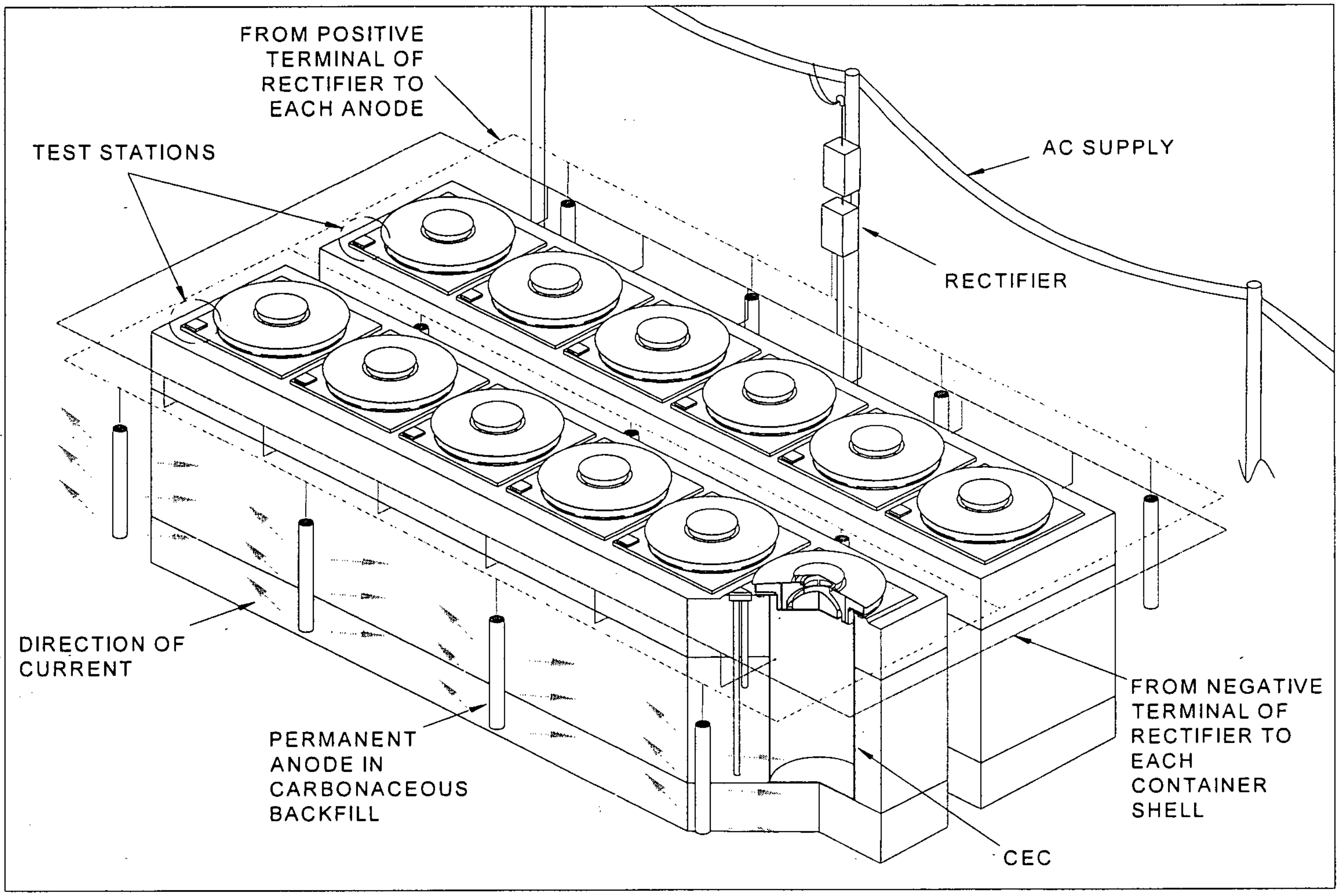

FIGURE 2.I.1: HI-STORM 100U SYSTEM EXAMPLE ICCPS DESIGN – 2 X 6 ARRAY DESIGN LAYOUT*

* The design features of the HI-STORM 100U System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Expansion joints between the VVM Interface Pad and the Top Surface Pad are not shown in this figure.

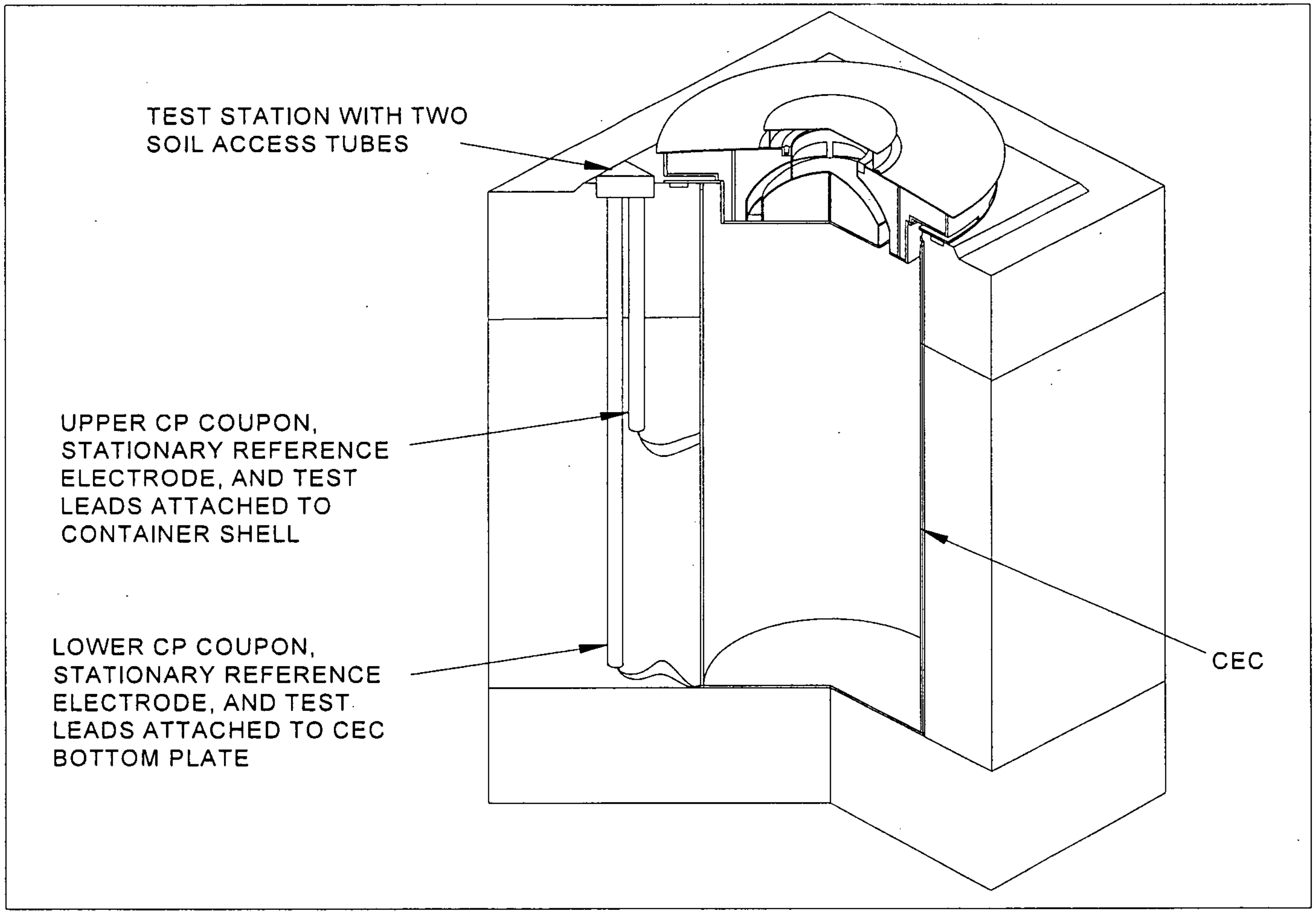

FIGURE 2.I.2: HI-STORM 100U SYSTEM EXAMPLE ICCPS DESIGN – TEST STATION*

*The design features of the HI-STORM 100U System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Expansion joints between VVM Interface Pad and Top Surface Pad are omitted from this figure.

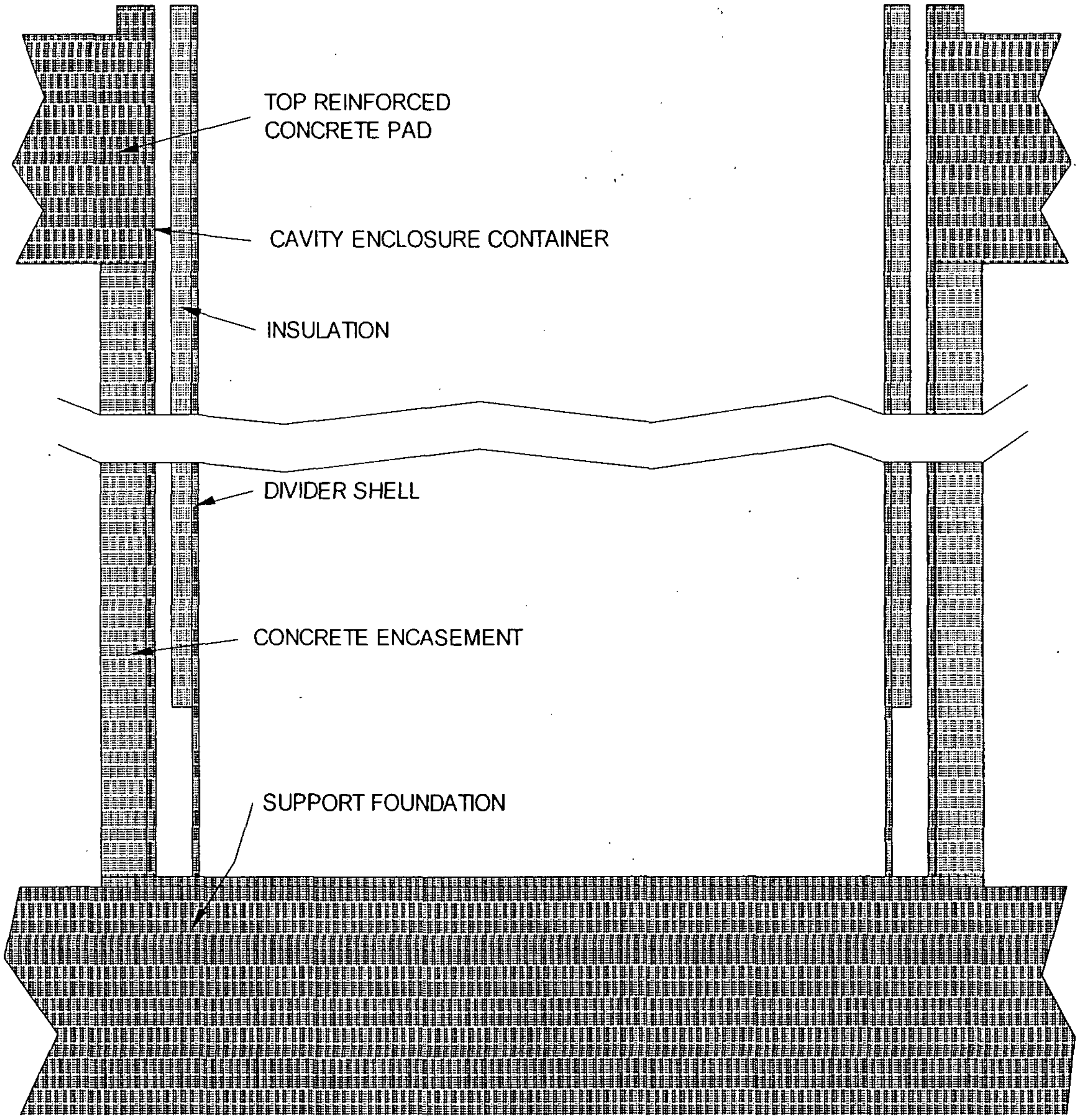

FIGURE 2.I.3: TYPICAL CONCRETE ENCASEMENT OF THE CEC

SUPPLEMENT 3.I

STRUCTURAL EVALUATION FOR THE HI-STORM 100U SYSTEM

3.I.0 OVERVIEW

In this supplement, the structural adequacy of the HI-STORM 100U Vertical Ventilated Module (VVM) is evaluated pursuant to the guidelines of NUREG-1536.

The organization of technical information in this supplement mirrors the format and content of Chapter 3 except that it only contains material directly pertinent to the HI-STORM 100U VVM.

The HI-STORM 100U VVM serves as the storage space for the loaded MPC and consists of the CEC(the Container Shell, the Divider Shell and MPC Guides, and a welded Bottom Plate), and a lid consisting of plain concrete encased in structural steel arranged to provide appropriate inlet and outlet air passages (the Closure Lid). Interfacing SSCs that surround and support the VVM but are not part of the certification are explained in Supplement 2.I. Section 1.I contains a complete description of the VVM structure components (accompanied by appropriate figures) and their function within the HI-STORM 100U VVM, and Supplement 2.I describes the function of each of the interfacing SSCs and the criteria applicable to their design.

The applicable codes, standards, and practices governing the structural analysis of the HI-STORM 100U module as well as the design criteria, are presented in Supplement 2.I. Throughout this supplement, the term "*safety factor*" is defined as the *ratio of the allowable stress (load) or displacement for the applicable load combination to the maximum computed stress (load) or displacement.* Where applicable, bounding safety factors are computed based on values that bound the calculated results.

MPC structural integrity has been evaluated in Chapter 3 of this submittal. In this supplement, integrity of the MPC, due to its rattling motion inside the VVM storage cavity during a seismic event, is considered.

3.I.1 STRUCTURAL DESIGN

3.I.1.1 Discussion

The HI-STORM 100U system consists of three principal components: the Multi-Purpose Canister (MPC), the HI-STORM 100U storage module, herein denoted as the Vertical Ventilated Module (VVM) (includes the Cavity Enclosure Container (CEC) and the Closure Lid), and the HI-TRAC transfer cask. This supplement to Chapter 3 presents the structural evaluation of a VVM for the applicable load cases summarized in Supplement 2.I (Table 2.I.5). Summary tables of bounding safety factors are provided for each load case considered. Licensing drawings for the HI-STORM 100U VVM are provided in Section 1.I.5. Table 2.I.1 provides a listing of the applicable regulations and codes and standards for the VVM.

3.I.1.2 Design Criteria

Design (and acceptance) criteria for the HI-STORM 100U are summarized in Tables 2.I.1 and 2.I.6.

3.I.1.3 Loads

Individual loads, applicable to the HI-STORM 100U System, are defined in Sections 2.I.4, 2.I.5, and 2.I.6, and load combinations (cases) relevant to this submittal summarized in Table 2.I.5.

3.I.1.4 Allowables

Allowable stresses for carbon steel used in the structural components of the HI-STORM 100U are provided in Sections 3.1 and 3.3. The relevant table data from those sections is reproduced here, as Tables 3.I.3 (a)-(c) to make the supplement self-contained.

3.I.1.5 Brittle Fracture

Brittle fracture considerations for HI-STORM 100U are bounded by HI-STORM 100 and 100S because of the VVM's underground configuration, and the use of the same material types and thicknesses as in the aboveground overpacks.

3.I.1.6 Fatigue

The HI-STORM 100U system is not subject to significant long-term cyclic loads. Therefore, failure due to fatigue is not a concern for the HI-STORM 100U system.

3.I.1.7 Buckling

The CEC Container Shell is the only component of the VVM subject to axial compression. However, since the shell is backed by a substrate, welded to a Bottom Plate at its base, and surrounded by the ISFSI Pad at the top, instability is not considered credible. The Divider Shell does not experience any axial compressive stress that might induce buckling.

3.I.2 WEIGHTS AND CENTERS OF GRAVITY

Table 3.I.1 provides bounding weights of the individual HI-STORM 100U components.

The locations of the calculated centers of gravity (C.G.s) are presented in Table 3.I.2 and are computed using the bounding weights. All centers of gravity are located on the VVM centerline.

Bounding weight values for the CEC and the Closure Lid include an overage on the weight generated by the CAD drawing package.

3.I.3 MECHANICAL PROPERTIES OF MATERIALS

Tables 2.I.3 and 2.I.8 list applicable codes, materials of construction, and ITS designations for all functional parts in the HI-STORM 100U system except for the MPC and its internals, which remain unchanged (listed in Table 2.2.6).

VVM Steel Properties

Applicable material property and allowable stress tables in Chapter 3 for the VVM are reproduced in Tables 3.I.3 (a)-(c) for convenience.

Unreinforced Concrete

The primary function of the unreinforced concrete in the HI-STORM 100U VVM Closure Lid is shielding. Unreinforced concrete is not considered as a primary load-bearing (structural) member. However, its ability to withstand compressive, bearing and penetrant loads under the design basis and various service conditions is analyzed. The allowable bearing strength of plain concrete for normal loading conditions is calculated in accordance with ACI 318-05 [2.I.5]. Table 3.I.4 provides a bearing limit consistent with the concrete compressive strength in the same table. The procedure specified in ASTM C-39 is utilized to verify that the assumed compressive strength will be realized in the actual in-situ pours. Unless specifically called out in Table 3.I.4, Appendix 1.D provides requirements on unreinforced concrete.

Reinforced Concrete

Reinforced concrete is used in the construction of the Top Surface Pad, the VVM Interface Pad (VIP) and the Support Foundation Pad. All reinforced concrete in the HI-STORM 100U ISFSI will conform to ACI 318(2005).

3.I.4 GENERAL STANDARDS FOR CASKS

In this section, new or additional material applicable to the HI-STORM 100U system is included. Section 3.4 contains all required information associated with the MPCs and with the HI-TRAC transfer cask and is not repeated here. Results reported in this supplement section are generally applicable only to the HI-STORM 100U VVM.

3.I.4.1 Chemical and Galvanic Reactions

In order to provide reasonable assurance that the VVM will meet its intended Design Life of 40 years (the License Life is 20 years) and perform its intended safety function(s), chemical and galvanic reactions and other potentially degrading mechanisms must be accounted for in its design and construction.

The HI-STORM 100U VVM is a buried structure and as such chemical and galvanic reactions and other potentially degrading factors are, in some respects, more challenging than for aboveground models. Although the CEC is not a part of the MPC containment boundary, it should not corrode to the extent where localized in-leakage of water occurs or where gross general corrosion prevents the component from performing its primary safety function. In the following, considerations in the VVM's design and construction consistent with the applicable guidance provided in ISG-15 [3.I.3] are summarized.

All VVM components are galvanically compatible. Except for the CEC exterior surfaces, all steel surfaces of the VVM are lined and coated with the same surface preservative that is used in the aboveground HI-STORM overpacks (The surface preservative used to protect HI-STORM 100S steel surfaces is a proven zinc rich inorganic/metallic material that protects galvanically and has self healing characteristics for added assurance). All exposed surfaces interior to the VVM, as stated in Supplement 1.I, are accessible for the reapplication of surface preservative, if necessary.

The steel Divider Shell requires insulation to perform its primary thermal function. The insulation selected shall be suitable for high temperature and high humidity operation and shall be foil faced, jacketed or otherwise made water resistant to ensure the required thermal resistance is maintained in accordance with Supplement 4.I. The high zinc content in the coating of the Divider Shell provides protection for both the Divider Shell and the jacketing or foil from any potential galvanic corrosion concerns. With respect to radiation resistance, the insulation blanket does not contain any organic binders. The damage threshold for ceramics is known to be approximately $1x10^{10}$ Rads. Chloride corrosion is not a concern since chloride leachables are limited and sufficiently low and the Divider Shell is not made from stainless steel [3.I.20]. Stress corrosion cracking of the foil or jacketing, whether made from stainless steel or other material is not an applicable corrosion mechanism due to minimal stresses derived from self-weight. The foil or jacketing and attachment hardware shall either have sufficient corrosion resistance (e.g. stainless steel, aluminum or galvanized steel) or shall be protected with a suitable surface preservative. The insulation is adequately secured to prevent significant blockage of the ventilation passages in case of failure of a single attachment (strap, clamp, bolt or other attachment hardware). The following table provides the acceptance criteria for the selection of insulation material for the Divider Shell and ranks them in order of importance.

Acceptance Criteria for the Selection of the Insulation Material	
Rank	**Criteria**
1	Adequate thermal resistance
2	Adequate high temperature resistance
3	Adequate humidity resistance
4	Adequate radiation resistance
5	Adequate resistance to the ambient environment
6	Sufficiently low chloride leachables
7	Adequate integrity and resistance to degradation and corrosion during long-

	term storage

Kaowool® ceramic fiber insulation [3.I.20] is selected as one that satisfies the acceptance criteria to the maximum degree. The Kaowool® insulation material provides excellent resistance to chemical attack and is not degraded by oil or water. Alternatively, a Holtec approved equivalent that meets the acceptance criteria set forth in the table above may be used.

The CEC Container Shell, which is exposed to the substrate, requires additional pre-emptive measures to prevent corrosion, if the substrate is of aggressive chemistry. This subsection provides a description of corrosion mitigation measures required to be implemented to protect the HI-STORM 100 VVM. Because the guiding principle in the HI-STORM Systems is to target a service life of 100 years so as to guarantee a design life of 40 years, these corrosion prevention measures are in addition to the preemptively incorporated standard corrosion allowance of 1/8-inch applied to the subterranean parts of the CEC in direct contact with the surrounding substrate. Calculation of the required CEC Container Shell and Bottom Plate thicknesses on a site-specific basis may indicate the availability of an additional corrosion reserve.

Soil Corrosivity and Corrosion Mitigation Measures for the Exterior of the CEC

Corrosion mitigation of the exterior of the CEC warrants special consideration for the following reasons, (i) inaccessibility of the exterior coated surface after installation (ii) potential for a highly aggressive (i.e., corrosive) soil environment at certain sites, and (iii) potential for a high radiation field. Since the buried configuration will not allow for the reapplication of surface preservative, corrosion mitigation measures shall be determined after careful evaluation of the soil's corrosivity at the user's ISFSI site.

To evaluate soil corrosivity, a "10 point" soil-test evaluation procedure, in accordance with the guidelines of Appendix A of ANSI/AWWA C105/A21 [3.I.4], will be utilized. The classical soil evaluation criteria in the aforementioned standard focuses on parameters such as: 1) resistivity, 2) pH, 3) redox (oxidation-reduction) potential, 4) sulfides, 5) moisture content, 6) potential for stray current, and 7) experience with existing installations in the area. Using the procedure outlined in ref. [3.I.4], the ISFSI soil environment corrosivity is categorized as either "mild" for a soil test evaluation resulting in 9 points or less or "aggressive" for a soil test evaluation resulting in 10 points or greater. The following table details the corrosion mitigation measures that shall be implemented based on soil environment corrosivity:

Implementation of Corrosion Mitigation Measures			
Soil Environment Corrosivity	**Corrosion Mitigation Measures**		
	Coating (see note i)	Concrete Encasement (see note ii)	Cathodic Protection (see note iii)
Mild	Required	Choice of either concrete encasement or cathodic protection; or both	
Aggressive	Required	Optional	Required

Notes:
i. An acceptable exterior surface preservative (coating) applied on the CEC.
ii. Concrete encasement of the CEC external surfaces to establish a high pH buffer around the metal mass.
iii. A suitably engineered impressed current cathodic protection system (ICCPS)

The corrosion mitigation measures tabulated above are further detailed in the following subsections:

i. <u>Coating</u>

In addition to the corrosion allowance, the CEC shall be coated with a radiation resistant surface preservative designed for below-grade and/or immersion service. Inorganic and/or metallic coatings are sufficiently radiation resistant for this application; therefore, radiation testing is not required [3.I.5]. Organic coatings such as epoxy, however, must have proven radiation resistance [3.I.5] or must be tested without failure to at least 10^7 Rad. Radiation resistance to lower radiation levels is acceptable on a site-specific basis. Radiation testing shall be performed in accordance with ASTM D 4082 [3.I.6] or equivalent. The coating should be conservatively treated as a Service Level II coating as described in Reg. Guide 1.54 [3.I.7]. As such, the coating shall be subjected to appropriate quality assurance in accordance with the applicable guidance provided by ASTM D 3843-00 [3.I.8]. The coating should preferably be shop applied in accordance with manufacturers instructions and, if appropriate, applicable guidance from ANSI C 210-03 [3.I.9]. The Keeler & Long polyamide-epoxy coating, according to the manufacturer's product data sheet [3.I.10], is pre-tested to radiation levels up to $1x10^9$ Rads without failure. The following table provides the acceptance criteria for the selection of coatings for the exterior surfaces of the CEC and ranks them in order of importance.

Acceptance Criteria for the Selection of Coatings	
Rank	**Criteria**
1	suitable for immersion and/or below grade service
2a	compatible with the ICCPS (if used) • adequate dielectric strength • adequate resistance to cathodic disbondment
2b	compatible with concrete encasement (if used) • adequate resistance to high alkalinity
3	adequate radiation resistance
4	adequate adhesion to steel
5	adequate bendability/ductility/cracking resistance/abrasion resistance
6	adequate strength to resist handling abuse and substrate stress

The Keeler & Long polyamide-epoxy coating is selected as one that satisfies the acceptance criteria to the maximum degree. Alternatively, a Holtec approved equivalent that meets the acceptance criteria set forth in the table above may be used.

ii. Concrete Encasement

The CEC concrete encasement shall provide a minimum of 5 inches of cover to provide a pH buffering effect for additional corrosion mitigation. The above concrete cover thickness has been conservatively determined for a 100-year service life in a strongly aggressive environment based on the concrete corrosion/degradation data provided in the literature [3.I.12, Table 5.3] (1.2 mm/yr surface depth failure rate). The required 5 inch minimum thickness is more conservative than that recommended in ACI Codes, such as ACI 318 [3.3.2], which call for up to 3 inches of concrete cover over steel reinforcement in aggressive environments. Considering that the concrete encasement is restricted to mild soil environments (unless used in conjunction with cathodic protection) and has a non-structural role, the 5 inch concrete encasement thickness is considered more than sufficient to provide reasonable assurance that a 40 year service life can be achieved. The lowest part of the CEC sits in a recessed region of the Support Foundation with an annular gap normally filled with substrate. If present, the CEC concrete encasement slurry will fill this annular gap during construction.

The function of the concrete encasement is for corrosion mitigation only; however, cracks larger than hairline cracks may significantly reduce its effectiveness. To control size and population of cracks, concrete reinforcement is included. The following reinforcement methods may be applied:

a. Fiber reinforcement: Fiber reinforcement may be of several materials, including steel, glass and plastic (polypropylene). The selection of the fiber reinforcement material shall be such that adequate resistance to radiation and high alkalinity is maintained. If using steel fibers, adequate damage protection of the CEC coating shall be ensured during concrete placement per written procedures. Steel fiber shall be implemented using written procedures and the applicable guidance from ACI 544.2R [3.I.25] or a similar consensus code or standard. Fiber reinforcement materials other than steel shall be implemented using written procedures, manufacturer recommendations and applicable guidance from ACI, ASCE and/or ASTM. One such document is ASTM C1116-03 [3.I.26].

b. Steel wire reinforcement: Steel wire reinforcement shall be implemented in accordance with written procedures and the guidance from ACI 318 [3.3.2] or more recent version. For corrosion protection, the steel wire reinforcement shall have a concrete cover of approximately 2 to 3 inches from the interfacing substrate.

Regardless of reinforcement method, the material selected shall be corrosion resistant or otherwise appropriately coated (e.g. epoxy coated steel wire) for corrosion resistance.

The concrete encasement shall be installed in accordance with Holtec approved procedures following applicable guidance from the ACI code (e.g. ACI 318 [3.3.2]), as appropriate, for commercial concrete. Installation procedures shall address mix designs (incorporating Portland cement), testing, mixing, placement, and reinforcement, with the aim to enhance concrete durability and minimize voids and micro-cracks.

iii. Impressed Current Cathodic Protection System (ICCPS)

For a particular ISFSI site, the user may choose to either extend an existing ICCPS to protect the installed ISFSI, or to establish an autonomous ICCPS. The initial startup of the ICCPS must occur within one year after installation of the VVM to ensure timely corrosion mitigation. In addition, the ICCPS should be maintained operable at all times after initial startup except for system shutdowns due to power outages, repair or preventive maintenance and testing, or system modifications. Because there are a multitude of ISFSI variables that will bear upon the design of the ICCPS for a particular site, the essential criteria for its performance and operational characteristics are set down in this FSAR, which the detailed design work for each ISFSI site must follow.

Design Criteria for the Impressed Current Cathodic Protection System
a. The cathodic protection system shall be capable of maintaining the CEC at a minimum (cathodic) potential as required by NACE Standard RP0285-2002 [3.I.21]. b. The ICCPS shall include provisions to infer its proper operation and effectiveness on a periodic basis. c. The system shall be designed to mitigate corrosion of the CEC for its design life. d. The cathodic protection system design, installation, operation, testing, and maintenance shall follow the applicable guidelines of: - 49CFR195 Subpart H "Corrosion Control", Oct. 1, 2004 edition [3.I.13] - NACE Standard RP0285-2002 "Corrosion Control of Underground Storage Tank Systems by Cathodic Protection" [3.I.21]

The following standards and/or publications may also be utilized for additional guidance in the design, installation, operation, testing, and maintenance of the ICCPS as needed (in case of conflict, the guidelines of item d above shall prevail):

- API RP1632, Cathodic Protection of Underground Petroleum Storage Tanks and Piping systems [3.I.22]
- NACE RP0169-96, "Control of External Corrosion on Underground or Submerged Piping Systems [3.I.23]
- 49CFR192 Subpart I "Requirements for Corrosion Control", Oct. 1, 2004 edition [3.I.24]
- Other standards or publications referenced by any of the above three standards and publications.

Records of system operating data necessary to adequately track the operable status of the ICCPS shall be maintained in accordance with the user's quality assurance program.

Finally, the surface preservative used to coat the CEC must meet the requirements described in (i) above but must also be compatible with cathodic protection and resistant to the alkaline conditions created by cathodic protection and/or concrete encasement. Organic coatings, such as the Keeler & Long coating selected for (i) above, are inherently compatible with both cathodic protection [3.I.11] and concrete [3.I.10].

3.I.4.2 Positive Closure

There are no quick-connect/disconnect ports in the confinement boundary of the HI-STORM 100U system. Because the only access to the MPC is through the VVM Closure Lid, which weighs well over 10 tons, inadvertent opening of the VVM cavity is not feasible.

3.I.4.3 Lifting Devices

As required by Reg. Guide 3.61, lifting operations applicable to the VVM lid are analyzed. Because of the nature of the HI-STORM 100U system, lid placement or removal may occur with a loaded MPC inside the VVM cavity; these are the sole operations requiring analysis in accordance with Reg. Guide 3.61 and are examined in this supplement.

As discussed in Subsection 3.4.3, the lifting component itself (the four lift lugs) must meet the primary stress limits prescribed by ANSI N14.6-1993; the welds in the load path, near the lifting holes, are required to meet the condition that stresses remain below yield under three times the lifted load (per Reg. Guide 3.61). Further, for additional conservatism, away from the lifting location, the ASME Code limit for the Level A service condition applies.

The lifting analysis results summarized below include a 15% inertia amplifier.

<u>HI-STORM 100U VVM Closure Lid Lifting Analysis (Load Case 05 in Table 2.I.5)</u>

The four lifting lugs are analyzed to ANSI N14.6 stress limits using simple strength of materials calculations. Each of four lugs is considered as a cantilever beam attached to the lid and carries 25% of the lid weight. The bending moment and shear force at the root of the cantilever (where it is attached to the lid) is computed and the maximum stress is compared with the minimum of the yield strength/6 or the ultimate strength/10. As required, increasing the lid weight by 15% includes inertia effects. Using the calculated bending moment and shear force at the root of the lug, the structural evaluation of the weld attaching the lug to the lid is performed and compared with the requirements of Regulatory Guide 3.61. The results from these two calculations demonstrate that the required safety factors are substantially greater than 1.0 (exceeding the requirements of ANSI N14-6 and Reg. Guide 3.61, respectively). The details of the calculations are presented in the calculation package supporting this submittal [3.I.27]. Lifting slings that attach to the lugs shall be sized to meet the safety factors set forth in ANSI B30.3.

To evaluate the global state of stress in the lid body, a finite element model of the lid, which includes contact interfaces between steel and concrete, is constructed to evaluate the state of stress under lifting conditions. Figure 3.I.1 shows the constructed ANSYS finite element model. The lifted scenario is simulated by fixing the four lifting locations at the lift lug sling attachment location, and applying an appropriate weight density to match the lifted weight. The results are evaluated for satisfaction of normal condition (ASME Level A) limits at the appropriate locations.

The table below summarizes key results obtained from the lifting analyses for the HI-STORM 100U VVM Closure Lid for a bounding set of input design loads.

HI-STORM 100U VVM Lid Lifting Analyses (Load Case 05 in Table 2.I.5)			
Item	Calculated Value	Allowable	Safety Factor
Bending of Lift Lugs (kip)(ANSI N14.6)	4.000	5.275	1.32 (see Note 1)
Shear in Lift Lugs (kip)(ANSI N14-6)	1.609	3.165	1.97 (see Note 1)
Load in Welds Near Lifting Lugs (kip) (Reg.Guide 3.61)	5.657	6.33	1.12 (see Note 2)
Primary Stress in Lid (ksi)(ASME Level A Limit)	< 10	26.25	> 2.63
Note 1: Computed safety factors represent the margin over that required by ANSI N14.6-1993 (0.1 x ultimate load). Note 2: Computed safety factor is based on 60% of yield strength for base metal and represents margin over limit set by Reg. Guide 3.61.			

It is concluded that all structural integrity requirements are met during a lift of the HI-STORM 100U VVM Closure Lid. All factors of safety, using applicable criteria from the ASME Code Section III, Subsection NF for Class 3 plate and shell supports, from USNRC Regulatory Guide 3.61, and from ANSI N14.6, are greater than 1.0.

3.I.4.4 Heat

Summary of Pressures and Temperatures

Tables 2.I.1 and 2.I.4 present applicable design inputs for the HI-STORM 100U VVM. No new inputs are required for the HI-TRAC and the MPC.

Differential Thermal Expansion

All clearances between the MPC and the HI-STORM 100U VVM are equal to or larger than the corresponding clearances in the aboveground HI-STORM 100 systems (see Section 4.4). Therefore, no interferences between the MPC and the VVM will occur due to thermal expansion of the loaded MPC. The Divider Shell is insulated on one surface and is exposed to heated air on the other shell surface. Therefore an analysis to demonstrate that free axial thermal expansion of the Divider Shell will not close the initial gap between the top end of the Divider Shell and the base of the Closure Lid is provided. The Divider Shell is considered as a heated member, subject to an average temperature increase over its entire length. The actual axial absolute temperature profile can be integrated over the length of the Divider Shell to define the average absolute temperature. Once the average absolute temperature is known, the free thermal growth is computed and compared with the provided gap between the Divider Shell and the Closure Lid.

The average temperature rise above ambient is bounded by DT (ambient is 80 Deg. F per Table 2.I.1, and average metal temperature over the length of the Divider Shell is from Table 4.I.3, footnote):

DT=(300 Deg. F – 80 Deg. F) = 220 Deg. F

From Table 3.I.3 (a), a bounding coefficient of thermal expansion, appropriate to DT, is:

$\alpha = 6.27 \times 10^{-6}$ in./in.-Deg. F.

The nominal length of the divider shell is:

L = 221.5625"

Therefore, the free thermal expansion, based on the nominal length is $\alpha \times L \times DT$, and is computed and compared against the nominal gap provided (as shown in the drawings).

Key Result From Free Thermal Growth Analysis of Divider Shell

Item	Bounding Value	Allowable Value*	Safety Factor
Thermal Growth (inch)	< 0.4	0.5	>1.25 (against contact)
*This is the nominal gap provided between the top end of the Divider Shell and the Closure Lid Surface (see Dwg. 4501, sheet 4 in Subsection 1.I.5).			

Stress Calculations

HI-STORM 100U VVM Stresses Under Transporter Loading and Substrate Overburden (Load Case 07 in Table 2.I.5)

During HI-STORM 100U system loading, a HI-TRAC transfer cask with a fully loaded MPC is placed over a HI-STORM 100U VVM using a specially designed transporter and a lifting device meeting "single-failure proof" requirements, as applicable. The transfer cask is connected to the CEC using an ancillary mating device. Although a handling accident is not credible, the HI-STORM 100U VVM CEC must, however, possess the capacity to support any transporter loads imposed at and below the substrate surface during the short time that the transporter is positioned over a VVM cavity and before the HI-TRAC is supported on the mating device. This event is deemed to be the most limiting if any sub-surface lateral pressures, arising from the transporter, transfer directly to the CEC Container Shell causing local increased stress and ovalization. This configuration also includes the loaded transporter traveling over a previously loaded VVM on its way to an empty CEC.

Table 3.I.1 gives the loaded weight of a transporter. A representative transporter, used by Holtec, has a track length and width of 197" and 29.5", respectively, for which, under the maximum weight of the loaded transporter (Table 3.I.1), the average normal pressure, Ps, at the transporter track/Top Surface Pad interface computes to 38.71 psi.

To determine the stress and displacement field in the CEC due to the combined action of the loaded transporter and the soil overburden, a 3-D ANSYS model of a VVM (see Figure 3.I.2) is prepared. The finite element model has the following attributes:

- The soil is modeled as an elastic continuum with properties consistent with those used in other qualifying analyses in this FSAR (see Table 3.I.10).
- The VVM Interface Pad (VIP), which is separated from the Top Surface Pad (TSP) by a construction joint, is unaffected by the movement (under load) of the TSP. The VIP essentially serves as a deadweight on the soil column below, which should be appropriately incorporated in the model. To appropriately model the VIP within the confines of a linearly elastic construct, it is represented by a "soft" material having very low Young's Modulus, but the correct weight density. The soft material artifact provides the appropriate weight on the substrate from the VIP but provides no additional strength to the Top Interface Pad or to the CEC.
- The pitch between the adjacent VVM cavities is assumed to be at the minimum specified in this FSAR (see Figure 1.I.5)
- The TSP is represented by its appropriate elastic properties.
- The substrate soil mass is assumed to be constrained from expansion across the planes of symmetry (so as to maximize the Poisson compression load on the CEC). The bottom of the soil continuum extends to the Foundation Pad.
- The CEC shell is assumed to have its nominal un-corroded thickness; the stress and strain results are adjusted upward to reflect the postulated corrosion allowance.
- To linearize the problem, the soil is assumed to be bonded to all interfacing surfaces.

Table 3.I.10 provides the input data used in the analysis.

The results of the stress analysis are pictorially shown in Figure 3.I.12 where stress intensity is plotted for convenience. As can be seen from this figure, the region of highest stress intensity is rather localized and its maximum primary stress intensity value is well below 3,000 psi, which if compared to the Level A membrane stress limit (per Table 2.I.5), leads to the factor of safety:

$$SF = \frac{allowable}{actual} = \frac{17.5}{3} = 5.87$$

based on the un-corroded thickness. Using the corroded thickness reduces the SF by 12.5%. Because the stresses in the CEC shell remain elastic, no reduction in the diametral opening of the CEC is indicated. Therefore, the retrievability of the MPC is assured.

Although the reference analysis documented in the foregoing uses conservative input data and shows a large safety margin, the ISFSI owner is required to perform a site-specific evaluation to demonstrate compliance with the Table 2.I.5 CEC stress criterion.

Structural Evaluation of the Top Surface Pad Subject to Live and Seismic Loadings from a Loaded Transporter

The Top Surface Pad (TSP) is classified as an ITS component. The function of the Top Surface Pad (TSP) is to provide haul paths for the transporter to deliver a HI-TRAC to an empty VVM. The Top Surface Pad is isolated from the VVM Interface Pad by appropriately located expansion joints to isolate the CEC from any unbalanced loads imparted by the transporter. The minimum characteristics of the TSP (pad thickness and strength, and reinforcing bar layout and strength) are provided in Table 2.I.7. The TSP is supported by the Lateral Subgrade, and the loaded transporter imparts a localized loading to the TSP. A structural evaluation is performed to demonstrate that the gross moment and shear capacities set forth in ACI 318-05 are not exceeded under a load of 450,000 lb, which bounds the weight of a typical transporter carrying a loaded HI-TRAC. A 3x3 array of VVMs is modeled using ANSYS, with the loaded transporter positioned directly over the central VVM cavity, or centered between two adjacent VVM cavities (see Figure 3.I.15). The substrate (with properties characteristic of an 800 ft/sec shear wave velocity) is extended beyond the TSP apron a distance equal to the depth of the subgrade below the TSP. The base of the substrate, grounded on the Support Foundation is assumed fixed, and the displacement normal to the four lateral free surfaces of the substrate is also zeroed. Figure 3.I.15 shows the models (two configurations) before meshing by the ANSYS finite element code. The steel structure of the CECs is not included in the model so as not to impart any additional stiffness to the supporting substrate. Similarly, the VIPs that are enclosed by the TSP are ignored as they are separated from the TSP by expansion joints. The transporter is not modeled; rather, a vertical pressure is applied to the top surface of the TSP to simulate the loaded interface. Consideration of these two configurations is expected to provide bounding safety factors for both bending moments and shear forces. The "strips" of concrete represent the interface areas where the transporter could be located. To ensure conservative results, a transporter with the smallest span that can be moved over a VVM is chosen. The configuration forms a gridwork of concrete beams with wide beams parallel to the transporter path (transporter path beams) and narrower cross-beams perpendicular to the transporter path (cross-beams). Figure 3.I.16 shows the first configuration after the meshing operation.

For each configuration, the first load case consists of an equal pressure of approximately 47 psi applied to each of two load patches straddling the VVM. This represents the weight of a loaded transporter divided over two tracks. In addition to the applied pressure, the weight of the TSP and the substrate is included using the maximum weight densities ascribed to these components in Tables 2.I.2 and 2.I.4. All loads are considered live loads when computing final safety factors.

The second load case in each configuration consists of the aforementioned live load pressure plus an additional vertical pressure increment on each load patch to balance the additional vertical force and overturning moment from the vertical and horizontal components of the design basis seismic acceleration (Table 2.I.4). For this analysis, the design basis accelerations are imposed at the top surface pad. The net seismic horizontal acceleration (in the most limiting direction) and the vertical acceleration are combined using the 100%-40%-40% rule (RG 1.92, Revision 2). To maximize the load on the TSP and bound all possible seismic load orientations, the vertical pressures on each load patch are calculated twice. First the pressures are calculated assuming that 100% of the net horizontal acceleration acts in the direction perpendicular to the transporter (i.e., parallel to the TSP cross-beams) combined with 40% of the vertical acceleration. Then the load patch pressures are recalculated assuming 100% of the vertical acceleration and 40% of the net horizontal acceleration oriented the direction perpendicular to the transporter (i.e., parallel to the TSP cross-beams). The bounding load patch pressures on each side of the VVM cavity are approximately 83 psi and 24 psi. These values are used as input to the ANSYS finite element solution for this second load case in each configuration.

Typical results are illustrated in Figures 3.I.17 and 3.I.18, which show the distribution of the normal stress directed along the TSP concrete beams for the first load configuration where the transporter straddles the VVM cavity. The effect of the horizontal seismic loading is clearly evident. It is also evident that the loaded transporter causes a localized response in terms of increased stress. Table 3.I.11 summarizes the key results for both load configurations and includes minimum safety factors in bending and shear. Safety factors are computed in accordance with the applicable concrete code (ACI 318-05) per the following steps. First, the appropriate finite element stresses are averaged across the width of each beam. Next the averaged stresses are used to compute cross-section bending moments and shear forces. The final safety factors are then computed using the code allowable bending moments and shear forces. The minimum safety factors reported for the cross-beam shear (for the second position of the transporter) show the effect of crediting the contribution from shear reinforcement bars in Table 2.I.7. Details of the calculations, including the complete set of ANSYS results, are found in the Calculation Package supporting this HI-STORM 100U application [3.I.27]. The results in Table 3.I.11 demonstrate the large margins of safety resulting from these bounding load cases. Because of the localized nature of the high stress areas, it is clear that these results are also representative of a transporter positioned at any location on a larger ISFSI pad.

<u>HI-STORM 100U Lid Integrity Evaluation for Normal plus Explosion Loads, CEC Container Shell Evaluation Under Bounding Vertical Load (Load Case 02 in Table 2.I.5), and Design Basis Fire (Load Case 06 in Table 2.I.5)</u>

The VVM Closure Lid rests on the CEC and resists vertical loads, arising from dead weight, and from induced loadings from explosions, from seismic accelerations, and from tornado missile impact. In this subsection, the analysis considers only the normal loading condition plus the steady pressure bounding the explosion pressure (see Table 2.I.1). The finite element model shown in Figure 3.I.1 is used to obtain this solution; the Closure Lid vertical support is now all around and is provided by the CEC Container Shell Flange (instead of by the lift lugs). The stresses from the solution are compared, per the criteria in Table 2.I.5, with allowable stress values for plate and shell structures as provided in ASME Section III Code, Subsection NF. The allowable stress intensity is per Table 3.I.3 (c) for Level D conditions at a bounding temperature of 350 Deg. F.

The vertical load on the Container Shell ring flange, which can be computed from equilibrium, does not bound the vertical load under normal conditions when the Closure Lid is removed and replaced by a loaded HI-TRAC plus a Mating Device. The bounding vertical load during the transfer operation is an input for the evaluation of the Container Shell for this load case using Strength of Materials methodology. Key results from the analysis of the Closure Lid under the normal loading condition plus the steady pressure, and the follow-on analysis of the corroded Container Shell under the bounding vertical load (during the MPC transfer operation) are summarized in the following table:

Stress Analysis of the Closure Lid and CEC Container Shell Under Bounding Vertical Load During Normal Operations (Load Case 02 in Table 2.I.5)			
Item	Bounding Value from calculations	Allowable Limit	Safety Factor
Maximum Primary Principal Stress Anywhere in Lid (ksi)	< 12.0	59.65(Level D Stress Intensity Limit) 26.25 (Level A Stress Limit)	> 4.97* > 2.19*
CEC Container Ring Flange Weld (kips)	< 300	3,018	> 10.06
Compression Stress in CEC Container Shell Under Bounding Vertical Load (ksi)	< 1.425**	17.5	> 12.28
* The results from the analysis are presented in terms of principal stresses for simplicity. Safety factors are determined by comparison with the Level D stress intensity limits (Table 3.I.3(c)), or with Level A stress limits (Table 3.I.3 (b)). Regardless of the measure used, the safety factors are large. ** The bounding compressive stress is based on a fully corroded shell thickness and also conservatively includes the full weight of the CEC in addition to the bounding load at the top.			

From the above results, it is concluded that there is minimum structural demand on the HI-STORM 100U Closure Lid and CEC Container Shell during normal operation (even if the explosion pressure is conservatively considered as a normal condition).

With respect to the fire event (Load Case 06 in Table 2.I.5), where the Closure Lid steel temperature rises to the limit set in Table 2.I.5, it is noted from Tables 3.I.3 (a) and (b) that the Level A stress limit is reduced to 0.68 of the room temperature value, the yield strength is reduced to 0.66 of its room temperature value, and the ultimate strength is reduced to 0.92 of its room temperature value. From the stress values obtained in the lid (even with the explosion 10 psi surface pressure load included), it is evident that a total collapse of the lid due to reduction of the ultimate strength is not credible.

Seismic loading on the lid is considered in Subsection 3.I.4.7 (Load Case 04 in Table 2.I.5). Subsection 3.I.4.8 considers tornado missile impact (Load Case 03 in Table 2.I.5).

3.I.4.5 Cold

Due to its subterranean configuration, the structural components of the VVM are relatively protected from extremes in the ambient temperature in comparison to the HI-STORM 100 or 100S overpacks. Therefore, no new analyses are identified for the HI-STORM 100U system.

3.I.4.6 Flood

The buried configuration of the HI-STORM 100U system renders it immune from sliding under the action of a design basis flood. No new analyses are needed for an actual extreme environmental event. However, the presence of standing water above TOG imposes an additional overburden to the value normally in place from the surrounding substrate. Assuming 11' of standing water above TOG imposes a surface pressure of 4.76 psi. Adding the 17.5 psi substrate overburden (at the base of the CEC) gives a total pressure at the base of the CEC pf 22.26, which is below the value of 23 psi considered for the induced pressure on the CEC shell from transporter operations. Although this flood pressure is an all around pressure on the CEC, note that the circumferential stress produced in the CEC is only 1130 psi. Clearly, 11' of standing water above TOG does not produce any significant stress in the CEC Container Shell.

Although the condition does not necessarily arise due to a flood, a limiting uplift scenario where the VVM CEC is in place and the surrounding substrate produces a buoyant force by unspecified means is considered. For this condition (Load Case 01 in Table 2.I.5), the limiting uplift condition determines the minimum weight that needs to be in place to prevent uplift during construction. This could be in the form of a temporary cover. The upward directed buoyant force exerted on the CEC cavity is computed assuming a weight density of water and compared with the dead weight of the CEC. Under the postulated condition, the net uplift load (Buoyant Force – Weight of CEC) can be calculated. The required temporary weight that is needed to produce a net downward force value is calculated in [3.I.27] and specified in Table 2.I.5.

For the case of a loaded VVM with the Closure Lid in place, or for an empty CEC with the Closure Lid in-place, the buoyant force is less than the vertical download, so there is no uplift.

Should the full buoyant force develop from any means, a lateral pressure load is imposed on the CEC bottom plate. Conservatively assuming an empty VVM, the full buoyant force provides a pressure causing bending of the CEC Bottom Plate, which is partially restrained against rotation by the CEC shells (note that in a loaded VVM, the MPC also helps to support the Bottom Plate of the CEC as its weight causes the central shim to act as a support for the Bottom Plate of the CEC). The stress intensity resulting from CEC Bottom Plate bending is compared to the Level D allowable stress intensity. Using the solutions for maximum stress in a clamped and simply supported plate, and averaging the results from the two solutions to approximately account for the rotational restraint provided by the CEC Container Shell, gives the following bounding safety factor for stress in the bottom plate under the postulated buoyancy loading:

Allowable Stress = 66,875 psi (Table 3.I.3(c) @ 125 deg. Per Table 2.I.5). Safety Factor is calculated to be > 4.0.

3.I.4.7 Seismic Event - HI-STORM 100U (Load Case 04 in Table 2.I.5)

The HI-STORM 100U system, plus its contents, may be subject to a seismic event. Because the VVM is buried in the substrate, tipover of the VVM is not credible. The entire VVM can move laterally with the surrounding and supporting substrate. The response of the VVM to a seismic event is intimately connected with the site substrate surrounding the CEC Container Shell. Therefore, the analysis and qualification of the VVM (as presented in the drawings in Subsection 1.I.5) under the Design Basis Earthquake must be carried out for each site using its unique substrate characteristics. Under the action of lateral seismic loads, the CEC Container Shell globally acts as a beam-like structure supported on a foundation driven by the site seismic accelerations. During a seismic event, the lateral loading on the CEC consists of:

i) Inertia force from CEC self-weight
ii) Inertia forces from the Closure Lid self-weight
iii) Inertia forces from the concrete top pad's (at the top of the CEC) self-weight
iv) Interface forces from the rattling of the MPC within its confines of the Divider Shell and the rattling of the contents inside the MPC
v) Interface forces from the surrounding and undergirding substrate, and from the Support Foundation

The CEC Container Shell develops longitudinal stresses as it bends like a beam to resist the input seismic loads. In addition, the CEC Container Shell tends to ovalize under the loads. Both effects need to be captured in the seismic analysis. Finally, the CEC Container Shell should be conservatively assumed to have corroded to its design limit (i.e., 1/8" is subtracted from the nominal thickness for the analysis).

At certain ISFSI sites, the bedrock may be at a much greater depth than the base of the VVM, and pilings or other means may be used to strengthen the Support Foundation. Likewise, the substrate may consist of discrete layers with different strength characteristics. To deal with the variety of possible circumstances at a given site, it is necessary to set down the essentials of the SSI model and to fix the solution methodology in the FSAR so as to ensure that the seismic evaluations for a particular site shall be carried out in a consistent and appropriate manner. The prescriptive approach, described in the following and incorporated into the Technical Specification by reference, has the following key features:

i. A single loaded VVM is modeled with the MPC, the fuel basket, and the stored fuel assemblies explicitly represented as free-to-rattle bodies. The loaded VVM is located at an edge of an axis of symmetry in a rectangular planform Support Foundation of

(N x M) VVMs. To limit the size of the model, if M (and/or N) is greater than 5, then the model may be truncated to M=5 (and/or N=5). (A Support Foundation of M x N VVMs means that a single monolithic slab supports the M x N array of VVMs.)

ii. Time history integration method is used to obtain the system response as a function of time using the site-specific motion at the site-specific control depth at the location of the proposed ISFSI.

The mandated analysis method is henceforth referred to as the Design Basis Seismic Model (DBSM) and incorporates applicable guidance from [3.I.28] and [3.I.29]. Analyses performed on a representative ISFSI and representative earthquake (Table 2.I.4) , summarized in a later section, indicate that the Design Basis Seismic Model will provide a conservative prognostication of the VVM response regardless of the size and level of occupancy (number of locations of loaded cavities) of an ISFSI.

3.I.4.7.1 Design Basis Seismic Analysis Model

NOTE

The text matter below, prescribed in bold typeface, are is incorporated into the HI-STORM 100 CoC by reference (CoC Appendix B, Section 3.4) and cannot be deleted or amended without prior NRC approval via a CoC amendment.

i. A recognized Code, such as SHAKE2000 (Ref. 3.I.1) or similar, shall be used to establish the strain compatible moduli from bedrock (or the specified lower boundary) to the free field *in the absence of any* VVM cavity. These properties shall be used as best estimate properties of the substrate for the Design Basis Seismic Model (DBSM).

ii. A single VVM model with Support Foundation, lateral substrate, and undergirding substrate modeled to the depth where the control seismic motion is applied shall be prepared.

The location of the lateral substrate boundaries shall be sufficiently far from the modeled Support Foundation so as not to significantly affect the response of the modeled VVM.

The lower boundary of the undergirding substrate shall be placed at a layer at which the shear wave velocity exceeds 3500 ft./sec. or at a substrate layer that has a modulus at least 10 times the modulus of the soil layer immediately below the Support Foundation pad. The lower boundary shall be treated as a rigid surface with the control motion applied on it.

iii. Uncertainties in SSI analysis shall be accounted for by varying the best estimate low strain shear modulus of the substrates between the best estimate values times (1+c) and the best estimate value divided by (1+c). If adequate soil investigation data is available, then c may be established based on the mean and standard deviation. c=1 if sufficient data is not available to determine a statistically meaningful mean and

standard deviation.

iv. **Proper element size and time step control in the dynamic model shall be considered following the guidance in references [3.I.28] and [3.I.29].**

v. **The dynamic model shall be implemented on a computer code that has been benchmarked and Q.A. validated for application in soil-structure problems involving non-linearities such as unfixed masses and unbonded internal interfaces. The Q.A. validation of the code shall be carried out by a Q.A. program approved under an NRC docket.**

The VVM model shall comply with the provisions set forth in the following:

a. **The Cavity Enclosure Container (CEC) shall be discretized by an appropriate finite element grid to simulate its Container Shell and Bottom plate, the Divider Shell, and the MPC guides in an explicit manner.**

b. **The MPC shell, baseplate, and top lid shall be modeled using sufficient element discretization to simulate the presence of welds at gross structural discontinuities (such as the baseplate-to-shell junction in the Enclosure Vessel) with accuracy.**

c. **The fuel basket shall be modeled with appropriate finite elements arrayed to simulate inter-cell connectivity in an explicit manner.**

d. **Nominal small gaps between the fuel basket and the MPC shall be explicitly modeled, as shall the nominal gap between the MPC and the CEC at the upper and lower MPC guide locations.**

e. **Each fuel assembly may be represented by an equivalent homogenous, isotropic prismatic beam of an equivalent elastic modulus whose fundamental lateral natural frequency accords with that of the actual fuel assembly. A bounding fuel assembly weight shall be used and the fuel basket shall be assumed to be fully populated with fuel assemblies.**

f. **The VVM Closure Lid shall be modeled to simulate its mass distribution and to approximately represent the load path between the Divider Shell and the CEC flange during the seismic event.**

g. **The site-specific surrounding and undergirding substrate/CEC interface in the model shall have "gap" elements to simulate the potential for relative movement at interfaces with the steel and concrete. Appropriate coefficients-of-friction at the substrate/structure interface shall be used at all interface locations.**

h. **The substrates shall be modeled with elastic- plastic material behavior using the determined strain compatible elastic moduli using the guidance provided in Figure 3.5.1 of [3.I.28], or by other justifiable data or methodology to set a limit on compressive stress.**

i. **The VVM Support Foundation and the Top Surface Pad shall be included in the dynamic model with the provision to account for possible cracking of the concrete using the guidance in Section 3.4 of [3.I.29], as appropriate. The loaded VVM shall be located at an edge of the support foundation with sufficient amount of the foundation modeled in both lateral (horizontal) directions to capture the effect of the flexing action of the Support Foundation.**

All safety factors associated with the CEC and its contents shall meet the limits summarized in Subsection 2.I (Table 2.I.6). The site-specific seismic/structural analysis shall be documented in a Q.A validated report to demonstrate compliance with all structural criteria (Table 2.I.6).

The Support Foundation is designated as an Interfacing Structure. The design of the Support Foundation for a particular site shall utilize the loads at the VVM/Support Foundation interface obtained from the Design Basis Seismic Model (using the single VVM model,for conservatism) described above. The Support Foundation Pad shall satisfy the American Concrete Institute (ACI) Code (2005 issue) strength limits. A static analysis that considers a fully populated, continuous Support Foundation, supported by the site undergirding substrate, is acceptable. Iterative analyses shall be performed until consistency is achieved between the Support Foundation thickness and strength used in the DBSM described above and the Support Foundation thickness and strength used in the structural model to establish ACI Code compliance.

3.I.4.7.2 Parametric Studies to Define the Design Basis Seismic Model

In this subsection the parametric studies to establish the Design Basis Seismic Model (DBSM) (abstracted in the foregoing) are summarized.

The first step in developing an appropriate DBSM is to recognize the manifest non-linearities, from the structural standpoint, in the VVM array, such as:

i. A large and massive unfixed canister containing unfixed fuel assemblies arrayed in a free-standing configuration inside the CEC.

ii. The CEC situated on a reinforced concrete pad without any anchor connections.

iii. The surrounding substrate free to slide with respect to the CEC metal structure during the seismic event.

Recognizing the inherent nonlinearities, a non-linear model of a single VVM using LS-DYNA is prepared. The major simplification in this model is the assumption that a single isolated VVM containing a loaded MPC is situated on a Support Foundation of limited lateral extent. The undergirding and surrounding substrate are included and seismic excitation (Table 2.I.4) is applied at the appropriate depth.

In other words, the Support Foundation is reduced to a "padlet", thus robbing it of virtually all bending flexibility. This so- called "padlet" solution is, nevertheless, a viable means to compare the severity of response from a non-linear solution with the linearized (SASSI) solution discussed below in the second step.

In the "padlet" model, a single VVM is assumed to be positioned on the truncated support pad and the lateral substrate boundary (where non-reflective elements are applied) is an appropriate distance beyond the edge of the Support Foundation. An engineered fill substrate supports the VVM Support Foundation down to bedrock (approximately 51' below the Top of Grade). The bedrock is driven by the seismic event listed in Table 2.I.4. Both the undergirding substrate and the lateral substrate are considered as homogeneous with specified shear wave velocities. Figure 3.I.3 shows the geometry analyzed.

The simulation is performed using LS-DYNA [3.I.2], which has been approved in Holtec's Q.A. system and has been demonstrated to be applicable to seismic analyses of buried structures [3.I.15]. The substrate is modeled using solid elements and is considered as elastic-perfectly plastic with a defined effective yield stress in the near field surrounding the single VVM, the Container Shell and Divider Shell are modeled using solid elements with elastic-plastic behavior, and an appropriate concrete material model is used for the solid elements in the VVM Interface Pad, in the Top Surface Pad, and in the VVM Support Foundation. Proper gaps between the recess in the Support Foundation and the CEC are included and the annular space is assumed to be filled with substrate. The heaviest loaded canister (MPC 32), including its fuel basket, is modeled using solid and shell elements with material behavior restricted to linear elastic. The fuel assemblies are modeled with solid elements.

The second step in the quest to define the DBSM is to determine whether a linearized model of the structure would be adequately conservative. To make this determination, a typical "100U" ISFSI consisting of a 5x5 VVM array was considered. Tables 2.I.4 and 3.I.4 contain the key input information for the representative problem.

The 5x5 VVM array is shown in Figures 3.I.4 and 3.I.5. A single monolithic foundation pad is assumed to support all 25 VVMs. To assess the effect of partial loading, six different cases are analyzed using the Soil-Structure Interaction (SSI) computer code SASSI. These loading cases, sequentially numbered as 1 through 6, correspond to different states of the ISFSI use that would likely obtain in actual practice. To limit the size of the numerical problem, all cases involve VVMs loaded about one axis of symmetry (Fig. 3.I.5).

The cases considered permit an assessment of the effect of the number of filled cavities, and the location of filled cavities on the system response. Applicable material properties and dimensions for steel, substrate, and concrete portions of the model are employed per Tables 2.I.4 and 3.I.4

Because SASSI is a linear program, the substrate is attached to the Container Shell at common nodes. The SASSI solution considers the array subject to each directional seismic input separately, with an SRSS combination of results from three directional inputs providing the final solution. For the case where a horizontal seismic input is considered, the mass of the contained MPC is conservatively "smeared" on the Container Shell to maximize the potential of the Container Shell to ovalize during the seismic event. For the case with vertical seismic input, the mass of the contained MPC is attached to the baseplate. The top concrete pads at grade are not modeled but their mass is attached to the top lid of each CEC.

Details of the SASSI model and the simulations are presented in a calculation package [3.I.14]. The key results are the seismically induced ovalization of the cavity and the beam-like membrane stress in the CEC of the loaded cavities; the results from the SASSI analyses are summarized in Table 3.I.5.

Major conclusions derived from the linear SSI analyses summarized are:

i. The loaded VVM at the boundary of the array produces maximum response.
ii. In all cases the response of the VVM structure is a fraction of the allowable response.
iii. The stress level in the Support Foundation, is too small to cause initial cracking of the concrete on the tension side; this is presumably due to the support provided by the underlying substrate.

Table 3.I.6 provides a comparison of the key results between the "padlet" non-linear solution and the linear (SASSI) solution. It is evident from the results that the non-linear (LS-DYNA) solution provides a uniformly stronger response. Therefore, the effort to define a Design Basis Seismic Model must be premised on a non-linear simulation. The development of the tabular results from the LS-DYNA output is documented in the calculation package [3.I.27].

In the third and last step of the investigation, the effects of support pad size and the variation in the substrate/reinforced concrete properties are studied with the non-linear (LS-DYNA) model as the analysis vehicle and a single loaded VVM located at the edge of the foundation on the symmetry axis. Specifically, the following three additional scenarios (the padlet solution discussed above is labeled as Case 1), were analyzed:

Case 1: Support Foundation Padlet with Inelastic Concrete Behavior (Reference "Padlet Solution")

Case 2: Support Foundation Padlet with Elastic Concrete Behavior – 50% reduced modulus per ASCE 4-98 (Reduced modulus padlet solution)

Case 3: Support Foundation 5x5 Pad with Elastic Concrete Behavior – 50% concrete modulus (flexible pad/ reduced modulus solution)

Case 4: Support Foundation 5x5 Pad with Elastic Concrete Behavior – 100% concrete modulus (flexible pad solution)

The geometry for the simulations applicable to Cases 3 and 4 is shown in Figure 3.I.6. Table 3.I.7 provides a comparison of the key response parameters from the "padlet" non-linear solution with the peer cases.

Table 3.I.8 provides additional results for the four cases: These additional results pertain to the peak interface load on the Support Foundation and its state of flexural stress. The calculation package

[3.I.27] contains the detailed LS-DYNA output, from which the results in Tables 3.I.7 and 3.I.8 are extracted.

The following conclusions are derived from the above case studies:

i. Cases 3 and 4 provide the largest response parameters.

ii. The interface loads and the magnitude of the support pad stress are either the maximum or close to the maximum for Case 3.

The above findings indicate that the "flexible pad" – single VVM model merits being designated as the Design Basis Seismic Model (DBSM). The application of this model within the framework of the guidelines of ASCE 4-98 has been presented in the preceding subsection as the mandated seismic qualification methodology for a HI-STORM 100U ISFSI.

3.I.4.7.3 Evaluation of Local Strains in the Confinement Boundary in the Impact Region

The small clearance between the MPC and the MPC guide plates can lead to a high localized strain in the region of the shell where the impact from rattling of the canister under a seismic event occurs. The extent of local strain from impact is minimized by locating the guide plate in the vertical direction such that the mid-height of the impact footprint is aligned with the bottom surface of the closure lid. Thus the location of impact patch is removed from the lid-to-shell weld junction. It is necessary to insure that the maximum value of the local (true) strain in the shell (confinement boundary) region of impact is well below the failure strain. For this purpose, the recommendation in [3.I.31] is used. The methodology for computing the local strain is presented in the following and applied to the representative seismic problem analyzed in this section.

A finite element model of the MPC suitable for implementation on LS-DYNA is prepared with special emphasis on the top region of the canister where a very fine grid is employed. All elements have elasto-plasic and large strain capability. The solid elements in the lid and the shell-to-lid weld are of type 2 (fully integrated) and those in the shell are type 16 (fully integrated). The integration across the shell wall employs the maximum number of points available in the code (10 points). A mesh sensitivity study has been performed using a finer grid size for the MPC shell to verify the results are acceptable.

The MPC contents, namely the fuel basket and the SNF, are modeled exactly as set forth in the Design Basis Seismic model in the foregoing (articles (c), (d), and (e) in subsection 3.I.4.7.1). To define a conservative scenario of MPC/guide impact, the velocity time history of the top of the MPC is surveyed from the dynamic analysis of the VVM using the Design Basis Seismic model. The maximum velocity thus obtained is assumed to exist as the initial condition in the LS-DYNA simulation. This assumption is most conservative because it assumes that the cyclic motion transmitted by the earthquake does not detract from the canister's momentum before impact occurs (observations show that the canister slows down by the earthquake's cyclic energy input, thus significantly lessening the severity of the impact). In addition, the MPC guide is fixed at its base, which conservatively ignores the deformation of the divider shell and therefore maximizes the impact. The finite element model is shown in Figure 3.I.13. To implement the above model on the representative problem, the search for the maximum velocity in the dynamic solution yielded less than 26 in/sec. Applying an initial velocity of 26 in/sec as the initial condition to the above model provided the strain field shown in Figure 3.I.14. The maximum plastic (true) strain is found to be less than 0.021, which is only a small fraction of the acceptable value (0.1) per [3.I.31]. Therefore the integrity of the confinement boundary is assured. Reference [3.I.27] contains the complete documentation of the calculations summarized above (a Holtec proprietary document).

The above confinement integrity analysis shall be performed for every underground ISFSI site using the methodology described above.

3.I.4.7.4 Seismic Event During ISFSI Excavation

Subject to the provisions of Paragraph 2.I.6 (xii),the excavation of land in the vicinity of an ISFSI with loaded MPCs is permitted if such excavation is carried out outside the perimeter of the radiation protection space set forth in the licensing drawing. Such a construction activity shall be treated as one of potential safety consequence to the operating ISFSI. An appropriate soil-structure interaction analysis shall be performed to support the §72.212 evaluation.

The seismic analysis will be carried out in accordance with the provisions of Subsection 3.I.7.1 with an explicit inclusion of the site excavation in the structurally most adverse configuration.

3.I.4.8 Tornado Missile Evaluation

3.I.4.8.1 HI-STORM 100U Lid Integrity Evaluation for Tornado Missile Strike (Load Case 03 in Table 2.I.5)

Design basis tornado missiles are specified in Table 2.2.5. The Closure Lid is the only above ground component of the VVM; therefore, missile impact analyses focus on this component. Large and intermediate tornado missiles are assumed to strike the center top surface of the lid at the design basis speed (see Table 2.2.5). For both missile analyses, a finite element model of the Closure Lid is employed (using typical dimensions from drawings and typical material properties), and includes contact between concrete and steel (see Figure 3.I.1). LSDYNA is used to perform dynamic simulations of the impacts to demonstrate that neither missile completely penetrates the composite structure. The ANSYS model shown in Figure 3.I.1 is simplified to develop an input file for the LS-DYNA simulation. Elastic-Plastic Material 24 is used for the steel and Material 72 is used for the concrete. For a conservative result, engineering stress relations for the lid steel work are used with an assumed ultimate strain of 21% (per ASME Code, Sec. II, Part A). As LSDYNA input expects that true stress-strain data is input, the use of true stress-strain data, to obtain a more realistic result, is permitted (if appropriate justification is provided for the true stress-strain relation). The solution obtained using engineering stress strain data is clearly conservative in that material failure is set at the engineering ultimate strain limit rather than reflecting the true strain at failure, which will be considerably larger. A strain rate effect is incorporated by increasing the yield and ultimate strengths by a maximum of 50% (depending on the rate) as suggested by data for SA-36 steel [3.I.19]. This is the same strain rate increase used in the evaluations to assess the performance of the aboveground HI-STORM when impacted by a jet fighter aircraft [3.I.16]. A time history normal pressure loading is applied over the metal annular region around the outlet opening to simulate the large missile, and the global deformation damage to the lid is assessed. The formula from "Topical Report – Design of Structures for Missile Impact", BC-TOP-9A, Rev. 2, 9/74 [3.I.17] is used to establish appropriate pressure-time data. For the speed and mass associated with the large missile, the impact force-time curve has the form

F(t) = 0.625 sec./ft x 184.8 ft/sec x 4000 lb x sin (20t) = 462,000 lb x sin (20t) for t< 0.0785 sec.
= 0 for t >= 0.0785 sec.

This representation of the large missile impact load is appropriate as recent full-scale impact testing of a modern passenger vehicle demonstrates. Figure 3.I.7 shows the force-time history from the full-scale test of a full-size Ford passenger vehicle (see [3.I.18]). The test was performed at an impact speed of 35 mph and the vehicle had approximately the same weight as the design basis large deformable missile. Since the force is directly proportional to the pre-impact momentum, an estimate of the peak force at 126 mph for the Ford is obtained by a simple ratioing of the impact velocities and missile mass. Estimating the peak value from the plot produces a resulting peak force of 496,000 lb, which is the same order of magnitude as the peak value predicted from the Bechtel Topical Report, although the shape and duration of the curve is different. The results from the analysis using the Load-Time function from the Bechtel formula show no significant lid damage from the large missile strike on the lid because of the concrete backing. Inspection of the result concludes that the deformed shape after the event does not preclude lid removal, the lid remains in-place, and the MPC has not been impacted. The maximum lid vertical deflection during the strike is less than 0.1 inch and there are a few local regions of permanent effective plastic strain. The details of this calculation are found in [3.I.27]. As noted from what follows, the large missile impact is not the bounding strike because of the large area of impact and significant energy loss that occurs when the vehicle is crushed upon impact; the rigid, intermediate missile imparts more local and global damage to the Closure Lid.

The impact of the intermediate missile, is conservatively simulated as a rigid 8" diameter cylindrical steel bar weighing 275 lb. (in accord with Table 2.2.5), traveling at 126 mph and striking the Closure Lid at the most vulnerable location, which is through the top vent opening. The strike can be at the inner shield dome either at the center, or slightly off-center so as to miss the central steel connecting bar. In order to strike the MPC top lid, the intermediate missile must penetrate the steel weldment and encased concrete (see drawings in Section 1.I.5). Figures 3.I.8 and 3.I.9 show the intermediate impact scenarios considered. Figures 3.I.10 and 3.I.11 show the lid state at the time of maximum bottom plate vertical displacement. For both cases, no dislodgement of the lid is indicated and plastic strains occur only in the immediate vicinity of the strike. A summary of results that bound the computed results for the two intermediate missile strikes is presented in Table 3.I.9.

Next, consider that the intermediate or large missile is traveling horizontally and strikes the side of the Closure Lid. A large missile strike at this location with a horizontal orientation is most likely not credible because of the low profile of the lid. The large missile would rotate as it broke up, resulting only in a glancing blow to the lid. However, an evaluation of the Closure Lid Flange ring in either missile side strike is needed to ensure that the Closure Lid will not be driven sideways under the impact and separate from the CEC. A key structural element is the weld connecting the Closure Lid restraint ring to the Closure Lid. The capacity of the welds in the load path that resist the lateral impact load is calculated as:

Closure Lid Weld Capacity = 8,381,000 lb.

This capacity is computed assuming a limiting weld stress of 60% of the ultimate tensile strength of the base material. In any of the evaluated missile strikes from above, the peak impact load (filtered at 350 Hz (see similar filtering in the HI-STAR 100 transport license)) does not exceed 1,200,000 lb. Interface loads from top impacts are expected to bound impact loads from side impacts because of the geometry involved; therefore, the safety factor on the CEC Container Shell Flange ring, acting to hold the lid in-place, is:

SF (flange ring) = Closure Lid Weld Capacity/ Filtered Peak Impact Load > 6.9

Finally, a small missile entering the outlet duct will not damage the MPC because there is no direct line-of-sight to the MPC, and even if it arrives at the MPC, it will have undergone multiple impacts with the duct walls, and can only impact the thick MPC lid. Therefore, MPC damage from the small missile is not credible.

An assessment of all simulation results concludes that the postulated missile strikes will not preclude MPC retrievability, will not cause loss of confinement, and will not affect sub-criticality. In no scenario, does the lid become dislodged.

3.I.4.8.2 Tornado Missile Protection during Construction

The number of VVMs in a HI-STORM 100U ISFSI may vary depending on a user's need. While there is a minimum spacing (pitch) requirement (see Table 2.I.2), there is no limitation on the maximum spacing. Furthermore, a module array may have a non-rectangular external contour such as shown in the licensing drawing with a trapezoidal contour. Finally, an ISFSI may be constructed in multiple campaigns to allow the user to align the VVM cavity construction schedule with the plant's fuel storage needs. Any ISFSI constructed in one campaign shall have the following mandatory perimeter protection features:

i. The Radiation Protection Space (RPS) shall extend to an appropriate distance beyond the outer surface of the CEC shell (see drawing in Subsection 1.I.5). Calculations have been performed [see 3.I.27] that confirm that a 10' distance beyond the outer surface of the CEC shell is sufficient to prevent the 8" diameter rigid cylindrical missile (defined in Table 2.I.1 and is the most penetrating of the missile types considered in this SAR) from contacting the CEC shell should this missile strike the exposed cut from the adjacent construction The penetration analysis conservatively assumed a substrate with minimum resistance to missile penetration and the formulation described in [3.I.30].

3.I.4.9 HI-STORM 100U VVM Service Life

The VVM is engineered for 40 years of design life, while satisfying the conservative design requirements defined in Supplement 2.I. For information supporting the 40 year design life addressing chemical and galvanic reactions as well as other potentially degrading factors see Subsection 3.I.4.1. Requirements for periodic inspection and maintenance of the HI-STORM 100U VVM throughout the 40-year design life are defined in Supplement 9.I. The VVM is designed, fabricated, and inspected under the comprehensive Quality Assurance Program discussed in Chapter 13.

3.I.5 FUEL RODS

No new analysis of fuel rods is required for storage of an MPC in a HI-STORM 100U VVM.

3.I.6 SUPPLEMENTAL DATA

3.I.6.1 Additional Codes and Standards Referenced in HI-STORM 100 System Design and Fabrication

No additional Codes and Standards are added for the HI-STORM 100U system.

3.I.6.2 Computer Programs

ANSYS 5.7, 7.0, 9.0, and LSDYNA (previously known as DYNA3D) [3.I.2] are used for the finite element analyses prepared by Holtec and summarized in this supplement.

ANSYS

ANSYS is a public domain code, well benchmarked code, which utilizes the finite element method for structural analyses. It can simulate both linear and non-linear material and geometric behavior. It includes contact algorithms to simulate surfaces making and breaking contact, and can be used for both static and dynamic simulations. ANSYS has been independently QA validated at Holtec International. In this FSAR submittal, ANSYS is used within [3.1.27] and the element size used in the application follows the recommendation of the code developers.

LS-DYNA

LS-DYNA is a nonlinear, explicit, three-dimensional finite element code for solid and structural mechanics. It was originally developed at Lawrence Livermore Laboratories and is ideally suited for study of short-time duration, highly nonlinear impact problems in solid mechanics. LS-DYNA is commercially available and has been independently validated at Holtec following Holtec's QA procedures for commercial computer codes. This code has been used to analyze the Non-Mechanistic Storage tipover for the HI-STORM 100 Part 72 general license. In this supplement, the code is used to establish the performance of the HI-STORM 100U under a design basis seismic event, and to evaluate the response to a design basis missile.

LS-DYNA and is currently supported and distributed by Livermore Software. Each update is independently subject to QA validation at Holtec.

3.I.6.3 Appendices Included in Supplement 3.I

None.

3.I.6.4 Calculation Packages

A Calculation package [3.1.27] containing the structural calculations supporting Supplement 3.I has been prepared, archived according to Holtec International's quality assurance program (see Chapter 13), and submitted in with this application. A second calculation report [3.I.14], documenting the SASSI analyses, has been prepared by a Holtec subcontractor under the subcontractor's QA program.

3.I.7 COMPLIANCE WITH NUREG-1536

The material in this supplement for the HI-STORM 100U system provides the same information as previously provided for the aboveground HI-STORM 100 systems. Therefore, to the extent applicable, the information provided is in compliance with NUREG-1536.

3.I.8 REFERENCES

The references in Section 3.8 apply to the VVM to the extent that they are appropriate for use with an underground system. The additional references below are specific to Supplement 3.I.

[3.I.1] SHAKE2000, A Computer Program for the 1-D Analysis of Geotechnical Earthquake Engineering Problems, G.A. Ordonez, Dec. 2000.

[3.I.2] LS-DYNA, Version 971, Livermore Software, 2006.

[3.I.3] USNRC Interim Staff Guidance (ISG-15), "Materials Evaluation", Revision 0, January 2001.

[3.I.4] ANSI/AWWA C105/A21.5-99, "American National Standard (ANSI) for Polyethylene Encasement for Ductile-Iron Pipe Systems".

[3.I.5] M. B. Bruce and M. V. Davis, "Radiation Effects on Organic Materials in Nuclear Plants", Final Report, 1981. (Prepared by Georgia Institute of Technology for EPRI)

[3.I.6] ANSI D 4082-02, "American National Standard (ANSI) Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Light Water Nuclear Power Plants".

[3.I.7] USNRC Regulatory Guide (RG-1.54), "Service Level I, II and III Protective Coatings Applied to Nuclear Power Plants, Revision 1, July, 2000.

[3.I.8] ANSI D 3843-00, "American National Standard (ANSI) Standard Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities".

[3.I.9] ANSI C 210-03, "American National Standard (ANSI) Standard Practice for Liquid-Epoxy Coating Systems for the Interior and Exterior of Steel Water Pipelines".

[3.I.10] Keeler & Long Inc. Product Data Sheet for Kolor-Proxy™ Primer KL3200 Series, Product Code KL3200.

[3.I.11] Samuel A. Bradford, "Practical Handbook of Corrosion Control in Soils", ASM International and CASTI Publishing Inc., 2004.

[3.I.12] L. M. Poukhonto, "Durability of Concrete Structures and Constructions – Silos, Bunkers, Reservoirs, Water Towers, Retaining Walls", A. A. Balkema Publishers, 2003.

[3.I.13] 49CFR Part 195 Subpart H "Corrosion Control", Title 49 of the Code of Federal Regulations, Oct, 1 2004 Edition, Office of the Federal Register, Washington, D.C.

[3.I.14] HI-2084023, SSI Analysis of HI-STORM 100U Using SASSI, Rev. 0 (a Subcontractor report prepared for Holtec by International Civil Engineering Consultants, Rev. 2, April 2008) (Holtec Proprietary) .

[3.I.15] S. Stojko, Application of DYNA3D to Non-Liner Soil Structure Interaction (SSI) Analysis of Retaining Wall Structures, International LS-DYNA3D Conference, March 1993.

[3.I.16] ASLB Hearings, Private Fuel Storage, LLC, Docket # 72-22-ISFSI, ASLBP 97-732-02-ISFSI, February 2005.

[3.1.17] Topical Report – Design of Structures for Missile Impact", BC-TOP-9A, Rev. 2, Bechtel Corporation, 9/74

[3.I.18] SAE Technical Paper 2000-01-0627, Development and Validation of High Fidelity Vehicle Crash Simulation Models, S.W. Kirkpatrick, Applied Research Associates, Inc.

[3.I.19] H. Boyer, Atlas of Stress Strain Curves, ASM International, 1987, p.189.

[3.I.20] Thermal Ceramics Inc., Product Data Sheet for Blanket Products (Kaowool® Blanket).

[3.I.21] NACE Standard RP0285-2002 "Corrosion Control of Underground Storage Tank Systems by Cathodic Protection", NACE International.

[3.I.22] API RP1632, Cathodic Protection of Underground Petroleum Storage Tanks and Piping systems, American Petroleum Institute.

[3.I.23] NACE RP0169-96, "Control of External Corrosion on Underground or Submerged Piping Systems", NACE International.

[3.I.24] 49CFR Part 192 Subpart I "Requirements for Corrosion Control, Title 49 of the Code of Federal Regulations, Oct, 1 2004 Edition, Office of the Federal Register, Washington, D.C.

[3.I.25] ACI 544.3R-93 (or latest), Guide for Specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete.

[3.I.26] ASTM C1116-03 (or latest) Standard Specification for Fiber-Reinforced Concrete and Shotcrete

[3.I.27] HI-2053389, Calculation Package Supporting Structural Evaluation of HI-STORM 100U, Revision 8, April 2009, (Holtec Proprietary)

[3.I.28] ASCE 4-98, Seismic Analysis of Safety-Related Nuclear Structures and Commentary, American Society of Civil Engineers, 2000.

[3.I.29] ASCE/SEI 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, American Society of Civil Engineers, 2005.

[3.I.30] Sandia National Laboratory Contractor Report SAND97-2426, Penetration Equations, C.Y. Young, Applied Research Associates, Inc., Albuquerque NM 87110.

[3.I.31] Doug Ammerman and Gordon Bjorkman, "Strain-Based Acceptance Criteria for Section III of the ASME Boiler and Pressure Vessel Code", Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2007, October 21-26, 2007, Miami, Florida, USA.

TABLE 3.I.1

HI-STORM 100U BOUNDING WEIGHT DATA

Item	Bounding Weight (lb)
MPCs	
• Without SNF	See Table 3.2.1
• Fully loaded with SNF and Fuel Spacers	90,000
HI-STORM 100U VVM	
• Closure Lid (with shielding concrete)	24,000
• CEC (empty without Closure Lid)	33,000
• Maximum Loaded Weight (with bounding MPC)	147,000
Loaded Transporter (Typical)	
• Carrying a loaded HI-TRAC	450,000
• Empty	200,000
Loaded HI-TRAC and Mating Device	275,000
Note 1: CEC and Closure Lid include an overage Note 2: Transporter weight is based on representative units used in the industry.	

TABLE 3.I.2

CENTER OF GRAVITY DATA FOR THE HI-STORM 100U SYSTEM

Component	Height of CG Above Datum (in)
MPC	See Table 3.2.3
HI-STORM 100U VVM CEC (empty without Closure Lid)	108.7
HI-STORM 100U VVM Closure Lid	20.26
Note: Datum for CEC is at the top surface of the foundation; datum for Closure Lid is at bottom surface of baseplate of lid.	

TABLE 3.I.3 (a)*
RELEVANT MATERIAL PROPERTIES FOR THE HI-STORM 100U
Yield, Ultimate, Linear Thermal Expansion, Young's Modulus

Temp. (Deg. F)	SA516 and SA515, Grade 70			
	S_y	S_u	α	E
-40	38.0	70.0	---	29.95
100	38.0	70.0	5.53 (5.73)	29.34
150	36.3	70.0	5.71 (5.91)	29.1
200	34.6	70.0	5.89 (6.09)	28.8
250	34.15	70.0	6.09 (6.27)	28.6
300	33.7	70.0	6.26 (6.43)	28.3
350	33.15	70.0	6.43 (6.59)	28.0
400	32.6	70.0	6.61 (6.74)	27.7
450	31.65	70.0	6.77 (6.89)	27.5
500	30.7	70.0	6.91 (7.06)	27.3
550	29.4	70.0	7.06 (7.18)	27.0
600	28.1	70.0	7.17 (7.28)	26.7
650	27.6	70.0	7.30 (7.40)	26.1
700	27.4	70.0	7.41 (7.51)	25.5
750	26.5	69.3	7.50 (7.61)	24.85
800	25.3	64.3	7.59 (7.71)	24.2
* Footnotes in corresponding table in Section 3.3 apply to the values in parentheses.				

TABLE 3.I.3 (b)
DESIGN AND LEVEL A: ALLOWABLE STRESS FROM ASME NF

Material: SA516 Grade 70, SA515 Grade 70
Service Conditions: Design and Level A Stress
Item: Stress

Temp. (Deg. F)	Classification and Value (ksi)		
	S	Membrane Stress	Membrane plus Bending Stress
-20 to 650	17.5	17.5	26.3
700	16.6	16.6	24.9
750	14.8	14.8	22.2
800	12.0	12.0	18.0

TABLE 3.I.3 (c)
LEVEL D: STRESS INTENSITY

Code: ASME NF
Material: SA516, Grade 70
Service Conditions: Level D
Item: Stress Intensity

Temp. (Deg. F)	Classification and Value (ksi)		
	S_m	P_m	$P_m + P_b$
-20 to 100	23.3	45.6	68.4
200	23.1	41.5	62.3
300	22.5	40.4	60.6
400	21.7	39.1	58.7
500	20.5	36.8	55.3
600	18.7	33.7	50.6
650	18.4	33.1	49.7
700	18.3	32.9	49.3

TABLE 3.I.4
Properties of the Foundation Pad and the Substrate Used in Typical Analyses

Property	**Value**
Concrete Compressive Strength (psi)	4,000
Concrete Rupture Strength (psi)	316.23
Allowable Bearing Stress (psi)	1,870*
Mean Coefficient of Thermal Expansion (in/in-deg. F)	5.5E-06
Modulus of Elasticity (psi)	57,000 x (Concrete Compressive strength (in psi))$^{1/2}$
Substrate Yield Stress (psi)	25
Substrate Modulus of Elasticity	Approximately 18 ksi above Support Foundation, 46 ksi below Support Foundation
Substrate Poisson's Ratio	0.4
Substrate Densities (lb/ft^3) used in representative structural calculations	120 lb/cu.ft. above Support Foundation 140 lb/cu.ft below Support Foundation

* From ACI 318-05, Sec. 22.5.5 and Sec. 9.3.5. Since shielding concrete is always confined, an increase in this value up to a limit of 2 x 1,870 psi is permitted by the ACI Code.

TABLE 3.I.5

KEY RESULTS FROM SASSI ANALYSES

Case Number	Cavity Number with Maximum Ovalization	Seismically Induced Container Shell Ovalization (in.)	Cavity Number with Maximum Seismic Longitudinal Primary Membrane Stress in the CEC Container Shell	Maximum Seismic Longitudinal Primary Membrane Stress (ksi)	Safety Factor*
1	#11, #15	0.02	#12, #14	4.8	8.42
2	#7, #9	0.01	#2, #4, #7, #9	3.8	10.6
3	#1, #5	0.01	#1, #5	4.4	9.19
4	#11, #15	0.02	#11, #15	4.3	9.40
5	#1, #5	0.01	#1, #5	4.4	9.19
6	#3	0.00	#3	3.5	11.5

* Defined based on Stress Intensity of 40,400 psi @ 300 deg. F

TABLE 3.I.6

COMPARISON OF RESULTS FROM SINGLE VVM ON A PADLET NON-LINEAR SOLUTION WITH SASSI LINEAR SOLUTION

Item	LS-DYNA (non-linear solution)	SASSI (linearized solution)	Ratio of LS-Dyna-to-SASSI results
Max.CEC primary stress	13.394 ksi	4.8 ksi	2.79
Maximum Ovality (measured at mid-height)	0.13 in	0.02 in	6.5
Displacement difference between top lid and base of VVM	3.87 in (include movement of lid relative to shell and rigid body rotation of shell)	0.155 in (includes some rigid body rotation of support pad)	25
Peak pad horizontal acceleration at base of pad directly under VVM centerline (unfiltered value)	27 G"S (includes effect of impacts)	0.735 G"S (no impact effect)	39

TABLE 3.I.7

KEY RESPONSE PARAMETERS FROM LS-DYNA SOLUTION OF THE REPRESENTATIVE PROBLEM

CASE #	1	2	3	4	REMARKS	MINIMUM SAFETY FACTOR
MPC/MPC Guides - Impact Force (lb.)	40,830	46,182	**90,000***	84,000	Top Guide at Symmetry Plane – Capacity based on Ultimate Load	6.22
Primary Stress Intensity - MPC (psi)	10,640	8,252	**12,286**	11,624	Primary stress intensity = 2 x primary shear stress; allowable is 36,800 psi @ 500 deg. F	3.00
Primary Stress Intensity - Fuel Basket (psi)	4,148	2,698	**6,932**	4,734	Primary stress intensity = 2 x primary shear stress; allowable is 33,100 psi @ 650 deg. F	4.77
Primary Stress Intensity - CEC Shell (psi)	13,394	14,650	9,216	**16,948**	Primary stress intensity = 2 x primary shear stress; allowable 40,400 psi @ 300 deg F	2.38
Ovalization (in.) at end of seismic event	0.09	0.06	0.092	**0.10**	CEC @ Mid-Height – See Table 3.I.5 for limit	60

* Figures in bold font are the maximum value of the particular response parameter.

TABLE 3.I.8

KEY RESULTS FOR SUPPORT FOUNDATION

CASE #	1	2	3	4	REMARKS
Peak Vertical Force - Foundation Pad/ CEC (lb.)	612,800	563,260	590,500	**651,800***	Values reported are twice calculated value because only one-half of interface modeled
Peak Horizontal Force - Foundation Pad/CEC (lb.)	**37,174**	31,782	31,004	33,104	Values reported are twice calculated value because only one-half of interface modeled
Primary Tensile Stress in Concrete (psi)	531.7	357.9	657.8	**900.4**	Peak value at a point (not an indicator of through thickness cracking)

* Figures in bold font are the maximum value of the particular response parameter.

TABLE 3.I.9*

RESULTS FROM TORNADO MISSILE ANALYSIS (LOAD CASE 03 OF TABLE 2.I.5)			
ITEM	Bounding Value, inch	Allowable Value, inch	Safety Factor
Maximum Vertical Displacement of lid (inch) (inclined impact)	< 3	12**	> 4
Perforation of Inner Shield Dome Steel	Yes (see Fig. 3.I.7)	N/A	N/A
Maximum Peak Impact Force (kips)	< 1,000	1,849	> 1.849
* Details of the calculations can be found in [3.I.27] ** This is the minimum distance between the lid Bottom Plate and the top lid of the MPC			

TABLE 3.I.10

INPUT DATA FOR LOAD CASE 07 IN TABLE 2.I.5	
Item	**Value**
Young's Modulus of soil (ksi)	18 (Table 3.I.4)
Weight Density of the soil substrate (pcf)	120 (Table 3.I.4)
Poisson's Ratio of the soil substrate	0.4 (Table 3.I.4)
Compressive strength of TSP concrete (ksi)	4 (Table 3.I.4)
Thickness of TSP (inch)	24 (Table 2.I.7)
Poisson ratio of TSP concrete1	0.16
Weight Density of Concrete VVM Interface Pad (pcf)**	155

1 Value based on data in "Properties of Concrete", A.M. Neville, 3rd Edition, Pitman, U.K. p. 370.
** Per "Properties of Concrete", Chapter 9.

TABLE 3.I.11
TOP SURFACE PAD MINIMUM SAFETY FACTORS AND DISPLACEMENT FOR TRANSPORTER LOADING CASE

CASE 1 – TRANSPORTER STRADDLING VVM CAVITY

ITEM	SF(BENDING)*	SF(SHEAR)	MAX. LOCAL DISPLACEMENT (INCH)
TRANSPORTER PATH – LOAD COMB. 1	8.32	4.65	0.052
CROSS-BEAM – LOAD COMB. 1	6.21	2.08	0.046
TRANSPORTER PATH – LOAD COMB. 2	8.21	4.18	0.068
CROSS-BEAM – LOAD COMB. 2	4.61	1.81	0.060

CASE 2 – TRANSPORTER STRADDLING TSP CROSS-BEAM

ITEM	SF(BENDING)*	SF(SHEAR)	MAX. LOCAL DISPLACEMENT (INCH)
TRANSPORTER PATH – LOAD COMB. 1	10.09	4.89	0.048
CROSS-BEAM – LOAD COMB. 1	4.60	1.47 **	0.048
TRANSPORTER PATH – LOAD COMB. 2	9.40	4.18	0.061
CROSS-BEAM – LOAD COMB. 2	3.28	1.30 **	0.061

* SF = SAFETY FACTOR = (ACI Allowable Moment or Shear Force)/(Calculated Factored Moment or Factored Shear Force).

** Does not credit any rebar shear reinforcement

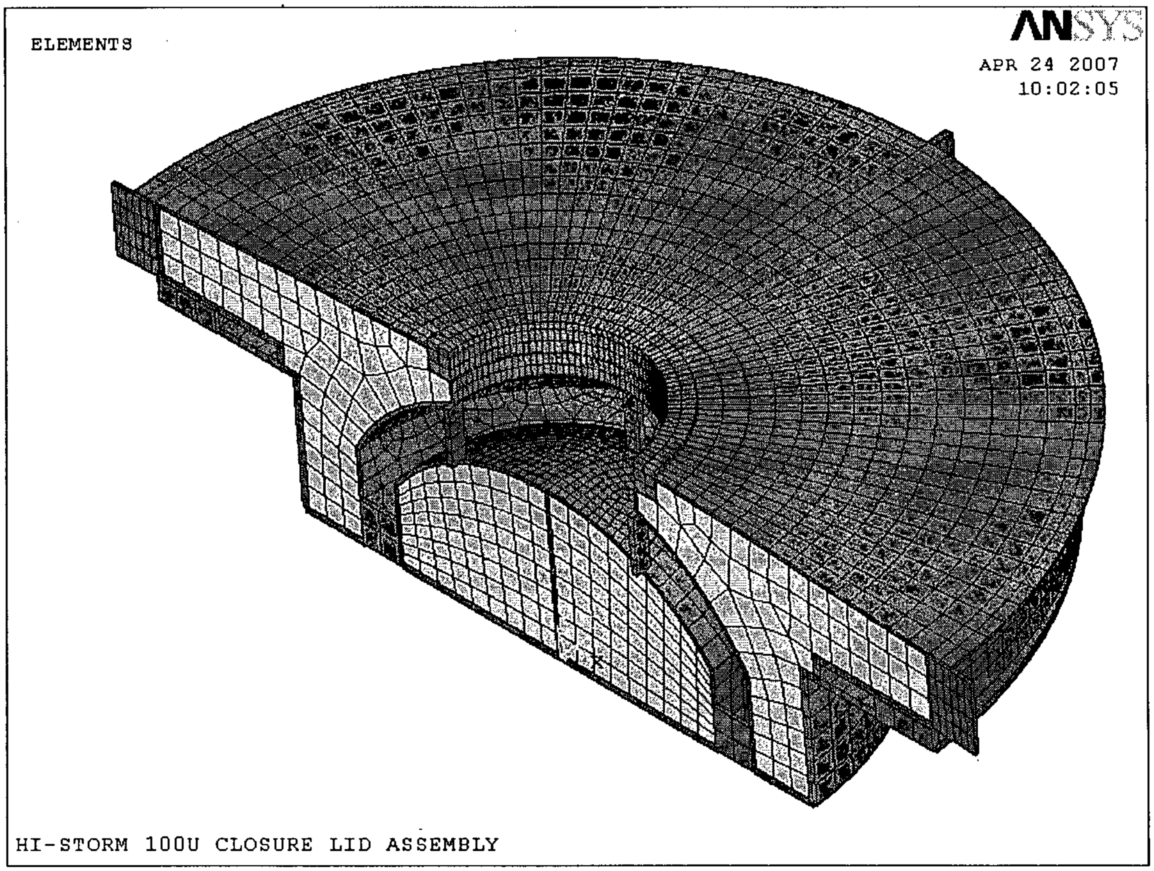

Figure 3.I.1; 3-D ANSYS/LSDYNA Finite Element Model of Closure Lid (Current Configuration)

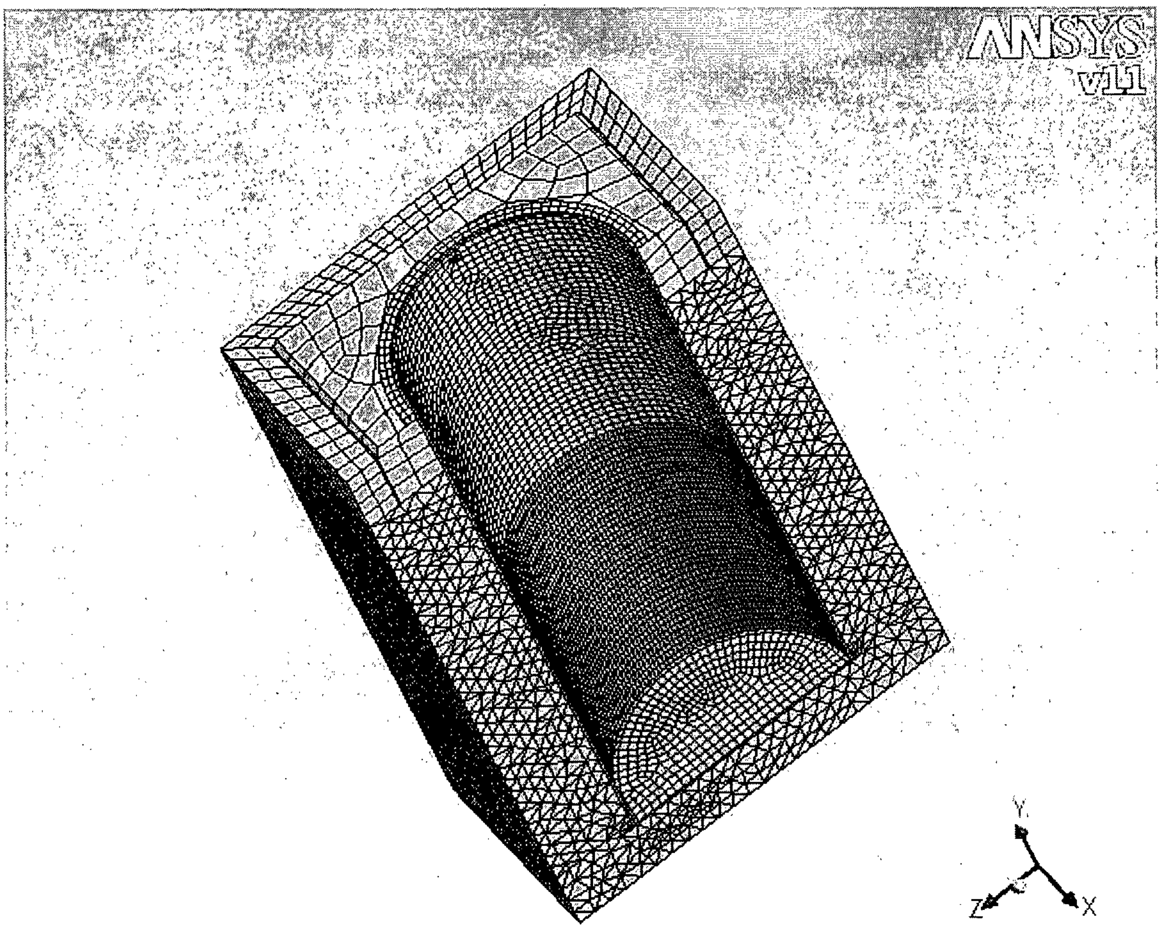

Figure 3.I.2; 3-D ANSYS Finite Element One-Half Model of Substrate Surrounding VVM, CEC Container Shell, TSP, and VIP

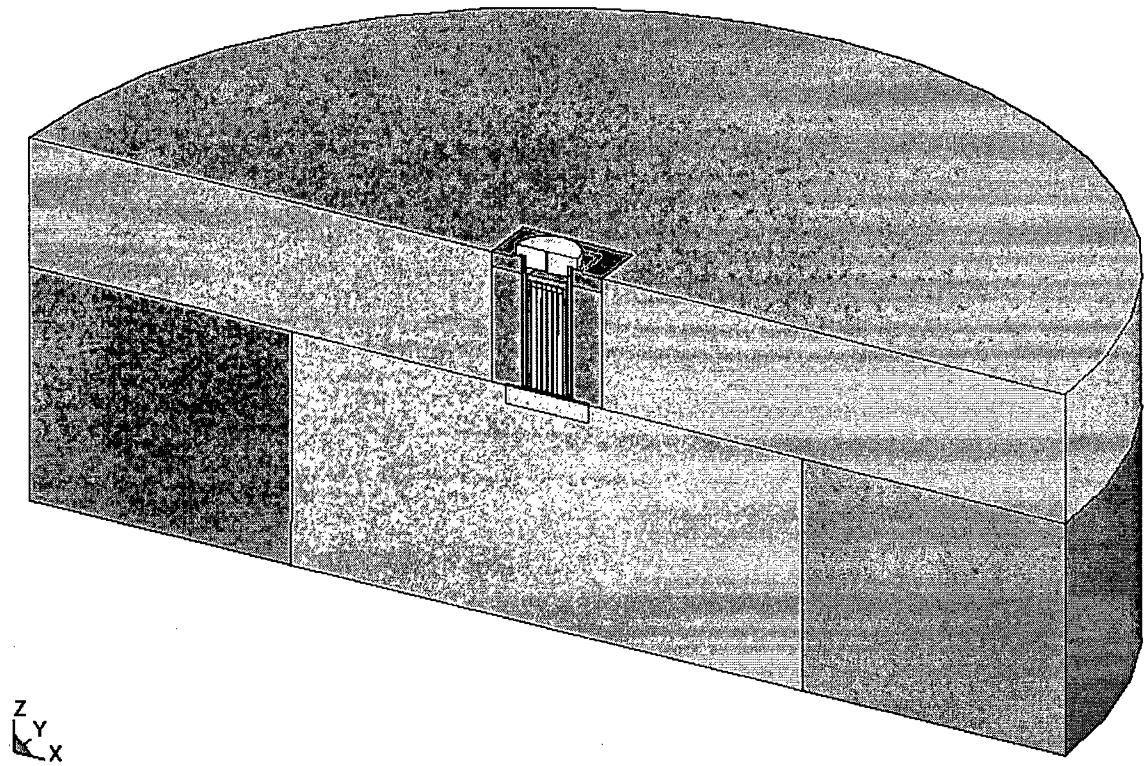

Figure 3.I.3; 3-D LSDYNA Model for Non-Linear SSI Analysis of VVM on Support Foundation Padlet

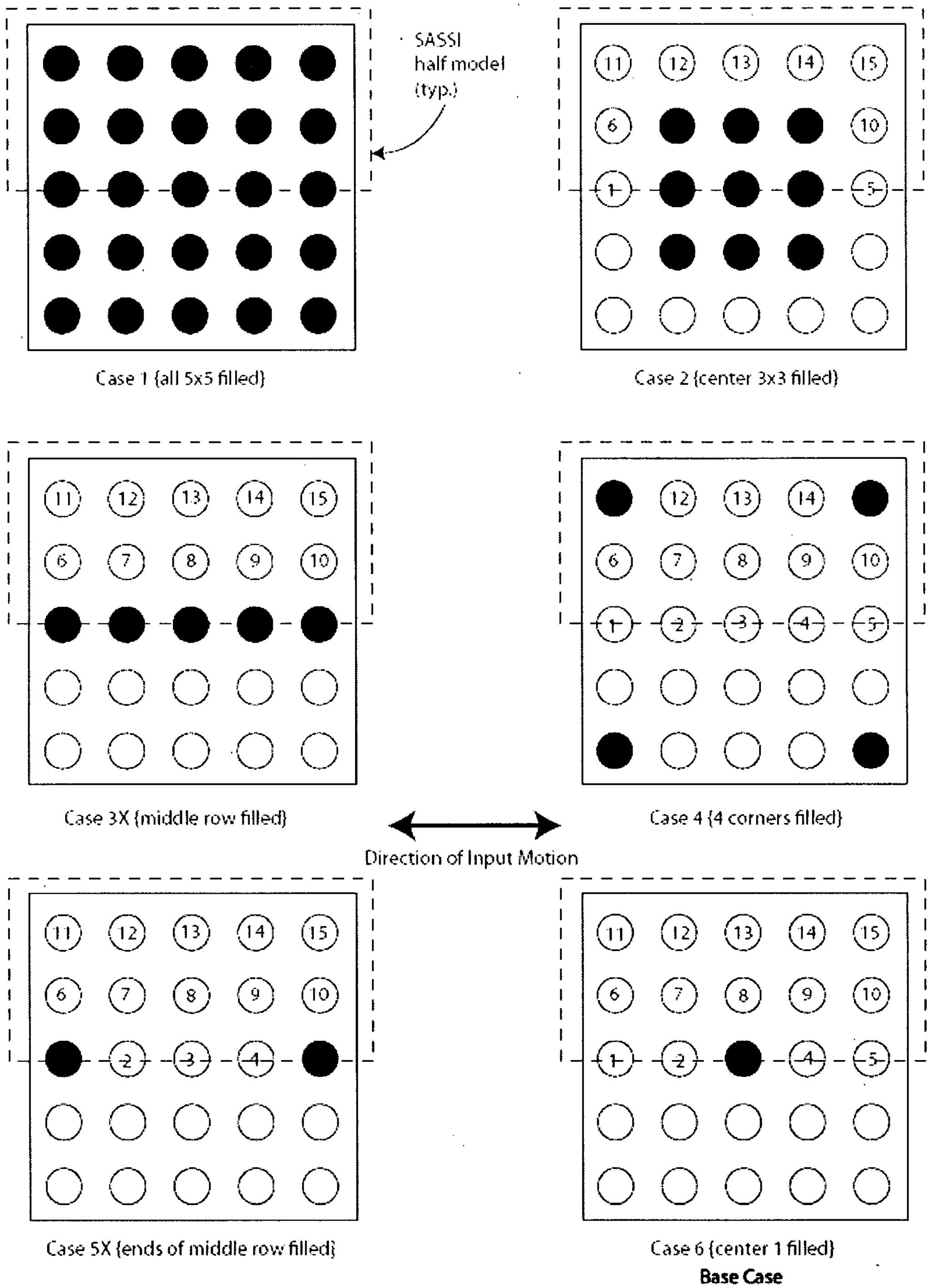

Figure 3.I.4; Location of Loaded VVMs for SASSI Linear Analyses

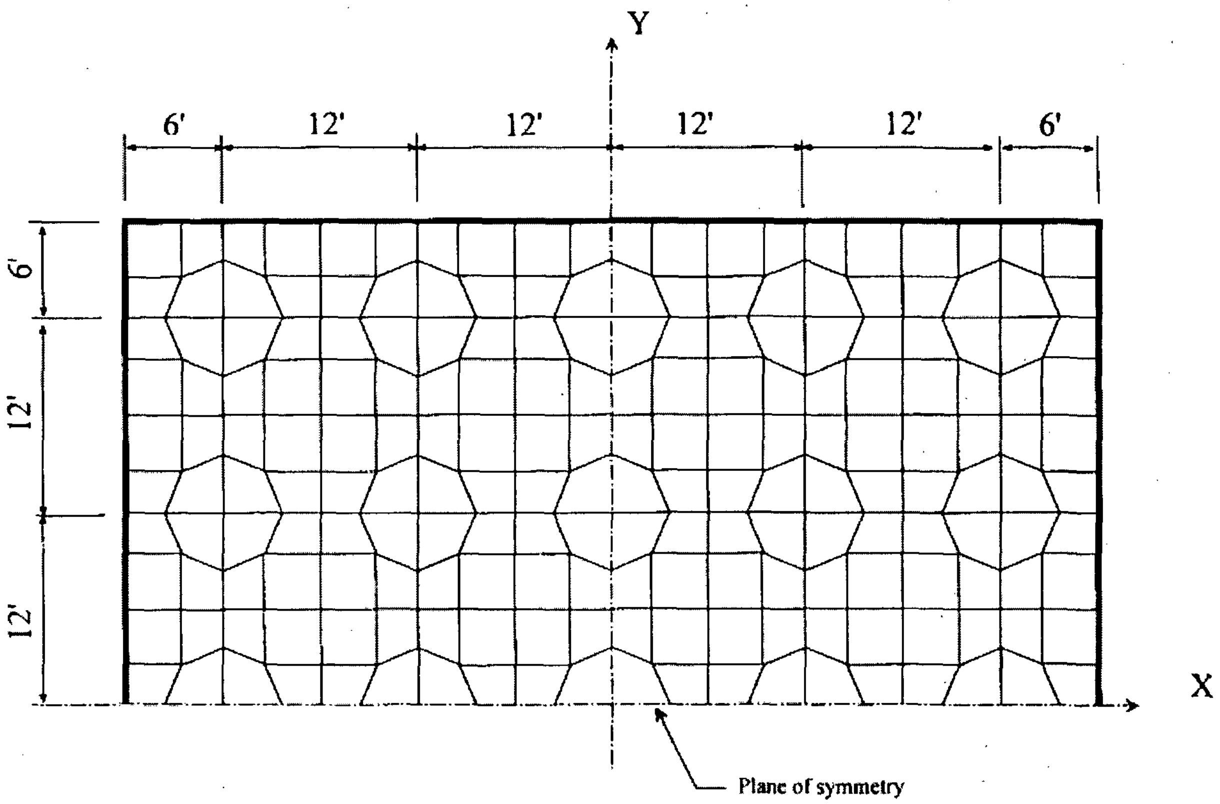

Figure 3.I.5; One-Half of 5 x 5 SASSI Finite Element Model (Looking Down)

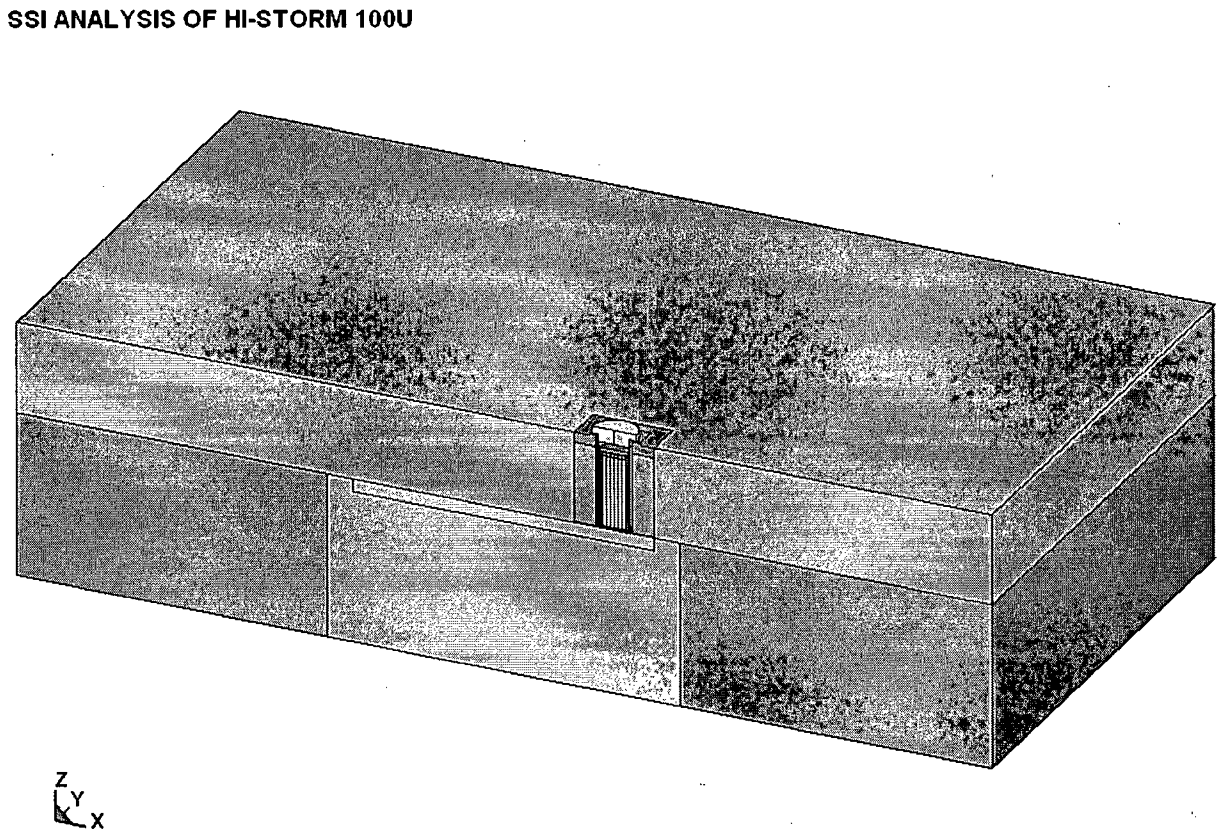

Figure 3.I.6; 3-D LSDYNA Model for Non-Linear SSI Analysis of VVM at Edge of 5x5 Support Foundation

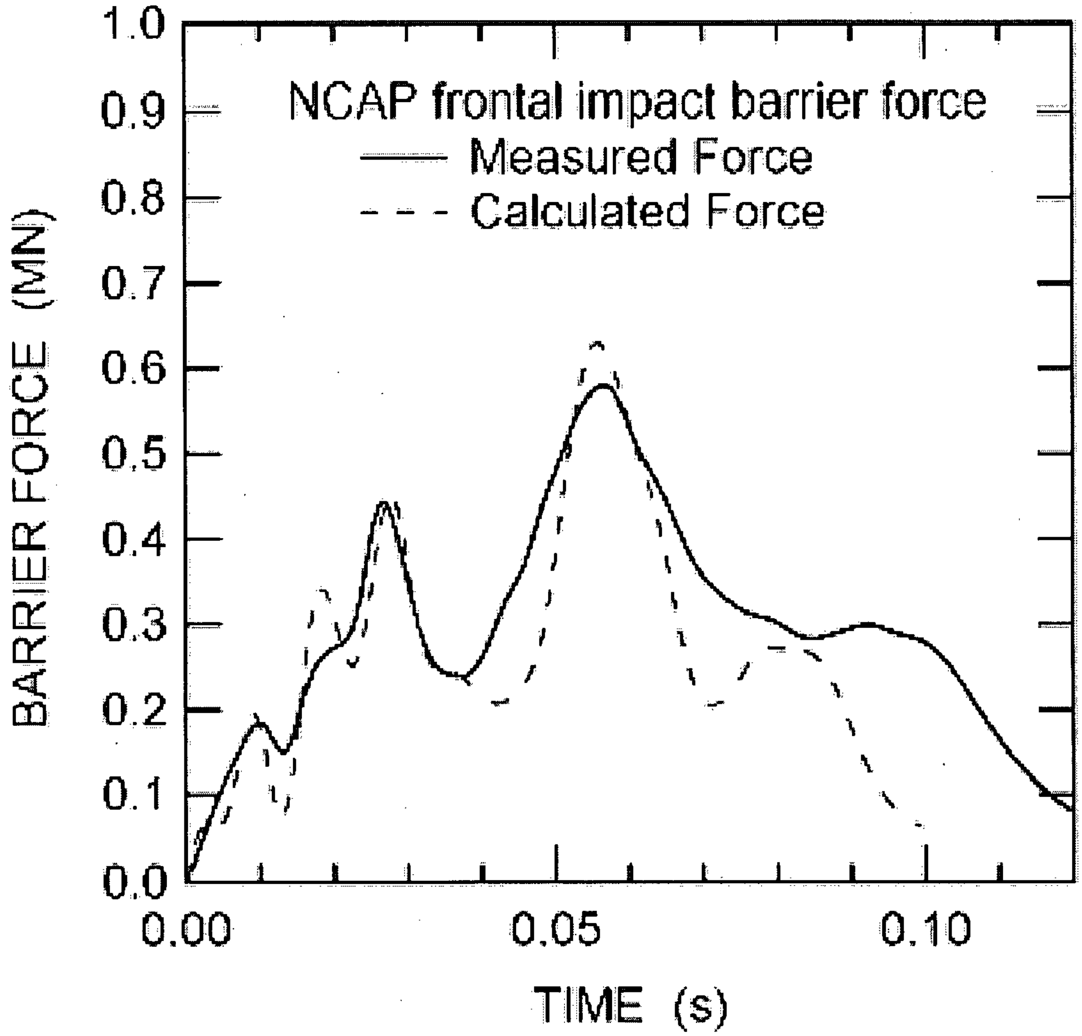

Figure 3.I.7; Test Results from 35mph Impact of a Ford (1705 Kg) Against a Rigid Wall

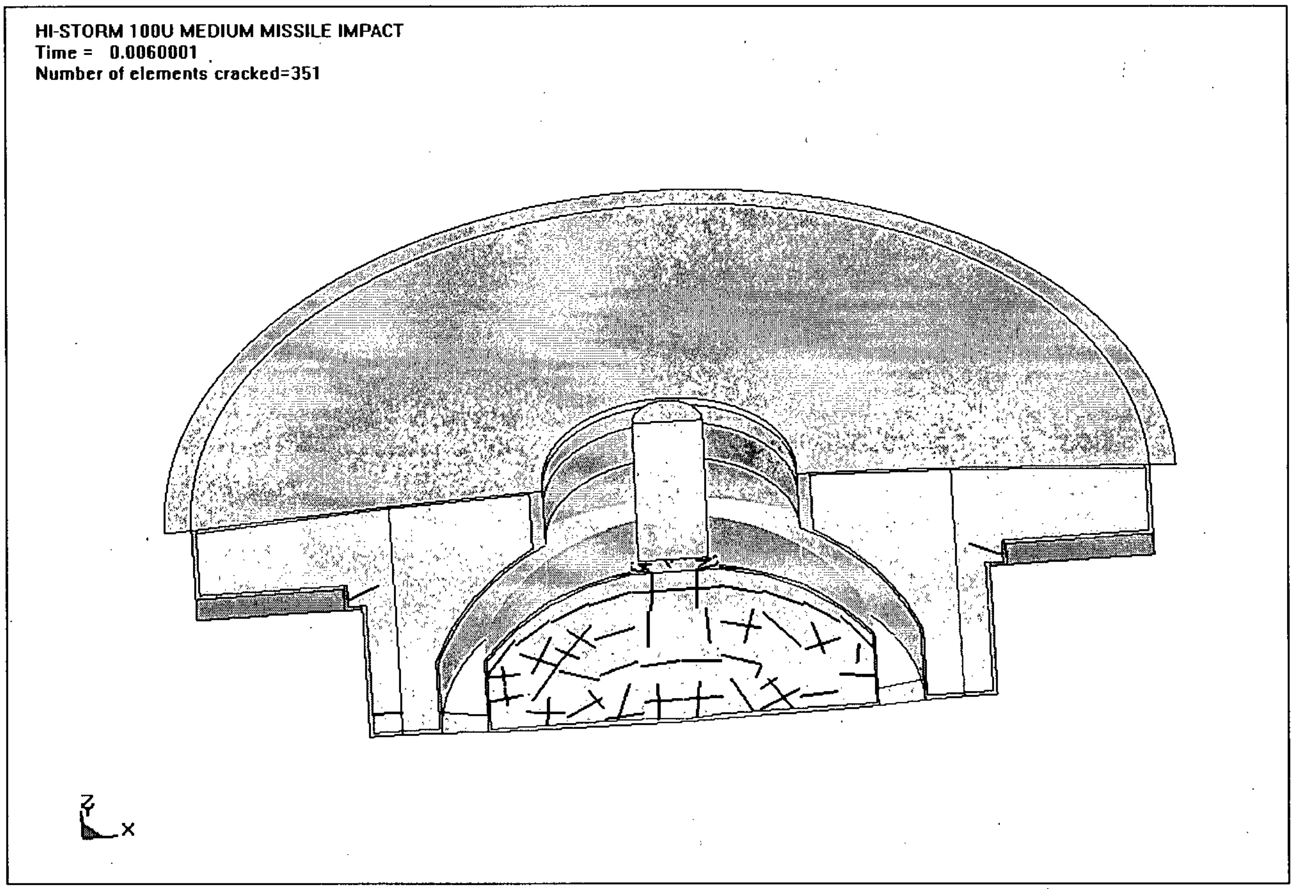

Figure 3.I.8; LSDYNA Model Section for Central Intermediate Missile Strike (subsequent to impact)

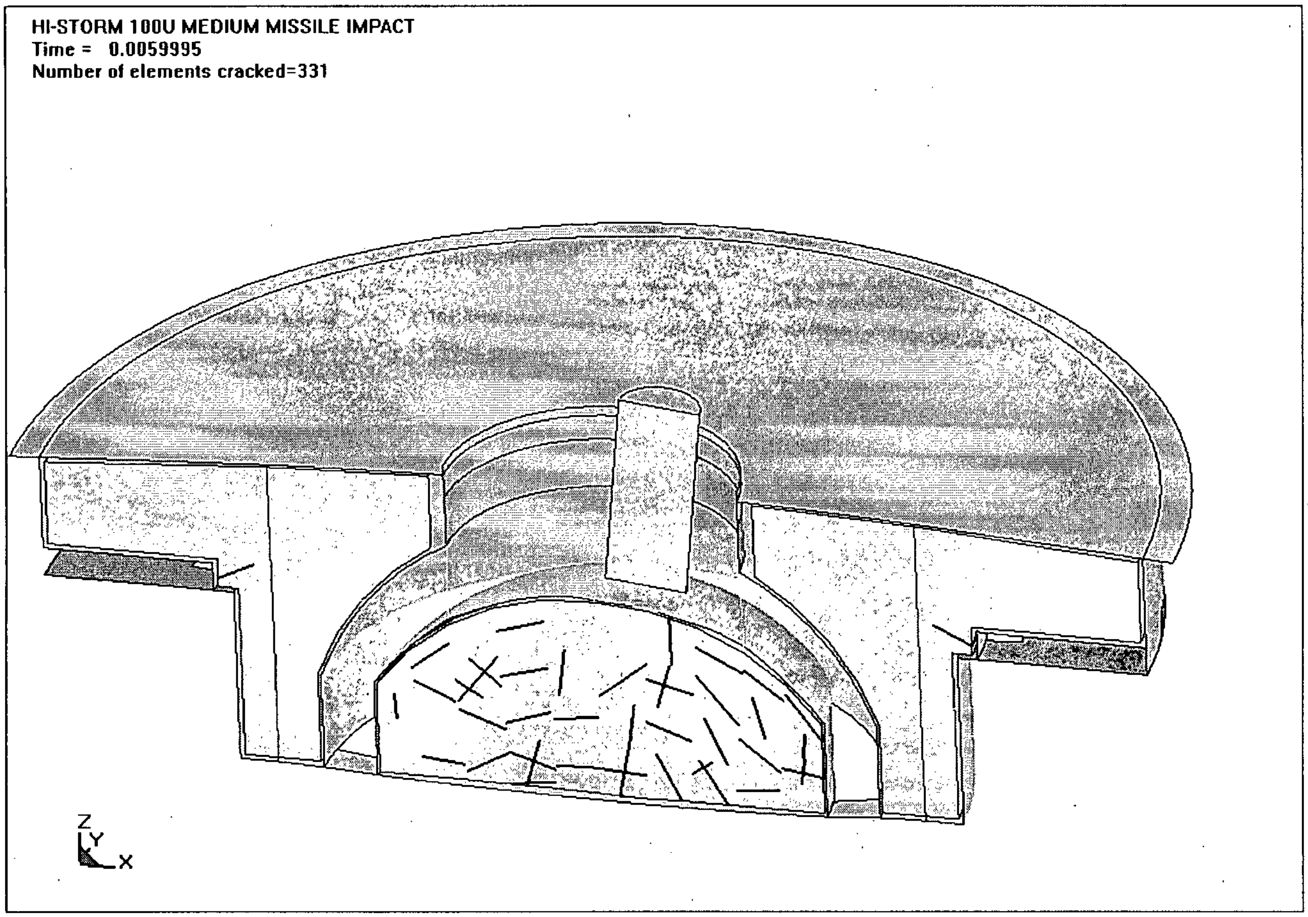

Figure 3.I.9; LSDYNA Model Section for Inclined Intermediate Missile Strike (subsequent to impact)

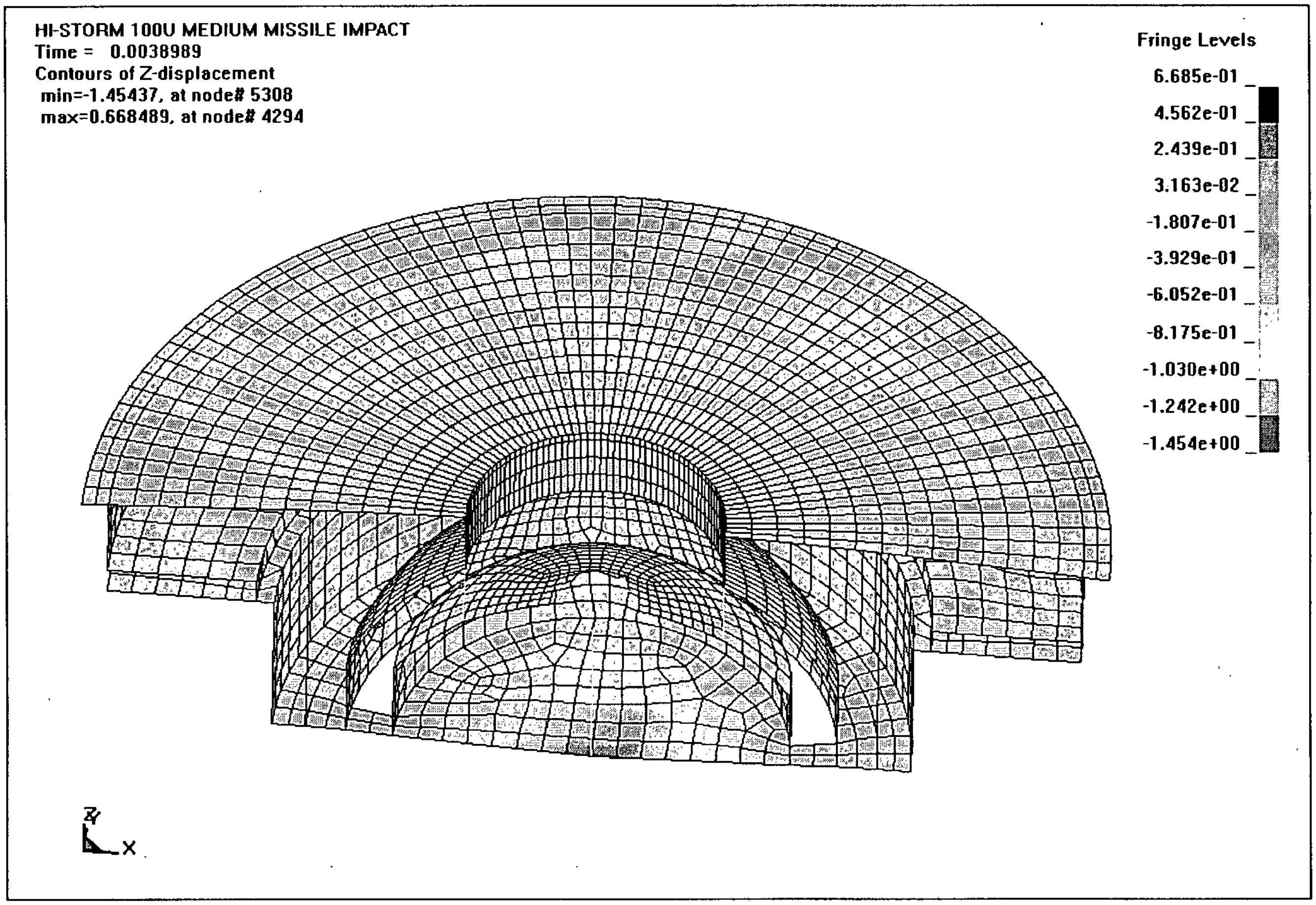

Figure 3.I.10; Deformation Profile at Time of Maximum Deformation – Central Strike

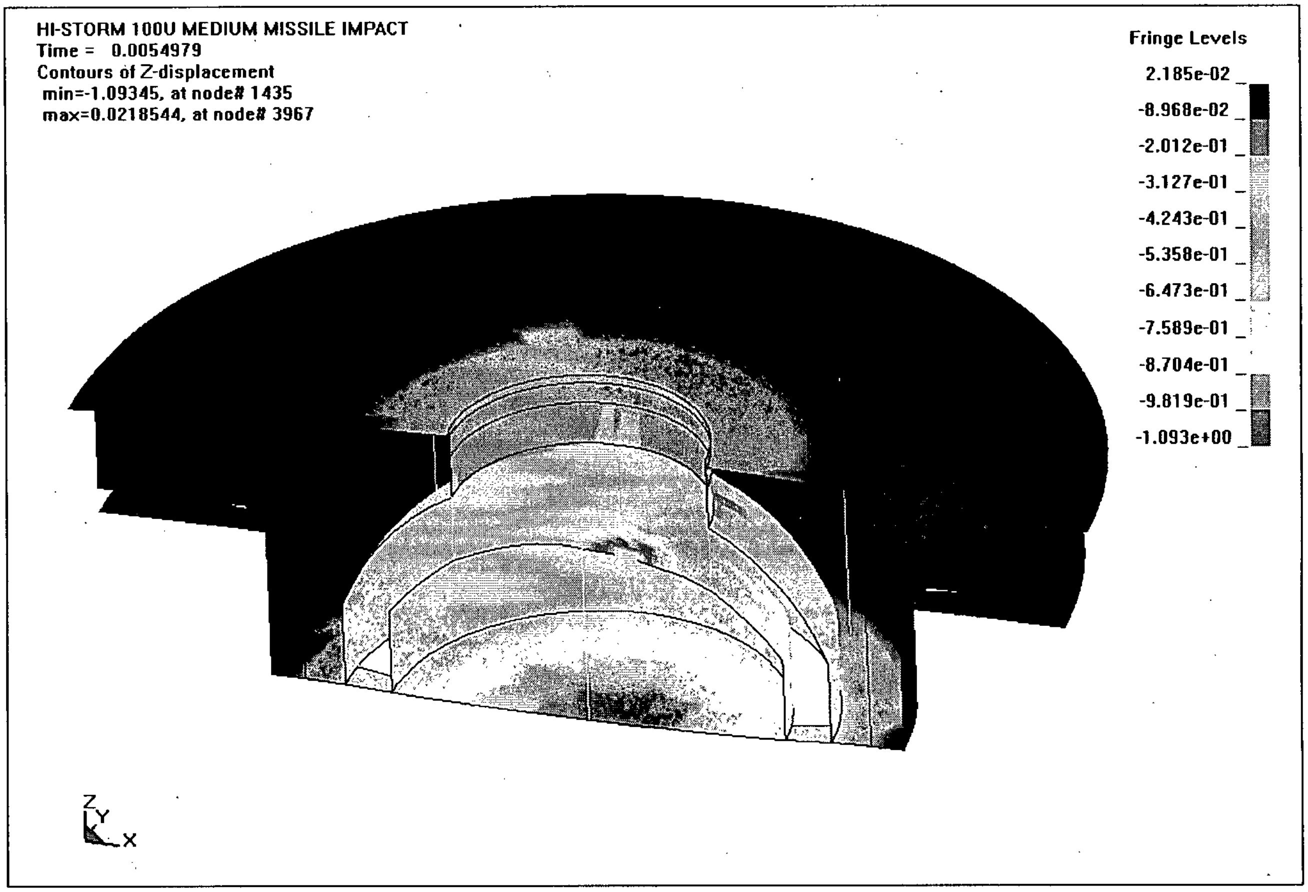

Figure 3.I.11; Deformation Profile at Time of Maximum Deformation – Inclined Strike

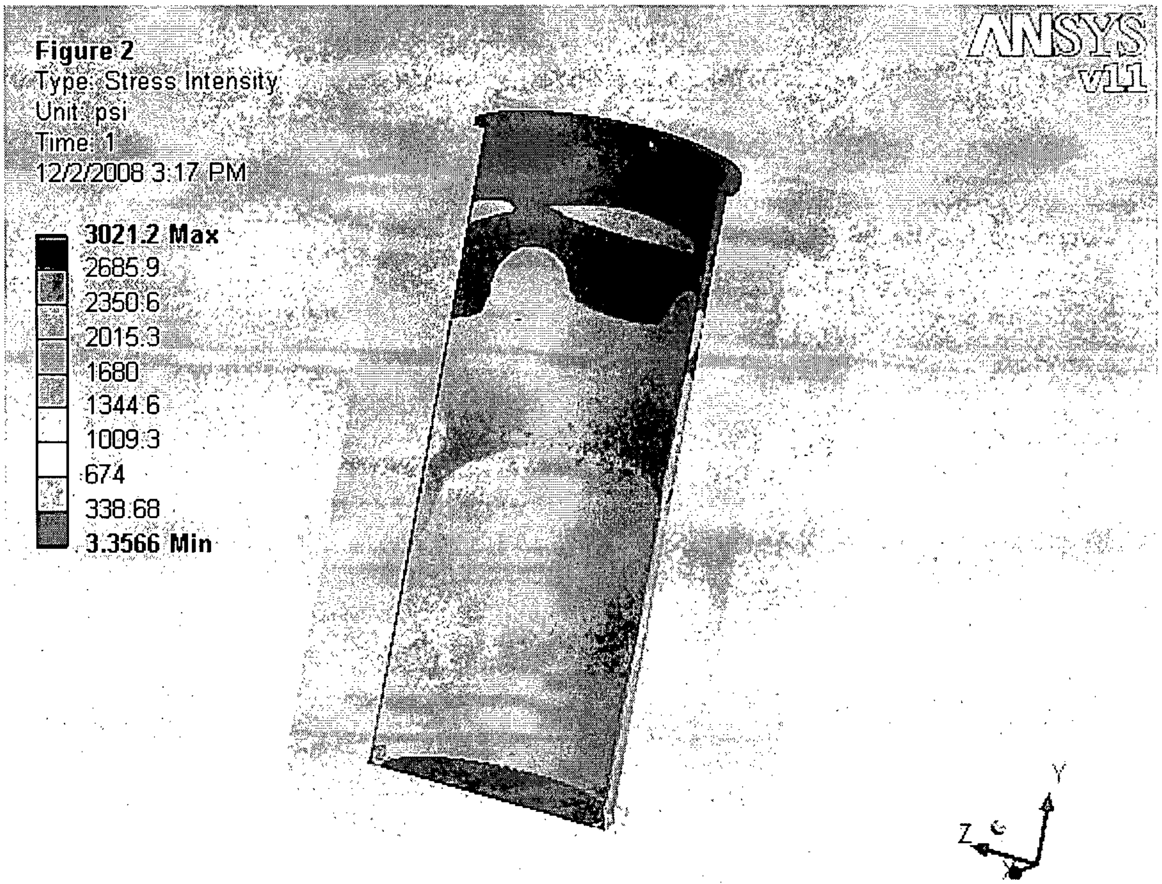

Figure 3.I.12; Stress Distribution in CEC Shell from Transporter and Substrate (Load Case 07)

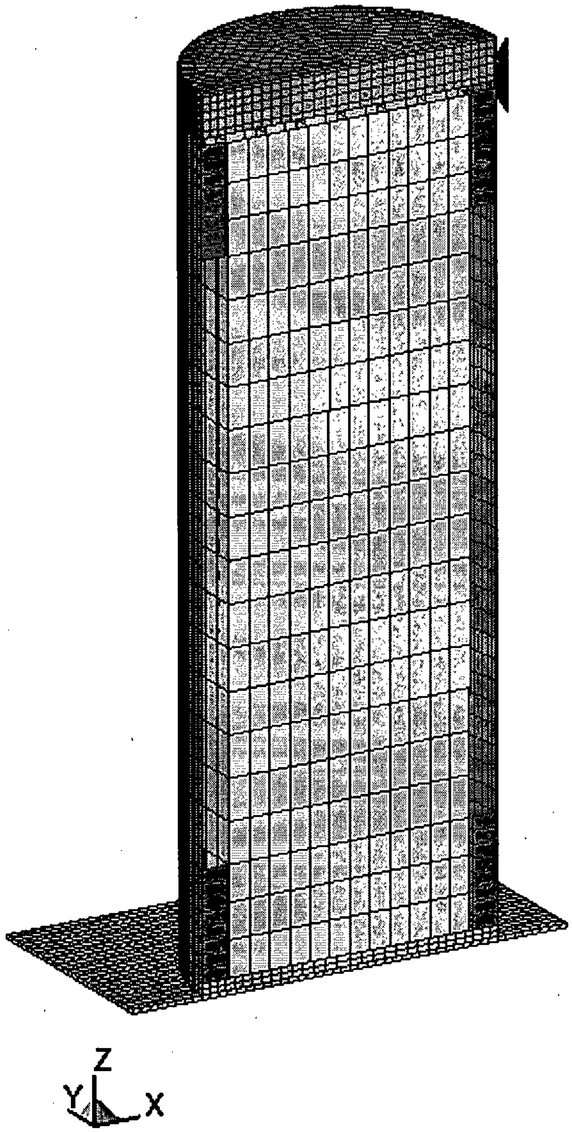

Figure 3.I.13; MPC Guide/MPC Impact LS-DYNA Model

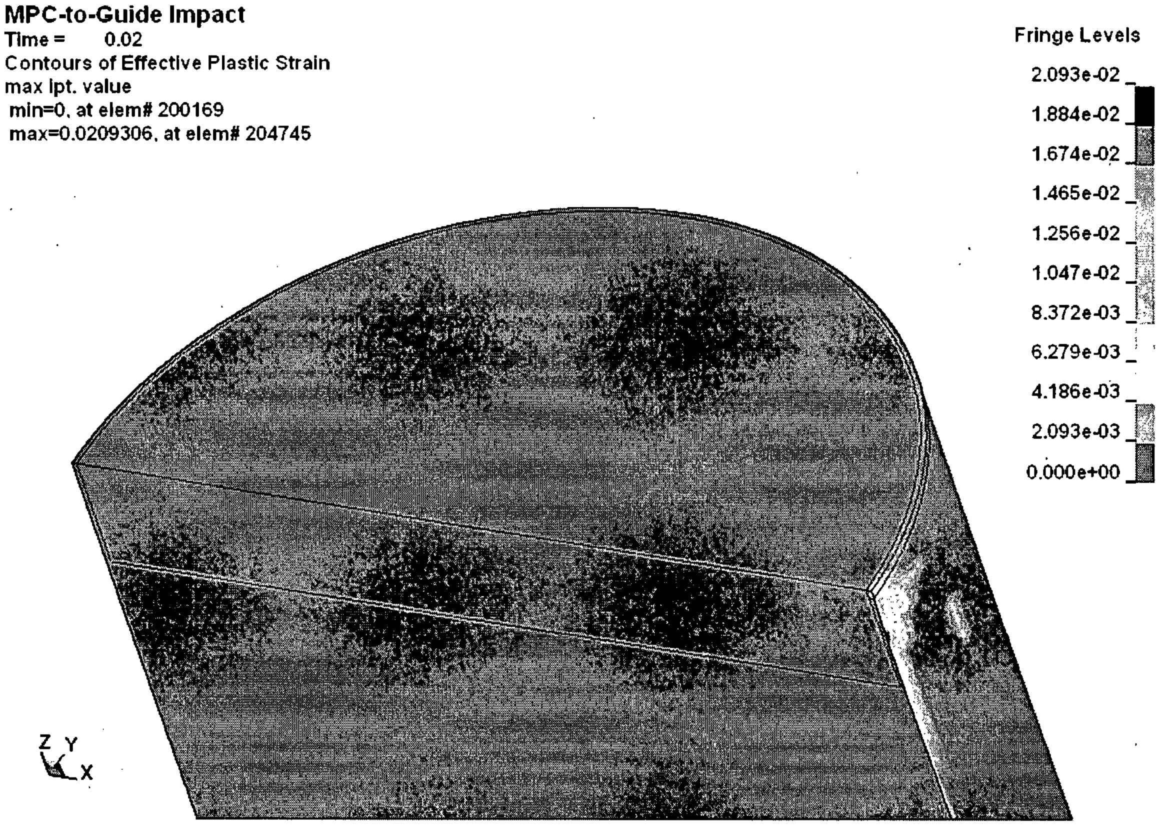

Figure 3.I.14; Maximum Plastic Strain of the MPC Enclosure Members in the Impact Region

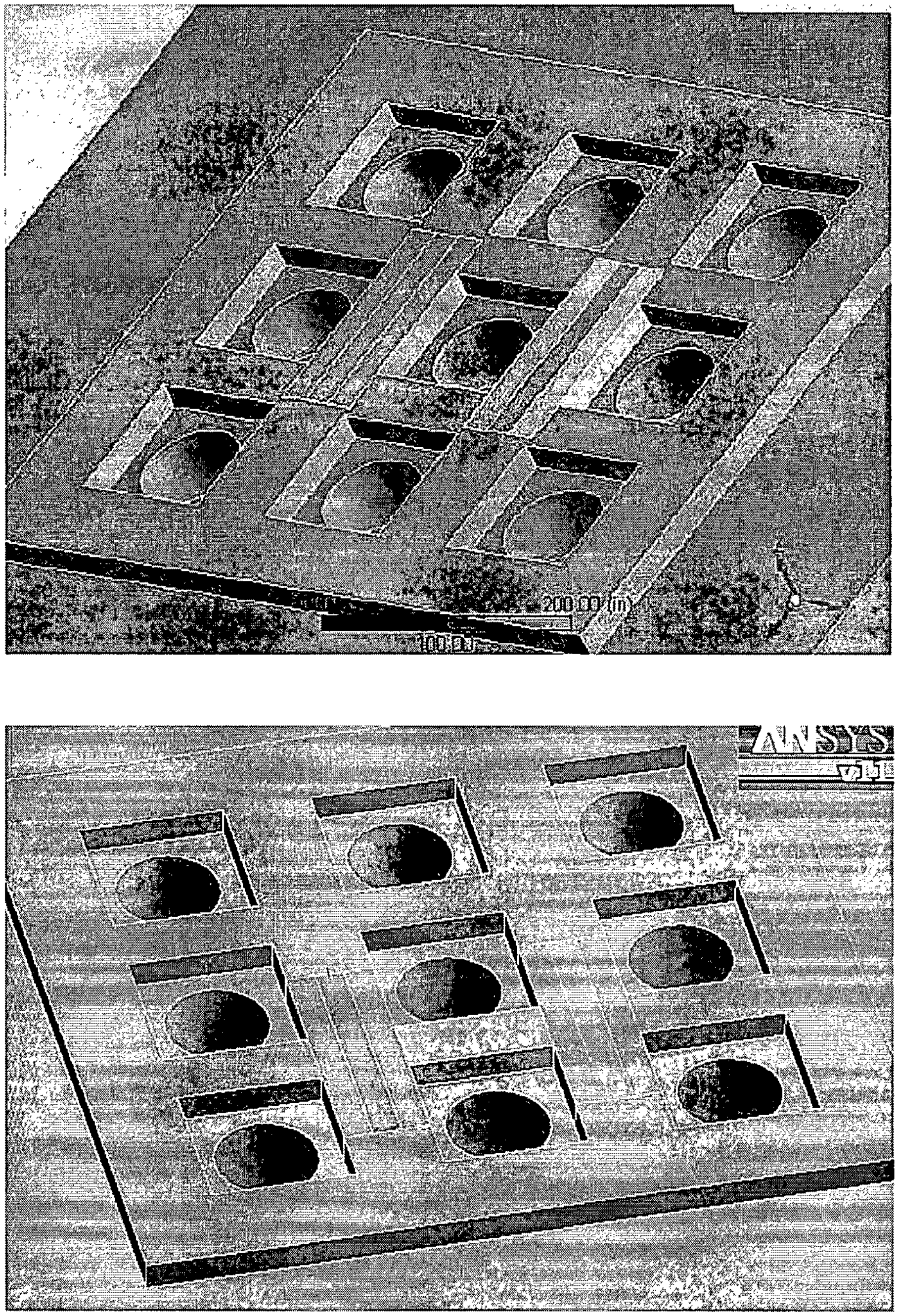

Figure 3.I.15; ANSYS Model of 3 x 3 Top Surface Pad – Two Configurations

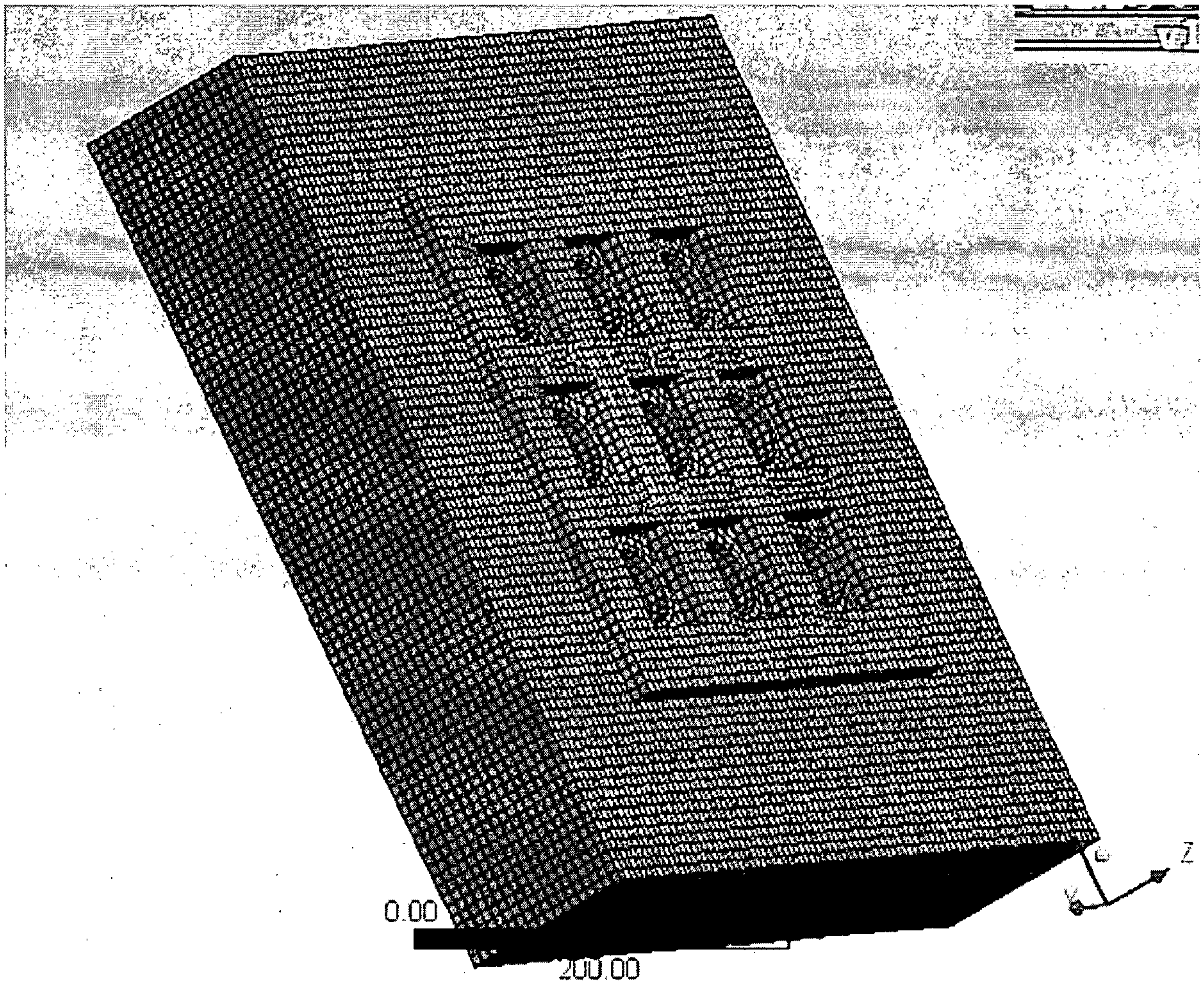

Figure 3.I.16; ANSYS Finite Element Mesh of 3 x 3 Top Surface Pad

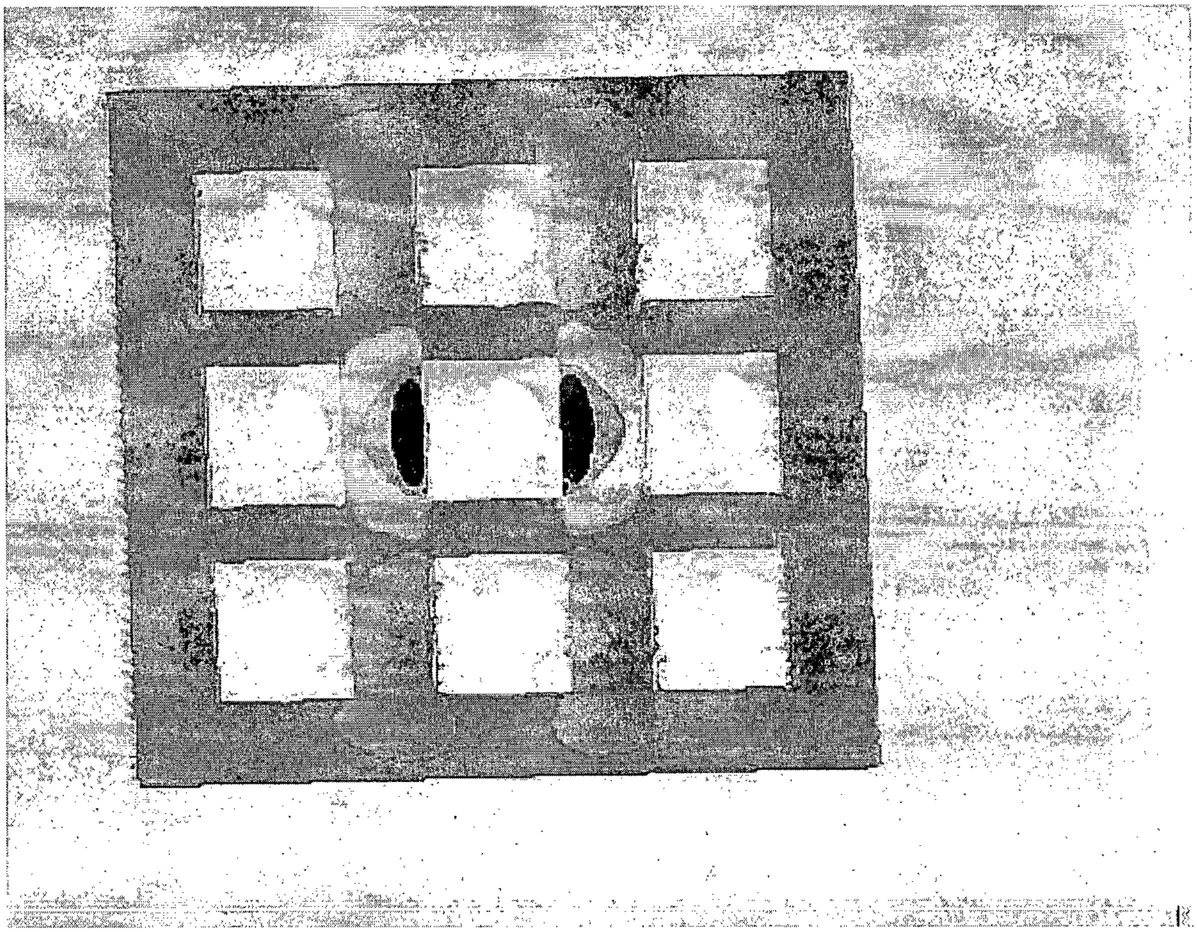

Figure 3.I.17; Top View of TSP showing Normal Stress in the Direction of the Transporter Path – Live Load only.

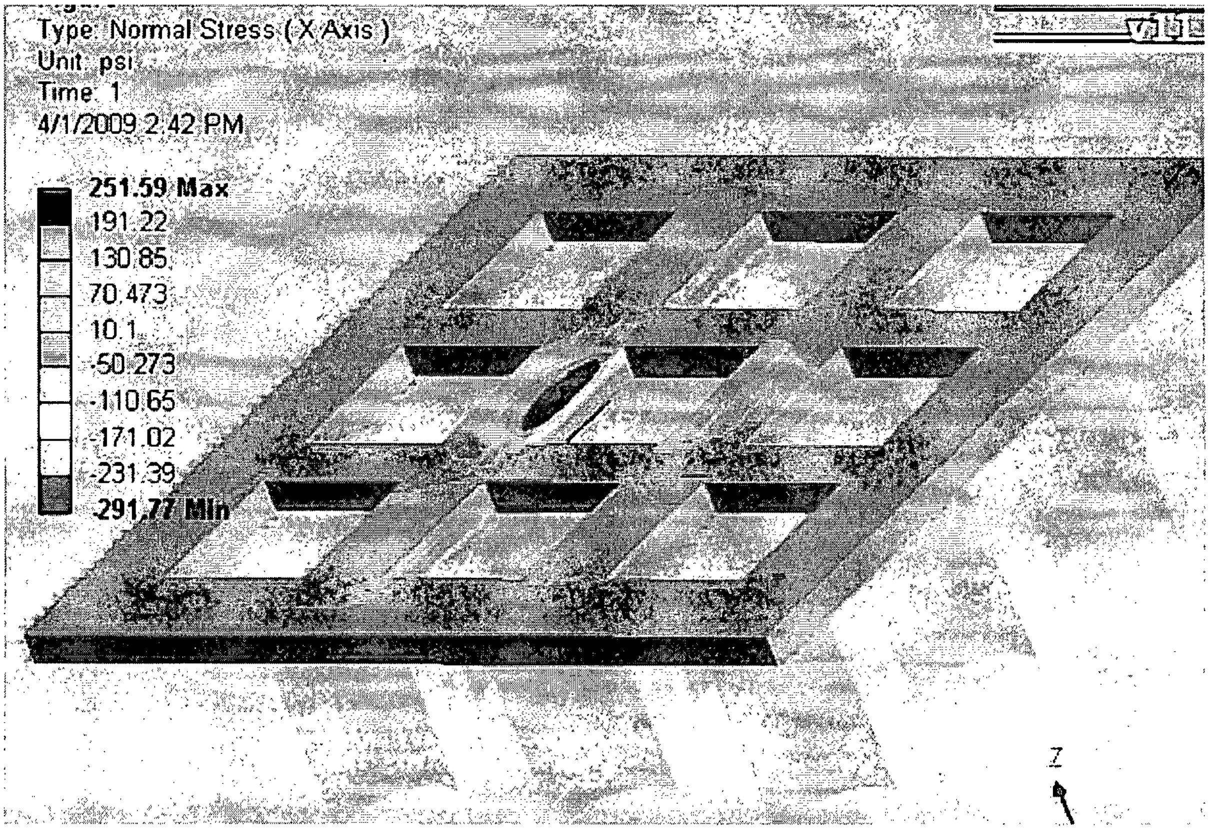

Figure 3.I.18; Top View of TSP showing Normal Stress in the Direction of the Transporter Path – Live Load + Seismic Load.

AFFIDAVIT PURSUANT TO 10 CFR 2.390

I, Tammy S. Morin, being duly sworn, depose and state as follows:

(1) I have reviewed the information described in paragraph (2) which is sought to be withheld, and am authorized to apply for its withholding.

(2) The information sought to be withheld is Holtec Report provided in Attachment 2 to Holtec letter Document ID 5014681, which contains Holtec Proprietary information.

(3) In making this application for withholding of proprietary information of which it is the owner, Holtec International relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4) and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10CFR Part 9.17(a)(4), 2.390(a)(4), and 2.390(b)(1) for "trade secrets and commercial or financial information obtained from a person and privileged or confidential" (Exemption 4). The material for which exemption from disclosure is here sought is all "confidential commercial information", and some portions also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

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(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by Holtec's competitors without license from Holtec International constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

c. Information which reveals cost or price information, production, capacities, budget levels, or commercial strategies of Holtec International, its customers, or its suppliers;

d. Information which reveals aspects of past, present, or future Holtec International customer-funded development plans and programs of potential commercial value to Holtec International;

e. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs 4.a and 4.b, above.

(5) The information sought to be withheld is being submitted to the NRC in confidence. The information (including that compiled from many sources) is of a sort customarily held in confidence by Holtec International, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by Holtec International. No public disclosure has been made, and it is not available in public sources. All

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disclosures to third parties, including any required transmittals to the NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within Holtec International is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his designee), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside Holtec International are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information classified as proprietary was developed and compiled by Holtec International at a significant cost to Holtec International. This information is classified as proprietary because it contains detailed descriptions of analytical approaches and methodologies not available elsewhere. This information would provide other parties, including competitors, with information from Holtec International's technical database and the results of evaluations performed by Holtec International. A substantial effort has been expended by Holtec International to develop this information. Release of this information would improve a competitor's position because it would enable Holtec's competitor to copy our technology and offer it for sale in competition with our company, causing us financial injury.

AFFIDAVIT PURSUANT TO 10 CFR 2.390

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to Holtec International's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of Holtec International's comprehensive spent fuel storage technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology, and includes development of the expertise to determine and apply the appropriate evaluation process.

The research, development, engineering, and analytical costs comprise a substantial investment of time and money by Holtec International.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

Holtec International's competitive advantage will be lost if its competitors are able to use the results of the Holtec International experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to Holtec International would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive Holtec International of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

AFFIDAVIT PURSUANT TO 10 CFR 2.390

STATE OF NEW JERSEY)
) ss:
COUNTY OF BURLINGTON)

Ms. Tammy S. Morin, being duly sworn, deposes and says:

That she has read the foregoing affidavit and the matters stated therein are true and correct to the best of her knowledge, information, and belief.

Executed at Marlton, New Jersey, this 22nd day of April, 2009.

Tammy S. Morin
Holtec International

Subscribed and sworn before me this 22nd day of April, 2009.

Maria C. Massi

MARIA C. MASSI
NOTARY PUBLIC OF NEW JERSEY
My Commission Expires April 25, 2010