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Mr. L. Raynard Wharton
c/o Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

January 16, 2009

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

Reference:
[1] NRC Letter (Wharton) to Holtec (Morin) dated December 4, 2008 (ML083400068)
[2] Holtec Letter 5014618, dated April 27, 2007, "License Amendment Request #6 to HI-STORM 100 CoC"
[3] Holtec Letter 5014664, dated August 21, 2008, "USNRC Docket No. 72-1014, HI-STORM 100 Certificate of Compliance 1014, HI-STORM 100 Final Safety Analysis Report Revision 7

Dear Mr. Wharton:

Holtec International is pleased to submit herewith the responses to U. S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) [1] for the review of the HI-STORM 100 System License Amendment Request (LAR) 1014-6 [2], in which Holtec requested approval of the underground storage system under the provisions of 10CFR 72, Subpart L, ahead of the requested submittal date of January 30, 2009.

This submittal includes the following: RAI questions with the Holtec responses (Attachment 1), updated proposed Certificate of Compliance (CoC) and Appendices (Attachment 2), and updated proposed Final Safety Analysis Report (FSAR), with list of effective pages or sections affected by this RAI, marked as Revision 7B (Attachment 3). Revision bars show changes from Revision 7 of the FSAR [3].

Any Holtec proprietary reports and licensing drawings supporting this response will be sent under separate cover.

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Holtec took the opportunity in this response to identify some additional proposed editorial changes to the updated CoC as described and justified in the response to RAI question G-2.

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.

Sincerely,

Tammy Morin
Acting Licensing Manager
Holtec International

cc (letter only): Mr. Eric Benner, USNRC
Mr. Nader Mamish, USNRC
Holtec Group 1

General Comments

G-1 Make the following changes to the TSs and the associated FSAR sections to correct inconsistencies:

a. TS Appendix B, Table 2.1-1, III.A.1.e.i (currently the first e) should be changed to III.A.1.d.i and the burnup units should read as "(MWd/MTIHM)."
b. TS Appendix B, Table 2.1-1, III.A.1.e.i (currently the second e), "6X6b" should be "6x6B."
c. The accuracy of notes indicating overpacks without shield shells have higher density concrete should be verified (e.g., see FSAR pages 1.2-20 and 9.1-9).
d. On page 2.1-9 of the FSAR, the definition of q for equation j, at the end, should read "or 2.1.9.1.2 (kW)."
e. Table 2.1.24, in "Other Limitations," does not list the correct allowable locations of neutron source assemblies (NSAs); the other tables for PWR MPCs should also be verified to list the correct allowable locations of NSAs – the TS descriptions are correct.
f. Table 5.1.9 is missing the footnotes.
g. The accuracy of the footnotes for class 14x14E assemblies on FSAR pages 6.1-10 and 6.1-18 should be verified.
h. Clarify the last sentence of the third paragraph of FSAR Section 6.2.4.1 that damaged BWR fuel assemblies or fuel debris may also be stored in the MPC-68 or MPC-68F
i. TS Appendix B 3.4.9 should have attached at the end the words "and must be evaluated to determine the applicable Quality Assurance Category."
j. TS Appendix B, Section 2.4 should include the decay heat limits for damaged fuel and fuel debris for each of the MPCs, as is indicated to be so per the respective entries in Table 2.1-1 of Appendix B for each MPC; Table 2.4-1 includes limits for only intact fuel assemblies.
k. TS Appendix B Table 2.1-1, IV.A.1.g and V.A.1.g should be modified to remove the two instances of "and DFC" in each statement unless intact fuel is to be/can be loaded into the MPC in damaged fuel canisters.

These items were found in a review of material submitted in response to question G-1 of the previous RAI. The FSAR should be internally consistent and consistent with the CoC and TSs to ensure proper understanding of the design and the supporting analyses. With regard to item j, the staff notes that the decay heat limits for damaged fuel and fuel debris previously differed from the limits for intact fuel. If the limits are to be the same, the basis for this change should be provided.

This information is needed to confirm compliance with 10 CFR 72.236(a), (c), and (d).

Holtec Response to G-1:

a. Revisions have been made to the proposed TS as requested.
b. Revisions have been made to the proposed TS as requested.
c. The notes on FSAR pages 1.2-20 and 9.1-9 have been modified to read "The shield shell design feature was deleted in June, 2001 after overpack serial number 7 was fabricated."

d. The published Revision 7 of the FSAR, dated August 9, 2008, correctly states "or 2.1.9.1.2 (kW)." on page 2.1-9.

e. Table 2.1.24, as well as Tables 2.1.17, 2.1.19, 2.1.20 and 2.1.22, have been reviewed and edited to correct inconsistencies between Amendment #5 and the current Revision 7 of the FSAR.

f. The published Revision 7 of the FSAR, dated August 9, 2008, correctly includes the footnotes to Table 5.1.9.

g. The published Revision 7 of the FSAR, dated August 9, 2008, contains the correct footnotes for class 14x14E assemblies on FSAR pages 6.1-10 and 6.1-18

h. The published Revision 7 of the FSAR, dated August 9, 2008, contains the correct text in subsection 6.2.4.1.

i. Revisions have been made to the proposed TS as requested. Note that due to additional proposed changes to this section of the TS as a result of the RAI, item 3.4.9 is now item 3.4.14.

j. Currently in Amendment 5 Appendix B Section 2.4 there are no specific decay heat limits for damaged fuel in each fuel storage location when using a uniform loading scheme. Holtec proposes to reinstate the decay heat limits for damaged fuel and fuel debris in the aboveground system from the previously approved CoC Amendment 3 for uniform loading. Damaged fuel and fuel debris will not be permitted in the underground system and clarification is provided in Appendix B Section 2.4.2 so that only intact fuel can be loaded using a regionalized loading scheme, therefore Holtec considers this change editorial. The proposed changes are provided in the accompanying TS Appendix B Section 2.4. Proposed FSAR Table 2.1.26 has also been modified.

k. Revisions have been made to the proposed TS as requested.

G-2 Verify that all CoC, TS and FSAR changes proposed in the current amendment request are properly marked and justified.

The staff noticed that a few items that are new to the CoC and TSs with this proposed amendment. Examples of these items include the addition of the text "for aboveground systems only" to Condition 10.j of the CoC, the addition of the definition of "Support Foundation" to the TS, Appendix A definitions, and the change of the page number of TS Appendix B, Section 3.4 (changed from 3-13 to 3-15). The nature of the changes should be described and justified.

This information is needed to confirm compliance with 10 CFR 72.244.

Holtec Response to G-2: The addition of the text "for aboveground systems only" to Condition 10.j of the CoC, the addition of the definition of "Support Foundation", and the page number in Appendix B Table of Contents, are now marked as proposed new text in this LAR.

Condition 10.j was clarified in this LAR since it does not apply to the underground system where the MPC will be loaded into the VVM directly at the ISFSI.

The definition of Support Foundation is added as part of this amendment to describe a part of the 100U system.

The Table of Contents for Appendix B was updated to reflect the additional pages in the TS.

In addition to the changes above, Holtec proposes to change the wording in CoC Condition 1.b "Description", to read "*All MPC components that may come into contact with spent fuel pool water or the ambient environment are made entirely of stainless steel or passivated aluminum/aluminum alloys such as the neutron absorbers.*" The current wording in Amendment 5 is "*All MPC components that may come into contact with spent fuel pool water or the ambient environment are made entirely of stainless steel except for the neutron absorbers, aluminum seals on vent and drain port caps, and aluminum heat conduction elements (AHCEs), which are installed in some early-vintage MPCs.*" The Amendment 5 text is unduly restrictive because it prohibits use of qualified materials in certain circumstances. For example, it allows the use of aluminum seals but not an aluminum alloy seal (which may be more effective as a seal material). The replacement language eliminates this weakness.

In our review, Holtec identified the following for Staff to consider:

Appendix B, Table 2.1-1 (page 12 of 24) h.i – the weight limit for intact 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A fuel should be 400 lbs, including channels. The weight limit of 550 lbs is for damaged fuel, including channels and the DFC. This appears to have been an editorial error in Amendment 5 due to the consolidation in the table of the MPC Model Types 68 and 68FF.

Appendix A, Section 5.5: The last sentence of the first paragraph should read …or is being handled by a device designed in accordance with the increased safety factors of ANSI N14.6 *and* having redundant drop protection".

Appendix B, footnote to Table 3-2; clarification was added for the underground system's code compliance, similar to the aboveground in Appendix B Section 3.3.

G-3 Verify the consistency of the CoC, TS and FSAR changes proposed in the current amendment request.

The staff noticed that some of the information submitted in response to question G-1 of the previous RAI does not appear to be internally consistent. In particular, there were some items that had been a part of Amendment 4, the focus of which was a version of the HI-STORM 100 system specific to Indian Point Unit 1 (IP 1), that were removed from the CoC, TSs, and FSAR, while others were retained. For example, the Amendment 4 version of the TS definition of Transport Operations was retained; however, this definition differs from how it appears in Amendment 5, which is the basis amendment for the current application. Also, notes regarding IP 1 are included in the technical drawings for the 100 S Version B overpack; however, notes for IP 1 are removed from the drawings for the MPC enclosure vessel and the MPC-32 fuel basket assembly. The basis for the removal or retention of various items associated with Amendment 4 should be explained and properly justified.

This information is needed to confirm compliance with 10 CFR 72.244.

Holtec Response to G-3: The Staff is correct in its determination that some of the already approved changes from Amendment 4 were proposed as part of this LAR. Holtec considers these changes to be generic rather than specific to only Indian Point 1. Holtec understands these changes were not properly identified or justified in this LAR and so provides the following justifications for the changes

Conditions 10.a and 10.e of the CoC, the text "or cask loading pool" is added since plants may have a configuration where a cask loading pool, separate from the spent fuel pool, is used for loading the MPC. Holtec proposes to keep this clarifying language which will allow users to load fuel in either the spent fuel pool or a cask loading pool.

The definition of Transport Operations in Appendix A and B is modified to replace the words "to and from the ISFSI" with "after LOADING OPERATIONS or before UNLOADING OPERATIONS". This proposed change to the Transport Operations definition broadens the definition and does not limit it only to the transfer of the loaded system to and from the ISFSI. Transport Operations should encompass all movements of the loaded Transfer Cask and Overpack. For consistency, Appendix A, Subsection 5.5.a.3 and 5.5.b.2 are modified by replacing "transportation between the FUEL BUILDING and the CTF and/or ISFSI pad" with "TRANSPORT OPERATIONS".

Subsection 5.5.a.1 is modified by adding the words "if applying the limits in Table 5-1" to clarify that the drop height limits in Table 5-1 are applicable only if the transport route meets the requirements of either Set A or Set B in HI-STORM FSAR Table 2.2.9.

Subsection 5.5.a.2 is modified by removing the first part of the first sentence "For site specific ... Table 2.2.9," to clarify that a user may choose to perform a site specific analysis to determine a drop height even if the transport route meets the conditions of Set A or Set B in the HI-STORM FSAR Table 2.2.9.

Chapter 2.I Principal Design Criteria

2-1 Provide detailed discussion describing how any alternative materials procured in accordance with ISO materials standards would comply with all the material property and quality (QA/QC) requirements of the ASME Code (the code of construction for the 100-U).

FSAR supplemental page 2.I-2 references the use of ISO standards for substitute materials for important to safety (ITS) components. Although the use of foreign standards is not precluded, the use of ISO materials standards (or any foreign standard) requires additional discussion/information demonstrating that the proposed material standard(s) comply with all of the material property and QA/QC requirements of the governing construction code (the ASME Code in the case of the 100-U design). Absent a specific foreign material specification or grade, the staff is unable to make a regulatory finding regarding the acceptability of a foreign material for an ITS component.

For containment or confinement boundary components, ASME Code materials are always preferred. Specific alternatives may be reviewed for acceptance. For other ITS components, ASME or ASTM materials are preferred. Specific alternatives may be reviewed for acceptance. ITS materials must meet all the property and quality (QA/QC) requirements of the governing construction code.

This change is necessary for compliance with 10 CFR 72.122(a).

Holtec Response to 2-1 A detailed discussion of the procedure used by Holtec to evaluate an ISO material as a substitute for an ASME material is added to the text matter cited in the RAI (section 2.I.0 and Table 2.I.10). The discussion clarifies that Confinement Boundary materials *shall always be made from an ASME Code material.* In *important-to-safety* parts in a component, the ASME Code materials shall be used, unless extenuating circumstances force the need to use a substitute material from another internationally recognized standard.

The overarching requirement of QA/QC compliance of all *ITS* materials, regardless of their origin, to Holtec's quality procedures is emphasized.

2-2 Clarify FSAR page 2.3-14 to specify that U.S. national standard (e.g. ASME, ASTM) material specifications will be used for ITS components.

Use of foreign materials specifications is generally not acceptable unless a detailed discussion shows how a specific material complies with the governing construction code.

This change is necessary for compliance with 10 CFR 72.122(a).

Holtec Response to 2-2 The text matter on page 2.3-14 of the FSAR (not a part of the present LAR) has been clarified and cross referenced to 2.I.0 to emphasize the preference for material specifications from U.S. National Standards (e.g., ASTM, ASME).

Chapter 3.I Structural Evaluation

3-1 Revise the stress analysis of the MPC confinement boundary in Calculation-07 of Calculation Package HI-2053389 to incorporate an evaluation of the maximum stresses occurring in the Multi-Purpose Canister (MPC) shell during the seismic event.

Calculation-07 evaluates the Cavity Enclosure Container (CEC) outer shell and the MPC shell. For the CEC evaluation it is stated that "The maximum stress (19.87 ksi) is smaller than the yield strength of the material (37.15 ksi), indicating that the structural integrity of the CEC shell is not compromised...." For the MPC shell neither the maximum stress nor the maximum stress intensity is evaluated. Instead, an estimate of an average maximum primary stress intensity (2 x 5.32 ksi = 10.64 ksi) resulting from the MPC shell acting in a beam-like fashion is derived from the colors on a stress contour plot (Calculation-07, Figure 7) and compared to the Level D allowable primary stress intensity (36.8 ksi, FSAR Table 3.I.7). This calculation needs to be carried a step further to include an evaluation of the maximum stress intensity acting on the confinement boundary. The maximum stress intensity should be compared to the appropriate allowable stress or an acceptance criterion that would demonstrate that the structural integrity of the confinement boundary is maintained.

This information is necessary to ensure compliance with 10 CFR 72.236(b).

Holtec Response to 3-1: The local response of the MPC Confinement Boundary (Enclosure Vessel) to the MPC/MPC guide impact under the seismic event has been re-analyzed using a highly discretized grid with fully integrated finite elements and elasto-plastic material properties. The upper region of the confinement boundary subject to impact from the MPC guide plates has been meshed with even smaller elements. The emphasis in the newly performed confinement boundary integrity analysis is to determine if the localized strains in the region of impact would threaten the integrity of the confinement boundary. The input impulse due to the impact between the MPC and the guide is simulated in a manner to maximize its value, as fully described in the new material added to paragraph 3.I.4.7.3 in the FSAR.

Comparing the maximum value of the "true" local strain to a recent published guideline in the literature (the ASME has no limits germane to this problem) shows a large margin of safety. The methodology is documented in the FASR and made a mandatory requirement for site-specific evaluations for an underground ISFSI. The updated Calculation Package (ref 3.I.27 in the FSAR) contains all archival details of this calculation.

Supplement 2.I, on Design Criteria, has also been modified to require the satisfaction of a local strain limit in the confinement boundary under the seismic loading case.

3-2 For the LS-DYNA seismic model, provide a convergence study to demonstrate that the maximum stresses in the MPC shell elements in the vicinity of the impact with the MPC Guide Ribs are reasonably accurate.

The MPC shell elements use single point integration in the plane of the element with three integration points through the thickness. This is the lowest order of integration, and as such, the element can only develop a constant moment along its length. In addition the shell mesh in the vicinity of the Guide Ribs is very coarse. The coarseness of the mesh combined with single point integration may lead to a significant underestimate of maximum stresses. Accuracy of the results from a finite element model is essential to demonstrating the structural integrity of the confinement boundary during an accident event.

This information is necessary to ensure compliance with 10 CFR 72.11.

Holtec Response to 3-2: As mentioned in response to RAI 3-1, a refined mesh for the MPC Confinement Boundary with fully integrated elements has been prepared and the local impact problem has been analyzed to determine local strains. The number of thru-thickness integration points has been set at the maximum available (10). A mesh convergence study has been performed using a finer grid size to verify that the results are acceptable. The new analysis, described in paragraph 3.I.4.7.3 would allay Staff's concern with respect to convergence and safety margins in the confinement boundary during the seismic event.

3-3 Revise the TSs and FSAR to require a site specific seismic analysis for any construction activity involving excavation near an installed independent spent fuel storage installation (ISFSI) to verify that the stability of the Support Foundation, the ISFSI Pad and the soil within the

Radiation Protection Space is bounded by the accident analysis in Chapter 11 (see question 11-1).

The HI-STORM 100 has structurally integral and secure shielding that remains integral with the system during all operational movements and under all accident conditions including any ISFSI site construction activities. Unlike the HI-STORM 100, the HI-STORM 100U has nonintegral shielding (soil) which is susceptible to being stripped from the system as a result of human error or a seismic event occurring during construction activities involving excavation near the installed ISFSI.

At an ISFSI site adjacent to an existing Vertical Ventilated Module (VVM) array, the FSAR calls for excavating the soil beneath the new Support Foundation down to bedrock and replacing the removed soil with engineered fill (FSAR page 3.I-21). For the VVM example array discussed in the FSAR, this would require a 30 foot deep excavation below the bottom of the Support Foundation, resulting in a total excavation depth of 50 feet, at a horizontal distance from the edge of the array that could be as little as the Radiation Protection Space distance. This constitutes a potentially large open pit excavation adjacent to an existing ISFSI site, where the consequences of soil instability and the resulting loss of shielding are significantly greater than they would be for an above ground ISFSI.

This information is necessary to ensure compliance with 10 CFR 72.236(b) and (g).

Holtec Response to 3-3: A scenario entitled "Construction Accident Proximate to an ISFSI" has been added in Subsection 2.I.6 (xii) that requires a retaining wall to be built at the edge of the Radiation Protection Space (also discussed in subsection 3.I.4.8.2) to prevent the loss of the earthen shielding material from the RPS under an extreme environmental phenomenon such as a tornado missile or an earthquake. A site-specific analysis to insure the physical integrity of the RPS substrate under the earthquake event is also prescribed in the FSAR and the Technical specification. The requirements on the strength and construction of the retaining wall are also spelled out in the Technical Specification.

3-4 Revise the design of the CEC outer shell or the calculations performed to determine the stresses in the CEC shell due to subsurface lateral pressure caused by transporter loading and substrate overburden to ensure that the shell stresses are less than the Service Level A allowable values. (See evaluation beginning on FSAR page 3.I-12.) Transporter loading and soil overburden pressure are normal loading conditions (FSAR Section 2.I.3). For Class 3 plate and shell structures the primary membrane plus bending allowable stress for Service Level A (normal conditions) is 26.3 ksi (FSAR Table 3.I.3 (b)). The allowable stress used in the evaluation of the CEC shell is 37.15 ksi, which is the yield stress.

The staff recognizes that Table 2.I.5 specifies the CEC shell material yield strength as the acceptance criteria for CEC loading by soil lateral pressure. However, due to the large uncertainty involving the calculation of lateral soil pressure and its effects on buried structures, and the fact that the CEC cannot be reliably inspected, the staff regards using the Service Level A stress limits to be more appropriate than the yield stress.

This information is necessary to ensure compliance with 10 CFR 72.236(b).

Holtec Response to 3-4: The acceptance criterion in Table 2.I.5 has been revised to require the maximum non-local stress limit (membrane plus bending) to meet Level A service condition limit for Class 3 "NF" plate and shell-type structures (in lieu of yield).

The evaluation of the stress field in the CEC shell due to soil overburden and the weight of the loaded transporter (load case 07 in Table 2.I.5) has been re-performed using a conservative 3-D ANSYS model as described in the subsection 3.I.4.4. The results show a large margin of safety in the CEC shell against the Level A limit. All primary (non-local) stresses (membrane plus bending) are shown to remain within elastic limits.

3-5 In Table 2.I.3, Item 12, Stress Analysis, Explanation and Applicability, the last sentence states "These conditions maybe, but are not required to be, invoked." Provide all instances where these conditions have not been invoked, and justify why the appropriate ASME Code paragraphs were not used.

VVM primary load bearing parts must be evaluated to appropriate standards and criteria.

This information is necessary to ensure compliance with 10 CFR 72.236(b).

Holtec Response to 3-5: The cited sentence in the FSAR implying possible transgression of "NF" paragraphs has been deleted. We confirm that NF stress limits are not exceeded in any loading case. Additionally, similar sentences were removed from TS Appendix B, Table 3-2.

3-6 Provide justification for allowing each VVM to potentially rest on its own Support Foundation "Padlet" (FSAR Section 1.I.4) rather than on a continuous reinforced concrete mat supporting all VVMs in an array.

The FSAR states that "The Support Foundation... must be designed... to minimize long-term settlement..." (FSAR page1.I-5). The use of individual padlets, to support a single VVM, works against this design requirement. Because VVMs may be either loaded or unloaded for long periods of time, the use of individual VVM padlets may lead to unacceptable differential settlement between adjacent VVMs. Such differential settlement can be completely avoided by using a continuous reinforced concrete Support Foundation. In addition, a continuous Support Foundation can span over potentially softer soil and provides added assurance against instability during construction activities associated with future ISFSI array construction.

This information is necessary to ensure compliance with 10 CFR 72.230(a) and 72.236(b).

Holtec Response to 3-6: The option for a "padlet" design has been deleted in the FSAR (see Section 1.I.4). A continuous Support Foundation is specified. Additionally, the requirement to compute the expected differential settlement in the Foundation Pad (mat) over the Design Life of the ISFSI has been added in the FSAR (See Section 2.I.4) and the Technical Specification. The loading due to the differential settlement is required to be considered in the factored load combination for the Foundation Pad.

3-7 Provide reinforced concrete design criteria in Table 2.1.1

Design criteria for unreinforced concrete has been specified in Table 2.1.1, however no design criteria has been specified for reinforced concrete. This information is necessary to ensure compliance with 10 CFR 72.236(b).

Holtec Response to 3-7: Table 2.1.1 has been amended to require that the reinforced concrete members, namely the VVM Interface Pad, the Top Support Pad and the Support Foundation Pad, be designed and qualified to meet the strength requirements of ACI 318(2005)

3-8 Provide a complete listing in the FSAR of all HI-STORM 100U components that are important to safety (ITS).

Table 2.1.8 provides only a partial list of ITS components. HI-STORM 100U components missing from this table include: the Support Foundation, the ISFSI Pad (consisting of the VVM Interface Pad and Top Surface Pad) and the lateral subgrade.

This information is necessary to ensure compliance with 10 CFR 72.24(c)(3).

Holtec Response to 3-8: The ITS designations for the VIP, the TSP, the foundation pad, and the lateral subgrade have been added to Table 2.1.8.

3-9 Provide the minimum steel reinforcement requirements for the Support Foundation based on the seismic analyses that have been performed and the structural criteria to minimize long-term settlement. Also, provide the minimum steel reinforcement requirements for the WM Interface Pad and Top Surface Pad necessary to safely carry the loaded transporter.

10 CFR 72.24 states that "The minimum information to be included in the SAR must consist of the following:

(c) The design of the ISFSI in sufficient detail to support the findings in 72.40, including: ...
  (2) the design bases and the relation of the design bases to the design criteria;
(d) an analysis and evaluation of the design ..."

10 CFR 72.3 defines design bases as "that information that identifies the specific functions to be performed by a structure, system, or component of a facility or of a spent fuel storage cask and the specific values or range of values chosen for controlling parameters as reference bounds for design."

In this regard a reinforced concrete pad or foundation slab constitutes a design when the thickness, concrete strength and reinforcement have been specified.

Regarding the Support Foundation, two additional points need to be made.

(1) In Holtec's June 12, 2008 response to RAI-3.12 it is stated that "The Support Foundation is characterized as an "interfacing SSC' in Supplement 3.1, an historically detailed design of an interfacing SSC is not the purview of the FSAR." The staff takes exception to this statement. The Support Foundation is a HISTORM 100U component that is important to safety. In 10 CFR 72.236(b) it is stated that "Design bases and design criteria must be provided for structures, systems and components important to safety."

(2)Holtec's response also states that "The Support Foundation structural analysis performed by the general licensee follows the same methodology applied to above ground ISFSI pads by Holtec International but is not a part of the FSAR..." The staff takes exception to this statement as well. The staff agrees that the design of ISFSI Pads for stand alone storage casks, such as the HI-STORM 100, is not a part of the FSAR. However, in the HI-STORM 100U FSAR the "ISFSI Pad, "the Support Foundation, is an essential component of the HI-STORM 100U design that is important to safety and is a part of the FSAR.

This information is necessary to ensure compliance with 10 CFR 72.236(b).

Holtec Response to 3-9: All three pads (i.e., the Foundation Support Pad, the VVM pad, and the Top Support Pad) have been designated as Important-to-Safety. Their design data set (consisting of pad thickness, rebar size and spacing, minimum concrete strength and rebar yield strength) used in the representative analysis (see Table 2.I.7) is set down in the Technical Specification as the minimum set of admissible strength properties. In addition the Technical Specification requires their strength evaluation for a particular site to be performed to meet ACI 318(2005).

3-10 Provide specific values or ranges of values in proposed CoC Section 3.4, Site-Specific Parameters and Analyses, for all the parameters involved in the seismic evaluations completed for an isolated HI-STORM 100U WM analyses in the FSAR, that must be verified by a potential user of the HI-STORM 100U System to determine whether their proposed site characteristics are encompassed by these values.

10 CFR 72.24 states that "The minimum information to be included in the SAR must consist of the following:

(c) The design of the ISFSI in sufficient detail to support the findings in 72.40, including:
  (2) the design bases and the relation of the design bases to the design criteria;
(d) an analysis and evaluation of the design ..."

10 CFR 72.3 defines design bases as "that information that identifies the specific functions to be performed by a structure, system, or component of a facility or of a spent fuel storage cask and the specific values or range of values chosen for controlling parameters as reference bounds for design."

This information is necessary to ensure compliance with 10 CFR 72.236(b)

Holtec Response to 3-10: A table of ISFSI structural design parameters guided by the seismic analysis in the FSAR has been added to the Technical Specification, as requested, with the additional requirement that a site specific seismic analysis be performed to demonstrate compliance with the structural criteria in Supplement 2.I.

3-11 Revise proposed CoC Section 3.4, Site-Specific Parameters and Analysis, Items 6(c) and 7 to change the shear wave velocity from 500 fps to 800 fps to reflect the actual shear wave velocity of the soil below the Support Foundation that was used in the seismic analyses.

The minimum information to be included in the FSAR must consist of "an analysis and evaluation of the design..." [72.24(d)]. The shear wave velocity of the soil below the

Support Foundation used in the analysis was 800 fps and constitutes the design that was evaluated.

This information is necessary to ensure compliance with 10 CFR 72.24(d).

Holtec Response to 3-11: The minimum shear wave velocity has been changed to 800 fps in the Tech Spec and also in the FSAR Table 2.I.2. The minimum Bousinesq stiffness (rigid punch stiffness) of the substrate has been revised upwards accordingly in Table 2.I.2 and the Technical Specification.

3-12 Provide an evaluation of the increase in internal pressure (if any) based on the increased temperatures in Section 4.I of the FSAR. Evaluate the stresses on the MPC confinement boundary.

An evaluation does not appear in the FSAR, and is needed to verify the integrity of the confinement system with increased internal pressures.

This information is needed to verify compliance with 10 CFR 72.236(d).

Holtec Response to 3-12: In the HI-STORM System, the MPC Pressure boundary has been analyzed for design pressures of 100 psig (normal), 110 psig (off-normal) and 200 psig (accident) (See Table 2.2.1 in the FSAR). The helium pressure in the MPC in the HI-STORM 100U VVM continues to meet these long standing limits as reported in Table 4.I.3 (normal), Tables 4.I.5 and 4.I.6 (off-normal), and Tables 4.I.8 and 4.I.9 (accident). Therefore, a new pressure vessel stress analysis for the confinement boundary is unnecessary.

Chapter 5.I Shielding Evaluation

5-1 Justify the use of a different source term for the dose evaluations for streaming from the empty VVM and the impressed current cathodic protection system (ICCPS) test station.

The applicant's response to question 5-2 of the previous RAI demonstrated that fuel with a burnup of 69,000 GWd/MTU and 5 years of cooling yielded the bounding dose rates for the

100U overpack. However, in responding to questions 10-3 and 10-4 of the previous RAI, regarding streaming from an empty neighboring VVM and through the ICCPS test station, fuel of a different burnup and cooling time was used for the source term. The shielding evaluation should be based upon analyses that use the bounding source term for the analyzed conditions to demonstrate that the system design basis meets the regulatory safety requirements. Staff recognizes that different source terms (i.e., fuel with different burnup values and cooling times) may be bounding in some conditions and not in others. However, it is not clear that the source term for the empty VVM and ICCPS is bounding for these cases.

This information is needed to confirm compliance with 10 CFR 72.236(d).

Holtec Response to 5-1: For streaming from an empty neighboring VVM and through the ICCPS test station, a different burnup and cooling time combination is bounding, i.e. leads to the highest dose rates. Appendix 5.I has been updated to clarify this.

5-2.1 Provide updated figures for proposed Section 5.I of the application.

The applicant's response to question 5-4 of the previous RAI indicates that the Section 5.I figures were modified; however, the figures were not included with the updated application.

This information is needed to confirm compliance with 10 CFR 72.236(d).

Holtec Response to 5-2.1: Supplement 5.I has been revised and now includes the updated figures. Note that in response to the previous RAI 5-4, the concrete thickness of 30" assumed in the analysis and the container flange thickness of 3" were added to Figure 5.I.2.

Chapter 8.I Operating Procedures

8-1 Provide a TS requirement stating that the fuel be maintained under water or shielded from the atmosphere by an inert gas during loading/unloading operations.

FSAR sections 8.1.5 and 8.3.3 describe loading /unloading operations and contain a caution about maintaining the fuel under water or in an inert atmosphere. This caution must be incorporated into the TS by reference and a note should be added to the FSAR language to indicate this is a TS requirement.

This change is necessary to comply with 10 CFR 72.122(h)(1).

Holtec Response to 8-1: A TS requirement has been proposed in Appendix B Section 3.11 to prevent oxidation of the fuel during loading and unloading. A "Caution" box is added to subsection 8.1.5.5 to require that the fuel be either covered by water or an inert gas during loading and this box will refer the user back to the TS requirement. Similarly the already existing "Caution" box in subsection 8.3.3.8 is updated to refer the user back to the TS requirement.

8-2 Provide a comment in FSAR sections 8.1 and 8.3 specifying that hydrogen monitoring during all lid welding or cutting operations is a TS requirement. This is an editorial change, as hydrogen monitoring is already a TS requirement, but no mention is made in FSAR Chapter 8.

This change is necessary for compliance with 10 CFR 72.120(d).

Holtec Response to 8-2: Since Revision 3 of the FSAR there has been a "note" box prior to step 8.1.5.3.e requiring combustible gas monitoring during the MPC lid to shell weld and it refers to the technical specifications. This note is further followed with a caution statement and step e instructs the user to perform combustible gas monitoring along with purging or exhausting the area. Similarly, a caution box prior to 8.3.3.8 step l, instructs the user to perform combustible gas monitoring along with purging or exhausting the area during cutting operations. More recently, the FSAR was updated via the 72.48 process to eliminate the option to exhaust in these steps and only allow the user to purge the area to ensure there is no build up of combustible gas. These changes are in FSAR Revision 7. A "note" box similar to the one in 8.1.5.3 is added to 8.3.3.8 to indicate combustible gas monitoring during cutting of the MPC lid-to-shell weld is required in the technical specifications.

The Technical Specifications Appendix B Section 3.8 currently requires combustible gas monitoring for MPC lid-to-shell welding operations only and does not explicitly require it for cutting operations. A proposed change has been made to TS Appendix B Section 3.8.

Chapter 9.I Acceptance Criteria and Maintenance

9-1 Revise TSs and FSAR Tables 2.0.1, 2.2.15, and 9.1.4 to require a fabrication-shop performed helium leakage rate test of the canister shell.

The NRC staff finds that, in accordance with ANSI N14.5 to "leak-tight" [10E-7](10-7 standard cubic centimeters/minute) criteria is acceptable in lieu of the Code-required pressure test.
A dose limit calculation is required by 10 CFR 72.126(d), which states, in part: "Analyses must be made to show that releases to the general environment during normal operations and anticipated occurrences will be within the exposure limit given in 10 CFR 72.104. Analyses of design basis accidents must be made to show that releases to the general environment will be within the exposure limits given in 10 CFR 72.106." However, the staff finds that performance of a helium leakage rate test, per ANSI N14.5, to "leak-tight" (10E-7) criteria is an acceptable alternative to performing the dose limit calculations required by 72.126(d).

Note: The staff finds that due to the reduced ability to perform a volumetric examination of the various lid closure welds, both a Code pressure test and helium leakage rate test to 10E-7 is required for the lid closure welds.

This change is necessary for compliance with 10 CFR 72.126(d), 72.104, and 72.106.

Holtec Response to 9-1: Holtec proposes to add the requirement for leakage rate test of the MPC fabrication welds to ANSI N14.5 "leak-tight" standards, therefore the dose limit calculations of 10CFR72.126(d) are not required. Section 2.0, 2.2 and 9.1have been updated.

Chapter 10.I Radiation Protection

10-1 Clarify the portion of FSAR Table 10.3.3c, referred to in part of the response to question 10-2 of the previous RAI.

In partial response to question 10-2 of the previous RAI regarding occupational dose incurred with installation of the 100U overpack lid, the applicant modified Section 10.I of the application. The modification references Table 10.3.3c of the FSAR; however, it is not clear what portion of the table is referred to as the basis for determining operation duration, and hence the estimated occupational dose, for the 100U overpack lid installation.

This information is needed to confirm compliance with 10 CFR 72.236(d).

Holtec Response to 10-1: Supplement 10.I has been revised to clarify the basis for determining the operational duration.

10-2 Justify the determination made in Section 10.I of the application regarding dose rates from the test station for the ICCPS.

In Section 5.I of the application, the applicant provided the dose rate calculated for the ICCPS surface and stated in Section 10.I of the application that this result indicated that streaming from the test station is not a concern. However, there are several assumptions included in the analysis and evaluation that are not explained nor justified as part of the evaluation. For example, it is not clear that the selected burnup and cooling times result in a bounding source for this location. There does not appear to be details in the application regarding the size (area) of the test station through which streaming occurs, including any limits on the test station size. Additionally, it is not clear where the test station is located in relation to the loaded VVM and whether or not the analyzed position is bounding, from a shielding or a dose rate perspective, with regard to the possible positions of the test station in relation to the VVM. For example, if the calculated dose rate is for a test station that is about 1 meter from the VVM lid, then the contribution to worker dose, for activities involving the test station, would be significant; the dose rate would be nearly double versus activities at the same distance from the VVM lid away from the test station. Even near the VVM lid, the dose rate for the test station is greater than 10% of the inlet vent dose rate. In either case, the FSAR should convey, to the user, the need to be aware that dose rates for activities near to/involving the ICCPS test station will be noticeably higher than for activities in similar locations relative to the VVM, but away from the test station.

This information is needed to ensure compliance with 10 CFR 72.104, 72.236(d) and 10 CFR 20.1101.

Holtec Response to 10-2: Supplements 5.I and 10.I have been expanded to specify the assumptions that were made in analyzing the ICCPS tube, and require the user to perform further evaluations if the actual tube could result in higher dose rates than analyzed.

Chapter 11.I Accident Analysis

11-1 Revise the Chapter 11 accident evaluations to address all accidents scenarios currently analyzed for storage conditions (including seismic) occurring with construction and excavation activities taking place next to an array of loaded VVMs. Also provide the necessary modifications to the technical evaluations and analyses (e.g., structural, shielding, etc.) that support, or are impacted by, the accident evaluations. (See also question 3-3.)

Section 1.I.1 of the application indicates that an ISFSI using the 100U design may be expanded to increase the number of storage modules as the need arises. This expansion requires the excavation of soil adjacent to an existing array of VVMs and further construction activities to install additional modules. The accident evaluations in the currently proposed SAR do not address accidents at an ISFSI using the 100U system with these activities occurring next to the array of loaded VVMs. The occurrence of these activities next to an array of already installed (and loaded) VVMs results in additional conditions that must be considered as part of the accident evaluations for the 100U system due to its unique design. Necessary modifications to other technical analyses and evaluations that support, or are impacted by, the accident evaluations (such as shielding and structural) should also be provided. These analyses and evaluations should consider the current design basis accidents and phenomena and any other accidents unique to construction and excavation activities near an operating ISFSI of 100U VVMs.

Staff notes that in response to the initial RAI (question 11-1) regarding this issue, the applicant only performed a tornado missile analysis and deferred all else to the site's 72.212 evaluation. Staff finds this response insufficient. The 72.212 evaluation is not used to do new accident analyses; the evaluation is used to show that the site parameters are "enveloped by the cask design bases considered" in the certificate holder's FSAR referenced by the CoC and the related NRC SER and to establish that conditions in the CoC and 72.104 have been met. Thus, the applicant should demonstrate that the system design meets the accident dose limits in 72.106(b), providing a bounding analysis for which this compliance can be demonstrated. Conditions that maximize accident consequences, such as the minimum distance between the loaded VVMs and the site of the excavation and construction activities to add new VVMs, should be properly addressed. Any assumptions used in the evaluations and analyses should be adequately justified. Any equipment or engineered features relied upon in the evaluations should be identified as Important To Safety (ITS) and, along with any assumed parameter limits relied upon in the evaluations, need to be included in the conditions of the certificate or the technical specifications.

This information is needed to confirm compliance with 10 CFR 72.106(b), 72.236(b) and 72.236(d).

Holtec Response to 11-1: As the response to RAI 3-3 indicates, both physical and analysis requirements have been added in the FSAR to protect the ISFSI against a construction accident in its immediate proximity. Specifically, the ISFSI owner is required to install an underground "retaining wall" at the perimeter of the Radiation Protection Space (RPS) (defined in Section 1.I.4) to provide a structurally competent barrier against dismemberment of the soil mass in the RPS if future construction involving excavation adjacent to the ISFSI is planned. The retaining wall, if made of reinforced concrete, shall comply with ACI 318 (05).

The FSAR now also requires a seismic re-analysis of the ISFSI using the Design Basis seismic model identified in the Technical Specification with the largest cavity adjacent to the ISFSI modeled appropriately. The acceptance criteria in Supplement 2.I must be met in the most vulnerable construction configuration.

The retaining wall has been designated as an important-to-safety structure. The text matter in Section 11.I.2.17 and 2.I.6 (xii) provides the relevant details.

Chapter 12.I Technical Specifications

12-1 Revise the TSs to address the following:

a. The dose rate limit in TS 5.7.4.c should be changed to "30 mrem/hr (gamma + neutron)" for the top of the underground overpack.
b. The commas before and after the phrase "containing the as-loaded MPC" should be removed in TS 5.7.6.b.
c. The phrase "can include a VVM" should be changed to "includes the VVM" in the definition of OVERPACK in TS Appendices A and B.
d. The definition of TRANSFER CASK in TS Appendix B should be changed to duplicate the definition as given in TS Appendix A (i.e. "a 125-Ton or a 100-Ton" should read as "the 125-Ton or the 100-Ton").
e. The definition of VERTICAL VENTILATED MODULE (VVM) should be changed to read "The VVM is a subterranean OVERPACK where ..."
f. The OR statement for SR 3.1.2 of TS 3.1.2 in Appendix A should explicitly read that the 155F and 137F limits are for aboveground OVERPACKS.

The change requested in a. was agreed to in response to question 12-1 of the previous RAI but was not made in the associated TS. The staff finds that the change requested in b. results in the clearest statement of the necessary action. The staff finds the change requested in c. results in the most accurate definition of OVERPACK in regards to the VVM. The change requested in d. was agreed to in response to question 12-3d of the previous RAI but was not made in the associated TS. The currently proposed definition of VVM is too generic versus the intended use in the amendment request and can include aboveground overpacks; the change requested in e. confines the scope of the definition to only the underground overpacks. The staff finds the change requested in f. is necessary for consistency and to clarify the applicability of the stated limits to the aboveground OVERPACKS only.

This information is needed to confirm compliance with 10 CFR 72.236(a), (b), (d), and (f).

Holtec Response to 12-1:

a. The dose rate limit in TS 5.7.4.c has been changed to "30 mrem/hr (gamma + neutron)" for the top of the underground overpack. Holtec apologizes for the confusion.
b. The commas before and after the phrase "containing the as-loaded MPC" have been removed in TS 5.7.6.b.

c. The definition of OVERPACK in TS Appendices A and B has been changed to "includes the VVM".
d. The definition of TRANSFER CASK in TS Appendix B now reads as in Appendix A. Since CoC Amendment 5 is written this same way, i.e. "the 125-Ton or the 100-Ton", this is no longer marked as a change in this LAR.
e. The definition of VERTICAL VENTILATED MODULE (VVM) has been changed to read "The VVM is a subterranean OVERPACK where ..."
f. The OR statement for SR 3.1.2 of TS 3.1.2 in Appendix A has been changed to explicitly read that the 155F and 137F limits are for aboveground OVERPACKS.

12-2 Justify the lack of a TS dose rate limit and associated measurements for the VVM Interface Pad (VIP) in the proposed TS 5.7, Radiation Protection Program (RPP).

In questions 12-4 and 12-5 of the previous RAI, the staff requested modifications of TS 5.7.3 and TS 5.7.4 to establish dose rate limits for locations/areas of the 100U overpack that contribute significantly to public and occupational dose and are most indicative of overpack shielding effectiveness. As part of these questions, the staff indicated that different areas of the overpack should be evaluated. These areas included the VIP. However, the response to these questions did not evaluate the VIP. The VIP is a part of the shielding design of the 100U system; therefore, some confirmation of its shielding effectiveness should be performed. It is not clear from the current application that the effectiveness of the as-fabricated VIP is ensured under the currently proposed TS 5.7, RPP, or by other means.

The degree of significance of the dose rates from the VIP on either public or occupational dose is also not clear. The significance to doses depends not only on the dose rate, but also on the extent of the surface area for which that dose rate is representative; the size (surface area) of the VIP is not clear from the descriptions in the application. The TS 5.7, RPP, should include appropriate dose rate limits and measurements that address these aspects of the 100U system. The staff notes that the dose rate limits and measurements for other areas of the cask, such as at the inlet vents, may be used to capture the VIP; however, justification should be provided as to the adequacy of these measurements to capture the effects of the VIP. The staff also notes that surface dose rate criteria were not specified for the 100U, different from the criteria in FSAR Section 5.1.1 for the aboveground overpacks. If different criteria are applied to the 100U, this should be clarified as well.

This information is needed to confirm compliance with 10 CFR 72.126(a) and 72.236(d).

Holtec Response to 12-2: Supplement 5.I has been expended and now shows a complete dose profile over the surface of the system, including the VIP, and an evaluation of the contribution of the VIP to the dose rate at 100m. Based on the evaluations, it is concluded that the dose location 1 m from the inlet vent should be sufficient to capture the effect of radiation through the soil and concrete on the site boundary dose rate. Therefore, no additional dose requirements were added to TS 5.7.

CERTIFICATE OF COMPLIANCE FOR SPENT FUEL STORAGE CASKS

The U.S. Nuclear Regulatory Commission is issuing this Certificate of Compliance pursuant to Title 10 of the Code of Federal Regulations, Part 72, "Licensing Requirements for Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste" (10 CFR Part 72). This certificate is issued in accordance with 10 CFR 72.238, certifying that the storage design and contents described below meet the applicable safety standards set forth in 10 CFR Part 72, Subpart L, and on the basis of the Final Safety Analysis Report (FSAR) of the cask design. This certificate is conditional upon fulfilling the requirements of 10 CFR Part 72, as applicable, and the conditions specified below.

Certificate No.	Effective Date	Expiration Date	Docket No.	Amendment No.	Amendment Effective Date	Package Identification No.
1014	05/31/00	06/01/20	72-1014	~~5~~TBD	TBD	USA/72-1014

Issued To: (Name/Address)

Holtec International
Holtec Center
555 Lincoln Drive West
Marlton, NJ 08053

Safety Analysis Report Title

Holtec International
Final Safety Analysis Report for the
HI-STORM 100 Cask System

CONDITIONS

This certificate is conditioned upon fulfilling the requirements of 10 CFR Part 72, as applicable, the attached Appendix A (Technical Specifications) and Appendix B (Approved Contents and Design Features), and the conditions specified below:

1. CASK

a. Model No.: HI-STORM 100 Cask System

The HI-STORM 100 Cask System (the cask) consists of the following components: (1) interchangeable multi-purpose canisters (MPCs), which contain the fuel; (2) a storage overpack (HI-STORM), which contains the MPC during storage; and (3) a transfer cask (HI-TRAC), which contains the MPC during loading, unloading and transfer operations. The cask stores up to 32 pressurized water reactor (PWR) fuel assemblies or 68 boiling water reactor (BWR) fuel assemblies.

b. Description

The HI-STORM 100 Cask System is certified as described in the Final Safety Analysis Report (FSAR) and in the U.S. Nuclear Regulatory Commission's (NRC) Safety Evaluation Report (SER) accompanying the Certificate of Compliance. The cask comprises three discrete components: the MPC, the HI-TRAC transfer cask, and the HI-STORM storage overpack.

The MPC is the confinement system for the stored fuel. It is a welded, cylindrical canister with a honeycombed fuel basket, a baseplate, a lid, a closure ring, and the canister shell. All MPC components that may come into contact with spent fuel pool water or the ambient environment are made entirely of stainless steel *or passivated aluminum/aluminum alloys such as the neutron absorbers.* ~~except for the neutron absorbers, aluminum seals on vent and drain port caps, and aluminum heat conduction elements (AHCEs), which are installed in some early-vintage MPCs.~~ The canister shell, baseplate, lid, vent and drain port cover plates, and closure ring are the main confinement boundary components. All confinement boundary components are made entirely of stainless steel. The honeycombed basket, which is equipped with neutron absorbers, provides criticality control.

1. b. Description (continued)

There are eight types of MPCs: the MPC-24, MPC-24E, MPC-24EF, MPC-32, MPC-32F, MPC-68, MPC-68F, and MPC-68FF. The number suffix indicates the maximum number of fuel assemblies permitted to be loaded in the MPC. All eight MPC models have the same external diameter.

The HI-TRAC transfer cask provides shielding and structural protection of the MPC during loading, unloading, and movement of the MPC from the spent fuel pool to the storage overpack. The transfer cask is a multi-walled (carbon steel/lead/carbon steel) cylindrical vessel with a neutron shield jacket attached to the exterior. Two sizes of HI-TRAC transfer casks are available: the 125 ton-HI-TRAC and the 100 ton HI-TRAC. The weight designation *indicates* ~~is~~ the *approximate* ~~maximum~~ weight of a loaded transfer cask during any loading, unloading or transfer operation. Both transfer cask sizes have identical cavity diameters. The 125 ton HI-TRAC transfer cask has thicker shielding and larger outer dimensions than the 100 ton HI-TRAC transfer cask.

The HI-STORM 100 or 100S storage overpack provides shielding and structural protection of the MPC during storage. The HI-STORM 100S is a variation of the HI-STORM 100 overpack design that includes a modified lid which incorporates the air outlet ducts into the lid, allowing the overpack body to be shortened. The overpack is a heavy-walled steel and concrete, cylindrical vessel. Its side wall consists of plain (un-reinforced) concrete that is enclosed between inner and outer carbon steel shells. The overpack has four air inlets at the bottom and four air outlets at the top to allow air to circulate naturally through the cavity to cool the MPC inside. The inner shell has supports attached to its interior surface to guide the MPC during insertion and removal, provide a medium to absorb impact loads, and allow cooling air to circulate through the overpack. A loaded MPC is stored within the HI- STORM 100 or 100S storage overpack in a vertical orientation. The HI-STORM 100A and 100SA are variants of the HI-STORM 100 family outfitted with an extended baseplate and gussets to enable the overpack to be anchored to the concrete storage pad in high seismic applications.

The HI-STORM 100U storage overpack is an underground storage system identified with the HI-STORM 100 Cask System. The HI-STORM 100U utilizes a storage design identified as an air-cooled vault or caisson. The HI-STORM 100U relies on vertical ventilation instead of conduction through the soil, while it is essentially a below-grade storage cavity. Air inlets and outlets allow air to circulate naturally through the cavity to cool the MPC inside. The subterranean steel structure is seal welded to prevent ingress of any groundwater from the surrounding subgrade and is placed on a stiff foundation. The surrounding subgrade and a top surface pad provide significant radiation shielding. A loaded MPC is stored within the HI-STORM 100U storage overpack in the vertical orientation.

2. OPERATING PROCEDURES

Written operating procedures shall be prepared for cask handling, loading, movement, surveillance, and maintenance. The user's site-specific written operating procedures shall be consistent with the technical basis described in Chapter 8 of the FSAR.

3. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Written cask acceptance tests and maintenance program shall be prepared consistent with the technical basis described in Chapter 9 of the FSAR.

4. QUALITY ASSURANCE

Activities in the areas of design, purchase, fabrication, assembly, inspection, testing, operation, maintenance, repair, modification of structures, systems and components, and decommissioning that are important to safety shall be conducted in accordance with a Commission-approved quality assurance program which satisfies the applicable requirements of 10 CFR Part 72, Subpart G, and which is established, maintained, and executed with regard to the cask system.

5. HEAVY LOADS REQUIREMENTS

Each lift of an MPC, a HI-TRAC transfer cask, or any HI-STORM overpack must be made in accordance to the existing heavy loads requirements and procedures of the licensed facility at which the lift is made. A plant-specific regulatory review (under 10 CFR 50.59 or 10 CFR 72.48, if applicable) is required to show operational compliance with existing plant specific heavy loads requirements. Lifting operations outside of structures governed by 10 CFR Part 50 must be in accordance with Section 5.5 of Appendix A and/or Sections 3.4.6 and Section 3.5 of Appendix B to this certificate, as applicable.

6. APPROVED CONTENTS

Contents of the HI-STORM 100 Cask System must meet the fuel specifications given in Appendix B to this certificate.

7. DESIGN FEATURES

Features or characteristics for the site, cask, or ancillary equipment must be in accordance with Appendix B to this certificate.

8. CHANGES TO THE CERTIFICATE OF COMPLIANCE

The holder of this certificate who desires to make changes to the certificate, which includes Appendix A (Technical Specifications) and Appendix B (Approved Contents and Design Features), shall submit an application for amendment of the certificate.

9. SPECIAL REQUIREMENTS FOR FIRST SYSTEMS IN PLACE

The air mass flow rate through the cask system will be determined by direct measurements of air velocity in the overpack cooling passages for the first *belowground and aboveground* HI-STORM Cask Systems placed into service by any user with a heat load equal to or greater than 20 kW. *In the aboveground HI-STORM models (HI-STORM 100, 100S, etc.), t*~~T~~he velocity will be measured in the annulus formed between the MPC shell and the overpack inner shell. *In the belowground HI-STORM model (HI-STORM 100U), the velocity will be measured in the vertical downcomer air passage.* An analysis shall be performed that demonstrates the measurements validate the analytic methods and thermal performance predicted by the licensing-basis thermal models in Chapter 4 of the FSAR.

Each first time user of a HI-STORM 100 Cask System Supplemental Cooling System (SCS) that uses components or a system that is not essentially identical to components or a system that has been previously tested, shall measure and record coolant temperatures for the inlet and outlet of cooling provided to the annulus between the HI-TRAC and MPC and the coolant flow rate. The user shall also record the MPC operating pressure and decay heat. An analysis shall be performed, using this information, that validates the thermal methods described in the FSAR which were used to determine the type and amount of supplemental cooling necessary.

CERTIFICATE OF COMPLIANCE FOR SPENT FUEL STORAGE CASKS

Supplemental Sheet

9. SPECIAL REQUIREMENTS FOR FIRST SYSTEMS IN PLACE (continued)

Letter reports summarizing the results of each thermal validation test and SCS validation test and analysis shall be submitted to the NRC in accordance with 10 CFR 72.4. Cask users may satisfy these requirements by referencing validation test reports submitted to the NRC by other cask users.

10. PRE-OPERATIONAL TESTING AND TRAINING EXERCISE

A dry run training exercise of the loading, closure, handling, unloading, and transfer of the HI-STORM 100 Cask System shall be conducted by the licensee prior to the first use of the system to load spent fuel assemblies. The training exercise shall not be conducted with spent fuel in the MPC. The dry run may be performed in an alternate step sequence from the actual procedures, but all steps must be performed. The dry run shall include, but is not limited to the following:

a. Moving the MPC and the transfer cask into the spent fuel pool *or cask loading pool.*

b. Preparation of the HI-STORM 100 Cask System for fuel loading.

c. Selection and verification of specific fuel assemblies to ensure type conformance.

d. Loading specific assemblies and placing assemblies into the MPC (using a dummy fuel assembly), including appropriate independent verification.

e. Remote installation of the MPC lid and removal of the MPC and transfer cask from the spent fuel pool *or cask loading pool.*

f. MPC welding, NDE inspections, pressure testing, draining, moisture removal (by vacuum drying or forced helium dehydration, as applicable), and helium backfilling. (A mockup may be used for this dry-run exercise.)

g. Operation of the Supplemental Cooling System, if applicable.

h. Transfer cask upending/downending on the horizontal transfer trailer or other transfer device, as applicable to the site's cask handling arrangement.

I. Transfer of the MPC from the transfer cask to the overpack.

j. Placement of the HI-STORM 100 Cask System at the ISFSI, *for aboveground systems only.*

k. HI-STORM 100 Cask System unloading, including flooding MPC cavity, removing MPC lid welds. (A mockup may be used for this dry-run exercise.)

11. When the Supplemental Cooling System is in operation to provide for decay heat removal in accordance with Section 3.1.4 of Appendix A the licensee is exempt from the requirements of 10 CFR 72.236(f).

CERTIFICATE OF COMPLIANCE FOR SPENT FUEL STORAGE CASKS

Supplemental Sheet

Certificate No. 1014

Amendment No. ~~5~~

12. AUTHORIZATION

The HI-STORM 100 Cask System, which is authorized by this certificate, is hereby approved for general use by holders of 10 CFR Part 50 licenses for nuclear reactors at reactor sites under the general license issued pursuant to 10 CFR 72.210, subject to the conditions specified by 10 CFR 72.212, and the attached Appendix A and Appendix B. The HI-STORM 100 Cask System may be fabricated and used in accordance with any approved amendment to CoC No. 1014 listed in 10 CFR 72.214. Each of the licensed HI-STORM 100 System components (i.e., the MPC, overpack, and transfer cask), if fabricated in accordance with any of the approved CoC Amendments, may be used with one another provided an assessment is performed by the CoC holder that demonstrates design compatibility.

FOR THE U. S. NUCLEAR REGULATORY COMMISSION

TBD, Chief
Licensing Section
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety and Safeguards
Washington, DC 20555

Dated, TBD

Attachments:
1. Appendix A
2. Appendix B

CERTIFICATE OF COMPLIANCE NO. 1014

APPENDIX A

TECHNICAL SPECIFICATIONS

FOR THE HI-STORM 100 CASK SYSTEM

TABLE OF CONTENTS

1.0 USE AND APPLICATION

1.1 Definitions

---NOTE---

The defined terms of this section appear in capitalized type and are applicable throughout these Technical Specifications and Bases.

Term	Definition
ACTIONS	ACTIONS shall be that part of a Specification that prescribes Required Actions to be taken under designated Conditions within specified Completion Times.
FUEL BUILDING	The FUEL BUILDING is the site-specific power plant facility, governed by the regulations of 10CFR Part 50, where the loaded OVERPACK or TRANSFER CASK is transferred to or from the transporter.
LOADING OPERATIONS	LOADING OPERATIONS include all licensed activities on an OVERPACK or TRANSFER CASK while it is being loaded with fuel assemblies. LOADING OPERATIONS begin when the first fuel assembly is placed in the MPC and end when the OVERPACK or TRANSFER CASK is suspended from or secured on the transporter. LOADING OPERATIONS does not include MPC transfer between the TRANSFER CASK and the OVERPACK, which begins when the MPC is lifted off the HI-TRAC bottom lid and ends when the MPC is supported from beneath by the OVERPACK.
MULTI-PURPOSE CANISTER (MPC)	MPCs are the sealed spent nuclear fuel canisters which consist of a honeycombed fuel basket contained in a cylindrical canister shell which is welded to a baseplate, lid with welded port cover plates, and closure ring. The MPC provides the confinement boundary for the contained radioactive materials.

(continued)

1.1 Definitions (continued)

OVERPACK	OVERPACKs are the casks which receive and contain the sealed MPCs for interim storage on the ISFSI. They provide gamma and neutron shielding, and provide for ventilated air flow to promote heat transfer from the MPC to the environs. The *term* OVERPACK *includes the VVM, but* does not include the TRANSFER CASK.
SPENT FUEL STORAGE CASKS (SFSCs)	SFSCs are containers approved for the storage of spent fuel assemblies at the ISFSI. The HI-STORM 100 SFSC System consists of the OVERPACK and its integral MPC.
STORAGE OPERATIONS	STORAGE OPERATIONS include all licensed activities that are performed at the ISFSI while an SFSC containing spent fuel is situated within the ISFSI perimeter. STORAGE OPERATIONS does not include MPC transfer between the TRANSFER CASK and the OVERPACK, which begins when the MPC is lifted off the HI-TRAC bottom lid and ends when the MPC is supported from beneath by the OVERPACK (or the reverse).
SUPPORT FOUNDATION	*The SUPPORT FOUNDATION is a reinforced concrete pad that supports the weight of a VVM in an underground storage facility.*
TRANSFER CASK	TRANSFER CASKs are containers designed to contain the MPC during and after loading of spent fuel assemblies and to transfer the MPC to or from the OVERPACK. The HI-STORM 100 System employs either the 125-Ton or the 100-Ton HI-TRAC TRANSFER CASK.

(continued)

1.1 Definitions (continued)

TRANSPORT OPERATIONS	TRANSPORT OPERATIONS include all licensed activities performed on an OVERPACK or TRANSFER CASK loaded with one or more fuel assemblies when it is being moved *after LOADING OPERATIONS or before UNLOADING OPERATIONS* ~~to and from the ISFSI~~. TRANSPORT OPERATIONS begin when the OVERPACK or TRANSFER CASK is first suspended from or secured on the transporter and end when the OVERPACK or TRANSFER CASK is at its destination and no longer secured on or suspended from the transporter. TRANSPORT OPERATIONS includes transfer of the MPC between the OVERPACK and the TRANSFER CASK, which begins when the MPC is lifted off the HI-TRAC bottom lid and ends when the MPC is supported from beneath by the OVERPACK (or the reverse).
UNLOADING OPERATIONS	UNLOADING OPERATIONS include all licensed activities on an SFSC to be unloaded of the contained fuel assemblies. UNLOADING OPERATIONS begin when the OVERPACK or TRANSFER CASK is no longer suspended from or secured on the transporter and end when the last fuel assembly is removed from the SFSC. UNLOADING OPERATIONS does not include MPC transfer between the TRANSFER CASK and the OVERPACK, which begins when the MPC is no longer supported from beneath by the OVERPACK and ends when the MPC is lowered onto the HI-TRAC bottom lid.
VERTICAL VENTILATED MODULE (VVM)	*The VVM is a subterranean OVERPACK where the contained fuel assemblies are supported in a vertical orientation and where air flow through cooling passages aid in rejecting heat to the environment.*

1.0 USE AND APPLICATION

1.2 Logical Connectors

PURPOSE

The purpose of this section is to explain the meaning of logical connectors.

Logical connectors are used in Technical Specifications (TS) to discriminate between, and yet connect, discrete Conditions, Required Actions, Completion Times, Surveillances, and Frequencies. The only logical connectors that appear in TS are AND and OR. The physical arrangement of these connectors constitutes logical conventions with specific meanings.

BACKGROUND

Several levels of logic may be used to state Required Actions. These levels are identified by the placement (or nesting) of the logical connectors and by the number assigned to each Required Action. The first level of logic is identified by the first digit of the number assigned to a Required Action and the placement of the logical connector in the first level of nesting (i.e., left justified with the number of the Required Action). The successive levels of logic are identified by additional digits of the Required Action number and by successive indentions of the logical connectors.

When logical connectors are used to state a Condition, Completion Time, Surveillance, or Frequency, only the first level of logic is used, and the logical connector is left justified with the statement of the Condition, Completion Time, Surveillance, or Frequency.

(continued)

1.2 Logical Connectors

EXAMPLES

The following examples illustrate the use of logical connectors.

EXAMPLE 1.2-1

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met.	A.1 VERIFY . . . AND A.2 Restore . . .	

In this example the logical connector AND is used to indicate that when in Condition A, both Required Actions A.1 and A.2 must be completed.

(continued)

1.2 Logical Connectors

EXAMPLES (continued)

EXAMPLE 1.2-2

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met.	A.1 Stop . . . OR A.2.1 Verify . . . AND A.2.2.1 Reduce . . . OR A.2.2.2 Perform . . . OR A.3 Remove . . .	

This example represents a more complicated use of logical connectors. Required Actions A.1, A.2, and A.3 are alternative choices, only one of which must be performed as indicated by the use of the logical connector OR and the left justified placement. Any one of these three ACTIONS may be chosen. If A.2 is chosen, then both A.2.1 and A.2.2 must be performed as indicated by the logical connector AND. Required Action A.2.2 is met by performing A.2.2.1 or A.2.2.2. The indented position of the logical connector OR indicates that A.2.2.1 and A.2.2.2 are alternative choices, only one of which must be performed.

1.0 USE AND APPLICATION

1.3 Completion Times

PURPOSE	The purpose of this section is to establish the Completion Time convention and to provide guidance for its use.
BACKGROUND	Limiting Conditions for Operation (LCOs) specify the lowest functional capability or performance levels of equipment required for safe operation of the facility. The ACTIONS associated with an LCO state Conditions that typically describe the ways in which the requirements of the LCO can fail to be met. Specified with each stated Condition are Required Action(s) and Completion Times(s).
DESCRIPTION	The Completion Time is the amount of time allowed for completing a Required Action. It is referenced to the time of discovery of a situation (e.g., equipment or variable not within limits) that requires entering an ACTIONS Condition unless otherwise specified, providing the HI-STORM 100 System is in a specified condition stated in the Applicability of the LCO. Required Actions must be completed prior to the expiration of the specified Completion Time. An ACTIONS Condition remains in effect and the Required Actions apply until the Condition no longer exists or the HI-STORM 100 System is not within the LCO Applicability. Once a Condition has been entered, subsequent subsystems, components, or variables expressed in the Condition, discovered to be not within limits, will <u>not</u> result in separate entry into the Condition unless specifically stated. The Required Actions of the Condition continue to apply to each additional failure, with Completion Times based on initial entry into the Condition.

(continued)

1.3 Completion Times (continued)

EXAMPLES

The following examples illustrate the use of Completion Times with different types of Conditions and changing Conditions.

EXAMPLE 1.3-1

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
B. Required Action and associated Completion Time not met.	B.1 Perform Action B.1	12 hours
	AND	
	B.2 Perform Action B.2	36 hours

Condition B has two Required Actions. Each Required Action has its own separate Completion Time. Each Completion Time is referenced to the time that Condition B is entered.

The Required Actions of Condition B are to complete action B.1 within 12 hours AND complete action B.2 within 36 hours. A total of 12 hours is allowed for completing action B.1 and a total of 36 hours (not 48 hours) is allowed for completing action B.2 from the time that Condition B was entered. If action B.1 is completed within 6 hours, the time allowed for completing action B.2 is the next 30 hours because the total time allowed for completing action B.2 is 36 hours.

(continued)

1.3 Completion Times

EXAMPLES (continued)

EXAMPLE 1.3-2

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. One system not within limit.	A.1 Restore system to within limit.	7 days
B. Required Action and associated Completion Time not met.	B.1 Complete action B.1. AND B.2 Complete action B.2.	12 hours 36 hours

When a system is determined not to meet the LCO, Condition A is entered. If the system is not restored within 7 days, Condition B is also entered and the Completion Time clocks for Required Actions B.1 and B.2 start. If the system is restored after Condition B is entered, Conditions A and B are exited, and therefore, the Required Actions of Condition B may be terminated.

(continued)

1.3 Completion Times

EXAMPLES (continued)

EXAMPLE 1.3-3

ACTIONS

-----------------------------------NOTE-----------------------------------
Separate Condition entry is allowed for each component.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met.	A.1 Restore compliance with LCO.	4 hours
B. Required Action and associated Completion Time not met.	B.1 Complete action B.1. AND B.2 Complete action B.2.	6 hours 12 hours

The Note above the ACTIONS table is a method of modifying how the Completion Time is tracked. If this method of modifying how the Completion Time is tracked was applicable only to a specific Condition, the Note would appear in that Condition rather than at the top of the ACTIONS Table.

The Note allows Condition A to be entered separately for each component, and Completion Times tracked on a per component basis. When a component is determined to not meet the LCO, Condition A is entered and its Completion Time starts. If subsequent components are determined to not meet the LCO, Condition A is entered for each component and separate Completion Times start and are tracked for each component.

(continued)

1.3 Completion Times (continued)

IMMEDIATE COMPLETION TIME	When "Immediately" is used as a Completion Time, the Required Action should be pursued without delay and in a controlled manner.

1.0 USE AND APPLICATION

1.4 Frequency

PURPOSE	The purpose of this section is to define the proper use and application of Frequency requirements.
DESCRIPTION	Each Surveillance Requirement (SR) has a specified Frequency in which the Surveillance must be met in order to meet the associated Limiting Condition for Operation (LCO). An understanding of the correct application of the specified Frequency is necessary for compliance with the SR. The "specified Frequency" is referred to throughout this section and each of the Specifications of Section 3.0, Surveillance Requirement (SR) Applicability. The "specified Frequency" consists of the requirements of the Frequency column of each SR. Situations where a Surveillance could be required (i.e., its Frequency could expire), but where it is not possible or not desired that it be performed until sometime after the associated LCO is within its Applicability, represent potential SR 3.0.4 conflicts. To avoid these conflicts, the SR (i.e., the Surveillance or the Frequency) is stated such that it is only "required" when it can be and should be performed. With an SR satisfied, SR 3.0.4 imposes no restriction.

(continued)

1.4 Frequency (continued)

EXAMPLES

The following examples illustrate the various ways that Frequencies are specified.

EXAMPLE 1.4-1

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
Verify pressure within limit	12 hours

Example 1.4-1 contains the type of SR most often encountered in the Technical Specifications (TS). The Frequency specifies an interval (12 hours) during which the associated Surveillance must be performed at least one time. Performance of the Surveillance initiates the subsequent interval. Although the Frequency is stated as 12 hours, an extension of the time interval to 1.25 times the interval specified in the Frequency is allowed by SR 3.0.2 for operational flexibility. The measurement of this interval continues at all times, even when the SR is not required to be met per SR 3.0.1 (such as when the equipment or variables are outside specified limits, or the facility is outside the Applicability of the LCO). If the interval specified by SR 3.0.2 is exceeded while the facility is in a condition specified in the Applicability of the LCO, the LCO is not met in accordance with SR 3.0.1.

If the interval as specified by SR 3.0.2 is exceeded while the facility is not in a condition specified in the Applicability of the LCO for which performance of the SR is required, the Surveillance must be performed within the Frequency requirements of SR 3.0.2 prior to entry into the specified condition. Failure to do so would result in a violation of SR 3.0.4

(continued)

1.4 Frequency

EXAMPLES (continued)

EXAMPLE 1.4-2

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
Verify flow is within limits.	Once within 12 hours prior to starting activity AND 24 hours thereafter

Example 1.4-2 has two Frequencies. The first is a one time performance Frequency, and the second is of the type shown in Example 1.4-1. The logical connector "AND" indicates that both Frequency requirements must be met. Each time the example activity is to be performed, the Surveillance must be performed within 12 hours prior to starting the activity.

The use of "once" indicates a single performance will satisfy the specified Frequency (assuming no other Frequencies are connected by "AND"). This type of Frequency does not qualify for the 25% extension allowed by SR 3.0.2.

"Thereafter" indicates future performances must be established per SR 3.0.2, but only after a specified condition is first met (i.e., the "once" performance in this example). If the specified activity is canceled or not performed, the measurement of both intervals stops. New intervals start upon preparing to restart the specified activity.

2.0

This section is intentionally left blank

3.0 LIMITING CONDITIONS FOR OPERATION (LCO) APPLICABILITY

LCO 3.0.1	LCOs shall be met during specified conditions in the Applicability, except as provided in LCO 3.0.2.
LCO 3.0.2	Upon discovery of a failure to meet an LCO, the Required Actions of the associated Conditions shall be met, except as provided in LCO 3.0.5. If the LCO is met or is no longer applicable prior to expiration of the specified Completion Time(s), completion of the Required Action(s) is not required, unless otherwise stated.
LCO 3.0.3	Not applicable.
LCO 3.0.4	When an LCO is not met, entry into a specified condition in the Applicability shall not be made except when the associated ACTIONS to be entered permit continued operation in the specified condition in the Applicability for an unlimited period of time. This Specification shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS or that are related to the unloading of an SFSC.
LCO 3.0.5	Equipment removed from service or not in service in compliance with ACTIONS may be returned to service under administrative control solely to perform testing required to demonstrate it meets the LCO or that other equipment meets the LCO. This is an exception to LCO 3.0.2 for the system returned to service under administrative control to perform the testing.

3.0 SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

SR 3.0.1	SRs shall be met during the specified conditions in the Applicability for individual LCOs, unless otherwise stated in the SR. Failure to meet a Surveillance, whether such failure is experienced during the performance of the Surveillance or between performances of the Surveillance, shall be failure to meet the LCO. Failure to perform a Surveillance within the specified Frequency shall be failure to meet the LCO except as provided in SR 3.0.3. Surveillances do not have to be performed on equipment or variables outside specified limits.
SR 3.0.2	The specified Frequency for each SR is met if the Surveillance is performed within 1.25 times the interval specified in the Frequency, as measured from the previous performance or as measured from the time a specified condition of the Frequency is met. For Frequencies specified as "once," the above interval extension does not apply. If a Completion Time requires periodic performance on a "once per..." basis, the above Frequency extension applies to each performance after the initial performance. Exceptions to this Specification are stated in the individual Specifications.
SR 3.0.3	If it is discovered that a Surveillance was not performed within its specified Frequency, then compliance with the requirement to declare the LCO not met may be delayed, from the time of discovery, up to 24 hours or up to the limit of the specified Frequency, whichever is less. This delay period is permitted to allow performance of the Surveillance. If the Surveillance is not performed within the delay period, the LCO must immediately be declared not met, and the applicable Condition(s) must be entered.

(continued)

SR 3.0.3 (continued)	When the Surveillance is performed within the delay period and the Surveillance is not met, the LCO must immediately be declared not met, and the applicable Condition(s) must be entered.
SR 3.0.4	Entry into a specified condition in the Applicability of an LCO shall not be made unless the LCO's Surveillances have been met within their specified Frequency. This provision shall not prevent entry into specified conditions in the Applicability that are required to comply with Actions or that are related to the unloading of an SFSC.

3.1 SFSC INTEGRITY

3.1.1 Multi-Purpose Canister (MPC)

LCO 3.1.1 The MPC shall be dry and helium filled.

Table 3-1 provides decay heat and burnup limits for forced helium dehydration (FHD) and vacuum drying. FHD is not subject to time limits. Vacuum drying is subject to the following time limits, from the end of bulk water removal until the start of helium backfill:

MPC Total Decay Heat (Q)	Vacuum Drying Time Limit
$Q \leq 23$ kW	None
23 kW < $Q \leq$28.74 kW	40 hours
Q > 28.74 kW	Not Permitted (see Table 3-1)

APPLICABILITY: During TRANSPORT OPERATIONS and STORAGE OPERATIONS.

ACTIONS

---NOTES---

Separate Condition entry is allowed for each MPC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. MPC cavity vacuum drying pressure or demoisturizer exit gas temperature limit not met.	A.1 Perform an engineering evaluation to determine the quantity of moisture left in the MPC.	7 days
	<u>AND</u>	
	A.2 Develop and initiate corrective actions necessary to return the MPC to compliance with Table 3-1.	30 days

CONDITION	REQUIRED ACTION	COMPLETION TIME
B. MPC cavity vacuum drying acceptance criteria not met during allowable time.	B.1 Backfill the MPC cavity with helium to a pressure of at least 0.5 atm.	6 hours
C. MPC helium backfill limit not met.	C.1 Perform an engineering evaluation to determine the impact of helium differential.	72 hours
	<u>AND</u>	
	C.2 Develop and initiate corrective actions necessary to return the MPC to an analyzed condition by adding helium to or removing helium from the MPC.	14 days
	<u>OR</u>	
	C.2.2 Develop and initiate corrective actions necessary to demonstrate through analysis, using the models and methods from the HI-STORM FSAR, that all limits for cask components and contents will be met.	

ACTIONS
(continued)

CONDITION	REQUIRED ACTION	COMPLETION TIME
D. MPC helium leak rate limit for vent and drain port cover plate welds not met.	D.1 Perform an engineering evaluation to determine the impact of increased helium leak rate on heat removal capability and offsite dose.	24 hours
	AND	
	D.2 Develop and initiate corrective actions necessary to return the MPC to compliance with SR 3.1.1.3.	7 days
E. Required Actions and associated Completion Times not met.	E.1 Remove all fuel assemblies from the SFSC.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.1.1	Verify that the MPC cavity has been dried in accordance with the applicable limits in Table 3-1, within the specified vacuum drying time limits as applicable.	Once, prior to TRANSPORT OPERATIONS
SR 3.1.1.2	Verify MPC helium backfill quantity is within the limit specified in Table 3-2 for the applicable MPC model. Re-performance of this surveillance is not required upon successful completion of Action C.2.2.	Once, prior to TRANSPORT OPERATIONS
SR 3.1.1.3	Verify that the helium leak rate through the MPC vent and drain port confinement welds meets the leaktight criteria of ANSI N14.5-1997.	Once, prior to TRANSPORT OPERATIONS

3.1 SFSC INTEGRITY

3.1.2 SFSC Heat Removal System

LCO 3.1.2 The SFSC Heat Removal System shall be operable

-----NOTE-----

The SFSC Heat Removal System is operable when 50% or more of the inlet and outlet vent areas are unblocked and available for flow or when air temperature requirements are met.

APPLICABILITY: During STORAGE OPERATIONS.

ACTIONS

-----NOTE-----

Separate Condition entry is allowed for each SFSC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. SFSC Heat Removal System operable, but partially (<50%) blocked.	A.1 Remove blockage.	N/A
B. SFSC Heat Removal System inoperable.	B.1 Restore SFSC Heat Removal System to operable status.	8 hours

CONDITION	REQUIRED ACTION	COMPLETION TIME
C. Required Action B.1 and associated Completion Time not met.	C.1 Measure SFSC dose rates in accordance with the Radiation Protection Program.	Immediately and once per 12 hours thereafter
	<u>AND</u>	
	C.2.1 Restore SFSC Heat Removal System to operable status.	64 hours (*aboveground OVERPACK*, MPC heat $\leq$ 28.74 kW) 24 hours (*aboveground OVERPACK*, MPC heat >28.74 kW) *16 hours (underground OVERPACK)*
	<u>OR</u>	
	C.2.2 Transfer the MPC into a TRANSFER CASK.	64 hours (*aboveground OVERPACK*, MPC heat $\leq$ 28.74 kW) 24 hours (*aboveground OVERPACK*, MPC heat >28.74 kW) *16 hours (underground OVERPACK)*

SURVEILLANCE REQUIREMENTS

	SURVEILLANCE	FREQUENCY
SR 3.1.2	Verify all OVERPACK inlets and outlets ~~air ducts~~ are free of blockage from solid debris or floodwater.	24 hours *(aboveground OVERPACK)* *16 hours (underground OVERPACK)*
	<u>OR</u>	
	For OVERPACKS with installed temperature monitoring equipment, verify that the difference between the average OVERPACK air outlet temperature and ISFSI ambient temperature is $\leq$ 155°F for *aboveground* OVERPACKS containing PWR MPCs, $\leq$ 137°F for *aboveground* OVERPACKS containing BWR MPCs, *$\leq$ 85°F for underground OVERPACKS containing PWR MPCs, $\leq$ 93°F for underground OVERPACKs containing BWR MPCs.*	24 hours *(aboveground OVERPACK)* *16 hours (underground OVERPACK)*

3.1 SFSC INTEGRITY

3.1.3 MPC Cavity Reflooding

LCO 3.1.3 The MPC cavity pressure shall be < 100 psig

-----NOTE-----
The LCO is only applicable to wet UNLOADING OPERATIONS.

APPLICABILITY: UNLOADING OPERATIONS prior to and during re-flooding.

ACTIONS
-----NOTE-----
Separate Condition entry is allowed for each MPC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. MPC cavity pressure not within limit.	A.1 Stop re-flooding operations until MPC cavity pressure is within limit.	Immediately
	<u>AND</u>	
	A.2 Ensure MPC vent port is not closed or blocked.	Immediately

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.3.1	Ensure via analysis or direct measurement that MPC cavity pressure is within limit.	Once, prior to MPC re-flooding operations. <u>AND</u> Once every 1 hour thereafter when using direct measurement.

3.1 SFSC INTEGRITY

3.1.4 Supplemental Cooling System

LCO 3.1.4 The Supplemental Cooling System (SCS) shall be operable

--NOTE--
Upon reaching steady state operation, the SCS may be temporarily disabled for a short duration ($\leq$ 7 hours) to facilitate necessary operational evolutions, such as movement of the TRANSFER CASK through a door way, or other similar operation.

APPLICABILITY: This LCO is applicable when the loaded MPC is in the TRANSFER CASK and:

a. Within 4 hours of the completion of MPC drying operations in accordance with LCO 3.1.1 or within 4 hours of transferring the MPC into the TRANSFER CASK if the MPC is to be unloaded

AND

b1. The MPC contains one or more fuel assemblies with an average burnup > 45,000 MWD/MTU

OR

b2. The MPC decay heat load exceeds 28.74 kW.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. SFSC Supplemental Cooling System inoperable.	A.1 Restore SFSC Supplemental Cooling System to operable status.	7 days
B. Required Action A.1 and associated Completion Time not met.	B.1 Remove all fuel assemblies from the SFSC.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.4.1	Verify Supplemental Cooling System is operable.	2 hours

3.1 SFSC INTEGRITY

3.1.5 Impressed Current Cathodic Protection System (ICCPS)

LCO 3.1.5 The ICCPS shall be maintained operative

APPLICABILITY: During STORAGE OPERATIONS for any ISFSI that uses an ICCPS for corrosion mitigation.

------------------------------NOTE------------------------------
Separate condition entry is allowed for each ICCPS at a particular ISFSI site.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. ICCPS inoperable after initial startup period.	A.1 Restore ICCPS to operable status	6 months
	OR	
	A.2 Perform engineering evaluation to determine that the affected VVM's will maintain adequate integrity for at least 4 more years.	1 year
B. ICCPS 70% operable status not met.	B.1 Perform engineering evaluation to determine that the affected VVM's will maintain adequate integrity for at least 3 more years.	1 year
	OR	
	B.2 Perform repairs necessary to re-establish integrity of the affected VVM's	3 years

ACTIONS
(continued)

CONDITION	REQUIRED ACTION	COMPLETION TIME
C. Required Actions and associated Completion Times not met.	C.1 Transfer MPC's from affected VVM's to unaffected VVM's or other approved overpacks.	3 years

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.5.1	Verify the ICCPS is operable 1 year after installation of the first VVM and remains operable after initial startup. The ICCPS may be shutdown temporarily as necessary for power outages, repair or preventive maintenance and testing, or system modifications after which the system should be returned to operable status as soon as practicable. This surveillance requirement is suspended for one year after action A.2 has been met	Once within 1 year <u>AND</u> Every 1 month thereafter
SR 3.1.5.2	Verify the ICCPS has been operable for at least 70% of the time after initial startup. The verification shall not be performed prior to 8 years from the time of initial startup. If the integrity of the VVM has previously been re-established per ACTION B.2, then the initial startup period may be reset. This surveillance is no longer applicable upon initiation of ACTION C.1.	Once within 10 years <u>AND</u> Every 5 years thereafter

3.2 SFSC RADIATION PROTECTION.

3.2.1 Deleted.

LCO 3.2.1 Deleted.

3.2 SFSC RADIATION PROTECTION.

3.2.2 TRANSFER CASK Surface Contamination.

LCO 3.2.2 Removable contamination on the exterior surfaces of the TRANSFER CASK and accessible portions of the MPC shall each not exceed:

a. 1000 dpm/100 cm^2 from beta and gamma sources

b. 20 dpm/100 cm^2 from alpha sources.

---NOTE---

This LCO is not applicable to the TRANSFER CASK if MPC transfer operations occur inside the FUEL BUILDING.

APPLICABILITY: During TRANSPORT OPERATIONS.

ACTIONS

---NOTE---

Separate Condition entry is allowed for each TRANSFER CASK.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. TRANSFER CASK or MPC removable surface contamination limits not met.	A.1 Restore removable surface contamination to within limits.	7 days

SURVEILLANCE REQUIREMENTS

	SURVEILLANCE	FREQUENCY
SR 3.2.2.1	Verify that the removable contamination on the exterior surfaces of the TRANSFER CASK and accessible portions of the MPC containing fuel is within limits.	Once, prior to TRANSPORT OPERATIONS

3.2 SFSC RADIATION PROTECTION.

3.2.3 Deleted.

LCO 3.2.3 Deleted.

3.3 SFSC CRITICALITY CONTROL

3.3.1 Boron Concentration

LCO 3.3.1 As required by CoC Appendix B, Table 2.1-2, the concentration of boron in the water in the MPC shall meet the following limits for the applicable MPC model and the most limiting fuel assembly array/class and classification to be stored in the MPC:

a. MPC-24 with one or more fuel assemblies having an initial enrichment greater than the value in Table 2.1-2 for no soluble boron credit and ≤ 5.0 wt% ^{235}U: ≥ 400 ppmb

b. MPC-24E or MPC-24EF (all INTACT FUEL ASSEMBLIES) with one or more fuel assemblies having an initial enrichment greater than the value in Table 2.1-2 for no soluble boron credit and ≤ 5.0 wt% ^{235}U: ≥ 300 ppmb

c. Deleted.

d. Deleted.

e. MPC-24E or MPC-24EF (one or more DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS) with one or more fuel assemblies having an initial enrichment > 4.0 wt% ^{235}U and ≤ 5.0 wt% ^{235}U: ≥ 600 ppmb

f. MPC-32/32F: Minimum soluble boron concentration as required by the table below†.

Array/Class	All INTACT FUEL ASSEMBLIES		One or more DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS	
	Maximum Initial Enrichment ≤ 4.1 wt% ^{235}U (ppmb)	Maximum Initial Enrichment 5.0 wt% ^{235}U (ppmb)	Maximum Initial Enrichment ≤ 4.1 wt% ^{235}U (ppmb)	Maximum Initial Enrichment 5.0 wt% ^{235}U (ppmb)
14x14A/B/C/D/E	1,300	1,900	1,500	2,300
15x15A/B/C/G	1,800	2,500	1,900	2,700
15x15D/E/F/H	1,900	2,600	2,100	2,900
16x16A	1,400	2,000	1,500	2,300
17x17A/B/C	1,900	2,600	2,100	2,900

† For maximum initial enrichments between 4.1 wt% and 5.0 wt% ^{235}U, the minimum soluble boron concentration may be determined by linear interpolation between the minimum soluble boron concentrations at 4.1 wt% and 5.0 wt%.

APPLICABILITY: During PWR fuel LOADING OPERATIONS with fuel and water in the MPC

AND

During PWR fuel UNLOADING OPERATIONS with fuel and water in the MPC.

ACTIONS

-----NOTE-----
Separate Condition entry is allowed for each MPC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Boron concentration not within limit.	A.1 Suspend LOADING OPERATIONS or UNLOADING OPERATIONS.	Immediately
	AND	
	A.2 Suspend positive reactivity additions.	Immediately
	AND	
	A.3 Initiate action to restore boron concentration to within limit.	Immediately

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
-----NOTE----- This surveillance is only required to be performed if the MPC is submerged in water or if water is to be added to, or recirculated through the MPC. ----------		
SR 3.3.1.1	Verify boron concentration is within the applicable limit using two independent measurements.	Once, within 4 hours prior to entering the Applicability of this LCO. AND Once per 48 hours thereafter.

Table 3-1
MPC Cavity Drying Limits

Fuel Burnup (MWD/MTU)	MPC Heat Load (kW)	Method of Moisture Removal (Notes 1 and 2)
All Assemblies ≤ 45,000	≤ 29 (MPC-24/24E/24EF) ≤ 26 (MPC-32/32F) ≤ 26 (MPC-68/68F/68FF)	VDS or FHD
All Assemblies ≤ 45,000	> 29 (MPC-24/24E/24EF) > 26 (MPC-32/32F) > 26 (MPC-68/68F/68FF)	FHD
One or more assemblies > 45,000	≤ 36.9	FHD

Notes:

1. VDS means Vacuum Drying System. The acceptance criterion for VDS is MPC cavity pressure shall be ≤ 3 torr for ≥ 30 minutes.

2. FHD means Forced Helium Dehydration System. The acceptance criterion for the FHD System is gas temperature exiting the demoisturizer shall be ≤ 21°F for ≥ 30 minutes or gas dew point exiting the MPC shall be ≤ 22.9°F for ≥ 30 minutes .

3. For total decay heat loads up to and including 20.88 kW for the MPC-24 and 21.52 kW for the MPC-68, vacuum drying of the MPC must be performed with the annular gap between the MPC and the HI-TRAC filled with water. For higher total decay heat loads in the MPC-24 and MPC-68 or for any decay heat load in an MPC-24E or MPC-32, the annular gap must be continuously flushed with water with sufficient flow to keep the exit water temperature below 125°F.

Table 3-2
MPC Helium Backfill Limits[1]

MPC MODEL	LIMIT
MPC-24/24E/24EF	
i. Cask Heat Load ≤ 27.77 kW (MPC-24) or ≤ 28.17 kW (MPC-24E/EF)	0.1212 +/-10% g-moles/l OR ≥ 29.3 psig and ≤ 48.5 psig
ii. Cask Heat Load >27.77 kW (MPC-24) or > 28.17 kW (MPC-24E/EF)	≥ 45.5 psig and ≤ 48.5 psig
MPC-68/68F/68FF	
i. Cask Heat Load ≤ 28.19 kW	0.1218 +/-10% g-moles/l OR ≥ 29.3 psig and ≤ 48.5 psig
ii. Cask Heat Load > 28.19 kW	≥ 45.5 psig and ≤ 48.5 psig
MPC-32/32F	
i Cask Heat Load ≤ 28.74 kW	≥ 29.3 psig and ≤ 48.5 psig
ii. Cask Heat Load >28.74 kW	≥ 45.5 psig and ≤ 48.5 psig

1 Helium used for backfill of MPC shall have a purity of ≥ 99.995%. Pressure range is at a reference temperature of 70°F

4.0

This section is intentionally left blank

5.0 ADMINISTRATIVE CONTROLS AND PROGRAMS

The following programs shall be established, implemented and maintained.

5.1 Deleted.

5.2 Deleted.5.3 Deleted.

5.4 Radioactive Effluent Control Program

This program implements the requirements of 10 CFR 72.44(d).

a. The HI-STORM 100 Cask System does not create any radioactive materials or have any radioactive waste treatment systems. Therefore, specific operating procedures for the control of radioactive effluents are not required. Specification 3.1.1, Multi-Purpose Canister (MPC), provides assurance that there are not radioactive effluents from the SFSC.

b. This program includes an environmental monitoring program. Each general license user may incorporate SFSC operations into their environmental monitoring programs for 10 CFR Part 50 operations.

c. An annual report shall be submitted pursuant to 10 CFR 72.44(d)(3).

(continued)

5.5 Cask Transport Evaluation Program

This program provides a means for evaluating various transport configurations and transport route conditions to ensure that the design basis drop limits are met. For lifting of the loaded TRANSFER CASK or OVERPACK using devices which are integral to a structure governed by 10 CFR Part 50 regulations, 10 CFR 50 requirements apply. This program is not applicable when the TRANSFER CASK or OVERPACK is in the FUEL BUILDING or is being handled by a device providing support from underneath (i.e., on a rail car, heavy haul trailer, air pads, etc...) or is being handled by a device designed in accordance with the increased safety factors of ANSI N14.6 and~~/or~~ having redundant drop protection. |

Pursuant to 10 CFR 72.212, this program shall evaluate the site-specific transport route conditions.

a. For free-standing OVERPACKS and the TRANSFER CASK, the following requirements apply:

1. The lift height above the transport route surface(s) shall not exceed the limits in Table 5-1 except as provided for in Specification 5.5.a.2. Also, *if applying the limits in Table 5-1,* the program shall ensure that the transport route conditions (i.e., surface hardness and pad thickness) are equivalent to or less limiting than either Set A or Set B in HI-STORM FSAR Table 2.2.9. |

2. ~~For site-specific transport route surfaces that are not bounded by either the Set A or Set B parameters of FSAR Table 2.2.9, t~~*T*he program may determine lift heights by analysis based on the site-specific conditions to ensure that the impact loading due to design basis drop events does not exceed 45 g's at the top of the MPC fuel basket. These alternative analyses shall be commensurate with the drop analyses described in the Final Safety Analysis Report for the HI-STORM 100 Cask System. The program shall ensure that these alternative analyses are documented and controlled. |
|

(continued)

ADMINISTRATIVE CONTROLS AND PROGRAMS

5.5 Cask Transport Evaluation Program (continued)

3. The TRANSFER CASK or OVERPACK, when loaded with spent fuel, may be lifted to any height necessary during *TRANSPORT OPERATIONS* ~~transportation between the FUEL BUILDING and the CTF and/or ISFSI pad~~, provided the lifting device is designed in accordance with ANSI N14.6 and has redundant drop protection features.

4. The TRANSFER CASK and MPC, when loaded with spent fuel, may be lifted to those heights necessary to perform cask handling operations, including MPC transfer, provided the lifts are made with structures and components designed in accordance with the criteria specified in Section 3.5 of Appendix B to Certificate of Compliance No. 1014, as applicable.

b. For the transport of OVERPACKS to be anchored to the ISFSI pad, the following requirements apply:

1. Except as provided in 5.5.b.2, user shall determine allowable OVERPACK lift height limit(s) above the transport route surface(s) based on site-specific transport route conditions. The lift heights shall be determined by evaluation or analysis, based on limiting the design basis cask deceleration during a postulated drop event to $\leq$ 45 g's at the top of the MPC fuel basket. Evaluations and/or analyses shall be performed using methodologies consistent with those in the HI-STORM 100 FSAR.

2. The OVERPACK, when loaded with spent fuel, may be lifted to any height necessary during *TRANSPORT OPERATIONS* ~~transportation between the FUEL BUILDING and the CTF and/or ISFSI pad~~ provided the lifting device is designed in accordance with ANSI N14.6 and has redundant drop protection features.

(continued)

5.5 Cask Transport Evaluation Program (continued)

Table 5-1

TRANSFER CASK and Free-Standing OVERPACK Lifting Requirements

ITEM	ORIENTATION	LIFTING HEIGHT LIMIT (in.)
TRANSFER CASK	Horizontal	42 (Notes 1 and 2)
TRANSFER CASK	Vertical	None Established (Note 2)
OVERPACK	Horizontal	Not Permitted
OVERPACK	Vertical	11 (Note 3)

Notes:
1. To be measured from the lowest point on the TRANSFER CASK (i.e., the bottom edge of the cask/lid assemblage)
2. See Technical Specification 5.5.a.3 and 4
3. See Technical Specification 5.5.a.3.

(continued)

ADMINISTRATIVE CONTROLS AND PROGRAMS

5.6 Deleted.

5.7 Radiation Protection Program

5.7.1 Each cask user shall ensure that the Part 50 radiation protection program appropriately addresses dry storage cask loading and unloading, as well as ISFSI operations, including transport of the loaded OVERPACK or TRANSFER CASK outside of facilities governed by 10 CFR Part 50. The radiation protection program shall include appropriate controls for direct radiation and contamination, ensuring compliance with applicable regulations, and implementing actions to maintain personnel occupational exposures As Low As Reasonably Achievable (ALARA). The actions and criteria to be included in the program are provided below.

5.7.2 As part of its evaluation pursuant to 10 CFR 72.212(b)(2)(i)(C), the licensee shall perform an analysis to confirm that the dose limits of 10 CFR 72.104(a) will be satisfied under the actual site conditions and ISFSI configuration, considering the planned number of casks to be deployed and the cask contents.

5.7.3 Based on the analysis performed pursuant to Section 5.7.2, the licensee shall establish individual cask surface dose rate limits for the HI-TRAC TRANSFER CASK and the HI-STORM OVERPACK to be used at the site. Total (neutron plus gamma) dose rate limits shall be established at the following locations:

a. The top of the TRANSFER CASK and the OVERPACK.
b. The side of the TRANSFER CASK and *aboveground* OVERPACK
c. The inlet and outlet ducts on the *aboveground* OVERPACK
d. The outlet vent on the underground OVERPACK

5.7.4 Notwithstanding the limits established in Section 5.7.3, the measured dose rates on a loaded OVERPACK shall not exceed the following values:

a. 30 mrem/hr (gamma + neutron) on the top of the *aboveground* OVERPACK
b. 300 mrem/hr (gamma + neutron) on the side of the *aboveground* OVERPACK, excluding inlet and outlet ducts
c. 30 mrem/hr (gamma+neutron) on the top of the underground OVERPACK

5.7.5 The licensee shall measure the TRANSFER CASK and OVERPACK surface neutron and gamma dose rates as described in Section 5.7.8 for comparison against the limits established in Section 5.7.3 or Section 5.7.4, whichever are lower.

5.7 Radiation Protection Program (cont'd)

5.7.6 If the measured surface dose rates exceed the lower of the two limits established in Section 5.7.3 or Section 5.7.4, the licensee shall:

a. Administratively verify that the correct contents were loaded in the correct fuel storage cell locations.

b. Perform a written evaluation to verify whether ~~placement of the as-loaded~~ *an* OVERPACK at the ISFSI *containing the as-loaded MPC* will cause the dose limits of 10 CFR 72.104 to be exceeded.

c. Perform a written evaluation within 30 days to determine why the surface dose rate limits were exceeded.

5.7.7 If the evaluation performed pursuant to Section 5.7.6 shows that the dose limits of 10 CFR 72.104 will be exceeded, the MPC shall not be placed into storage *or, in the case of the underground OVERPACK or the aboveground OVERPACK loaded at the ISFSI, shall be removed from storage* until appropriate corrective action is taken to ensure the dose limits are not exceeded.

5.7.8 TRANSFER CASK and OVERPACK surface dose rates shall be measured at approximately the following locations:

a. A minimum of four (4) dose rate measurements shall be taken on the side of the TRANSFER CASK approximately at the cask mid-height plane. The measurement locations shall be approximately 90 degrees apart around the circumference of the cask. Dose rates shall be measured between the radial ribs of the water jacket.

b. A minimum of four (4) TRANSFER CASK top lid dose rates shall be measured at locations approximately half way between the edge of the hole in the top lid and the outer edge of the top lid, 90 degrees apart around the circumference of the top lid.

c. A minimum of twelve (12) dose rate measurements shall be taken on the side of the *aboveground* OVERPACK in three sets of four measurements. One measurement set shall be taken approximately at the cask mid-height plane, 90 degrees apart around the circumference of the cask. The second and third measurement sets shall be taken approximately 60 inches above and below the mid-height plane, respectively, also 90 degrees apart around the circumference of the cask.

5.7 Radiation Protection Program (cont'd)

d. A minimum of five (5) dose rate measurements shall be taken on the top of the *aboveground* OVERPACK. One dose rate measurement shall be taken at approximately the center of the lid and four measurements shall be taken at locations on the top concrete shield, approximately half way between the center and the edge of the top concrete shield, 90 degrees apart around the circumference of the lid.

e. *A minimum of four (4) dose rate measurements shall be taken on the top of the underground OVERPACK. These measurements shall be taken approximately 90 degrees apart around the circumference of the lid, approximately 18 inches radially inward from the edge of the lid.*

f. *A minimum of four (4) dose rate measurements shall be taken adjacent to the outlet vent screen of the underground OVERPACK, approximately 90 degrees apart.*

ge. A dose rate measurement shall be taken on contact at the surface of each inlet and outlet vent duct screen of the *aboveground* OVERPACK.

5.7.9 *The "Radiation Protection Space" (RPS) is a prismatic subgrade buffer zone surrounding a loaded underground OVERPACK. The RPS boundary is located at a minimum of fourteen (14) feet from the centerline of a loaded underground OVERPACK on the periphery of an operating ISFSI, and at a minimum of twenty-one (21) feet from the centerline of a loaded underground OVERPACK not on the periphery. The RPS boundary shall not be encroached upon during any site construction activity. The jurisdictional boundary of the RPS extends from the top surface of the foundation pad to the top of the VVM interface pad and the top surface pad. The ISFSI design shall ensure that there is no significant loss of shielding in the RPS due to a credible accident or an extreme environment event during construction involving excavation adjacent to the RPS boundary.*

CERTIFICATE OF COMPLIANCE NO. 1014

APPENDIX B

APPROVED CONTENTS AND DESIGN FEATURES

FOR THE HI-STORM 100 CASK SYSTEM

TABLE OF CONTENTS

1.0 Definitions

---NOTE---
The defined terms of this section appear in capitalized type and are applicable throughout these Technical Specifications and Bases.

Term	Definition
CASK TRANSFER FACILITY (CTF)	A CASK TRANSFER FACILITY is an aboveground or underground system used during the transfer of a loaded MPC between a transfer cask and a storage OVERPACK. The CASK TRANSFER FACILITY includes the following components and equipment: (1) a Cask Transfer Structure used to stabilize the OVERPACK, TRANSFER CASK and/or MPC during lifts involving spent fuel not bounded by the regulations of 10 CFR Part 50, and (2) Either a stationary lifting device or a mobile lifting device used in concert with the stationary structure to lift the OVERPACK, TRANSFER CASK, and/or MPC.
DAMAGED FUEL ASSEMBLY	DAMAGED FUEL ASSEMBLIES are fuel assemblies with known or suspected cladding defects, as determined by a review of records, greater than pinhole leaks or hairline cracks, empty fuel rod locations that are not filled with dummy fuel rods, missing structural components such as grid spacers, whose structural integrity has been impaired such that geometric rearrangement of fuel or gross failure of the cladding is expected based on engineering evaluations, or that cannot be handled by normal means. Fuel assemblies that cannot be handled by normal means due to fuel cladding damage are considered FUEL DEBRIS.
DAMAGED FUEL CONTAINER (DFC)	DFCs are specially designed enclosures for DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS which permit gaseous and liquid media to escape while minimizing dispersal of gross particulates. DFCs authorized for use in the HI-STORM 100 System are as follows: 1. Holtec Dresden Unit 1/Humboldt Bay design 2. Transnuclear Dresden Unit 1 design 3. Holtec Generic BWR design 4. Holtec Generic PWR design

(continued)

1.0 Definitions (continued)

FUEL DEBRIS	FUEL DEBRIS is ruptured fuel rods, severed rods, loose fuel pellets, containers or structures that are supporting these loose fuel assembly parts, or fuel assemblies with known or suspected defects which cannot be handled by normal means due to fuel cladding damage.
INTACT FUEL ASSEMBLY	INTACT FUEL ASSEMBLIES are fuel assemblies without known or suspected cladding defects greater than pinhole leaks or hairline cracks and which can be handled by normal means. Fuel assemblies without fuel rods in fuel rod locations shall not be classified as INTACT FUEL ASSEMBLIES unless dummy fuel rods are used to displace an amount of water greater than or equal to that displaced by the fuel rod(s).
LOADING OPERATIONS	LOADING OPERATIONS include all licensed activities on an OVERPACK or TRANSFER CASK while it is being loaded with fuel assemblies. LOADING OPERATIONS begin when the first fuel assembly is placed in the MPC and end when the OVERPACK or TRANSFER CASK is suspended from or secured on the transporter. LOADING OPERATIONS does not included MPC transfer between the TRANSFER CASK and the OVERPACK, which begins when the MPC is lifted off the HI-TRAC bottom lid and ends when the MPC is supported from beneath by the OVERPACK.
MINIMUM ENRICHMENT	MINIMUM ENRICHMENT is the minimum assembly average enrichment. Natural uranium blankets are not considered in determining minimum enrichment.
MULTI-PURPOSE CANISTER (MPC)	MPCs are the sealed spent nuclear fuel canisters which consist of a honeycombed fuel basket contained in a cylindrical canister shell which is welded to a baseplate, lid with welded port cover plates, and closure ring. The MPC provides the confinement boundary for the contained radioactive materials.
NON-FUEL HARDWARE	NON-FUEL HARDWARE is defined as Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Devices (TPDs), Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs), Wet Annular Burnable Absorbers (WABAs), Rod Cluster Control Assemblies (RCCAs), Control Element Assemblies (CEAs), Neutron Source Assemblies (NSAs), water displacement guide tube plugs, orifice rod assemblies, and vibration suppressor inserts, and components of these devices such as individual rods.

(continued)

1.0 Definitions (continued)

OVERPACK	OVERPACKs are the casks which receive and contain the sealed MPCs for interim storage on the ISFSI. They provide gamma and neutron shielding, and provide for ventilated air flow to promote heat transfer from the MPC to the environs. The *term* OVERPACK *includes the VVM, but* does not include the TRANSFER CASK.
PLANAR-AVERAGE INITIAL ENRICHMENT	PLANAR AVERAGE INITIAL ENRICHMENT is the average of the distributed fuel rod initial enrichments within a given axial plane of the assembly lattice.
SPENT FUEL STORAGE CASKS (SFSCs)	An SFSC is a container approved for the storage of spent fuel assemblies at the ISFSI. The HI-STORM 100 SFSC System consists of the OVERPACK and its integral MPC.
TRANSFER CASK	TRANSFER CASKs are containers designed to contain the MPC during and after loading of spent fuel assemblies and to transfer the MPC to or from the OVERPACK. The HI-STORM 100 System employs either the 125-Ton or the 100-Ton HI-TRAC TRANSFER CASK.
TRANSPORT OPERATIONS	TRANSPORT OPERATIONS include all licensed activities performed on an OVERPACK or TRANSFER CASK loaded with one or more fuel assemblies when it is being moved *after LOADING OPERATIONS or before UNLOADING OPERATIONS* ~~to and from the ISFSI~~. TRANSPORT OPERATIONS begin when the OVERPACK or TRANSFER CASK is first suspended from or secured on the transporter and end when the OVERPACK or TRANSFER CASK is at its destination and no longer secured on or suspended from the transporter. TRANSPORT OPERATIONS include transfer of the MPC between the OVERPACK and the TRANSFER CASK which begins when the MPC is lifted off the HI-TRAC bottom lid and ends when the MPC is supported from beneath by the OVERPACK (or the reverse).

(continued)

1.0 Definitions (continued)

UNLOADING OPERATIONS	UNLOADING OPERATIONS include all licensed activities on an SFSC to be unloaded of the contained fuel assemblies. UNLOADING OPERATIONS begin when the OVERPACK or TRANSFER CASK is no longer suspended from or secured on the transporter and end when the last fuel assembly is removed from the SFSC. UNLOADING OPERATIONS does not include MPC transfer between the TRANSFER CASK and the OVERPACK which begins when the MPC is no longer supported from beneath by the OVERPACK and ends when the MPC is lowered onto the HI-TRAC bottom lid.
ZR	ZR means any zirconium-based fuel cladding or fuel channel material authorized for use in a commercial nuclear power plant reactor.

2.0 APPROVED CONTENTS

2.1 Fuel Specifications and Loading Conditions

2.1.1 Fuel To Be Stored In The HI-STORM 100 SFSC System

a. INTACT FUEL ASSEMBLIES, DAMAGED FUEL ASSEMBLIES, FUEL DEBRIS, and NON-FUEL HARDWARE meeting the limits specified in Table 2.1-1 and other referenced tables may be stored in the HI-STORM 100 SFSC System.

b. For MPCs partially loaded with stainless steel clad fuel assemblies, all remaining fuel assemblies in the MPC shall meet the decay heat generation limit for the stainless steel clad fuel assemblies.

c. For MPCs partially loaded with array/class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A fuel assemblies, all remaining ZR clad INTACT FUEL ASSEMBLIES in the MPC shall meet the decay heat generation limits for the 6x6A, 6x6B, 6x6C, 7x7A and 8x8A fuel assemblies.

d. All BWR fuel assemblies may be stored with or without ZR channels with the exception of array/class 10x10D and 10x10E fuel assemblies, which may be stored with or without ZR or stainless steel channels.

2.1.2 Uniform Fuel Loading

Any authorized fuel assembly may be stored in any fuel storage location, subject to other restrictions related to DAMAGED FUEL, FUEL DEBRIS, and NON-FUEL HARDWARE specified in the CoC.

(continued)

2.0 Approved Contents

2.1 Fuel Specifications and Loading Conditions (cont'd)

2.1.3 Regionalized Fuel Loading

Users may choose to store fuel using regionalized loading in lieu of uniform loading to allow higher heat emitting fuel assemblies to be stored than would otherwise be able to be stored using uniform loading. Regionalized loading is limited to those fuel assemblies with ZR cladding. Figures 2.1-1 through 2.1-4 define the regions for the MPC-24, MPC-24E, MPC-24EF, MPC-32, MPC-32F, MPC-68, and MPC-68FF models, respectively[1]. Fuel assembly burnup, decay heat, and cooling time limits for regionalized loading are specified in Section 2.4.2. Fuel assemblies used in regionalized loading shall meet all other applicable limits specified in Tables 2.1-1 through 2.1-3.

2.2 Violations

If any Fuel Specifications or Loading Conditions of 2.1 are violated, the following actions shall be completed:

2.2.1 The affected fuel assemblies shall be placed in a safe condition.

2.2.2 Within 24 hours, notify the NRC Operations Center.

2.2.3 Within 30 days, submit a special report which describes the cause of the violation, and actions taken to restore compliance and prevent recurrence.

2.3 Not Used

[1] These figures are only intended to distinguish the fuel loading regions. Other details of the basket design are illustrative and may not reflect the actual basket design details. The design drawings should be consulted for basket design details.

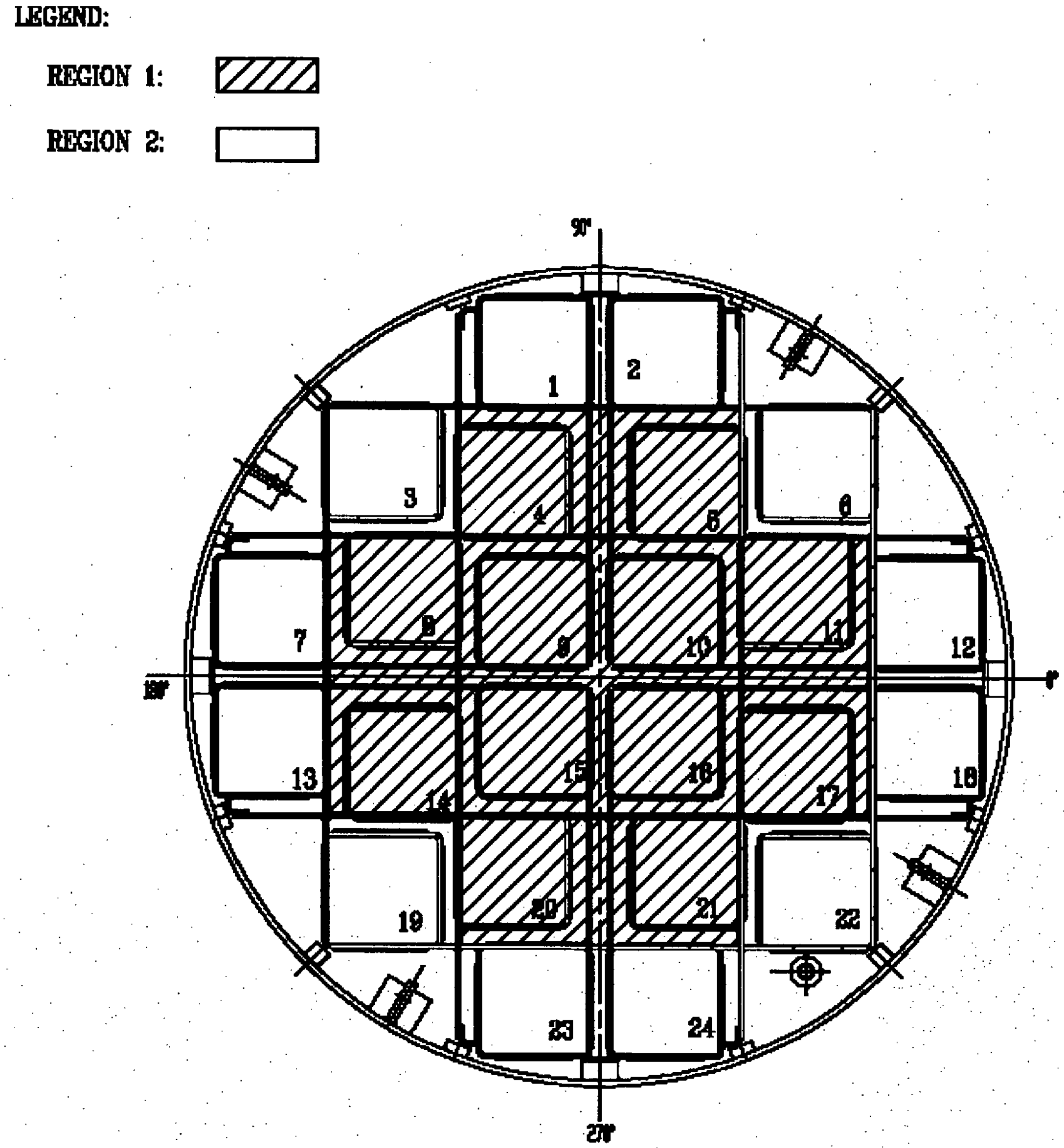

Figure 2.1-1
Fuel Loading Regions - MPC-24

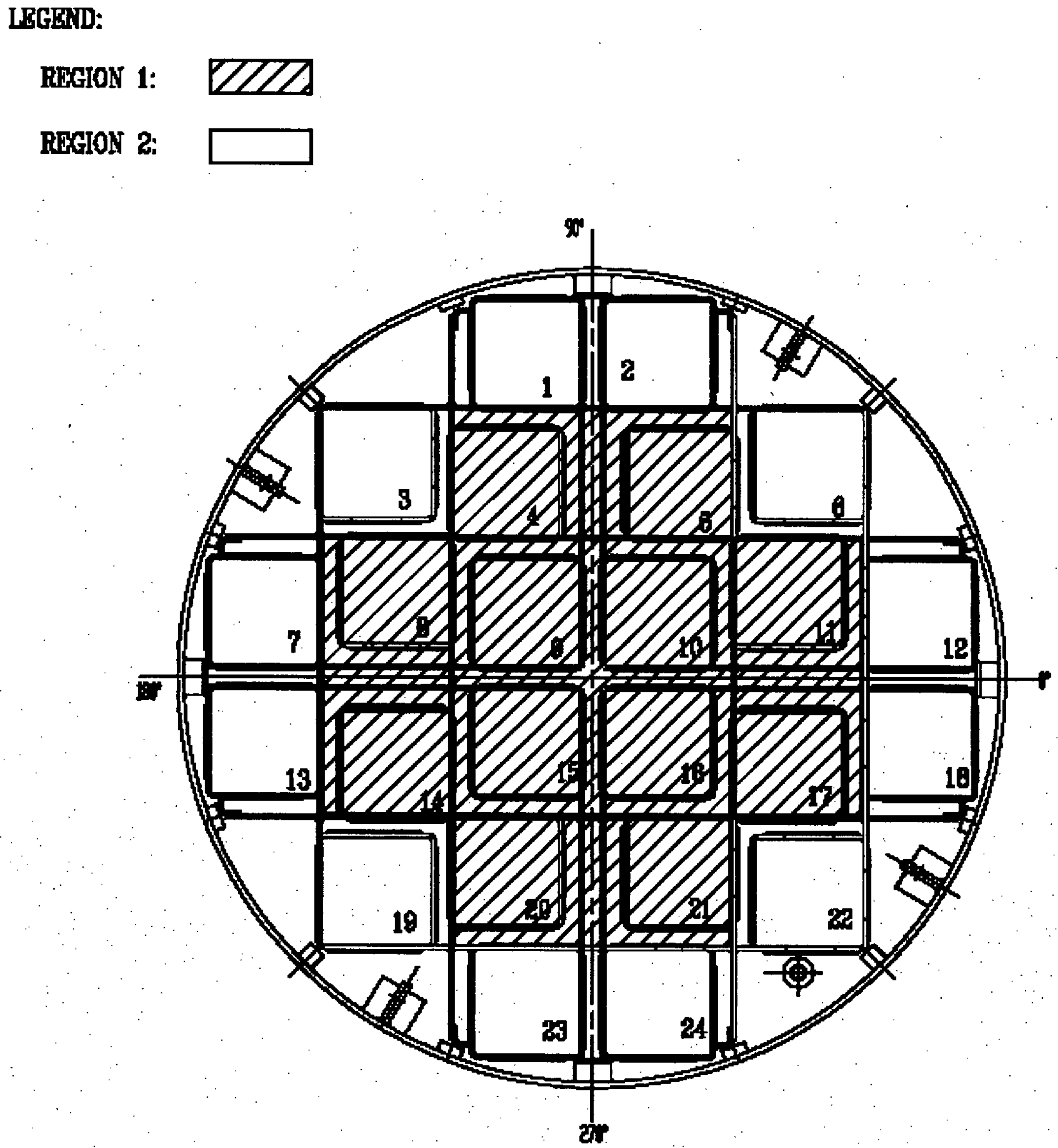

Figure 2.1-2
Fuel Loading Regions - MPC-24E/24EF

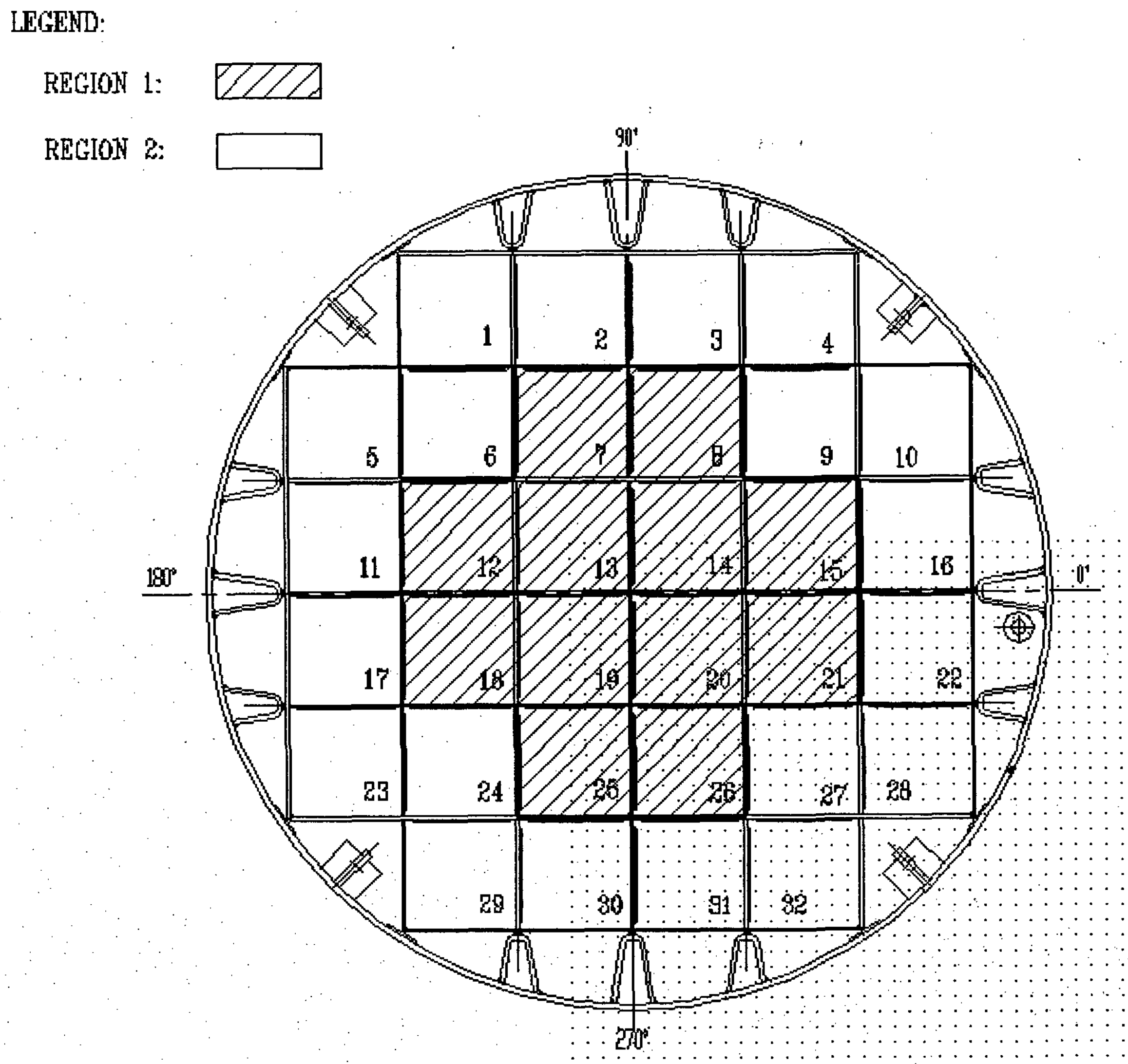

Figure 2.1-3
Fuel Loading Regions - MPC-32/32F

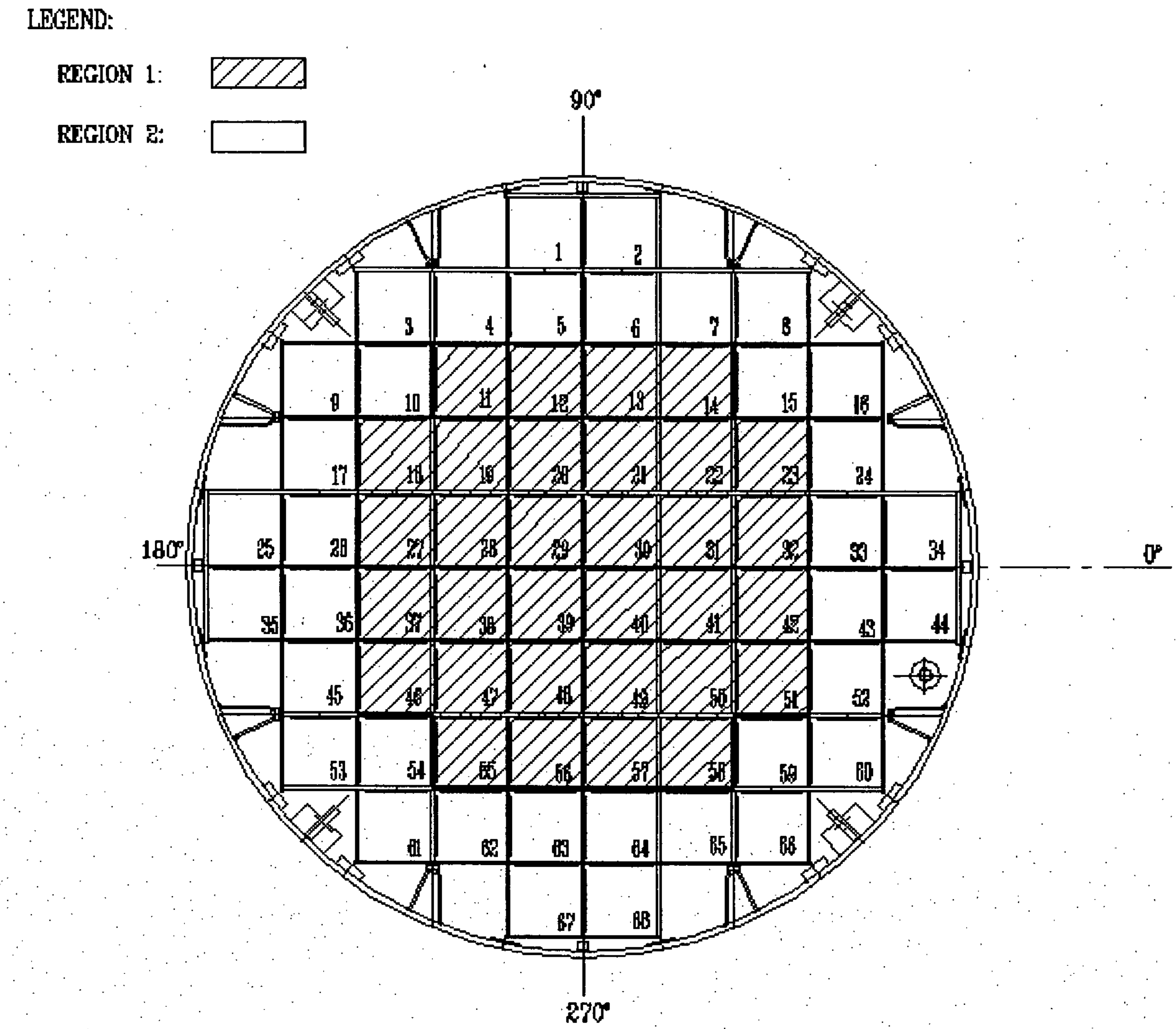

Figure 2.1-4
Fuel Loading Regions - MPC-68/68FF

Table 2.1-1 (page 1 of 24)
Fuel Assembly Limits

I. MPC MODEL: MPC-24

A. Allowable Contents

1. Uranium oxide, PWR INTACT FUEL ASSEMBLIES listed in Table 2.1-2, with or without NON-FUEL HARDWARE and meeting the following specifications (Note 1):

a. Cladding Type:	ZR or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class.
b. Initial Enrichment:	As specified in Table 2.1-2 for the applicable fuel assembly array/class.
c. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 14x14D,14x14E, and 15x15G	Cooling time $\geq$ 8 years and an average burnup $\leq$ 40,000 MWD/MTU.
ii. All Other Array/Classes	Cooling time and average burnup as specified in Section 2.4.
iii. NON-FUEL HARDWARE	As specified in Table 2.1-8.

Table 2.1-1 (page 2 of 24)
Fuel Assembly Limits

I. MPC MODEL: MPC-24 (continued)

A. Allowable Contents (continued)

d. Decay Heat Per Fuel Storage Location:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	≤ 710 Watts
ii All Other Array/Classes	As specified in Section 2.4.
e. Fuel Assembly Length:	≤ 176.8 inches (nominal design)
f. Fuel Assembly Width:	≤ 8.54 inches (nominal design)
g. Fuel Assembly Weight:	≤ 1720 lbs (including NON-FUEL HARDWARE) for assemblies that do not require fuel spacers, otherwise ≤ 1680 lbs (including NON-FUEL HARDWARE)

B. Quantity per MPC: Up to 24 fuel assemblies.

C. Deleted.

D. DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS are not authorized for loading into the MPC-24.

E. One NSA is authorized for loading into the MPC-24.

Note 1: Fuel assemblies containing BPRAs, TPDs, WABAs, water displacement guide tube plugs, orifice rod assemblies, or vibration suppressor inserts may be stored in any fuel storage location. Fuel assemblies containing APSRs or NSAs may only be loaded in fuel storage locations 9, 10, 15, and/or 16. Fuel assemblies containing CRAs, RCCAs, CEAs may only be stored in fuel storage locations 4, 5, 8 - 11, 14 - 17, 20 and/or 21 (see Figure 2.1-1). These requirements are in addition to any other requirements specified for uniform or regionalized fuel loading.

Table 2.1-1 (page 3 of 24)
Fuel Assembly Limits

II. MPC MODEL: MPC-68F

A. Allowable Contents

1. Uranium oxide, BWR INTACT FUEL ASSEMBLIES, with or without ZR channels. Uranium oxide BWR INTACT FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array class 6x6A, 6x6C, 7x7A or 8x8A, and meet the following specifications:

a. Cladding Type:	ZR
b Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time $\geq$ 18 years and an average burnup $\leq$ 30,000 MWD/MTU.
e. Decay Heat Per Assembly	$\leq$ 115 Watts
f. Fuel Assembly Length:	$\leq$ 135.0 inches (nominal design)
g. Fuel Assembly Width:	$\leq$ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	$\leq$ 400 lbs, including channels

Table 2.1-1 (page 4 of 24)
Fuel Assembly Limits

II. MPC MODEL: MPC-68F (continued)

A. Allowable Contents (continued)

2. Uranium oxide, BWR DAMAGED FUEL ASSEMBLIES, with or without ZR channels, placed in DAMAGED FUEL CONTAINERS. Uranium oxide BWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6A, 6x6C, 7x7A, or 8x8A, and meet the following specifications:

a. Cladding Type:	ZR
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU.
e. Decay Heat Per Assembly:	≤ 115 Watts
f. Fuel Assembly Length:	≤ 135.0 inches (nominal design)
g. Fuel Assembly Width:	≤ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	≤ 550 lbs, including channels and DFC

Table 2.1-1 (page 5 of 24)
Fuel Assembly Limits

II. MPC MODEL: MPC-68F (continued)

A. Allowable Contents (continued)

3. Uranium oxide, BWR FUEL DEBRIS, with or without ZR channels, placed in DAMAGED FUEL CONTAINERS. The original fuel assemblies for the uranium oxide BWR FUEL DEBRIS shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6A, 6x6C, 7x7A, or 8x8A, and meet the following specifications:

a. Cladding Type:	ZR
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable original fuel assembly array/class.
c Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for the applicable original fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly	Cooling time $\geq$ 18 years and an average burnup $\leq$ 30,000 MWD/MTU for the original fuel assembly.
e. Decay Heat Per Assembly	$\leq$ 115 Watts
f. Original Fuel Assembly Length	$\leq$ 135.0 inches (nominal design)
g. Original Fuel Assembly Width	$\leq$ 4.70 inches (nominal design)
h. Fuel Debris Weight	$\leq$ 550 lbs, including channels and DFC

Table 2.1-1 (page 6 of 24)
Fuel Assembly Limits

II. MPC MODEL: MPC-68F (continued)

A. Allowable Contents (continued)

4. Mixed oxide (MOX), BWR INTACT FUEL ASSEMBLIES, with or without ZR channels. MOX BWR INTACT FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	ZR
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time $\geq$ 18 years and an average burnup $\leq$ 30,000 MWD/MTIHM.
e. Decay Heat Per Assembly	$\leq$ 115 Watts
f. Fuel Assembly Length:	$\leq$ 135.0 inches (nominal design)
g. Fuel Assembly Width:	$\leq$ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	$\leq$ 400 lbs, including channels

Table 2.1-1 (page 7of 24)
Fuel Assembly Limits

II. MPC MODEL: MPC-68F (continued)

A. Allowable Contents (continued)

5. Mixed oxide (MOX), BWR DAMAGED FUEL ASSEMBLIES, with or without ZR channels, placed in DAMAGED FUEL CONTAINERS. MOX BWR DAMAGED FUEL ASSEMBLIES shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	ZR
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for fuel assembly array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time $\geq$ 18 years and an average burnup $\leq$ 30,000 MWD/MTIHM.
e. Decay Heat Per Assembly	$\leq$ 115 Watts
f. Fuel Assembly Length:	$\leq$ 135.0 inches (nominal design)
g. Fuel Assembly Width:	$\leq$ 4.70 inches (nominal design)
h. Fuel Assembly Weight:	$\leq$ 550 lbs, including channels and DFC

Table 2.1-1 (page 8 of 24)
Fuel Assembly Limits

II. MPC MODEL: MPC-68F (continued)

A. Allowable Contents (continued)

6. Mixed Oxide (MOX), BWR FUEL DEBRIS, with or without ZR channels, placed in DAMAGED FUEL CONTAINERS. The original fuel assemblies for the MOX BWR FUEL DEBRIS shall meet the criteria specified in Table 2.1-3 for fuel assembly array/class 6x6B, and meet the following specifications:

a. Cladding Type:	ZR
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for original fuel assembly array/class 6x6B.
c. Initial Maximum Rod Enrichment:	As specified in Table 2.1-3 for original fuel assembly array/class 6x6B.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	Cooling time $\geq$ 18 years and an average burnup $\leq$ 30,000 MWD/MTIHM for the original fuel assembly.
e. Decay Heat Per Assembly	$\leq$ 115 Watts
f. Original Fuel Assembly Length:	$\leq$ 135.0 inches (nominal design)
g. Original Fuel Assembly Width:	$\leq$ 4.70 inches (nominal design)
h. Fuel Debris Weight:	$\leq$ 550 lbs, including channels and DFC

Table 2.1-1 (page 9 of 24)
Fuel Assembly Limits

II. MPC MODEL: MPC-68F (continued)

A. Allowable Contents (continued)

7. Thoria rods (ThO_2 and UO_2) placed in Dresden Unit 1 Thoria Rod Canisters and meeting the following specifications:

a. Cladding Type:	ZR
b. Composition:	98.2 wt.% ThO_2, 1.8 wt. % UO_2 with an enrichment of 93.5 wt. % ^{235}U.
c. Number of Rods Per Thoria Rod Canister:	$\leq$ 18
d. Decay Heat Per Thoria Rod Canister:	$\leq$ 115 Watts
e. Post-irradiation Fuel Cooling Time and Average Burnup Per Thoria Rod Canister:	A fuel post-irradiation cooling time $\geq$ 18 years and an average burnup $\leq$ 16,000 MWD/MTIHM.
f. Initial Heavy Metal Weight:	$\leq$ 27 kg/canister
g. Fuel Cladding O.D.:	$\geq$ 0.412 inches
h. Fuel Cladding I.D.:	$\leq$ 0.362 inches
i. Fuel Pellet O.D.:	$\leq$ 0.358 inches
j. Active Fuel Length:	$\leq$ 111 inches
k. Canister Weight:	$\leq$ 550 lbs, including fuel

Table 2.1-1 (page 10 of 24)
Fuel Assembly Limits

II. MPC MODEL: MPC-68F (continued)

B. Quantity per MPC (up to a total of 68 assemblies):
(All fuel assemblies must be array/class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A):

Up to four (4) DFCs containing uranium oxide BWR FUEL DEBRIS or MOX BWR FUEL DEBRIS. The remaining MPC-68F fuel storage locations may be filled with fuel assemblies of the following type, as applicable:

1. Uranium oxide BWR INTACT FUEL ASSEMBLIES;

2. MOX BWR INTACT FUEL ASSEMBLIES;

3. Uranium oxide BWR DAMAGED FUEL ASSEMBLIES placed in DFCs;

4. MOX BWR DAMAGED FUEL ASSEMBLIES placed in DFCs; or

5. Up to one (1) Dresden Unit 1 Thoria Rod Canister.

C. Fuel assemblies with stainless steel channels are not authorized for loading in the MPC-68F.

D. Dresden Unit 1 fuel assemblies with one Antimony-Beryllium neutron source are authorized for loading in the MPC-68F. The Antimony-Beryllium source material shall be in a water rod location.

Table 2.1-1 (page 11 of 24)
Fuel Assembly Limits

III. MPC MODEL: MPC-68 and MPC-68FF

A. Allowable Contents

1. Uranium oxide or MOX BWR INTACT FUEL ASSEMBLIES listed in Table 2.1-3, with or without channels and meeting the following specifications:

a. Cladding Type:	ZR or Stainless Steel (SS) as specified in Table 2.1-3 for the applicable fuel assembly array/class
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
c. Initial Maximum Rod Enrichment	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
~~e.~~*d.* Post-irradiation Cooling Time and Average Burnup Per Assembly	
i. Array/Classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A	Cooling time ≥ 18 years and an average burnup ≤ 30,000 MWD/MTU (or M~~TU~~*WD*/MTIHM).
ii. Array/Class 8x8F	Cooling time ≥ 10 years and an average burnup ≤ 27,500 MWD/MTU.
iii. Array/Classes 10x10D and 10x10E	Cooling time ≥ 10 years and an average burnup ≤ 22,500 MWD/MTU.
iv. All Other Array/Classes	As specified in Section 2.4.

Table 2.1-1 (page 12 of 24)
Fuel Assembly Limits

III. MPC MODEL: MPC-68 and MPC-68FF (continued)

A. Allowable Contents (continued)

e. Decay Heat Per Assembly

i. Array/Classes 6x6A, 6X6~~b~~*B*, 6x6C, 7x7A, and 8x8A	≤ 115 Watts
ii. Array/Class 8x8F	≤ 183.5 Watts
iii. Array/Classes 10x10D and 10x10E	≤ 95 Watts
iv. All Other Array/Classes	As specified in Section 2.4.

f. Fuel Assembly Length

i. Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 135.0 inches (nominal design)
ii. All Other Array/Classes	≤ 176.5 inches (nominal design)

g. Fuel Assembly Width

i. Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 4.70 inches (nominal design)
ii. All Other Array/Classes	≤ 5.85 inches (nominal design)

h. Fuel Assembly Weight

i. Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ ~~550~~400 lbs, including channels
ii. All Other Array/Classes	≤ 730 lbs, including channels

Table 2.1-1 (page 13 of 24)
Fuel Assembly Limits

III. MPC MODEL: MPC-68 and MPC-68FF (continued)

A. Allowable Contents (continued)

2. Uranium oxide or MOX BWR DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS, with or without channels, placed in DAMAGED FUEL CONTAINERS. Uranium oxide and MOX BWR DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS shall meet the criteria specified in Table 2.1-3, and meet the following specifications:

a. Cladding Type:	ZR or Stainless Steel (SS) in accordance with Table 2.1-3 for the applicable fuel assembly array/class.
b. Maximum PLANAR-AVERAGE INITIAL ENRICHMENT:	
i. Array/Classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A.	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
ii. All Other Array Classes	$\leq$ 4.0 wt.% ^{235}U.
c. Initial Maximum Rod Enrichment	As specified in Table 2.1-3 for the applicable fuel assembly array/class.
d. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	Cooling time $\geq$ 18 years and an average burnup $\leq$ 30,000 MWD/MTU (or MWD/MTIHM).
ii. Array/Class 8x8F	Cooling time $\geq$ 10 years and an average burnup $\leq$ 27,500 MWD/MTU.
iii. Array/Class 10x10D and 10x10E	Cooling time $\geq$ 10 years and an average burnup $\leq$ 22,500 MWD/MTU.
iv. All Other Array/Classes	As specified in Section 2.4.

Table 2.1-1 (page 14 of 24)
Fuel Assembly Limits

III. MPC MODEL: MPC-68 and MPC-68FF (continued)

A. Allowable Contents (continued)

e. Decay Heat Per Assembly

i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 115 Watts
ii.	Array/Class 8x8F	≤ 183.5 Watts
iii.	Array/Classes 10x10D and 10x10E	≤ 95 Watts
iv.	All Other Array/Classes	As specified in Section 2.4.

f. Fuel Assembly Length

i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 135.0 inches (nominal design)
ii.	All Other Array/Classes	≤ 176.5 inches (nominal design)

g. Fuel Assembly Width

i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 4.70 inches (nominal design)
ii.	All Other Array/Classes	≤ 5.85 inches (nominal design)

h. Fuel Assembly Weight

i.	Array/Class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A	≤ 550 lbs, including channels and DFC
ii.	All Other Array/Classes	≤ 730 lbs, including channels and DFC

Table 2.1-1 (page 15 of 24)
Fuel Assembly limits

III. MPC MODEL: MPC-68 and MPC-68FF (continued)

A. Allowable Contents (continued)

3. Thoria rods (ThO_2 and UO_2) placed in Dresden Unit 1 Thoria Rod Canisters and meeting the following specifications:

a.	Cladding type	ZR
b.	Composition:	98.2 wt.% ThO_2, 1.8 wt.% UO_2 with an enrichment of 93.5 wt.% ^{235}U.
c.	Number of Rods per Thoria Rod Canister:	$\leq$ 18
d.	Decay Heat Per Thoria Rod Canister:	$\leq$ 115 Watts
e.	Post-irradiation Fuel Cooling Time and Average Burnup per Thoria Rod Canister:	A fuel post-irradiation cooling time $\geq$ 18 years and an average burnup $\leq$16,000 MWD/MTIHM
f.	Initial Heavy Metal Weight:	$\leq$ 27 kg/canister
g.	Fuel Cladding O.D.:	$\geq$ 0.412 inches
h.	Fuel Cladding I.D.:	$\leq$ 0.362 inches
i.	Fuel Pellet O.D.:	$\leq$ 0.358 inches
j.	Active Fuel Length:	$\leq$ 111 inches
k.	Canister Weight:	$\leq$ 550 lbs, including fuel

Table 2.1-1 (page 16 of 24)
Fuel Assembly Limits

III. MPC MODEL: MPC-68 and MPC-68FF (continued)

B. Quantity per MPC (up to a total of 68 assemblies)

1. For fuel assembly array/classes 6x6A, 6X6B, 6x6C, 7x7A, or 8x8A, up to 68 BWR INTACT FUEL ASSEMBLIES and/or DAMAGED FUEL ASSEMBLIES. Up to eight (8) DFCs containing FUEL DEBRIS from these array/classes may be stored.

2. For all other array/classes, up to sixteen (16) DFCs containing BWR DAMAGED FUEL ASSEMBLIES and/or up to eight (8) DFCs containing FUEL DEBRIS. DFCs shall be located only in fuel storage locations 1, 2, 3, 8, 9, 16, 25, 34, 35, 44, 53, 60, 61, 66, 67, and/or 68. The remaining fuel storage locations may be filled with fuel assemblies of the following type:

   i. Uranium Oxide BWR INTACT FUEL ASSEMBLIES; or

   ii. MOX BWR INTACT FUEL ASSEMBLIES.

3. Up to one (1) Dresden Unit 1 Thoria Rod Canister

C. Dresden Unit 1 fuel assemblies with one Antimony-Beryllium neutron source are authorized for loading. The Antimony-Beryllium source material shall be in a water rod location.

D. Array/Class 10x10D and 10x10E fuel assemblies in stainless steel channels must be stored in fuel storage locations 19 - 22, 28 - 31, 38 -41, and/or 47 - 50 (see Figure 2.1-4).

Table 2.1-1 (page 17 of 24)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E and MPC-24EF

A. Allowable Contents

1. Uranium oxide, PWR INTACT FUEL ASSEMBLIES listed in Table 2.1-2, with or without NON-FUEL HARDWARE and meeting the following specifications (Note 1):

a. Cladding Type:	ZR or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class
b. Initial Enrichment:	As specified in Table 2.1-2 for the applicable fuel assembly array/class.
c. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	Cooling time $\geq$ 8 years and an average burnup $\leq$ 40,000 MWD/MTU.
ii. All Other Array/Classes	As specified in Section 2.4.
iii. NON-FUEL HARDWARE	As specified in Table 2.1-8.

Table 2.1-1 (page 18 of 24)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E and MPC-24EF (continued)

A. Allowable Contents (continued)

d. Decay Heat Per Fuel Storage Location:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	≤ 710 Watts.
ii. All other Array/Classes	As specified in Section 2.4.
e. Fuel Assembly Length:	≤ 176.8 inches (nominal design)
f. Fuel Assembly Width:	≤ 8.54 inches (nominal design)
g. Fuel Assembly Weight:	≤ 1,720 lbs (including NON-FUEL HARDWARE ~~and DFC~~) for assemblies that do not require fuel spacers, otherwise, ≤ 1,680 lbs (including NON-FUEL HARDWARE ~~and DFC~~)

Table 2.1-1 (page 19 of 24)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E and MPC-24EF (continued)

A. Allowable Contents (continued)

2. Uranium oxide, PWR DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS, with or without NON-FUEL HARDWARE, placed in DAMAGED FUEL CONTAINERS. Uranium oxide PWR DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS shall meet the criteria specified in Table 2.1-2 and meet the following specifications (Note 1):

a. Cladding Type:	ZR or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class
b. Initial Enrichment:	As specified in Table 2.1-2 for the applicable fuel assembly array/class.
c. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	Cooling time ≥ 8 years and an average burnup ≤ 40,000 MWD/MTU.
ii. All Other Array/Classes	As specified in Section 2.4.
iii. NON-FUEL HARDWARE	As specified in Table 2.1-8.

Table 2.1-1 (page 20 of 24)
Fuel Assembly Limits

IV. MPC MODEL: MPC-24E and MPC-24EF (continued)

A. Allowable Contents (continued)

d. Decay Heat Per Fuel Storage Location:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	≤ 710 Watts.
ii. All Other Array/Classes	As specified in Section 2.4.
e. Fuel Assembly Length	≤ 176.8 inches (nominal design)
f. Fuel Assembly Width	≤ 8.54 inches (nominal design)
g. Fuel Assembly Weight	≤ 1,720 lbs (including NON-FUEL HARDWARE and DFC) for assemblies that do not require fuel spacers, otherwise, ≤ 1,680 lbs (including NON-FUEL HARDWARE *and DFC*)

B. Quantity per MPC: Up to four (4) DAMAGED FUEL ASSEMBLIES and/or FUEL DEBRIS in DAMAGED FUEL CONTAINERS, stored in fuel storage locations 3, 6, 19 and/or 22. The remaining fuel storage locations may be filled with PWR INTACT FUEL ASSEMBLIES meeting the applicable specifications.

C. One NSA is permitted for loading.

Note 1: Fuel assemblies containing BPRAs, TPDs, WABAs, water displacement guide tube plugs, orifice rod assemblies, or vibration suppressor inserts may be stored in any fuel storage location. Fuel assemblies containing APSRs or NSAs may only be loaded in fuel storage locations 9, 10, 15, and/or 16 (see Figure 2.1-2). Fuel assemblies containing CRAs, RCCAs, or CEAs may only be stored in fuel storage locations 4, 5, 8-11, 14-17, 20 and/or 21 (see Figure 2.1-2). These requirements are in addition to any other requirements specified for uniform or regionalized fuel loading.

Table 2.1-1 (page 21 of 24)
Fuel Assembly Limits

V. MPC MODEL: MPC-32 and MPC-32F

A. Allowable Contents

1. Uranium oxide, PWR INTACT FUEL ASSEMBLIES listed in Table 2.1-2, with or without NON-FUEL HARDWARE and meeting the following specifications (Note 1):

a. Cladding Type:	ZR or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class
b. Initial Enrichment:	As specified in Table 2.1-2 for the applicable fuel assembly array/class.
c. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	Cooling time $\geq$ 9 years and an average burnup $\leq$ 30,000 MWD/MTU or cooling time $\geq$ 20 years and an average burnup $\leq$ 40,000 MWD/MTU.
ii. All Other Array/Classes	As specified in Section 2.4.
iii. NON-FUEL HARDWARE	As specified in Table 2.1-8.

Table 2.1-1 (page 22 of 24)
Fuel Assembly Limits

V. MPC MODEL: MPC-32 and MPC-32F (cont'd)

A. Allowable Contents (cont'd)

d. Decay Heat Per Fuel Storage Location:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	≤ 500 Watts.
ii. All Other Array/Classes	As specified in Section 2.4.
e. Fuel Assembly Length	≤ 176.8 inches (nominal design)
f. Fuel Assembly Width	≤ 8.54 inches (nominal design)
g. Fuel Assembly Weight	≤ 1,720 lbs (including NON-FUEL HARDWARE ~~and DFC~~) for assemblies that do not require fuel spacers, otherwise, ≤ 1,680 lbs (including NON-FUEL HARDWARE ~~and DFC~~)

Table 2.1-1 (page 23 of 24)
Fuel Assembly Limits

V. MPC MODEL: MPC-32 and MPC-32F (cont'd)

A. Allowable Contents (cont'd)

2. Uranium oxide, PWR DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS, with or without NON-FUEL HARDWARE, placed in DAMAGED FUEL CONTAINERS. Uranium oxide PWR DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS shall meet the criteria specified in Table 2.1-2 and meet the following specifications (Note 1):

a. Cladding Type:	ZR or Stainless Steel (SS) as specified in Table 2.1-2 for the applicable fuel assembly array/class
b. Initial Enrichment:	As specified in Table 2.1-2 for the applicable fuel assembly array/class.
c. Post-irradiation Cooling Time and Average Burnup Per Assembly:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	Cooling time $\geq$ 9 years and an average burnup $\leq$ 30,000 MWD/MTU or cooling time $\geq$ 20 years and an average burnup $\leq$ 40,000 MWD/MTU.
ii. All Other Array/Classes	As specified in Section 2.4.
iii. NON-FUEL HARDWARE	As specified in Table 2.1-8.

Table 2.1-1 (page 24 of 24)
Fuel Assembly Limits

V. MPC MODEL: MPC-32 and MPC-32F (cont'd)

A. Allowable Contents (cont'd)

d. Decay Heat Per Fuel Storage Location:	
i. Array/Classes 14x14D, 14x14E, and 15x15G	≤ 500 Watts.
ii. All Other Array/Classes	As specified in Section 2.~~3~~4.
e. Fuel Assembly Length	≤ 176.8 inches (nominal design)
f. Fuel Assembly Width	≤ 8.54 inches (nominal design)
g. Fuel Assembly Weight	≤ 1,720 lbs (including NON-FUEL HARDWARE and DFC) for assemblies that do not require fuel spacers, otherwise, ≤ 1,680 lbs (including NON-FUEL HARDWARE and DFC)

B. Quantity per MPC: Up to eight (8) DAMAGED FUEL ASSEMBLIES and/or FUEL DEBRIS in DAMAGED FUEL CONTAINERS, stored in fuel storage locations 1, 4, 5, 10, 23, 28, 29, and/or 32. The remaining fuel storage locations may be filled with PWR INTACT FUEL ASSEMBLIES meeting the applicable specifications.

C. One NSA is permitted for loading.

Note 1: Fuel assemblies containing BPRAs, TPDs, WABAs, water displacement guide tube plugs, orifice rod assemblies, or vibration suppressor inserts may be stored in any fuel storage location. Fuel assemblies containing NSAs may only be loaded in fuel storage locations 13, 14, 19 and/or 20 (see Figure 2.1-3). Fuel assemblies containing CRAs, RCCAs, CEAs or APSRs may only be loaded in fuel storage locations 7, 8, 12-15, 18-21, 25 and/or 26 (see Figure 2.1-3). These requirements are in addition to any other requirements specified for uniform or regionalized fuel loading.

Table 2.1-2 (page 1 of 4)
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**14x14A**	**14x14B**	**14x14C**	**14x14D**	**14x14E**
Clad Material	ZR	ZR	ZR	SS	SS
Design Initial U (kg/assy.) (Note 3)	≤ 365	≤ 412	≤ 438	≤ 400	≤ 206
Initial Enrichment (MPC-24, 24E and 24EF without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.6 (24) ≤ 5.0 (24E/24EF)	≤ 4.6 (24) ≤ 5.0 (24E/24EF)	≤ 4.6 (24) ≤ 5.0 (24E/24EF)	≤ 4.0 (24) ≤ 5.0 (24E/24EF)	≤ 5.0 (24) ≤ 5.0 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, 32, or 32F with soluble boron credit - see Note 5) (wt % ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	179	179	176	180	173
Fuel Rod Clad O.D. (in.)	≥ 0.400	≥ 0.417	≥ 0.440	≥ 0.422	≥ 0.3415
Fuel Rod Clad I.D. (in.)	≤ 0.3514	≤ 0.3734	≤ 0.3880	≤ 0.3890	≤ 0.3175
Fuel Pellet Dia. (in.) (Note 8)	≤ 0.3444	≤ 0.3659	≤ 0.3805	≤ 0.3835	≤ 0.3130
Fuel Rod Pitch (in.)	≤ 0.556	≤ 0.556	≤ 0.580	≤ 0.556	Note 6
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 144	≤ 102
No. of Guide and/or Instrument Tubes	17	17	5 (Note 4)	16	0
Guide/Instrument Tube Thickness (in.)	≥ 0.017	≥ 0.017	≥ 0.038	≥ 0.0145	N/A

Table 2.1-2 (page 2 of 4)
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**15x15A**	**15x15B**	**15x15C**	**15x15D**	**15x15E**	**15x15F**
Clad Material	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 473	≤ 473	≤ 473	≤ 495	≤ 495	≤ 495
Initial Enrichment (MPC-24, 24E and 24EF without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, 32, or 32F with soluble boron credit - see Note 5) (wt % ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	204	204	204	208	208	208
Fuel Rod Clad O.D. (in.)	≥ 0.418	≥ 0.420	≥ 0.417	≥ 0.430	≥ 0.428	≥ 0.428
Fuel Rod Clad I.D. (in.)	≤ 0.3660	≤ 0.3736	≤ 0.3640	≤ 0.3800	≤ 0.3790	≤ 0.3820
Fuel Pellet Dia. (in.) (Note 8)	≤ 0.3580	≤ 0.3671	≤ 0.3570	≤ 0.3735	≤ 0.3707	≤ 0.3742
Fuel Rod Pitch (in.)	≤ 0.550	≤ 0.563	≤ 0.563	≤ 0.568	≤ 0.568	≤ 0.568
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	21	21	21	17	17	17
Guide/Instrument Tube Thickness (in.)	≥ 0.0165	≥ 0.015	≥ 0.0165	≥ 0.0150	≥ 0.0140	≥ 0.0140

Table 2.1-2 (page 3 of 4)
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/ Class	**15x15G**	**15x15H**	**16x16A**	**17x17A**	**17x17B**	**17x17C**
Clad Material	SS	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 420	≤ 495	≤ 448	≤ 433	≤ 474	≤ 480
Initial Enrichment (MPC-24, 24E, and 24EF without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.0 (24) ≤ 4.5 (24E/24EF)	≤ 3.8 (24) ≤ 4.2 (24E/24EF)	≤ 4.6 (24) ≤ 5.0 (24E/24EF)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, 32, or 32F with soluble boron credit - see Note 5) (wt % ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	204	208	236	264	264	264
Fuel Rod Clad O.D. (in.)	≥ 0.422	≥ 0.414	≥ 0.382	≥ 0.360	≥ 0.372	≥ 0.377
Fuel Rod Clad I.D. (in.)	≤ 0.3890	≤ 0.3700	≤ 0.3350	≤ 0.3150	≤ 0.3310	≤ 0.3330
Fuel Pellet Dia. (in.) (Note 8)	≤ 0.3825	≤ 0.3622	≤ 0.3255	≤ 0.3088	≤ 0.3232	≤ 0.3252
Fuel Rod Pitch (in.)	≤ 0.563	≤ 0.568	≤ 0.506	≤ 0.496	≤ 0.496	≤ 0.502
Active Fuel Length (in.)	≤ 144	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	21	17	5 (Note 4)	25	25	25
Guide/Instrument Tube Thickness (in.)	≥ 0.0145	≥ 0.0140	≥ 0.0350	≥ 0.016	≥ 0.014	≥ 0.020

Table 2.1-2 (page 4 of 4)
PWR FUEL ASSEMBLY CHARACTERISTICS

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.

2. Deleted.

3. Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or reactor user. For each PWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 2.0 percent for comparison with users' fuel records to account for manufacturer's tolerances.

4. Each guide tube replaces four fuel rods.

5. Soluble boron concentration per LCO 3.3.1.

6. This fuel assembly array/class includes only the Indian Point Unit 1 fuel assembly. This fuel assembly has two pitches in different sectors of the assembly. These pitches are 0.441 inches and 0.453 inches.

7. For those MPCs loaded with both INTACT FUEL ASSEMBLIES and DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS, the maximum initial enrichment of the INTACT FUEL ASSEMBLIES, DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS is 4.0 wt.% ^{235}U.

8. Annular fuel pellets are allowed in the top and bottom 12" of the active fuel length.

Table 2.1-3 (page 1 of 5)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**6x6A**	**6x6B**	**6x6C**	**7x7A**	**7x7B**	**8x8A**
Clad Material	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	$\leq$ 110	$\leq$ 110	$\leq$ 110	$\leq$ 100	$\leq$ 198	$\leq$ 120
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) (Note 14)	$\leq$ 2.7	$\leq$ 2.7 for the UO_2 rods. See Note 4 for MOX rods	$\leq$ 2.7	$\leq$ 2.7	$\leq$ 4.2	$\leq$ 2.7
Initial Maximum Rod Enrichment (wt.% ^{235}U)	$\leq$ 4.0	$\leq$ 4.0	$\leq$ 4.0	$\leq$ 5.5	$\leq$ 5.0	$\leq$ 4.0
No. of Fuel Rod Locations	35 or 36	35 or 36 (up to 9 MOX rods)	36	49	49	63 or 64
Fuel Rod Clad O.D. (in.)	$\geq$ 0.5550	$\geq$ 0.5625	$\geq$ 0.5630	$\geq$ 0.4860	$\geq$ 0.5630	$\geq$ 0.4120
Fuel Rod Clad I.D. (in.)	$\leq$ 0.5105	$\leq$ 0.4945	$\leq$ 0.4990	$\leq$ 0.4204	$\leq$ 0.4990	$\leq$ 0.3620
Fuel Pellet Dia. (in.)	$\leq$ 0.4980	$\leq$ 0.4820	$\leq$ 0.4880	$\leq$ 0.4110	$\leq$ 0.4910	$\leq$ 0.3580
Fuel Rod Pitch (in.)	$\leq$ 0.710	$\leq$ 0.710	$\leq$ 0.740	$\leq$ 0.631	$\leq$ 0.738	$\leq$ 0.523
Active Fuel Length (in.)	$\leq$ 120	$\leq$ 120	$\leq$ 77.5	$\leq$ 80	$\leq$ 150	$\leq$ 120
No. of Water Rods (Note 11)	1 or 0	1 or 0	0	0	0	1 or 0
Water Rod Thickness (in.)	> 0	> 0	N/A	N/A	N/A	$\geq$ 0
Channel Thickness (in.)	$\leq$ 0.060	$\leq$ 0.060	$\leq$ 0.060	$\leq$ 0.060	$\leq$ 0.120	$\leq$ 0.100

Table 2.1-3 (2 of 5)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**8x8B**	**8x8C**	**8x8D**	**8x8E**	**8x8F**	**9x9A**
Clad Material	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 192	≤ 190	≤ 190	< 190	≤ 191	≤ 180
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) (Note 14)	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.0	≤ 4.2
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	63 or 64	62	60 or 61	59	64	74/66 (Note 5)
Fuel Rod Clad O.D. (in.)	≥ 0.4840	≥ 0.4830	≥ 0.4830	≥ 0.4930	≥ 0.4576	≥ 0.4400
Fuel Rod Clad I.D. (in.)	≤ 0.4295	≤ 0.4250	≤ 0.4230	≤ 0.4250	≤ 0.3996	≤ 0.3840
Fuel Pellet Dia. (in.)	≤ 0.4195	≤ 0.4160	≤ 0.4140	≤ 0.4160	≤ 0.3913	≤ 0.3760
Fuel Rod Pitch (in.)	≤ 0.642	≤ 0.641	≤ 0.640	≤ 0.640	≤ 0.609	≤ 0.566
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 11)	1 or 0	2	1 - 4 (Note 7)	5	N/A (Note 12)	2
Water Rod Thickness (in.)	≥ 0.034	> 0.00	> 0.00	≥ 0.034	≥ 0.0315	> 0.00
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.100	≤ 0.055	≤ 0.120

Table 2.1-3 (page 3 of 5)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**9x9B**	**9x9C**	**9x9D**	**9x9E (Note 13)**	**9x9F (Note 13)**	**9x9G**
Clad Material	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 180	≤ 182	≤ 182	≤ 183	≤ 183	≤ 164
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) (Note 14)	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.0	≤ 4.0	≤ 4.2
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	72	80	79	76	76	72
Fuel Rod Clad O.D. (in.)	≥ 0.4330	≥ 0.4230	≥ 0.4240	≥ 0.4170	≥ 0.4430	≥ 0.4240
Fuel Rod Clad I.D. (in.)	≤ 0.3810	≤ 0.3640	≤ 0.3640	≤ 0.3640	≤ 0.3860	≤ 0.3640
Fuel Pellet Dia. (in.)	≤ 0.3740	≤ 0.3565	≤ 0.3565	≤ 0.3530	≤ 0.3745	≤ 0.3565
Fuel Rod Pitch (in.)	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 11)	1 (Note 6)	1	2	5	5	1 (Note 6)
Water Rod Thickness (in.)	> 0.00	≥ 0.020	≥ 0.0300	≥ 0.0120	≥ 0.0120	≥ 0.0320
Channel Thickness (in.)	≤ 0.120	≤ 0.100	≤ 0.100	≤ 0.120	≤ 0.120	≤ 0.120

Table 2.1-3 (page 4 of 5)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**10x10A**	**10x10B**	**10x10C**	**10x10D**	**10x10E**
Clad Material	ZR	ZR	ZR	SS	SS
Design Initial U (kg/assy.) (Note 3)	≤ 188	≤ 188	≤ 179	≤ 125	≤ 125
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) (Note 14)	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.0	≤ 4.0
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	92/78 (Note 8)	91/83 (Note 9)	96	100	96
Fuel Rod Clad O.D. (in.)	≥ 0.4040	≥ 0.3957	≥ 0.3780	≥ 0.3960	≥ 0.3940
Fuel Rod Clad I.D. (in.)	≤ 0.3520	≤ 0.3480	≤ 0.3294	≤ 0.3560	≤ 0.3500
Fuel Pellet Dia. (in.)	≤ 0.3455	≤ 0.3420	≤ 0.3224	≤ 0.3500	≤ 0.3430
Fuel Rod Pitch (in.)	≤ 0.510	≤ 0.510	≤ 0.488	≤ 0.565	≤ 0.557
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 83	≤ 83
No. of Water Rods (Note 11)	2	1 (Note 6)	5 (Note 10)	0	4
Water Rod Thickness (in.)	≥ 0.0300	> 0.00	≥ 0.031	N/A	≥ 0.022
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.055	≤ 0.080	≤ 0.080

Table 2.1-3 (page 5 of 5)
BWR FUEL ASSEMBLY CHARACTERISTICS

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.

2. Deleted.

3. Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or reactor user. For each BWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 1.5 percent for comparison with users' fuel records to account for manufacturer tolerances.

4. $\leq$ 0.635 wt. % ^{235}U and $\leq$ 1.578 wt. % total fissile plutonium (^{239}Pu and ^{241}Pu), (wt. % of total fuel weight, i.e., UO_2 plus PuO_2).

5. This assembly class contains 74 total rods; 66 full length rods and 8 partial length rods.

6. Square, replacing nine fuel rods.

7. Variable.

8. This assembly contains 92 total fuel rods; 78 full length rods and 14 partial length rods.

9. This assembly class contains 91 total fuel rods; 83 full length rods and 8 partial length rods.

10. One diamond-shaped water rod replacing the four center fuel rods and four rectangular water rods dividing the assembly into four quadrants.

11. These rods may also be sealed at both ends and contain Zr material in lieu of water.

12. This assembly is known as "QUAD+." It has four rectangular water cross segments dividing the assembly into four quadrants.

13. For the SPC 9x9-5 fuel assembly, each fuel rod must meet either the 9x9E or the 9x9F set of limits for clad O.D., clad I.D., and pellet diameter.

14. For those MPCs loaded with both INTACT FUEL ASSEMBLIES and DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS, the maximum PLANAR AVERAGE INITIAL ENRICHMENT for the INTACT FUEL ASSEMBLIES is limited to 3.7 wt.% ^{235}U, as applicable.

Table 2.1-4

TABLE DELETED

Table 2.1-5

TABLE DELETED

Table 2.1-6

TABLE DELETED

Table 2.1-7

TABLE DELETED

Table 2.1-8
NON-FUEL HARDWARE COOLING AND AVERAGE BURNUP (Notes 1, 2, and 3)

Post-irradiation Cooling Time (years)	INSERTS (Note 4) BURNUP (MWD/MTU)	NSA or GUIDE TUBE HARDWARE (Note 5) BURNUP (MWD/MTU)	CONTROL COMPONENT (Note 6) BURNUP (MWD/MTU)	APSR BURNUP (MWD/MTU)
≥ 3	≤ 24,635	NA (Note 7)	NA	NA
≥ 4	≤ 30,000	≤ 20,000	NA	NA
≥ 5	≤ 36,748	≤ 25,000	≤ 630,000	≤ 45,000
≥ 6	≤ 44,102	≤ 30,000	-	≤ 54,500
≥ 7	≤ 52,900	≤ 40,000	-	≤ 68,000
≥ 8	≤ 60,000	≤ 45,000	-	≤ 83,000
≥ 9	-	≤ 50,000	-	≤ 111,000
≥ 10	-	≤ 60,000	-	≤ 180,000
≥ 11	-	≤ 75,000	-	≤ 630,000
≥ 12	-	≤ 90,000	-	-
≥ 13	-	≤ 180,000	-	-
≥ 14	-	≤ 630,000	-	-

Notes:
1. Burnups for NON-FUEL HARDWARE are to be determined based on the burnup and uranium mass of the fuel assemblies in which the component was inserted during reactor operation.
2. Linear interpolation between points is permitted, except that NSA or Guide Tube Hardware and APSR burnups > 180,000 MWD/MTU and ≤ 630,000 MWD/MTU must be cooled ≥ 14 years and ≥ 11 years, respectively.
3. Applicable to uniform loading and regionalized loading.
4. Includes Burnable Poison Rod Assemblies (BPRAs), Wet Annular Burnable Absorbers (WABAs), and vibration suppressor inserts..
5. Includes Thimble Plug Devices (TPDs), water displacement guide tube plugs, and orifice rod assemblies.
6. Includes Control Rod Assemblies (CRAs), Control Element Assemblies (CEAs), and Rod Cluster Control Assemblies (RCCAs).
7. NA means not authorized for loading at this cooling time.

2.4 Decay Heat, Burnup, and Cooling Time Limits for ZR-Clad Fuel

This section provides the limits on ZR-clad fuel assembly decay heat, burnup, and cooling time for storage in the HI-STORM 100 System. The method to calculate the limits and verify compliance, including examples, is provided in Chapter 12 of the HI-STORM 100 FSAR.

2.4.1 Uniform Fuel Loading Decay Heat Limits for ZR-clad fuel

Table 2.4-1 provides the maximum allowable decay heat per fuel storage location for ZR-clad fuel in uniform fuel loading for each MPC model *for aboveground and underground systems*.

Table 2.4-1

Maximum Allowable Decay Heat per Fuel Storage Location
(Uniform Loading, ZR-Clad)

MPC Model	**Decay Heat per Fuel Storage Location *(aboveground)*** (kW)	***Decay Heat per Fuel Storage Location (underground)*** *(kW)*
Intact Fuel Assemblies		
MPC-24	≤ 1.416	*≤ 1.266*
MPC-24E/24EF	≤ 1.416	*≤ 1.266*
MPC-32/32F	≤ 1.062	*≤ 0.949*
MPC-68/68FF	≤ 0.500	*≤ 0.447*
Damaged Fuel Assemblies and Fuel Debris		
MPC-24E/24EF	*≤ 1.114*	*Not Permitted*
MPC-32/32F	*≤ 0.718*	*Not Permitted*
MPC-68/68FF	*≤ 0.393*	*Not Permitted*

2.4.2 Regionalized Fuel Loading Decay Heat Limits for ZR-Clad Fuel *(Intact Fuel only)*

2.4.2.1 Aboveground Storage

The maximum allowable decay heat per fuel storage location for fuel in regionalized loading is determined using the following equations:

$Q(X) = 2 \times Q_0 / (1 + X^y)$

$y = 0.23 / X^{0.1}$

$q_2 = Q(X) / (n_1 \times X + n_2)$

$q_1 = q_2 \times X$

Where:
Q_0 = Maximum uniform storage MPC decay heat (34 kW)
X = Inner region to outer region assembly decay heat ratio ($0.5 \leq X \leq 3$)
n_1 = Number of storage locations in inner region from Table 2.4-2.
n_2 = Number of storage locations in outer region from Table 2.4-2.

2.4.2.2 Underground Storage

The maximum allowable decay heat per fuel storage location for fuel in regionalized loading is determined using the following equations:

$Q(X) = 2 \times \alpha \times Q_0 / (1 + X^y)$

$y = 0.23 / X^{0.1}$

$q_2 = Q(X) / (n_1 \times X + n_2)$

$q_1 = q_2 \times X$

Where:
Q_0 = Maximum uniform storage MPC decay heat (34 kW)
α = Penalty Factor (0.894)
X = Inner region to outer region assembly decay heat ratio ($0.5 \leq X \leq 3$)
n_1 = Number of storage locations in inner region from Table 2.4-2.
n_2 = Number of storage locations in outer region from Table 2.4-2.

Table 2.4-2

Fuel Storage Regions per MPC

MPC Model	Number of Storage Locations in Inner Region (Region 1)	Number of Storage Locations in Outer Region (Region 2)
MPC-24 and MPC-24E/EF	12	12
MPC- 32/32F	12	20
MPC-68/68FF	32	36

2.4.3 Burnup Limits as a Function of Cooling Time for ZR-Clad Fuel

The maximum allowable fuel assembly average burnup varies with the following parameters:

- Minimum fuel assembly cooling time
- Maximum fuel assembly decay heat
- Minimum fuel assembly average enrichment

2.4.3 Burnup Limits as a Function of Cooling Time for ZR-Clad Fuel (cont'd)

The maximum allowable ZR-clad fuel assembly average burnup for a given MINIMUM ENRICHMENT is calculated as described below for minimum cooling times between 3 and 20 years using the maximum permissible decay heat determined in Section 2.4.1 or 2.4.2. Different fuel assembly average burnup limits may be calculated for different minimum enrichments (by individual fuel assembly) for use in choosing the fuel assemblies to be loaded into a given MPC.

2.4.3.1 Choose a fuel assembly minimum enrichment, E_{235}.

2.4.3.2 Calculate the maximum allowable fuel assembly average burnup for a minimum cooling time between 3 and 20 years using the equation below.

$$Bu = (A \times q) + (B \times q^2) + (C \times q^3) + [D \times (E_{235})^2] + (E \times q \times E_{235}) + (F \times q^2 \times E_{235}) + G$$

Where:

Bu = Maximum allowable average burnup per fuel assembly (MWD/MTU)

q = Maximum allowable decay heat per fuel storage location determined in Section 2.4.1 or 2.4.2 (kW)

E_{235} = Minimum fuel assembly average enrichment (wt. % ^{235}U) (e.g., for 4.05 wt.%, use 4.05)

A through G = Coefficients from Tables 2.4-3 and 2.4-4 for the applicable fuel assembly array/class and minimum cooling time

2.4.3.3 Calculated burnup limits shall be rounded down to the nearest integer.

2.4.3.4 Calculated burnup limits greater than 68,200 MWD/MTU for PWR fuel and 65,000 MWD/MTU for BWR must be reduced to be equal to these values.

2.4.3.5 Linear interpolation of calculated burnups between cooling times for a given fuel assembly maximum decay heat and minimum enrichment is permitted. For example, the allowable burnup for a cooling time of 4.5 years may be interpolated between those burnups calculated for 4 year and 5 years.

2.4.3.6 Each ZR-clad fuel assembly to be stored must have a MINIMUM ENRICHMENT greater than or equal to the value used in Step 2.4.3.2.

2.4.4 When complying with the maximum fuel storage location decay heat limits, users must account for the decay heat from both the fuel assembly and any NON-FUEL HARDWARE, as applicable for the particular fuel storage location, to ensure the decay heat emitted by all contents in a storage location does not exceed the limit.

Table 2.4-3 (Page 1 of 8)

PWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 14x14A						
	A	B	C	D	E	F	G
≥ 3	19311.5	275.367	-59.0252	-139.41	2851.12	-451.845	-615.413
≥ 4	33865.9	-5473.03	851.121	-132.739	3408.58	-656.479	-609.523
≥ 5	46686.2	-13226.9	2588.39	-150.149	3871.87	-806.533	-90.2065
≥ 6	56328.9	-20443.2	4547.38	-176.815	4299.19	-927.358	603.192
≥ 7	64136	-27137.5	6628.18	-200.933	4669.22	-1018.94	797.162
≥ 8	71744.1	-34290.3	9036.9	-214.249	4886.95	-1037.59	508.703
≥ 9	77262	-39724.2	11061	-228.2	5141.35	-1102.05	338.294
≥ 10	82939.8	-45575.6	13320.2	-233.691	5266.25	-1095.94	-73.3159
≥ 11	86541	-49289.6	14921.7	-242.092	5444.54	-1141.6	-83.0603
≥ 12	91383	-54456.7	17107	-242.881	5528.7	-1149.2	-547.579
≥ 13	95877.6	-59404.7	19268	-240.36	5524.35	-1094.72	-933.64
≥ 14	97648.3	-61091.6	20261.7	-244.234	5654.56	-1151.47	-749.836
≥ 15	102533	-66651.5	22799.7	-240.858	5647.05	-1120.32	-1293.34
≥ 16	106216	-70753.8	24830.1	-237.04	5647.63	-1099.12	-1583.89
≥ 17	109863	-75005	27038	-234.299	5652.45	-1080.98	-1862.07
≥ 18	111460	-76482.3	28076.5	-234.426	5703.52	-1104.39	-1695.77
≥ 19	114916	-80339.6	30126.5	-229.73	5663.21	-1065.48	-1941.83
≥ 20	119592	-86161.5	33258.2	-227.256	5700.49	-1100.21	-2474.01

Table 2.4-3 (Page 2 of 8)

PWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 14x14B						
	A	B	C	D	E	F	G
≥ 3	18036.1	63.7639	-24.7251	-130.732	2449.87	-347.748	-858.192
≥ 4	30303.4	-4304.2	598.79	-118.757	2853.18	-486.453	-459.902
≥ 5	40779.6	-9922.93	1722.83	-138.174	3255.69	-608.267	245.251
≥ 6	48806.7	-15248.9	3021.47	-158.69	3570.24	-689.876	833.917
≥ 7	55070.5	-19934.6	4325.62	-179.964	3870.33	-765.849	1203.89
≥ 8	60619.6	-24346	5649.29	-189.701	4042.23	-795.324	1158.12
≥ 9	64605.7	-27677.1	6778.12	-205.459	4292.35	-877.966	1169.88
≥ 10	69083.8	-31509.4	8072.42	-206.157	4358.01	-875.041	856.449
≥ 11	72663.2	-34663.9	9228.96	-209.199	4442.68	-889.512	671.567
≥ 12	74808.9	-36367	9948.88	-214.344	4571.29	-942.418	765.261
≥ 13	78340.3	-39541.1	11173.8	-212.8	4615.06	-957.833	410.807
≥ 14	81274.8	-42172.3	12259.9	-209.758	4626.13	-958.016	190.59
≥ 15	83961.4	-44624.5	13329.1	-207.697	4632.16	-952.876	20.8575
≥ 16	84968.5	-44982.1	13615.8	-207.171	4683.41	-992.162	247.54
≥ 17	87721.6	-47543.1	14781.4	-203.373	4674.3	-988.577	37.9689
≥ 18	90562.9	-50100.4	15940.4	-198.649	4651.64	-982.459	-247.421
≥ 19	93011.6	-52316.6	17049.9	-194.964	4644.76	-994.63	-413.021
≥ 20	95567.8	-54566.6	18124	-190.22	4593.92	-963.412	-551.983

Table 2.4-3 (Page 3 of 8)

PWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 14x14C						
	A	B	C	D	E	F	G
≥ 3	18263.7	174.161	-57.6694	-138.112	2539.74	-369.764	-1372.33
≥ 4	30514.5	-4291.52	562.37	-124.944	2869.17	-481.139	-889.883
≥ 5	41338	-10325.7	1752.96	-141.247	3146.48	-535.709	-248.078
≥ 6	48969.7	-15421.3	2966.33	-163.574	3429.74	-587.225	429.331
≥ 7	55384.6	-20228.9	4261.47	-180.846	3654.55	-617.255	599.251
≥ 8	60240.2	-24093.2	5418.86	-199.974	3893.72	-663.995	693.934
≥ 9	64729	-27745.7	6545.45	-205.385	3986.06	-650.124	512.528
≥ 10	68413.7	-30942.2	7651.29	-216.408	4174.71	-702.931	380.431
≥ 11	71870.6	-33906.7	8692.81	-218.813	4248.28	-704.458	160.645
≥ 12	74918.4	-36522	9660.01	-218.248	4283.68	-696.498	-29.0682
≥ 13	77348.3	-38613.7	10501.8	-220.644	4348.23	-702.266	-118.646
≥ 14	79817.1	-40661.8	11331.2	-218.711	4382.32	-710.578	-236.123
≥ 15	82354.2	-42858.3	12257.3	-215.835	4405.89	-718.805	-431.051
≥ 16	84787.2	-44994.5	13185.9	-213.386	4410.99	-711.437	-572.104
≥ 17	87084.6	-46866.1	14004.8	-206.788	4360.3	-679.542	-724.721
≥ 18	88083.1	-47387.1	14393.4	-208.681	4420.85	-709.311	-534.454
≥ 19	90783.6	-49760.6	15462.7	-203.649	4403.3	-705.741	-773.066
≥ 20	93212	-51753.3	16401.5	-197.232	4361.65	-692.925	-964.628

Table 2.4-3 (Page 4 of 8)

PWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 15x15A/B/C						
	A	B	C	D	E	F	G
≥ 3	15037.3	108.689	-18.8378	-127.422	2050.02	-242.828	-580.66
≥ 4	25506.6	-2994.03	356.834	-116.45	2430.25	-350.901	-356.378
≥ 5	34788.8	-7173.07	1065.9	-124.785	2712.23	-424.681	267.705
≥ 6	41948.6	-11225.3	1912.12	-145.727	3003.29	-489.538	852.112
≥ 7	47524.9	-14770.9	2755.16	-165.889	3253.9	-542.7	1146.96
≥ 8	52596.9	-18348.8	3699.72	-177.17	3415.69	-567.012	1021.41
≥ 9	56055.4	-20837.1	4430.93	-192.168	3625.93	-623.325	1058.61
≥ 10	59611.3	-23402.1	5179.52	-195.105	3699.18	-626.448	868.517
≥ 11	62765.3	-25766.5	5924.71	-195.57	3749.91	-627.139	667.124
≥ 12	65664.4	-28004.8	6670.75	-195.08	3788.33	-628.904	410.783
≥ 13	67281.7	-29116.7	7120.59	-202.817	3929.38	-688.738	492.309
≥ 14	69961.4	-31158.6	7834.02	-197.988	3917.29	-677.565	266.561
≥ 15	72146	-32795.7	8453.67	-195.083	3931.47	-681.037	99.0606
≥ 16	74142.6	-34244.8	9023.57	-190.645	3905.54	-663.682	10.8885
≥ 17	76411.4	-36026.3	9729.98	-188.874	3911.21	-663.449	-151.805
≥ 18	77091	-36088	9884.09	-188.554	3965.08	-708.55	59.3839
≥ 19	79194.5	-37566.4	10477.5	-181.656	3906.93	-682.4	-117.952
≥ 20	81600.4	-39464.5	11281.9	-175.182	3869.49	-677.179	-367.705

Table 2.4-3 (Page 5 of 8)

PWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 15x15D/E/F/H						
	A	B	C	D	E	F	G
≥ 3	14376.7	102.205	-20.6279	-126.017	1903.36	-210.883	-493.065
≥ 4	24351.4	-2686.57	297.975	-110.819	2233.78	-301.615	-152.713
≥ 5	33518.4	-6711.35	958.544	-122.85	2522.7	-371.286	392.608
≥ 6	40377	-10472.4	1718.53	-144.535	2793.29	-426.436	951.528
≥ 7	46105.8	-13996.2	2515.32	-157.827	2962.46	-445.314	1100.56
≥ 8	50219.7	-16677.7	3198.3	-175.057	3176.74	-492.727	1223.62
≥ 9	54281.2	-19555.6	3983.47	-181.703	3279.03	-499.997	1034.55
≥ 10	56761.6	-21287.3	4525.98	-195.045	3470.41	-559.074	1103.3
≥ 11	59820	-23445.2	5165.43	-194.997	3518.23	-561.422	862.68
≥ 12	62287.2	-25164.6	5709.9	-194.771	3552.69	-561.466	680.488
≥ 13	64799	-27023.7	6335.16	-192.121	3570.41	-561.326	469.583
≥ 14	66938.7	-28593.1	6892.63	-194.226	3632.92	-583.997	319.867
≥ 15	68116.5	-29148.6	7140.09	-192.545	3670.39	-607.278	395.344
≥ 16	70154.9	-30570.1	7662.91	-187.366	3649.14	-597.205	232.318
≥ 17	72042.5	-31867.6	8169.01	-183.453	3646.92	-603.907	96.0388
≥ 18	73719.8	-32926.1	8596.12	-177.896	3614.57	-592.868	46.6774
≥ 19	75183.1	-33727.4	8949.64	-172.386	3581.13	-586.347	3.57256
≥ 20	77306.1	-35449	9690.02	-173.784	3636.87	-626.321	-205.513

Table 2.4-3 (Page 6 of 8)

PWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 16X16A						
	A	B	C	D	E	F	G
≥ 3	16226.8	143.714	-32.4809	-136.707	2255.33	-291.683	-699.947
≥ 4	27844.2	-3590.69	444.838	-124.301	2644.09	-411.598	-381.106
≥ 5	38191.5	-8678.48	1361.58	-132.855	2910.45	-473.183	224.473
≥ 6	46382.2	-13819.6	2511.32	-158.262	3216.92	-532.337	706.656
≥ 7	52692.3	-18289	3657.18	-179.765	3488.3	-583.133	908.839
≥ 8	57758.7	-22133.7	4736.88	-199.014	3717.42	-618.83	944.903
≥ 9	62363.3	-25798.7	5841.18	-207.025	3844.38	-625.741	734.928
≥ 10	66659.1	-29416.3	6993.31	-216.458	3981.97	-642.641	389.366
≥ 11	69262.7	-31452.7	7724.66	-220.836	4107.55	-681.043	407.121
≥ 12	72631.5	-34291.9	8704.8	-219.929	4131.5	-662.513	100.093
≥ 13	75375.3	-36589.3	9555.88	-217.994	4143.15	-644.014	-62.3294
≥ 14	78178.7	-39097.1	10532	-221.923	4226.28	-667.012	-317.743
≥ 15	79706.3	-40104	10993.3	-218.751	4242.12	-670.665	-205.579
≥ 16	82392.6	-42418.9	11940.7	-216.278	4274.09	-689.236	-479.752
≥ 17	84521.8	-44150.5	12683.3	-212.056	4245.99	-665.418	-558.901
≥ 18	86777.1	-45984.8	13479	-204.867	4180.8	-621.805	-716.366
≥ 19	89179.7	-48109.8	14434.5	-206.484	4230.03	-648.557	-902.1
≥ 20	90141.7	-48401.4	14702.6	-203.284	4245.54	-670.655	-734.604

Table 2.4-3 (Page 7 of 8)

PWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 17x17A						
	A	B	C	D	E	F	G
≥ 3	15985.1	3.53963	-9.04955	-128.835	2149.5	-260.415	-262.997
≥ 4	27532.9	-3494.41	428.199	-119.504	2603.01	-390.91	-140.319
≥ 5	38481.2	-8870.98	1411.03	-139.279	3008.46	-492.881	388.377
≥ 6	47410.9	-14479.6	2679.08	-162.13	3335.48	-557.777	702.164
≥ 7	54596.8	-19703.2	4043.46	-181.339	3586.06	-587.634	804.05
≥ 8	60146.1	-24003.4	5271.54	-201.262	3830.32	-621.706	848.454
≥ 9	65006.3	-27951	6479.04	-210.753	3977.69	-627.805	615.84
≥ 10	69216	-31614.7	7712.58	-222.423	4173.4	-672.33	387.879
≥ 11	73001.3	-34871.1	8824.44	-225.128	4238.28	-657.259	101.654
≥ 12	76326.1	-37795.9	9887.35	-226.731	4298.11	-647.55	-122.236
≥ 13	78859.9	-40058.9	10797.1	-231.798	4402.14	-669.982	-203.383
≥ 14	82201.3	-43032.5	11934.1	-228.162	4417.99	-661.61	-561.969
≥ 15	84950	-45544.6	12972.4	-225.369	4417.84	-637.422	-771.254
≥ 16	87511.8	-47720	13857.7	-219.255	4365.24	-585.655	-907.775
≥ 17	90496.4	-50728.9	15186	-223.019	4446.51	-613.378	-1200.94
≥ 18	91392.5	-51002.4	15461.4	-220.272	4475.28	-636.398	-1003.81
≥ 19	94343.9	-53670.8	16631.6	-214.045	4441.31	-616.201	-1310.01
≥ 20	96562.9	-55591.2	17553.4	-209.917	4397.67	-573.199	-1380.64

Table 2.4-3 (Page 8 of 8)

PWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 17x17B/C						
	A	B	C	D	E	F	G
≥ 3	14738	47.5402	-13.8187	-127.895	1946.58	-219.289	-389.029
≥ 4	25285.2	-3011.92	350.116	-115.75	2316.89	-319.23	-220.413
≥ 5	34589.6	-7130.34	1037.26	-128.673	2627.27	-394.58	459.642
≥ 6	42056.2	-11353.7	1908.68	-150.234	2897.38	-444.316	923.971
≥ 7	47977.6	-15204.8	2827.4	-173.349	3178.25	-504.16	1138.82
≥ 8	52924	-18547.6	3671.08	-183.025	3298.64	-501.278	1064.68
≥ 9	56465.5	-21139.4	4435.67	-200.386	3538	-569.712	1078.78
≥ 10	60190.9	-23872.7	5224.31	-203.233	3602.88	-562.312	805.336
≥ 11	63482.1	-26431.1	6035.79	-205.096	3668.84	-566.889	536.011
≥ 12	66095	-28311.8	6637.72	-204.367	3692.68	-555.305	372.223
≥ 13	67757.4	-29474.4	7094.08	-211.649	3826.42	-606.886	437.412
≥ 14	70403.7	-31517.4	7807.15	-207.668	3828.69	-601.081	183.09
≥ 15	72506.5	-33036.1	8372.59	-203.428	3823.38	-594.995	47.5175
≥ 16	74625.2	-34620.5	8974.32	-199.003	3798.57	-573.098	-95.0221
≥ 17	76549	-35952.6	9498.14	-193.459	3766.52	-556.928	-190.662
≥ 18	77871.9	-36785.5	9916.91	-195.592	3837.65	-599.45	-152.261
≥ 19	79834.8	-38191.6	10501.9	-190.83	3812.46	-589.635	-286.847
≥ 20	81975.5	-39777.2	11174.5	-185.767	3795.78	-595.664	-475.978

Table 2.4-4 (Page 1 of 10)

BWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 7x7B						
	A	B	C	D	E	F	G
≥ 3	26409.1	28347.5	-16858	-147.076	5636.32	-1606.75	1177.88
≥ 4	61967.8	-6618.31	-4131.96	-113.949	6122.77	-2042.85	-96.7439
≥ 5	91601.1	-49298.3	17826.5	-132.045	6823.14	-2418.49	-185.189
≥ 6	111369	-80890.1	35713.8	-150.262	7288.51	-2471.1	86.6363
≥ 7	126904	-108669	53338.1	-167.764	7650.57	-2340.78	150.403
≥ 8	139181	-132294	69852.5	-187.317	8098.66	-2336.13	97.5285
≥ 9	150334	-154490	86148.1	-193.899	8232.84	-2040.37	-123.029
≥ 10	159897	-173614	100819	-194.156	8254.99	-1708.32	-373.605
≥ 11	166931	-186860	111502	-193.776	8251.55	-1393.91	-543.677
≥ 12	173691	-201687	125166	-202.578	8626.84	-1642.3	-650.814
≥ 13	180312	-215406	137518	-201.041	8642.19	-1469.45	-810.024
≥ 14	185927	-227005	148721	-197.938	8607.6	-1225.95	-892.876
≥ 15	191151	-236120	156781	-191.625	8451.86	-846.27	-1019.4
≥ 16	195761	-244598	165372	-187.043	8359.19	-572.561	-1068.19
≥ 17	200791	-256573	179816	-197.26	8914.28	-1393.37	-1218.63
≥ 18	206068	-266136	188841	-187.191	8569.56	-730.898	-1363.79
≥ 19	210187	-273609	197794	-182.151	8488.23	-584.727	-1335.59
≥ 20	213731	-278120	203074	-175.864	8395.63	-457.304	-1364.38

Table 2.4-4 (Page 2 of 10)

BWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 8x8B						
	A	B	C	D	E	F	G
≥ 3	28219.6	28963.7	-17616.2	-147.68	5887.41	-1730.96	1048.21
≥ 4	66061.8	-10742.4	-1961.82	-123.066	6565.54	-2356.05	-298.005
≥ 5	95790.7	-53401.7	19836.7	-134.584	7145.41	-2637.09	-298.858
≥ 6	117477	-90055.9	41383.9	-154.758	7613.43	-2612.69	-64.9921
≥ 7	134090	-120643	60983	-168.675	7809	-2183.3	-40.8885
≥ 8	148186	-149181	81418.7	-185.726	8190.07	-2040.31	-260.773
≥ 9	159082	-172081	99175.2	-197.185	8450.86	-1792.04	-381.705
≥ 10	168816	-191389	113810	-195.613	8359.87	-1244.22	-613.594
≥ 11	177221	-210599	131099	-208.3	8810	-1466.49	-819.773
≥ 12	183929	-224384	143405	-207.497	8841.33	-1227.71	-929.708
≥ 13	191093	-240384	158327	-204.95	8760.17	-811.708	-1154.76
≥ 14	196787	-252211	169664	-204.574	8810.95	-610.928	-1208.97
≥ 15	203345	-267656	186057	-208.962	9078.41	-828.954	-1383.76
≥ 16	207973	-276838	196071	-204.592	9024.17	-640.808	-1436.43
≥ 17	213891	-290411	211145	-202.169	9024.19	-482.1	-1595.28
≥ 18	217483	-294066	214600	-194.243	8859.35	-244.684	-1529.61
≥ 19	220504	-297897	219704	-190.161	8794.97	-10.9863	-1433.86
≥ 20	227821	-318395	245322	-194.682	9060.96	-350.308	-1741.16

Table 2.4-4 (Page 3 of 10)

BWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 8x8C/D/E						
	A	B	C	D	E	F	G
≥ 3	28592.7	28691.5	-17773.6	-149.418	5969.45	-1746.07	1063.62
≥ 4	66720.8	-12115.7	-1154	-128.444	6787.16	-2529.99	-302.155
≥ 5	96929.1	-55827.5	21140.3	-136.228	7259.19	-2685.06	-334.328
≥ 6	118190	-92000.2	42602.5	-162.204	7907.46	-2853.42	-47.5465
≥ 7	135120	-123437	62827.1	-172.397	8059.72	-2385.81	-75.0053
≥ 8	149162	-152986	84543.1	-195.458	8559.11	-2306.54	-183.595
≥ 9	161041	-177511	103020	-200.087	8632.84	-1864.4	-433.081
≥ 10	171754	-201468	122929	-209.799	8952.06	-1802.86	-755.742
≥ 11	179364	-217723	137000	-215.803	9142.37	-1664.82	-847.268
≥ 12	186090	-232150	150255	-216.033	9218.36	-1441.92	-975.817
≥ 13	193571	-249160	165997	-213.204	9146.99	-1011.13	-1119.47
≥ 14	200034	-263671	180359	-210.559	9107.54	-694.626	-1312.55
≥ 15	205581	-275904	193585	-216.242	9446.57	-1040.65	-1428.13
≥ 16	212015	-290101	207594	-210.036	9212.93	-428.321	-1590.7
≥ 17	216775	-299399	218278	-204.611	9187.86	-398.353	-1657.6
≥ 18	220653	-306719	227133	-202.498	9186.34	-181.672	-1611.86
≥ 19	224859	-314004	235956	-193.902	8990.14	145.151	-1604.71
≥ 20	228541	-320787	245449	-200.727	9310.87	-230.252	-1570.18

Table 2.4-4 (Page 4 of 10)

BWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 9x9A						
	A	B	C	D	E	F	G
≥ 3	30538.7	28463.2	-18105.5	-150.039	6226.92	-1876.69	1034.06
≥ 4	71040.1	-16692.2	1164.15	-128.241	7105.27	-2728.58	-414.09
≥ 5	100888	-60277.7	24150.1	-142.541	7896.11	-3272.86	-232.197
≥ 6	124846	-102954	50350.8	-161.849	8350.16	-3163.44	-91.1396
≥ 7	143516	-140615	76456.5	-185.538	8833.04	-2949.38	-104.802
≥ 8	158218	-171718	99788.2	-196.315	9048.88	-2529.26	-259.929
≥ 9	172226	-204312	126620	-214.214	9511.56	-2459.19	-624.954
≥ 10	182700	-227938	146736	-215.793	9555.41	-1959.92	-830.943
≥ 11	190734	-246174	163557	-218.071	9649.43	-1647.5	-935.021
≥ 12	199997	-269577	186406	-223.975	9884.92	-1534.34	-1235.27
≥ 13	207414	-287446	204723	-228.808	10131.7	-1614.49	-1358.61
≥ 14	215263	-306131	223440	-220.919	9928.27	-988.276	-1638.05
≥ 15	221920	-321612	239503	-217.949	9839.02	-554.709	-1784.04
≥ 16	226532	-331778	252234	-216.189	9893.43	-442.149	-1754.72
≥ 17	232959	-348593	272609	-219.907	10126.3	-663.84	-1915.3
≥ 18	240810	-369085	296809	-219.729	10294.6	-859.302	-2218.87
≥ 19	244637	-375057	304456	-210.997	10077.8	-425.446	-2127.83
≥ 20	248112	-379262	309391	-204.191	9863.67	100.27	-2059.39

Table 2.4-4 (Page 5 of 10)

BWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 9x9B						
	A	B	C	D	E	F	G
≥ 3	30613.2	28985.3	-18371	-151.117	6321.55	-1881.28	988.92
≥ 4	71346.6	-15922.9	631.132	-128.876	7232.47	-2810.64	-471.737
≥ 5	102131	-60654.1	23762.7	-140.748	7881.6	-3156.38	-417.979
≥ 6	127187	-105842	51525.2	-162.228	8307.4	-2913.08	-342.13
≥ 7	146853	-145834	79146.5	-185.192	8718.74	-2529.57	-484.885
≥ 8	162013	-178244	103205	-197.825	8896.39	-1921.58	-584.013
≥ 9	176764	-212856	131577	-215.41	9328.18	-1737.12	-1041.11
≥ 10	186900	-235819	151238	-218.98	9388.08	-1179.87	-1202.83
≥ 11	196178	-257688	171031	-220.323	9408.47	-638.53	-1385.16
≥ 12	205366	-280266	192775	-223.715	9592.12	-472.261	-1661.6
≥ 13	215012	-306103	218866	-231.821	9853.37	-361.449	-1985.56
≥ 14	222368	-324558	238655	-228.062	9834.57	3.47358	-2178.84
≥ 15	226705	-332738	247316	-224.659	9696.59	632.172	-2090.75
≥ 16	233846	-349835	265676	-221.533	9649.93	913.747	-2243.34
≥ 17	243979	-379622	300077	-222.351	9792.17	1011.04	-2753.36
≥ 18	247774	-386203	308873	-220.306	9791.37	1164.58	-2612.25
≥ 19	254041	-401906	327901	-213.96	9645.47	1664.94	-2786.2
≥ 20	256003	-402034	330566	-215.242	9850.42	1359.46	-2550.06

Table 2.4-4 (Page 6 of 10)

BWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 9x9C/D						
	A	B	C	D	E	F	G
≥ 3	30051.6	29548.7	-18614.2	-148.276	6148.44	-1810.34	1006
≥ 4	70472.7	-14696.6	-233.567	-127.728	7008.69	-2634.22	-444.373
≥ 5	101298	-59638.9	23065.2	-138.523	7627.57	-2958.03	-377.965
≥ 6	125546	-102740	49217.4	-160.811	8096.34	-2798.88	-259.767
≥ 7	143887	-139261	74100.4	-184.302	8550.86	-2517.19	-275.151
≥ 8	159633	-172741	98641.4	-194.351	8636.89	-1838.81	-486.731
≥ 9	173517	-204709	124803	-212.604	9151.98	-1853.27	-887.137
≥ 10	182895	-225481	142362	-218.251	9262.59	-1408.25	-978.356
≥ 11	192530	-247839	162173	-217.381	9213.58	-818.676	-1222.12
≥ 12	201127	-268201	181030	-215.552	9147.44	-232.221	-1481.55
≥ 13	209538	-289761	203291	-225.092	9588.12	-574.227	-1749.35
≥ 14	216798	-306958	220468	-222.578	9518.22	-69.9307	-1919.71
≥ 15	223515	-323254	237933	-217.398	9366.52	475.506	-2012.93
≥ 16	228796	-334529	250541	-215.004	9369.33	662.325	-2122.75
≥ 17	237256	-356311	273419	-206.483	9029.55	1551.3	-2367.96
≥ 18	242778	-369493	290354	-215.557	9600.71	659.297	-2589.32
≥ 19	246704	-377971	302630	-210.768	9509.41	1025.34	-2476.06
≥ 20	249944	-382059	308281	-205.495	9362.63	1389.71	-2350.49

Table 2.4-4 (Page 7 of 10)

BWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 9x9E/F						
	A	B	C	D	E	F	G
≥ 3	30284.3	26949.5	-16926.4	-147.914	6017.02	-1854.81	1026.15
≥ 4	69727.4	-17117.2	1982.33	-127.983	6874.68	-2673.01	-359.962
≥ 5	98438.9	-58492	23382.2	-138.712	7513.55	-3038.23	-112.641
≥ 6	119765	-95024.1	45261	-159.669	8074.25	-3129.49	221.182
≥ 7	136740	-128219	67940.1	-182.439	8595.68	-3098.17	315.544
≥ 8	150745	-156607	88691.5	-193.941	8908.73	-2947.64	142.072
≥ 9	162915	-182667	109134	-198.37	8999.11	-2531	-93.4908
≥ 10	174000	-208668	131543	-210.777	9365.52	-2511.74	-445.876
≥ 11	181524	-224252	145280	-212.407	9489.67	-2387.49	-544.123
≥ 12	188946	-240952	160787	-210.65	9478.1	-2029.94	-652.339
≥ 13	193762	-250900	171363	-215.798	9742.31	-2179.24	-608.636
≥ 14	203288	-275191	196115	-218.113	9992.5	-2437.71	-1065.92
≥ 15	208108	-284395	205221	-213.956	9857.25	-1970.65	-1082.94
≥ 16	215093	-301828	224757	-209.736	9789.58	-1718.37	-1303.35
≥ 17	220056	-310906	234180	-201.494	9541.73	-1230.42	-1284.15
≥ 18	224545	-320969	247724	-206.807	9892.97	-1790.61	-1381.9
≥ 19	226901	-322168	250395	-204.073	9902.14	-1748.78	-1253.22
≥ 20	235561	-345414	276856	-198.306	9720.78	-1284.14	-1569.18

Table 2.4-4 (Page 8 of 10)

BWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 9x9G						
	A	B	C	D	E	F	G
≥ 3	35158.5	26918.5	-17976.7	-149.915	6787.19	-2154.29	836.894
≥ 4	77137.2	-19760.1	2371.28	-130.934	8015.43	-3512.38	-455.424
≥ 5	113405	-77931.2	35511.2	-150.637	8932.55	-4099.48	-629.806
≥ 6	139938	-128700	68698.3	-173.799	9451.22	-3847.83	-455.905
≥ 7	164267	-183309	109526	-193.952	9737.91	-3046.84	-737.992
≥ 8	182646	-227630	146275	-210.936	10092.3	-2489.3	-1066.96
≥ 9	199309	-270496	184230	-218.617	10124.3	-1453.81	-1381.41
≥ 10	213186	-308612	221699	-235.828	10703.2	-1483.31	-1821.73
≥ 11	225587	-342892	256242	-236.112	10658.5	-612.076	-2134.65
≥ 12	235725	-370471	285195	-234.378	10604.9	118.591	-2417.89
≥ 13	247043	-404028	323049	-245.79	11158.2	-281.813	-2869.82
≥ 14	253649	-421134	342682	-243.142	11082.3	400.019	-2903.88
≥ 15	262750	-448593	376340	-245.435	11241.2	581.355	-3125.07
≥ 16	270816	-470846	402249	-236.294	10845.4	1791.46	-3293.07
≥ 17	279840	-500272	441964	-241.324	11222.6	1455.84	-3528.25
≥ 18	284533	-511287	458538	-240.905	11367.2	1459.68	-3520.94
≥ 19	295787	-545885	501824	-235.685	11188.2	2082.21	-3954.2
≥ 20	300209	-556936	519174	-229.539	10956	2942.09	-3872.87

Table 2.4-4 (Page 9 of 10)

BWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 10x10A/B						
	A	B	C	D	E	F	G
≥ 3	29285.4	27562.2	-16985	-148.415	5960.56	-1810.79	1001.45
≥ 4	67844.9	-14383	395.619	-127.723	6754.56	-2547.96	-369.267
≥ 5	96660.5	-55383.8	21180.4	-137.17	7296.6	-2793.58	-192.85
≥ 6	118098	-91995	42958	-162.985	7931.44	-2940.84	60.9197
≥ 7	135115	-123721	63588.9	-171.747	8060.23	-2485.59	73.6219
≥ 8	148721	-151690	84143.9	-190.26	8515.81	-2444.25	-63.4649
≥ 9	160770	-177397	104069	-197.534	8673.6	-2101.25	-331.046
≥ 10	170331	-198419	121817	-213.692	9178.33	-2351.54	-472.844
≥ 11	179130	-217799	138652	-209.75	9095.43	-1842.88	-705.254
≥ 12	186070	-232389	151792	-208.946	9104.52	-1565.11	-822.73
≥ 13	192407	-246005	164928	-209.696	9234.7	-1541.54	-979.245
≥ 14	200493	-265596	183851	-207.639	9159.83	-1095.72	-1240.61
≥ 15	205594	-276161	195760	-213.491	9564.23	-1672.22	-1333.64
≥ 16	209386	-282942	204110	-209.322	9515.83	-1506.86	-1286.82
≥ 17	214972	-295149	217095	-202.445	9292.34	-893.6	-1364.97
≥ 18	219312	-302748	225826	-198.667	9272.27	-878.536	-1379.58
≥ 19	223481	-310663	235908	-194.825	9252.9	-785.066	-1379.62
≥ 20	227628	-319115	247597	-199.194	9509.02	-1135.23	-1386.19

Table 2.4-4 (Page 10 of 10)

BWR Fuel Assembly Cooling Time-Dependent Coefficients
(ZR-Clad Fuel)

Cooling Time (years)	Array/Class 10x10C						
	A	B	C	D	E	F	G
≥ 3	31425.3	27358.9	-17413.3	-152.096	6367.53	-1967.91	925.763
≥ 4	71804	-16964.1	1000.4	-129.299	7227.18	-2806.44	-416.92
≥ 5	102685	-62383.3	24971.2	-142.316	7961	-3290.98	-354.784
≥ 6	126962	-105802	51444.6	-164.283	8421.44	-3104.21	-186.615
≥ 7	146284	-145608	79275.5	-188.967	8927.23	-2859.08	-251.163
≥ 8	162748	-181259	105859	-199.122	9052.91	-2206.31	-554.124
≥ 9	176612	-214183	133261	-217.56	9492.17	-1999.28	-860.669
≥ 10	187756	-239944	155315	-219.56	9532.45	-1470.9	-1113.42
≥ 11	196580	-260941	174536	-222.457	9591.64	-944.473	-1225.79
≥ 12	208017	-291492	204805	-233.488	10058.3	-1217.01	-1749.84
≥ 13	214920	-307772	221158	-234.747	10137.1	-897.23	-1868.04
≥ 14	222562	-326471	240234	-228.569	9929.34	-183.47	-2016.12
≥ 15	228844	-342382	258347	-226.944	9936.76	117.061	-2106.05
≥ 16	233907	-353008	270390	-223.179	9910.72	360.39	-2105.23
≥ 17	244153	-383017	304819	-227.266	10103.2	380.393	-2633.23
≥ 18	249240	-395456	321452	-226.989	10284.1	169.947	-2623.67
≥ 19	254343	-406555	335240	-220.569	10070.5	764.689	-2640.2
≥ 20	260202	-421069	354249	-216.255	10069.9	854.497	-2732.77

3.0 DESIGN FEATURES

3.1 Site

3.1.1 Site Location

The HI-STORM 100 Cask System is authorized for general use by 10 CFR Part 50 license holders at various site locations under the provisions of 10 CFR 72, Subpart K.

3.2 Design Features Important for Criticality Control

3.2.1 MPC-24

1. Flux trap size: ≥ 1.09 in.

2. ^{10}B loading in the neutron absorbers: ≥ 0.0267 g/cm^2 (Boral) and ≥ 0.0223 g/cm^2 (METAMIC)

3.2.2 MPC-68 and MPC-68FF

1. Fuel cell pitch: ≥ 6.43 in.

2. ^{10}B loading in the neutron absorbers: ≥ 0.0372 g/cm^2 (Boral) and ≥ 0.0310 g/cm^2 (METAMIC)

3.2.3 MPC-68F

1. Fuel cell pitch: ≥ 6.43 in.

2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.01 g/cm^2

3.2.4 MPC-24E and MPC-24EF

1. Flux trap size:

   i. Cells 3, 6, 19, and 22: ≥ 0.776 inch

   ii. All Other Cells: ≥ 1.076 inches

2. ^{10}B loading in the neutron absorbers: ≥ 0.0372 g/cm^2 (Boral) and ≥ 0.0310 g/cm^2 (METAMIC)

3.2.5 MPC-32 and MPC-32F

1. Fuel cell pitch: ≥ 9.158 inches

2. ^{10}B loading in the neutron absorbers: ≥ 0.0372 g/cm^2 (Boral) and ≥ 0.0310 g/cm^2 (METAMIC)

DESIGN FEATURES

3.2 Design features Important for Criticality Control (cont'd)

3.2.6 Fuel spacers shall be sized to ensure that the active fuel region of intact fuel assemblies remains within the neutron poison region of the MPC basket with water in the MPC.

3.2.7 The B_4C content in METAMIC shall be $\leq$ 33.0 wt.%.

3.2.8 Neutron Absorber Tests

Section 9.1.5.3 of the HI-STORM 100 FSAR is hereby incorporated by reference into the HI-STORM 100 CoC. The minimum ^{10}B for the neutron absorber shall meet the minimum requirements for each MPC model specified in Sections 3.2.1 through 3.2.5 above.

3.3 Codes and Standards

The American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), 1995 Edition with Addenda through 1997, is the governing Code for the HI-STORM 100 System MPCs, *aboveground* OVERPACKs, and TRANSFER CASKs, as clarified in Specification 3.3.1 below, except for Code Sections V and IX. *The ASME Code paragraphs applicable to the underground OVERPACKS are listed in Table 3-2.* The latest effective editions of ASME Code Sections V and IX, including addenda, may be used for activities governed by those sections, provided a written reconciliation of the later edition against the 1995 Edition, including addenda, is performed by the certificate holder. American Concrete Institute (ACI) 349-85 is the governing Code for plain concrete as clarified in Appendix 1.D of the Final Safety Analysis Report for the HI-STORM 100 Cask System.

3.3.1 <u>Alternatives to Codes, Standards, and Criteria</u>

Table 3-1 lists approved alternatives to the ASME Code for the design of the MPCs, OVERPACKs, and TRANSFER CASKs of the HI-STORM 100 Cask System.

3.3.2 <u>Construction/Fabrication Alternatives to Codes, Standards, and Criteria</u>

Proposed alternatives to the ASME Code, Section III, 1995 Edition with Addenda through 1997 including modifications to the alternatives allowed by Specification 3.3.1 may be used on a case-specific basis when authorized by the Director of the Office of Nuclear Material Safety and Safeguards or designee. The request for such alternative should demonstrate that:

1. The proposed alternatives would provide an acceptable level of quality and safety, or

(continued)

DESIGN FEATURES

3.3.2 Construction/Fabrication Alternatives to Codes, Standards, and Criteria (cont'd)

2. Compliance with the specified requirements of the ASME Code, Section III, 1995 Edition with Addenda through 1997, would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Requests for alternatives shall be submitted in accordance with 10 CFR 72.4.

(continued)

DESIGN FEATURES

Table 3-1 (page 1 of 9)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 CASK SYSTEM *(for Aboveground OVERPACK)*

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC, MPC basket assembly, HI-STORM OVERPACK steel structure, and HI-TRAC TRANSFER CASK steel structure	Subsection NCA	General Requirements. Requires preparation of a Design Specification, Design Report, Overpressure Protection Report, Certification of Construction Report, Data Report, and other administrative controls for an ASME Code stamped vessel.	Because the MPC, OVERPACK, and TRANSFER CASK are not ASME Code stamped vessels, none of the specifications, reports, certificates, or other general requirements specified by NCA are required. In lieu of a Design Specification and Design Report, the HI-STORM FSAR includes the design criteria, service conditions, and load combinations for the design and operation of the HI-STORM 100 System as well as the results of the stress analyses to demonstrate that applicable Code stress limits are met. Additionally, the fabricator is not required to have an ASME-certified QA program. All important-to-safety activities are governed by the NRC-approved Holtec QA program. Because the cask components are not certified to the Code, the terms "Certificate Holder" and "Inspector" are not germane to the manufacturing of NRC-certified cask components. To eliminate ambiguity, the responsibilities assigned to the Certificate Holder in the various articles of Subsections NB, NG, and NF of the Code, as applicable, shall be interpreted to apply to the NRC Certificate of Compliance (CoC) holder (and by extension, to the component fabricator) if the requirement must be fulfilled. The Code term "Inspector" means the QA/QC personnel of the CoC holder and its vendors assigned to oversee and inspect the manufacturing process.
MPC	NB-1100	Statement of requirements for Code stamping of components.	MPC enclosure vessel is designed and will be fabricated in accordance with ASME Code, Section III, Subsection NB to the maximum practical extent, but Code stamping is not required.

Table 3-1 (page 2 of 9)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 CASK SYSTEM *(for Aboveground OVERPACK)*

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC basket supports and lift lugs	NB-1130	NB-1132.2(d) requires that the first connecting weld of a nonpressure-retaining structural attachment to a component shall be considered part of the component unless the weld is more than 2t from the pressure-retaining portion of the component, where t is the nominal thickness of the pressure-retaining material. NB-1132.2(e) requires that the first connecting weld of a welded nonstructural attachment to a component shall conform to NB-4430 if the connecting weld is within 2t from the pressure-retaining portion of the component.	The MPC basket supports (nonpressure-retaining structural attachments)and lift lugs (nonstructural attachments (relative to the function of lifting a loaded MPC) that are used exclusively for lifting an empty MPC) are welded to the inside of the pressure-retaining MPC shell, but are not designed in accordance with Subsection NB. The basket supports and associated attachment welds are designed to satisfy the stress limits of Subsection NG and the lift lugs and associated attachment welds are designed to satisfy the stress limits of Subsection NF, as a minimum. These attachments and their welds are shown by analysis to meet the respective stress limits for their service conditions. Likewise, non-structural items, such as shield plugs, spacers, etc. if used, can be attached to pressure-retaining parts in the same manner.
MPC	NB-2000	Requires materials to be supplied by ASME-approved material supplier.	Materials will be supplied by Holtec-approved suppliers with Certified Material Test Reports (CMTRs) in accordance with NB-2000 requirements.

Table 3-1 (page 3 of 9)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 CASK SYSTEM *(for Aboveground OVERPACK)*

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC, MPC basket assembly, HI-STORM OVERPACK and HI-TRAC TRANSFER CASK	NB-3100 NG-3100 NF-3100	Provides requirements for determining design loading conditions, such as pressure, temperature, and mechanical loads.	These requirements are not applicable. The HI-STORM FSAR, serving as the Design Specification, establishes the service conditions and load combinations for the storage system.
MPC	NB-3350	NB-3352.3 requires, for Category C joints, that the minimum dimensions of the welds and throat thickness shall be as shown in Figure NB-4243-1.	Due to MPC basket-to-shell interface requirements, the MPC shell-to-baseplate weld joint design (designated Category C) does not include a reinforcing fillet weld or a bevel in the MPC baseplate, which makes it different than any of the representative configurations depicted in Figure NB-4243-1. The transverse thickness of this weld is equal to the thickness of the adjoining shell (1/2 inch). The weld is designed as a full penetration weld that receives VT and RT or UT, as well as final surface PT examinations. Because the MPC shell design thickness is considerably larger than the minimum thickness required by the Code, a reinforcing fillet weld that would intrude into the MPC cavity space is not included. Not including this fillet weld provides for a higher quality radiographic examination of the full penetration weld. From the standpoint of stress analysis, the fillet weld serves to reduce the local bending stress (secondary stress) produced by the gross structural discontinuity defined by the flat plate/shell junction. In the MPC design, the shell and baseplate thicknesses are well beyond that required to meet their respective membrane stress intensity limits.

Table 3-1 (page 4 of 9)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 CASK SYSTEM *(for Aboveground OVERPACK)*

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC, MPC Basket Assembly, HI-STORM OVERPACK steel structure, and HI-TRAC TRANSFER CASK steel structure	NB-4120 NG-4120 NF-4120	NB-4121.2, NG-4121.2, and NF-4121.2 provide requirements for repetition of tensile or impact tests for material subjected to heat treatment during fabrication or installation.	In-shop operations of short duration that apply heat to a component, such as plasma cutting of plate stock, welding, machining, coating, and pouring of lead are not, unless explicitly stated by the Code, defined as heat treatment operations. For the steel parts in the HI-STORM 100 System components, the duration for which a part exceeds the off-normal temperature limit defined in Chapter 2 of the FSAR shall be limited to 24 hours in a particular manufacturing process (such as the HI-TRAC lead pouring process).
MPC, MPC basket assembly, HI-STORM OVERPACK steel structure, and HI-TRAC TRANSFER CASK steel structure	NB-4220 NF-4220	Requires certain forming tolerances to be met for cylindrical, conical, or spherical shells of a vessel.	The cylindricity measurements on the rolled shells are not specifically recorded in the shop travelers, as would be the case for a Code-stamped pressure vessel. Rather, the requirements on inter-component clearances (such as the MPC-to-TRANSFER CASK) are guaranteed through fixture-controlled manufacturing. The fabrication specification and shop procedures ensure that all dimensional design objectives, including inter-component annular clearances are satisfied. The dimensions required to be met in fabrication are chosen to meet the functional requirements of the dry storage components. Thus, although the post-forming Code cylindricity requirements are not evaluated for compliance directly, they are indirectly satisfied (actually exceeded) in the final manufactured components.
MPC Lid and Closure Ring Welds	NB-4243	Full penetration welds required for Category C Joints (flat head to main shell per NB-3352.3).	MPC lid and closure ring are not full penetration welds. They are welded independently to provide a redundant seal. Additionally, a weld efficiency factor of 0.45 has been applied to the analyses of these welds.

Table 3-1 (page 5 of 9)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 CASK SYSTEM *(for Aboveground OVERPACK)*

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC Lid to Shell Weld	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required	Only UT or multi-layer liquid penetrant (PT) examination is permitted. If PT alone is used, at a minimum, it will include the root and final weld layers and each approximately 3/8 inch of weld depth.
MPC Closure Ring, Vent and Drain Cover Plate Welds	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required	Root (if more than one weld pass is required) and final liquid penetrant examination to be performed in accordance with NB-5245. The closure ring provides independent redundant closure for vent and drain cover plates.
MPC Enclosure Vessel and Lid	NB-6111	All completed pressure retaining systems shall be pressure tested.	The MPC enclosure vessel is seal welded in the field following fuel assembly loading. The MPC enclosure vessel shall then be pressure tested as defined in Chapter 9. Accessibility for leakage inspections preclude a Code compliant pressure test. All MPC enclosure vessel welds (except closure ring and vent/drain cover plate) are inspected by volumetric examination, except the MPC lid-to-shell weld shall be verified by volumetric or multi-layer PT examination. If PT alone is used, at a minimum, it must include the root and final layers and each approximately 3/8 inch of weld depth. For either UT or PT, the maximum undetectable flaw size must be demonstrated to be less than the critical flaw size. The critical flaw size must be determined in accordance with ASME Section XI methods. The critical flaw size shall not cause the primary stress limits of NB-3000 to be exceeded. The inspection results, including relevant findings (indications), shall be made a permanent part of the user's records by video, photographic, or other means which provide an equivalent retrievable record of weld integrity. The video or photographic records should be taken during the final interpretation period described in ASME Section V, Article 6, T-676. The vent/drain cover plate and the closure ring welds are confirmed by liquid penetrant examination. The inspection of the weld must be performed by qualified personnel and shall meet the acceptance requirements of ASME Code Section III, NB-5350 for PT or NB-5332 for UT.

Table 3-1 (page 6 of 9)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 CASK SYSTEM *(for Aboveground OVERPACK)*

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC Enclosure Vessel	NB-7000	Vessels are required to have overpressure protection	No overpressure protection is provided. The function of the MPC enclosure vessel is to contain the radioactive contents under normal, off-normal, and accident conditions. The MPC vessel is designed to withstand maximum internal pressure considering 100% fuel rod failure and maximum accident temperatures.
MPC Enclosure Vessel	NB-8000	States requirements for nameplates, stamping and reports per NCA-8000.	The HI-STORM100 System is to be marked and identified in accordance with 10CFR71 and 10CFR72 requirements. Code stamping is not required. QA data package to be in accordance with Holtec approved QA program.
MPC Basket Assembly	NG-2000	Requires materials to be supplied by ASME-approved material supplier.	Materials will be supplied by Holtec-approved supplier with CMTRs in accordance with NG-2000 requirements.

Table 3-1 (page 7 of 9)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 CASK SYSTEM *(for Aboveground OVERPACK)*

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC basket assembly	NG-4420	NG-4427(a) allows a fillet weld in any single continuous weld to be less than the specified fillet weld dimension by not more than 1/16 inch, provided that the total undersize portion of the weld does not exceed 10 percent of the length of the weld. Individual undersize weld portions shall not exceed 2 inches in length.	Modify the Code requirement (intended for core support structures) with the following text prepared to accord with the geometry and stress analysis imperatives for the fuel basket: For the longitudinal MPC basket fillet welds, the following criteria apply: 1) The specified fillet weld throat dimension must be maintained over at least 92 percent of the total weld length. All regions of undersized weld must be less than 3 inches long and separated from each other by at least 9 inches. 2) Areas of undercuts and porosity beyond that allowed by the applicable ASME Code shall not exceed 1/2 inch in weld length. The total length of undercut and porosity over any 1-foot length shall not exceed 2 inches. 3) The total weld length in which items (1) and (2) apply shall not exceed a total of 10 percent of the overall weld length. The limited access of the MPC basket panel longitudinal fillet welds makes it difficult to perform effective repairs of these welds and creates the potential for causing additional damage to the basket assembly (e.g., to the neutron absorber and its sheathing) if repairs are attempted. The acceptance criteria provided in the foregoing have been established to comport with the objectives of the basket design and preserve the margins demonstrated in the supporting stress analysis. From the structural standpoint, the weld acceptance criteria are established to ensure that any departure from the ideal, continuous fillet weld seam would not alter the primary bending stresses on which the design of the fuel baskets is predicated. Stated differently, the permitted weld discontinuities are limited in size to ensure that they remain classifiable as local stress elevators ("peak stress", F, in the ASME Code for which specific stress intensity limits do not apply).
MPC Basket Assembly	NG-8000	States requirements for nameplates, stamping and reports per NCA-8000.	The HI-STORM100 System is to be marked and identified in accordance with 10CFR71 and 10CFR72 requirements. Code stamping is not required. The MPC basket data package to be in accordance with Holtec approved QA program.
OVERPACK Steel Structure	NF-2000	Requires materials to be supplied by ASME-approved material supplier.	Materials will be supplied by Holtec-approved supplier with CMTRs in accordance with NF-2000 requirements.

Table 3-1 (page 8 of 9)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 CASK SYSTEM *(for Aboveground OVERPACK)*

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
TRANSFER CASK Steel Structure	NF-2000	Requires materials to be supplied by ASME-approved material supplier.	Materials will be supplied by Holtec-approved supplier with CMTRs in accordance with NF-2000 requirements.
OVERPACK Baseplate and Lid Top Plate	NF-4441	Requires special examinations or requirements for welds where a primary member of thickness 1 inch or greater is loaded to transmit loads in the through thickness direction.	The margins of safety in these welds under loads experienced during lifting operations or accident conditions are quite large. The OVERPACK baseplate welds to the inner shell, pedestal shell, and radial plates are only loaded during lifting conditions and have large safety factors during lifting. Likewise, the top lid plate to lid shell weld has a large structural margin under the inertia loads imposed during a non-mechanistic tipover event.
OVERPACK Steel Structure	NF-3256 NF-3266	Provides requirements for welded joints.	Welds for which no structural credit is taken are identified as "Non-NF" welds in the design drawings. These non-structural welds are specified in accordance with the pre-qualified welds of AWS D1.1. These welds shall be made by welders and weld procedures qualified in accordance with AWS D1.1 or ASME Section IX. Welds for which structural credit is taken in the safety analyses shall meet the stress limits for NF-3256.2, but are not required to meet the joint configuration requirements specified in these Code articles. The geometry of the joint designs in the cask structures are based on the fabricability and accessibility of the joint, not generally contemplated by this Code section governing supports.

Table 3-1 (page 9 of 9)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 CASK SYSTEM *(for Aboveground OVERPACK)*

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
HI-STORM OVERPACK and HI-TRAC TRANSFER CASK	NF-3320 NF-4720	NF-3324.6 and NF-4720 provide requirements for bolting	These Code requirements are applicable to linear structures wherein bolted joints carry axial, shear, as well as rotational (torsional) loads. The OVERPACK and TRANSFER CASK bolted connections in the structural load path are qualified by design based on the design loadings defined in the FSAR. Bolted joints in these components see no shear or torsional loads under normal storage conditions. Larger clearances between bolts and holes may be necessary to ensure shear interfaces located elsewhere in the structure engage prior to the bolts experiencing shear loadings (which occur only during side impact scenarios). Bolted joints that are subject to shear loads in accident conditions are qualified by appropriate stress analysis. Larger bolt-to-hole clearances help ensure more efficient operations in making these bolted connections, thereby minimizing time spent by operations personnel in a radiation area. Additionally, larger bolt-to-hole clearances allow interchangeability of the lids from one particular fabricated cask to another.

Table 3-2
Applicable Code Paragraphs for Underground OVERPACKs

	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.	Structural Analysis of Interfacing SSCs	ACI 318-05	The VVM Interface Pad and Support Foundation are reinforced concrete structures. Loadings come from the external environment and from the VVM. Sections of the Code that may reasonably be applied to subterranean application are applicable.
7.	Welding procedure	Section IX	
8.	Welding material	Section II	
9.	Loading conditions	NF-3111	
10.	Allowable stress values	NF-3112.3	
11.	Rolling and sliding supports	NF-3424	
12.	Differential thermal expansion	NF-3127	
13.	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 CEC shells and CLOSURE LID.
14.	Cutting of plate stock	NF-4211 NF-4211.1	
15.	Forming	NF-4212	
16.	Forming tolerance	NF-4221	Applies to the CEC Divider Shell and CEC Container Shell
17.	Fitting and Aligning Tack Welds	NF-4231 NF-4231.1	
18.	Alignment	NF-4232	
19.	Storage of Welding Materials	NF-4411	
20.	Cleanliness of Weld Surfaces	NF-4412	Applies to structural and non-structural welds

Table 3-2 (continued)
Applicable Code Paragraphs for Underground OVERPACKs

vider Shellshell	**Item**	**Code Paragraph†**	**Explanation and Applicability**
21.	Backing Strips, Peening	NF-4421 NF-4422	Applies to structural and non-structural welds
22.	Pre-heating and Interpass Temperature	NF-4611 NF-4612 NF-4613	Applies to structural and non-structural welds
23.	Non-Destructive Examination	NF-5360	Invokes Section V
24.	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, except for Code Sections V and IX, where the latest effective editions of ASME Code Sections V and IX, including addenda, may be used, provided a written reconciliation of the later edition against the 1995 Edition, including addenda, is performed by the certificate holder.

DESIGN FEATURES (continued)

3.4 Site-Specific Parameters and Analyses

Site-specific parameters and analyses that will require verification by the system user are, as a minimum, as follows:

1. The temperature of 80° F is the maximum average yearly temperature.

2. The allowed temperature extremes, averaged over a 3-day period, shall be greater than -40° F and less than 125° F.

3. a. For storage in freestanding aboveground OVERPACKs, the resultant horizontal acceleration (vectorial sum of two horizontal Zero Period Accelerations (ZPAs) at a three-dimensional seismic site), G_H, and vertical ZPA, G_V, on the top surface of the ISFSI pad, expressed as fractions of 'g', shall satisfy the following inequality:

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

where μ is either the Coulomb friction coefficient for the cask/ISFSI pad interface or the ratio r/h, where 'r' is the radius of the cask and 'h' is the height of the cask center-of-gravity above the ISFSI pad surface. The above inequality must be met for both definitions of μ, but only applies to ISFSIs where the casks are deployed in a freestanding configuration. Unless demonstrated by appropriate testing that a higher coefficient of friction value is appropriate for a specific ISFSI, the value used shall be 0.53. If acceleration time-histories on the ISFSI pad surface are available, G_H and G_V may be the coincident values of the instantaneous net horizontal and vertical accelerations. If instantaneous accelerations are used, the inequality shall be evaluated at each time step in the acceleration time history over the total duration of the seismic event.

If this static equilibrium based inequality cannot be met, a dynamic analysis of the cask/ISFSI pad assemblage with appropriate recognition of soil/structure interaction effects shall be performed to ensure that the casks will not tip over or undergo excessive sliding under the site's Design Basis Earthquake.

(continued)

3.4 Site-Specific Parameters and Analyses (continued)

b. For free-standing *aboveground* casks, under environmental conditions that may degrade the pad/cask interface friction (such as due to icing) the response of the casks under the site's Design Basis Earthquake shall be established using the best estimate of the friction coefficient in an appropriate analysis model. The analysis should demonstrate that the earthquake will not result in cask tipover or cause a cask to fall off the pad. In addition, impact between casks should be precluded, or should be considered an accident for which the maximum g-load experienced by the stored fuel shall be limited to 45 g's.

c. For those ISFSI sites with design basis seismic acceleration values that may overturn or cause excessive sliding of free-standing *aboveground* casks, the HI-STORM 100 System OVERPACKs shall be anchored to the ISFSI pad. The site seismic characteristics and the anchorage system shall meet the following requirements:

i. The site acceleration response spectra at the top of the ISFSI pad shall have ZPAs that meet the following inequalities:

$$G_H \leq 2.12$$

AND

$$G_V \leq 1.5$$

Where:

G_H is the vectorial sum of the two horizontal ZPAs at a three-dimensional seismic site (or the horizontal ZPA at a two-dimensional site) and G_V is the vertical ZPA.

ii. Each HI-STORM 100 dry storage cask shall be anchored with twenty-eight (28), 2-inch diameter studs and compatible nuts of material suitable for the expected ISFSI environment. The studs shall meet the following requirements:

Yield Strength at Ambient Temperature: $\geq$ 80 ksi

Ultimate Strength at Ambient Temperature: $\geq$ 125 ksi

Initial Tensile Pre-Stress: $\geq$ 55 ksi AND $\leq$ 65 ksi

(continued)

3.4 Site-Specific Parameters and Analyses (continued)

NOTE: The above anchorage specifications are required for the seismic spectra defined in item 3.4.3.c.i. Users may use fewer studs or those of different diameter to account for site-specific seismic spectra less severe than those specified above. The embedment design shall comply with Appendix B of ACI-349-97. A later edition of this Code may be used, provided a written reconciliation is performed.

iii. Embedment Concrete Compressive Strength: $\geq$ 4,000 psi at 28 days

4. The analyzed flood condition of 15 fps water velocity and a height of 125 feet of water (full submergence of the loaded cask) are not exceeded.

5. The potential for fire and explosion shall be addressed, based on site-specific considerations. This includes the condition that the on-site transporter fuel tank will contain no more than 50 gallons of diesel fuel while handling a loaded OVERPACK or TRANSFER CASK.

6. a. For freestanding *aboveground* casks, the ISFSI pad shall be verified by analysis to limit cask deceleration during design basis drop and non-mechanistic tip-over events to $\leq$ 45 g's at the top of the MPC fuel basket. Analyses shall be performed using methodologies consistent with those described in the HI-STORM 100 FSAR. A *restriction on the* lift *and/or drop* height ~~above the ISFSI pad~~ is not required ~~to be established~~ if the cask is lifted with a device designed in accordance with ANSI N14.6 and ha*s*~~ving~~ redundant drop protection features.

b. For anchored *aboveground* casks, the ISFSI pad shall be designed to meet the embedment requirements of the anchorage design. A cask tip-over event for an anchored cask is not credible. The ISFSI pad shall be verified by analysis to limit cask deceleration during a design basis drop event to $\leq$ 45 g's at the top of the MPC fuel basket, except as provided for in this paragraph below. Analyses shall be performed using methodologies consistent with those described in the HI-STORM 100 FSAR. A *restriction on the* lift *and/or drop* height~~above the ISFSI pad~~ is not required to be established if the cask is lifted with a device designed in accordance with ANSI N14.6 and *has*~~ving~~ redundant drop protection features.

c. *For underground casks (VVMs), the depth weighted average low strain shear wave velocity of the substrate below the SUPPORT FOUNDATION (used to determine best estimate substrate property values) shall be greater than or equal to 800 ft/s. The total depth used in computing the average low strain shear wave velocity shall be from the base of the SUPPORT FOUNDATION to the lesser of: 1) the depth to the top of a layer*

(continued)

3.4 Site-Specific Parameters and Analyses (continued)

having a low strain shear velocity of 3500 ft/s, 2) the depth to the top of a layer where the low strain shear velocity exceeds ten (10) times the low strain shear wave velocity of the layer immediately below the SUPPORT FOUNDATION, or 3) three (3) times the depth of the VVM below the top of grade. (See paragraphs 7, 8 and 12 below).

d. *For underground casks, the substrate surrounding the VVM, out to a distance equal to five (5) times the diameter of the VVM cavity, shall have a depth weighted average density of 120 lb/ft³.*

7. *If any of the requirements in sub-paragraph 3.4.6.c on the substrate below the support foundation are not satisfied, then site remediation may be performed to achieve compliance. Site remediation using pilings or other forms of reinforcement is permitted. Sub-paragraph 3.4.6.c is considered to be satisfied either by demonstrating that the minimum low strain shear velocity of 800 ft/s is met by the remediated substrate, or by demonstrating that the vertical stiffness, K, of the remediated substrate under the VVM meets or exceeds the value 5.1×10^6 1b/in. The vertical stiffness, K, is defined as:*

$$K = P / d$$

Where P is a vertical force applied to a rigid circular punch having a diameter equal to the diameter of the VVM baseplate with the punch vertically positioned on the surface of the substrate underlying the foundation pad, and d is the vertical displacement of the punch into the substrate.

8. *For HI-STORM 100U ISFSI only: The Support Foundation Pad (mat) for a VVM array established in a construction shall be of monolithic construction to maximize the physical stability of the underground installation. The underground earthen support shall be engineered to minimize long term differential settlement. The extent of projected settlement over the service life of the ISFSI shall be computed and factored in the strength qualification of the mat as set forth in paragraph (12) below.*

9. *For HI-STORM 100U ISFSI only: Radiation Protection Space (RPS) as defined in Subsection 5.7.9 of Appendix A, is intended to ensure that the substrate material (such as natural subgrade, and engineered fill) remains essentially intact under all service conditions including during an excavation activity adjacent to the RPS. A retainer wall at the edge of the RPS shall be constructed to prevent possible loss of shielding within the RPS during excavation under any credible event such as human error or an earthquake. If possible, RPS retaining wall(s) shall be keyed to the reinforced concrete pads at the bottom and top of the VVM. The RPS retaining wall shall be important-to-safety and shall be designed to comply with a national consensus standard (such as ACI 318 (2005)).*

(continued)

DESIGN FEATURES

3.4 Site-Specific Parameters and Analyses (continued)

10. *For HI-STORM 100U ISFSI only: Table 3-3 provides the value of the ISFSI parameters that bear upon the structural response of the ISFSI under an ISFSI site's Design Basis Earthquake (DBE). The ISFSI owner shall verify that the value of each parameter meets the specification in Table 3-3.*

Table 3-3
Values of Principal Design Parameters for the Underground Overpack ISFSI

Thickness of the Foundation Pad, inch	*≥30*
Thickness of the VVM Interface Pad, inch	*≥28*
Thickness of the Top Surface Pad, inch	*≥24*
Rebar Size (min.) and Layout* (max)*	*#10 @ 9" each face, each direction*
Rebar Concrete Cover (top and bottom), inch*	*per 7.7.1 of ACI 318 (2005)*
Compressive Strength of Concrete, psi*	*≥4000*
Shear Wave Velocity in the Substrate lateral to the VVM, fps	*≥800*
Shear Wave Velocity in the Substrate Below the Foundation pad, fps	*≥800*

** Applies to Foundation, VVM Interface, and Top Surface Pads*

11. *For HI-STORM 100U ISFSI only: a site-specific seismic evaluation of a single VVM shall be performed using the methodology set forth in Subsection 3.I.4.7.1 of the HI-STORM 100 FSAR. The boldface text in Subsection 3.I.4.7.1 of the HI-STORM 100 FSAR is hereby incorporated by reference into this Technical Specification.*

12. *For HI-STORM 100U ISFSI only: The foundation Pad (mat) shall be analyzed for the combined effect of the dead load of the VVMs, any applicable live loads (such as that from a loaded transporter), seismic loads, and from the long-term differential settlement. The Foundation Pad (mat) must meet the ACI 318 strength limits under all applicable factored load combinations.*

13. *For HI-STORM 100U ISFSI only: Prior to an excavation activity contiguous to an RPS, a seismic qualification of the ISFSI in the structurally most vulnerable configuration (i.e., maximum amount of earth removed) shall be performed to verify that the stability of the Support Foundation, the ISFSI pad and the shielding material within the RPS is maintained, and that the structural strength of the retaining wall is not exceeded.*

(continued)

DESIGN FEATURES

3.4 Site-Specific Parameters and Analyses (continued)

~~7.~~ *14.* In cases where engineered features (i.e., berms and shield walls) are used to ensure that the requirements of 10CFR72.104(a) are met, such features are to be considered important to safety *and must be evaluated to determine the applicable quality assurance category.*

~~8.~~ *15.* LOADING OPERATIONS, TRANSPORT OPERATIONS, and UNLOADING OPERATIONS shall only be conducted with working area ambient temperatures $\geq$ 0° F.

~~9.~~ *16.* For those users whose site-specific design basis includes an event or events (e.g., flood) that result in the blockage of any OVERPACK inlet or outlet air ducts for an extended period of time (i.e, longer than the total Completion Time of LCO 3.1.2), an analysis or evaluation may be performed to demonstrate adequate heat removal is available for the duration of the event. Adequate heat removal is defined as fuel cladding temperatures remaining below the short term temperature limit. If the analysis or evaluation is not performed, or if fuel cladding temperature limits are unable to be demonstrated by analysis or evaluation to remain below the short term temperature limit for the duration of the event, provisions shall be established to provide alternate means of cooling to accomplish this objective.

~~10.~~ *17.* Users shall establish procedural and/or mechanical barriers to ensure that during LOADING OPERATIONS and UNLOADING OPERATIONS, either the fuel cladding is covered by water, or the MPC is filled with an inert gas.

DESIGN FEATURES

3.5 Cask Transfer Facility (CTF)

3.5.1 TRANSFER CASK and MPC Lifters

The CTF used to transfer a loaded TRANSFER CASK and/or MPC outside of the 10 CFR 50 radiological control boundary can be an aboveground structure that complies with the provisions of 3.5.2 below or an underground cavity that complies with the provisions of 3.5.3 below.

Lifting of a loaded TRANSFER CASK and MPC using devices that are not integral to structures governed by 10 CFR Part 50 shall be performed with a CTF that is designed, operated, fabricated, tested, inspected, and maintained in accordance with the guidelines of NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants" *,as applicable,* and the below clarifications. The CTF Structure requirements below do not apply to heavy loads bounded by the regulations of 10 CFR Part 50~~, to the loading of an *aboveground* OVERPACK in a belowground restraint system which permits MPC transfer near grade level and does not require an aboveground CTF, *or to the loading of an underground OVERPACK*~~.

3.5.2 CTF Structure Requirements

3.5.2.1 Cask Transfer Station and Stationary Lifting Devices

1. The metal weldment structure of the CTF structure shall be designed to comply with the stress limits of ASME Section III, Subsection NF, Class 3 for linear structures. The applicable loads, load combinations, and associated service condition definitions are provided in Table 3-~~2~~*4*. All compression loaded members shall satisfy the buckling criteria of ASME Section III, Subsection NF.

2. If a portion of the CTF structure is constructed of reinforced concrete, then the factored load combinations set forth in ACI-318 (89) for the loads defined in Table 3-~~2~~*4* shall apply.

3. The TRANSFER CASK and MPC lifting device used with the CTF shall be designed, fabricated, operated, tested, inspected and maintained in accordance with NUREG-0612, Section 5.1.

4. The CTF shall be designed, constructed, and evaluated to ensure that if the MPC is dropped during inter-cask transfer operations, its confinement boundary would not be breached. This requirements applies to CTFs with either stationary or mobile lifting devices.

(continued)

DESIGN FEATURES

3.5 Cask Transfer Facility (CTF) (continued)

3.5.2.2 Mobile Lift Devices

If a mobile lifting device is used as the lifting device, in lieu of a stationary lifting device, it shall meet the guidelines of NUREG- 0612, Section 5.1, with the following clarifications:

1. Mobile lifting devices shall have a minimum safety factor of two over the allowable load table for the lifting device in accordance with the guidance of NUREG-0612, Section 5.1.6(1)(a) and shall be capable of stopping and holding the load during a Design Basis Earthquake (DBE) event.

2. Mobile lifting devices shall conform to meet the requirements of ANSI B30.5, “Mobile and Locomotive Cranes,” in lieu of the requirements of ANSI B30.2, “Overhead and Gantry Cranes.”

3. Mobile cranes are not required to meet the requirements of NUREG-0612, Section 5.1.6(2) for new cranes.

4. Horizontal movements of the TRANSFER CASK and MPC using a mobile crane are prohibited.

3.5.3 Underground CTF Requirements

An underground CTF shall comply with the following requirements:

1. The bottom foundation pad shall have an equal or greater flexural and shear strength than the top ISFSI pad.

2. The bottom foundation pad shall have design features to prevent sideways or tip-over of the staged equipment.

3. The lifting device(s) used to lift the TRANSFER CASK and/or MPC at the underground CTF shall be designed, operated, fabricated, tested, inspected, and maintained in accordance with guidelines of NUREG-0612, Section 5.1.6.

The Vertical Ventilated Module (VVM) in HI-STORM 100U is an underground CTF since it meets the above requirements (the Top Surface Pad is interpreted as the ISFSI pad and the bottom foundation pad is interpreted as the SUPPORT FOUNDATION).

(continued)

DESIGN FEATURES

3.5 Cask Transfer Facility (CTF)(continued)

Table 3-~~2~~4

Load Combinations and Service Condition Definitions for the CTF Structure (Note 1)

Load Combination	ASME III Service Condition for Definition of Allowable Stress	Comment
D* D + S	Level A	All primary load bearing members must satisfy Level A stress limits
D + M + W' (Note 2) D + F D + E D + Y	Level D	Factor of safety against overturning shall be ≥ 1.1

D = Dead load
D* = Apparent dead load
S = Snow and ice load for the CTF site
M = Tornado missile load for the CTF site
W' = Tornado wind load for the CTF site
F = Flood load for the CTF site
E = Seismic load for the CTF site
Y = Tsunami load for the CTF site

Notes:
1. The reinforced concrete portion of the CTF structure shall also meet the factored combinations of loads set forth in ACI-318(89).
2. Tornado missile load may be reduced or eliminated based on a PRA for the CTF site.

DESIGN FEATURES

3.6 Forced Helium Dehydration System

3.6.1 System Description

Use of the Forced Helium Dehydration (FHD) system, (a closed-loop system) is an alternative to vacuum drying the MPC for moderate burnup fuel ($\leq$ 45,000 MWD/MTU) and mandatory for drying MPCs containing one or more high burnup fuel assemblies. The FHD system shall be designed for normal operation (i.e., excluding startup and shutdown ramps) in accordance with the criteria in Section 3.6.2.

3.6.2 Design Criteria

3.6.2.1 The temperature of the helium gas in the MPC shall be at least 15°F higher than the saturation temperature at coincident pressure.

3.6.2.2 The pressure in the MPC cavity space shall be $\leq$ 60.3 psig (75 psia).

3.6.2.3 The hourly recirculation rate of helium shall be $\geq$ 10 times the nominal helium mass backfilled into the MPC for fuel storage operations.

3.6.2.4 The partial pressure of the water vapor in the MPC cavity will not exceed 3 torr. The limit is met if the gas temperature at the demoisturizer outlet is verified by measurement to remain $\leq$ 21°F for a period of 30 minutes or if the dew point of the gas exiting the MPC is verified by measurement to remain $\leq$ 22.9°F for $\geq$ 30 minutes.

3.6.2.5 The condensing module shall be designed to de-vaporize the recirculating helium gas to a dew point $\leq$ 120°F.

3.6.2.6 The demoisturizing module shall be configured to be introduced into its helium conditioning function after the condensing module has been operated for the required length of time to assure that the bulk moisture vaporization in the MPC (defined as Phase 1 in FSAR Appendix 2.B) has been completed.

3.6.2.7 The helium circulator shall be sized to effect the minimum flow rate of circulation required by these design criteria.

3.6.2.8 The pre-heater module shall be engineered to ensure that the temperature of the helium gas in the MPC meets these design criteria.

(continued)

DESIGN FEATURES

3.6 Forced Helium Dehydration System (continued)

3.6.3 Fuel Cladding Temperature

A steady-state thermal analysis of the MPC under the forced helium flow scenario shall be performed using the methodology described in HI-STORM 100 FSAR Section 4.4, with due recognition of the forced convection process during FHD system operation. This analysis shall demonstrate that the peak temperature of the fuel cladding under the most adverse condition of FHD system operation, is below the peak cladding temperature limit for normal conditions of storage for the applicable fuel type (PWR or BWR) and cooling time at the start of dry storage.

3.6.4 Pressure Monitoring During FHD Malfunction

During an FHD malfunction event, described in HI-STORM 100 FSAR Section 11.1 as a loss of helium circulation, the system pressure must be monitored to ensure that the conditions listed therein are met.

DESIGN FEATURES

3.7 Supplemental Cooling System

3.7.1 System Description

The SCS is a water circulation system for cooling the MPC inside the HI-TRAC transfer cask during on-site transport. Use of the Supplemental Cooling System (SCS) is required for post-backfill HI-TRAC operations of an MPC containing one or more high burnup (> 45,000 MWD/MTU) fuel assemblies. The SCS shall be designed for normal operation (i.e., excluding startup and shutdown ramps) in accordance with the criteria in Section 3.7.2.

3.7.2 Design Criteria

3.7.2.1 Not Used.

3.7.2.2 If water is used as the coolant, the system shall be sized to limit the coolant temperature to below 180°F under steady-state conditions for the design basis heat load at an ambient air temperature of 100°F. Any electric motors shall have a backup power supply for uninterrupted operation.

3.7.2.3 The system shall utilize a contamination-free fluid medium in contact with the external surfaces of the MPC and inside surfaces of the HI -TRAC transfer cask to minimize corrosion.

3.7.2.4 All passive components such as tubular heat exchangers, manually operated valves and fittings shall be designed to applicable standards (TEMA, ANSI).

3.7.2.5 The heat dissipation capacity of the SCS shall be equal to or greater than the minimum necessary to ensure that the peak cladding temperature is below 400°C (752°F). All heat transfer surfaces in heat exchangers shall be assumed to be fouled to the maximum limits specified in a widely used heat exchange equipment standard such as the Standards of Tubular Exchanger Manufacturers Association.

3.7.2.6 The coolant utilized to extract heat from the MPC shall be high purity water or air. Antifreeze may be used to prevent water from freezing if warranted by operating conditions.

DESIGN FEATURES

3.7 Supplemental Cooling System (continued)

3.7.2.7 All pressure boundaries (as defined in the ASME Boiler and Pressure Vessel Code, Section VIII Division 1) shall have pressure ratings that are greater than the maximum system operating pressure by at least 15 psi.

3.7.2.8 All ASME Code components shall comply with Section VIII Division 1 of the ASME Boiler and Pressure Vessel Code.

3.7.2.9 All gasketed and packed joints shall have a minimum design pressure rating of the pump shut-off pressure plus 15 psi.

DESIGN FEATURES

3.8 Combustible Gas Monitoring During MPC Lid Welding *and Cutting*

During MPC lid-to-shell welding *and cutting* operations, combustible gas monitoring of the space under the MPC lid is required, to ensure that there is no combustible mixture present~~ in the welding area~~.

DESIGN FEATURES

3.9 Corrosion Mitigation Measures

The HI-STORM 100U VVM CEC Container Shell and Bottom Plate shall be protected from corrosion damage due to the corrosivity of the surrounding environment using the following means:

Implementation and Requirements of Corrosion Mitigation Measures			
Surrounding Environment 's Corrosivity (see note iv)	**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 exterior surface preservative (coating) applied on the CEC in accordance with the acceptance criteria set forth in the FSAR.

ii. Concrete encasement of the CEC external surfaces to establish a high pH buffer around the CEC metal mass in accordance with the requirements set forth in the FSAR.

iii. An impressed current cathodic protection system (ICCPS) in accordance with the design criteria set forth in the FSAR.

iv. Surrounding environment corrosivity is categorized as either mild or aggressive in accordance with the requirements set forth in the FSAR.

DESIGN FEATURES

3.10 Periodic Corrosion Inspections for Underground Systems

HI-STORM 100U VVM ISFSIs not employing an impressed current cathodic protection system shall be subject to visual and UT inspection of at least one representative VVM to check for significant corrosion of the CEC Container Shell and Bottom Plate at an interval not to exceed 20 years. The VVM chosen for inspection is not required to be in use or to have previously contained a loaded MPC. The VVM considered to be most vulnerable to corrosion degradation shall be selected for inspection. If significant corrosion is identified, either an evaluation to demonstrate sufficient continued structural integrity (sufficient for at least the remainder of the licensing period) shall be performed or the affected VVM shall be promptly scheduled for repair or decommissioning. Through wall corrosion shall not be permitted without promptly scheduling for repair or decommissioning. Promptness of repair or decommissioning shall be commensurate with the extent of degradation of the VVM but shall not exceed 3 years from the date of inspection.

If the representative VVM is determined to require repair or decommissioning, the next most vulnerable VVM shall be selected for inspection. This inspection process shall conclude when a VVM is found that does not require repair or decommissioning. Since the last VVM inspected is considered more prone to corrosion than the remaining un-inspected VVMs, the last VVM inspected becomes the representative VVM for the remaining VVMs.

Inspections

Visual Inspection: Visual inspection of the inner surfaces of the CEC Container Shell and Bottom Plate for indications of significant or through wall corrosion (i.e., holes).

UT Inspection: The UT inspection is performed on the inside surfaces of the CEC. A minimum of 16 data points shall be obtained, 4 near the top, 4 near the mid-height and 4 near the bottom of the CEC Container Shell all approximately 0, 90, 180, and 270 degrees apart; and 4 on the CEC Bottom Plate near the CEC Container Shell approximately 0, 90, 180, and 270 degrees apart. Locations where visual inspection has identified potentially significant corrosion shall also receive UT inspection. Locations suspected of significant corrosion may receive further UT inspection to determine the extent of corrosion.

Inspection Criteria

General wall thinning exceeding 1/8" in depth and local pitting exceeding 1/4" in depth are conditions of significant corrosion.

DESIGN FEATURES

3.11 Preventing Oxidation of Fuel

During loading and unloading operations, the fuel shall be either maintained underwater or in an inert atmosphere.

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1.2.1.3.3 Gamma Shielding Material

For gamma shielding, the HI-STORM 100 storage overpack primarily relies on massive concrete sections contained in a robust steel vessel. A carbon steel plate, the shield shell, is located adjacent to the overpack inner shell to provide additional gamma shielding (Figure 1.2.7)†. Carbon steel supplements the concrete gamma shielding in most portions of the storage overpack, most notably the pedestal (HI-STORM 100 and –100S overpack designs only) and the lid. To reduce the radiation streaming through the overpack air inlets and outlets, gamma shield cross plates are installed in the ducts (Figures 1.2.8 and 1.2.8A) to scatter the radiation. This scattering acts to significantly reduce the local dose rates adjacent to the overpack air inlets and outlets. See Figure 5.3.19 and the drawings in Section 1.5 for more details of the gamma shield cross plate designs for each overpack design.

In the HI-TRAC transfer cask, the primary gamma shielding is provided by lead. As in the storage overpack, carbon steel supplements the lead gamma shielding of the HI-TRAC transfer cask.

1.2.1.4 Lifting Devices

Lifting of the HI-STORM 100 System may be accomplished either by attachment at the top of the storage overpack ("top lift"), as would typically be done with a crane, or by attachment at the bottom ("bottom lift"), as would be effected by a number of lifting/handling devices.

For a top lift, the storage overpack is equipped with four threaded anchor blocks arranged circumferentially around the overpack. These anchor blocks are used for overpack lifting as well as securing the overpack lid to the overpack body. The storage overpack may be lifted with a lifting device that engages the anchor blocks with threaded studs and connects to a crane or similar equipment.

A bottom lift of the HI-STORM 100 storage overpack is affected by the insertion of four hydraulic jacks underneath the inlet vent horizontal plates (Figure 1.2.1). A slot in the overpack baseplate allows the hydraulic jacks to be placed underneath the inlet vent horizontal plate. The hydraulic jacks lift the loaded overpack to provide clearance for inserting or removing a device for transportation.

The standard design HI-TRAC transfer cask is equipped with two lifting trunnions and two pocket trunnions. The HI-TRAC 100D and 125D are equipped with only lifting trunnions. The lifting trunnions are positioned just below the top forging. The two pocket trunnions are located above the bottom forging and attached to the outer shell. The pocket trunnions are designed to allow rotation of the HI-TRAC. All trunnions are built from a high strength alloy with proven corrosion and non-galling characteristics. The lifting trunnions are designed in accordance with NUREG-0612 and ANSI N14.6. The lifting trunnions are installed by threading into tapped holes just below the top forging.

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† The shield shell design feature was deleted in June, 2001 after overpack serial number 7 was fabricated.

SUPPLEMENT 1.I

GENERAL DESCRIPTION OF HI-STORM 100U SYSTEM

1.I.0 GENERAL INFORMATION

The HI-STORM 100U System is an alternative Vertical Ventilated Module (VVM) design to be used with the Holtec International Multi-purpose Canisters (MPCs) for dry storage of spent nuclear fuel at an Independent Spent Fuel Storage Installation (ISFSI). Information pertaining to the HI-STORM 100U System is generally contained in the "I" supplements to each chapter of this FSAR. Certain sections of the main FSAR are also affected and are appropriately modified for continuity with the "I" supplements. Unless superseded or specifically modified by information in the "I" supplements, the information in the main FSAR is applicable to the HI-STORM 100U System. Drawings specific to the HI-STORM 100U VVM are in Subsection 1.I.5. The Glossary has been appropriately augmented to include the terms particular to the HI-STORM 100U VVM.

1.I.1 INTRODUCTION

HI-STORM 100U, like HI-STORM 100[1] and HI-STORM 100S[2], is a vertical, ventilated dry spent fuel storage system engineered to be fully compatible with the presently certified HI-TRAC transfer casks and MPCs. HI-STORM 100U is an underground vertical ventilated module (VVM) designed to accept all MPC models for storage at an ISFSI (see Figure 1.I.1). ISFSIs employing the VVM may be designed for any number of MPCs and expanded to add additional storage modules as the need arises. Each VVM stores one MPC.

The design and operational attributes of the HI-STORM 100U VVM, described in the following paragraphs pursuant to the provisions of 10CFR72.24(b), are subject to intellectual property rights in the U.S. and abroad under the patent laws governing the respective jurisdictions.

1.I.2 GENERAL DESCRIPTION OF HI-STORM 100U SYSTEM

1.I.2.1 HI-STORM 100U Vertical Ventilated Module

The VVM provides for storage of MPCs in a vertical configuration inside a subterranean cylindrical cavity entirely below the top-of-the-grade (TOG) of the ISFSI (Figure 1.I.2 provides identification of the TOG). The MPC Storage Cavity is defined by the Cavity Enclosure Container (CEC), consisting of the Container Shell integrally welded to the Bottom Plate. The top of the Container Shell is stiffened by the Container Flange (a ring shaped flange), which is also integrally welded. As shown in licensing basis drawings provided in Section 1.I.5, all of the constituent parts of the CEC are made of thick low carbon steel plate (See Table 2.I.8 for component materials). In its installed configuration, the CEC is interfaced with the surrounding subgrade for most of its height except for

[1] U.S. Patent No. 6,064,710 dated May 16, 2000.

[2] U.S. Patent No. 6,718,000 dated April 6, 2004.

the top region where it is girdled by the ISFSI pad. The ISFSI pad serves several purposes in the HI-STORM 100U storage system, such as:

- It provides an essentially impervious barrier of reinforced concrete against seepage of water from rain/snow into the subgrade.

- It provides the interface surface for the CEC flange.

- It helps maintain a clean, debris-free region around the VVMs.

- It provides the necessary riding surface for the cask transporter (see Figure 1.I.7).

The ISFSI pad is actually composed of two distinct regions separated by suitably engineered expansion joints. These are referred to as (see Figure 1.I.3):

i. the VVM Interface Pad (VIP) and
ii. the Top Surface Pad (TSP).

As its name implies, the VIP is in close contact with the Container Flange and the upper part of the Container Shell for sealing and shielding purposes. In Figures 1.I.1 and 1.I.2, the elevated portion of the ISFSI pad is the VIP.

The balance of the ISFSI pad, lower in elevation than the VIP, is the top surface pad (TSP). The TSP carries no significant loads except during the movement of the cask transporter over portions of its surface. The substantial difference in the dead load patterns on the two regions of the ISFSI pad warrants that the two regions be physically disconnected so that differential settlement between the two do not produce (undesirable) flexural and shear loadings. Governing codes for the ISFSI pad design and construction are described (see Supplement 2.I) to ensure a high integrity design. Expansion joints are placed between the two pads where necessary to ensure that vertical movements are independent. As discussed in Supplement 3.I, an optional concrete encasement around the coated external surface of the CEC may be added to control the pH at the CEC-to-subgrade interface.

Corrosion mitigation measures commensurate with site-specific conditions are implemented on below-grade external surfaces of the CEC. A corrosion allowance (metal wastage) equal to 1/8" on the external surfaces of the VVM in contact with the subgrade is nevertheless assumed in the structural evaluation in Supplement 3.I. All external and internal surfaces of the VVM are coated with an appropriate surface preservative. The top surfaces of the MPC Bearing Pads are equipped with stainless steel liners so that the MPC is not resting directly on carbon steel components. Details of corrosion mitigation measures are described in Section 3.I.4.

With the Closure Lid removed, the CEC is a closed bottom, open top, thick walled cylindrical vessel that has no penetrations or openings. Thus, groundwater has no path for intrusion into the interior space of the MPC storage cavity. Likewise, any water that may be introduced into the MPC storage cavity through the air passages in the top lid will not drain out on its own. The Bottom Plate of the CEC is round and slightly larger in diameter than the Container Shell to accommodate an all around weld between the plate and the shell.

The Support Foundation has circular VVM Lateral Support Recessed Regions to locate and contain lateral motion of each VVM with respect to the Support Foundation. The VVM Support Foundation and the underlying substrate must be sufficiently strong to prevent significant long-term settlement under the weight of the loaded storage cavities. The appropriate requirements on the Support Foundation's structural strength and the applicable industry code are specified in Supplement 2.I of this FSAR. Like the ISFSI pad above, the Support Foundation is classified as an "interfacing structure" in this FSAR.

The MPC Bearing Pads and the Divider Shell, two parts internal to the CEC, are important to the VVM's thermal performance. The Divider Shell, as its name implies, is a vertical cylindrical shell concentrically situated in the CEC. The Divider Shell creates an outer annular coolant air or intake plenum and an inner annular coolant air space around the MPC. The bottom end of the Divider Shell has cutouts to enable incoming air streaming down the intake plenum to enter the inner coolant air space from around the circumference of the Divider Shell in a symmetric manner (Figures 1.I.2 and 1.I.4). The sectors of the Divider Shell that rest on the CEC Bottom Plate are also the locations where MPC Bearing Pads provide for a Bottom Plenum underneath the MPC for access of coolant air. The cutouts in the Divider Shell are sufficiently tall to ensure that if the cavity were to be filled with water, the bottom region of the MPC would be submerged for several inches before the water level reaches the top edge of the cutouts. This design feature is important to ensure uncompromised thermal performance of the system under any conceivable accidental flooding of the cavity by any means whatsoever. The Divider Shell is laterally restrained in the horizontal plane at its bottom end by the Divider Shell Restraints and rotationally restrained in the horizontal plane by the MPC Bearing Pads. The Divider Shell is not attached to the CEC; this allows convenient removal for decommissioning, for unplanned in-service maintenance, or for any other unforeseeable reason. The Divider Shell's interface with the Closure Lid features a small gap to permit the Divider Shell to expand freely from heating by ventilation air.

In addition to the lateral restraints at the bottom, the Divider Shell is also restrained against lateral movement at the top by the cylindrical protrusion in the Closure Lid. In addition, the Divider Shell is equipped with Upper and Lower MPC Guides. The Upper MPC Guides are radially symmetric rib-like components located at the elevation of the MPC's top lid. The Upper MPC Guides serve to guide the MPC down to the Lower MPC Guides and MPC Bearing Pads during the MPC's lowering operation, as well as to limit the MPC's lateral movement relative to the CEC, during an earthquake event, to a fraction of an inch.

The cylindrical surface of the Divider Shell is equipped with insulation to ensure that the heated air streaming up around the MPC in the inner coolant air space causes minimal preheating of the air streaming down the intake plenum. As discussed in Supplement 3.I.4, the insulation material is selected to be water and radiation resistant and non-degradable under accidental wetting.

Finally, the Closure Lid shown in Figure 1.I.6 completes the physical embodiment to the VVM. The Closure Lid is a steel structure filled with shielding concrete. The design of the top lid fulfills the following principal performance objectives:

i. Both the inlet and outlet air passages are located in the Closure Lid, so there are no lateral radiation leakage paths during the MPC lowering or raising operation. The need for shield blocks (necessary to close off vents in some aboveground HI-STORM 100 overpacks) is eliminated.

ii. Both inlet and outlet passages are radially symmetric so that the air cooling action in the system is not affected by the change in the horizontal direction of the wind.

iii. By locating the air inlet at the periphery of the Closure Lid and the air outlet at its top central axis, mixing of entering and exiting air streams is essentially eliminated.

iv. The inlet and outlet air passages are made of "formed and flued" heads (i.e., surfaces of revolution) that serve three major design objectives as noted below.

   a. The curved passages eliminate any direct line of sight to the MPC storage space and serve as an effective means to scatter the photons streaming from the stored fuel.

   b. The curved steel plates significantly increase the load bearing capacity of the Closure Lid much in the manner as a curved beam exhibits considerably greater lateral load bearing capacity in comparison to its straight counterpart. This design feature is a valuable attribute if a "beyond-the-design basis" impact scenario involving a large and energetic missile needs to be evaluated for a particular ISFSI site.

   c. The curved passages, as is well known in classical hydraulics, provide for minimum loss of pressure in the coolant air stream, resulting in a more vigorous ventilation action.

v. The Closure Lid rests on the Container Flange and is gasketed to minimize foreign material intrusion.

vi. The top surface of the Closure Lid is also curved and extended beyond the air inlet perimeter to efficiently drain off rainwater.

vii. The Container Flange restrains the Closure Lid against horizontal movement, during a Design Basis Earthquake event or a tornado missile strike.

viii. The radially symmetric air inlet passage in the lid is geometrically aligned with the annular opening formed between by the Divider Shell and the CEC Shell.

ix. Because the inlet opening extends around the circumference of the Closure Lid, the hydraulic resistance to the incoming airflow, a common limitation in ventilated modules, is minimized. A similar airflow resistance minimization facility is built into the pathway for the exiting air. A circumferentially circumscribing vent opening is also quite obviously less apt to be completely blocked under even most extreme environmental phenomena involving substantial quantities of debris.

x. To minimize the VVM's height, a portion of the Closure Lid extends into the cylindrical space above the MPC. This cylindrical below-surface extension of the Closure Lid is also made of steel filled with shielding concrete to maximize the blockage of skyward radiation issuing from the MPC.

xi. All inlet and outlet air passages are equipped with screens, as in the aboveground HI-STORM overpacks, to prevent debris, insects, and small animals from entering the VVM. Although the screen is a non-structural member, it is designed for long-term durability and easy maintainability to ensure that its installation, removal, and maintenance are ALARA.

Finally, particular attention is paid to the design of the exit vent assembly (at the top of the outlet air passages in Figure 1.I.2) to ensure that wind-driven rain at up to 45° inclination from the vertical will not have a direct line of sight to the vertically oriented portion of the air passage in the Closure Lid.

xii. As can be seen from the drawings in Section 1.I.5, the Closure Lid is substantially larger in diameter than the Divider Shell in the CEC and the MPC is positioned to be at a significant vertical depth below the top of the Container Flange. These geometric provisions ensure that the Closure Lid will not fall into the MPC storage cavity space and strike the MPC if it were accidentally dropped during its handling. An accidental drop of the MPC, however, can lead to a collision with the top of the Divider Shell. The Divider Shell, if damaged due to a handling accident, can be readily removed and repaired or replaced without affecting any other parts of the VVM. Because the Closure Lid is the only removable heavy load, the carefully engineered design features to facilitate recovery from its accidental drop provide added assurance that a handling accident at the ISFSI will not lead to radiological release. This additional measure against accidental Closure Lid drop does not replace the drop prevention features mandated in this FSAR on heavy load lifting devices such as the cask transporter (illustrated in Figure 1.I.7) that have been a standard and established requirement in the HI-STORM 100 docket.

From a jurisdictional standpoint, the CEC, the Container Flange, and the Closure Lid, constitute the body of the VVM. The Support Foundation on which the VVM rests, however, must be designed to meet certain structural criteria to minimize long-term settlement and physical degradation from aggressive attack of the materials in the surrounding subgrade. Likewise, the Top Surface Pad serves to augment shielding, but is mainly needed to provide a sufficiently stiff roadway for the transporter. Similarly, the VVM Interface Pad (Figure 1.I.2) serves to augment shielding, as a barrier against gravity induced seepage of rain or floodwater around the VVM body, and as a barrier against a missile directed towards the underground portion of the CEC structure. The essential structural requirements applicable to the design of the Support Foundation, the VVM Interface Pad, and the Top Surface Pad for proper functioning of the VVM are provided in Supplement 2.I (Principal Design Criteria). Similarly, typical physical characteristics of the surrounding substrate are provided in Supplement 2.I. This data is intended to provide guidelines for the design of SSCs proximate to the VVM to ensure that the VVM, regardless of the wide variations in the properties at an ISFSI site, will render its intended function for the duration of its Design Life.

The foregoing description of the VVM clearly indicates that the principal function of the VVM structure is to provide the biological shield and cooling facility. However, for conservatism, stress limits of the "Level A" service condition in Subsection NF of the ASME Code are applied to establish the embedded structural margins of safety in the primary load bearing parts of the VVM under normal conditions of storage. For short term and accident conditions (i.e., earthquakes, missile strike, etc.), the continued functional adequacy of the system is the appropriate criterion. For the VVM, continued functional adequacy under accident or extreme environmental events demands absence of a complete blockage of the ventilation passages and a non-significant amount of loss of shielding. Supplement 2.I provides complete details on the applicable design criteria.

All MPC types certified for storage in the aboveground overpacks can be stored in the below ground VVM. The chief distinguishing features of the VVM are its low profile and subterranean configuration. The Container Shell is buried below the ISFSI Pad for virtually its entire height, resulting in a near complete blockage of laterally emanating radiation from the stored fuel.

In summary, the notable design and operational features of the HI-STORM 100U System are:

i. The MPC is supported on MPC Bearing Pads to provide an inlet air plenum at the bottom of the storage cavity (Figure 1.I.2). The bottom of the MPC, however, will be in contact with water if the cutouts at the bottom of the Divider Shell were to be filled with water cutting off feed air. As long as the MPC is wetted with water, the peak cladding temperature of the stored spent fuel will not exceed the regulatory off-normal condition temperature limit. Thus, the VVM configuration provides a built-in protection against flood events.

ii. Like the HI-STORM 100A and 100SA models, tipover of the canister in storage is not possible.

iii. Although the modules may be closely spaced, as illustrated in Figure 1.I.5, the design permits any MPC located in any cavity to be independently accessed and retrieved using a HI-TRAC transfer cask.

iv. A cask transporter typical of those used in numerous Holtec ISFSI projects for on-site transport of loaded HI-TRACs and HI-STORMs can provide the means to deliver the loaded HI-TRAC to the HI-STORM 100U VVM and to carry out the MPC lowering operation (Figure 1.I.7). The same cask transporter can also be used to remove an MPC from storage and place it in a recipient HI-TRAC transfer cask.

v. To exploit the biological shielding provided by the surrounding soil subgrade, the MPC is entirely situated well below the top-of-grade level. The open plenum above the MPC also acts to boost the ventilation action of the coolant air.

vi. Because the VVM is rendered into an integral part of the subgrade, it cannot be translocated to another ISFSI site. It also cannot be lifted and, therefore, is not subject to the potential for a handling accident.

vii. Removal of water from the bottom of the storage cavity can be carried out by the simple expedient use of a flexible hose inserted through either the inlet or the outlet passageway.

viii. As discussed in Supplement 3.I.4, all exposed surfaces of the VVM are coated with proven surface preservatives that meet the toxilogical and exctraction test requirements of ANSI/NSF Standard 61.

ix. The VVM is a formed metallic welded structure with a removable Closure Lid. The Closure Lid is also a formed metallic welded structure but filled with shielding concrete. The requirements on the shielding concrete are specified in Appendix 1.D.

As can be readily deduced from the above description of the VVM, the MPC storage cavity (consisting of the Container Shell and Bottom Plate) is at or near ambient temperature during normal operations. The only portions of the VVM in contact with heated ventilation air are the Divider Shell and the domed annular outlet in the Closure Lid, neither of which is in contact with the subgrade soil.

It should be recognized that the depth of the MPC Storage cavity determines the height of the hot air column in the annular region during the system's operation. Therefore, deepening the cavity has the beneficial effect of increasing the quantity of the ventilation air and, thus, enhancing the rate of heat rejection from the stored MPC. Further, lowering the MPC in the MPC Storage cavity will increase the subterranean depth of the radiation source, making the site boundary dose even more miniscule. To ensure that the thermal and shielding performance is the bounding minimum, the top of the MPC is assumed to be at its maximum permissible elevation with respect to the Top-of-the-Grade and the MPC Storage Cavity depth is assumed to be accordingly at its permitted minimum in all thermal and shielding analyses reported in Supplements 4.I and 5.I, respectively, and in the drawings provided in Section 1.I.5. At a specific ISFSI site, the user has the latitude to deepen the VVM cavity and situate the MPC at a deeper depth using the §72.48 process.

The VVM implements seals or gaskets at the Closure Lid. The outer seal is a weather seal (between the Closure Lid and the top of the Divider Shell), which facilitates maintenance by minimizing foreign material intrusion into the MPC storage cavity. The inner seal (between the Closure Lid skirt and the Divider Shell (not shown on the licensing drawing 4501)) provides an enhanced barrier against mixing of inlet and outlet air in the annular space between the Divider Shell and the cylindrical protrusion in the Closure Lid (even though the pressure differential between the two sides is extremely low – less than a few inches of water). The outer seal relies on the weight of the Closure Lid to insure sealing. A polymeric gasket made from EPDM[3] is preferred for this purpose. The inner seal is made of a durable radiation and heat resistant material and designed to have no credible mechanism for significant degradation or detachment from its sealing location. The seals do not

[3] Radiation resistant polymeric gasket materials are available from the Presray and Pawling Corporations, for example.

provide a safety function because their loss during operation would not have an effect on safe operation of the system.

Finally, the physical hardening of the VVM against impulsive and impactive loadings is a major consideration in the embodiment of the HI-STORM 100U System. Quite obviously, the low physical profile of the VVM reduces the probability of impact from a missile or a projectile. In addition, to impute maximum margin against extreme environmental phenomena loads, the Closure Lid is a METCON® (metal/concrete) structure engineered to possess considerably greater strength reserve than that required to prevent design basis missiles from penetrating into the MPC storage cavity, as demonstrated by analysis in Supplement 3.I. Another design consideration is protection against intrusion of rainwater and other liquid matter into the MPC storage cavity. In contrast to typical ventilated modules, the VVM air passages are elevated above the Top-of-the-Grade, providing a physical barrier against the intrusion of any accumulating pool of fluid (including combustibles) on the ISFSI surfaces into the module cavity. A significantly enhanced level of protection against incident missiles and an improved barrier against ingress of rainwater or spilled fluids into the module cavity space, and a design that is ideally configured for a flood event, are among the many distinguishing features of the HI-STORM 100U System.

1.I.2.2 HI-STORM 100U System Sequence of Operations

Fuel loading operations and MPC preparation are identical for the VVM as they are with the other HI-STORM overpack designs. The HI-TRAC transfer cask is used for on-site transport of the loaded MPC from the MPC preparation area to the VVM at the ISFSI. The Closure Lid will have been previously removed from the VVM. The cask transporter carrying the transfer cask and the MPC moves over the top of the open VVM where the HI-STORM mating device (shown beneath the HI-TRAC in Figure 1.I.7) is in place. The MPC inside the transfer cask is lifted slightly by the cask transporter (or an equivalent heavy load handling device) to allow the transfer cask pool lid to be removed. Once the pool lid is removed, the heavy load handling device is used to lower the MPC into the VVM. The transfer cask and mating device are removed from the top of the VVM, the MPC lift connectors are removed, and the VVM Closure Lid is installed. Supplement 8.I provides a more detailed discussion of operations involving the HI-STORM 100U System. (The "mating device" aided MPC transfer operation is an exclusive intellectual property of Holtec International under U.S. Patent No. 6,853,797 B2 dated February 8, 2005.)

1.I.3 IDENTIFICATION OF AGENTS AND CONTRACTORS

Same as in Section 1.3.

1.I.4 GENERIC CASK ARRAYS

An ISFSI deploying the HI-STORM 100U System may use an unlimited number of VVMs. The preferred embodiment of the VVM array is a rectangular grid as illustrated in Figure 1.I.5. The minimum pitch between the VVM cavities is shown in Figure 1.I.5. In either or both directions, the spacing can be increased by the site to ensure that any of the commercially available cask transporters can traverse the VVM arrays to provide autonomous access to each stored MPC. This minimum spacing also serves to provide adequate shielding around each storage cavity.

No limit is placed on the maximum spacing. Multiple VVMs in an ISFSI shall be founded on a continuous support foundation to prevent an unacceptable level of differential settlement between adjacent VVMs and to enhance the seismic response characteristics of the ISFSI.

The design of the expansion joints between the VVM Interface Pad and the Top Surface Pad regions of the ISFSI Pad is guided by the need to physically decouple the settlement of the two regions due to long term creep effects.

Additional VVMs may be built adjacent to existing VVMs without imparting excessive dose to the construction crew, if a sufficient distance to loaded VVMs is kept. To ensure that this distance is kept, a "Radiation Protection Space" (RPS) boundary is specified in the drawing package in Section 1.I.5. This boundary shall not be encroached upon during any site construction effort. Subsection 2.I.6(xii) contains additional requirements on the design and qualification of the RPS to insure that the earthen shielding in the RPS shall be protected against a significant loss due to human error or natural events such as earthquakes and tornado borne missiles.

1.I.5 FIGURES AND DRAWINGS

Figures associated with Supplement 1.I and the licensing drawing package of the HI-STORM 100U VVM, pursuant to the requirements of 10CFR72.24(c)(3), are provided in this subsection. The material in the licensing drawing package in this section contains sufficient information to articulate major design features and general operational characteristics of the HI-STORM 100U VVM. Further, it is intended to serve as the control information to guide the preparation of the documents required to manufacture the components under the company's quality assurance system. Some key document types needed for manufacturing in the factory under the company's fail-safe configuration control protocol are:

- Purchasing Specifications (PSs)
- Manufacturing Drawing Package
- Holtec Standard Procedures (HSPs)
- Holtec Project Procedures (HPPs)
- Bill-of-Materials
- Fabrication and NDE Procedures
- Shop Travelers

Holtec's Quality Assurance Program requires that the entire array of manufacturing documents must remain in complete consonance with the Licensing Drawing Package (and other provisions in this FSAR) at all times.

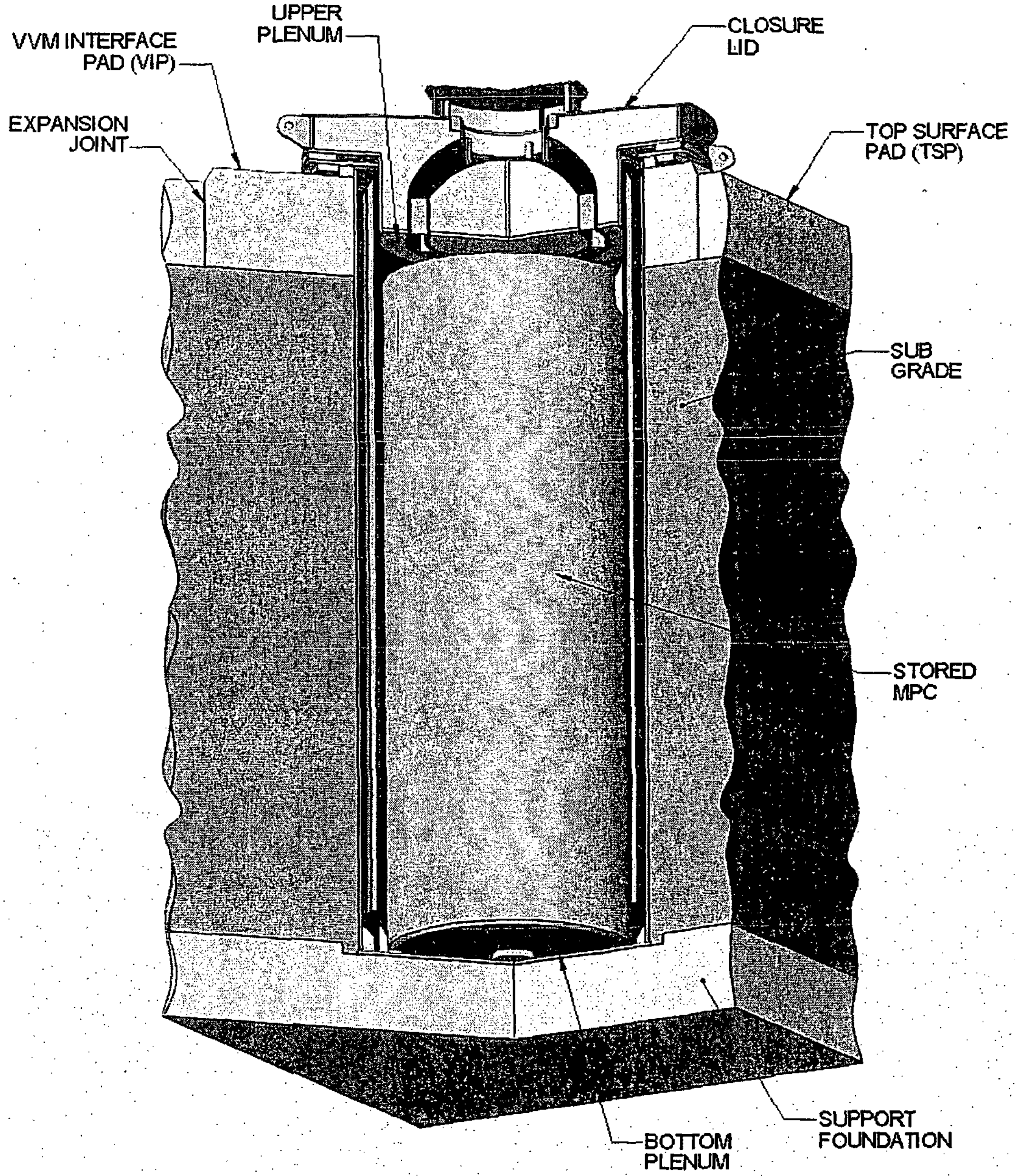

FIGURE 1.I.1: CUT-AWAY VIEW OF HI-STORM 100U SYSTEM)

Note: 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. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

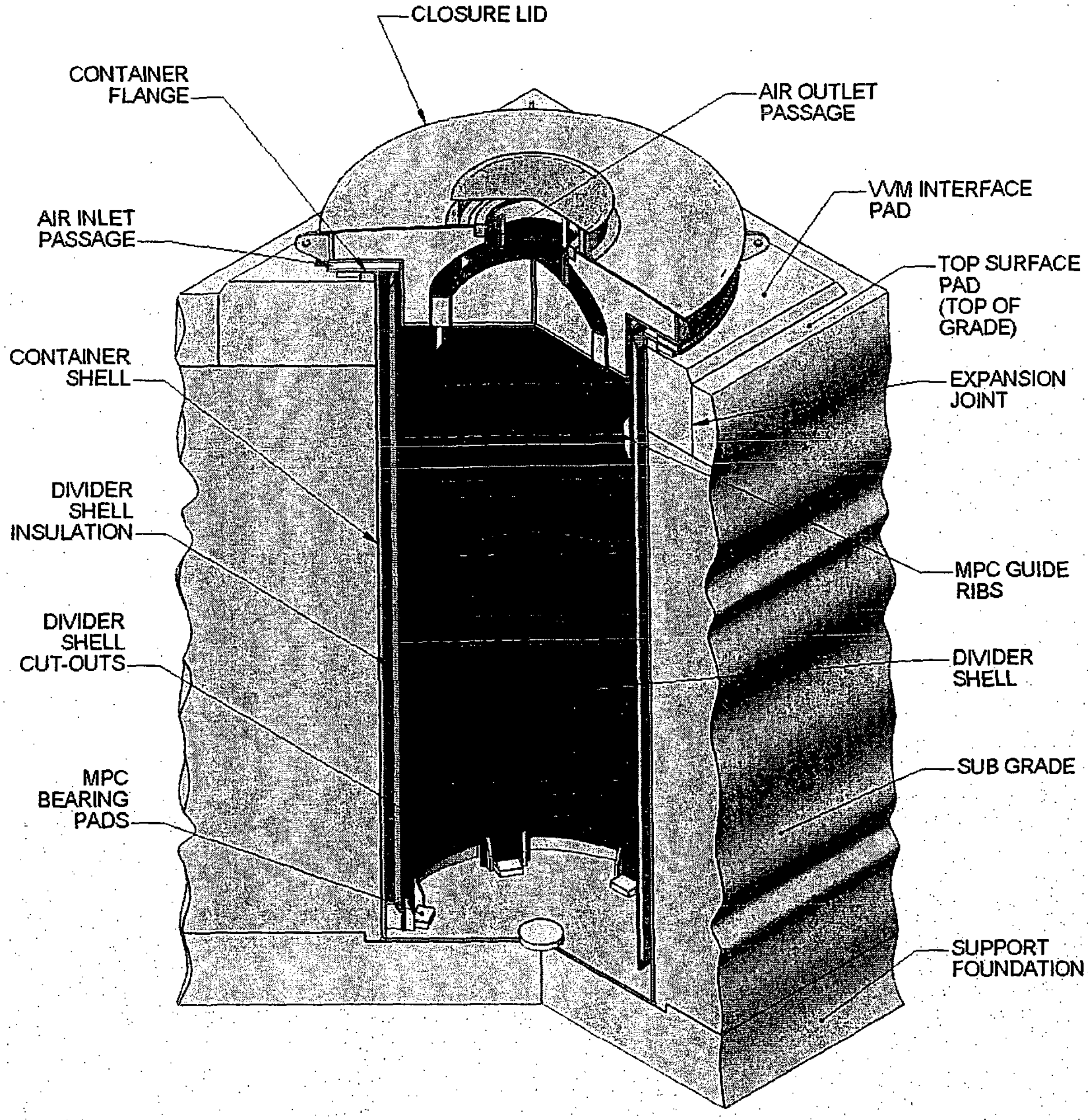

FIGURE 1.I.2: CUT-AWAY VIEW OF THE HI-STORM 100U VVM

Note: 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. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

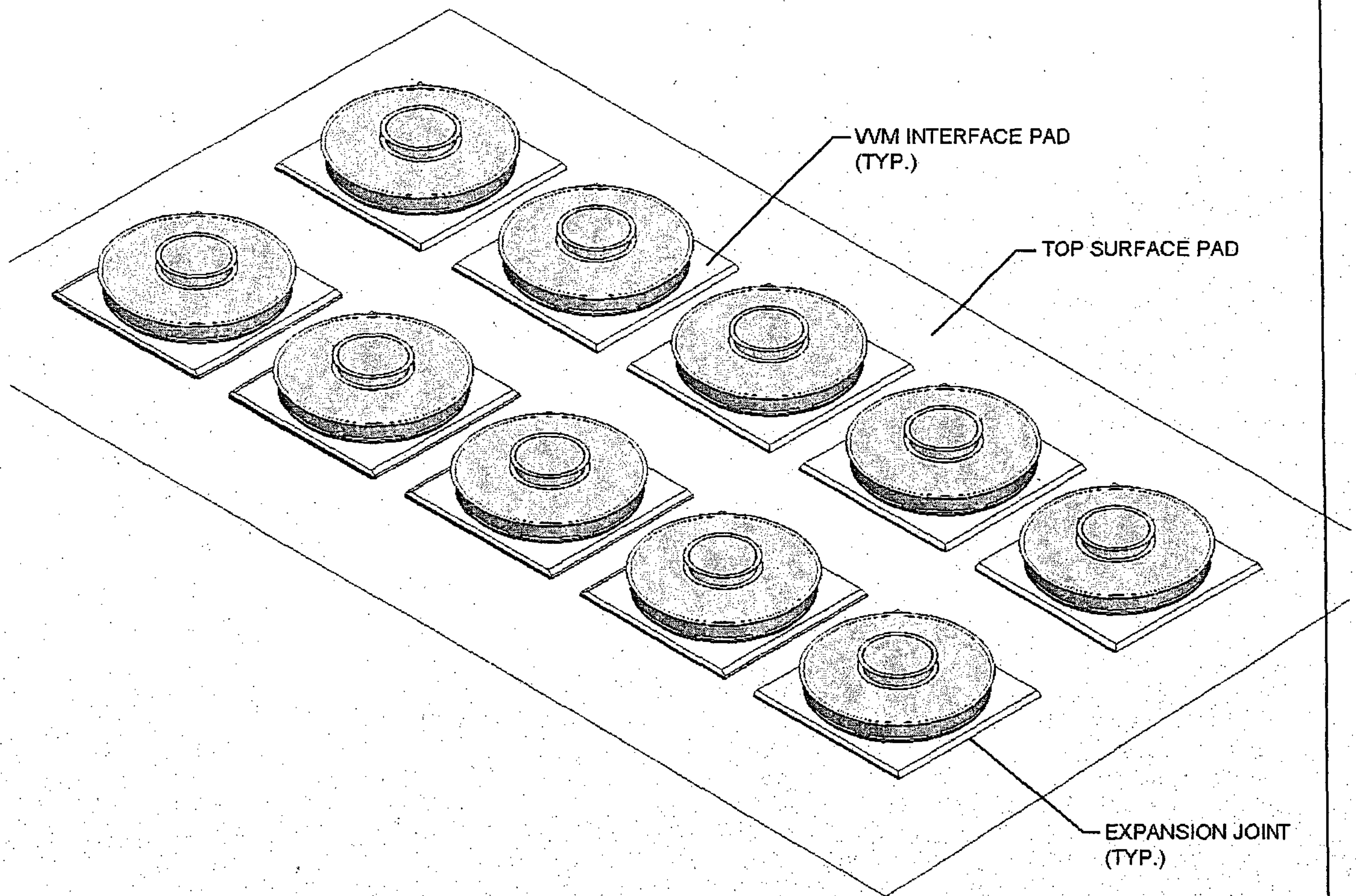

FIGURE 1.I.3: TYPICAL HI-STORM 100U SYSTEM ISFSI 2 x 5 ARRAY

Note: 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. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

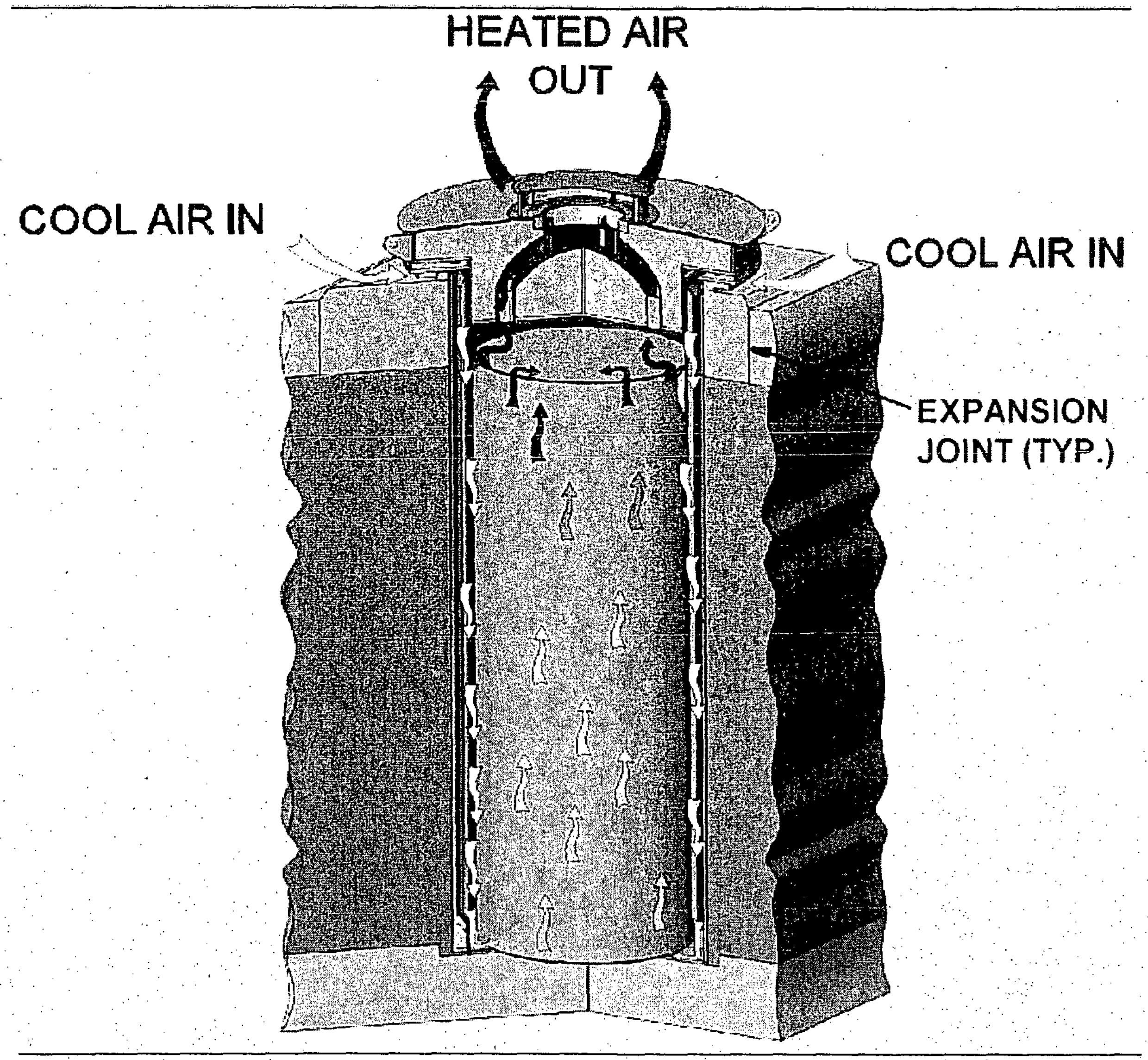

FIGURE 1.I.4: HI-STORM 100U SYSTEM AIR FLOW PATTERN

Note: 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. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

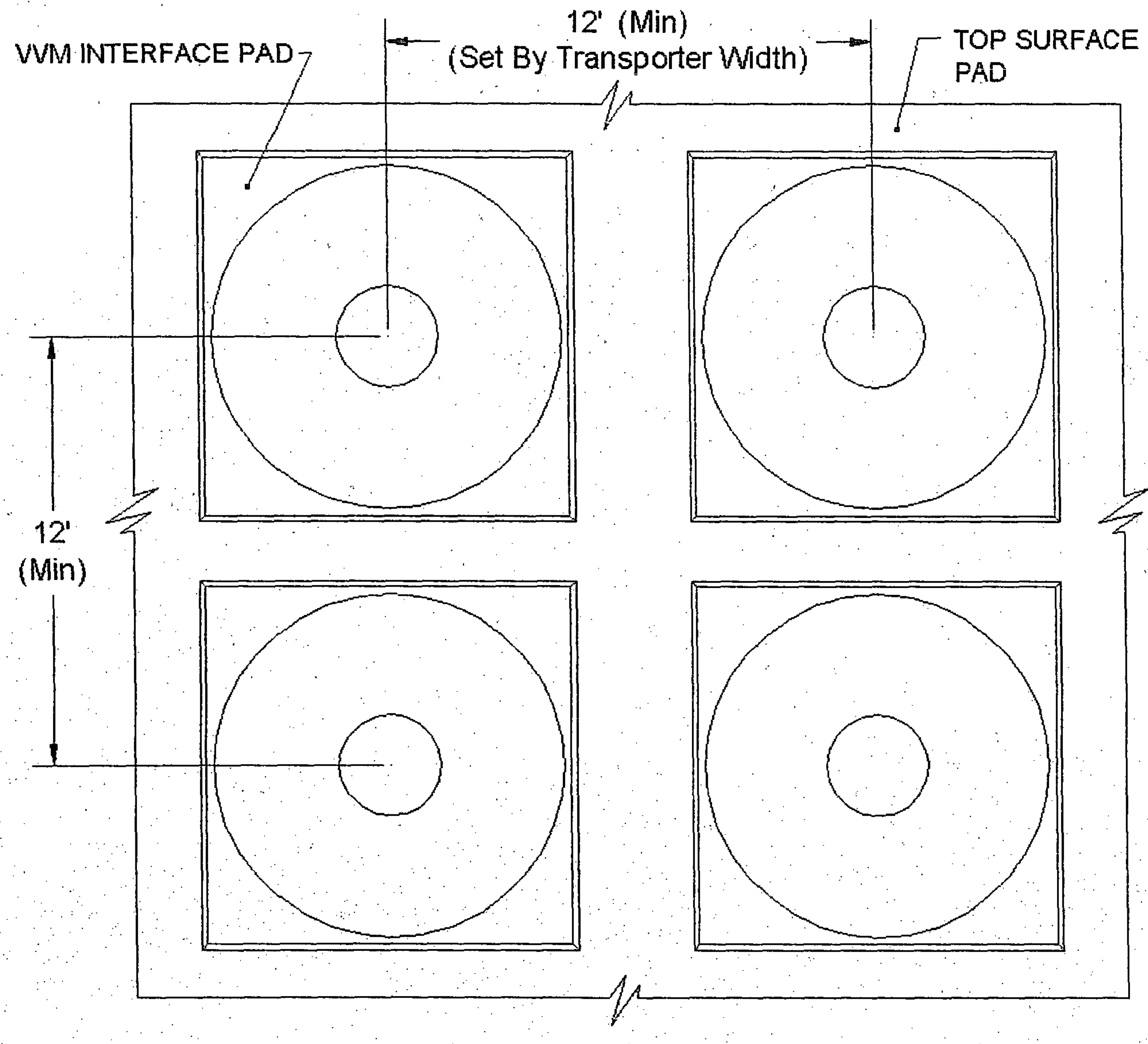

FIGURE 1.I.5: PLAN VIEW OF A 2X2 HI-STORM 100U SYSTEM STORAGE ARRAY

Note: 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. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

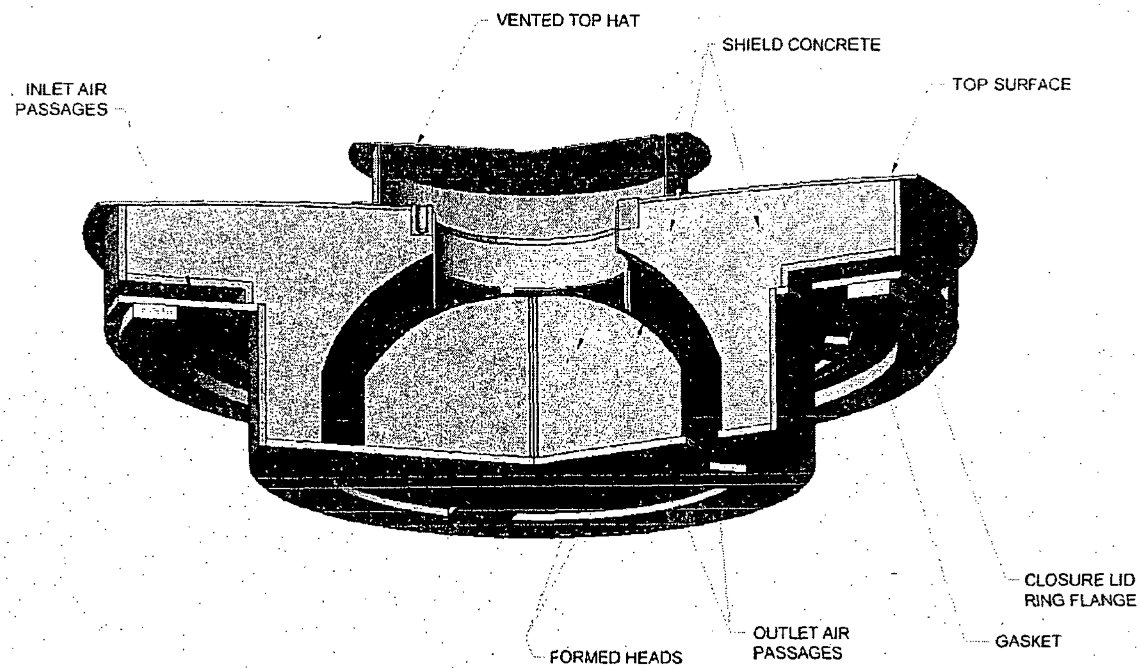

FIGURE 1.I.6; HI-STORM 100U VVM CLOSURE LID GENERAL ARRANGEMENT (SHOWN IN CUT-AWAY VIEW)

Note: 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. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

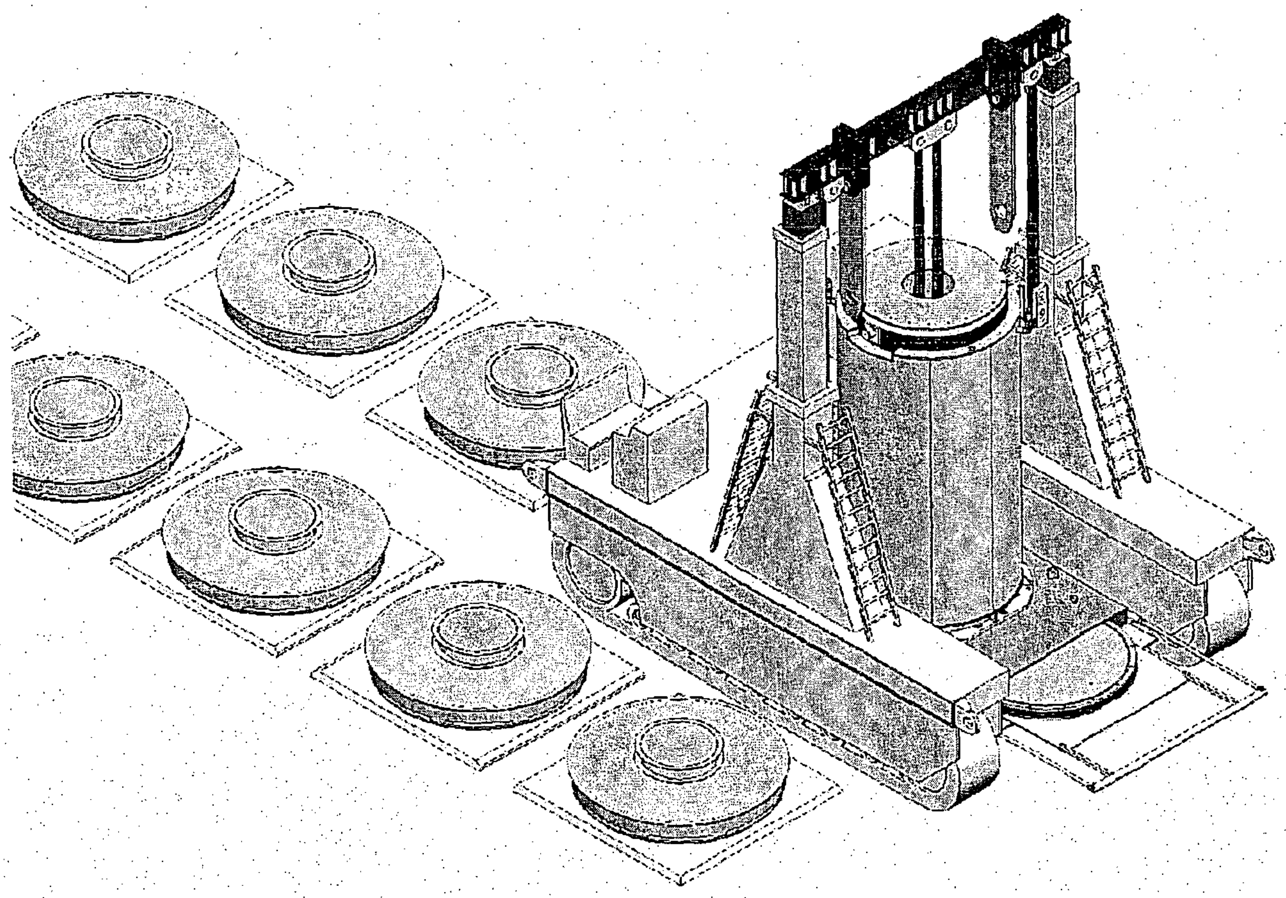

FIGURE 1.I.7; MPC TRANSFER IN A HI-STORM 100U VVM USING A VERTICAL CASK TRANSPORTER

Note: 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. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

the MPC lid are designed in accordance with the requirements of ANSI N14.6 for critical lifts to facilitate vertical MPC transfer.

The MPC closure welds are partial penetration welds that are structurally qualified by analysis, as presented in Chapter 3. The MPC lid and closure ring welds are inspected by performing a liquid penetrant examination of the root pass and/or final weld surface (if more than one weld pass was required), in accordance with the drawings contained in Section 1.5. The integrity of the MPC lid weld is further verified by performing a volumetric (or multi-layer liquid penetrant) examination, and a Code pressure test.

The structural analysis of the MPC, in conjunction with the redundant closures and nondestructive examination, pressure testing, and helium leak testing, (performed on shop welds and the vent and drain port cover plates), provides assurance of canister closure integrity in lieu of the specific weld joint requirements of Section III, Subsection NB.

Compliance with the ASME Code as it is applied to the design and fabrication of the MPC and the associated justification are discussed in Section 2.2.4. The MPC is designed for all design basis normal, off-normal, and postulated accident conditions, as defined in Section 2.2. These design loadings include postulated drop accidents while in the cavity of the HI-STORM overpack or the HI-TRAC transfer cask. The load combinations for which the MPC is designed are defined in Section 2.2.7. The maximum allowable weight and dimensions of a fuel assembly to be stored in the MPC are limited in accordance with Section 2.1.5.

Thermal

The design and operation of the HI-STORM 100 System meets the intent of the review guidance contained in ISG-11, Revision 3 [2.0.8]. Specifically, the ISG-11 provisions that are explicitly invoked and satisfied are:

i. The thermal acceptance criteria for all commercial spent fuel (CSF) authorized by the USNRC for operation in a commercial reactor are unified into one set of requirements.

ii. The maximum value of the *calculated* temperature for all CSF (including ZR and stainless steel fuel cladding materials) under long-term normal conditions of storage must remain below 400°C (752°F). For short-term operations, including canister drying, helium backfill, and on-site cask transport operations, the fuel cladding temperature must not exceed 400°C (752°F) for high burnup fuel and 570°C (1058°F) for moderate burnup fuel.

iii. The maximum fuel cladding temperature as a result of an off-normal or accident event must not exceed 570°C (1058°F).

iv. For High Burnup Fuel (HBF), operating restrictions are imposed to limit the maximum temperature excursion during short-term operations to 65°C (117°F).

To achieve compliance with the above criteria, certain design and operational changes are necessary, MPC is verified through pressure testing and helium leak testing on the shop welds and vent and drain port cover plates, and weld examinations performed in accordance with the acceptance test program in Chapter 9.

Operations

There are no radioactive effluents that result from storage or transfer operations. Effluents generated during MPC loading are handled by the plant's radwaste system and procedures.

Generic operating procedures for the HI-STORM 100 System are provided in Chapter 8. Detailed operating procedures will be developed by the licensee based on Chapter 8, site-specific requirements that comply with the 10CFR50 Technical Specifications for the plant, and the HI-STORM 100 System CoC.

Acceptance Tests and Maintenance

The fabrication acceptance basis and maintenance program to be applied to the MPCs are described in Chapter 9. The operational controls and limits to be applied to the MPCs are discussed in Chapter 12. Application of these requirements will assure that the MPC is fabricated, operated, and maintained in a manner that satisfies the design criteria defined in this chapter.

Decommissioning

The MPCs are designed to be transportable in the HI-STAR overpack and are not required to be unloaded prior to shipment off-site. Decommissioning of the HI-STORM 100 System is addressed in Section 2.4.

2.0.2 HI-STORM Overpack Design Criteria

General

The HI-STORM overpack is designed for 40 years of service, while satisfying the requirements of 10CFR72. The adequacy of the overpack design for the design life is discussed in Section 3.4.11.

Structural

The HI-STORM overpack includes both concrete and structural steel components that are classified as important to safety.

The concrete material is defined as important to safety because of its importance to the shielding analysis. The primary function of the HI-STORM overpack concrete is shielding of the gamma and neutron radiation emitted by the spent nuclear fuel.

Unlike other concrete storage casks, the HI-STORM overpack concrete is enclosed in steel inner and outer shells connected to each other by radial ribs, and top and bottom plates. Where typical concrete

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
	HI-TRAC		
Confinement:		10CFR72.128(a)(3) and 10CFR72.236(d) and (e)	
Closure Welds:			
Shell Seams and Shell-to-Baseplate	Full Penetration	-	Section 1.5 and Table 9.1.4
MPC Lid	Multi-pass Partial Penetration	10CFR72.236(e)	Section 1.5 and Table 9.1.4
MPC Closure Ring	Partial Penetration		
Port Covers	Partial Penetration		
NDE:			
Shell Seams and Shell-to-Baseplate	100% RT or UT	-	Table 9.1.4
MPC Lid	Root Pass and Final Surface 100% PT; Volumetric Inspection or 100% Surface PT each 3/8" of weld depth	-	Chapter 8 and Table 9.1.4
Closure Ring	Root Pass (if more than one pass is required) and Final Surface 100% PT	-	Chapter 8 and Table 9.1.4
Port Covers	Root Pass (if more than one pass is required) and Final Surface 100% PT	-	Chapter 8 and Table 9.1.4
Leak Testing:			
Welds Tested	MPC Shell seams, MPC Shell-to-Baseplate, and Port covers-to-MPC lid	-	Section 9.1
Medium	Helium	ANSI N14.5	Section 9.1
Max. Leak Rate	Leaktight	ANSI N14.5	Section 9.1
Monitoring System	None	10CFR72.128(a)(1)	Section 2.3.2.1
Pressure Testing:			

2.1 SPENT FUEL TO BE STORED

2.1.1 Determination of The Design Basis Fuel

The HI-STORM 100 System is designed to store most types of fuel assemblies generated in the commercial U.S. nuclear industry. Boiling-water reactor (BWR) fuel assemblies have been supplied by The General Electric Company (GE), Siemens, Exxon Nuclear, ANF, UNC, ABB Combustion Engineering, and Gulf Atomic. Pressurized-water reactor (PWR) fuel assemblies are generally supplied by Westinghouse, Babcock & Wilcox, ANF, and ABB Combustion Engineering. ANF, Exxon, and Siemens are historically the same manufacturing company under different ownership. Within this report, SPC is used to designate fuel manufactured by ANF, Exxon, or Siemens. Publications such as Refs. [2.1.1] and [2.1.2] provide a comprehensive description of fuel discharged from U.S. reactors. A central object in the design of the HI-STORM 100 System is to ensure that a majority of SNF discharged from the U.S. reactors can be stored in one of the MPCs.

The cell openings and lengths in the fuel basket have been sized to accommodate the BWR and PWR assemblies listed in Refs. [2.1.1] and [2.1.2] except as noted below. Similarly, the cavity lengths of the multi-purpose canisters have been set at dimensions which permit storing most types of PWR fuel assemblies and BWR fuel assemblies with or without fuel channels. The one exception is as follows:

i. The South Texas Units 1 & 2 SNF, and CE 16x16 System 80 SNF are too long to be accommodated in the available MPC cavity lengths.

In addition to satisfying the cross sectional and length compatibility, the active fuel region of the SNF must be enveloped in the axial direction by the neutron absorber located in the MPC fuel basket. Alignment of the neutron absorber with the active fuel region is ensured by the use of upper and lower fuel spacers suitably designed to support the bottom and restrain the top of the fuel assembly. The spacers axially position the SNF assembly such that its active fuel region is properly aligned with the neutron absorber in the fuel basket. Figure 2.1.5 provides a pictorial representation of the fuel spacers positioning the fuel assembly active fuel region. Both the upper and lower fuel spacers are designed to perform their function under normal, off-normal, and accident conditions of storage.

In summary, the geometric compatibility of the SNF with the MPC designs does not require the definition of a design basis fuel assembly. This, however, is not the case for structural, confinement, shielding, thermal-hydraulic, and criticality criteria. In fact, a particular fuel type in a category (PWR or BWR) may not control the cask design in all of the above-mentioned criteria. To ensure that no SNF listed in Refs. [2.1.1] and [2.1.2] which is geometrically admissible in the MPC is precluded, it is necessary to determine the governing fuel specification for each analysis criterion. To make the necessary determinations, potential candidate fuel assemblies for each qualification criterion were considered. Table 2.1.1 lists the PWR fuel assemblies that were evaluated. These fuel assemblies were evaluated to define the governing design criteria for PWR fuel. The BWR fuel assembly designs evaluated are listed in Table 2.1.2. Tables 2.1.3 and 2.1.4 provide the fuel characteristics determined to be acceptable for storage in the HI-STORM 100 System. Section 2.1.9 summarizes the authorized contents for the HI-STORM 100 System. Any fuel assembly that has fuel characteristics within the range of Tables 2.1.3 and 2.1.4 and meets the other limits specified in Section 2.1.9 is acceptable for storage in the HI-STORM 100 System. Tables 2.1.3 and 2.1.4 present the groups of fuel assembly types defined as "array/classes" as described in further detail in Chapter 6. Table 2.1.5 lists the BWR and PWR fuel assembly designs which are found to govern for three qualification criteria, namely reactivity, shielding, and thermal. Additional information on the design basis fuel definition is presented in the following subsections.

2.1.2 Intact SNF Specifications

Intact fuel assemblies are defined as fuel assemblies without known or suspected cladding defects greater than pinhole leaks and hairline cracks, and which can be handled by normal means. The design payload for the HI-STORM 100 System is intact ZR or stainless steel (SS) clad fuel assemblies with the characteristics listed in Tables 2.1.17 through 2.1.24.

Intact fuel assemblies without fuel rods in fuel rod locations cannot be loaded into the HI-STORM 100 unless dummy fuel rods, which occupy a volume greater than or equal to the original fuel rods, replace the missing rods prior to loading. Any intact fuel assembly that falls within the geometric, thermal, and nuclear limits established for the design basis intact fuel assembly, as defined in Section 2.1.9 can be safely stored in the HI-STORM 100 System.

The range of fuel characteristics specified in Tables 2.1.3 and 2.1.4 have been evaluated in this FSAR and are acceptable for storage in the HI-STORM 100 System within the decay heat, burnup, and cooling time limits specified in Section 2.1.9 for intact fuel assemblies.

2.1.3 Damaged SNF and Fuel Debris Specifications

Damaged fuel and fuel debris are defined in Table 1.0.1.

Damaged fuel assemblies and fuel debris will be loaded into stainless steel damaged fuel containers (DFCs) provided with mesh screens having between 40x40 and 250x250 openings per inch, for storage in the HI-STORM 100 System (see Figures 2.1.1 and 2.1.2B, C, and D). The MPC-24, MPC-24EF, MPC-32 and MPC-32F are designed to accommodate PWR damaged fuel and fuel debris. The MPC-68, MPC-68F and MPC-68FF are designed to accommodate BWR damaged fuel and fuel debris. The appropriate structural, thermal, shielding, criticality, and confinement analyses have been performed to account for damaged fuel and fuel debris and are described in their respective chapters that follow. The limiting design characteristics for damaged fuel assemblies and restrictions on the number and location of damaged fuel containers authorized for loading in each MPC model are provided in Section 2.1.9. Dresden Unit 1 fuel assemblies contained in Transnuclear-designed damaged fuel canisters and one Dresden Unit 1 thoria rod canister have been approved for storage directly in the HI-STORM 100 System without re-packaging (see Figures 2.1.2 and 2.1.2A).

MPC contents classified as fuel debris are required to be stored in DFCs. The basket designs for the standard and "F" model MPCs are identical. The lid and shell designs of the "F" models are unique in that the upper shell portion of the canister is thickened for additional strength needed to qualify as a secondary containment, which used to be required under hypothetical accident conditions of transportation under 10 CFR 71. Figure 2.1.9 shows the details of the differences between the standard and "F" model MPC shells. These details are common for both the PWR and BWR series MPC models.

2.1.4 Deleted

2.1.5 Structural Parameters for Design Basis SNF

The main physical parameters of an SNF assembly applicable to the structural evaluation are the fuel assembly length, envelope (cross sectional dimensions), and weight. These parameters, which define the mechanical and structural design, are specified in Section 2.1.9. The centers of gravity reported in Section 3.2 are based on the maximum fuel assembly weight. Upper and lower fuel spacers (as appropriate) maintain the axial position of the fuel assembly within the MPC basket and, therefore, the location of the center of gravity. The upper and lower fuel spacers are designed to withstand normal, off-normal, and accident conditions of storage. An axial clearance of approximately 2 to 2-1/2 inches is provided to account for the irradiation and thermal growth of the fuel assemblies. The suggested upper and lower fuel spacer lengths are listed in Tables 2.1.9 and 2.1.10. In order to qualify for storage in the MPC, the SNF must satisfy the physical parameters listed in Section 2.1.9.

2.1.6 Thermal Parameters for Design Basis SNF

The principal thermal design parameter for the stored fuel is the peak fuel cladding temperature, which is a function of the maximum heat generation rate per assembly and the decay heat removal capabilities of the HI-STORM 100 System. No attempt is made to link the maximum allowable decay heat per fuel assembly with burnup, enrichment, or cooling time. Rather, the decay heat per fuel assembly is adjusted to yield peak fuel cladding temperatures with an allowance for margin to the temperature limit.

To ensure the permissible fuel cladding temperature limits are not exceeded, Section 2.1.9 specifies the allowable decay heat per assembly for each MPC model. For both uniform and regionalized loading of moderate and high burnup fuel assemblies, the allowable decay heat per assembly is presented in Section 2.1.9.

Section 2.1.9 also includes separate cooling time, burnup, and decay heat limits for uniform fuel loading and regionalized fuel loading. Regionalized loading allows higher heat emitting fuel assemblies to be stored in the center fuel storage locations than would otherwise be authorized for storage under uniform loading conditions.

The fuel cladding temperature is also affected by the heat transfer characteristics of the fuel assemblies. The bounding fuel assembly design for thermal calculations for each fuel type is provided in Table 2.1.5.

Finally, the axial variation in the heat generation rate in the design basis fuel assembly is defined based on the axial burnup distribution. For this purpose, the data provided in Refs. [2.1.7] and [2.1.8] are utilized and summarized in Table 2.1.11 and Figures 2.1.3 and 2.1.4 for reference. These distributions are representative of fuel assemblies with the design basis burnup levels considered. These distributions are used for analyses only, and do not provide a criteria for fuel assembly acceptability for storage in the HI-STORM 100 System.

Except for MPC-68F, fuel may be stored in the MPC using one of two storage strategies, namely, uniform loading and regionalized loading. Uniform loading allows storage of any fuel assembly in any fuel storage location, subject to additional restrictions, such as those for loading of fuel assemblies containing non-fuel hardware as defined in Table 1.0.1. Regionalized fuel loading allows for higher heat emitting fuel assemblies to be stored in some storage locations with lower heat emitting fuel assemblies in the remaining fuel storage locations. Regionalized loading allows storage of higher heat emitting fuel assemblies than would otherwise be permitted using the uniform loading strategy. The definition of the regions for each MPC model is provided in Table 2.1.27. Regionalized fuel loading is not permitted in MPC-68F.

2.1.7 Radiological Parameters for Design Basis SNF

The principal radiological design criteria for the HI-STORM 100 System are the 10CFR72.104 site boundary dose rate limits and maintaining operational dose rates as low as reasonably achievable (ALARA). The radiation dose is directly affected by the gamma and neutron source terms of the SNF assembly.

The gamma and neutron sources are separate and are affected differently by enrichment, burnup, and cooling time. It is recognized that, at a given burnup, the radiological source terms increase monotonically as the initial enrichment is reduced. The shielding design basis fuel assembly, therefore, is evaluated at conservatively high burnups, low cooling times, and low enrichments, as discussed in Chapter 5. The shielding design basis fuel assembly thus bounds all other fuel assemblies.

The design basis dose rates can be met by a variety of burnup levels and cooling times. Section 2.1.9 provides the procedure for determining burnup and cooling time limits for all of the authorized fuel assembly array/classes for both uniform fuel loading and regionalized loading. Table 2.1.11 and Figures 2.1.3 and 2.1.4 provide the axial distribution for the radiological source terms for PWR and BWR fuel assemblies based on the axial burnup distribution. The axial burnup distributions are representative of fuel assemblies with the design basis burnup levels considered. These distributions are used for analyses only, and do not provide a criteria for fuel assembly acceptability for storage in the HI-STORM 100 System.

Thoria rods placed in Dresden Unit 1 Thoria Rod Canisters meeting the requirements of Table 2.1.12 and Dresden Unit 1 fuel assemblies with one Antimony-Beryllium neutron source have been qualified for storage. Up to one Thoria Rod Canister is authorized for storage in combination with other intact and damaged fuel, and fuel debris as specified in Section 2.1.9.

Non-fuel hardware, as defined in Table 1.0.1, has been evaluated and is authorized for storage in the PWR MPCs as specified in Section 2.1.9.

2.1.8 Criticality Parameters for Design Basis SNF

As discussed earlier, the MPC-68, MPC-68F, MPC-68FF, MPC-32 and MPC-32F feature a basket without flux traps. In the aforementioned baskets, there is one panel of neutron absorber between two adjacent fuel assemblies. The MPC-24, MPC-24E, and MPC-24EF employ a construction wherein two neighboring fuel assemblies are separated by two panels of neutron absorber with a water gap between them (flux trap construction).

The minimum ^{10}B areal density in the neutron absorber panels for each MPC model is shown in Table 2.1.15.

For all MPCs, the ^{10}B areal density used for the criticality analysis is conservatively established below the minimum values shown in Table 2.1.15. For Boral, the value used in the analysis is 75% of the minimum value, while for METAMIC, it is 90% of the minimum value. This is consistent with NUREG-1536 [2.1.5] which suggests a 25% reduction in ^{10}B areal density credit when subject to standard acceptance tests, and which allows a smaller reduction when more comprehensive tests of the areal density are performed.

The criticality analyses for the MPC-24, MPC-24E, and MPC-24EF (all with higher enriched fuel), as well as the MPC-32 and MPC-32F were performed with credit taken for soluble boron in the MPC water during wet loading and unloading operations. Table 2.1.14 and 2.1.16 provide the required soluble boron concentrations for these MPCs.

2.1.9 Summary of Authorized Contents

Tables 2.1.3, 2.1.4, 2.1.12, and 2.1.17 through 2.1.29 together specify the limits for spent fuel and non-fuel hardware authorized for storage in the HI-STORM 100 System. The limits in these tables are derived from the safety analyses described in the following chapters of this FSAR. Fuel classified as damaged fuel assemblies or fuel debris must be stored in damaged fuel containers for storage in the HI-STORM 100 System.

Tables 2.1.17 through 2.1.24 are the baseline tables that specify the fuel assembly limits for each of the MPC models, with appropriate references to the other tables in this section for certain other limits. Tables 2.1.17 through 2.1.24 refer to Section 2.1.9.1 for ZR-clad fuel limits on minimum cooling time, maximum decay heat, and maximum burnup for uniform and regionalized fuel loading.

2.1.9.1 Decay Heat, Burnup, and Cooling Time Limits for ZR-Clad Fuel

Each ZR-clad fuel assembly and any PWR integral non-fuel hardware (NFH) to be stored in the HI-STORM 100 System must meet the following limits, in addition to meeting the physical limits specified elsewhere in this section, to be authorized for storage in the HI-STORM 100 System. The contents of each fuel storage location (fuel assembly and NFH) to be stored must be verified to have, as applicable:

- A decay heat less than or equal to the maximum allowable value.
- An assembly average enrichment greater than or equal to the minimum value used in determining the maximum allowable burnup.
- A burnup less than or equal to the maximum allowable value.
- A cooling time greater than or equal to the minimum allowable value.

The maximum allowable ZR-clad fuel storage location decay heat values are determined using the methodology described in Section 2.1.9.1.1 or 2.1.9.1.2 depending on whether uniform fuel loading or regionalized fuel loading is being implemented†. The decay heat limits are independent of burnup, cooling time, or enrichment and are based strictly on the thermal analysis described in Chapter 4. Decay heat limits must be met for all contents in a fuel storage location (i.e., fuel and PWR non-fuel hardware, as applicable).

The maximum allowable average burnup per fuel storage location is determined by calculation as a function of minimum enrichment, maximum allowable decay heat, and minimum cooling time from 3 to 20 years, as described in Section 2.1.9.1.3.

Section 12.2.10 describes how compliance with these limits may be verified, including practical examples.

2.1.9.1.1 Uniform Fuel Loading Decay Heat Limits for ZR-Clad Fuel

Table 2.1.26 provides the maximum allowable decay heat per fuel storage location for ZR-clad fuel in uniform fuel loading for each MPC model *in aboveground storage**.

2.1.9.1.2 Design Heat Load for ZR-Clad Fuel

The Design Basis heat load for the *aboveground* HI-STORM System, Q_d, is provided in Table 2.1.26. Q_d is based on the assumption that every SNF in the MPC is generating an equal amount of heat. In other words, the specific heat generation rate, r, of each SNF is equal. Thus, in an MPC with n storage locations,

$$Q_d = n\ r \qquad \text{Equation a}$$

In reality, however, the population of SNF loaded in the MPC invariably has unequal r. If r_i denotes the heat generation rate of SNF in location i, then its cumulative (total) heat generation, Q_t, is given by a simple summation, i.e.,

$$Q_t = \sum_{i}^{n} r_i \qquad \text{Equation b}$$

For purposes of the CoC compliance, however, the MPC heat generation rate is

$$Q_{CoC} = r_{max}\ n \qquad \text{Equation c}$$

where r_{max} is the largest value of r_i in the population of SNF loaded in the MPC, i.e.,

$$r_{max} = \max \text{ of } [r_i,\ i = 1,2\ldots n] \qquad \text{Equation d}$$

Q_{CoC} must be less than Q_d to meet the thermal loading criterion.

† Note that the stainless steel-clad fuel decay heat limits apply to all fuel in the MPC, if a mixture of stainless steel and ZR-clad fuel is stored in the same MPC. The stainless steel-clad fuel assembly decay heat limits may be found in Table 2.1.17 through 2.1.24

* *Maximum allowable heat loads in 100U underground storage are defined in Supplement 2.I.*

In most cases, the total heat generation rate in the loaded MPC, Q_t, is much smaller than Q_{CoC}. This scenario can be illustrated by considering the example of a batch of PWR SNF for MPC-32 that has 31 SNF emitting 0.5kW and one SNF emitting 1 kW. The total heat load in the MPC, therefore, is (31)(0.5) + 1 = 16.5kW. However, because r_{max} = 1 kW, the CoC basis heat load Q_{CoC} = (32)(1) = 32kW. Thus, $Q_{CoC} >> Q_t$. This condition prevails in most loaded MPCs to a varying degree.

To make the disconnect between Q_t and Q_{CoC} less severe, the aggregate of storage cells in the MPC is divided into two regions. The SNF in the inner region (henceforth referred to as Region 1) and that in the outer region (henceforth referred to as Region 2) are allowed maximum specific heat generation rate q_1 and q_2, respectively. The maximum permitted values of q_1 and q_2 are quite obviously related. The case where q_1 and q_2 are equal is referred to as "uniform storage". Once again, the CoC basis heat load is computed by assuming that each SNF is emitting the maximum permitted heat load for its region. The heat load for CoC compliance is then

$$Q_{CoC} = n_1 q_1 + n_2 q_2 \qquad \text{Equation e}$$

where n_1 and n_2 are the number of cells in Regions 1 and 2, respectively.

By performing the thermal analysis iteratively, a lowerbound expression for Q as a function of X (X is the ratio of q_1 to q_2) is found for all PWR and BWR MPCs. The functional relationship between Q and X is set down such that the computed peak cladding temperature is constant within a small band as X is varied over a wide range (between 0.5 and 3). For determining the decay heat limits under regionalized storage this analyzed variation in X (i.e. $0.5 \leq X \leq 3$) is adopted as the permissible range for X. The functional relationship Q(X) is presented below.

$$Q(X) = \frac{2Q_d}{1+X^y} \qquad \text{Equation f}$$

where y is a function of X as defined below:

$$y = \frac{0.23}{X^{0.1}} \qquad \text{Equation g}$$

Using the previous example of assumed SNF inventory, the heat load for CoC compliance and the actual total heat load of the batch of 32 SNF in MPC-32 can be compared under the regionalized storage scenario. Let us assume that the single SNF emitting the highest heat load r_{max} = 1 kW is placed in Region 1. Eleven other locations of Region 1 and all twenty locations of Region 2 have heat emitting fuel at 0.5kW. Therefore, for this loaded MPC-32, X = 2. The heat load for CoC compliance is computed using the formula given above as Q = 31.48 kW.

Next we can compute the maximum permissible heat loads in the two regions (q_1 and q_2) by the following steps:

(i) Choose a value of *X in the permissible range ($0.5 \leq X \leq 3$). In the example above X is equal to 2.*

(ii) Calculate q_2 using the following equation:

$$q_2 = \frac{2 \times Q_d}{\left(1 + X^y\right) \times \left(n_1 \times X + n_2\right)} \quad \text{Equation h}$$

where:

$y = 0.23/X^{0.1}$
q_2 = Maximum allowable decay heat per fuel storage location in Region 2 (kW)
Q_d = *Design MPC heat load from Table 2.1.26 (kW)*
X = Ratio of q_2 to q_1 chosen in Step (i)
n_1 = *Number of fuel storage locations in Region 1 from Table 2.1.27*
n_2 = *Number of fuel storage locations in Region 2 from Table 2.1.27*

(iii) Calculate q_1 using the following equation:

$$q_1 = X \times q_2 \quad \text{Equation i}$$

Using the steps provided above we find $q_1 = 1.43$ kW (actual q_1 is 1 kW) and $q_2 = 0.715$ kW (actual q_2 is 0.5 kW), which are greater than the actual values of r_i in the MPC for all locations in Regions 1 and 2, and are therefore acceptable. We note that the CoC heat load on the regionalized basis also significantly exceeds Q_t (the actual total heat load of 16.5kW) but by a smaller margin than the uniform storage scheme.

It should be emphasized that the two-region scheme of storage does not introduce any new complication in the dry storage implementation: it is merely a means to recognize the real life variation in the heat generation rates in a batch of fuel loaded in an MPC in a simplified manner. A plant expecting to transport the MPC within the near future will seek to locate the fuel such that X is as large as possible (i.e., cooler fuel in the outer region). On the other hand, a plant focused on placing some relatively hot fuel in dry storage will place them in Region 2 (i.e., $X < 1$). Finally, because Q(X) is a continuous function of X, the heat load corresponding to $X = 1$ (i.e., uniform storage) is the reference design basis heat load of the system.

2.1.9.1.3 Burnup Limits as a Function of Cooling Time for ZR-Clad Fuel

The maximum allowable ZR-clad fuel assembly average burnup varies with the following parameters, based on the shielding analysis in Chapter 5:

- Minimum required fuel assembly cooling time
- Maximum allowable fuel assembly decay heat
- Minimum fuel assembly average enrichment

The calculation described in this section is used to determine the maximum allowable fuel assembly burnup for minimum cooling times between 3 and 20 years, using maximum decay heat and minimum enrichment as input values. This calculation may be used to create multiple burnup versus cooling time tables for a particular fuel assembly array/class and different minimum enrichments. The allowable maximum burnup for a specific fuel assembly may be calculated based on the assembly's particular enrichment and cooling time.

(i) Choose a fuel assembly minimum enrichment, E_{235}.

(ii) Calculate the maximum allowable fuel assembly average burnup for a minimum cooling time between 3 and 20 years using the equation below:

$$Bu = (A \times q) + (B \times q^2) + (C \times q^3) + [D \times (E_{235})^2] + (E \times q \times E_{235}) + (F \times q^2 \times E_{235}) + G$$

Equation j

Where:

Bu = Maximum allowable assembly average burnup (MWD/MTU)

q = Maximum allowable decay heat per fuel storage location determined in Section 2.1.9.1.1 or 2.1.9.*1*.2 (kW)

E_{235} = Minimum fuel assembly average enrichment (wt. % ^{235}U) (e.g., for 4.05 wt. %, use 4.05)

A through G = Coefficients from Tables 2.1.28 or 2.1.29 for the applicable fuel assembly array/class and minimum cooling time.

2.1.9.1.4 Other Considerations

In computing the allowable maximum fuel storage location decay heats and fuel assembly average burnups, the following requirements apply:

- Calculated burnup limits shall be rounded down to the nearest integer
- Calculated burnup limits greater than 68,200 MWD/MTU for PWR fuel and 65,000 MWD/MTU for BWR fuel must be reduced to be equal to these values.
- Linear interpolation of calculated burnups between cooling times for a given fuel assembly maximum decay heat and minimum enrichment is permitted. For example, the allowable burnup for a minimum cooling time of 4.5 years may be interpolated between those burnups calculated for 4 and 5 years.
- ZR-clad fuel assemblies must have a minimum enrichment, as defined in Table 1.0.1, greater than or equal to the value used in determining the maximum allowable burnup per Section 2.1.9.1.3 to be authorized for storage in the MPC.
- When complying with the maximum fuel storage location decay heat limits, users must account

for the decay heat from both the fuel assembly and any PWR non-fuel hardware, as applicable for the particular fuel storage location, to ensure the decay heat emitted by all contents in a storage location does not exceed the limit.

Section 12.2.10 provides a practical example of determining fuel storage location decay heat, burnup, and cooling time limits and verifying compliance for a set of example fuel assemblies.

Table 2.1.1

PWR FUEL ASSEMBLIES EVALUATED TO DETERMINE DESIGN BASIS SNF

Assembly Class	**Array Type**
B&W 15x15	All
B&W 17x17	All
CE 14x14	All
CE 16x16	All except System 80™
WE 14x14	All
WE 15x15	All
WE 17x17	All
St. Lucie	All
Ft. Calhoun	All
Haddam Neck (Stainless Steel Clad)	All
San Onofre 1 (Stainless Steel Clad)	All
Indian Point 1	All

Table 2.1.2

BWR FUEL ASSEMBLIES EVALUATED TO DETERMINE DESIGN BASIS SNF

Assembly Class	Array Type			
GE BWR/2-3	All 7x7	All 8x8	All 9x9	All 10x10
GE BWR/4-6	All 7x7	All 8x8	All 9x9	All 10x10
Humboldt Bay	All 6x6	All 7x7 (ZR Clad)		
Dresden-1	All 6x6	All 8x8		
LaCrosse (Stainless Steel Clad)	All			

Table 2.1.3
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/ Class	**14x14 A**	**14x14 B**	**14x14 C**	**14x14 D**	**14x14E**
Clad Material (Note 2)	ZR	ZR	ZR	SS	SS
Design Initial U (kg/assy.) (Note 3)	≤ 365	≤ 412	≤ 438	≤ 400	≤ 206
Initial Enrichment (MPC-24, 24E, and 24EF without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.6 (24) ≤ 5.0 (24E/24EF)	≤ 4.6 (24) ≤ 5.0 (24E/24EF)	≤ 4.6 (24) ≤ 5.0 (24E/24EF)	≤ 4.0 (24) ≤ 5.0 (24E/24EF)	≤ 5.0 (24) ≤ 5.0 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, 32 or 32F with soluble boron credit - see Note 5) (wt % ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	179	179	176	180	173
Fuel Clad O.D. (in.)	≥ 0.400	≥ 0.417	≥ 0.440	≥ 0.422	≥ 0.3415
Fuel Clad I.D. (in.)	≤ 0.3514	≤ 0.3734	≤ 0.3880	≤ 0.3890	≤ 0.3175
Fuel Pellet Dia. (in.) (Note 8)	≤ 0.3444	≤ 0.3659	≤ 0.3805	≤ 0.3835	≤ 0.3130
Fuel Rod Pitch (in.)	≤ 0.556	≤ 0.556	≤ 0.580	≤ 0.556	Note 6
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 144	≤ 102
No. of Guide and/or Instrument Tubes	17	17	5 (Note 4)	16	0
Guide/Instrument Tube Thickness (in.)	≥ 0.017	≥ 0.017	≥ 0.038	≥ 0.0145	N/A

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

Fuel Assembly Array/Class	**15x15 A**	**15x15 B**	**15x15 C**	**15x15 D**	**15x15 E**	**15x15 F**
Clad Material (Note 2)	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 473	≤ 473	≤ 473	≤ 495	≤ 495	≤ 495
Initial Enrichment (MPC-24, 24E, and 24EF without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, 32 or 32F with soluble boron credit – see Note 5) (wt % ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	204	204	204	208	208	208
Fuel Clad O.D. (in.)	≥ 0.418	≥ 0.420	≥ 0.417	≥ 0.430	≥ 0.428	≥ 0.428
Fuel Clad I.D. (in.)	≤ 0.3660	≤ 0.3736	≤ 0.3640	≤ 0.3800	≤ 0.3790	≤ 0.3820
Fuel Pellet Dia. (in.) (Note 8)	≤ 0.3580	≤ 0.3671	≤ 0.3570	≤ 0.3735	≤ 0.3707	≤ 0.3742
Fuel Rod Pitch (in.)	≤ 0.550	≤ 0.563	≤ 0.563	≤ 0.568	≤ 0.568	≤ 0.568
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	21	21	21	17	17	17
Guide/Instrument Tube Thickness (in.)	≥ 0.0165	≥ 0.015	≥ 0.0165	≥ 0.0150	≥ 0.0140	≥ 0.0140

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

Fuel Assembly Array and Class	**15x15 G**	**15x15H**	**16x16 A**	**17x17A**	**17x17 B**	**17x17 C**
Clad Material (Note 2)	SS	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 420	≤ 495	≤ 448	≤ 433	≤ 474	≤ 480
Initial Enrichment (MPC-24, 24E, and 24EF without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.0 (24) ≤ 4.5 (24E/24EF)	≤ 3.8 (24) ≤ 4.2 (24E/24EF)	≤ 4.6 (24) ≤ 5.0 (24E/24EF)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, 32 or 32F with soluble boron credit – see Note 5) (wt % ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	204	208	236	264	264	264
Fuel Clad O.D. (in.)	≥ 0.422	≥ 0.414	≥ 0.382	≥ 0.360	≥ 0.372	≥ 0.377
Fuel Clad I.D. (in.)	≤ 0.3890	≤ 0.3700	≤ 0.3350	≤ 0.3150	≤ 0.3310	≤ 0.3330
Fuel Pellet Dia. (in.) (Note 8)	≤ 0.3825	≤ 0.3622	≤ 0.3255	≤ 0.3088	≤ 0.3232	≤ 0.3252
Fuel Rod Pitch (in.)	≤ 0.563	≤ 0.568	≤ 0.506	≤ 0.496	≤ 0.496	≤ 0.502
Active Fuel length (in.)	≤ 144	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	21	17	5 (Note 4)	25	25	25
Guide/Instrument Tube Thickness (in.)	≥ 0.0145	≥ 0.0140	≥ 0.0350	≥ 0.016	≥ 0.014	≥ 0.020

Table 2.1.3 (continued)
PWR FUEL ASSEMBLY CHARACTERISTICS

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.

2. See Table 1.0.1 for the definition of "ZR."

3. Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or reactor user. For each PWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 2.0 percent for comparison with users' fuel records to account for manufacturer's tolerances.

4. Each guide tube replaces four fuel rods.

5. Soluble boron concentration per Tables 2.1.14 and 2.1.16, as applicable.

6. This fuel assembly array/class includes only the Indian Point Unit 1 fuel assembly. This fuel assembly has two pitches in different sectors of the assembly. These pitches are 0.441 inches and 0.453 inches.

7. For those MPCs loaded with both intact fuel assemblies and damaged fuel assemblies or fuel debris, the maximum initial enrichment of the intact fuel assemblies, damaged fuel assemblies and fuel debris is 4.0 wt.% ^{235}U.

8. Annular fuel pellets are allowed in the top and bottom 12" of the active fuel length.

Table 2.1.4
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**6x6 A**	**6x6 B**	**6x6 C**	**7x7 A**	**7x7 B**	**8x8 A**
Clad Material (Note 2)	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 110	≤ 110	≤ 110	≤ 100	≤ 198	≤ 120
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 14)	≤ 2.7	≤ 2.7 for UO_2 rods. See Note 4 for MOX rods	≤ 2.7	≤ 2.7	≤ 4.2	≤ 2.7
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 4.0	≤ 4.0	≤ 4.0	≤ 5.5	≤ 5.0	≤ 4.0
No. of Fuel Rod Locations	35 or 36	35 or 36 (up to 9 MOX rods)	36	49	49	63 or 64
Fuel Clad O.D. (in.)	≥ 0.5550	≥ 0.5625	≥ 0.5630	≥ 0.4860	≥ 0.5630	≥ 0.4120
Fuel Clad I.D. (in.)	≤ 0.5105	≤ 0.4945	≤ 0.4990	≤ 0.4204	≤ 0.4990	≤ 0.3620
Fuel Pellet Dia. (in.)	≤ 0.4980	≤ 0.4820	≤ 0.4880	≤ 0.4110	≤ 0.4910	≤ 0.3580
Fuel Rod Pitch (in.)	≤ 0.710	≤ 0.710	≤ 0.740	≤ 0.631	≤ 0.738	≤ 0.523
Active Fuel Length (in.)	≤ 120	≤ 120	≤ 77.5	≤ 80	≤ 150	≤ 120
No. of Water Rods (Note 11)	1 or 0	1 or 0	0	0	0	1 or 0
Water Rod Thickness (in.)	> 0	> 0	N/A	N/A	N/A	≥ 0
Channel Thickness (in.)	≤ 0.060	≤ 0.060	≤ 0.060	≤ 0.060	≤ 0.120	≤ 0.100

Table 2.1.4 (continued)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**8x8 B**	**8x8 C**	**8x8 D**	**8x8 E**	**8x8F**	**9x9 A**
Clad Material (Note 2)	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 192	≤ 190	≤ 190	≤ 190	≤ 191	≤ 180
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 14)	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.0	≤ 4.2
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	63 or 64	62	60 or 61	59	64	74/66 (Note 5)
Fuel Clad O.D. (in.)	≥ 0.4840	≥ 0.4830	≥ 0.4830	≥ 0.4930	≥ 0.4576	≥ 0.4400
Fuel Clad I.D. (in.)	≤ 0.4295	≤ 0.4250	≤ 0.4230	≤ 0.4250	≤ 0.3996	≤ 0.3840
Fuel Pellet Dia. (in.)	≤ 0.4195	≤ 0.4160	≤ 0.4140	≤ 0.4160	≤ 0.3913	≤ 0.3760
Fuel Rod Pitch (in.)	≤ 0.642	≤ 0.641	≤ 0.640	≤ 0.640	≤ 0.609	≤ 0.566
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 11)	1 or 0	2	1 - 4 (Note 7)	5	N/A (Note 12)	2
Water Rod Thickness (in.)	≥ 0.034	> 0.00	> 0.00	≥ 0.034	≥ 0.0315	> 0.00
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.100	≤ 0.055	≤ 0.120

Table 2.1.4 (continued)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**9x9 B**	**9x9 C**	**9x9 D**	**9x9 E (Note 13)**	**9x9 F (Note 13)**	**9x9 G**
Clad Material (Note 2)	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 180	≤ 182	≤ 182	≤ 183	≤ 183	≤ 164
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 14)	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.0	≤ 4.0	≤ 4.2
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	72	80	79	76	76	72
Fuel Clad O.D. (in.)	≥ 0.4330	≥ 0.4230	≥ 0.4240	≥ 0.4170	≥ 0.4430	≥ 0.4240
Fuel Clad I.D. (in.)	≤ 0.3810	≤ 0.3640	≤ 0.3640	≤ 0.3640	≤ 0.3860	≤ 0.3640
Fuel Pellet Dia. (in.)	≤ 0.3740	≤ 0.3565	≤ 0.3565	≤ 0.3530	≤ 0.3745	≤ 0.3565
Fuel Rod Pitch (in.)	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 11)	1 (Note 6)	1	2	5	5	1 (Note 6)
Water Rod Thickness (in.)	> 0.00	≥ 0.020	≥ 0.0300	≥ 0.0120	≥ 0.0120	≥ 0.0320
Channel Thickness (in.)	≤ 0.120	≤ 0.100	≤ 0.100	≤ 0.120	≤ 0.120	≤ 0.120

Table 2.1.4 (continued)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**10x10 A**	**10x10 B**	**10x10 C**	**10x10 D**	**10x10 E**
Clad Material (Note 2)	ZR	ZR	ZR	SS	SS
Design Initial U (kg/assy.) (Note 3)	≤ 188	≤ 188	≤ 179	≤ 125	≤ 125
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 14)	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.0	≤ 4.0
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	92/78 (Note 8)	91/83 (Note 9)	96	100	96
Fuel Clad O.D. (in.)	≥ 0.4040	≥ 0.3957	≥ 0.3780	≥ 0.3960	≥ 0.3940
Fuel Clad I.D. (in.)	≤ 0.3520	≤ 0.3480	≤ 0.3294	≤ 0.3560	≤ 0.3500
Fuel Pellet Dia. (in.)	≤ 0.3455	≤ 0.3420	≤ 0.3224	≤ 0.3500	≤ 0.3430
Fuel Rod Pitch (in.)	≤ 0.510	≤ 0.510	≤ 0.488	≤ 0.565	≤ 0.557
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 83	≤ 83
No. of Water Rods (Note 11)	2	1 (Note 6)	5 (Note 10)	0	4
Water Rod Thickness (in.)	≥ 0.030	> 0.00	≥ 0.031	N/A	≥ 0.022
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.055	≤ 0.080	≤ 0.080

Table 2.1.4 (continued)
BWR FUEL ASSEMBLY CHARACTERISTICS

NOTES:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.

2. See Table 1.0.1 for the definition of "ZR."

3. Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or reactor user. For each BWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 1.5 percent for comparison with users' fuel records to account for manufacturer tolerances.

4. $\leq$ 0.635 wt. % ^{235}U and $\leq$ 1.578 wt. % total fissile plutonium (^{239}Pu and ^{241}Pu), (wt. % of total fuel weight, i.e., UO_2 plus PuO_2)

5. This assembly class contains 74 total rods; 66 full length rods and 8 partial length rods.

6. Square, replacing nine fuel rods.

7. Variable.

8. This assembly contains 92 total fuel rods; 78 full length rods and 14 partial length rods.

9. This assembly class contains 91 total fuel rods; 83 full length rods and 8 partial length rods.

10. One diamond-shaped water rod replacing the four center fuel rods and four rectangular water rods dividing the assembly into four quadrants.

11. These rods may also be sealed at both ends and contain Zr material in lieu of water.

12. This assembly is known as "QUAD+." It has four rectangular water cross segments dividing the assembly into four quadrants.

13. For the SPC 9x9-5 fuel assembly, each fuel rod must meet either the 9x9E or the 9x9F set of limits or clad O.D., clad I.D., and pellet diameter.

14. For those MPCs loaded with both intact fuel assemblies and damaged fuel assemblies or fuel debris, the maximum planar average initial enrichment for the intact fuel assemblies is limited to 3.7 wt.% ^{235}U, as applicable.

Table 2.1.5

DESIGN BASIS FUEL ASSEMBLY FOR EACH DESIGN CRITERION

Criterion	**BWR**	**PWR**
Reactivity (Criticality)	GE12/14 10x10 with Partial Length Rods (Array/Class 10x10A)	B&W 15x15 (Array/Class 15x15F)
Shielding	GE 7x7	B&W 15x15
Thermal-Hydraulic	GE-12/14 10x10	W 17x17 OFA

Tables 2.1.6 through 2.1.8

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Table 2.1.9

SUGGESTED PWR UPPER AND LOWER FUEL SPACER LENGTHS

Fuel Assembly Type	Assembly Length w/o NFH[1] (in.)	Location of Active Fuel from Bottom (in.)	Max. Active Fuel Length (in.)	Upper Fuel Spacer Length (in.)	Lower Fuel Spacer Length (in.)
CE 14x14	157	4.1	137	9.5	10.0
CE 16x16	176.8	4.7	150	0	0
BW 15x15	165.7	8.4	141.8	6.7	4.1
W 17x17 OFA	159.8	3.7	144	8.2	8.5
W 17x17 Std	159.8	3.7	144	8.2	8.5
W 17x17 V5H	160.1	3.7	144	7.9	8.5
W 15x15	159.8	3.7	144	8.2	8.5
W 14x14 Std	159.8	3.7	145.2	9.2	7.5
W 14x14 OFA	159.8	3.7	144	8.2	8.5
Ft. Calhoun	146	6.6	128	10.25	20.25
St. Lucie 2	158.2	5.2	136.7	10.25	8.05
B&W 15x15 SS	137.1	3.873	120.5	19.25	19.25
W 15x15 SS	137.1	3.7	122	19.25	19.25
W 14x14 SS	137.1	3.7	120	19.25	19.25
Indian Point 1	137.2	17.705	101.5	18.75	20.0

Note: Each user shall specify the fuel spacer length based on their fuel assembly length, presence of a DFC, and allowing an approximate two to 2-1/2 inch gap under the MPC lid. Fuel spacers shall be sized to ensure that the active fuel region of intact fuel assemblies remains within the neutron poison region of the MPC basket with water in the MPC.

[1] NFH is an abbreviation for non-fuel hardware, including control components. Fuel assemblies with control components may require shorter fuel spacers.

Table 2.1.10

SUGGESTED BWR UPPER AND LOWER FUEL SPACER LENGTHS

Fuel Assembly Type	Assembly Length (in.)	Location of Active Fuel from Bottom (in.)	Max. Active Fuel Length (in.)	Upper Fuel Spacer Length (in.)	Lower Fuel Spacer Length (in.)
GE/2-3	171.2	7.3	150	4.8	0
GE/4-6	176.2	7.3	150	0	0
Dresden 1	134.4	11.2	110	18.0	28.0
Humboldt Bay	95.0	8.0	79	40.5	40.5
Dresden 1 Damaged Fuel or Fuel Debris	142.1†	11.2	110	17.0	16.9
Humboldt Bay Damaged Fuel or Fuel Debris	105.5†	8.0	79	35.25	35.25
LaCrosse	102.5	10.5	83	37.0	37.5

Note: Each user shall specify the fuel spacer length based on their fuel assembly length, presence of a DFC, and allowing an approximate two to 2-1/2 inch gap under the MPC lid. Fuel spacers shall be sized to ensure that the active fuel region of intact fuel assemblies remains within the neutron poison region of the MPC basket with water in the MPC.

† Fuel assembly length includes the damaged fuel container.

Table 2.1.11
NORMALIZED DISTRIBUTION BASED ON BURNUP PROFILE

PWR DISTRIBUTION[1]		
Interval	**Axial Distance From Bottom of Active Fuel (% of Active Fuel Length)**	**Normalized Distribution**
1	0% to 4-1/6%	0.5485
2	4-1/6% to 8-1/3%	0.8477
3	8-1/3% to 16-2/3%	1.0770
4	16-2/3% to 33-1/3%	1.1050
5	33-1/3% to 50%	1.0980
6	50% to 66-2/3%	1.0790
7	66-2/3% to 83-1/3%	1.0501
8	83-1/3% to 91-2/3%	0.9604
9	91-2/3% to 95-5/6%	0.7338
10	95-5/6% to 100%	0.4670
BWR DISTRIBUTION[2]		
Interval	**Axial Distance From Bottom of Active Fuel (% of Active Fuel Length)**	**Normalized Distribution**
1	0% to 4-1/6%	0.2200
2	4-1/6% to 8-1/3%	0.7600
3	8-1/3% to 16-2/3%	1.0350
4	16-2/3% to 33-1/3%	1.1675
5	33-1/3% to 50%	1.1950
6	50% to 66-2/3%	1.1625
7	66-2/3% to 83-1/3%	1.0725
8	83-1/3% to 91-2/3%	0.8650
9	91-2/3% to 95-5/6%	0.6200
10	95-5/6% to 100%	0.2200

1. Reference 2.1.7
2. Reference 2.1.8

Table 2.1.12

DESIGN CHARACTERISTICS FOR THORIA RODS IN D-1 THORIA ROD CANISTERS

PARAMETER	MPC-68 or MPC-68F
Cladding Type	Zircaloy
Composition	98.2 wt.% ThO_2, 1.8 wt.% UO_2 with an enrichment of 93.5 wt. % ^{235}U
Number of Rods Per Thoria Canister	$\leq$ 18
Decay Heat Per Thoria Canister	$\leq$ 115 watts
Post-Irradiation Fuel Cooling Time and Average Burnup Per Thoria Canister	Cooling time $\geq$ 18 years and average burnup $\leq$ 16,000 MWD/MTIHM
Initial Heavy Metal Weight	$\leq$ 27 kg/canister
Fuel Cladding O.D.	$\geq$ 0.412 inches
Fuel Cladding I.D.	$\leq$ 0.362 inches
Fuel Pellet O.D.	$\leq$ 0.358 inches
Active Fuel Length	$\leq$ 111 inches
Canister Weight	$\leq$ 550 lbs., including Thoria Rods
Canister Material	Type 304 SS

Table 2.1.13

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Table 2.1.14

Soluble Boron Requirements for MPC-24/24E/24EF Fuel Wet Loading and Unloading Operations

MPC MODEL	**FUEL ASSEMBLY MAXIMUM AVERAGE ENRICHMENT (wt % ^{235}U)**	**MINIMUM SOLUBLE BORON CONCENTRATION (ppmb)**
MPC-24	All fuel assemblies with initial enrichment[1] less than the prescribed value for soluble boron credit	0
MPC-24	One or more fuel assemblies with an initial enrichment[1] greater than or equal to the prescribed value for no soluble boron credit and ≤ 5.0 wt. %	≥ 400
MPC-24E/24EF	All fuel assemblies with initial enrichment[1] less than the prescribed value for soluble boron credit	0
MPC-24E/24EF	All fuel assemblies classified as intact fuel assemblies and one or more fuel assemblies with an initial enrichment[1] greater than or equal to the prescribed value for no soluble boron credit and ≤ 5.0 wt. %	≥ 300
MPC-24E/24EF	One or more fuel assemblies classified as damaged fuel or fuel debris and one or more fuel assemblies with initial enrichment > 4.0 wt.% and ≤ 5.0 wt.%	≥ 600

[1]Refer to Table 2.1.3 for these enrichments.

Table 2.1.15

MINIMUM BORAL ^{10}B LOADING IN NEUTRON ABSORBER PANELS

MPC MODEL	MINIMUM ^{10}B LOADING (g/cm^2)	
	Boral Neutron Absorber Panels	**METAMIC Neutron Absorber Panels**
MPC-24	0.0267	0.0223
MPC-24E and MPC-24EF	0.0372	0.0310
MPC-32/32F	0.0372	0.0310
MPC-68 and MPC-68FF	0.0372	0.0310
MPC-68F	0.01	N/A (Note 1)

Notes:

1. All MPC-68F canisters are equipped with Boral neutron absorber panels.

Table 2.1.16

Soluble Boron Requirements for MPC-32 and MPC-32F Wet Loading and Unloading Operations

Fuel Assembly Array/Class	**All Intact Fuel Assemblies**		**One or More Damaged Fuel Assemblies or Fuel Debris**	
	Max. Initial Enrichment $\leq$ 4.1 wt.% ^{235}U (ppmb)	**Max. Initial Enrichment 5.0 wt.% ^{235}U (ppmb)**	**Max. Initial Enrichment $\leq$ 4.1 wt.% ^{235}U (ppmb)**	**Max. Initial Enrichment 5.0 wt.% ^{235}U (ppmb)**
14x14A/B/C/D/E	1,300	1,900	1,500	2,300
15x15A/B/C/G	1,800	2,500	1,900	2,700
15x15D/E/F/H	1,900	2,600	2,100	2,900
16x16A	1,400	2,000	1,500	2,300
17x17A/B/C	1,900	2,600	2,100	2,900

Note:

1. For maximum initial enrichments between 4.1 wt% and 5.0 wt% ^{235}U, the minimum soluble boron concentration may be determined by linear interpolation between the minimum soluble boron concentrations at 4.1 wt% and 5.1 wt% ^{235}U.

Table 2.1.17

LIMITS FOR MATERIAL TO BE STORED IN MPC-24

PARAMETER	VALUE
Fuel Type	Uranium oxide, PWR intact fuel assemblies meeting the limits in Table 2.1.3 for the applicable array/class
Cladding Type	ZR or Stainless Steel (SS) as specified in Table 2.1.3 for the applicable array/class
Maximum Initial Enrichment per Assembly	As specified in Table 2.1.3 for the applicable array/class
Post-irradiation Cooling Time and Average Burnup per Assembly	ZR clad: As specified in Section 2.1.9.1 SS clad: $\geq$ 8 years and $\leq$ 40,000 MWD/MTU
Decay Heat Per Fuel Storage Location	ZR clad: As specified in Section 2.1.9.1 SS clad: $\leq$ 710 Watts
Non-Fuel Hardware Burnup and Cooling Time	As specified in Table 2.1.25
Fuel Assembly Length	$\leq$ 176.8 in. (nominal design)
Fuel Assembly Width	$\leq$ 8.54 in. (nominal design)
Fuel Assembly Weight	$\leq$ 1,720 lbs (including non-fuel hardware) for array/classes that do not require fuel spacers, otherwise $\leq$ 1,680 lbs (including non-fuel hardware)
Other Limitations	▪ Quantity is limited to up to 24 PWR intact fuel assemblies. ▪ Damaged fuel assemblies and fuel debris are not permitted for ~~storage~~ *loading* in MPC-24. ▪ One NSA is ~~permitted~~ *authorized to be loaded with a fuel assembly* in ~~MPC-24~~ *fuel storage location 9, 10, 15, or 16.* ▪ BPRAs, TPDs, WABAs, water displacement guide tube plugs, orifice rod assemblies, and/or vibration suppressor inserts may be stored with fuel assemblies in any fuel cell location. ▪ APSRs may be ~~stored~~ *loaded* with fuel assemblies in fuel cell locations 9, 10, 15, and/or 16 ▪ CRAs, RCCAs and/or CEAs may be stored with fuel assemblies in fuel cell locations 4, 5, 8 through 11, 14 through 17, 20, and/or 21. ▪ Soluble boron requirements during wet loading and unloading are specified in Table 2.1.14.

Table 2.1.18

[INTENTIONALLY DELETED]

Table 2.1.19

LIMITS FOR MATERIAL TO BE STORED IN MPC-68F

PARAMETER	VALUE (Notes 1 and 2)			
Fuel Type(s)	Uranium oxide, BWR intact fuel assemblies meeting the limits in Table 2.1.4 for array/class 6x6A, 6x6C, 7x7A, or 8x8A, with or without Zircaloy channels	Uranium oxide, BWR damaged fuel assemblies or fuel debris meeting the limits in Table 2.1.4 for array/class 6x6A, 6x6C, 7x7A, or 8x8A, with or without Zircaloy channels, placed in Damaged Fuel Containers (DFCs)	Mixed Oxide (MOX) BWR intact fuel assemblies meeting the limits in Table 2.1.4 for array/class 6x6B, with or without Zircaloy channels	Mixed Oxide (MOX) BWR damaged fuel assemblies or fuel debris meeting the limits in Table 2.1.4 for array/class 6x6B, with or without Zircaloy channels, placed in Damaged Fuel Containers (DFCs)
Cladding Type	ZR	ZR	ZR	ZR
Maximum Initial Planar-Average Enrichment per Assembly and Rod Enrichment	As specified in Table 2.1.4 for the applicable array/class	As specified in Table 2.1.4 for the applicable array/class	As specified in Table 2.1.4 for array/class 6x6B	As specified in Table 2.1.4 for array/class 6x6B
Post-irradiation Cooling Time, Average Burnup, and Minimum Initial Enrichment per Assembly	Cooling time ≥ 18 years and average burnup ≤ 30,000 MWD/MTU.	Cooling time ≥ 18 years and average burnup ≤ 30,000 MWD/MTU.	Cooling time ≥ 18 years and average burnup ≤ 30,000 MWD/MTIHM.	Cooling time ≥ 18 years and average burnup ≤ 30,000 MWD/MTIHM.
Decay Heat Per Fuel Storage Location	≤ 115 Watts	≤ 115 Watts	≤ 115 Watts	≤ 115 Watts
Fuel Assembly Length	≤ 135.0 in. (nominal design)	≤ 135.0 in. (nominal design)	≤ 135.0 in. (nominal design)	≤ 135.0 in. (nominal design)
Fuel Assembly Width	≤ 4.70 in. (nominal design)	≤ 4.70 in. (nominal design)	≤ 4.70 in. (nominal design)	≤ 4.70 in. (nominal design)
Fuel Assembly Weight	≤ 400 lbs, (including channels)	≤ 550 lbs, (including channels and DFC)	≤ 400 lbs, (including channels)	≤ 550 lbs, (including channels and DFC)

Table 2.1.19 (cont'd)

LIMITS FOR MATERIAL TO BE STORED IN MPC-68F

PARAMETER	VALUE
Other Limitations	▪ Quantity is limited to up to four (4) DFCs containing Dresden Unit 1 or Humboldt Bay uranium oxide or MOX fuel debris. The remaining fuel storage locations may be filled with array/class 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A fuel assemblies of the following type, as applicable: - uranium oxide BWR intact fuel assemblies - MOX BWR intact fuel assemblies - uranium oxide BWR damaged fuel assemblies in DFCs - MOX BWR damaged fuel assemblies in DFCs - up to one (1) Dresden Unit 1 thoria rod canister meeting the specifications listed in Table 2.1.12. ▪ Stainless steel channels are not permitted. ▪ Dresden Unit 1 fuel assemblies with one antimony-beryllium neutron source are permitted. The antimony-beryllium neutron source material shall be in a water rod location.

Notes:

1. A fuel assembly must meet the requirements of any one column and the other limitations to be authorized for storage.
2. Only fuel from the Dresden Unit 1 and Humboldt Bay plants are permitted for storage in the MPC-68F.

Table 2.1.20

LIMITS FOR MATERIAL TO BE STORED IN MPC-24E AND MPC-24EF

PARAMETER	VALUE (Note 1)	
Fuel Type	Uranium oxide PWR intact fuel assemblies meeting the limits in Table 2.1.3 for the applicable array/class	Uranium oxide PWR damaged fuel assemblies and/or fuel debris meeting the limits in Table 2.1.3 for the applicable array/class, placed in a Damaged Fuel Container (DFC)
Cladding Type	ZR or Stainless Steel (SS) assemblies as specified in Table 2.1.3 for the applicable array/class	ZR or Stainless Steel (SS) assemblies as specified in Table 2.1.3 for the applicable array/class
Maximum Initial Enrichment per Assembly	As specified in Table 2.1.3 for the applicable array/class	As specified in Table 2.1.3 for the applicable array/class
Post-irradiation Cooling Time, and Average Burnup per Assembly	ZR clad: As specified in Section 2.1.9.1 SS clad: ≥ 8 yrs and ≤ 40,000 MWD/MTU	ZR clad: As specified in Section 2.1.9.1 SS clad: ≥ 8 yrs and ≤ 40,000 MWD/MTU
Decay Heat Per Fuel Storage Location	ZR clad: As specified in Section 2.1.9.1 SS clad: ≤ 710 Watts	ZR clad: As specified in Section 2.1.9.1 SS clad: ≤ 710 Watts
Non-fuel hardware post-irradiation Cooling Time and Burnup	As specified in Table 2.1.25	As specified in Table 2.1.25
Fuel Assembly Length	≤ 176.8 in. (nominal design)	≤ 176.8 in. (nominal design)
Fuel Assembly Width	≤ 8.54 in. (nominal design)	≤ 8.54 in. (nominal design)
Fuel Assembly Weight	≤ 1,720 lbs (including non-fuel hardware) for array/classes that do not require fuel spacers, otherwise ≤ 1680 lbs (including non-fuel hardware)	≤ 1,720 lbs (including DFC and non-fuel hardware) for array/classes that do not require fuel spacers, otherwise ≤ 1680 lbs (including DFC and non-fuel hardware)

Table 2.1.20 (cont'd)

LIMITS FOR MATERIAL TO BE STORED IN MPC-24E AND MPC-24EF

PARAMETER	VALUE
Other Limitations	▪ Quantity is limited to up to 24 PWR intact fuel assemblies or up to four (4) damaged fuel assemblies *and/or fuel classified as fuel debris* in DFCs may be stored in fuel storage locations 3, 6, 19, and/or 22. The remaining fuel storage locations may be filled with intact fuel assemblies. ~~▪Fuel debris is not authorized for storage in the MPC-24E.~~ ▪ One NSA is permitted *for loading with a fuel assembly* in ~~MPC-24E~~*fuel storage location 9, 10, 15, or 16.* ▪ BPRAs, TPDs, WABAs, water displacement guide tube plugs, orifice rod assemblies, and/or vibration suppressor inserts may be stored with fuel assemblies in any fuel cell location. ▪ APSRs may be ~~stored~~ *loaded* with fuel assemblies in fuel cell locations 9, 10, 15, and/or 16. ▪ CRAs, RCCAs and/or CEAs may be stored with fuel assemblies in fuel cell locations 4, 5, 8 through 11, 14 through 17, 20, and/or 21. ▪ Soluble boron requirements during wet loading and unloading are specified in Table 2.1.14.

Notes:

1. A fuel assembly must meet the requirements of any one column and the other limitations to be authorized for storage.

Table 2.1.21

[INTENTIONALLY DELETED]

Table 2.1.22

LIMITS FOR MATERIAL TO BE STORED IN MPC-68 AND MPC-68FF

PARAMETER	VALUE (Note 1)	
Fuel Type	Uranium oxide or MOX BWR intact fuel assemblies meeting the limits in Table 2.1.4 for the applicable array/class, with or without channels.	Uranium oxide or MOX BWR damaged fuel assemblies or fuel debris meeting the limits in Table 2.1.4 for the applicable array/class, with or without channels, in DFCs.
Cladding Type	ZR or Stainless Steel (SS) assemblies as specified in Table 2.1.4 for the applicable array/class	ZR or Stainless Steel (SS) assemblies as specified in Table 2.1.4 for the applicable array/class
Maximum Initial Planar Average Enrichment per Assembly and Rod Enrichment	As specified in Table 2.1.4 for the applicable fuel assembly array/class	Planar Average: ≤ 2.7 wt% ^{235}U for array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A; ≤ 4.0 wt% ^{235}U for all other array/classes Rod: As specified in Table 2.1.4
Post-irradiation cooling time and average burnup per Assembly	ZR clad: As specified in Section 2.1.9.1; except as provided in Notes 2 and 3. SS clad: Note 4	ZR clad: As specified in Section 2.1.9.1; except as provided in Notes 2 and 3. SS clad: Note 4.
Decay Heat Per Fuel Storage Location	ZR clad: As specified in Section 2.1.9.1; except as provided in Notes 2 and 3. SS clad: ≤ 95 Watts	ZR clad: As specified in Section 2.1.9.1; except as provided in Notes 2 and 3. SS clad: ≤ 95 Watts
Fuel Assembly Length	Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ 135.0 in. (nominal design) All Other array/classes: ≤ 176.5 in. (nominal design)	Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ 135.0 in. (nominal design) All Other array/classes: ≤ 176.5 in. (nominal design)

Table 2.1.22 (cont'd)

LIMITS FOR MATERIAL TO BE STORED IN MPC-68 AND MPC-68FF

PARAMETER	VALUE (Note 1)	
Fuel Assembly Width	Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ 4.7 in. (nominal design) All Other array/classes: ≤ 5.85 in. (nominal design)	Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ 4.7 in. (nominal design) All Other array/classes: ≤ 5.85 in. (nominal design)
Fuel Assembly Weight	Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ ~~550~~ *400* lbs. (including channels) All Other array/classes: ≤ 730 lbs. (including channels)	Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ 550 lbs. (including channels and DFC) All Other array/classes: ≤ 730 lbs. (including channels and DFC)
Other Limitations	▪ ~~Quantity is limited to up to one (1) Up to eight (8) Dresden Unit 1 or Humboldt Bay fuel assemblies classified as fuel debris in DFCs, and any combination of Dresden Unit 1 or Humboldt Bay damaged fuel assemblies in DFCs and intact fuel assemblies up to a total of 68.~~ ▪ *For assembly/class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A, up to 68 intact fuel assemblies or damaged fuel assemblies in DFCs may be stored. Fuel debris in DFCs may be stored in up to 8 locations. A Dresden Unit 1 Thoria Rod Container may be stored in one location.* ▪ *For all other array/classes,* ~~U~~up to 16 *DFCs containing* damaged fuel assemblies and/or up to eight (8) *DFCs containing* fuel assemblies classified as fuel debris ~~from plants other than Dresden Unit 1 or Humboldt Bay~~ may be stored ~~in DFCs in MPC-68FF~~. DFCs shall be located only in fuel cell locations 1, 2, 3, 8, 9, 16, 25, 34, 35, 44, 53, 60, 61, 66, 67, and/or 68, with the balance comprised of intact fuel assemblies meeting the above specifications, up to a total of 68. ▪ SS-clad fuel assemblies with stainless steel channels must be stored in fuel cell locations 19 through 22, 28 through 31, 38 through 41, and/or 47 through 50. ▪ Dresden Unit 1 fuel assemblies with one antimony-beryllium neutron source are permitted. The antimony-beryllium neutron source material shall be in a water rod location.	

NOTES:

1. A fuel assembly must meet the requirements of any one column and the other limitations to be authorized for storage.

2. Array/class 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A fuel assemblies shall have a cooling time ≥ 18 years, an average burnup ≤ 30,000 MWD/MTU *or MWD/MTIHM*, and a ~~maximum~~ decay heat ≤ 115 Watts.

3. Array/class 8x8F fuel assemblies shall have a cooling time ≥ 10 years, an average burnup ≤ 27,500 MWD/MTU, and a ~~maximum~~ decay *heat* ≤ 183.5 Watts.

4. SS-clad fuel assemblies shall have a cooling time ≥ 10 years, and an average burnup ≤ 22,500 MWD/MTU.

Table 2.1.23

[INTENTIONALLY DELETED]

Table 2.1.24

LIMITS FOR MATERIAL TO BE STORED IN MPC-32 AND MPC-32F

PARAMETER	VALUE (Note 1)	
Fuel Type	Uranium oxide, PWR intact fuel assemblies meeting the limits in Table 2.1.3 for the applicable fuel assembly array/class	Uranium oxide, PWR damaged fuel assemblies and fuel debris in DFCs meeting the limits in Table 2.1.3 for the applicable fuel assembly array/class
Cladding Type	ZR or Stainless Steel (SS) as specified in Table 2.1.3 for the applicable fuel assembly array/class	ZR or Stainless Steel (SS) as specified in Table 2.1.3 for the applicable fuel assembly array/class
Maximum Initial Enrichment per Assembly	As specified in Table 2.1.3	As specified in Table 2.1.3
Post-irradiation Cooling Time, Average Burnup, and Minimum Initial Enrichment per Assembly	ZR clad: As specified in Section 2.1.9.1 SS clad: $\geq$ 9 years and $\leq$ 30,000 MWD/MTU or $\geq$ 20 years and $\leq$ 40,000MWD/MTU	ZR clad: As specified in Section 2.1.9.1 SS clad: $\geq$ 9 years and $\leq$ 30,000 MWD/MTU or $\geq$ 20 years and $\leq$ 40,000MWD/MTU
Decay Heat Per Fuel Storage Location	ZR clad: As specified in Section 2.1.9.1 SS clad: $\leq$ 500 Watts	ZR clad: As specified in Section 2.1.9.1 SS clad: $\leq$ 500 Watts
Non-fuel hardware post-irradiation Cooling Time and Burnup	As specified in Table 2.1.25	As specified in Table 2.1.25
Fuel Assembly Length	$\leq$ 176.8 in. (nominal design)	$\leq$ 176.8 in. (nominal design)
Fuel Assembly Width	$\leq$ 8.54 in. (nominal design)	$\leq$ 8.54 in. (nominal design)
Fuel Assembly Weight	$\leq$ 1,720 lbs (including non-fuel hardware) for array/classes that do not require fuel spacers, otherwise $\leq$ 1,680 lbs (including non-fuel hardware)	$\leq$ 1,720 lbs (including DFC and non-fuel hardware) for array/classes that do not require fuel spacers, otherwise $\leq$ 1,680 lbs (including DFC and non-fuel hardware)

Table 2.1.24 (cont'd)

LIMITS FOR MATERIAL TO BE STORED IN MPC-32 AND MPC-32F

PARAMETER	VALUE
Other Limitations	▪ Quantity is limited to up to 32 PWR intact fuel assemblies and/or up to eight (8) damaged fuel assemblies *and/or fuel classified as fuel debris* in DFCs in fuel cell locations 1, 4, 5, 10, 23, 28, 29, and/or 32, with the balance intact fuel assemblies up to a total of 32. ▪ One NSA is permitted for ~~storage~~ *loading with a fuel assembly* in ~~MPC-32~~*fuel storage location 13, 14, 19, or 20.* ▪ BPRAs, TPDs, WABAs, water displacement guide tube plugs, orifice rod assemblies, and/or vibration suppressor inserts may be stored with fuel assemblies in any fuel cell location. ▪ CRAs, RCCAs, CEAs, ~~NSAs, and/~~or APSRs may *only* be ~~stored~~ *loaded* with fuel assemblies in fuel cell locations 7, 8, 12-15, 18-21, 25 and/or 26. ▪ Soluble boron requirements during wet loading and unloading are specified in Table 2.1.16.

NOTES:

1. A fuel assembly must meet the requirements of any one column and the other limitations to be authorized for storage.

Table 2.1.25

NON-FUEL HARDWARE BURNUP AND COOLING TIME LIMITS (Notes 1, 2, and 3)

Post-irradiation Cooling Time (yrs)	Inserts (Note 4) Maximum Burnup (MWD/MTU)	NSA or Guide Tube Hardware (Note 5) Maximum Burnup (MWD/MTU)	Control Component (Note 6) Maximum Burnup (MWD/MTU)	APSR Maximum Burnup (MWD/MTU)
≥ 3	$\leq 24,635$	N/A (Note 7)	N/A	N/A
≥ 4	$\leq 30,000$	$\leq 20,000$	N/A	N/A
≥ 5	$\leq 36,748$	$\leq 25,000$	$\leq 630,000$	$\leq 45,000$
≥ 6	$\leq 44,102$	$\leq 30,000$	-	$\leq 54,500$
≥ 7	$\leq 52,900$	$\leq 40,000$	-	$\leq 68,000$
≥ 8	$\leq 60,000$	$\leq 45,000$	-	$\leq 83,000$
≥ 9	-	$\leq 50,000$	-	$\leq 111,000$
≥ 10	-	$\leq 60,000$	-	$\leq 180,000$
≥ 11	-	$\leq 75,000$	-	$\leq 630,000$
≥ 12	-	$\leq 90,000$	-	-
≥ 13	-	$\leq 180,000$	-	-
≥ 14	-	$\leq 630,000$	-	-

NOTES:

1. Burnups for non-fuel hardware are to be determined based on the burnup and uranium mass of the fuel assemblies in which the component was inserted during reactor operation.

2. Linear interpolation between points is permitted, except that NSA or Guide Tube Hardware and APSR burnups > 180,000 MWD/MTU and $\leq$ 630,000 MWD/MTU must be cooled $\geq$ 14 years and $\geq$ 11 years, respectively.

3. Applicable to uniform loading and regionalized loading.

4. Includes Burnable Poison Rod Assemblies (BPRAs), Wet Annular Burnable Absorbers (WABAs), and vibration suppressor inserts.

5. Includes Thimble Plug Devices (TPDs), water displacement guide tube plugs, and orifice rod assemblies.

6. Includes Control Rod Assemblies (CRAs), Control Element Assemblies (CEAs), and Rod Cluster Control Assemblies (RCCAs).

7. N/A means not authorized for loading at this cooling time.

Table 2.1.26

DESIGN HEAT EMISSION RATES
(UNIFORM LOADING, ZR-CLAD, *ABOVEGROUND STORAGE**)

MPC	Decay Heat (kW)	
	Per *Intact* Fuel Assembly	*Per* MPC
MPC-24/24E/24EF	≤ 1.416	≤ 34
MPC-32/32F	≤ 1.062	≤ 34
MPC-68/68FF	≤ 0.5	≤ 34
	Per Damaged Fuel Assembly or Fuel Debris	*Per MPC with Damaged Fuel Assembly or Fuel Debris*
MPC-24E/24EF	*≤ 1.114*	*≤ 26.7*
MPC-32/32F	*≤ 0.718*	*≤ 23*
MPC-68/68FF	*≤ 0.393*	*≤ 26.7*

* *Maximum allowable heat loads in 100U underground storage are defined in Supplement 2.1*

Table 2.1.27

MPC FUEL STORAGE REGIONS

MPC	Number of Storage Cells		Storage Cell IDs**	
	Inner Region (n_1)	Outer Region (n_2)	Inner Region	Outer Region
MPC-24/24E/24EF	12	12	4, 5 8 through 11 14 through 17 20 and 21	All other locations
MPC-32/32F	12	20	7, 8, 12 through 15, 18 through 21, 25 and 26	All other locations
MPC-68/68FF	32	36	11 through 14, 18 through 23, 27 through 32, 37 through 42, 46 through 51, 55 through 58	All other locations

** See Figures 1.2.2 through 1.2.4 for storage cell numbering

Table 2.1.28

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 14x14A**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	19311.5	275.367	-59.0252	-139.41	2851.12	-451.845	-615.413
≥ 4	33865.9	-5473.03	851.121	-132.739	3408.58	-656.479	-609.523
≥ 5	46686.2	-13226.9	2588.39	-150.149	3871.87	-806.533	-90.2065
≥ 6	56328.9	-20443.2	4547.38	-176.815	4299.19	-927.358	603.192
≥ 7	64136	-27137.5	6628.18	-200.933	4669.22	-1018.94	797.162
≥ 8	71744.1	-34290.3	9036.9	-214.249	4886.95	-1037.59	508.703
≥ 9	77262	-39724.2	11061	-228.2	5141.35	-1102.05	338.294
≥ 10	82939.8	-45575.6	13320.2	-233.691	5266.25	-1095.94	-73.3159
≥ 11	86541	-49289.6	14921.7	-242.092	5444.54	-1141.6	-83.0603
≥ 12	91383	-54456.7	17107	-242.881	5528.7	-1149.2	-547.579
≥ 13	95877.6	-59404.7	19268	-240.36	5524.35	-1094.72	-933.64
≥ 14	97648.3	-61091.6	20261.7	-244.234	5654.56	-1151.47	-749.836
≥ 15	102533	-66651.5	22799.7	-240.858	5647.05	-1120.32	-1293.34
≥ 16	106216	-70753.8	24830.1	-237.04	5647.63	-1099.12	-1583.89
≥ 17	109863	-75005	27038	-234.299	5652.45	-1080.98	-1862.07
≥ 18	111460	-76482.3	28076.5	-234.426	5703.52	-1104.39	-1695.77
≥ 19	114916	-80339.6	30126.5	-229.73	5663.21	-1065.48	-1941.83
≥ 20	119592	-86161.5	33258.2	-227.256	5700.49	-1100.21	-2474.01

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 14x14B**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	18036.1	63.7639	-24.7251	-130.732	2449.87	-347.748	-858.192
≥ 4	30303.4	-4304.2	598.79	-118.757	2853.18	-486.453	-459.902
≥ 5	40779.6	-9922.93	1722.83	-138.174	3255.69	-608.267	245.251
≥ 6	48806.7	-15248.9	3021.47	-158.69	3570.24	-689.876	833.917
≥ 7	55070.5	-19934.6	4325.62	-179.964	3870.33	-765.849	1203.89
≥ 8	60619.6	-24346	5649.29	-189.701	4042.23	-795.324	1158.12
≥ 9	64605.7	-27677.1	6778.12	-205.459	4292.35	-877.966	1169.88
≥ 10	69083.8	-31509.4	8072.42	-206.157	4358.01	-875.041	856.449
≥ 11	72663.2	-34663.9	9228.96	-209.199	4442.68	-889.512	671.567
≥ 12	74808.9	-36367	9948.88	-214.344	4571.29	-942.418	765.261
≥ 13	78340.3	-39541.1	11173.8	-212.8	4615.06	-957.833	410.807
≥ 14	81274.8	-42172.3	12259.9	-209.758	4626.13	-958.016	190.59
≥ 15	83961.4	-44624.5	13329.1	-207.697	4632.16	-952.876	20.8575
≥ 16	84968.5	-44982.1	13615.8	-207.171	4683.41	-992.162	247.54
≥ 17	87721.6	-47543.1	14781.4	-203.373	4674.3	-988.577	37.9689
≥ 18	90562.9	-50100.4	15940.4	-198.649	4651.64	-982.459	-247.421
≥ 19	93011.6	-52316.6	17049.9	-194.964	4644.76	-994.63	-413.021
≥ 20	95567.8	-54566.6	18124	-190.22	4593.92	-963.412	-551.983

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 14x14C**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	18263.7	174.161	-57.6694	-138.112	2539.74	-369.764	-1372.33
≥ 4	30514.5	-4291.52	562.37	-124.944	2869.17	-481.139	-889.883
≥ 5	41338	-10325.7	1752.96	-141.247	3146.48	-535.709	-248.078
≥ 6	48969.7	-15421.3	2966.33	-163.574	3429.74	-587.225	429.331
≥ 7	55384.6	-20228.9	4261.47	-180.846	3654.55	-617.255	599.251
≥ 8	60240.2	-24093.2	5418.86	-199.974	3893.72	-663.995	693.934
≥ 9	64729	-27745.7	6545.45	-205.385	3986.06	-650.124	512.528
≥ 10	68413.7	-30942.2	7651.29	-216.408	4174.71	-702.931	380.431
≥ 11	71870.6	-33906.7	8692.81	-218.813	4248.28	-704.458	160.645
≥ 12	74918.4	-36522	9660.01	-218.248	4283.68	-696.498	-29.0682
≥ 13	77348.3	-38613.7	10501.8	-220.644	4348.23	-702.266	-118.646
≥ 14	79817.1	-40661.8	11331.2	-218.711	4382.32	-710.578	-236.123
≥ 15	82354.2	-42858.3	12257.3	-215.835	4405.89	-718.805	-431.051
≥ 16	84787.2	-44994.5	13185.9	-213.386	4410.99	-711.437	-572.104
≥ 17	87084.6	-46866.1	14004.8	-206.788	4360.3	-679.542	-724.721
≥ 18	88083.1	-47387.1	14393.4	-208.681	4420.85	-709.311	-534.454
≥ 19	90783.6	-49760.6	15462.7	-203.649	4403.3	-705.741	-773.066
≥ 20	93212	-51753.3	16401.5	-197.232	4361.65	-692.925	-964.628

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 15x15A/B/C**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	15037.3	108.689	-18.8378	-127.422	2050.02	-242.828	-580.66
≥ 4	25506.6	-2994.03	356.834	-116.45	2430.25	-350.901	-356.378
≥ 5	34788.8	-7173.07	1065.9	-124.785	2712.23	-424.681	267.705
≥ 6	41948.6	-11225.3	1912.12	-145.727	3003.29	-489.538	852.112
≥ 7	47524.9	-14770.9	2755.16	-165.889	3253.9	-542.7	1146.96
≥ 8	52596.9	-18348.8	3699.72	-177.17	3415.69	-567.012	1021.41
≥ 9	56055.4	-20837.1	4430.93	-192.168	3625.93	-623.325	1058.61
≥ 10	59611.3	-23402.1	5179.52	-195.105	3699.18	-626.448	868.517
≥ 11	62765.3	-25766.5	5924.71	-195.57	3749.91	-627.139	667.124
≥ 12	65664.4	-28004.8	6670.75	-195.08	3788.33	-628.904	410.783
≥ 13	67281.7	-29116.7	7120.59	-202.817	3929.38	-688.738	492.309
≥ 14	69961.4	-31158.6	7834.02	-197.988	3917.29	-677.565	266.561
≥ 15	72146	-32795.7	8453.67	-195.083	3931.47	-681.037	99.0606
≥ 16	74142.6	-34244.8	9023.57	-190.645	3905.54	-663.682	10.8885
≥ 17	76411.4	-36026.3	9729.98	-188.874	3911.21	-663.449	-151.805
≥ 18	77091	-36088	9884.09	-188.554	3965.08	-708.55	59.3839
≥ 19	79194.5	-37566.4	10477.5	-181.656	3906.93	-682.4	-117.952
≥ 20	81600.4	-39464.5	11281.9	-175.182	3869.49	-677.179	-367.705

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 15x15D/E/F/H**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	14376.7	102.205	-20.6279	-126.017	1903.36	-210.883	-493.065
≥ 4	24351.4	-2686.57	297.975	-110.819	2233.78	-301.615	-152.713
≥ 5	33518.4	-6711.35	958.544	-122.85	2522.7	-371.286	392.608
≥ 6	40377	-10472.4	1718.53	-144.535	2793.29	-426.436	951.528
≥ 7	46105.8	-13996.2	2515.32	-157.827	2962.46	-445.314	1100.56
≥ 8	50219.7	-16677.7	3198.3	-175.057	3176.74	-492.727	1223.62
≥ 9	54281.2	-19555.6	3983.47	-181.703	3279.03	-499.997	1034.55
≥ 10	56761.6	-21287.3	4525.98	-195.045	3470.41	-559.074	1103.3
≥ 11	59820	-23445.2	5165.43	-194.997	3518.23	-561.422	862.68
≥ 12	62287.2	-25164.6	5709.9	-194.771	3552.69	-561.466	680.488
≥ 13	64799	-27023.7	6335.16	-192.121	3570.41	-561.326	469.583
≥ 14	66938.7	-28593.1	6892.63	-194.226	3632.92	-583.997	319.867
≥ 15	68116.5	-29148.6	7140.09	-192.545	3670.39	-607.278	395.344
≥ 16	70154.9	-30570.1	7662.91	-187.366	3649.14	-597.205	232.318
≥ 17	72042.5	-31867.6	8169.01	-183.453	3646.92	-603.907	96.0388
≥ 18	73719.8	-32926.1	8596.12	-177.896	3614.57	-592.868	46.6774
≥ 19	75183.1	-33727.4	8949.64	-172.386	3581.13	-586.347	3.57256
≥ 20	77306.1	-35449	9690.02	-173.784	3636.87	-626.321	-205.513

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 16x16A**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	16226.8	143.714	-32.4809	-136.707	2255.33	-291.683	-699.947
≥ 4	27844.2	-3590.69	444.838	-124.301	2644.09	-411.598	-381.106
≥ 5	38191.5	-8678.48	1361.58	-132.855	2910.45	-473.183	224.473
≥ 6	46382.2	-13819.6	2511.32	-158.262	3216.92	-532.337	706.656
≥ 7	52692.3	-18289	3657.18	-179.765	3488.3	-583.133	908.839
≥ 8	57758.7	-22133.7	4736.88	-199.014	3717.42	-618.83	944.903
≥ 9	62363.3	-25798.7	5841.18	-207.025	3844.38	-625.741	734.928
≥ 10	66659.1	-29416.3	6993.31	-216.458	3981.97	-642.641	389.366
≥ 11	69262.7	-31452.7	7724.66	-220.836	4107.55	-681.043	407.121
≥ 12	72631.5	-34291.9	8704.8	-219.929	4131.5	-662.513	100.093
≥ 13	75375.3	-36589.3	9555.88	-217.994	4143.15	-644.014	-62.3294
≥ 14	78178.7	-39097.1	10532	-221.923	4226.28	-667.012	-317.743
≥ 15	79706.3	-40104	10993.3	-218.751	4242.12	-670.665	-205.579
≥ 16	82392.6	-42418.9	11940.7	-216.278	4274.09	-689.236	-479.752
≥ 17	84521.8	-44150.5	12683.3	-212.056	4245.99	-665.418	-558.901
≥ 18	86777.1	-45984.8	13479	-204.867	4180.8	-621.805	-716.366
≥ 19	89179.7	-48109.8	14434.5	-206.484	4230.03	-648.557	-902.1
≥ 20	90141.7	-48401.4	14702.6	-203.284	4245.54	-670.655	-734.604

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 17x17A**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	15985.1	3.53963	-9.04955	-128.835	2149.5	-260.415	-262.997
≥ 4	27532.9	-3494.41	428.199	-119.504	2603.01	-390.91	-140.319
≥ 5	38481.2	-8870.98	1411.03	-139.279	3008.46	-492.881	388.377
≥ 6	47410.9	-14479.6	2679.08	-162.13	3335.48	-557.777	702.164
≥ 7	54596.8	-19703.2	4043.46	-181.339	3586.06	-587.634	804.05
≥ 8	60146.1	-24003.4	5271.54	-201.262	3830.32	-621.706	848.454
≥ 9	65006.3	-27951	6479.04	-210.753	3977.69	-627.805	615.84
≥ 10	69216	-31614.7	7712.58	-222.423	4173.4	-672.33	387.879
≥ 11	73001.3	-34871.1	8824.44	-225.128	4238.28	-657.259	101.654
≥ 12	76326.1	-37795.9	9887.35	-226.731	4298.11	-647.55	-122.236
≥ 13	78859.9	-40058.9	10797.1	-231.798	4402.14	-669.982	-203.383
≥ 14	82201.3	-43032.5	11934.1	-228.162	4417.99	-661.61	-561.969
≥ 15	84950	-45544.6	12972.4	-225.369	4417.84	-637.422	-771.254
≥ 16	87511.8	-47720	13857.7	-219.255	4365.24	-585.655	-907.775
≥ 17	90496.4	-50728.9	15186	-223.019	4446.51	-613.378	-1200.94
≥ 18	91392.5	-51002.4	15461.4	-220.272	4475.28	-636.398	-1003.81
≥ 19	94343.9	-53670.8	16631.6	-214.045	4441.31	-616.201	-1310.01
≥ 20	96562.9	-55591.2	17553.4	-209.917	4397.67	-573.199	-1380.64

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 17x17B/C**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	14738	47.5402	-13.8187	-127.895	1946.58	-219.289	-389.029
≥ 4	25285.2	-3011.92	350.116	-115.75	2316.89	-319.23	-220.413
≥ 5	34589.6	-7130.34	1037.26	-128.673	2627.27	-394.58	459.642
≥ 6	42056.2	-11353.7	1908.68	-150.234	2897.38	-444.316	923.971
≥ 7	47977.6	-15204.8	2827.4	-173.349	3178.25	-504.16	1138.82
≥ 8	52924	-18547.6	3671.08	-183.025	3298.64	-501.278	1064.68
≥ 9	56465.5	-21139.4	4435.67	-200.386	3538	-569.712	1078.78
≥ 10	60190.9	-23872.7	5224.31	-203.233	3602.88	-562.312	805.336
≥ 11	63482.1	-26431.1	6035.79	-205.096	3668.84	-566.889	536.011
≥ 12	66095	-28311.8	6637.72	-204.367	3692.68	-555.305	372.223
≥ 13	67757.4	-29474.4	7094.08	-211.649	3826.42	-606.886	437.412
≥ 14	70403.7	-31517.4	7807.15	-207.668	3828.69	-601.081	183.09
≥ 15	72506.5	-33036.1	8372.59	-203.428	3823.38	-594.995	47.5175
≥ 16	74625.2	-34620.5	8974.32	-199.003	3798.57	-573.098	-95.0221
≥ 17	76549	-35952.6	9498.14	-193.459	3766.52	-556.928	-190.662
≥ 18	77871.9	-36785.5	9916.91	-195.592	3837.65	-599.45	-152.261
≥ 19	79834.8	-38191.6	10501.9	-190.83	3812.46	-589.635	-286.847
≥ 20	81975.5	-39777.2	11174.5	-185.767	3795.78	-595.664	-475.978

Table 2.1.29

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 7x7B**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	26409.1	28347.5	-16858	-147.076	5636.32	-1606.75	1177.88
≥ 4	61967.8	-6618.31	-4131.96	-113.949	6122.77	-2042.85	-96.7439
≥ 5	91601.1	-49298.3	17826.5	-132.045	6823.14	-2418.49	-185.189
≥ 6	111369	-80890.1	35713.8	-150.262	7288.51	-2471.1	86.6363
≥ 7	126904	-108669	53338.1	-167.764	7650.57	-2340.78	150.403
≥ 8	139181	-132294	69852.5	-187.317	8098.66	-2336.13	97.5285
≥ 9	150334	-154490	86148.1	-193.899	8232.84	-2040.37	-123.029
≥ 10	159897	-173614	100819	-194.156	8254.99	-1708.32	-373.605
≥ 11	166931	-186860	111502	-193.776	8251.55	-1393.91	-543.677
≥ 12	173691	-201687	125166	-202.578	8626.84	-1642.3	-650.814
≥ 13	180312	-215406	137518	-201.041	8642.19	-1469.45	-810.024
≥ 14	185927	-227005	148721	-197.938	8607.6	-1225.95	-892.876
≥ 15	191151	-236120	156781	-191.625	8451.86	-846.27	-1019.4
≥ 16	195761	-244598	165372	-187.043	8359.19	-572.561	-1068.19
≥ 17	200791	-256573	179816	-197.26	8914.28	-1393.37	-1218.63
≥ 18	206068	-266136	188841	-187.191	8569.56	-730.898	-1363.79
≥ 19	210187	-273609	197794	-182.151	8488.23	-584.727	-1335.59
≥ 20	213731	-278120	203074	-175.864	8395.63	-457.304	-1364.38

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 8x8B**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	28219.6	28963.7	-17616.2	-147.68	5887.41	-1730.96	1048.21
≥ 4	66061.8	-10742.4	-1961.82	-123.066	6565.54	-2356.05	-298.005
≥ 5	95790.7	-53401.7	19836.7	-134.584	7145.41	-2637.09	-298.858
≥ 6	117477	-90055.9	41383.9	-154.758	7613.43	-2612.69	-64.9921
≥ 7	134090	-120643	60983	-168.675	7809	-2183.3	-40.8885
≥ 8	148186	-149181	81418.7	-185.726	8190.07	-2040.31	-260.773
≥ 9	159082	-172081	99175.2	-197.185	8450.86	-1792.04	-381.705
≥ 10	168816	-191389	113810	-195.613	8359.87	-1244.22	-613.594
≥ 11	177221	-210599	131099	-208.3	8810	-1466.49	-819.773
≥ 12	183929	-224384	143405	-207.497	8841.33	-1227.71	-929.708
≥ 13	191093	-240384	158327	-204.95	8760.17	-811.708	-1154.76
≥ 14	196787	-252211	169664	-204.574	8810.95	-610.928	-1208.97
≥ 15	203345	-267656	186057	-208.962	9078.41	-828.954	-1383.76
≥ 16	207973	-276838	196071	-204.592	9024.17	-640.808	-1436.43
≥ 17	213891	-290411	211145	-202.169	9024.19	-482.1	-1595.28
≥ 18	217483	-294066	214600	-194.243	8859.35	-244.684	-1529.61
≥ 19	220504	-297897	219704	-190.161	8794.97	-10.9863	-1433.86
≥ 20	227821	-318395	245322	-194.682	9060.96	-350.308	-1741.16

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 8x8C/D/E**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	28592.7	28691.5	-17773.6	-149.418	5969.45	-1746.07	1063.62
≥ 4	66720.8	-12115.7	-1154	-128.444	6787.16	-2529.99	-302.155
≥ 5	96929.1	-55827.5	21140.3	-136.228	7259.19	-2685.06	-334.328
≥ 6	118190	-92000.2	42602.5	-162.204	7907.46	-2853.42	-47.5465
≥ 7	135120	-123437	62827.1	-172.397	8059.72	-2385.81	-75.0053
≥ 8	149162	-152986	84543.1	-195.458	8559.11	-2306.54	-183.595
≥ 9	161041	-177511	103020	-200.087	8632.84	-1864.4	-433.081
≥ 10	171754	-201468	122929	-209.799	8952.06	-1802.86	-755.742
≥ 11	179364	-217723	137000	-215.803	9142.37	-1664.82	-847.268
≥ 12	186090	-232150	150255	-216.033	9218.36	-1441.92	-975.817
≥ 13	193571	-249160	165997	-213.204	9146.99	-1011.13	-1119.47
≥ 14	200034	-263671	180359	-210.559	9107.54	-694.626	-1312.55
≥ 15	205581	-275904	193585	-216.242	9446.57	-1040.65	-1428.13
≥ 16	212015	-290101	207594	-210.036	9212.93	-428.321	-1590.7
≥ 17	216775	-299399	218278	-204.611	9187.86	-398.353	-1657.6
≥ 18	220653	-306719	227133	-202.498	9186.34	-181.672	-1611.86
≥ 19	224859	-314004	235956	-193.902	8990.14	145.151	-1604.71
≥ 20	228541	-320787	245449	-200.727	9310.87	-230.252	-1570.18

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 9x9A**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	30538.7	28463.2	-18105.5	-150.039	6226.92	-1876.69	1034.06
≥ 4	71040.1	-16692.2	1164.15	-128.241	7105.27	-2728.58	-414.09
≥ 5	100888	-60277.7	24150.1	-142.541	7896.11	-3272.86	-232.197
≥ 6	124846	-102954	50350.8	-161.849	8350.16	-3163.44	-91.1396
≥ 7	143516	-140615	76456.5	-185.538	8833.04	-2949.38	-104.802
≥ 8	158218	-171718	99788.2	-196.315	9048.88	-2529.26	-259.929
≥ 9	172226	-204312	126620	-214.214	9511.56	-2459.19	-624.954
≥ 10	182700	-227938	146736	-215.793	9555.41	-1959.92	-830.943
≥ 11	190734	-246174	163557	-218.071	9649.43	-1647.5	-935.021
≥ 12	199997	-269577	186406	-223.975	9884.92	-1534.34	-1235.27
≥ 13	207414	-287446	204723	-228.808	10131.7	-1614.49	-1358.61
≥ 14	215263	-306131	223440	-220.919	9928.27	-988.276	-1638.05
≥ 15	221920	-321612	239503	-217.949	9839.02	-554.709	-1784.04
≥ 16	226532	-331778	252234	-216.189	9893.43	-442.149	-1754.72
≥ 17	232959	-348593	272609	-219.907	10126.3	-663.84	-1915.3
≥ 18	240810	-369085	296809	-219.729	10294.6	-859.302	-2218.87
≥ 19	244637	-375057	304456	-210.997	10077.8	-425.446	-2127.83
≥ 20	248112	-379262	309391	-204.191	9863.67	100.27	-2059.39

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 9x9B**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	30613.2	28985.3	-18371	-151.117	6321.55	-1881.28	988.92
≥ 4	71346.6	-15922.9	631.132	-128.876	7232.47	-2810.64	-471.737
≥ 5	102131	-60654.1	23762.7	-140.748	7881.6	-3156.38	-417.979
≥ 6	127187	-105842	51525.2	-162.228	8307.4	-2913.08	-342.13
≥ 7	146853	-145834	79146.5	-185.192	8718.74	-2529.57	-484.885
≥ 8	162013	-178244	103205	-197.825	8896.39	-1921.58	-584.013
≥ 9	176764	-212856	131577	-215.41	9328.18	-1737.12	-1041.11
≥ 10	186900	-235819	151238	-218.98	9388.08	-1179.87	-1202.83
≥ 11	196178	-257688	171031	-220.323	9408.47	-638.53	-1385.16
≥ 12	205366	-280266	192775	-223.715	9592.12	-472.261	-1661.6
≥ 13	215012	-306103	218866	-231.821	9853.37	-361.449	-1985.56
≥ 14	222368	-324558	238655	-228.062	9834.57	3.47358	-2178.84
≥ 15	226705	-332738	247316	-224.659	9696.59	632.172	-2090.75
≥ 16	233846	-349835	265676	-221.533	9649.93	913.747	-2243.34
≥ 17	243979	-379622	300077	-222.351	9792.17	1011.04	-2753.36
≥ 18	247774	-386203	308873	-220.306	9791.37	1164.58	-2612.25
≥ 19	254041	-401906	327901	-213.96	9645.47	1664.94	-2786.2
≥ 20	256003	-402034	330566	-215.242	9850.42	1359.46	-2550.06

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 9x9C/D						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	30051.6	29548.7	-18614.2	-148.276	6148.44	-1810.34	1006
≥ 4	70472.7	-14696.6	-233.567	-127.728	7008.69	-2634.22	-444.373
≥ 5	101298	-59638.9	23065.2	-138.523	7627.57	-2958.03	-377.965
≥ 6	125546	-102740	49217.4	-160.811	8096.34	-2798.88	-259.767
≥ 7	143887	-139261	74100.4	-184.302	8550.86	-2517.19	-275.151
≥ 8	159633	-172741	98641.4	-194.351	8636.89	-1838.81	-486.731
≥ 9	173517	-204709	124803	-212.604	9151.98	-1853.27	-887.137
≥ 10	182895	-225481	142362	-218.251	9262.59	-1408.25	-978.356
≥ 11	192530	-247839	162173	-217.381	9213.58	-818.676	-1222.12
≥ 12	201127	-268201	181030	-215.552	9147.44	-232.221	-1481.55
≥ 13	209538	-289761	203291	-225.092	9588.12	-574.227	-1749.35
≥ 14	216798	-306958	220468	-222.578	9518.22	-69.9307	-1919.71
≥ 15	223515	-323254	237933	-217.398	9366.52	475.506	-2012.93
≥ 16	228796	-334529	250541	-215.004	9369.33	662.325	-2122.75
≥ 17	237256	-356311	273419	-206.483	9029.55	1551.3	-2367.96
≥ 18	242778	-369493	290354	-215.557	9600.71	659.297	-2589.32
≥ 19	246704	-377971	302630	-210.768	9509.41	1025.34	-2476.06
≥ 20	249944	-382059	308281	-205.495	9362.63	1389.71	-2350.49

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 9x9E/F**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	30284.3	26949.5	-16926.4	-147.914	6017.02	-1854.81	1026.15
≥ 4	69727.4	-17117.2	1982.33	-127.983	6874.68	-2673.01	-359.962
≥ 5	98438.9	-58492	23382.2	-138.712	7513.55	-3038.23	-112.641
≥ 6	119765	-95024.1	45261	-159.669	8074.25	-3129.49	221.182
≥ 7	136740	-128219	67940.1	-182.439	8595.68	-3098.17	315.544
≥ 8	150745	-156607	88691.5	-193.941	8908.73	-2947.64	142.072
≥ 9	162915	-182667	109134	-198.37	8999.11	-2531	-93.4908
≥ 10	174000	-208668	131543	-210.777	9365.52	-2511.74	-445.876
≥ 11	181524	-224252	145280	-212.407	9489.67	-2387.49	-544.123
≥ 12	188946	-240952	160787	-210.65	9478.1	-2029.94	-652.339
≥ 13	193762	-250900	171363	-215.798	9742.31	-2179.24	-608.636
≥ 14	203288	-275191	196115	-218.113	9992.5	-2437.71	-1065.92
≥ 15	208108	-284395	205221	-213.956	9857.25	-1970.65	-1082.94
≥ 16	215093	-301828	224757	-209.736	9789.58	-1718.37	-1303.35
≥ 17	220056	-310906	234180	-201.494	9541.73	-1230.42	-1284.15
≥ 18	224545	-320969	247724	-206.807	9892.97	-1790.61	-1381.9
≥ 19	226901	-322168	250395	-204.073	9902.14	-1748.78	-1253.22
≥ 20	235561	-345414	276856	-198.306	9720.78	-1284.14	-1569.18

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 9x9G**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	35158.5	26918.5	-17976.7	-149.915	6787.19	-2154.29	836.894
≥ 4	77137.2	-19760.1	2371.28	-130.934	8015.43	-3512.38	-455.424
≥ 5	113405	-77931.2	35511.2	-150.637	8932.55	-4099.48	-629.806
≥ 6	139938	-128700	68698.3	-173.799	9451.22	-3847.83	-455.905
≥ 7	164267	-183309	109526	-193.952	9737.91	-3046.84	-737.992
≥ 8	182646	-227630	146275	-210.936	10092.3	-2489.3	-1066.96
≥ 9	199309	-270496	184230	-218.617	10124.3	-1453.81	-1381.41
≥ 10	213186	-308612	221699	-235.828	10703.2	-1483.31	-1821.73
≥ 11	225587	-342892	256242	-236.112	10658.5	-612.076	-2134.65
≥ 12	235725	-370471	285195	-234.378	10604.9	118.591	-2417.89
≥ 13	247043	-404028	323049	-245.79	11158.2	-281.813	-2869.82
≥ 14	253649	-421134	342682	-243.142	11082.3	400.019	-2903.88
≥ 15	262750	-448593	376340	-245.435	11241.2	581.355	-3125.07
≥ 16	270816	-470846	402249	-236.294	10845.4	1791.46	-3293.07
≥ 17	279840	-500272	441964	-241.324	11222.6	1455.84	-3528.25
≥ 18	284533	-511287	458538	-240.905	11367.2	1459.68	-3520.94
≥ 19	295787	-545885	501824	-235.685	11188.2	2082.21	-3954.2
≥ 20	300209	-556936	519174	-229.539	10956	2942.09	-3872.87

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 10x10A/B**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	29285.4	27562.2	-16985	-148.415	5960.56	-1810.79	1001.45
≥ 4	67844.9	-14383	395.619	-127.723	6754.56	-2547.96	-369.267
≥ 5	96660.5	-55383.8	21180.4	-137.17	7296.6	-2793.58	-192.85
≥ 6	118098	-91995	42958	-162.985	7931.44	-2940.84	60.9197
≥ 7	135115	-123721	63588.9	-171.747	8060.23	-2485.59	73.6219
≥ 8	148721	-151690	84143.9	-190.26	8515.81	-2444.25	-63.4649
≥ 9	160770	-177397	104069	-197.534	8673.6	-2101.25	-331.046
≥ 10	170331	-198419	121817	-213.692	9178.33	-2351.54	-472.844
≥ 11	179130	-217799	138652	-209.75	9095.43	-1842.88	-705.254
≥ 12	186070	-232389	151792	-208.946	9104.52	-1565.11	-822.73
≥ 13	192407	-246005	164928	-209.696	9234.7	-1541.54	-979.245
≥ 14	200493	-265596	183851	-207.639	9159.83	-1095.72	-1240.61
≥ 15	205594	-276161	195760	-213.491	9564.23	-1672.22	-1333.64
≥ 16	209386	-282942	204110	-209.322	9515.83	-1506.86	-1286.82
≥ 17	214972	-295149	217095	-202.445	9292.34	-893.6	-1364.97
≥ 18	219312	-302748	225826	-198.667	9272.27	-878.536	-1379.58
≥ 19	223481	-310663	235908	-194.825	9252.9	-785.066	-1379.62
≥ 20	227628	-319115	247597	-199.194	9509.02	-1135.23	-1386.19

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time **(years)**	**Array/Class 10x10C**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	31425.3	27358.9	-17413.3	-152.096	6367.53	-1967.91	925.763
≥ 4	71804	-16964.1	1000.4	-129.299	7227.18	-2806.44	-416.92
≥ 5	102685	-62383.3	24971.2	-142.316	7961	-3290.98	-354.784
≥ 6	126962	-105802	51444.6	-164.283	8421.44	-3104.21	-186.615
≥ 7	146284	-145608	79275.5	-188.967	8927.23	-2859.08	-251.163
≥ 8	162748	-181259	105859	-199.122	9052.91	-2206.31	-554.124
≥ 9	176612	-214183	133261	-217.56	9492.17	-1999.28	-860.669
≥ 10	187756	-239944	155315	-219.56	9532.45	-1470.9	-1113.42
≥ 11	196580	-260941	174536	-222.457	9591.64	-944.473	-1225.79
≥ 12	208017	-291492	204805	-233.488	10058.3	-1217.01	-1749.84
≥ 13	214920	-307772	221158	-234.747	10137.1	-897.23	-1868.04
≥ 14	222562	-326471	240234	-228.569	9929.34	-183.47	-2016.12
≥ 15	228844	-342382	258347	-226.944	9936.76	117.061	-2106.05
≥ 16	233907	-353008	270390	-223.179	9910.72	360.39	-2105.23
≥ 17	244153	-383017	304819	-227.266	10103.2	380.393	-2633.23
≥ 18	249240	-395456	321452	-226.989	10284.1	169.947	-2623.67
≥ 19	254343	-406555	335240	-220.569	10070.5	764.689	-2640.2
≥ 20	260202	-421069	354249	-216.255	10069.9	854.497	-2732.77

structural or non-structural part, as applicable, during the transient event. These enveloping values, therefore, will bound the maximum temperature reached anywhere in the part, excluding skin effects during or immediately after, a transient event.

The off-normal/accident design temperatures for stainless steel and carbon steel components are chosen such that the material's ultimate tensile strength does not fall below 30% of its room temperature value, based on data in published references [2.2.12 and 2.2.13]. This ensures that the material will not fail due to creep rupture during these short duration transient events.

2.2.2.4 Leakage of One Seal

The MPC enclosure vessel is designed to have no credible leakage under all normal, off-normal, and hypothetical accident conditions of storage.

The confinement boundary is defined by the MPC shell, baseplate, MPC lid, port cover plates, closure ring, and associated welds. *MPC shell welds and shell to baseplate weld are subject to helium leakage testing.* Most confinement boundary welds are inspected by radiography or ultrasonic examination. Field welds are examined by the liquid penetrant method on the root (if more than one weld pass is required) and final weld passes. In addition to liquid penetrant examination, the MPC lid-to-shell weld is pressure tested, and volumetrically examined or multi-pass liquid penetrant examined. The vent and drain port cover plates are subject to liquid penetrant examination and helium leakage testing. These inspection and testing techniques are performed to verify the integrity of the confinement boundary.

2.2.2.5 Partial Blockage of Air Inlets

The HI-STORM 100 System must withstand the partial blockage of the overpack air inlets. This event is defined in Table 2.0.2 as 50% blockage of the four air inlets. Because the overpack air inlets and outlets are covered by screens, located 90° apart, and inspected routinely (or alternatively, exit vent air temperature monitored), significant blockage of all vents by blowing debris, animals, etc. is very unlikely. To demonstrate the inherent thermal stability of the HI-STORM 100 System all four air inlets are assumed to be 50% blocked.

2.2.2.6 Off-Normal HI-TRAC Handling

During upending and/or downending of the HI-TRAC 100 or HI-TRAC 125 transfer cask, the total lifted weight is distributed among both the upper lifting trunnions and the lower pocket trunnions. Each of the four trunnions on the HI-TRAC therefore supports approximately one-quarter of the total weight. This even distribution of the load would continue during the entire rotation operation. The HI-TRAC 100D and 125D transfer cask designs do not include pocket trunnions. Therefore, the entire load is held by the lifting trunnions.

If the lifting device cables begin to "go slack" while upending or downending the HI-TRAC 100 or HI-TRAC 125, the eccentricity of the pocket trunnions would immediately cause the cask to pivot, restoring tension on the cables. Nevertheless, the pocket trunnions are conservatively analyzed to

Table 2.2.15 (continued)

LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC Lid and Closure Ring Welds	NB-4243	Full penetration welds required for Category C Joints (flat head to main shell per NB-3352.3)	MPC lid and closure ring are not full penetration welds. They are welded independently to provide a redundant seal. Additionally, a weld efficiency factor of 0.45 has been applied to the analyses of these welds.
MPC Closure Ring, Vent and Drain Cover Plate Welds	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required.	Root (if more than one weld pass is required) and final liquid penetrant examination to be performed in accordance with NB-5245. The closure ring provides independent redundant closure for vent and drain cover plates. Vent and drain port cover plate welds are helium leakage tested.
MPC Lid to Shell Weld	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required.	Only UT or multi-layer liquid penetrant (PT) examination is permitted. If PT examination alone is used, at a minimum, it will include the root and final weld layers and each approx. 3/8" of weld depth.
MPC Enclosure Vessel and Lid	NB-6111	All completed pressure retaining systems shall be pressure tested.	The MPC vessel is seal welded in the field following fuel assembly loading. The MPC vessel shall then be pressure tested as defined in Chapter 9. Accessibility for leakage inspections precludes a Code compliant pressure test. *Since the shell welds of the MPC cannot be checked for leakage during this pressure test, the shop leakage test to 10^{-7} ref cc/sec (as described in Chapter 9) provides reasonable assurance as to its leak tightness.* All MPC vessel welds (except closure ring and vent/drain cover plate) are inspected by volumetric examination, except the MPC lid-to-shell weld shall be verified by volumetric or multi-layer PT examination. If PT alone is used, at a minimum, it must include the root and final layers and each approximately 3/8 inch of weld depth. For either UT or PT, the maximum undetectable flaw size must be determined in accordance with ASME Section XI methods. The critical flaw size shall not cause the primary stress limits of NB-3000 to be exceeded.

v. Specific Requirements for Mobile Lifting Devices and Vertical Cask Transporters:

A mobile lifting device, if used in the CTF in the role of the HI-TRAC lifter or MPC lifter is governed in part by ANSI/ASME N45.2.15 with technical requirements specified in ANSI B30.5 (1994). {2}

When lifting the MPC from an overpack to the HI-TRAC transfer cask, limit switches or load limiters shall be set to ensure that the loads are lifted in excess of 110% of the loaded MPC weight.{2,3}

An analysis of the consequences of a potential MPC vertical drop which conforms to the guidelines of Appendix A to NUREG-0612 shall be performed. The analysis shall demonstrate that a postulated drop would not result in the MPC experiencing a deceleration in excess of its design basis deceleration specified in this FSAR.{2}

vi. Lift Height Limitation: The HI-TRAC lift heights shall be governed by the Technical Specifications.{1,2,3}

vii. Control of Side Sway: Procedures shall provide provisions to ensure that the load is lifted essentially vertically with positive control of the load. Key cask lifting and transfer procedures, as determined by the user, should be reviewed by the Certificate Holder before their use. {1, 2, 3}

D. Loads and Load Combinations for the CTF Structure

The applicable loadings for the CTF have been summarized in paragraph B in the preceding. A stress analysis of the CTF structure shall be performed to demonstrate compliance with the Subsection NF stress limits for Class 3 linear structures for the service condition germane to each load combination. Table 2.3.2 provides the load combinations (the symbols in Table 2.3.2 are defined in the preceding text and in Table 2.2.13). {1}

E. Materials and Failure Modes

i. Acceptable Materials and Material Properties: All materials used in the design of the CTF shall be *ASME or* ASTM approved or equal, consistent with the ITS category of the part *(see discussion in subsection 2.1.0)*. Reinforced concrete, if used, shall comply with the provisions of ACI 318 (89). The material property and allowable stress values for all steel structures shall be taken from the ASME and B&PV Code, Section

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

2.I.0 <u>OVERVIEW OF THE PRINCIPAL DESIGN CRITERIA</u>

<u>General</u>

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.

<u>Structural</u>

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". 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, the Top Support Pad and the Retaining Wall (if required).The methodology to perform the seismic qualification of the storage system is 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.*

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

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 the 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).

<u>Thermal</u>

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.

<u>*Shielding*</u>

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. *<u>The VVM Support Foundation</u>*

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. *<u>VVM Interface Pad and Top Surface Pad</u>*

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 test station is used to ensure proper performance of the ICCPS at both the mid-point and the bottom of the CEC Shell.

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. *<u>Tornado</u>*

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. <u>*Flood*</u>

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. <u>*Earthquake*</u>

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*

~~*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). Because 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 seismic event.*~~

~~*To prevent the loss of earthen shielding from the RPS under all such eventualities, the ISFSI owner will ensure that:*~~

- ~~*A site-specific analysis of the operating ISFSI, in the most vulnerable state during the proximate construction (excavation work), shall be performed using the analysis methodology specified in the Technical Specification.*~~

- ~~*The site construction procedures will contain appropriate quality assurance measures (including Q.A. validated construction procedures and craft labor supervision training) to ensure that the RPS space will not be disturbed by worker error. The construction procedures and site safety plan will be reviewed by Holtec International. All construction work shall be in literal compliance of the approved construction procedures.*~~

~~*It is recommended that the ISFSI owner build a structurally qualified retaining wall around the RPS perimeter in those areas where a significant excavation work adjacent to the RPS is anticipated in the future. The retaining wall (or a similar barrier) shall be qualified to ensure complete prophylactic protection to the subgrade in the RPS under all potential events (including postulated earthquakes) that may act to disturb it.*~~*As shown in the licensing drawings (Section 1.5) a radiation protection* ~~*zone*~~*space (RPS) around a loaded ISFSI is specified within which any activity that may disturb the* ~~*ground*~~ *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 ~~large~~ 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 ca~~paei~~vity. 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 ~~that are credible~~ for the ISFSI ~~under the provisions of 10CFR72.212~~. 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 .*

~~*It is recommended that the*~~

To prevent the loss of subgrade shielding material in the RPS, the ISFSI owner should build a structurally qualified retaining wall around the RPS perimeter in those areas where a significant excavation work adjacent to the RPS is planned in the future. The retaining wall (or a similar barrier) shall be qualified to ensure complete prophylactic protection to the subgrade in the RPS under all potential events (including postulated earthquakes) that may act to disturb it. If built from reinforced concrete, the retaining wall shall be qualified to the strength criteria of ACI-318 (2005). If built with steel and other construction materia~~s~~ls, the retaining wall shall be designed to a recognized industry consensus standard. To insure that the performance objective of the retaining wall is met, the ISFSI owner shall designate the retaining wall as important-to safety and subject its design and construction to the following requirements:

~~*To prevent the loss of earthen shielding from the RPS under all such eventualities, the ISFSI owner will ensure that:*~~

~~*A site specific analysis of the operating ISFSI, in the most vulnerable state during the proximate construction (excavation work), shall be performed using the analysis methodology specified in the Technical Specification.*~~

~~*Define a Design Basis Earthquake for the retaining wall with due consideration of the PRA for the duration of the excavation evolution.*~~ *i. Perform a seismic analysis of the retaining wall and the adjacent substrate/pads in the -most vulnerable configuration using an appropriate finite element model .Qualify the retaining wall -to maintain structural integrity under the applicable load combinations.*

ii. *The site construction procedures will contain appropriate quality assurance measures (including Q.A. validated construction procedures and craft labor supervision training) to ensure that the RPS space will not be disturbed by worker error. The construction procedures and site safety plan will be reviewed by Holtec International. All construction work shall be in literal compliance of the Holtec approved construction procedures.*

~~*It is recommended that the ISFSI owner build a structurally qualified retaining wall around the RPS perimeter in those areas where a significant excavation work adjacent to the RPS is anticipated in the future. The retaining wall (or a similar barrier) shall be qualified to ensure complete prophylactic protection to the subgrade in the RPS under all potential events (including postulated earthquakes) that may act to disturb it.Additional protection, such as an in-ground retaining wall at the perimeter of the Radiation Protection Space, may be necessary at an ISFSI if the site-specific loads so warrant.*~~

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.I.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.I.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.I.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.I.8 Service Limits

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

2.I.9 Loads and Acceptance Criteria

Subsections 2.I.4, 2.I.5, and 2.I.6 describe the loadings for normal, off-normal, and extreme environmental phenomena and accident conditions, respectively, for the HI-STORM 100U System. Tables 2.I.1 and 2.I.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.I.4.7.

Bounding load cases that are significant to the structural performance of the VVM and require evaluation are compiled in Table 2.I.5 using information provided in Sections 2.I.4, 2.I.5, and 2.I.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.

Load Case 01: Buoyant Force

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).

Load Case 02: Dead Load plus Design Basis Explosion Pressure

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 ISFSI owner is required to carry out the analyses in accordance with the DBSM (see the Technical Specification) and ensure that the appropriate acceptance criteria are met regardless of the strength of the earthquake (i.e., no matter how ostensibly feeble the Design Basis Earthquake may be). This mandatory soil-structure interaction requirement is in contrast to the aboveground HI-STORMs where a dynamic analysis for an ISFSI site is required only if the empirical static equilibrium based limits are not satisfied.~~

The D~~The D~~esign 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.

<u>Load Case 05: Closure Lid Handling</u>

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.

<u>Load Case 06: Design Basis Fire Event</u>

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 ≤ 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)*	~~2,200,000~~ 5,114,000	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 800 ft./sec., and a Poisson's Ratio of 0.4. (see Note 1)~~The minimum stiffness is based on limiting the immediate elastic settlement at the TOF (based on the interface load listed in Table 3.I.5 and the weight of the Closure Lid per Table 3.I.1). This minimum prescribed stiffness prevents excessive Support Foundation settlement under load (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	γ	*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~~106~~	γ_s	*~~The~~ A lower average density value ~~is~~may be used in shielding analysis in Supplement 5.I for conservatism.~~; use of a greater value will enhance shielding even further. The maximum value, used in the reference seismic analysis, is given in Table 2.I.4~~*
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. ~~*This stiffness value is equivalent to a homogeneous substrate (with homogeneous best estimate properties corresponding to a shear wave speed of 500-800 ft./sec.) subject to vertical loading from a rigid punch having the diameter equal to that of the CEC bottom plate.*~~

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.* ~~*These conditions may be, but are not required to be, invoked.*~~
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 ~~e~~are derived from ~~a~~ 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*	*Buoyant Force From CEC Displaced Volume*	*125*	*The minimum weight of the anti-buoyancy cover is 16,000lb.*
		• CEC Bottom Plate	*< 8 psi*	*125*	*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*	*2.I.1; 3.I.1*	*125*	*Primary stresses do not exceed applicable Level A stress limits of ASME Subsection NF (or Level D limits with explosion)*
		• Closure Lid	*2.I.1*	*350*	
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*	~~*Primary circumferential stresses do not exceed yield strength.*~~ *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 ~~Z~~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~~bounded by the 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 PROXIMATE STRUCTURE

	Interfacing SSC	*Reference Design Data*
1.	*Support Foundation*	*~~24~~30" thick reinforced concrete pad founded on subgrade.* *~~Final Thickness and Reinforcement is Site Specific.~~* *Concrete density = 145 lb/~~cubic feet~~ft³* *Minimum concrete compressive strength @ ≤ 28 days = 4,000 psi* *Minimum yield strength of rebar~~s~~ = 40,000 psi* *Minimum concrete cover ~~to~~on rebar~~s~~ ~~on all surfaces = 32"~~per section 7.7.1 of ACI 318 (2005)*
2.	*Subgrade Under Support Foundation*	*Minimum Shear Wave Speed = ~~5~~800 fps (see Note 1); Density from Table 2.I.4*
3~~2~~.	*Subgrade Surrounding VVMs*	*Minimum Shear Wave Speed = ~~5~~800 fps (see Note 1); Density from Table 2.I.2*
4~~3~~.	*VVM Interface Pad (See Licensing Dwg. In Section 1.I.5)*	*Reinforced Concrete Thickness per Table 2.I.2* *~~Reinforcement size and placement is Site Specific~~* *Concrete density per Table 2.I.2* *Minimum concrete compressive strength @ ≤ 28 days = 4,000 psi* *Minimum yield strength of rebar~~s~~ = 40,000 psi* *-Minimum Concrete cover on rebar per section 7.7.1 of ACI 318 (2005)~~= 3" for surfaces adjacent to subgrade; 2" adjacent to top surface.~~*
4~~5~~.	*Top Surface Pad*	*24" thick reinforced concrete pad; other parameters same as VVM Interface Pad ~~(expansion joint not modeled)~~*

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) ~~shall be greater than or equal to 5800 ft./sec~~is specified above. ~~This same minimum value of shear wave speed shall also apply to the substrate surrounding the VVM (averaged over a distance of 5 CEC shell diameters).~~ Should these conditions not be satisfied, then substrate remediation ~~must occur~~ is required~~ to achieve this minimum,~~ prior to installation of the HI-STORM 100U facility.~~ Design analysis shall be carried out with this minimum best estimate value, unless the actual value after remediation is known and validated.~~ The

remediation may consist of installing pilings, concrete columns, engineered fill, etc..., to ensure that the stiffness of the foundation meets the minimum specified value in the Technical Specification. 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)		Special Surface Finish/ Coating (note 1)	Interfacing Matl. (if dissimilar)
					Normal Storage (Long-Term Limit)	Off-normal, extreme environmental phenomena, and accident conditions		
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)	C	Reinforced Concrete Per ACI-318 (2005)	150	350	N/A	Steel
12	Shielding and Physical Protection	Top Surface Pad (TCSP)	C	Reinforced Concrete Per ACI-318 (2005)	150	350	N/A	—
13	Shielding and Physical Protection	Substrate Below VIP and TSP	C	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 δ_{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.*

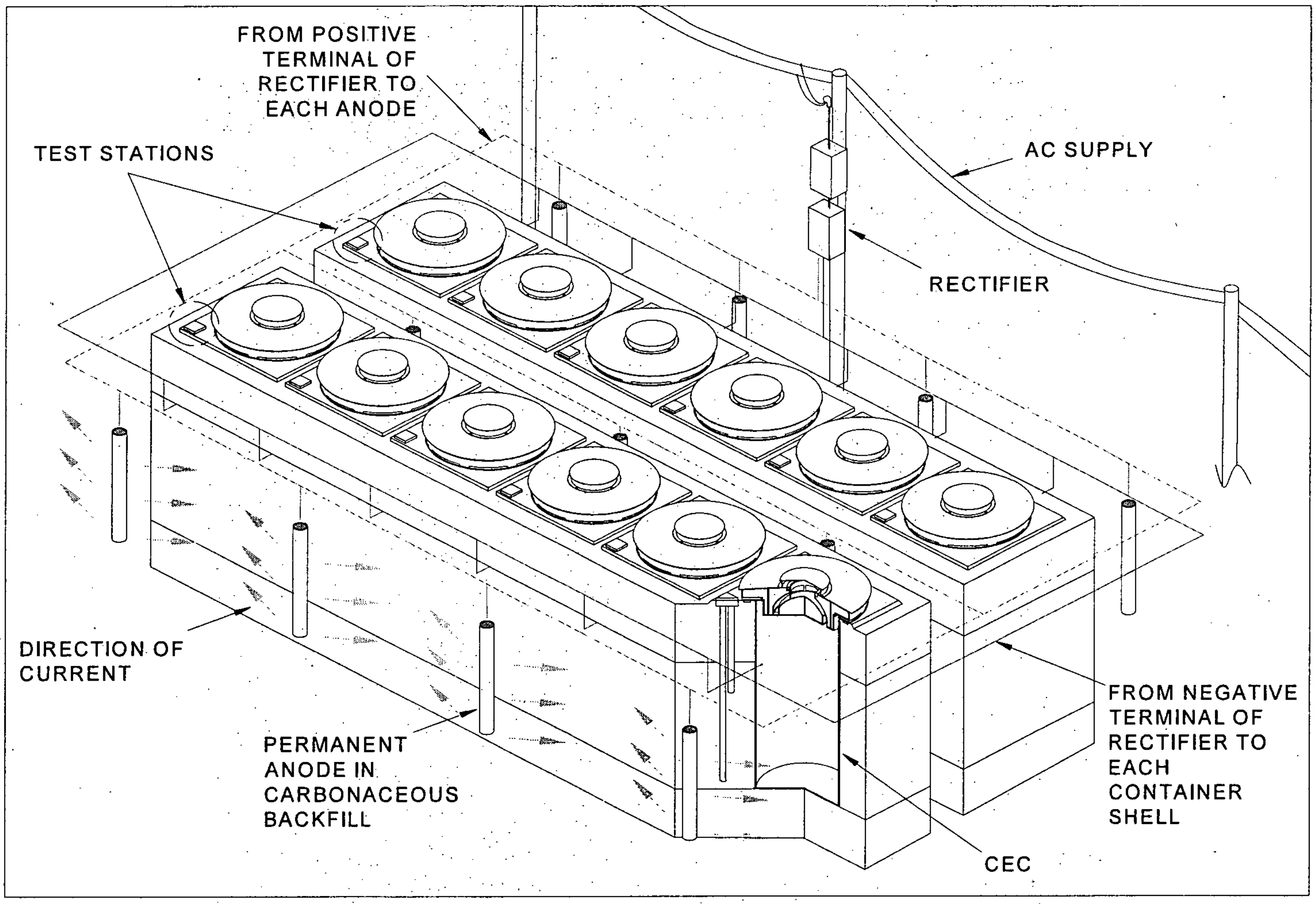


FIGURE 2.I.1: HI-STORM 100U SYSTEM EXAMPLE ICCPS DESIGN – 2 X 6 ARRAY DESIGN LAYOUT*

* 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 Support Pad are not shown in this figure.

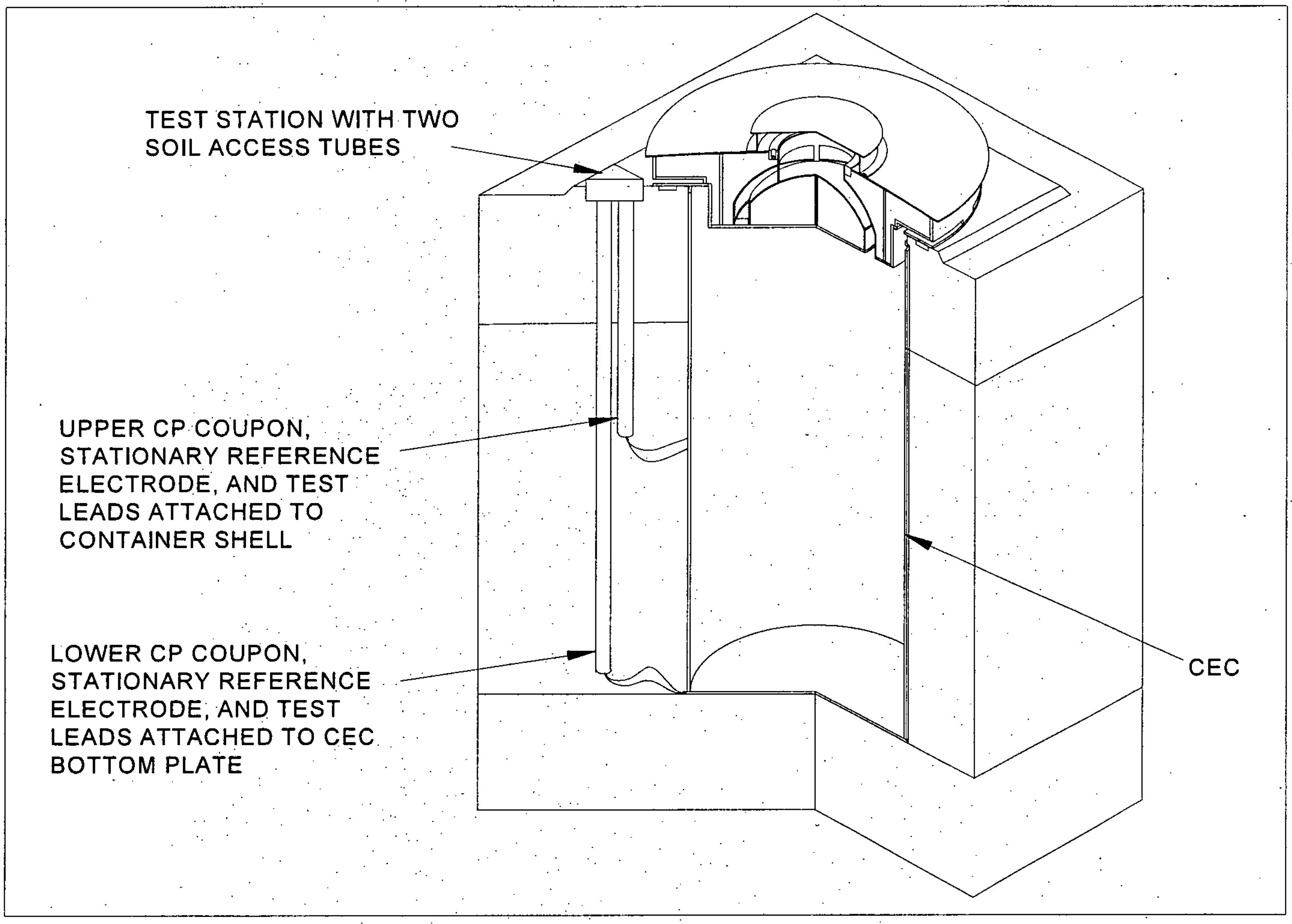


FIGURE 2.I.2: HI-STORM 100U SYSTEM EXAMPLE ICCPS DESIGN – TEST STATION*

*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 Support Pad are omitted from this figure.

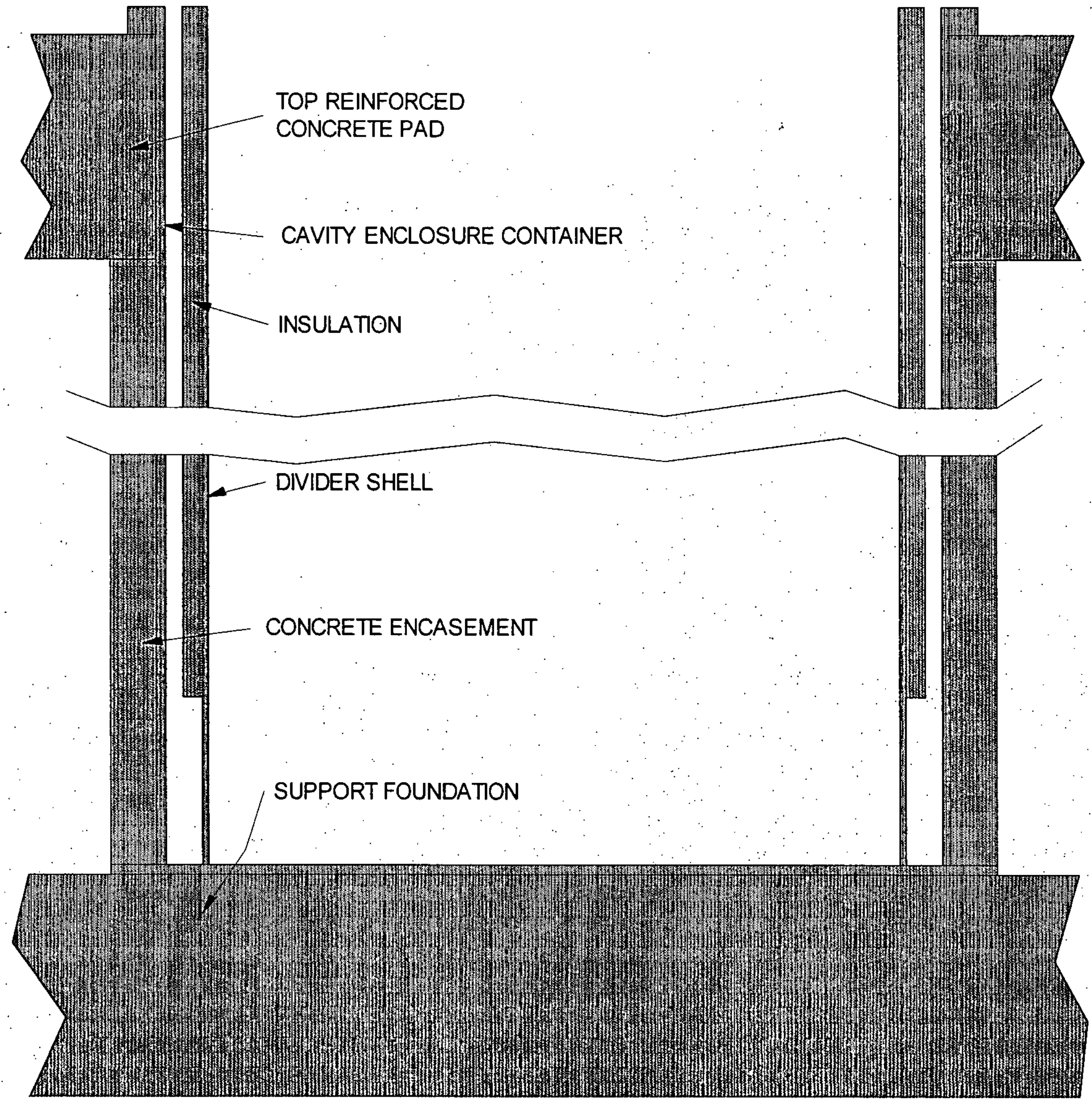


FIGURE 2.I.3: TYPICAL CONCRETE ENCASEMENT OF THE CEC

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.

A~~s can be ascertained from Table 2.I.7, a~~ll 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 site 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. *<u>Impressed Current Cathodic Protection System (ICCPS)</u>*

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 α *x L x 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), ~~normal conditions,~~ the average normal pressure, Ps, at the transporter track/Top Surface Pad interface computes to 38.71 psi. ~~to less than 40 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.~~1~~22)~~($AIS)~~ is prepared. ~~:-T~~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 ~~I~~interface P~~pad~~ (VIP), which is separated from the Top Surface Pad (TSP) by a construction joint~~—and~~, ~~therefore,~~ is unaffected by the movement (under load) of the TSP. ~~Similarly, the TSP and the CEC should not gain additional strength from the presence of the VIP~~The VIP- essentially serves as a deadweight on the soil column below, which should be appropriately incorporated in the model.~~,~~ To appropriately model ~~this~~ the VIP- within the confines of a linearly elastic construct, ~~the VIP~~ it is ~~replaced~~ 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. ~~pressure loading on the soil.~~*
- *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 ~~maximum material loss from~~postulated corrosion ~~be corroded to the maximum extent specified in this FSAR~~ 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~~is~~ pictorially shown in Figure 3.I.~~$~~12 where stress intensity is plotted for convenience~~3~~. 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 L~~l~~evel A membrane stress limit (per Table 2.I.5), leads to the~~a~~ 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~~se~~ 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.~~, if any of the input parameters in Table 3.I.10 exceeds the value used in the reference analysis that may increase the computed stress level.~~

~~Assuming an 18" thick Top Surface Pad (conservatively set less than the minimum value in the Dwg. For this calculation) and a conservative spread angle of 30 degrees through the concrete pad, the normal pressure at the Pad/Substrate interface computes to:~~

~~Ps= < 23 psi~~

~~For certain substrates, this normal pressure may create a lateral pressure on the CEC Container Shell that is maximum near the top of the Container Shell, decreases with depth below grade, and obviously, cannot exceed Ps.~~

~~The overburden (weight) of the substrate also develops a lateral pressure on the CEC Container Shell that is proportional to substrate weight density times CEC height. This overburden pressure is maximum near the base of the CEC. Using the maximum substrate dry density surrounding the VVM (Table 2.I.4) and assuming a height of 21' from CEC base to TOG for this computation, the magnitude of the lateral pressure at the base is of:~~

~~Pob = γH = 17.5 psi~~

~~An appropriate simulation model to evaluate the effects of both of these concurrent pressures on the CEC would be a full-height model of the CEC plus the surrounding substrate (similar to what is employed later to examine seismic loads). The loading would be the normal pressure from the loaded transporter plus a gravity load on the substrate and would include a coefficient of friction between the CEC and the substrate. Rather than examine a 3-D simulation to demonstrate that there is no structural issue from the transporter loading, a simple, yet conservative approach is reported here. From the pressure estimate calculated above for the transporter normal pressure, the lateral pressure exerted by the substrate on the CEC Container Shell cylindrical surface should be bounded by that value calculated since the lateral pressure primarily arises from a Poisson's Ratio effect. To examine the effect of this induced lateral pressure using a simplified bounding analysis, a 2-D finite element model is developed (rather than a 3-D model) and the relation between applied substrate lateral pressure and circumferential stress and displacement in a unit length of Container Shell is determined. The substrate is assumed to have representative properties and is considered as elastic. The Container Shell thickness is conservatively assumed fully corroded. A contact surface is~~

~~modeled between the substrate and the Container Shell to permit separation to occur if the solution so indicates. The substrate has a Young's Modulus of 20 ksi and a Poisson's Ratio of 0.4. Figure 3.I.2 shows the one-quarter model with appropriate boundary conditions. Note that the substrate boundary where a uniform lateral pressure is applied (the right-hand edge of the substrate in Figure 3.I.2) is set at one-inch beyond the Container Shell outer surface to conservatively simulate the condition at the top of the shell where the vertical load from the transporter track (at the Top Surface Pad/substrate interface) is likely to have spread out but will be no closer than 3".~~

~~The stress and deformation results in the table below, based on a bounding input pressure value, show large safety factors in spite of the overly conservative modeling assumptions (listed below) made to simplify the analysis.~~

- ~~The 2-D analysis conservatively neglects the lateral support provided by the encircling Top Pad and the Container Shell flange ring and any support from the CEC shell below the loaded region near the top of the CEC.~~
- ~~The model conservatively assumes a free boundary on the substrate edge perpendicular to the surface where a uniform lateral pressure is applied.~~

~~In a site-specific analysis, a 3-D finite element model with the pressure data applicable to the ISFSI, may be used in lieu of the 2-D analysis model utilized herein.~~

~~Evaluation of CEC Outer Shell for Effects of Substrate Lateral Pressure (Load Case 07 in Table 2.I.5)~~

~~Item~~	~~Bounding Value (psi)~~	~~Allowable Value (ksi)~~	~~Safety Factor~~
~~Primary Membrane + Bending Circumferential Stress in Container Shell~~	~~< 27,500~~	~~37,150~~	~~> 1.35~~
~~Maximum Inward Elastic Deflection of the Container Shell (inch)~~	~~< 1.1~~	~~2.5*~~	~~> 2.27~~
~~* This is the gap available between the insulation and the inner surface of the Containment Shell.~~			

~~At the base of the CEC, the effect of the substrate is to apply an all-around radial pressure on the shell. The Container Shell is welded to the CEC Bottom Plate, which resists this applied pressure; however, conservatively neglecting this support, the Container Shell develops a circumferential membrane stress of less than 1150 psi (acting as a ring under the action of an all-around 23 psi radial pressure applied to a fully corroded ring segment of the Container Shell).~~

~~From the results of the calculations, it is evident that movement of the loaded transporter, substrate overburden, and any combination of the two, does not cause a lateral pressure on the Container Shell sufficient to exceed the material yield strength and does not cause ovalization of the Container~~

~~*Shell to the extent that the local gap between the Container Shell and the Divider Shell insulation is closed, even for a small time period. Therefore, there is no effect on retrievability, confinement, or criticality.*~~

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)

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*

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*
** 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~~substrate. Assuming 11' of standing water above TOG imposes a surface pressure of 4.76 psi. Adding the 17.5 psi ~~substrate~~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~~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~~substrate, tipover of the VVM is not credible. The entire VVM can move laterally with the surrounding and supporting ~~substrate~~substrate. The response of the VVM to a seismic event is intimately connected with the site ~~substrate~~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~~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~~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~~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 ~~every specific~~ 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 *<u>Design Basis Seismic Analysis Model</u>~~(DBSM)~~*

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. ~~and as such, its design is not directly within the purview of this SAR.~~ The design of the Support Foundation for a particular site shall utilize the loads ~~However, the vertical and horizontal force-time response~~ at the VVM/Support Foundation interface~~,~~ obtained from the Design Basis Seismic Model (using the single VVM model for conservatism) described above~~,~~. ~~shall provide the input loads to qualify the Support Foundation design under the applicable~~ The Support Foundation Pad shall satisfy the American Concrete Institute (ACI) Code (2005 issue) strength limits.~~Therefore, the site-specific dynamic analysis shall determine the interface load (horizontal and vertical) time history responses at the interface between the single VVM and the reinforced concrete Support Foundation. The interface loads from the single VVM model shall be applied in a conservative manner to each VVM in the Support Foundation structural design model.~~ 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.~~7.4.2~~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 ~~subgrade~~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 ~~L~~local ~~S~~strains in the Confinement Boundary in the ~~I~~impact ~~R~~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 ~~s~~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- ~~an~~ very ~~extremely~~ 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~~elast-plastic~~) and those in the shell are type 16 (fully integrated~~-elast-plastic~~). 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. ~~8.~~

-To implement the above model on the representative problem~~-~~, the search for the maximum velocity in the dynamic solution yielded less than ~~\$~~26 in~~ch per~~/sec~~-~~. Applying an initial velocity of 26~~" per sec~~ in/sec ~~-~~as the -initial condition to the above model provided the strain field shown in Figure 3.I~~8~~.14. The maximum plastic (true) strain is found to be less than 0.021, which- is only a small fraction of the ~~acceptable value~~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.~~1.7.4.3.~~I.4.7.4 *Seismic Event During ISFSI Excavation*

Subject to the provisions of Paragraph 2.I.6 (~~XII~~xii),~~T~~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. ~~and unless the facility's probabilistic risk assessment analysis identitfies an earthquake to be non-credible in the period that the proximate land cavity is present, a~~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~~-modification due to construction in the model~~ 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

$$F(t) = 0.625 \text{ sec./ft} \times 184.8 \text{ ft/sec} \times 4000 \text{ lb} \times \sin(20t) = 462{,}000 \text{ lb} \times \sin(20t) \text{ for } t < 0.0785 \text{ sec.}$$
$$= 0 \text{ for } t >= 0.0785 \text{ sec.}$$

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 <u>Tornado Missile Protection during Construction</u>

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].

In addition to the above perimeter feature, a vertical~~retention~~ retaining wall between the TSP and the Foundation Pad ~~may~~ shall be erected for additional protection if an excavation activity contiguous to the radiation protection perimeter is planned in the future (such as to build another VVM array). ~~If a retention wall is considered, then t~~The Top Surface Pad (TSP) and the Support Foundation may extend to the outer edge of the RPS around the perimeter of the VVM array adjacent to planned construction~~.~~ so that the retaining wall is keyed to them.

3.I.4.9 <u>HI-STORM 100U VVM Service Life</u>

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 <u>FUEL RODS</u>

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

3.I.6 <u>SUPPLEMENTAL DATA</u>

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

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

3.I.6.2 <u>Computer Programs</u>

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.

<u>ANSYS</u>

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.I.27] and the element size used in the application follows the recommendation of the code developers.

<u>LS-DYNA</u>

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 <u>Appendices Included in Supplement 3.I</u>

None.

3.I.6.4 <u>Calculation Packages</u>

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 <u>COMPLIANCE WITH NUREG-1536</u>

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 <u>REFERENCES</u>

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 54, December~~May~~ 2008, (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

~~KEY INPUT DATA PROPERTIES USED IN CALCULATIONS~~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	~~*140 lb/cu.ft below Support Foundation*~~ *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 ~~subgrade~~substrate (pcf)	*120 (Table 3.I.4)*
Poisson's Ratio of the soil ~~subgrade~~substrate	*0.4 (Table 3.I.4)*
Compressive strength of TSP concrete~~,~~ (ksi)	*~~4,000 psi~~ (Table 3.I~~i~~.4)*
Thickness of TSP (inch)	*24~~8"~~ (Table 2.I.7)*
Poisson ratio of TSP concrete1	*0.16*
*Weight Density of Concrete VVM Interface Pad~~,~~ (~~$AIS~~ pcf)**~~er cubic feet~~*	*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.~~, range of standard concrete weight densities is 140-160 pcf.~~*

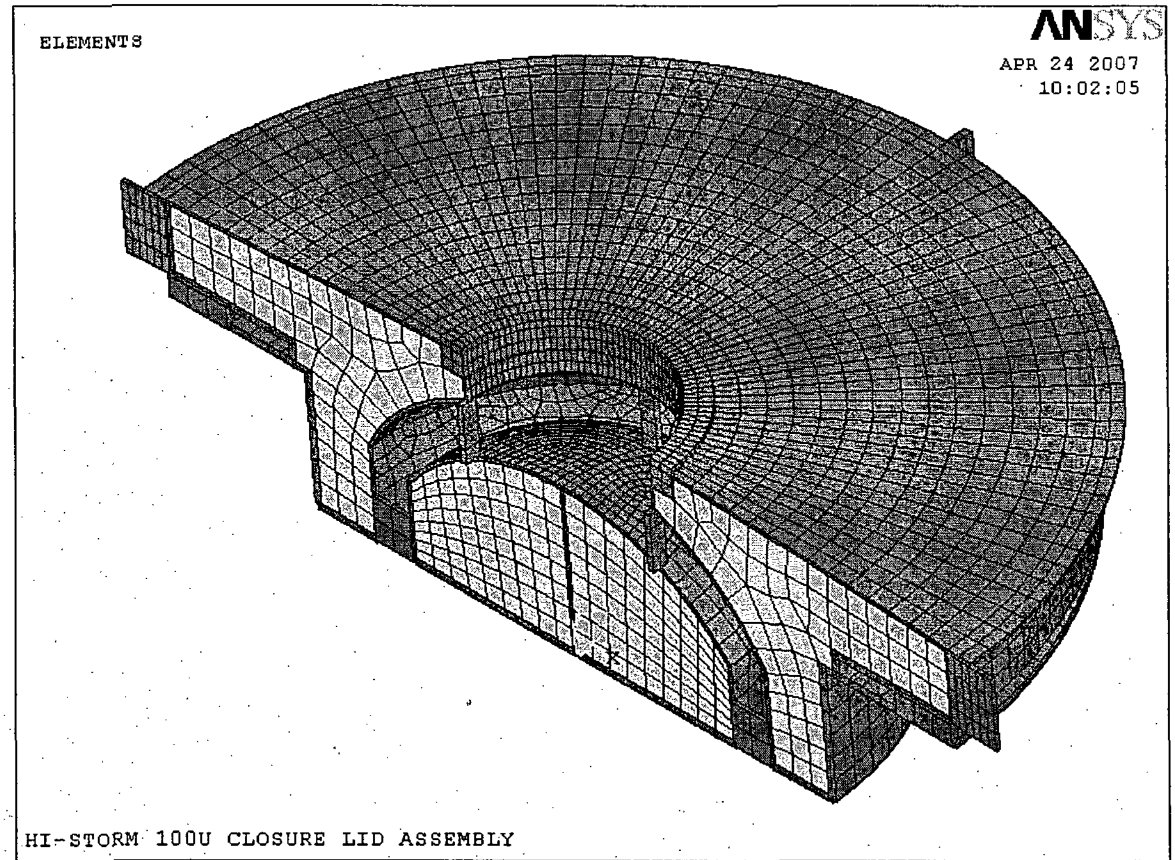


Figure 3.I.1; 3-D ANSYS/LSDYNA Finite Element Model of Closure Lid (Current Configuration)

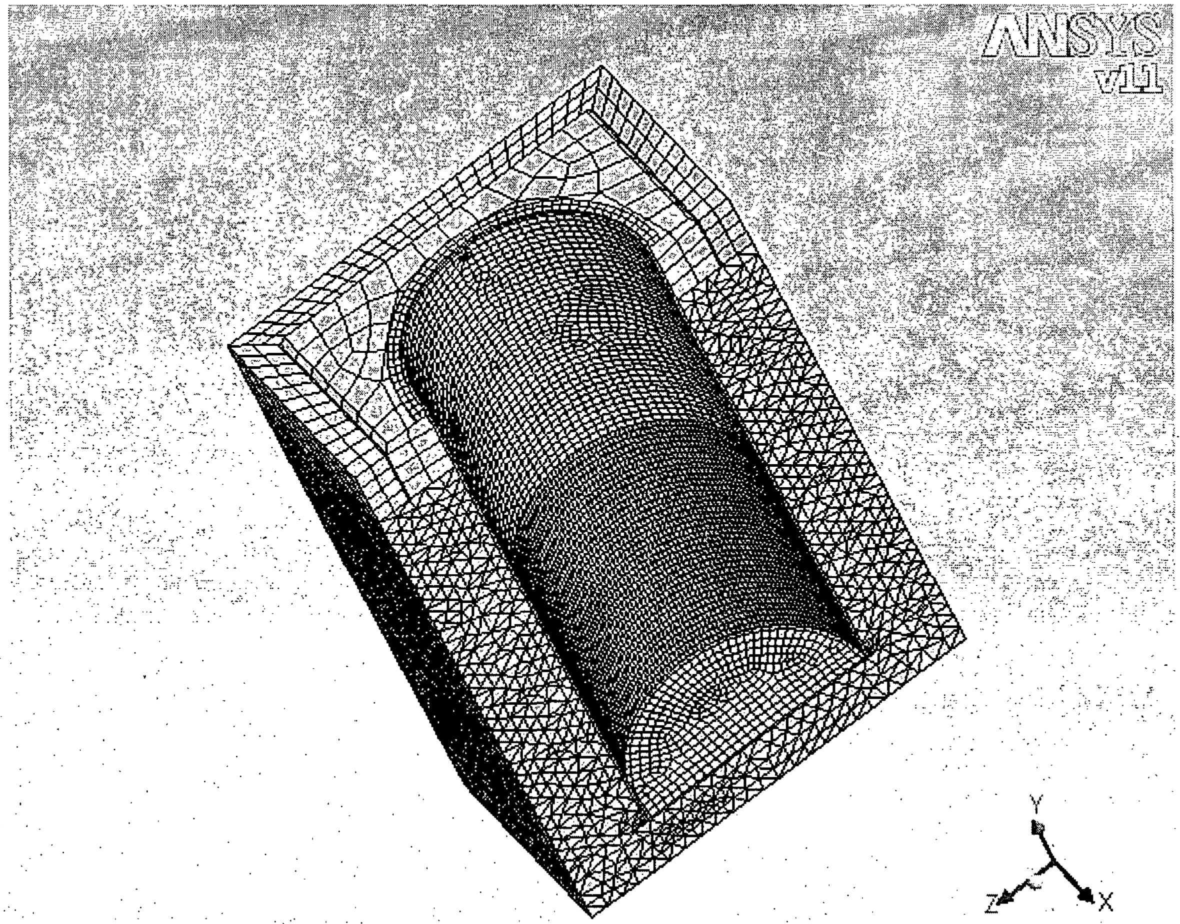
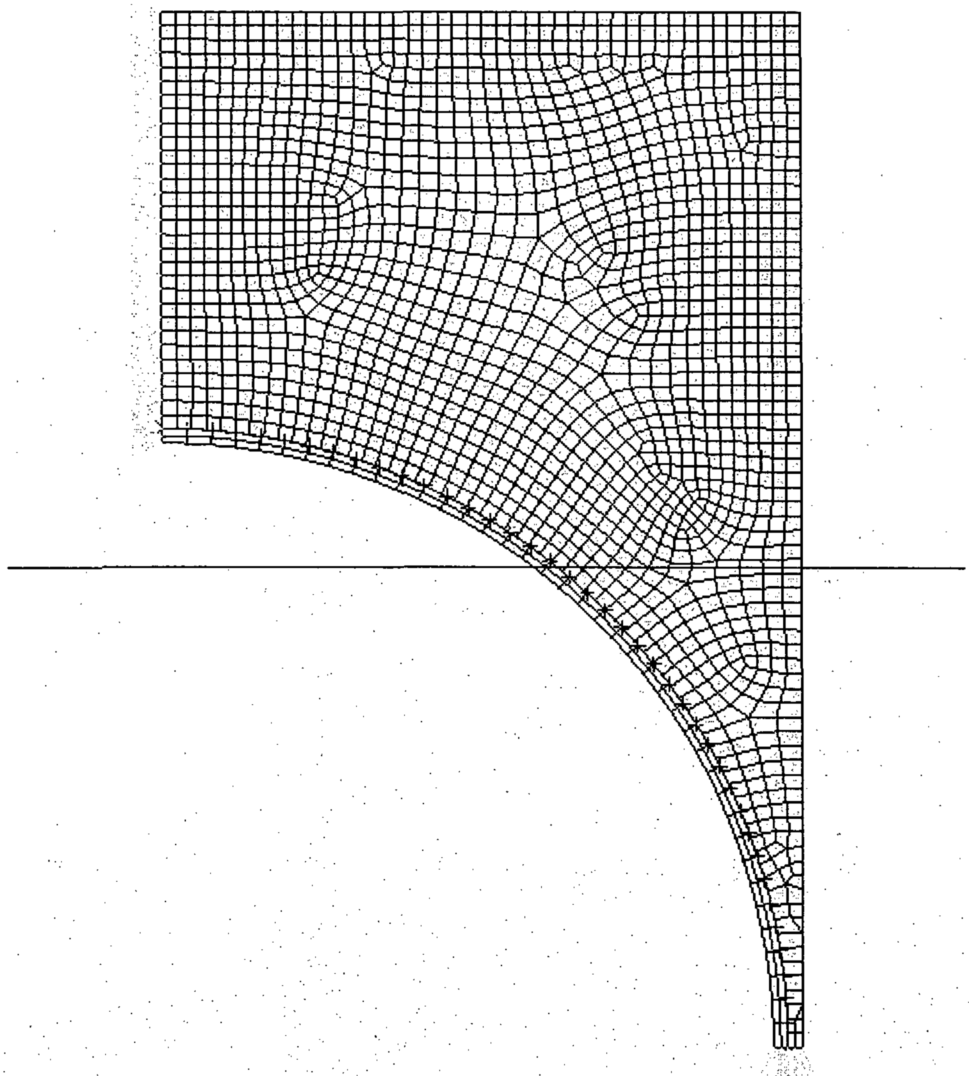


Figure 3.I.2; 3-D ANSYS Finite Element One-Half Model of Substrate Surrounding VVM, CEC Container Shell, TSP, and VIP



~~Figure 3.I.2; 2-D ANSYS Finite Element Model of Substrate and Container Shell~~

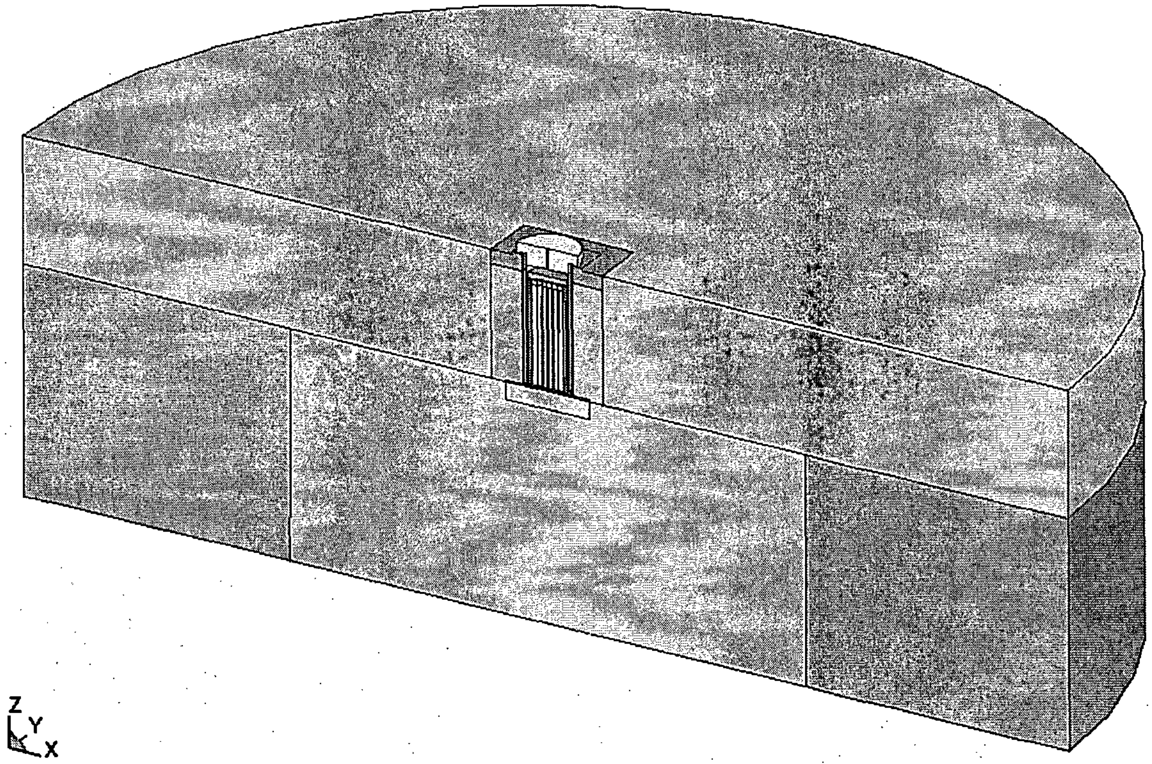


Figure 3.I.3; 3-D LSDYNA Model for Non-Linear SSI Analysis of VVM on Support Foundation Padlet

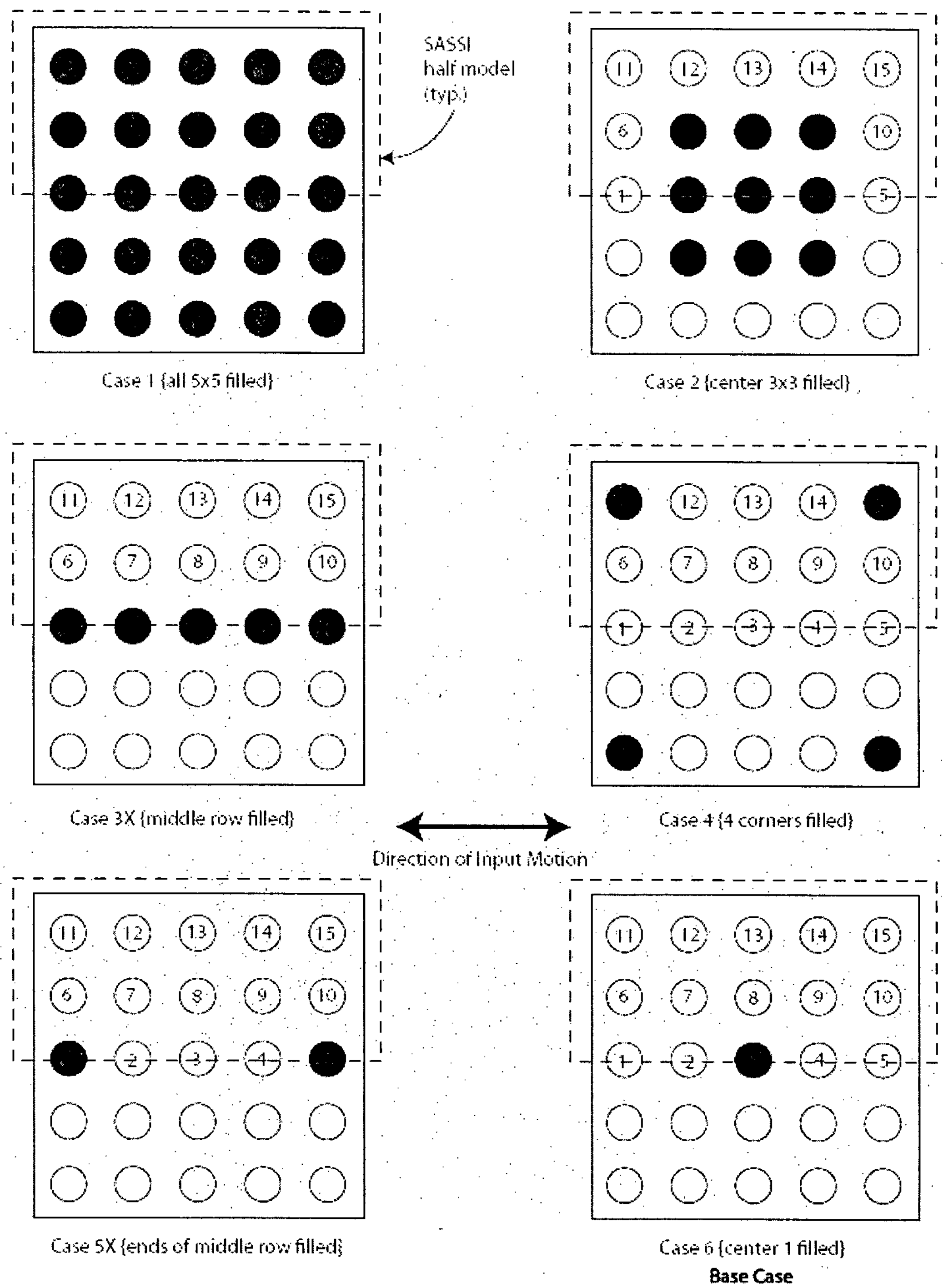


Figure 3.I.4; Location of Loaded VVMs for SASSI Linear Analyses

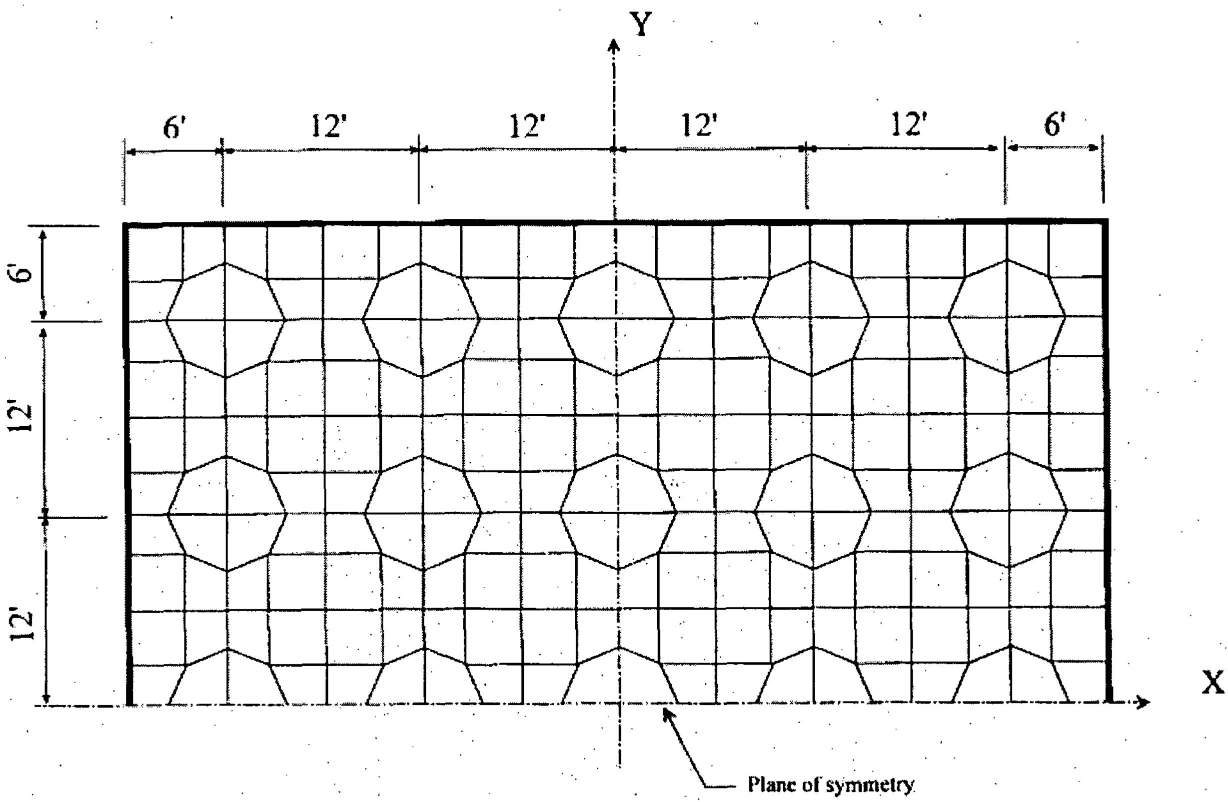


Figure 3.I.5; One-Half of 5 x 5 SASSI Finite Element Model (Looking Down)

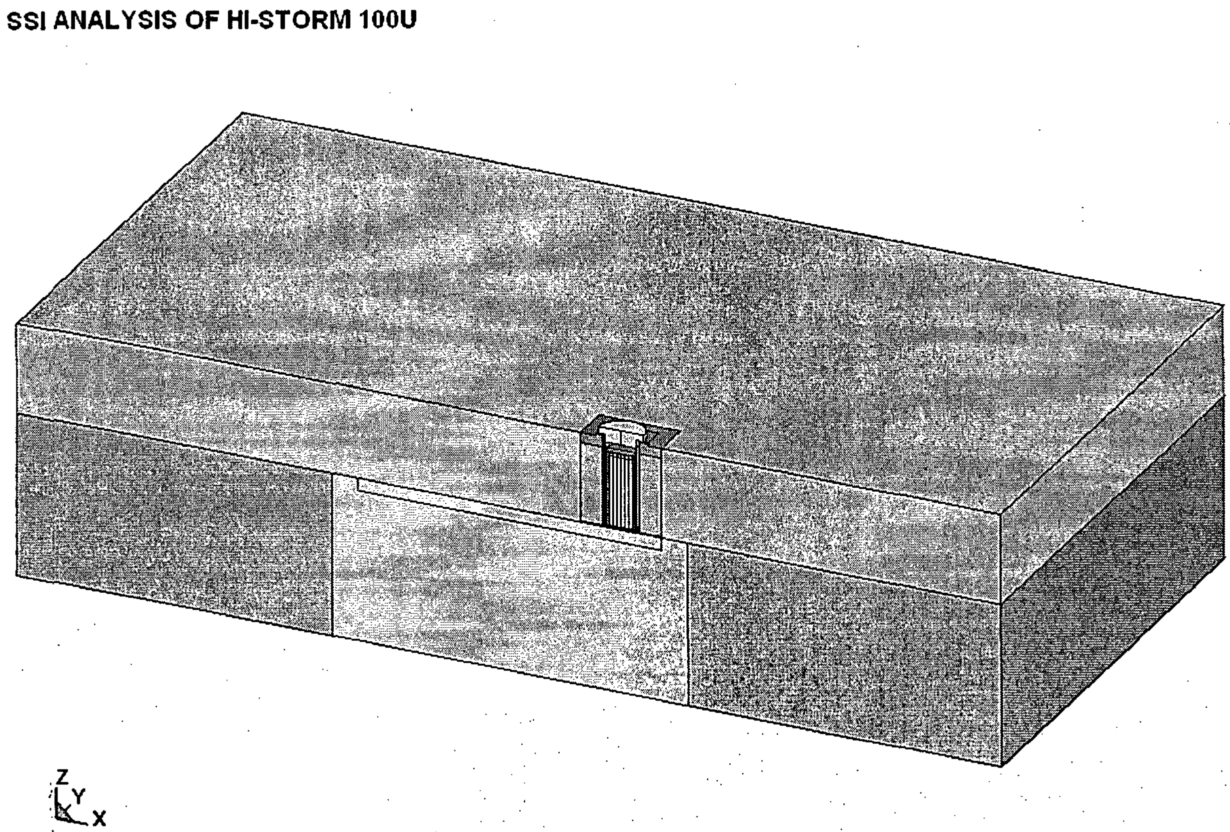


Figure 3.I.6; 3-D LSDYNA Model for Non-Linear SSI Analysis of VVM at Edge of 5x5 Support Foundation

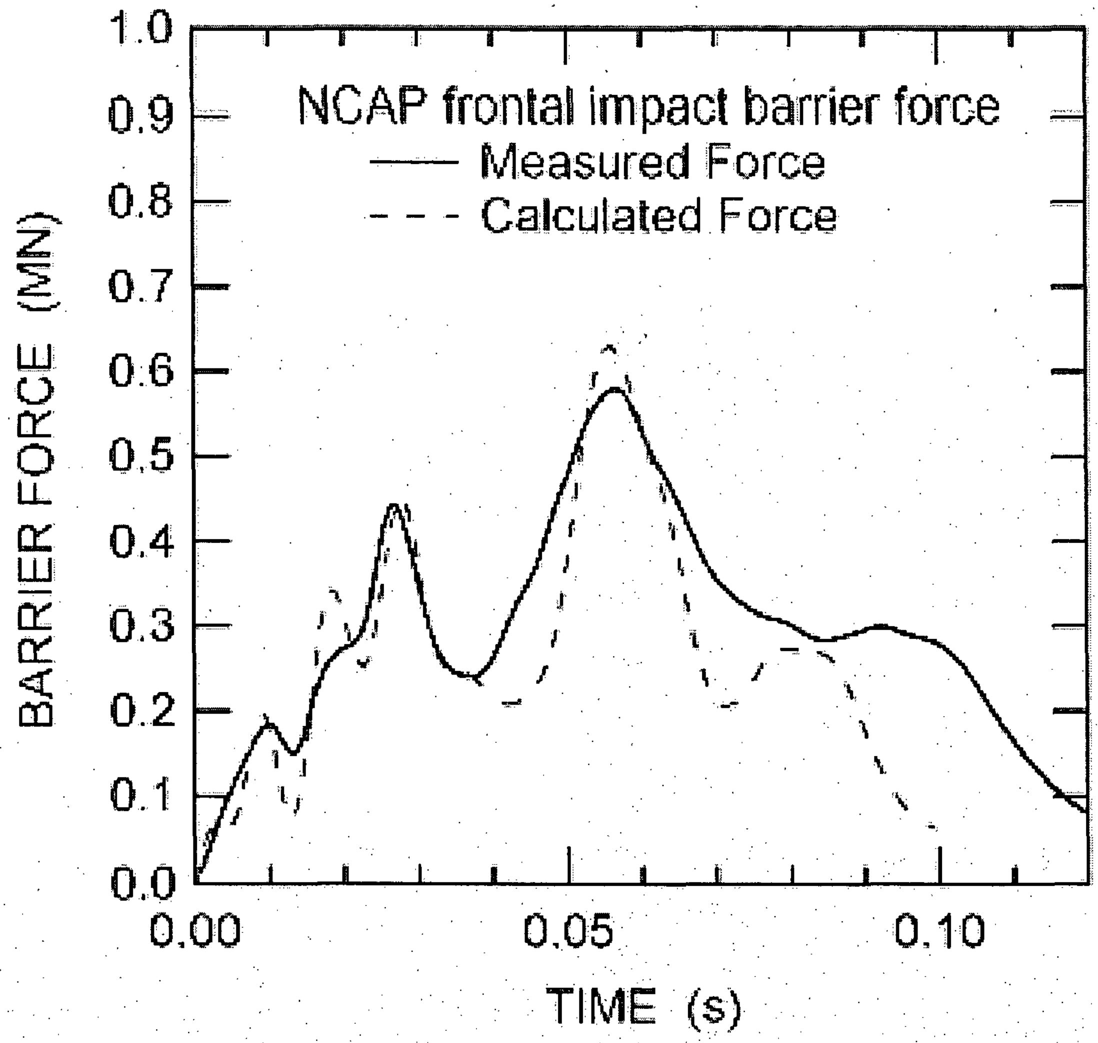


Figure 3.I.7; Test Results from 35mph Impact of a Ford (1705 Kg) Against a Rigid Wall

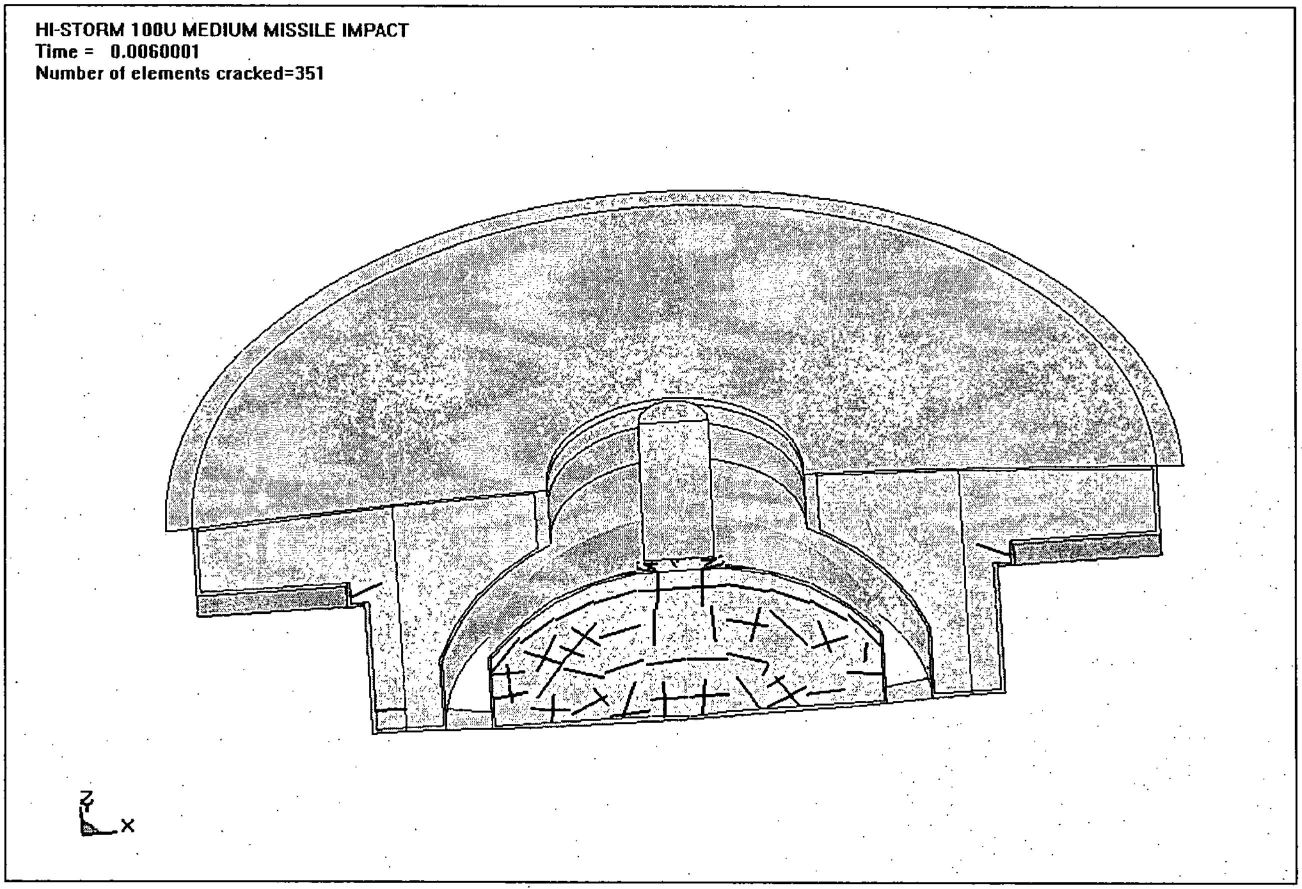


Figure 3.I.8; LSDYNA Model Section for Central Intermediate Missile Strike (subsequent to impact)

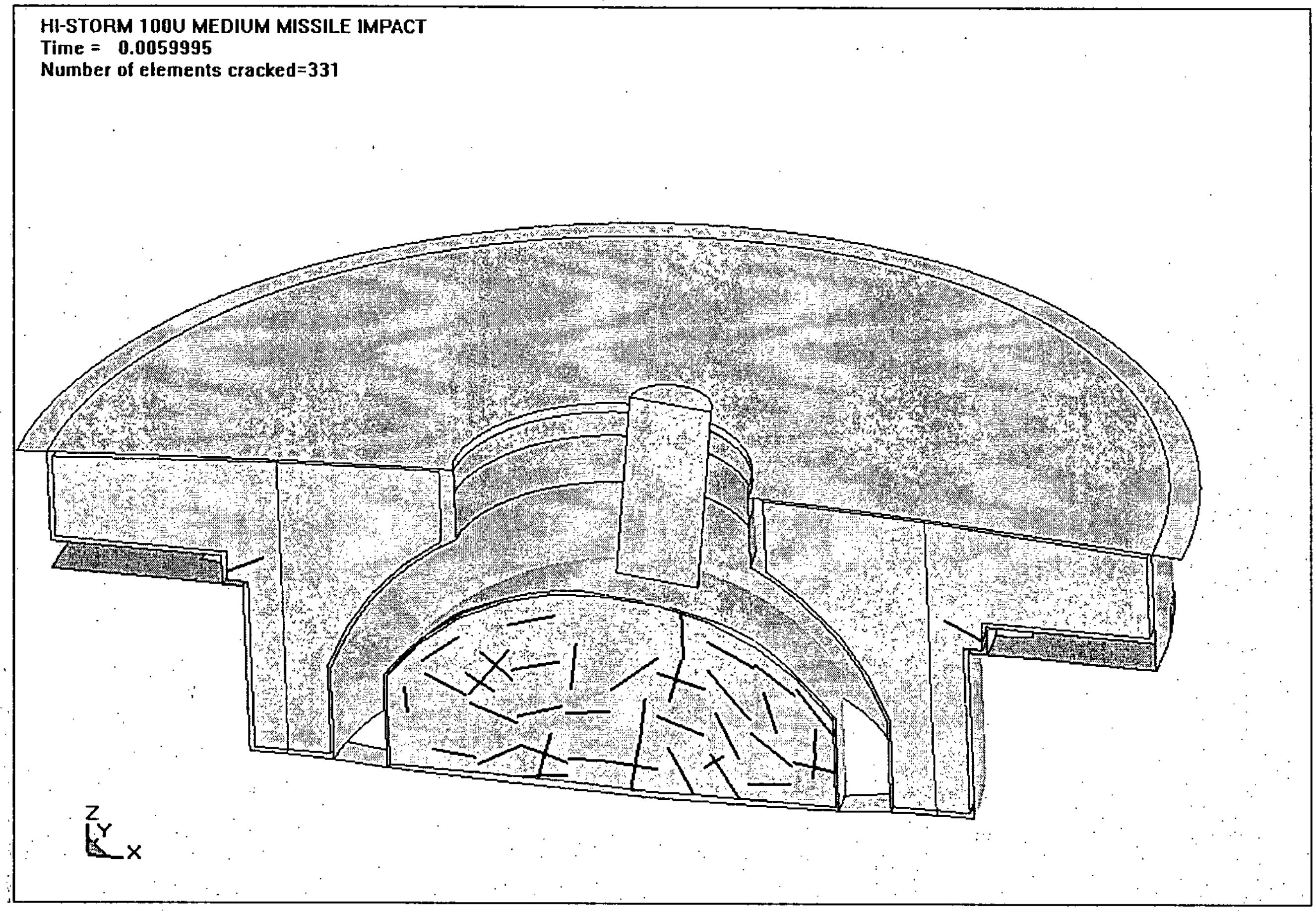


Figure 3.I.9; LSDYNA Model Section for Inclined Intermediate Missile Strike (subsequent to impact)

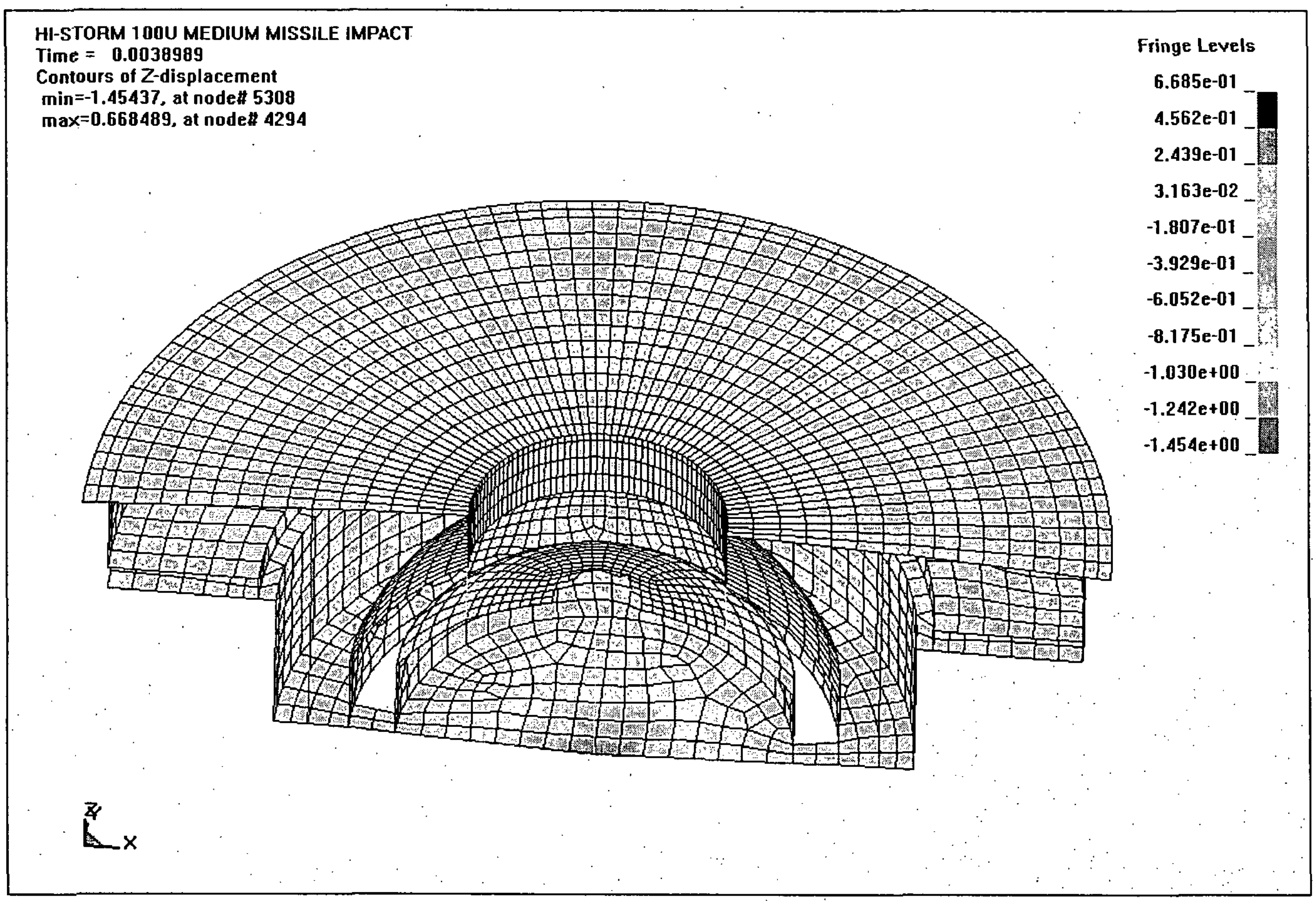


Figure 3.I.10; Deformation Profile at Time of Maximum Deformation – Central Strike

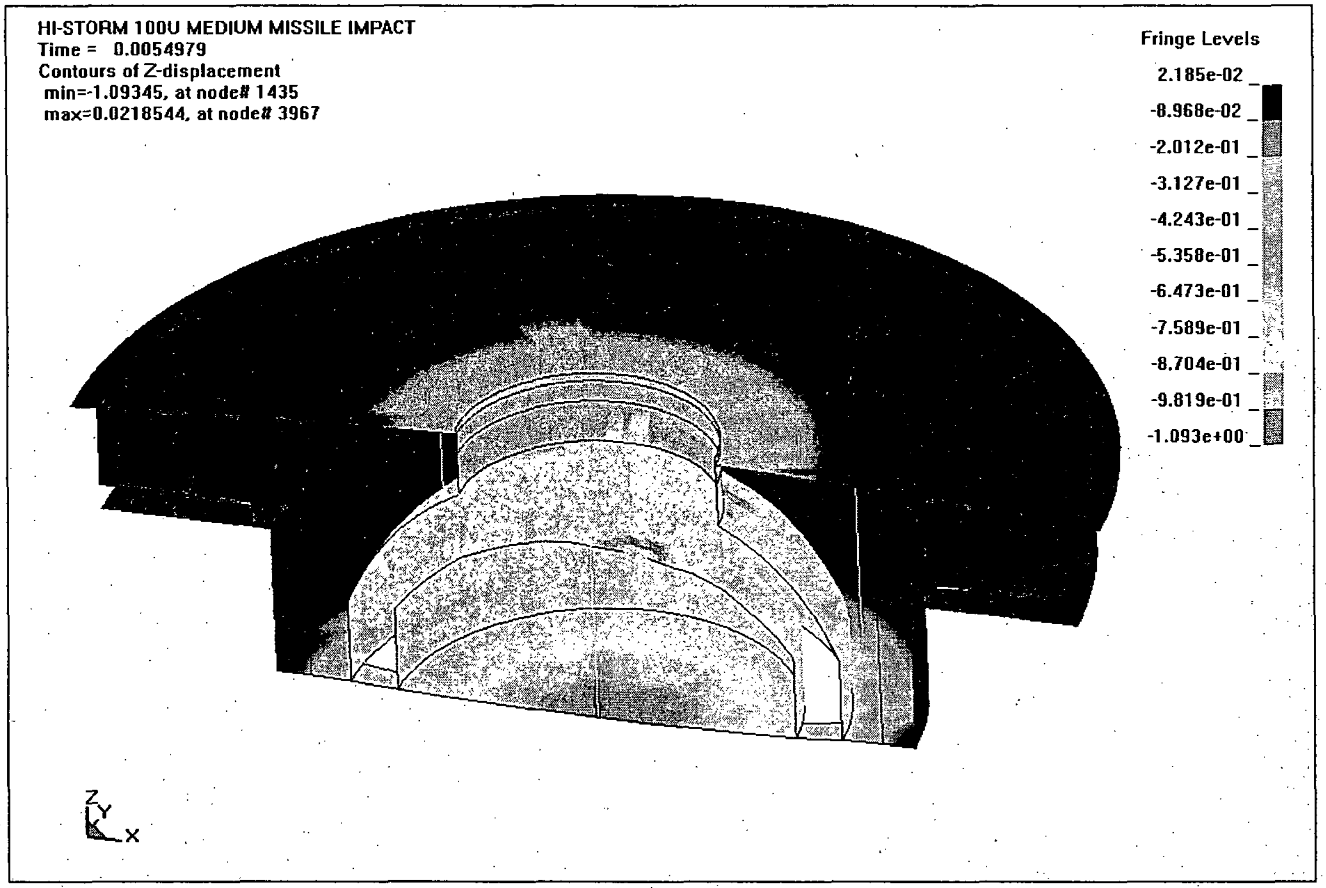


Figure 3.I.11; Deformation Profile at Time of Maximum Deformation – Inclined Strike

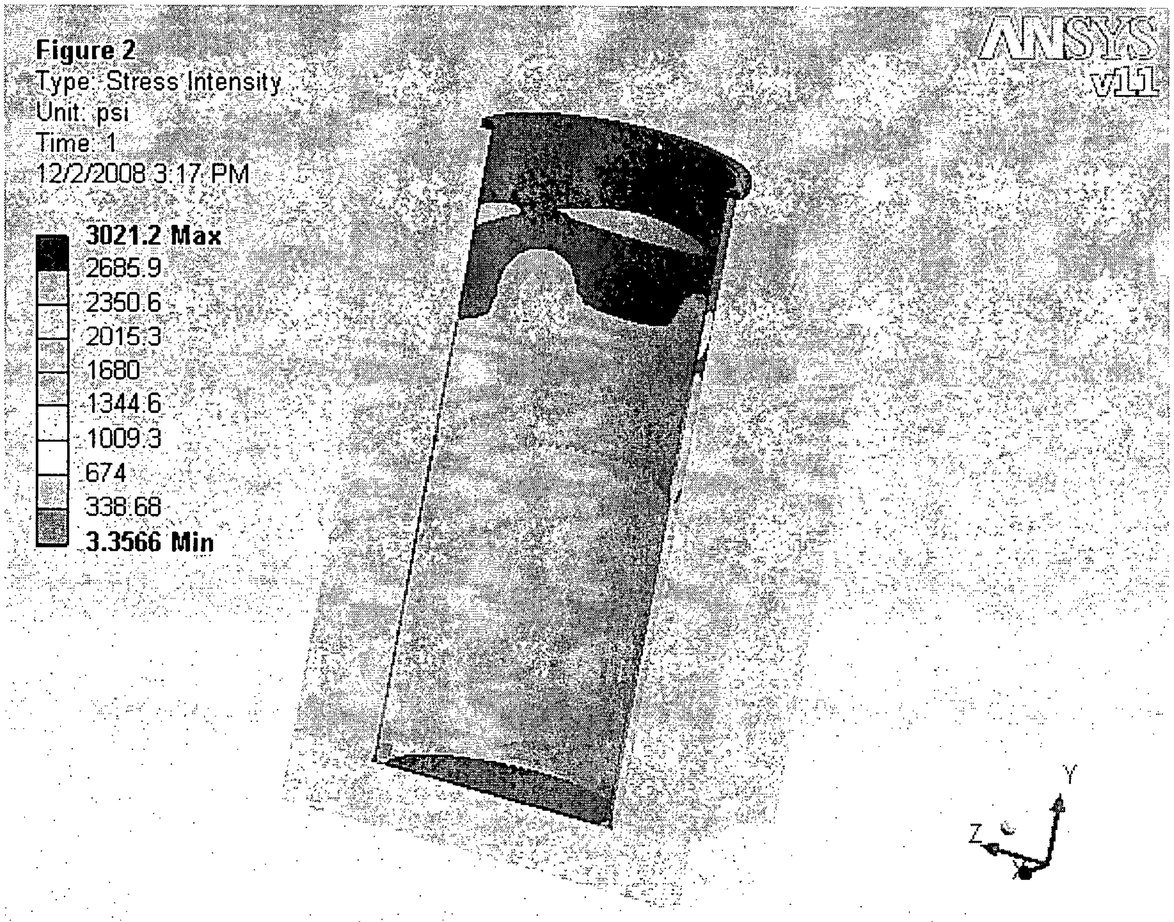


Figure 3.I.12; Stress Distribution in CEC Shell from Transporter and Substrate (Load Case 07)

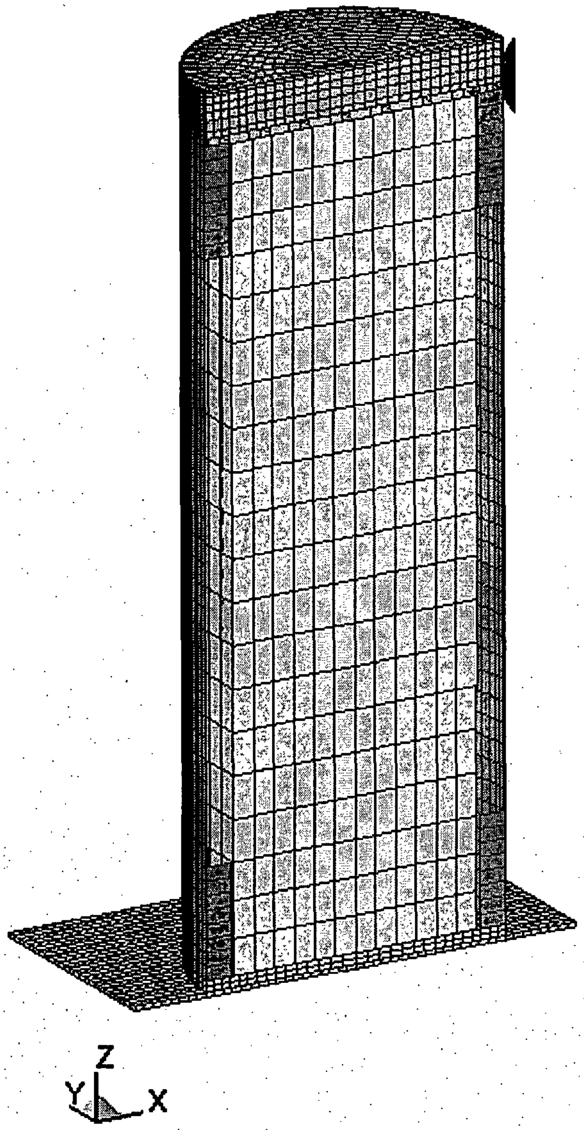


Figure 3.I.13; MPC Guide/MPC Impact LS-DYNA Model

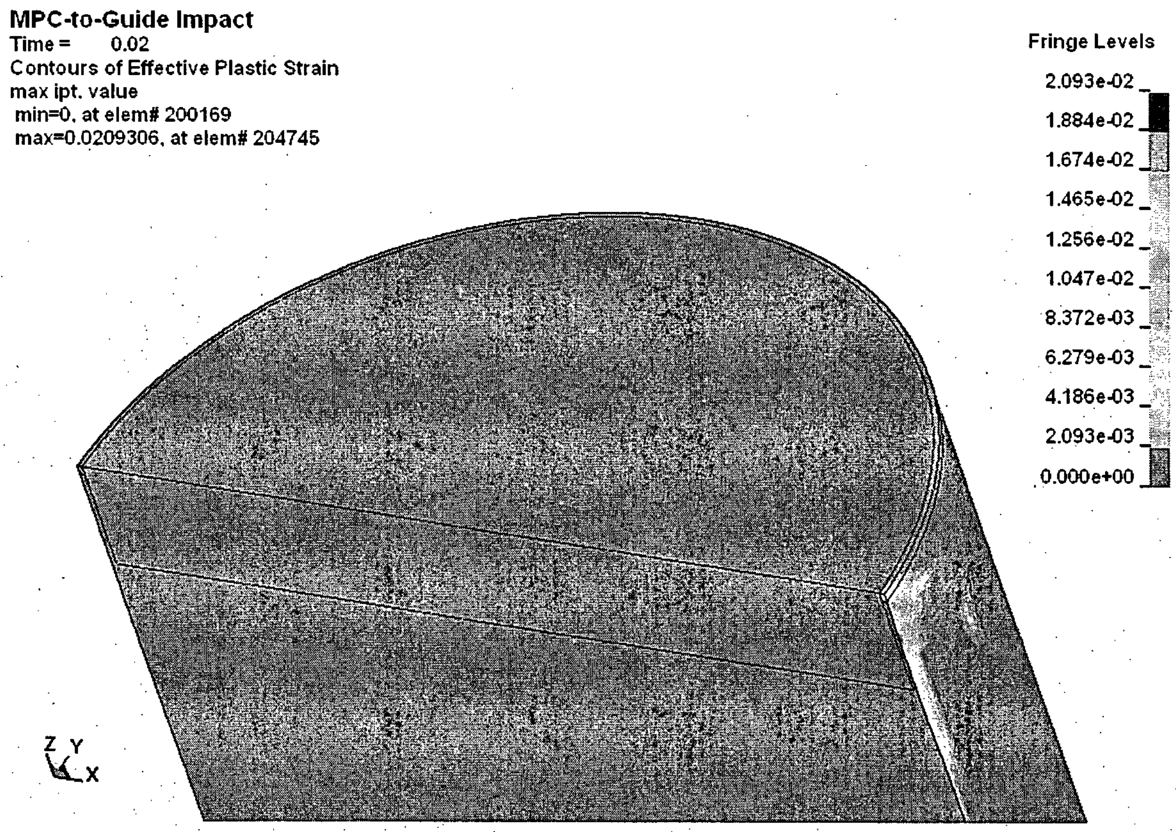


Figure 3.I.14; Maximum Plastic Strain of the MPC Enclosure Members in the Impact Region

SUPPLEMENT 5.I

SHIELDING EVALUATION OF THE HI-STORM 100U SYSTEM

5.I.0 INTRODUCTION

This supplement is focused on providing a shielding evaluation of the HI-STORM 100U system pursuant to the guidelines in NUREG-1536. The evaluation presented herein supplements those evaluations of the HI-STORM overpacks contained in the main body of Chapter 5 of this FSAR, and information in the main body of Chapter 5 that remains applicable to the HI-STORM 100U is not repeated in this supplement. To aid the reader, the sections in this supplement are numbered in the same fashion as the corresponding sections in the main body of this chapter, i.e., Sections 5.I.1 through 5.I.6 correspond to Sections 5.1 through 5.6. Tables and figures in this supplement are labeled sequentially.

5.I.1 DISCUSSION AND RESULTS

The HI-STORM 100U system differs from the HI-STORM system evaluated in the main body of this chapter only in the use of a different storage overpack, the HI-STORM 100U vertical ventilated module (VVM). All MPCs and HI-TRAC transfer casks are identical between the systems. All calculations, results and conclusions regarding the HI-TRAC transfer cask presented in the main body of Chapter 5 are therefore directly applicable to the HI-STORM 100U system, and no further calculations for the HI-TRAC transfer cask are presented in this supplement.

The shielding design of the HI-STORM 100U VVM is similar to the overpack designs evaluated in the main body of this chapter, with gamma shielding provided by the concrete and the steel of the module, and neutron shielding provided by the module concrete. However, the VVM is mostly located below the surface of the surrounding soil. This results in additional shielding, and a significant reduction in the directly accessible surface for the VVM compared to the other overpacks. Dose rates from a HI-STORM 100U VVM at the site boundary are therefore significantly lower than, and bounded by, dose rates from the above ground HI-STORM systems evaluated in the main body of this chapter.

Shielding analyses were performed for the HI-STORM 100U with an MPC-32 loaded with intact design basis zircaloy clad fuel assemblies. As discussed in Section 5.1, ~~The~~three burnup and cooling time combinations are analyzed ~~are the same combinations reported in Section 5.1~~ for the MPC-32, ~~or more conservative than those,~~ namely 45,000 MWD/MTU and 3 years, 60,000 MWD/MTU and 4 years, and 69,000 MWD/MTU and 5 years cooling time. These burnup and cooling time combinations bound all assemblies permitted to be loaded in any of the uniform or regionalized loading configurations in the MPC-32. All calculations for the HI-STORM 100 are performed for all three combinations, and the results corresponding to the highest total dose rate at each dose location are reported. Dose rates at some locations are more dominated by the contribution from the neutron source. In this case, the highest burnup will result in the highest dose rates. At other locations, dose rates are more dominated by the contribution from the photon source terms. In this case, the shortest cooling time will result in the highest dose rates. In the result table, the burnup and cooling time combination that leads to the highest dose rate is indicated for each dose location. It should further be noted that~~Further,~~ *while the number and location of assemblies with such burnup and cooling time combinations would be restricted for any actually loaded cask, it was assumed in the shielding evaluations presented here that all assemblies have the same characteristics. To indicate the level of conservatism in this approach, note that the burnup and cooling time combinations evaluated here correspond to a heat load of about 2.2 kW per assembly, or about 70 kW for the entire MPC-32. This is an important fact in respect to the choice to perform analyses for the MPC-32, and not for the other MPCs. While* calculated *dose rates for the other baskets could potentially be slightly higher than those for the MPC-32, based on the differences in the MPC design, fuel type, and burnup and cooling times, it is not expected that actual dose rates for any MPC would exceed those calculated here for the MPC-32. This justifies restricting the analyses here to the MPC-32.* Table 5.I.1 presents the results for those~~ate~~ burnup and cooling time combinations out of those listed above that resulted in the maximum dose rates at each location. *Figure 5.I.1 identifies the locations of the dose points referenced in the table. Dose Points #1 and #2 are the locations of the inlet and outlet vents, respectively. The dose values reported adjacent to these dose points were averaged over the vent opening while the dose values reported at 1 meter from these dose locations were taken at the mid-plane of the vent. Dose Point #3, which is positioned approximately over the air flow annulus, is the location of the highest dose rate on the lid in the final storage configuration. Dose Point # 4 is averaged over the vertical air flow passage shown in Figure 5.I.1. Dose Point #4, adjacent to the overpack, is not accessible in the final storage configuration as depicted in Figure 5.I.1. Dose Point #5 is located over a tube that would be required for the ICCPS test station. Dose Point #6 is located over an empty VVM located adjacent to a loaded VVM. Except for conditions during construction discussed further below, c~~C~~alculations were only performed for normal conditions, since Subsections 5.1.1 and 5.1.2 concluded that off-normal and accident conditions for the HI-STORM overpack are identical or equivalent to normal conditions for the purpose of the shielding evaluation.*

The tube for the ICCPS test station is modeled as a cylindrical hole that extends from the VIP down to the base plate of the MPC. The tube is modeled with a diameter of 4 inches, located about 5.5 feet from the center of the VVM. If the actual tube has characteristics that could result in higher dose rates, i.e. is larger or closer to the VVM than modeled here, the ~~the~~actual tube characteristics should be considered in the site specific dose calculations. Depending on the results of those calculations, additional measures, such as added shielding at the top of the tube, may be required.

A comparison between the dose rates in Table 5.I.1 and dose rates presented in Tables 5.1.11 and 5.1.14 of the main body of this chapter show that the maximum dose rate for the HI-STORM 100U module with an MPC-32 is well below the maximum dose rate for the HI-STORM 100S Version B with an MPC-32. Furthermore, the area associated with the maximum dose rate for *the HI-STORM 100U module is the inlet vent. This area is much smaller than the area associated with the maximum dose rate for the overpack analyzed in the main part of this chapter, which is the outer radial surface of the overpack. It can therefore be concluded that the HI-STORM 100U is bounded by the HI-STORM 100 systems analyzed in the main body of this chapter, since the HI-STORM 100U has a smaller directly accessible surface, lower maximum dose rates and smaller areas associated with these maximum dose rates. Nevertheless, calculations were performed to determine the dose rate from the HI-STORM 100U at a distance of 100 meters from the inlet vent. These results, which are presented in Table 5.I.2, indicate that the HI-STORM 100U easily meets the requirements of 10CFR72.104 at 100 meters. Comparing these results to the results in Table 5.4.7 demonstrates that the off-site dose from the HI-STORM 100U is a very small fraction of the off-site dose from an above ground overpack.*

ISFSIs with HI-STORM 100U VVMs might be built in one stage or in several stages. If the ISFSI is built in several stages, then excavation work will be necessary in the vicinity of the section of the ISFSI that is already in operation and contains loaded modules. To protect workers from radiation from the loaded modules, a radiation protection space (RPS) boundary is defined around the ISFSI in the drawing in Section 1.I.5. The RPS boundary is placed so that in a *radial direction, a minimum of 10.5 ft of engineered fill remains between the construction site and the closest loaded module. For a loaded module on the periphery of the ISFSI, this places the boundary 14 ft from the center of the module (10.5 ft + radius of the VVM of 3.5 ft). For a loaded module not on the periphery of the ISFSI, this places the boundary ~~17~~21 feet from the center of the module (10.5 ft + diameter of the outer empty VVM of 7 ft + radius of the loaded VVM of 3.5 ft).* ~~Calculations during excavations were performed for both normal and accident conditions.~~ Additionally, as discussed in Subsection 2.I.6 (xii), a retaining wall is required on the radiation protection boundary that is designed to secure the soil placed around the VVMs under all normal and accident conditions. Dose rates under accident conditions would therefore be the same as those under normal conditions. Nevertheless, in addition to dose rates during excavation under normal conditions, dose rates are also evaluated for an assumed accident condition *Under normal conditions, calculations were conservatively performed with the 6.5 ft remaining fill around a loaded VVM instead of the 10.5 ft required by the RPS.* Note that the retaining wall is conservatively neglected in all shielding analyses. The calculations~~y~~ *result in a maximum dose rate of only about 0.2 mrem/hr at the surface of the excavation. This dose rate is very low, specifically lower than the dose rates at 1 m from the inlet vents of the modules. The dose rates at a construction site might therefore be dominated by the direct dose rates from the inlet vents, and depending on the loading condition of the operating part of the ISFSI, temporary shielding might be used to reduce dose rates to the construction site. Note that the dose rate of -0.2 mrem/hr is calculated using soil with a density of 1.7 g/cm*^{3} *for the 6.5 ft layer. This is conservative since the material in and around the VVM modules would be engineered fill which has a typical density of more than 1.7 g/cm*^{3}*. The bounding accident condition is identified in Supplement 3.I, Section 3.I.4.8.2 to be the impact of a tornado missile with a diameter of 8 inches. This missile would penetrate the soil about 10 ft, and this case was used as the basis for selecting the size of the RPS. This is the bounding condition since smaller missiles have less energy, and larger missiles (automotive) have a much larger impact area thus resulting in a much smaller indentation of the soil. Under* *the bounding condition, the maximum dose over a period of 30 days at a distance of 100 m from the VVM would be 1.4 rem. This is less than the limit in 10CFR72, and also less than the dose for the bounding accident condition discussed in the main body of Chapter 5.*

Finally, as observed in Section 1.I.2, the HI-STORM 100U VVM is deliberately engineered to permit the MPC cavity to be deepened such that the MPC is located deeper inside the module. The elevation of the MPC shown in the drawings in Section 1.5 and analyzed in this supplement is the highest permitted elevation. Of course, lowering the MPC in the VVM would further reduce the radiation dose rates below those computed herein.

5.I.2 SOURCE SPECIFICATION

The analyses in this supplement are performed for intact design basis zircaloy clad fuel assemblies as described in Section 5.2.

5.I.3 MODEL SPECIFICATIONS

The shielding analyses of the HI-STORM 100U module are performed with MCNP-4A, which is the same code used for the analyses presented in the main body of this chapter.

Section 1.I.5 provides the drawings that describe the HI-STORM 100U System. These drawings, using nominal dimensions, were used to create the MCNP models used in the radiation transport calculations. Modeling deviations from these drawings are discussed below. Figure 5.I.2 shows cross sectional views of the HI-STORM 100U module as it was modeled in MCNP for normal conditions. *Note that the inlet and outlet vents were modeled explicitly, therefore, streaming through these components is accounted for in the dose calculations. Note again that the MPC is assumed to be positioned at its highest permissible elevation in relation to the inlet ducts (i.e., in the configuration shown in the drawings in Section 1.5) to maximize the calculated dose rates.*

For the assumed *accident condition during the construction phase, the model contains a VVM surrounded by 6.5 feet of soil (i.e. a thinner soil layer than the one required by the RPS of 10.5 ft), with a horizontal cylindrical hole (8 inches diameter) extending from the metal surface of the VVM to the outer surface of the soil. This condition is the result of the impact of a tornado missile with a diameter of 8 inches. Note that in the model the displaced soil and the missile itself are conservatively assumed to be lost. Also, the cylinder is conservatively assumed to be on the mid-height of the fuel. The dose location is on the axis of the cylindrical hole, 100 m from the VVM.*

Since the HI-STORM 100U model uses principally the same MPC model as the calculations in the main body of this chapter, all figures, conservative modeling approximations, and modeling differences for the MPC shown in Section 5.3 are applicable to the calculations in this supplement. The differences between models and drawings for the module are listed and discussed here.

1. *Minor penetrations in the body of the module (e.g. lift locations) are not modeled as these are small localized effects which will not affect the off-site dose rates.*

2. *The MPC supports and guides were conservatively neglected.*

3. *The closure lid cover plate was modeled as flat. This conservatively reduces the amount of concrete in the lid near the outlet vent.*

4. *The insulation installed on the divider shell was conservatively modeled as a void.*

5. *The cavities representing the ICCPS tube and the empty VVM are modeled as empty volumes surrounded by soil, i.e. any steel liner or other material in these areas, or any covers that would be located on top of those cavities, are conservatively neglected*

6. *The lid design contains a buttress rod at the center. This rod is not explicitly modeled, i.e. the steel of the rod is replaced with concrete in the model. This has a negligible effect on the dose rates.*

Composition and densities of the various materials in Table 5.3.2 were used in the analyses, except for the ~~concrete density and the~~ soil composition. ~~For the concrete density, a value of 2.24 g/cm³ is used.~~ The soil composition and density is shown in Table 5.I.3, and represent typical soil conditions [5.I.1]. This is conservative, since the areas between and around the modules would contain engineered fill with a typical density higher than soil. Furthermore, the dose rates around the VVM are dominated by the streaming through the inlet and outlet vents, and not by direct radiation through the soil and concrete. This is evident by the fact that the dose rate calculated for the excavation site through 6.5 ft of radial soil (see Section 5.I.1) is much less than the dose rates around the inlet and outlet vents. *To further substantiate this, a complete dose rate profile across the lid and the VIP was determined. For the VIP, two conditions were evaluated, the normal condition and a condition where the streaming from the inlets and outlets were artificially blocked. For this second condition, dose rates were also calculated at a distance of 100 m from the VVM. This would indicate what portion of the dose rate results from direct radiation through the concrete and soil of the VIP as opposed to radiation from the streaming from the air inlet and outlet. The dose locations for the profile are shown in Figure 5.I.3, and are labeled alphabetically (A through X). The calculated dose rates are listed in Table 5.I.4. For the VIP, dose rates are shown with the open inlets and outlets, and with the artificially closed inlets and outlets. The following conclusions can be drawn from the results:*

- *The profile did not reveal any locations with dose rates higher than those shown in Figure 5.I.1 and Table 5.I.1.*
- *On the VIP, the dose rates are fairly low compared to other areas.*

- *Comparison of the results on the VIP surface with open and artificially closed inlets and outlets show that closer to the VVM, the dose rate on the surface is dominated by the direct radiation through the concrete and soil, while at larger distances, the relative contribution of the direct radiation through the soil and concrete reduces. At a distance of 100 m, the dose rate from the VIP surface contributes about one third of the total dose rate.*

Note that the dose location 1 m from the inlet vents (see Figure 5.I.1) is approximately above dose locations W and X shown in Figure 5.I.3. The 1 m dose will therefore include contributions from the inlet vent as well as the VIP surface, and does therefore represent both the contribution from streaming through the inlet vent and from direct radiation through the soil and concrete of the VIP.

~~*Thus*~~*In summary, soil properties are conservative and its effect is included in the dose rate at 1 m from the inlet vent*~~*have a small effect on dose rates, and*~~. The use of *typical soil properties is therefore appropriate. Nevertheless, site specific analyses to demonstrate compliance with regulatory requirements should use appropriate site specific soil properties if these are substantially different from the properties used in this Supplement.*

5.I.4 SHIELDING EVALUATION

Table 5.I.1 provides dose rates adjacent to and at 1 meter distance from the HI-STORM 100U module during normal conditions for the MPC-32. The table also includes dose rates at the top of the ICCPS tube and at the top of an empty cavity next to a loaded VVM. These results demonstrate that the dose rates around the HI-STORM 100U are exceptionally low for the very conservative burnup and cooling time combination analyzed. These results also show that the higher dose rate at the inlet vent is reduced by more than an order of magnitude at a distance of 1 meter from the vent.

Table 5.I.2 provides the annual dose at 100 meters from a HI-STORM 100U module for the MPC-32 including the contribution from BPRAs. These results clearly demonstrate that the off-site contribution from a HI-STORM 100U is a small fraction of the off-site dose from the above ground HI-STORM overpacks.

The bounding accident condition is the impact of a tornado missile during the expansion of an array of 100U modules. The dose calculated for this condition at a distance of 100 m is 1.4 rem, which is below the limit specified in 10CFR72, and also below the dose for the bounding accident condition determined in the main section of Chapter 5.

5.I.5 REGULATORY COMPLIANCE

In summary it can be concluded that dose rates from the HI-STORM 100U module are bounded by the dose rates for the overpacks analyzed in the main body of the report. The shielding system of the HI-STORM 100U System is therefore in compliance with 10CFR72 and satisfies the *applicable design and acceptance criteria including 10CFR20. Thus, the shielding evaluation presented in this supplement provides reasonable assurance that the HI-STORM 100U System will allow safe storage of spent fuel.*

5.I.6 REFERENCES

[5.I.1] ANSI/ANS-6.6.1-1987, "Calculation and Measurement of Direct and Scattered Gamma Radiation from LWR Nuclear Power Plants"

Table 5.I.1

DOSE RATES ADJACENT TO AND 1 METER FROM THE
HI-STORM 100U MODULE
FOR NORMAL CONDITIONS
MPC-32 DESIGN BASIS ZIRCALOY CLAD FUEL AT BOUNDING
BURNUP AND COOLING TIME
~~(69,000 MWD/MTU AND 5-YEAR COOLING FOR LOCATIONS 1 THROUGH 4;~~
~~45,000 MWD/MTU AND 3-YEAR COOLING FOR LOCATIONS 5 AND 6)~~

Dose Point† Location	*Burnup and Cooling Time (MWD/MTU / Years)*	**Fuel Gammas†† (mrem/hr)**	**^{60}Co Gammas (mrem/hr)**	**Neutrons (mrem/hr)**	**Totals (mrem/hr)**	**Totals with BPRAs (mrem/hr)**
			Surface			
1	*69,000 / 5*	41.70	8.24	15.08	65.02	69.43
2	*69,000 / 5*	3.03	1.07	4.84	8.94	9.39
3	*69,000 / 5*	16.83	3.59	5.08	25.50	27.91
4	*69,000 / 5*	11.62	10.23	25.69	47.54	51.73
5	*45,000 / 3*	3.38	2.83	7.60E-02	6.29	7.49
6‡	*45,000 / 3*	0.40	6.6E-02	1.85E-02	0.48	0.52
			One Meter			

† *Refer to Figure 5.I.1.*
†† *Gammas generated by neutron capture are included with fuel gammas.*
‡ *Calculated for an empty VVM surrounded by four loaded VVMs.*

1	*69,000 / 5*	3.44	0.70	1.41	5.56	5.92
2	*69,000 / 5*	0.93	0.44	0.92	2.30	2.49
3	*69,000 / 5*	5.10	1.07	1.50	7.67	8.49
4	*69,000 / 5*	2.97	0.68	1.96	5.61	6.03

Table 5.I.2

ANNUAL DOSE AT 100 METERS FROM A SINGLE HI-STORM 100U OVERPACK WITH AN MPC-32 WITH DESIGN BASIS ZIRCALOY CLAD FUEL†

Dose Component	***69,000 MWD/MTU 5-Year Cooling (mrem/yr)***
Fuel gammas††	*4.01*
^{60}Co Gammas	*1.22*
Neutrons	*3.27*
Total	*8.50*

† *8760 hour annual occupancy is assumed.*

†† *Gammas generated by neutron capture are included with fuel gammas.*

Table 5.I.3

COMPOSITION OF THE MATERIALS IN THE HI-STORM 100U SYSTEM

Component	**Density (g/cm^3)**	**Elements**	**Mass Fraction (%)**
Soil	*1.7*	*H*	*0.962*
		O	*54.361*
		Al	*12.859*
		Si	*31.818*

Table 5.I.1

DOSE RATES ADJACENT TO THE HI-STORM 100U MODULE FOR NORMAL CONDITIONS AT DOSE LOCATIONS SHOWN IN FIGURE 5.I.3.

Note: All Values Are For 69,000 MWD/MTU And 5 Years Cooling, Except For Dose Location I Which Is For 60,000 MWD/MTU And 4 Years Cooling

Dose Location††	*Dose Rate (mrem/hr unless noted)*		*Dose Location*	*Dose Rate (mrem/hr unless noted)*	
	Inlet/Outlet Open	*Inlet/Outlet Artificially Closed*		*Inlet/Outlet Open*	*Inlet/Outlet Artificially Closed*
A	*33.1*	*N/C*†	*N*	*2.0*	*N/C*
B	*16.7*	*N/C*	*O*	*3.5*	*N/C*
C	*15.7*	*N/C*	*P*	*9.3*	*N/C*
D	*9.3*	*N/C*	*Q*	*6.8*	*6.5*
E	*6.5*	*N/C*	*R*	*4.1*	*3.5*
F	*7.0*	*N/C*	*S*	*3.0*	*2.0*
G	*4.8*	*N/C*	*T*	*2.5*	*2.0*
H	*6.6*	*N/C*	*U*	*2.2*	*1.5*
I	*33.2*	*N/C*	*V*	*2.0*	*1.5*
J	*27.8*	*N/C*	*W*	*1.7*	*1.0*
K	*3.7*	*N/C*	*X*	*1.6*	*1.0*
L	1.1	N/C	Y	~~8.5 mrem/year~~ *8.5 mrem/year*	~~mrem/year~~ *2.8 mrem/year*
M	1.3	N/C			

†† *See Figure 5.I.3*
† *N/C = Not Calculated*

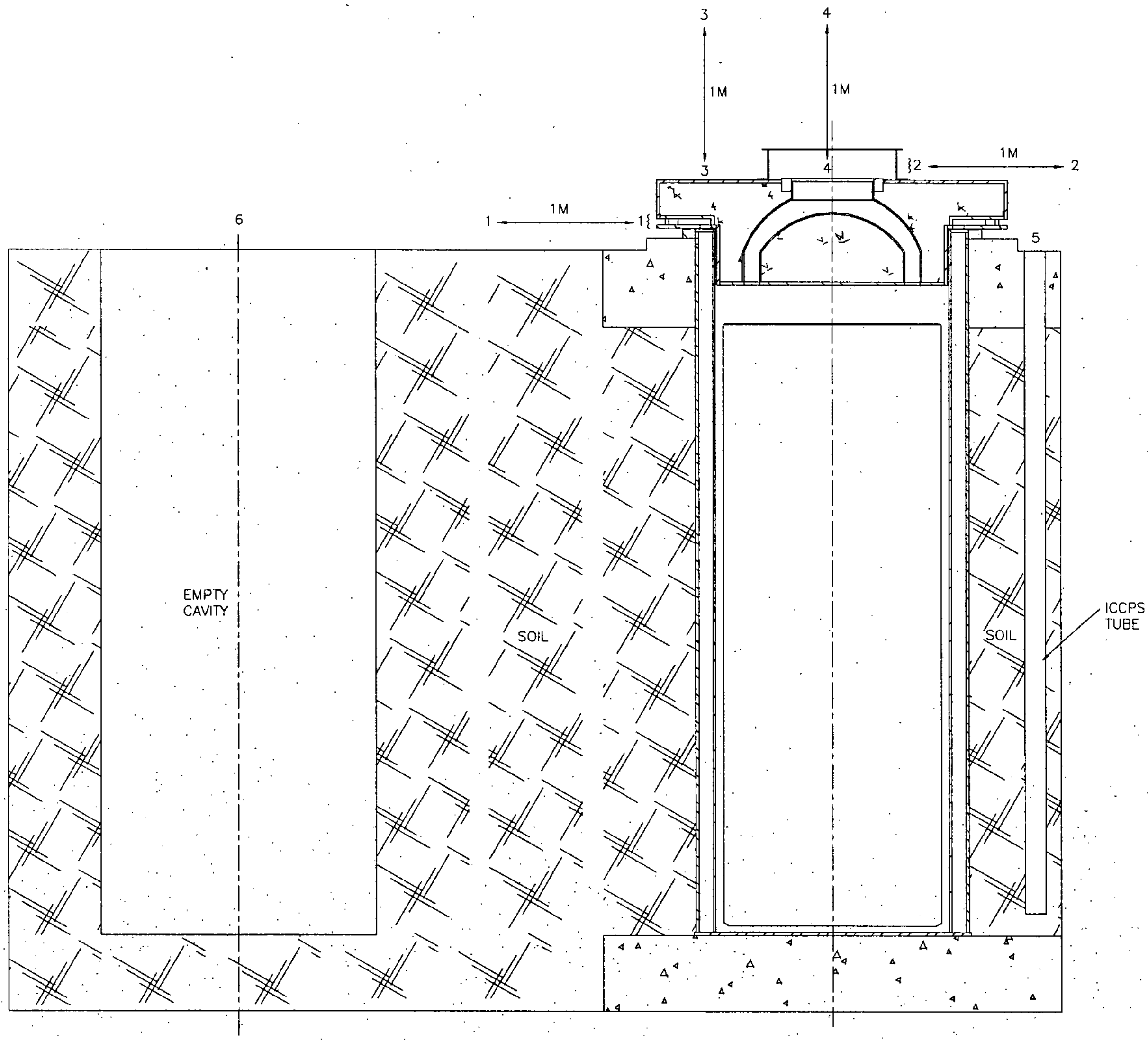


FIGURE 5.I.1; HI-STORM 100U MODULE CROSS SECTIONAL ELEVATION VIEW WITH DOSE POINT LOCATION

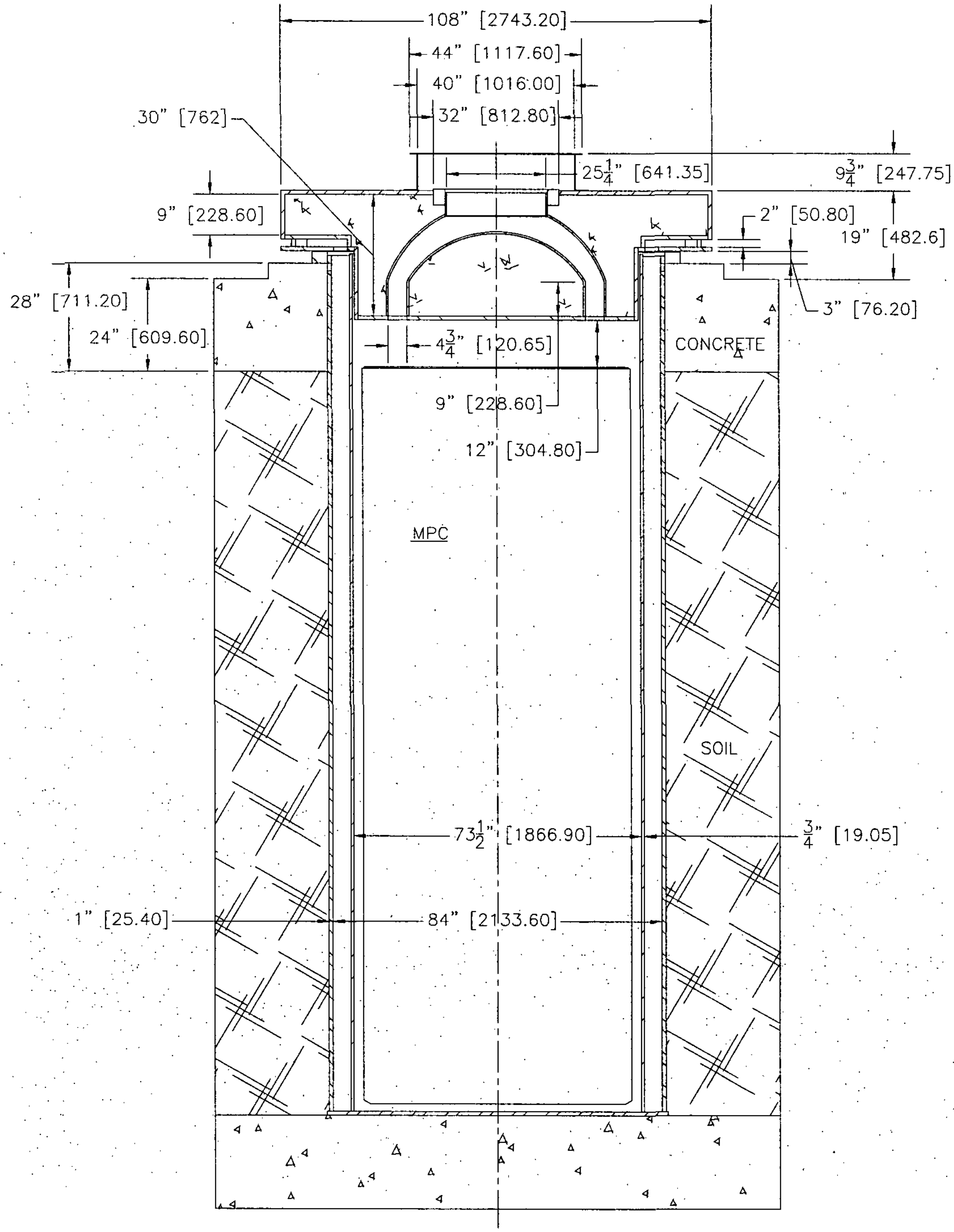


FIGURE 5.I.2; HI-STORM 100U MODULE CROSS SECTIONAL ELEVATION VIEW. VALUES IN BRACKETS ARE IN MILLIMETERS.

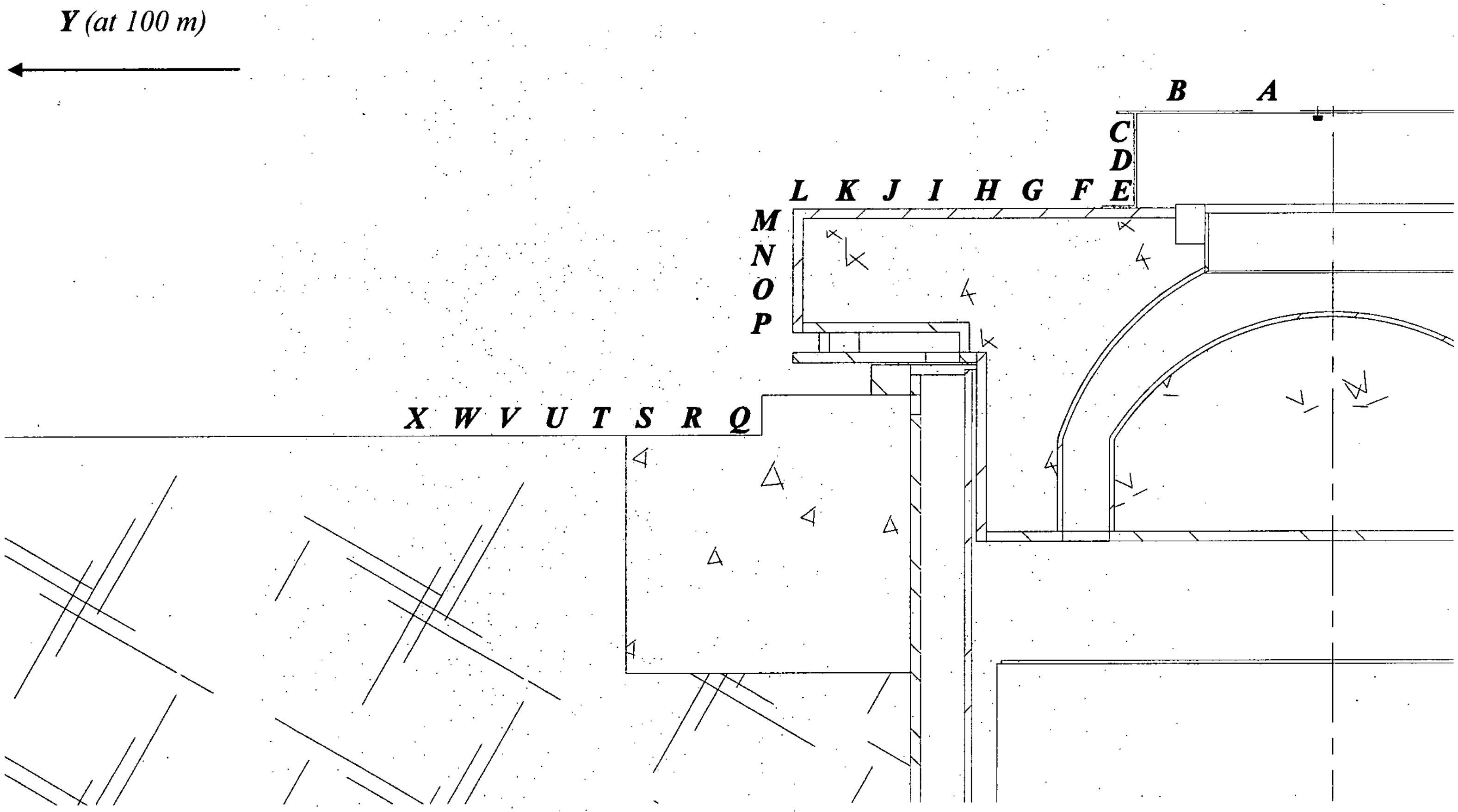


FIGURE 5.I.3; HI-STORM 100U MODULE CROSS SECTIONAL ELEVATION VIEW WITH DOSE POINT LOCATIONS

a. If performing a hydrostatic test, attach the drain line to the vent port and route the drain line to the spent fuel pool or the plant liquid radwaste system and connect the pressurized water supply to the drain port. If performing a pneumatic test, attach the pressure supply and vent line to the vent port and route the vent line to a suitable radwaste connection. See Figure 8.1.20 for the pressure test arrangement.

ALARA Warning:
Water flowing from the MPC may carry activated particles and fuel particles. Apply appropriate ALARA practices around the drain line.

b. If performing a hydrostatic test, fill the MPC with either spent fuel pool water or plant demineralized water until water is observed flowing out of the vent port drain hose. Refer to Tables 2.1.14 and 2.1.16 for boron concentration requirements.

c. Perform the pressure test of the MPC as follows:

1. Close the drain/vent valve and pressurize the MPC to minimum test pressure listed in Table 2.0.1 +5/-0 psig.
2. Close the supply valve and monitor the pressure for a minimum of 10 minutes. The pressure shall not drop during the performance of the test.
3. Following the 10-minute hold period, visually examine the MPC lid-to-shell weld for leakage of water (hydrostatic test) or helium using a bubble test solution (pneumatic test). The acceptance criterion is no observable leakage.

d. Release the MPC internal pressure, disconnect the inlet line and drain line from the vent and drain port RVOAs leaving the vent and drain port caps open.

1. Repeat the liquid penetrant examination on the MPC lid final pass.

e. Repair any weld defects in accordance with the site's approved weld repair procedures. Re-perform the Ultrasonic (if necessary), PT, and pressure tests if weld repair is performed.

5. Drain the MPC as follows:

Caution:
This Caution block is required by the HI-STORM 100 CoC (CoC Appendix B, Section 3.11) and may not be deleted without prior NRC approval via CoC amendment. To prevent the oxidation of the fuel the MPC interior shall be filled with helium or another suitable inert gas to avoid exposing the fuel to oxidizing agents while at elevated temperatures. Exposing fuel at elevated temperatures to oxidizing agents can lead to deleterious oxidation of the fuel.

ALARA Note:
The MPC vent and drain ports are equipped with metal-to-metal seals to minimize leakage and withstand the long-term effects of temperature and radiation. The vent and drain port design prevents the need to hot tap into the penetrations during unloading operation and eliminate the risk of a pressurized release of gas from the MPC.

7. Take an MPC gas sample as follows:

Note:
Users may select alternate methods of obtaining a gas sample.

a. Attach the RVOAs (See Figure 8.1.16).

b. Attach a sample bottle to the vent port RVOA as shown on Figure 8.3.3.

c. Using the vacuum drying system, evacuate the RVOA and Sample Bottle.

d. Slowly open the vent port cap using the RVOA and gather a gas sample from the MPC internal atmosphere.

e. Close the vent port cap and disconnect the sample bottle.

ALARA Note:
The gas sample analysis is performed to determine the condition of the fuel cladding in the MPC. The gas sample may indicate that fuel with damaged cladding is present in the MPC. The results of the gas sample test may affect personnel protection and how the gas is processed during MPC depressurization.

f. Turn the sample bottle over to the site's Radiation Protection or Chemistry Department for analysis.

g. Deleted.

8. Fill the MPC cavity with water as follows:

Caution:
*This Caution block is required by the HI-STORM 100 CoC (CoC Appendix B, Section 3.11) and may not be deleted without prior NRC approval via CoC amendment. To prevent the oxidation of the fuel t*he MPC interior shall be filled with helium or another suitable inert gas to avoid exposing the fuel to oxidizing agents while at elevated temperatures. Exposing fuel at elevated temperatures to oxidizing agents can lead to deleterious oxidation of the fuel.

a. Open the vent and drain port caps using the RVOAs.

b. Deleted.

c. Deleted.

d. Deleted.

e. Deleted.

f. Deleted.

g. Deleted.

h. Deleted.

Caution:
The introduction of water into the MPC may create steam. Re-flooding operations shall be closely controlled to insure that the internal pressure in the MPC does not exceed design limits. The water flow rate shall be adjusted to maintain the internal pressure below design limits.

i. Prepare the MPC fill and vent lines as shown on Figure 8.1.20. Route the vent port line several feet below the spent fuel pool surface or to the radwaste gas facility. Attach the vent line to the MPC vent port and slowly open the vent line valve to depressurize the MPC.

Note:
When unloading MPCs requiring soluble boron, the boron concentration of the water shall be checked in accordance with Tables 2.1.14 and 2.1.16 before and during operations with fuel and water in the MPC.

j. Attach the water fill line to the MPC drain port and slowly open the water supply valve and establish a pressure less than 90 psi. (Refer to Tables 2.1.14 and 2.1.16 for boron concentration requirements). Fill the MPC until bubbling from the vent line has terminated. Close the water supply valve on completion.

k. If used, cease operation of the SCS and remove the system from the HI-TRAC.

Caution:
Combustible gas monitoring as described this Caution block is required by the HI-STORM 100 CoC (CoC Appendix B, Section 3.8) and may not be deleted without prior NRC approval via CoC amendment. Oxidation of Boral panels contained in the MPC may create hydrogen gas while the MPC is filled with water. Appropriate monitoring for combustible gas concentrations shall be performed prior to, and during MPC lid cutting operations. The space below the MPC lid shall be purged with inert gas prior to, and during MPC lid cutting operations to provide additional assurance that flammable gas concentrations will not develop in this space.

l. Disconnect both lines from the drain and vent ports leaving the drain port cap open to allow for thermal expansion of the water during MPC lid weld removal.

m. Connect a combustible gas monitor to the MPC vent port and check for combustible gas concentrations prior to and periodically during weld removal activities. Purge the gas space under the lid as necessary

The MPC confinement boundary pressure test shall be repeated until all required examinations are found to be acceptable. Test results shall be documented and maintained as part of the loaded MPC quality documentation package.

9.1.2.3 Materials Testing

The majority of materials used in the HI-TRAC transfer cask and a portion of the material in the HI-STORM overpack are ferritic steels. ASME Code, Section II and Section III require that certain materials be tested in order to assure that these materials are not subject to brittle fracture failures.

Materials of the HI-TRAC transfer cask and HI-STORM overpack, as required, shall be Charpy V-notch tested in accordance with ASME Section IIA and/or ASME Section III, Subsection NF, Articles NF-2300, and NF-2430. The materials to be tested include the components identified in Table 3.1.18 and applicable weld materials. Table 3.1.18 provides the test temperatures and test acceptance criteria to be used when performing the material testing specified above.

The concrete utilized in the construction of the HI-STORM overpack shall be mixed, poured, and tested as described in FSAR Appendix 1.D in accordance with written and approved procedures. Testing shall verify the composition, compressive strength, and density meet design requirements.

Concrete testing shall be performed for each lot of concrete. Concrete testing shall comply with Appendix 1.D.

Test results shall be documented and become part of the final quality documentation package.

9.1.3 Leakage Testing

Leakage testing shall be performed in accordance with the requirements of ANSI N14.5 [9.1.5]. Testing shall be performed in accordance with written and approved procedures.

At completion of welding the MPC shell to the baseplate, an MPC confinement boundary weld helium leakage test shall be performed using a helium mass spectrometer leak detector (MSLD). A temporary test closure lid is used in order to provide a sealed MPC. The confinement boundary welds leakage rate test shall be performed in accordance with ANSI N14.5 to "leak-tight" criteria. If a leakage rate exceeding the acceptance criterion is detected, then the area of leakage shall be determined and the area repaired per ASME Code Section III, Subsection NB, Article NB-4450 requirements. Re-testing shall be performed until the leakage rate acceptance criterion is met.

The helium leakage test of the vent and drain port cover plate welds shall be performed using a helium mass spectrometer leak detector (MSLD). If a leakage rate exceeding the acceptance criterion is detected, then the area of leakage shall be determined and the area repaired per ASME Code Section III, Subsection NB, Article NB-4450 requirements. Re-testing shall be performed until the leakage rate acceptance criterion is met.

Leakage testing of the ~~MPC shop welds (shell seams and shell-to-baseplate shop welds) and the~~ field welded MPC lid-to-shell weld and closure ring welds are not required.

Leak testing results for the MPC shall be documented and shall become part of the quality record documentation package.

Leakage testing of the vent and drain port cover plates shall be performed after welding of the cover plates and subsequent NDE. The description and procedures for these field leakage tests are provided in FSAR Section 8.1 and the acceptance criteria are defined in the Technical Specifications in Appendix A to CoC 72-1014

9.1.4 Component Tests

9.1.4.1 Valves, Rupture Discs, and Fluid Transport Devices

There are no fluid transport devices or rupture discs associated with the HI-STORM 100 System. The only valve-like components in the HI-STORM 100 System are the specially designed caps installed in the MPC lid for the drain and vent ports. These caps are recessed inside the MPC lid and covered by the fully-welded vent and drain port cover plates. No credit is taken for the caps' ability to confine helium or radioactivity. After completion of drying and backfill operations, the drain and vent port cover plates are welded in place on the MPC lid and are liquid penetrant examined and leakage tested to verify the MPC confinement boundary.

There are two pressure relief valves installed in the upper ledge surface of the HI-TRAC transfer cask water jacket. These pressure relief valves are provided for venting of the neutron shield jacket fluid under hypothetical fire accident conditions in which the design pressure of the water jacket may be exceeded. The pressure relief valves shall relieve at 60 psig and 65 psig.

9.1.4.2 Seals and Gaskets

There are no confinement seals or gaskets included in the HI-STORM 100 System.

9.1.5 Shielding Integrity

The HI-STORM overpack and MPC have two designed shields for neutron and gamma ray attenuation. The HI-STORM overpack concrete provides both neutron and gamma shielding. Additional neutron shielding is provided by the encased neutron absorber attached to the fuel basket cell surfaces inside the MPCs. The overpack's inner and outer steel shells, and the steel shield shell[†], provide radial gamma shielding. Concrete and steel plates provide axial neutron and gamma

[†] The shield shell design feature was deleted in June, 2001 after overpack serial number 7 was fabricated. ~~Those overpacks without the shield shell are required to have a higher concrete density in the overpack body to provide compensatory shielding. See Table 1.D.1.~~

Table 9.1.1 (continued)
MPC INSPECTION AND TEST ACCEPTANCE CRITERIA

Function	Fabrication	Pre-operation	Maintenance and Operations
Structural	a) Assembly and welding of MPC components shall be performed per ASME Code Section IX and III, Subsections NB and NG, as applicable. b) Materials analysis (steel, neutron absorber, etc.), shall be performed and records shall be kept in a manner commensurate with "important to safety" classifications.	a) None.	a) An ultrasonic (UT) examination or multi-layer liquid penetrant (PT) examination of the MPC lid-to-shell weld shall be performed per ASME Section V, Article 5 (or ASME Section V, Article 2). Acceptance criteria for the examination are defined in Subsection 9.1.1.1 and in the Design Drawings. b) ASME Code NB-6000 pressure test shall be performed after MPC closure welding. Acceptance criteria are defined in the Code.
Leak Tests	a) *Helium leak rate testing shall be performed on all MPC pressure boundary shop welds.*~~None.~~	a) None.	a) Helium leak rate testing shall be performed on the vent and drain port cover plate to MPC lid field welds. See Technical Specification Bases in Chapter 12 for guidance on acceptance criteria.

SUPPLEMENT 10.I

RADIATION PROTECTION

The HI-STORM 100U is a modular, underground vertical ventilated module (VVM) designed to accept all MPC models for storage at an ISFSI in lieu of above ground overpacks, like the HI-STORM 100 and HI-STORM 100S. As such, the radiological dose to plant personnel as well as members of the general public is well below those of the HI-STORM 100 and HI-STORM 100S when the MPC is in the overpack. Since the determination of off-site doses is necessarily site-specific, dose assessments similar to those described in Chapter 10 are to be prepared by the licensee as part of implementing the HI-STORM 100U System in accordance with 10CFR72.212 [10.0.1].

HI-STORM 100U Loading and Unloading Operations

The operations associated with the use of the HI-STORM 100U, described in Supplements 1.I and 8.I, are quite similar to the operations for all other variations of the HI-STORM 100 system. In both the aboveground and underground overpack, the MPC is transferred between the HI-TRAC and the overpack and in both cases the lid of the overpack is placed atop the overpack once the HI-TRAC is removed from the overpack. The only significant difference between the aboveground and underground overpack is the position of the HI-TRAC relative to ground level. For the aboveground overpack, the bottom of the HI-TRAC is approximately 18 feet above the ground and for the underground overpack, the bottom of the HI-TRAC is essentially at ground level. From an operations perspective, it will be easier to access the mating device and the pool lid bolts when the HI-TRAC is positioned atop the underground overpack rather than the aboveground overpack. In both cases, the same bolting and unbolting operations around the base of the HI-TRAC must be performed. Therefore, the estimated occupational dose for these scenarios is the same. The fact that the body of the HI-TRAC is closer to the ground when the underground overpack is being loaded will not affect the occupational dose rate since it is assumed that the workers not performing a task are positioned far enough away as to receive minimal dose.

Once the MPC transfer is complete and the HI-TRAC has been removed, the lid is placed on the overpack. For the underground overpack, this is a relatively simple operation of lifting the lid and placing it in the correct location. Unlike the aboveground overpack, the lid is not bolted to the body of the overpack. However, the outlet vent cover is installed on the overpack lid after the lid is placed upon the HI-STORM 100U, which installation requires bolting. Installation of the outlet vent cover places workers over the lid and adds some time to the operation. The duration of this operation can be estimated based on information provided in the tables in Section 10.3. Installation of the vent cover would be similar to the installation and alignment of the closure ring on top of the MPC. This activity is listed with an estimated duration of 5 min, for a single operator, in the tables in Section 10.3. Since the outlet vent cover is closer to the center of the lid than the closure ring, it is assumed here that two operators are required. There are four bolts, and bolt installation is typically listed in Section 10.3 to be performed at 2 bolts per minute, resulting in a duration of 2 minutes.

Again, due to the location of those bolts, it is assumed that two operators are necessary to perform this activity. In total, i~~I~~t is then conservatively estimated ~~based on operator activities described in Table 10.3.3c~~ that it will take 10 minutes for two operators to perform the installation. *The dose rate on top of the overpack lid is 31.53 mrem/hr (see Table 5.1.1), which translates to a dose to the individual of 5.26 mrem and a total dose of 10.51 person-mrem. This is a small increase (about 1 %) in the total dose when considering the entire MPC transfer into the HI-STORM system. However, it is recommended that the operators do not spend any unnecessary time on top of the lid to ensure/meet the ALARA principle. It should also be mentioned that actual occupational dose during loading vary widely depending on site specific conditions. Experience has shown that the dose rates are in general significantly lower than those estimated in Chapter 10 of this FSAR.*

In conclusion, the operator dose rates will be similar to those described in Chapter 10 for the aboveground overpack. Therefore, occupational exposure estimates for typical canister loading, closure, transfer operations, and ISFSI inspections may be calculated using the information presented in the tables of Chapter 10 for the site-specific application of the HI-STORM 100U system. For the fuel loading/unloading, transportation, and storage operations utilizing the HI-STORM 100U, the dose information provided in Chapter 10 may be considered bounding.

Excavation Activities

In the event it is desired to expand an ISFSI utilizing the HI-STORM 100U design, excavation of material (i.e., soil) is required. Radiation protection of the excavation activities will is achieved~~be limited~~ *by prescribing a minimum proximity of any excavation to an existing HI-STORM 100U array.* To protect the soil within this proximity, a retaining wall is required, as specified in Subsection 2.I.6 (xii). *Site specific radiation protection measures for excavation activities need to include confirmation of the minimum soil properties along with the minimum distances between the excavation area and the loaded VVMs, as well as radiological monitoring of the excavation area.*

Site specific evaluations also need to be performed to ensure that the radiation protection space boundary is maintained. Site specific accident scenarios (e.g., seismic conditions) will need to be accounted for in these evaluations. A general accident scenario evaluation, however, has been performed for the HI-STORM 100U design. The impact of a tornado missile penetrating the soil creating a horizontal hole extending from the metal surface of the VVM to the outer surface of the soil was considered. This evaluation, presented in Supplement 5.I, demonstrates that the dose at the site boundary is below the limit specified in 10 CFR 72.

Normal Operation of Storage

During normal operation of storage, radiation will predominantly emanate from the inlet and outlet vents and the top of the lid. However, there are also some additional radiation streaming *paths and scenarios that may have to be considered in the radiation protection program. The following two scenarios have been evaluated for the HI-STORM 100U design.*

The first scenario evaluated address radiation streaming from a loaded VVM through an adjacent empty VVM. An empty VVM adjacent to a loaded VVM could potentially constitute a radiation streaming path since the soil providing shielding is limited between adjacent VVMs. Therefore, radiation passing through the soil to the unloaded VVM will have a path of less shielding and could contribute to occupational dose. This evaluation is presented in detail in Supplement 5.I, and concluded that there are no concerns about the dose rates contributing to occupational dose across the top of the empty VVM due to radiation streaming from the loaded neighboring VVM.

The second scenario concerns the soil access tube, or test station, that is part of the ICCPS design (see Figure 2.I.1) and could represent a potential streaming path. Therefore, radiation passing through the soil access tube could contribute to occupational dose. This evaluation is presented in detail in Supplement 5.I, and assumes a tube located about 5.5 feet from the center of the VVM with a diameter of 4 i~~I~~nches, that reaches down to the support foundation. With these dimensions, it is ~~and~~ shown~~ed~~ *that there are no concerns about the dose rates contributing to occupational dose on the top of the soil access tube due to radiation streaming from a loaded VVM.* However, if the tube is larger, or located closer to the VVM, then the actual dimensions should be considered in the site specific dose rate calculations, and the result of the calculations should be considered in the site specific radiation protection program.

SUPPLEMENT 11.I

ACCIDENT EVALUATION FOR THE HI-STORM 100U SYSTEM

11.I.0 INTRODUCTION

This supplement is focused on the off-normal and accident condition evaluations of the HI-STORM 100U vertical ventilated module (VVM). Only those events that are actually affected by the design of the overpack are discussed in detail herein. The reader is referred to the main body of Chapter 11 for discussions of any off-normal or accident conditions that are not dependent on the design of the storage overpack (i.e., MPC-only or HI-TRAC events).

The evaluations described herein parallel those of the HI-STORM 100 overpack contained in the main body of Chapter 11 of this FSAR. To ensure readability, the sections in this supplement are numbered to be directly analogous to the sections in the main body of the chapter. For example, the fire accident evaluation presented in Supplement Subsection 11.I.2.4 for the HI-STORM 100U is analogous to the evaluation presented in Subsection 11.2.4 of the main body of Chapter 11 for the HI-STORM 100. Tables and figures (if any) in this supplement, however, are labeled sequentially by section. If there is an analogous table or figure in the main body of Chapter 11, an appropriate notation is made in the supplement table or figure.

11.I.1 OFF-NORMAL EVENTS

A general discussion of off-normal events is presented in Section 11.1 of the main body of Chapter 11. The following off-normal events are discussed in this supplement:

Off-Normal Pressure
Off-Normal Environmental Temperature
Leakage of One MPC Seal Weld
Partial Blockage of Air Inlets
Off-Normal Handling of HI-TRAC Transfer Cask
Malfunction of FHD System
SCS Power Failure
Off-Normal Wind

The results of the evaluations presented herein demonstrate that the HI-STORM 100U System can withstand the effects of off-normal events without affecting its ability to perform its intended function, and is in compliance with the applicable acceptance criteria.

11.I.1.1 Off-Normal Pressure

A discussion of this off-normal condition is presented in Subsection 11.1.1 of the main body of Chapter 11. A description of the cause of, detection of, corrective actions for and radiological impact of this event is presented therein.

Structural

The structural evaluation of the MPC enclosure vessel for off-normal internal pressure conditions is discussed in Section 3.4. The applicable pressure boundary stress limits are confirmed to bound the stresses resulting from the off-normal pressure.

Thermal

In 4.6.1 the MPC internal pressure under the conditions of 10% fuel rods ruptured, insolation and a limiting fuel storage configuration in an aboveground overpack is evaluated. This evaluation is bounding as the MPC temperatures in the 100U overpack are bounded by the aboveground overpack.

Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event. As discussed in the structural evaluation mentioned above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this off-normal event.

Based on this evaluation, it is concluded that the off-normal pressure does not affect the safe operation of the HI-STORM 100U System.

11.I.1.2 Off-Normal Environmental Temperatures

A discussion of this off-normal condition is presented in Subsection 11.1.2 of the main body of Chapter 11. A description of the cause of, detection of, corrective actions for and radiological impact of this event is presented therein.

Structural

The effect on the MPC for the upper off-normal thermal conditions (i.e., 100°F) is an increase in the internal pressure. However, as shown previously the resultant pressure is below the off-normal design pressure (Table 2.2.1). The effect of the lower off-normal thermal conditions (i.e., -40°F) requires an evaluation of the potential for brittle fracture. Such an evaluation is presented in Subsections 3.1.2 and 3.I.1.

Thermal

Supplement 4.I calculates bounding temperatures and pressures for the HI-STORM 100U under the elevated temperature condition. The calculated temperatures and pressures are reported in Table 4.I.5 and are below the off-normal limits (Tables 2.2.3, 2.I.8 and 2.2.1).

The off-normal event considering an environmental temperature of -40°F and no solar insolation for a duration sufficient to reach thermal equilibrium is evaluated with respect to material design temperatures of the HI-STORM 100U overpack. The HI-STORM 100U overpack is conservatively assumed to reach -40°F throughout the structure. Chapter 3, Subsection 3.1.2 details the structural analysis and testing performed to assure prevention of brittle fracture failure of the HI-STORM 100U System.

Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this off-normal event.

Based on this evaluation, it is concluded that the specified off-normal environmental temperatures do not affect the safe operation of the HI-STORM 100U System.

11.I.1.3 Leakage of One MPC Seal Weld

A discussion of this off-normal condition is presented in Subsection 11.1.3 of the main body of Chapter 11. The discussion presented therein is applicable in its entirety to an MPC in a HI-STORM 100U VVM as well.

11.I.1.4 Partial Blockage of Air Inlets

A discussion of this off-normal condition is presented in Subsection 11.1.4 of the main body of Chapter 11. A description of the cause of, detection of, corrective actions for and radiological impact of this event is presented therein.

Structural

There are no structural consequences as a result of this off-normal event.

Thermal

Supplement 4.I calculates bounding temperatures for 50% blockage of the air inlets. The calculated bounding temperatures are reported in Table 4.I.6 and are below the MPC and VVM off-normal design temperatures (Tables 2.2.3 and 2.I.8). Additionally, the increased temperatures generate an elevated MPC internal pressure, also reported in Table 4.I.6, which is less than the off-normal design pressure (Table 2.2.1).

Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this off-normal event.

Based on this evaluation, it is concluded that the specified off-normal partial blockage of air inlet ducts event does not affect the safe operation of the HI-STORM 100U System.

11.I.1.5 Off-Normal Handling of HI-TRAC

A discussion of this off-normal condition is presented in Subsection 11.1.5 of the main body of Chapter 11. The discussion presented therein remains completely applicable, as the design and method of operation of the HI-TRAC is the same as with the HI-STORM 100U.

11.I.1.6 Failure of FHD System

A discussion of this off-normal condition is presented in Subsection 11.1.6 of the main body of Chapter 11. The discussion presented therein remains completely applicable for all MPCs.

11.I.1.7 SCS Power Failure

A discussion of this off-normal condition is presented in Subsection 11.1.7 of the main body of Chapter 11. The discussion presented therein remains completely applicable to all MPCs.

11.I.1.8 Off-Normal Wind

The HI-STORM 100U is designed for use at any site in the United States. Supplement 4.I evaluates the effects of off-normal wind (>0 and up to 15 MPH). The off-normal wind is postulated as a constant horizontal wind caused by extreme weather conditions (see Table 2.I.1). To determine the effects of the off-normal wind, it is conservatively assumed that these winds persist for a sufficient duration to allow the HI-STORM 100U System to reach thermal equilibrium. Because of the large mass of the HI-STORM 100U System with its corresponding large thermal inertia and the unlikely condition of a unidirectional wind for a long period of time, this assumption is conservative. The analyses presented in Supplement 4.I shows that the peak fuel cladding and material temperatures remains below the off-normal limits (Tables 2.2.3 and 2.I.8). Because the HI-STORM 100U System is designed to withstand the off-normal wind without any effect on its ability to maintain safe storage conditions, there is no requirement for detection of the off-normal wind.

Structural

There are no structural consequences as a result of this off-normal event.

Thermal

Supplement 4.I calculates peak fuel cladding temperatures for horizontal wind speeds of up to 15 miles per hour. The calculated temperatures (reported in Table 4.I.7) are below the off-normal limits (Table 2.2.3).

Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this off-normal event.

Based on this evaluation, it is concluded that the specified off-normal wind event does not affect the safe operation of the HI-STORM 100U System. The HI-STORM 100U System is designed to withstand the off-normal wind without any effect on its ability to maintain safe storage conditions. There are no corrective actions required for the off-normal wind. The off-normal wind has no radiological impact, and the confinement barrier and shielding integrity are not affected.

11.I.2 ACCIDENT EVENTS

A general discussion of accident events is presented in Section 11.1 of the main body of Chapter 11. The following accident events are discussed in this supplement section:

HI-TRAC Transfer Cask Handling Accident
HI-STORM 100U Overpack Handling Accident
Tip-Over
Fire Accident
Partial Blockage of MPC Basket Vent Holes
Tornado
Flood
Earthquake
100% Fuel Rod Rupture
Confinement Boundary Leakage
Explosion
Lightning
100% Blockage of Air Inlets
Burial Under Debris
Extreme Environmental Temperature
SCS Failure

The results of the evaluations performed herein demonstrate that the HI-STORM 100U System can withstand the effects of all credible and hypothetical accident conditions and natural phenomena without affecting safety function, and is in compliance with the applicable acceptance criteria.

In addition to the above accidents events, identification of additional hazards during construction proximate to an operating ISFSI is treated in 11.I.2.17.

11.I.2.1 HI-TRAC Transfer Cask Handling Accident

A discussion of this accident condition is presented in Subsection 11.2.1 of the main body of Chapter 11. The discussion presented therein is applicable in its entirety, as the design and method of operation of the HI-TRAC is the same for the HI-STORM 100U.

11.I.2.2 HI-STORM Overpack Handling Accident

This accident event is not applicable to the HI-STORM 100U as this is an underground overpack surrounded by soil.

11.I.2.3 Tip-Over

This accident event is not applicable to the HI-STORM 100U. Due to the subterranean installation of the VVM with a surrounding subgrade for lateral support, tip-over is precluded.

11.I.2.4 Fire Accident

A discussion of this accident condition is presented in Subsection 11.2.4 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein. In addition, the discussion of the fire analysis for the HI-TRAC transfer cask presented therein remains completely applicable, as the design and method of operation of the HI-TRAC do not need to be changed for use with the HI-STORM 100U.

Structural

There are no structural consequences as a result of the fire accident condition.

Thermal

Supplement 4.I discusses the impact of a fire on the HI-STORM 100U System. As justified therein, the evaluation for the fire effects on an aboveground cask presented in Section 11.2 bound the effects on the HI-STORM 100U System. As described in Section 11.2, the effects of the fire do not cause any system component or the contained fuel to exceed any design limit. As such, the results are bounding for the HI-STORM 100U System.

Shielding

With respect to concrete damage from a fire, NUREG-1536 (4.0,V,5.b) states: "the loss of a small amount of shielding material is not expected to cause a storage system to exceed the regulatory requirements in 10 CFR 72.106 and, therefore, need not be estimated or evaluated in the SAR."

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event.

Radiation Protection

Since there is a very localized reduction in shielding and no effect on the confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the overpack fire accident does not affect the safe operation of the HI-STORM 100U System.

11.I.2.5 Partial Blockage of MPC Basket Vent Holes

A discussion of this accident condition is presented in Subsection 11.2.5 of the main body of Chapter 11. The discussion presented therein is applicable in its entirety to an MPC in a HI-STORM 100U VVM.

11.I.2.6 Tornado

A discussion of this accident condition is presented in Subsection 11.2.6 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Because of its underground construction, the HI-STORM 100U is not affected by the tornado wind. The effect of tornado missiles propelled by high velocity winds that attempt to penetrate the exposed portions of the HI-STORM 100U must, however, be considered.

Structural

Analyses presented in Supplement 3.I show that the impact of an intermediate tornado missile on the HI-STORM 100U closure lid does not result in the perforation of the lid or result in a *structural collapse. The result of the tornado missile impact on the VVM is limited to localized damage of the shielding.*

Thermal

There are no thermal consequences as a result of the tornado beyond those discussed for the wind herein.

Shielding

A tornado missile may cause localized damage to the HI-STORM 100U closure lid. As the HI-STORM 100U top is heavily shielded (a thick MPC lid backed up by a steel-concrete-steel top) the overall damage consequences (site boundary dose) are insignificant.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event.

Radiation Protection

There is no degradation in confinement capabilities of the MPC, since the tornado missiles do not impact the MPC, as discussed above. A tornado missile may cause localized damage in the HI-STORM 100U closure lid. However, the damage will have a negligible effect on the site boundary dose.

Based on this evaluation, it is concluded that the tornado accident does not affect the safe operation of the HI-STORM 100U System.

11.I.2.7 Flood

A discussion of this accident condition is presented in Subsection 11.2.7 of the main body of Chapter 11. A description of the cause of this event is presented therein.

Structural

The structural evaluation of the MPC for the accident condition external pressure (Table 2.2.1) is presented in Section 3.4 and the resulting stresses from this event are shown to be well within the allowable values.

Thermal

The thermal consequences of flood are bounded by the 100% air inlets blockage accident (see Subsection 4.I.6.2).

Shielding

There is no effect on the shielding performance of the system as a result of this accident event. The floodwater provides additional shielding which reduces radiation dose.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event. The criticality analysis is unaffected because under the flooding condition water does not enter the MPC cavity and therefore the reactivity would be less than the loading condition in the spent fuel pool, which is presented in Section 6.1.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the flood accident does not affect the safe operation of the HI-STORM 100U System.

Flood Accident Corrective Action

The configuration of the VVM makes it uniquely suited to withstand a flooding event. Indeed, introducing water in the CEC is an effective method to lower the MPC contents' temperature. However, solid debris packed around the Divider Shell is an undesirable condition. Thus, while the thermal evaluations discussed in Supplement 4.I demonstrate that the HI-STORM 100U System will safely withstand a flood, corrective actions after such an event may be necessary. Periodic VVM air temperature monitoring, required for the HI-STORM 100U System, will identify any blockage of the cooling passages that results in a non-normal thermal condition, including blockages due to a flood borne debris.

If the measured temperature rise exceeds the allowable value, then corrective actions to alleviate the condition will be required. To restore the system to a normal configuration, all flood water and any debris deposited by the receding water must be removed. The specific methods to be *used are appropriately site specific and shall be addressed in the site emergence action plan. Examples of acceptable cleaning approaches include:*

1. *The MPC is removed from the VVM using the HI-TRAC transfer cask, allowing direct access to the interior of the VVM through both the inlet vents and the top of the module cavity. Water sprays and vacuuming is used to directly clean the VVM passages and surfaces.*

2. *Appropriate vacuuming equipment is inserted through the inlet ducts and down to the bottom plenum. Water is sprayed in through the outlet vents. Remote cameras are used to inspect the VVM cooling passages to identify debris and remove debris.*

The adequacy of the cooling passages clearance operation is verified by visual inspection or, if the optional air temperature monitoring is used, the return of the air outlet temperatures to within allowable limits.

11.I.2.8 <u>Earthquake</u>

A discussion of this accident condition is presented in Subsection 11.2.8 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

<u>Structural</u>

Because of its underground construction, the HI-STORM 100U VVM is inherently safe under seismic events. Analyses presented in Supplement 3.I show that the VVM will continue to render its intended function under a seismic event whose ZPAs are bounded by the values set forth in Supplement 2.I.

<u>Thermal</u>

There is no effect on the thermal performance of the system as a result of this accident event.

<u>Shielding</u>

There is no effect on the shielding performance of the system as a result of this accident event.

<u>Criticality</u>

There is no effect on the criticality control features of the system as a result of this accident event.

<u>Confinement</u>

There is no effect on the confinement function of the MPC as a result of this accident event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the earthquake does not affect the safe operation of the HI-STORM 100U System.

11.I.2.9 100% Fuel Rod Rupture

A discussion of this accident condition is presented in Subsection 11.2.9 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Structural

The structural evaluation of the MPC for the accident condition internal pressure presented in Section 3.4 demonstrates that the MPC stresses are well within the allowable values.

Thermal

A bounding MPC internal pressure for the 100% fuel rod rupture condition is presented in Table 4.4.9. The design basis accident condition MPC internal pressure (Table 2.2.1) used in the structural evaluation bounds the calculated value.

Shielding

There is no effect on the shielding performance of the system as a result of this accident event.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the non-mechanistic 100% fuel rod rupture accident does not affect the safe operation of the HI-STORM 100U System.

11.I.2.10 <u>Confinement Boundary Leakage</u>

A discussion of this accident condition is presented in Subsection 11.2.10 of the main body of Chapter 11. The discussion presented therein remains completely applicable to an MPC in a HI-STORM 100U VVM as well.

11.I.2.11 <u>Explosion</u>

A discussion of this accident condition is presented in Subsection 11.2.11 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

<u>Structural</u>

Because of its underground construction, the HI-STORM 100U and the MPC contained within are essentially shielded by the surrounding earth. Thus, no evaluation of the VVM or the contained MPC is required. The HI-STORM 100U closure lid is, however, aboveground and exposed to the explosion-induced pressure wave. Supplement 3.I includes an evaluation of the effect of the design-basis 10 psi pressure wave applied as a static pressure on the closure lid. This evaluation shows that the overpressure wave does not result in lid separation, and that all lid stresses are a fraction of the allowable limits.

<u>Thermal</u>

There is no effect on the thermal performance of the system as a result of this accident event.

<u>Shielding</u>

There is no effect on the shielding performance of the system as a result of this accident event.

<u>Criticality</u>

There is no effect on the criticality control features of the system as a result of this accident event.

<u>Confinement</u>

There is no effect on the confinement function of the MPC as a result of this accident event. As discussed in the structural evaluation above, all stresses remain well within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the explosion accident does not affect the safe operation of the HI-STORM 100U System.

11.I.2.12 Lightning

A discussion of this accident condition is presented in Subsection 11.2.12 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Because of its underground construction, the subterranean portion of the HI-STORM 100U would not be subjected to a direct lightning strike. The HI-STORM 100U closure lid is, however, aboveground and could be subjected to a direct strike. The closure lid is, however, a steel encased concrete structure just like on the aboveground casks. Thus, the discussion presented in Subsection 11.2.12 remains completely applicable to the exposed portions of the HI-STORM 100U System. Therefore, it is concluded that a lightning event will not prevent the VVM from rendering its intended function.

11.I.2.13 100% Blockage of Air Inlets

A discussion of this accident condition is presented in Subsection 11.2.13 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Structural

There are no structural consequences as a result of this accident event.

Thermal

Supplement 4.I calculates bounding temperatures for the 100% blockage of the air inlets. The calculated bounding temperatures after 24 hours of 100% blockage are reported in Table 4.I.9. The results are below the MPC and VVM accident temperature limits (Tables 2.2.3 and 2.I.8). Additionally, the increased temperatures generate an elevated MPC internal pressure, also reported in Table 4.I.9, which is less than the design basis accident pressure listed in Table 2.2.1.

Shielding

There is no effect on the shielding performance of the system as a result of this accident event, since the concrete temperatures do not exceed the accident temperature limit.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the 100% blockage of air inlets accident does not affect the safe operation of the HI-STORM 100 System, if the blockage is removed in the specified time period.

11.I.2.14 Burial Under Debris

A discussion of this accident condition is presented in Subsection 11.2.14 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Structural

The structural evaluation of the MPC enclosure vessel for accident internal pressure conditions bounds the pressure calculated herein. Therefore, the resulting stresses from this event are well within the allowable values, as demonstrated in Section 3.4.

Thermal

Supplement 4.I discusses the impact of burial under debris on the HI-STORM 100U System. As explained therein, the evaluation for the effects of such an event on an aboveground cask presented in Section 11.2 bound the HI-STORM 100U.

Shielding

There is no adverse effect on the shielding performance of the system as a result of this accident event.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the burial under debris accident does not affect the safe operation of the HI-STORM 100U System, if the debris is removed within the specified time period.

11.I.2.15 Extreme Environmental Temperature

A discussion of this accident condition is presented in Subsection 11.2.15 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Structural

The structural evaluation of the MPC enclosure vessel for accident condition internal pressure bounds the pressure resulting from this event. Therefore, the resulting stresses from this event are bounded by the design-basis internal pressure and are well within the allowable values, as discussed in Section 3.4.

Thermal

Supplement 4.I calculates bounding temperatures for the HI-STORM 100U under the extreme environmental temperature condition. The calculated bounding temperatures and pressures are reported in Table 4.I.8 and are below the MPC and VVM accident temperature and pressure limits (Tables 2.2.3, 2.I.8 and 2.2.1).

Shielding

There is no effect on the shielding performance of the system as a result of this accident event, since the concrete temperature does not exceed the short-term temperature limit specified in Table 2.2.3.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the extreme environment temperature accident does not affect the safe operation of the HI-STORM 100U System.

11.I.2.16 Supplemental Cooling System (SCS) Failure

A discussion of this off-normal condition is presented in Subsection 11.2.16 of the main body of Chapter 11. The discussion presented therein remains completely applicable, as the design and method of operation of the SCS and the HI-TRAC is unchanged for use with the HI-STORM 100U System.

11.I.2.17 Additional Hazards during Construction Proximate to the ISFSI

To protect an installed ISFSI from any site construction activity in its proximity, a certain minimum ground buffer distance beyond the edge of the perimeter of the VVM arrays is prescribed in the licensing drawings. This radiation protection space (RPS) defines the no-construction zone around the installed and loaded VVMs (see Section 1.I.4).

As is required for deploying casks certified under 10CFR72, Subpart L, every site modification that may potentially impact the continued operability of the ISFSI must be evaluated for acceptability under 10CFR72.212. A generic evaluation of the shielding consequences of digging a cavity adjacent to the radiation protection zone has been considered in Supplement 5.I of this FSAR. The analyses show that the dose at the edge of the cavity is below 0.2 mrem/hr, which is well below the customary limit that requires radiation posting at nuclear power plants.

Subsection 2.I.4 considers loadings from extreme environmental phenomena assuming that a deep cavity at the edge of the RPS perimeter has been created as a part of site construction work and an accidental mechanical loading event across such cavity is credible. Analyses summarized in Subsection 3.I.4 show that the design basis projectiles (large, medium, or small), specified in

Chapter 2 of this FSAR, applied in the most vulnerable location of the construction cavity, will fail to reach the CEC.

In addition to the generic analyses documented in this FSAR to validate the sufficiency of the RPS boundary, analyses of the consequences of any credible site specific loads or events during site construction work shall be performed with due consideration of the duration and nature of the site construction activity. The user's §72.212 evaluation program, used in considering ISFSI-proximate activities at aboveground ISFSIs, shall apply to the HI-STORM 100U installation as well without limitation.

To summarize, as discussed in Supplement 2.I and documented in the licensing drawing package in Section 1.5, and the technical specifications; a radiation protection space (RPS) has been established per supplement 5.I with sufficient margin (ground buffer) against design basis projectiles analyzed in supplement 3.I. As documented in the technical specifications, the RPS boundary shall not be encroached upon during any site construction activity (this includes excavation). For additional defense in depth, subsection 2.I.6 (xii) requires that the ISFSI owner construct a retaining wall to protect the subgrade in the RPS against an accidental encroachment by personnel engaged in excavation work contiguous to the RPS, if a future construction adjacent to the ISFSI is planned. In addition to the generic analyses documented in this FSAR, site specific evaluation pursuant to §72.212 shall be performed for all other credible hazards that can be postulated during site construction. Administrative controls to guard against accidental human error in excavations (such as encroachment of the RPS) shall be addressed through written procedures consistent with the required controls needed for a safety significant activity within a Part 50 controlled area.

Subsection 2.I.6(xii) also requires the ISFSI owner to perform a seismic analysis of the ISFSI for the instance when the maximum amount of excavation of the area adjacent to the RPS will exist. The site's Design Basis Earthquake (DBE) will be used. PRA considerations shall not be used to diminish the strength of the seismic input. The Design Basis Seismic Model, described in 3.I.4, shall be used with appropriate representation of the construction cavity.

Because the actual projectiles for a specific ISFSI site are often different from the tornado borne missiles analyzed in Supplement 3.I herein, a site specific analysis of the effect of all credible missiles shall be performed assuming that the largest construction cavity adjacent to the ISFSI exists. PRA considerations shall not be used to rule out any missile that has been determined to be credible in the plant's FSAR.

Furthermore, the ISFSI owner ~~is encouraged to~~ shall implement ameliorative measures to prevent unacceptable damage to the ISFSI from ~~all~~any other credible adverse ~~effects~~ scenarios unique to a site that has not been considered in this FSAR.~~of a construction activity on a "100U" ISFSI at a specific site~~ An ~~E~~example~~s~~ of such a measure~~s~~ ~~are~~is the installation of ~~a retaining wall to prevent soil erosion or of~~ a berm to protect against environmental events such as soil erosion and mud slides. Such site specific design initiatives at any "100U" ISFSI, like its aboveground counterpart, are within the purview of the plant's §72.212 process.