CHAPTER 12†: ACCIDENT ANALYSIS

12.0 INTRODUCTION

This chapter presents the evaluation of the HI-STORM FW System for the effects of off-normal and postulated accident conditions; and other scenarios that warrant safety analysis (such as MPC reflood during fuel unloading operations), pursuant to the guidelines in NUREG-1536. The design basis off-normal and postulated accident events, including those based on non-mechanistic postulation as well as those caused by natural phenomena, are identified. For each postulated event, the event cause, means of detection, consequences, and corrective actions are discussed and evaluated. For other miscellaneous events (i.e., those not categorized as either design basis off-normal or accident condition events), a similar outline for safety analysis is followed. As applicable, the evaluation of consequences includes the impact on the structural, thermal, shielding, criticality, confinement, and radiation protection performance of the HI-STORM FW System due to each postulated event.

The structural, thermal, shielding, criticality, and confinement features and performance of the HI-STORM FW System under the short-term operations and various conditions of storage are discussed in Chapters 3, 4, 5, 6, and 7. The evaluations provided in this chapter are based on the design features and analyses reported therein.

Chapter 12 is in full compliance with NUREG-1536; no exceptions are taken.

† This chapter has been prepared in the format and section organization set forth in Regulatory Guide 3.61. However, the material content of this chapter also fulfills the requirements of NUREG-1536. Pagination and numbering of sections, figures, and tables are consistent with the convention set down in Chapter 1, Section 1.0, herein. Finally, all terms-of-art used in this chapter are consistent with the terminology of the Glossary.

12.1 OFF-NORMAL CONDITIONS

Off-normal operations, as defined in accordance with ANSI/ANS-57.9, are those conditions, which, although not occurring regularly, are expected to occur no more than once a year. In this section, design events pertaining to off-normal operation for expected operational occurrences are considered. The off-normal conditions are described in Subsection 2.2.2.

The following off-normal operation events have been considered in the design of the HI-STORM FW:

1. Off-Normal Pressure
2. Off-Normal Environmental Temperatures
3. Leakage of One Seal
4. Partial Blockage of Air Inlets
5. Malfunction of FHD System

For each event, the postulated cause of the event, detection of the event, analysis of the event effects and consequences, corrective actions, and radiological impact from the event are presented.

The results of the evaluations performed herein demonstrate that the HI-STORM FW System can withstand the effects of off-normal events and remain in compliance with the applicable acceptance criteria. The following subsections present the evaluation of the HI-STORM FW System for the design basis off-normal conditions that demonstrate that the requirements of 10CFR72.122 are satisfied, and that the corresponding radiation doses meet the requirements of 10CFR72.104(a) and 10CFR20, with appropriate margins.

12.1.1 Off-Normal Pressure

The sole pressure boundary in the HI-STORM FW System is the MPC enclosure vessel. The off-normal pressure condition is specified in Subsection 2.2.2. The off-normal pressure for the MPC internal cavity is a function of the initial helium fill pressure and the temperature reached within the MPC cavity under normal storage. The MPC internal pressure under the off-normal condition is evaluated with 10% of the fuel rods ruptured and with 100% of ruptured rods fill gas and 30% of ruptured rods fission gases released to the cavity.

12.1.1.1 Postulated Cause of Off-Normal Pressure

After fuel assembly loading, the MPC is drained, dried, and backfilled with an inert gas (helium) to assure long-term fuel cladding integrity during dry storage. Therefore, the probability of failure of intact fuel rods in dry storage is extremely low. Nonetheless, the event is postulated and evaluated.

12.1.1.2 Detection of Off-Normal Pressure

The HI-STORM FW System is designed to withstand the MPC off-normal internal pressure without any effects on its ability to meet its safety requirements. There is no requirement or safety imperative for detection of off-normal pressure and, therefore, no monitoring is required.

12.1.1.3 Analysis of Effects and Consequences of Off-Normal Pressure

The MPC off-normal internal pressure is reported in Subsection 4.6.1 for the following conditions: limiting fuel storage scenario, tech. spec. maximum helium backfill pressure with a 10% rod rupture that causes a 100% of the ruptured rod fill gas and 30% of the ruptured rod gaseous fission products released into the MPC cavity along with off-normal ambient temperature. The analysis shows that the MPC pressure remains below the design MPC internal pressure (given in Table 2.2.1). The corresponding fuel cladding temperature is provided in Table 4.6.1. It should be noted that this bounding temperature rise does not take any credit for the increase in thermosiphon action that would accompany the pressure increase that results from both the temperature rise and the addition of the gaseous fission products to the MPC cavity. As any such increase in thermosiphon action would reduce the temperature rise, therefore the calculated pressure is higher than that would actually occur.

i. Structural

The structural evaluation of the MPC enclosure vessel for off-normal internal pressure conditions is discussed in Section 3.4. The stresses resulting from the off-normal pressure are confirmed to be bounded by the applicable pressure boundary stress limits.

ii. Thermal

The MPC internal pressure for off-normal conditions is reported in Subsection 4.6.1. The design basis internal pressure used in the structural evaluation (Table 2.2.1) bounds the off-normal condition pressure.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

v. 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 above, all pressure boundary stresses remain within allowable ASME Code values, assuring Confinement Boundary integrity.

vi. 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 FW System.

12.1.1.4 Corrective Action for Off-Normal Pressure

The HI-STORM FW System is designed to withstand the off-normal pressure without any effects on its ability to maintain safe storage conditions. Therefore, there is no corrective action requirement for off-normal pressure.

12.1.1.5 Radiological Impact of Off-Normal Pressure

The event of off-normal pressure has no radiological impact because the confinement barrier and shielding integrity are not affected.

12.1.2 Off-Normal Environmental Temperatures

The HI-STORM FW System is designed for use at any site in the United States. Off-normal environmental temperatures of -40 to 100°F (loaded HI-STORM FW overpack) and 0°F to 100°F (loaded HI-TRAC VW transfer cask) have been conservatively selected to bound off-normal temperatures at these sites. The off-normal temperature range affects the entire HI-STORM FW System and must be evaluated against the allowable component design temperatures. The off-normal temperatures are evaluated against the off-normal condition temperature limits for HI-STORM FW components listed in Table 2.2.3.

12.1.2.1 Postulated Cause of Off-Normal Environmental Temperatures

The off-normal environmental temperature is postulated as a constant ambient temperature caused by extreme weather conditions. To determine the effects of the off-normal temperatures, it is conservatively assumed that these temperatures persist for a sufficient duration to allow the HI-STORM FW System to achieve thermal equilibrium. Because of the large mass of the HI-STORM FW System with its corresponding large thermal inertia and the limited duration for the off-normal temperatures, this assumption is conservative.

12.1.2.2 Detection of Off-Normal Environmental Temperatures

The HI-STORM FW System is designed to withstand the off-normal environmental temperatures without any effects on its ability to maintain safe storage conditions. There is no requirement for detection of off-normal environmental temperatures for the HI-STORM FW overpack and MPC. Chapter 2 provides operational limitations on the use of the HI-TRAC VW transfer cask at temperatures ≤32°F and prohibits use of the HI-TRAC VW transfer cask below 0°F.

12.1.2.3 Analysis of Effects and Consequences of Off-Normal Environmental Temperatures

The off-normal event considers an environmental temperature of 100°F with insolation for sufficient duration to reach thermal equilibrium. The evaluation is performed for a limiting fuel storage configuration. The Off-Normal ambient temperature condition is evaluated in Subsection 4.6.1. The results are in compliance with off-normal pressure and temperature limits in Tables 2.2.1 and 2.2.3, respectively.

The off-normal event considering an environmental temperature of -40°F and no solar insolation for a sufficient duration to reach thermal equilibrium is evaluated with respect to material design temperatures of the HI-STORM FW overpack. The HI-STORM FW overpack and MPC are conservatively assumed to reach -40°F throughout the structure. The minimum off-normal environmental temperature specified for the HI-TRAC VW transfer cask is 0°F and the HI-TRAC VW is conservatively assumed to reach 0°F throughout the structure. Subsection 3.1.2, details the structural analysis and testing performed to assure prevention of brittle fracture failure of the HI-STORM FW System.

i. Structural

The effect on the MPC for the upper off-normal thermal conditions (i.e., 100°F) is an increase in the internal pressure. As shown in Subsection 4.6.1, the resultant pressure is below the off-normal design pressure (Table 2.2.1). The stresses resulting from the off-normal pressure are confirmed to be bounded by the applicable pressure boundary stress limits. 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 Subsection 3.1.2.

ii. Thermal

The resulting off-normal system and fuel assembly cladding temperatures for the hot conditions are provided in Subsection 4.6.1 for the HI-STORM FW overpack and MPC. The evaluation in Subsection 4.6.1 indicates that all temperatures for the off-normal environmental temperatures event are within the allowable values for off-normal conditions listed in Table 2.2.3.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

v. 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 above, all pressure boundary stresses remain within allowable ASME Code values, assuring Confinement Boundary integrity.

vi. 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 FW System.

12.1.2.4 Corrective Action for Off-Normal Environmental Temperatures

The HI-STORM FW System is designed to withstand the off-normal environmental temperatures without any effects on its ability to maintain safe storage conditions. For ambient temperatures from 0° to 32°F, ethylene glycol fortified water must be used in the water jacket of the HI-TRAC VW transfer cask to prevent freezing. There are no corrective actions required for off-normal environmental temperatures.

12.1.2.5 Radiological Impact of Off-Normal Environmental Temperatures

Off-normal environmental temperatures have no radiological impact, as the confinement barrier and shielding integrity are not affected.

12.1.3 Leakage of One Seal

The HI-STORM FW System has a high integrity welded boundary to contain radioactive fission products within the Confinement Boundary. The Confinement Boundary is defined by the MPC shell, baseplate, MPC lid, vent and drain port cover plates, closure ring, and associated welds. The closure ring provides a redundant welded closure to further protect against the release of radioactive material from the MPC cavity through the field-welded MPC lid closures. Confinement boundary welds are inspected by radiography or ultrasonic examination except for field welds that are examined by the liquid penetrant method on the root (for multi-pass welds) and final pass, at a minimum. The fabrication shop welds for the confinement boundary are tested for helium leakage. Field welds are performed on the MPC lid, the MPC vent and drain port covers, and the MPC closure ring. The welds on the vent and drain port cover plates are helium leakage tested. Additionally, the MPC lid weld is subjected to a pressure test to verify its integrity. There are no seals present in the design of the MPC confinement boundary.

Section 7.1 provides the narrative that demonstrates that the MPC design, welding, testing and inspection meet the requirements such that leakage from the Confinement Boundary is considered non-credible.

12.1.4 Partial Blockage of Air Inlets

The HI-STORM FW System is designed with debris screens on the inlet and outlet air openings. These screens ensure the openings are protected from the incursion of foreign objects. There are multiple inlet openings and an axisymmetric outlet and it is highly unlikely that blowing debris during normal or off-normal operation could block all air inlet openings. As required by the design criteria presented in Chapter 2, it is conservatively assumed that 50% of the air inlet openings are completely blocked. The scenario of the partial blockage of air inlets is evaluated with a normal ambient temperature of 80°F (Table 2.2.2), full solar insolation, and maximum SNF decay heat values. This condition is analyzed to demonstrate the thermal performance of the HI-STORM FW System during this event.

12.1.4.1 Postulated Cause of Partial Blockage of Air Inlets

The presence of screens prevents foreign objects from entering the openings and the screens are either inspected periodically or the outlet air temperature is monitored per the technical specifications. It is, however, possible that blowing debris may partially block the inlet openings for a short time until the openings are cleared of debris.

12.1.4.2 Detection of Partial Blockage of Air Inlets

The detection of the partial blockage of air inlet openings will occur during the routine visual inspection of the screens or temperature monitoring of the outlet air required by the technical specifications. The frequency of inspection is based on an assumed complete blockage of all air inlet openings. There is no inspection requirement as a result of the postulated partial inlet blockage, because the complete blockage of all air inlet openings is bounding.

12.1.4.3 Analysis of Effects and Consequences of Partial Blockage of Air Inlets

i. Structural

There are no structural consequences as a result of this off-normal event since the HI-STORM FW components do not exceed the off-normal temperature limits (Table 2.2.3).

ii. Thermal

The thermal analysis for the 50% blocked inlet openings off-normal condition is performed in Subsection 4.6.1. The analysis demonstrates that under bounding (steady-state) conditions, no system components exceed the off-normal temperature limits in Table 2.2.3.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event.

vi. 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 openings does not affect the safe operation of the HI-STORM FW System.

12.1.4.4 Corrective Action for Partial Blockage of Air Inlets

The corrective action for the partial blockage of air inlet openings is the removal, cleaning, and replacement of the affected mesh screens. After clearing of the blockage, the storage module temperatures will return to the normal temperatures reported in Chapter 4. Partial blockage of air inlet openings does not affect the safe operation of the HI-STORM FW System.

Periodic inspection of the HI-STORM FW overpack air opening screens is required per the technical specifications. Alternatively, per the technical specifications, the outlet air temperature is monitored. The frequency of inspection is based on an assumed blockage of all air inlet openings analyzed in Section 12.2.

12.1.4.5 Radiological Impact of Partial Blockage of Air Inlets

The off-normal event of partial blockage of the air inlet openings has no radiological impact because the confinement barrier is not breached and the system's shielding effectiveness is not diminished.

12.1.5 Malfunction of FHD System

A FHD system is a forced helium circulation device used to effectuate moisture removal from loaded MPCs. For circulating helium, a FHD system is equipped with active components requiring external power for normal operation.

12.1.5.1 Postulated Cause of FHD Malfunction

Likely causes of FHD malfunction are (i) a loss of external power to the FHD System and (ii) an active component trips the FHD System. In both cases a stoppage of forced helium circulation occurs. Such a circulation stoppage does not result in helium leakage from the MPC or the FHD.

12.1.5.2 Detection of FHD Malfunction

The FHD System is monitored during its operation. An FHD malfunction is detected by operator response to control panel visual displays and alarms.

12.1.5.3 Analysis of Effects and Consequences of FHD Malfunction

i. Structural

The FHD System is required to be equipped with safety relief devices* to prevent the MPC structural boundary pressures from exceeding the normal condition pressure limits. Consequently there is no adverse effect.

ii. Thermal

Malfunction of the FHD System is categorized as an off-normal condition, for which the

* The relief pressure is below the off-normal design pressure (Table 2.2.1) to prevent MPC overpressure and above 7 atm to enable MPC pressurization for adequate heat transfer.

applicable peak cladding temperature limit (see Table 2.2.3) must not be exceeded. The FHD System malfunction event is evaluated assuming the following bounding conditions:

a. Steady state maximum temperatures have been reached
b. Design maximum heat load in the limiting MPC-37
c. Air in the HI-TRAC VW annulus
d. The helium pressure in the MPC is at the minimum possible value from the technical specification.

The results of a steady state analysis (which implies an extended period of FHD unavailability) are provided in Section 4.6. The results provide the assurance that the peak fuel cladding temperature in the MPC will remain below the ISG-11 limit (see Table 2.2.3) in the event of a prolonged unavailability of the FHD system under the most thermally adverse conditions (highest possible heat load absence of any forced heat removal measures and minimum system helium pressure).

iii. Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

iv. Criticality

There is no effect on the criticality control of the system as a result of this off-normal event.

v. 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 above, the MPC structural boundary internal pressures cannot exceed the normal condition pressure limits, assuring Confinement Boundary integrity.

vi. Radiation Protection

As there is no adverse effect on the shielding or confinement functions, 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 FHD malfunction does not affect the safe operation of the HI-STORM FW System.

12.1.5.4 Corrective Action for FHD Malfunction

The HI-STORM FW System is designed to withstand the FHD malfunction without an adverse effect on its safety functions. Consequently no corrective action is required.

12.1.5.5 Radiological Impact of FHD Malfunction

The event has no radiological impact because the confinement barrier and shielding integrity are not affected.

12.2 ACCIDENTS

Accidents, in accordance with ANSI/ANS-57.9, are either infrequent events that could reasonably be expected to occur during the lifetime of the HI-STORM FW System or events postulated because their consequences may affect the public health and safety. Subsection 2.2.3 defines the design basis accidents considered. By analyzing for these design basis events, safety margins inherently provided in the HI-STORM FW System design can be quantified.

The results of the evaluations performed herein demonstrate that the HI-STORM FW System can withstand the effects of all credible and hypothetical accident conditions and natural phenomena without affecting safety function, and are in compliance with the acceptable criteria. In the following, the evaluation of the design basis postulated accident conditions and natural phenomena is presented. The evaluations demonstrate that the requirements of 10CFR72.122 are satisfied, and that the corresponding radiation doses satisfy the requirements of 10CFR72.106(b) and 10CFR20.

The load combinations evaluated for postulated accident conditions are defined in Table 2.2.13. The accident load combination evaluations are provided in Section 3.4.

Table 12.2.1 provides a listing of the accident events considered in this section and their probability of occurrence.

12.2.1 HI-TRAC VW Transfer Cask Handling Accident

During the operation of the HI-STORM FW System, the loaded HI-TRAC VW transfer cask is lifted and handled in a vertical orientation at all times (with the rare handling exception of the transfer cask as described in Subsection 4.5.1). A vertical drop of the loaded HI-TRAC VW transfer cask is not a credible accident as the loaded HI-TRAC VW transfer cask shall be lifted and handled in the vertical orientation by devices designed in accordance with the criteria specified in Subsection 2.3.3 to prevent uncontrolled lowering. Therefore, postulating an uncontrolled lowering of a HI-TRAC VW transfer cask in the realm of Part 72 operations is non-credible.

12.2.2 HI-STORM FW Overpack Handling Accident

During the operation of the HI-STORM FW System, the loaded HI-STORM FW overpack is lifted and handled in a vertical orientation at all times. A vertical drop of the loaded HI-STORM FW is not a credible accident as the loaded HI-STORM FW shall be lifted and handled in the vertical orientation by devices designed in accordance with the criteria specified in Subsection 2.3.3 to prevent uncontrolled lowering. Therefore, postulating an uncontrolled lowering of a HI-STORM FW in the Part 72 space is non-credible.

12.2.3 HI-STORM FW Overpack Non-Mechanistic Tip-Over

The freestanding HI-STORM FW storage overpack, containing a loaded MPC, cannot tip over as a result of postulated natural phenomenon events, including tornado wind, a tornado-generated missile, a seismic or a hydrological event (flood). However, to demonstrate the defense-in-depth features of the design, a *non-mechanistic* tip-over scenario per NUREG-1536 is analyzed (Subsection 2.2.3) in Chapter 3.

12.2.3.1 Cause of Tip-Over

The tip-over accident is stipulated as a non-mechanistic accident because a credible mechanism for the cask to tip over cannot be identified. Detailed discussions are provided in Subsections 3.1.2 and 3.4.4.

However, it is recognized that the mechanical loadings at a specific ISFSI may be sufficiently strong to cause a tip-over event, even though such a scenario is determined to be counterfactual under the loads treated in this FSAR. To enable the safety evaluation of a postulated tip-over scenario, it is necessary to set down an analysis methodology and the associated acceptance criteria. In Sections 2.2 and 3.4, the methodology and acceptance criteria are presented and a reference tip-over problem is solved. The reference tip-over problem corresponds to a free rotation of the HI-STORM FW overpack from the condition of rest at the incipient tipping point (i.e., C.G.-over-corner). The evaluations presented below refer to the above non-mechanistic tip-over scenario.

12.2.3.2 Tip-Over Analysis

The tip-over accident analysis evaluates the effects of the loaded overpack tipping-over onto a reinforced concrete pad. The tip-over analysis is provided in Subsection 3.4.4. The structural analysis demonstrates the following:

(i) The lateral plastic deformation of the basket panels in the active fuel region is less than the limiting value in Table 2.2.11.

(ii) The impact between the MPC guide tubes and the MPC does not cause a thru-wall penetration of the MPC shell.

The side impact will cause some localized damage to the concrete and outer shell of the overpack in the local area of impact. However, there is no significant adverse effect on the structural, confinement, thermal, or criticality performance.

As mentioned earlier the non-mechanistic tip-over accident has been addressed to demonstrate the defense-in-depth features of the design.

12.2.3.3 Tip-over Accident Corrective Actions

Corrective action after a tip-over would include a radiological and visual inspection to determine the extent of the damage to the overpack and the contained MPC. Special handling procedures, including the use of temporary shielding, will be developed and approved by the ISFSI operator.

12.2.4 Fire

12.2.4.1 Cause of Fire

The potential of a fire accident near an ISFSI pad is considered to be rendered extremely remote by ensuring that there are no significant combustible materials in the area. The only credible concern is related to a transport vehicle fuel tank fire engulfing the loaded HI-STORM FW overpack or HI-TRAC VW transfer cask during their handling.

12.2.4.2 Fire Analysis

The HI-STORM FW System must withstand elevated temperatures due to a fire event. The HI-STORM FW overpack and HI-TRAC VW transfer cask fire accidents for storage are conservatively postulated as described in Subsection 4.6.2. The acceptance criteria for the fire accident are provided in Subsection 2.2.3.

12.2.4.2.1 Fire Analysis for HI-STORM FW Overpack

The analysis for the fire accident including the methodology has been provided in Subsection 4.6.2. The transport vehicle fuel tank fire has been analyzed to evaluate the outer layers of the storage overpack heated by the incident thermal radiation and forced convection heat fluxes and to evaluate fuel cladding and MPC temperatures.

i. Structural

As discussed in Section 3.4, there are no structural consequences as a result of the fire accident condition since the short-term temperature limit on great majority of the concrete is not exceeded and all component temperatures remain within applicable temperature limits (Table 2.2.3). The MPC structural boundary remains within normal condition internal pressure and temperature limits.

ii. Thermal

Based on a conservative analysis discussed in Subsection 4.6.2, of the HI-STORM FW System response to the hypothetical fire event, it is concluded that the fire event does not significantly affect the temperature of the MPC or contained fuel. Furthermore, the ability of the HI-STORM FW System to maintain cooling of the spent nuclear fuel within temperature limits (Table 2.2.3) during and after fire is not compromised.

iii. 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 FSAR." Less than one-inch of the overpack concrete (~4% of the overpack radial concrete thickness) is computed to exceed the short-term temperature limit therefore the effect of this small amount of degraded (not lost) shielding material is not estimated or evaluated in this FSAR.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event since the structural integrity of the confinement boundary is unaffected.

vi. Radiation Protection

Since there is minimal reduction, if any, 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 FW System.

12.2.4.2.2 Fire Analysis for HI-TRAC VW Transfer Cask

To demonstrate the fuel cladding and MPC pressure boundary integrity under an exposure to a hypothetical short duration fire event during on-site handling operations, a fire accident analysis of the loaded HI-TRAC VW transfer cask is performed. The analysis for the fire accident including the methodology has been provided in Subsection 4.6.2.

i. Structural

As discussed in Section 3.4, there are no adverse structural consequences as a result of the fire accident condition.

ii. Thermal

The thermal analysis of the MPC in the HI-TRAC VW transfer cask under a fire accident is performed in Subsection 4.6.2. The analysis shows that the MPC internal pressure and fuel temperature increases as a result of the fire accident. The fire accident MPC internal pressure and peak fuel cladding temperature are substantially less than the accident limits for MPC internal pressure and maximum cladding temperature (Tables 2.2.1 and 2.2.3).

As can be concluded from the analysis, the temperatures for fuel cladding and components are below the accident temperature limits.

iii. Shielding

The conservatively assumed loss of all the water in the water jacket results in an increase in the radiation dose rates at locations adjacent to the water jacket. The shielding evaluation presented in Chapter 5 demonstrates that the requirements of 10CFR72.106 are not exceeded.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event, since the internal pressure does not exceed the accident condition design pressure and the MPC Confinement Boundary temperatures do not exceed the short-term allowable temperature limits.

vi. Radiation Protection

There is no degradation in confinement capabilities of the MPC, as discussed above. Increases in the local dose rates adjacent to the water jacket are evaluated in Chapter 5. Immediately after the fire accident a radiological inspection of the HI-TRAC VW transfer cask shall be performed and temporary shielding shall be installed if necessary to limit exposure to site personnel.

12.2.4.3 Fire Dose Calculations

The complete loss of the HI-TRAC VW transfer cask neutron shield along with the water jacket shell is assumed in the shielding analysis for the post-accident analysis of the loaded HI-TRAC VW transfer cask in Chapter 5 and bounds the determined fire accident consequences. The loaded HI-TRAC VW transfer cask following a fire accident meets the accident dose rate requirement of 10CFR72.106.

The elevated temperatures experienced by the HI-STORM FW overpack concrete shield are limited to the outermost layer of steel and concrete. Therefore, overall reduction in neutron shielding capabilities is quite small. Any increase in the neutron dose rate as a result of the concrete in the outer inch reaching elevated temperatures will not significantly increase the site boundary dose rate. This is due to the limited amount of the concrete shielding which is affected and the already low site boundary dose rates. The loaded HI-STORM FW overpack following a fire accident meets the accident dose rate requirement of 10CFR72.106.

The analysis of the fire accident shows that the MPC Confinement Boundary is not compromised and therefore, there is no release of airborne radioactive materials.

12.2.4.4 Fire Accident Corrective Actions

Upon detection of a fire adjacent to a loaded HI-TRAC VW transfer cask or HI-STORM FW overpack, the ISFSI owner shall take the appropriate immediate actions necessary to extinguish the fire. Fire fighting personnel should take appropriate radiological precautions, particularly with the HI-TRAC VW transfer cask as the water jacket rupture discs may open with resulting water loss and increase in radiation doses. Following the termination of the fire, a visual and radiological inspection of the equipment shall be performed.

As appropriate, temporary shielding around the HI-TRAC VW transfer cask shall be installed. Specific attention shall be taken during the inspection of the water jacket of the HI-TRAC VW transfer cask. If damage to the HI-TRAC VW transfer cask is limited to the loss of water in the water jacket due to the pressure increase, the water may be replaced. If damage to the HI-TRAC VW transfer cask is extensive and/or radiological conditions require (based on dose rate measurements), the HI-TRAC VW transfer cask shall be unloaded in accordance with Chapter 9, prior to repair.

If damage to the HI-STORM FW storage overpack as the result of a fire event is widespread and/or as radiological conditions require (based on dose rate measurements), the MPC shall be removed from the HI-STORM FW overpack in accordance with Chapter 9. However, the thermal analysis described herein demonstrates that only the outermost layer of the radial concrete which is behind the carbon steel outer shell exceeds its design temperature. The HI-STORM FW overpack may be returned to service after appropriate restoration (reapplication of coatings etc.) if there is no significant increase in the measured dose rates (i.e., the shielding effectiveness of the overpack is confirmed) and if the visual inspection is satisfactory.

12.2.5 Partial Blockage of MPC Basket Flow Holes

Each MPC basket fuel cell wall has flow holes near the bottom to allow thermosiphon action to assist the cooling of MPC internals. The flow holes in the bottom of the fuel basket in each MPC are located to ensure that the amount of crud listed in Table 2.2.8 does not block the internal helium circulation. Therefore the partial blockage of the HI-STORM FW MPC basket flow holes is not credible.

12.2.6 Tornado

12.2.6.1 Cause of Tornado

The HI-STORM FW System will be stored on an unsheltered ISFSI concrete pad and thus will be subject to ambient environmental conditions throughout the storage period. Additionally, the transfer of the MPC between the HI-TRAC VW transfer cask and the storage overpack may be performed at the unsheltered ISFSI concrete pad. It is therefore possible that the HI-STORM FW System (and/or the HI-TRAC VW transfer cask) may experience the extreme environmental conditions, resulting in the impact from a tornado-borne projectile.

12.2.6.2 Tornado Analysis

A tornado event is characterized by high wind velocities and tornado-generated missiles. The reference missiles considered in this FSAR (see Section 2.2) are of three sizes: small, medium, and large. A small projectile, upon collision with a cask, would tend to penetrate it. A large projectile, such as an automobile, on the other hand, would tend to destabilize a free-standing cask. Accordingly, the tornado event has two distinct effects on the HI-STORM FW System. First, the tornado winds and/or tornado missile attempt to tip-over the loaded HI-STORM FW overpack or HI-TRAC VW transfer cask. The pressure loading of the high velocity winds and/or the impact of the large tornado missiles act to apply an overturning moment. The second effect is tornado missiles propelled by high velocity winds, which attempt to penetrate the HI-STORM FW overpack or HI-TRAC VW transfer cask.

During handling operations at the ISFSI pad, the loaded HI-TRAC VW transfer cask, while in the vertical orientation, shall be attached to a lifting device designed in accordance with the requirements specified in Subsection 2.3.3. Therefore, it is not credible that the tornado missile and/or wind could tip-over the loaded HI-TRAC VW transfer cask while it is being handled in the vertical orientation. Penetration by a small missile, however, is credible. The tornado wind and missile are assumed to act synergistically in the safety evaluation in Section 3.4 to determine the kinematic stability of the HI-STORM FW overpack.

i. Structural

Section 3.4 provides the analysis of the pressure loading which attempts to tip-over the HI-STORM FW overpack and the analysis of the effects of the different types of tornado missiles. These analyses show that the loaded storage overpack does not tip-over as a result of the tornado winds and/or large tornado missiles.

Analyses provided in Section 3.4 also show that there is a potential for a tornado missile (8 inch steel cylinder) to penetrate the water jacket of the HI-TRAC VW transfer cask. The HI-STORM FW overpack will suffer minor local damages due to the missile impact with no significant damage in the shielding and there will be no damage to the MPC.

ii. Thermal

The thermal consequences of the complete loss of water due to rupture of the water jacket from a tornado missile has been analyzed in Section 4.6. It has been demonstrated that the consequences are within the short term fuel cladding and material temperature limits.

iii. Shielding

Since the structural evaluation shows that the tornado missiles may penetrate the HI-TRAC VW water jacket and cause loss of water, for a conservative estimate of the dose rates a complete loss of water in the water jacket is assumed and is bounded by the fire condition assumptions. This assumption results in an increase in the radiation dose rates however the shielding analysis results presented in Chapter 5 demonstrate that the requirements of 10CFR72.106 are not exceeded.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event.

vi. Radiation Protection

HI-STORM FW overpack: There is no degradation in confinement capabilities of the MPC, since the tornado missiles do not impact the MPC. Since there is only a possibility of minimal reduction in localized shielding and there is 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.

HI-TRAC VW transfer cask: There is no degradation in confinement capabilities of the MPC, since the tornado missiles do not impact the MPC. Increases in the local dose rates as a result of the possible loss of water in the HI-TRAC VW transfer cask water jacket are evaluated in Chapter 5. Immediately after the tornado accident a radiological inspection of the HI-TRAC VW transfer cask shall be performed and temporary shielding shall be installed if necessary to limit the exposure to the site personnel.

12.2.6.3 Tornado Dose Calculations

The tornado winds do not tip-over the loaded HI-STORM FW overpack; damage the shielding materials of the HI-STORM FW overpack or HI-TRAC VW transfer cask; or damage the MPC Confinement Boundary. There is no affect on the radiation dose as a result of the tornado winds.

A tornado missile may cause localized damage in the concrete radial shielding of the HI-STORM FW overpack. However, the damage will have a negligible effect on the site boundary dose. A tornado missile may penetrate the HI-TRAC VW transfer cask water jacket shell causing the loss of the neutron shielding (water). The effects of the tornado missile damage on the loaded HI-TRAC

VW transfer cask is bounded by the post-accident dose assessment performed in Chapter 5, which conservatively assumes complete loss of the water in the water jacket and the water jacket shell.

12.2.6.4 Tornado Accident Corrective Action

Following exposure of the HI-STORM FW System to a tornado, the ISFSI owner shall perform a visual and radiological inspection of the overpack and/or HI-TRAC VW transfer cask.

Damage sustained by the overpack outer shell, concrete, or vent screens shall be inspected and may be repaired, if required, while in-service. The HI-STORM FW overpack may continue its service after appropriate restoration (reapplication of coatings etc.) if there is no significant increase in the measured dose rates (i.e., the overpack's shielding effectiveness is confirmed) and if the final visual inspection is satisfactory.

Damage sustained by the HI-TRAC VW transfer cask shall be inspected and repaired. As appropriate, temporary shielding around the HI-TRAC VW transfer cask shall be installed. If damage to the HI-TRAC VW transfer cask water jacket or HI-TRAC VW transfer cask body is extensive and/or radiological conditions require (based on dose rate measurements), the HI-TRAC VW transfer cask shall be unloaded in accordance with Chapter 9, prior to repair.

12.2.7 Flood

12.2.7.1 Cause of Flood

Many ISFSIs are located in flood plains susceptible to floods. Therefore, it is necessary for such ISFSIs to define a Design Basis Flood (DBF). The potential sources for the flood water could be unusually high water from a river or stream, a dam break, a seismic event, or a hurricane.

A flood event is characterized by two parameters:

a. flood water velocity
b. flood height over the ISFSI pad as a function of time

The design basis flood (DBF) event for an ISFSI site should provide the maximum flood water velocity. The highest flood height, on the other hand, is not the governing condition for the flood event because of the vented construction of the overpack. The bottom vents in the HI-STORM FW overpack ensure that the flood level inside and outside the overpack will be equal. When the flood waters are high and the MPC is fully submerged then there is no short-term threat to the storage system because the MPC's heat rejection to water is far more efficient than the (normal condition) heat rejection to air. The most adverse flood condition, therefore, exists when the flood waters are high enough to block the inlet openings but no higher. In this scenario, the MPC surface has minimum submergence in water and the ventilation air is completely blocked. In fact, as the flood water begins to accumulate on the ISFSI pad, the air passage size in the inlet vents begins to get smaller. Therefore, the rate of floodwater rise with time is necessary to analyze the thermal-hydraulic problem. For the reference design basis flood (DBF) analysis in this FSAR, the flood waters are assumed to rise instantaneously to the height to block the inlet vents and stay at that precise elevation for 32 hours. For each ISFSI site subject to a DBF, the flood time-history will be incorporated in determining the acceptability of the flood event. The acceptance criteria are provided in Section 2.2.

The analysis results for the reference DBF are presented below.

12.2.7.2 Flood Analysis

i. Structural

The flood accident affects the HI-STORM FW overpack structure in two ways. The flood water velocity acts to apply an overturning moment, which attempts to tip-over the loaded overpack. The flood accident affects the MPC by applying an external pressure.

Section 3.4 provides the analysis of the flowing floodwater applying an overturning moment. The results of the analysis show that the loaded overpack does not tip over if the flood velocity does not exceed the value stated in Table 2.2.8.

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.

ii. Thermal

As stated above, for a flood of sufficient height to allow the water to come into extensive contact with the MPC, there is no adverse effect on the thermal performance of the system. The thermal consequence of such a flood is an increase in the rejection of the decay heat. Because the storage overpack is ventilated, water from a submerged flood will enter the annulus between the MPC and the overpack. The water would provide cooling that would be an order of magnitude greater than that available in the air filled annulus (due to water's higher heat transfer coefficient).

The reference DBF that is most adverse to heat rejection is treated for 100% blockage of air inlets in Subsection 12.2.13. If the duration of the flood blockage exceeds the DBF blockage specified in Subsection 4.6.2 then a site specific evaluation shall be performed in accordance with the methodology presented in Chapter 4 and evaluated for compliance with Subsection 2.2.3 criteria.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this event. The flood water provides additional shielding that reduces radiation doses.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this 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 fuel pool, which is presented in Section 6.1.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring Confinement Boundary integrity.

vi. 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 event.

Based on this evaluation, it is concluded that the flood accident does not affect the safe operation of the HI-STORM FW System.

12.2.7.3 Flood Dose Calculations

Since the flood accident produces no leakage of radioactive material and no reduction in shielding effectiveness, there are no adverse radiological consequences.

12.2.7.4 Flood Accident Corrective Action

As shown in the analysis of the flood accident, the HI-STORM FW System sustains no damage as a result of the flood, which is a short-duration event. At the completion of the flood, exposed surfaces may need debris and adherent foreign matter removal.

12.2.8 Earthquake

12.2.8.1 Cause of Earthquake

The HI-STORM FW System may be employed at any reactor or ISFSI facility in the United States. It is possible that during the use of the HI-STORM FW System, the ISFSI may experience an earthquake. The earthquake event postulated for the ISFSI is referred to as the “Design Basis Earthquake” (DBE). The DBE is defined in Subsection 2.2.3.

12.2.8.2 Earthquake Analysis

The earthquake accident analysis evaluates the effects of a seismic event on the loaded HI-STORM FW overpack based on a static stability criteria discussed in Subsection 2.2.3.

Some ISFSI sites will have earthquakes that exceed the static stability limit specified in Subsection 2.2.3. For these high-seismic sites, a dynamic analysis shall be performed based on the methodology provided in Subsection 3.4.4.

i. Structural

The methodology for the evaluation of the earthquake consequences has been presented in Subsection 3.4.4. An earthquake is a vibratory event, which is fully described by an acceleration time-history. However, for "weak" earthquakes, a static equilibrium based calculation suffices. However, for stronger DBEs, a dynamic analysis is required. The results from the reference DBE analyzed in Subsection 3.4.4 are used to evaluate the safety case for the earthquake using the acceptance criteria in Section 2.2.

The following conclusions can be reached from the structural analysis of the HI-STORM FW System under the reference DBE event:

a. The MPC Confinement Boundary remains unbreached.
b. The HI-STORM FW overpack structure remains intact; i.e., the lid is not displaced.
c. There is no physical damage to the HI-STORM FW overpack shielding concrete.
d. The HI-STORM FW overpack does not tip over.

ii. Thermal

There is no effect on the thermal performance of the system as a result of this event.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event.

vi. 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 event.

Based on this evaluation, it is concluded that the reference DBE does not affect the continued safe operation of the HI-STORM FW System.

12.2.8.3 Earthquake Dose Calculations

Structural analysis of the earthquake accident shows that the loaded overpack will not tip over as a result of the specified seismic activity. Since the loaded overpack does not tip-over, there is no increase in radiation dose rates at the site boundary.

12.2.8.4 Earthquake Accident Corrective Action

Following the earthquake accident, the ISFSI operator shall perform a visual and radiological inspection of the overpacks in storage to determine if any of the overpacks have displaced from their installed position or tipped over. In the unlikely event of a tip-over, the corrective actions shall be in accordance with Subsection 12.2.3.

12.2.9 100% Fuel Rod Rupture

This accident event postulates the non-mechanistic condition that all the fuel rods rupture and that the quantities of fission product gases and fill gas are released from the fuel rods into the MPC cavity consistent with ISG-5, Revision 1.

12.2.9.1 Cause of 100% Fuel Rod Rupture

Through all credible accident conditions, the HI-STORM FW System maintains the spent nuclear fuel in an inert environment while maintaining the peak fuel cladding temperature below the required short-term temperature limits, thereby providing assurance of fuel cladding integrity. Therefore, there is no credible cause for 100% fuel rod rupture. This accident is presumably postulated in NUREG-1536 to evaluate the MPC confinement barrier for the maximum possible internal pressure based on the non-mechanistic failure of 100% of the fuel rods.

12.2.9.2 100% Fuel Rod Rupture Analysis

The 100% fuel rod rupture accident has no containment consequences. The event does not change the reactivity of the stored fuel, the magnitude of the radiation source, the shielding capability of the system, or the criticality control features of the fuel basket; and does not challenge the structural integrity of the MPC.

i. Structural

The structural analysis provided in Chapter 3 evaluates the MPC Confinement Boundary under the accident condition design internal pressure limit set in Table 2.2.1. Calculations in Chapter 4 show that the accident internal pressure limit bounds the pressure from 100% fuel rod rupture.

ii. Thermal

The determination of the maximum accident pressure is provided in Chapter 4. The MPC internal pressure for the 100% fuel rod rupture condition is presented in Table 4.4.5, which is bounded by the design basis accident condition MPC internal pressure limit set in Table 2.2.1.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event.

vi. 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 event.

Based on this evaluation, it is concluded that the non-mechanistic 100% fuel rod rupture accident event does not affect the safe operation of the HI-STORM FW System.

12.2.9.3 100% Fuel Rod Rupture Dose Calculations

The breach of fuel cladding postulated in this accident event does not result in any physical change to the storage system other than some release of gases and a limited quantity of solids (particulates) into the gaseous helium space. The amount of the radiation source remains unaffected. Hence, the radiation dose at the site boundary will not change perceptibly, i.e., there are no consequences to the site boundary dose.

12.2.9.4 100% Fuel Rod Rupture Accident Corrective Action

As shown in the analysis of the 100% fuel rod rupture accident, the MPC Confinement Boundary is not damaged. The HI-STORM FW System is designed to withstand this accident and continue performing the safe storage of spent nuclear fuel under normal storage conditions. No corrective actions are required.

12.2.10 Confinement Boundary Leakage

None of the postulated environmental phenomenon or accident conditions identified would cause failure of the confinement boundary. The MPC uses redundant confinement closures to assure that there is no release of radioactive materials. The analyses presented in Chapter 3 and this chapter demonstrate that the MPC remains intact during all postulated accident conditions. The information contained in Chapter 7 demonstrates that MPC is designed, fabricated, tested and inspected to meet the guidance of ISG-18 such that unacceptable leakage from the Confinement Boundary is non-credible.

12.2.11 Explosion

12.2.11.1 Cause of Explosion

An explosion within the protected area of an ISFSI is improbable since there are no explosive materials permitted within the site boundary. However, an explosion as a result of combustion of the fuel contained in cask transport vehicle is possible. As the fuel available for the explosion is limited in quantity the effects of an explosion on a reinforced structure are minimal. Explosions that are credible for a specific ISFSI would require a site hazards evaluation under the provisions of 72.212 regulations by the ISFSI owner using the methodology set forth in Section 3.1.

12.2.11.2 Explosion Analysis

Any credible explosion accident is bounded by the accident external design pressure (Table 2.2.1) analyzed as a result of the flood accident water depth in Subsection 12.2.7 and the tornado missile accident of Subsection 12.2.6, because explosive materials are not stored within close proximity to the casks. The bounding analysis shows that the MPC and the overpack can withstand the effects of substantial accident external pressures without collapse or rupture.

An ISFSI where a credible explosion event produces a pressure wave greater than analyzed in Subsection 12.2.7 or an impactive load greater than considered in Subsection 12.2.6, shall be evaluated within the purview of §72.212. The results of the safety evaluation of the postulated limiting explosion in this subsection are as follows:

i. Structural

The structural evaluations for the MPC accident condition external pressure and overpack pressure differential are presented in Section 3.4 and demonstrate that all stresses are within allowable values.

ii. Thermal

There is no effect on the thermal performance of the system as a result of this event.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring Confinement Boundary integrity.

vi. 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 event.

Based on this evaluation, it is concluded that the reference explosion accident does not affect the safe operation of the HI-STORM FW System.

12.2.11.3 Explosion Dose Calculations

The reference bounding external pressure load has no effect on the HI-STORM FW Overpack and MPC. Therefore, no effect on the shielding, criticality, thermal or confinement capabilities of the HI-STORM FW System is experienced as a result of the explosion pressure load. The effects of explosion generated (reference) missiles on the HI-STORM FW System structure is bounded by the analysis of tornado generated missiles.

12.2.11.4 Explosion Accident Corrective Action

The explosive overpressure caused by an explosion is bounded by the external pressure exerted by the flood accident. The external pressure from the flood is shown not to damage the HI-STORM FW

System. Following an explosion, the ISFSI owner shall perform a visual and radiological inspection of the overpack. If the outer shell or concrete is damaged as a result of explosion generated missiles, the overpack will be repaired as necessary.

12.2.12 Lightning

12.2.12.1 Cause of Lightning

As the HI-STORM FW System will be stored on an unsheltered ISFSI concrete pad, there is the potential for lightning to strike the overpack. This analysis evaluates the effects of lightning striking the overpack.

12.2.12.2 Lightning Analysis

The HI-STORM FW System is a large metal/concrete cask stored in an unsheltered ISFSI. As such, it may be subject to lightning strikes. When the HI-STORM FW overpack is struck with lightning, the lightning will discharge through the steel shell of the overpack to the ground. Lightning strikes have high currents, but their duration is short (i.e., less than a second). The overpack outer shell is composed of conductive carbon steel and, as such, provides a direct path to the ground through the optional grounding cable.

The MPC provides the Confinement Boundary for the spent nuclear fuel. The effects of a lightning strike will be limited to the overpack. The lightning current will discharge into the overpack and directly into the ground. Therefore, the MPC will be unaffected.

i. Structural

There is no structural consequence as a result of this event.

ii. Thermal

There is no effect on the thermal performance of the system as a result of this event.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event.

vi. 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 event.

Based on this evaluation, it is concluded that the lightning accident does not affect the safe operation of the HI-STORM FW System.

12.2.12.3 Lightning Dose Calculations

An evaluation of lightning strikes demonstrates that the effect of a lightning strike has no effect on the Confinement Boundary or shielding materials. Therefore, no further analysis is necessary.

12.2.12.4 Lightning Accident Corrective Action

The HI-STORM FW System will not sustain any damage from the lightning accident. There is no surveillance or corrective action required.

12.2.13 100% Blockage of Air Inlets

12.2.13.1 Cause of 100% Blockage of Air Inlets

This event is defined as a complete blockage of all bottom inlets. A blockage of all of the circumferentially arrayed inlets cannot be realistically postulated to occur at most sites. However, a flood, blizzard snow accumulation, tornado debris, or volcanic activity, where applicable, can cause a significant blockage.

12.2.13.2 100% Blockage of Air Inlets Analysis

The immediate consequence of a complete blockage of the air inlet openings is that the normal circulation of air for cooling the MPC is stopped. An amount of heat will continue to be removed by localized air circulation patterns in the overpack annulus and outlet opening, and the MPC will continue to radiate heat to the relatively cooler storage overpack. As the temperatures of the MPC and its contents rise, the rate of heat rejection will increase correspondingly. Under this condition, the temperatures of the HI-STORM FW overpack, the MPC and the stored fuel assemblies will rise as a function of time.

As a result of the large mass and correspondingly large thermal capacity of the HI-STORM FW overpack, it is expected that a significant temperature rise is only possible if the blocked condition is allowed to persist for an extended duration. This accident condition is, however, a short duration event that will be identified by the ISFSI staff, at worst, during scheduled periodic surveillance at the ISFSI site and corrected using the site's emergency response process.

i. Structural

There are no structural consequences as a result of this event.

ii. Thermal

A thermal analysis is performed in Subsection 4.6.2 to determine the effect of a complete blockage of all inlets for an extended duration. For this event, both the fuel cladding and component temperatures remain below their short-term temperature limits. The MPC internal pressure for this event is evaluated in Subsection 4.6.2 and is bounded by the design basis internal pressure for accident conditions (Table 2.2.1).

iii. Shielding

There is no effect on the shielding performance of the system as a result of this event, since the concrete temperatures do not exceed the short-term condition design temperature provided in Table 2.2.3.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event.

vi. 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 event.

Based on the above evaluation, it is concluded that the 100% blockage of air inlets accident does not affect the safe operation of the HI-STORM FW System, as the ISFSI's emergency response process required to act to remove the blockage is the first priority activity.

12.2.13.3 100% Blockage of Air Inlets Dose Calculations

As shown in the analysis of the 100% blockage of air inlets accident, the shielding capabilities of the HI-STORM FW overpack are unchanged because the peak concrete temperature does not exceed its short-term condition design temperature. The elevated temperatures will not cause the breach of the confinement system and the short term fuel cladding temperature limit is not exceeded. Therefore, there is no radiological impact.

12.2.13.4 100% Blockage of Air Inlets Accident Corrective Action

Analysis of the 100% blockage of air inlet accident shows that the temperatures for cask system components and fuel cladding are within the accident temperature limits if the blockage is cleared within the maximum elapsed period between scheduled surveillance inspections. Upon detection of the complete blockage of the air inlet openings, the ISFSI owner shall activate its emergency response procedure to remove the blockage with mechanical and manual means as necessary. After clearing the overpack openings, the overpack shall be visually and radiologically inspected for any damage. If exit air temperature monitoring is performed in lieu of direct visual inspections, the difference between the ambient air temperature and the exit air temperature will be the basis for the assurance that the temperature limits are not exceeded.

For an accident event that completely blocks the inlet or outlet air openings for greater than the analyzed duration, a site-specific evaluation or analysis may be performed to whether adequate heat removal for the duration of the event would occur. Adequate heat removal is defined as the minimum rate of heat dissipation that ensures cladding temperatures limits are met and structural integrity of the MPC and overpack is not compromised. For those events where an evaluation or analysis is not performed or is not successful in showing that cladding temperatures remain below their short term temperature limits, the site's emergency plan shall include provisions to address removal of the material blocking the air inlet openings and to provide alternate means of cooling prior to exceeding the time when the fuel cladding temperature reaches its short-term temperature limit. Alternate means of cooling could include, for example, spraying water into the air outlet opening using pumps or fire-hoses or blowing air into the air outlet opening, to directly cool the MPC.

12.2.14 Burial Under Debris

12.2.14.1 Cause of Burial Under Debris

Complete burial of the HI-STORM FW System under debris is not a credible accident. During storage at the ISFSI, there are no structures above the casks that may collapse and surround them. The minimum regulatory distance(s) from the ISFSI to the nearest site boundary and the controlled area around the ISFSI concrete pad precludes the close proximity of substantial amounts of vegetation.

There is no credible mechanism for the HI-STORM FW System to become completely buried under debris. However, for conservatism, complete burial under debris is considered. Blockage of the HI-STORM FW overpack air inlet openings has already been considered in Subsection 12.2.12.

12.2.14.2 Burial Under Debris Analysis

Burial of the HI-STORM FW System does not impose a condition that would have more severe consequences for criticality, confinement, shielding, and structural analyses than that performed for the other accidents analyzed. A perverse effect of the overlaid debris would be to provide additional shielding to reduce radiation doses. The accident external pressure considered in this FSAR during the flood bounds any credible pressure loading caused by the burial under debris.

Burial under debris can affect thermal performance because the debris acts as an insulator and heat sink. This will cause the HI-STORM FW System and fuel cladding temperatures to increase. A thermal analysis has been performed to determine the time for the fuel cladding temperatures to reach the short term accident condition temperature limit during a burial under debris accident, assuming that the debris has the consistency of a typical pile of rocks (pebbles).

i. Structural

The structural evaluation of the MPC enclosure vessel for accident internal pressure conditions set in Table 2.1.1 bounds the pressure calculated for this event. Therefore, the resulting stresses from this event are well within the allowable values, as demonstrated in Section 3.4.

ii. Thermal

The fuel cladding and MPC integrity is evaluated in Subsection 4.6.2. The evaluation demonstrates that the fuel cladding and confinement function of the MPC are not compromised even if the burial event lasts for a substantial duration.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring Confinement Boundary integrity.

vi. Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no deleterious effect on the site boundary dose a result of this event.

Based on the above evaluation, it is concluded that the burial under debris accident does not affect the safe operation of the HI-STORM FW System, as the ISFSI's emergency response process required to act to remove the debris is the first priority activity.

12.2.14.3 Burial Under Debris Dose Calculations

As discussed in burial under debris analysis, the shielding is enhanced while the HI-STORM FW System is covered.

The elevated temperatures will not cause the breach of the confinement system and the short term fuel cladding temperature limit is not exceeded. Therefore, there is no adverse radiological impact.

12.2.14.4 Burial Under Debris Accident Corrective Action

Analysis of the burial under debris accident shows that the fuel cladding peak temperatures are not exceeded even for an extended duration of burial. Upon detection of the burial under debris accident, the ISFSI operator shall assign personnel to remove the debris with mechanical and manual means as necessary. After uncovering the storage overpack, the storage overpack shall be visually and radiologically inspected for any damage. The loaded MPC shall be removed from the storage overpack with the HI-TRAC VW transfer cask to allow complete inspection of the overpack air inlets and outlets, and annulus. Removal of obstructions to the air flow path shall be performed prior to the re-insertion of the MPC. The site's emergency action plan shall include provisions for the implementation of this corrective action.

12.2.15 Extreme Environmental Temperature

12.2.15.1 Cause of Extreme Environmental Temperature

The extreme environmental temperature is postulated (see Table 2.2.2) as a 3-day average temperature caused by extreme weather conditions.

12.2.15.2 Extreme Environmental Temperature Analysis

To determine the effects of the extreme temperature, it is conservatively assumed that the temperature persists for a sufficient duration (3 days) to allow the HI-STORM FW overpack to achieve thermal equilibrium.

The accident condition considering an extreme environmental temperature (Table 2.2.2) for a duration sufficient to reach thermal equilibrium is evaluated with respect to accident condition design temperatures listed in Table 2.2.3.

i. 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 that of the accident condition and are well within the allowable values, as discussed in Section 3.4.

ii. Thermal

The resulting temperatures for the system and fuel assembly cladding are provided in evaluation performed in Subsection 4.6.2. As concluded from this evaluation, all temperatures are within the short-term accident condition allowable values specified in Table 2.2.3.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this event, since the concrete temperature does not exceed the short-term temperature limit specified in Table 2.2.3.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring Confinement Boundary integrity.

vi. 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 event.

Based on this evaluation, it is concluded that the extreme environment temperature accident does not affect the safe operation of the HI-STORM FW System.

12.2.15.3 Extreme Environmental Temperature Dose Calculations

The extreme environmental temperature will not cause the concrete to exceed its normal design temperature. Therefore, there will be no degradation of the concrete's shielding effectiveness. The elevated temperatures will not cause a breach of the confinement system and the short-term fuel cladding temperature is not exceeded. Therefore, there is no radiological impact on the HI-STORM FW System for the extreme environmental temperature and the dose calculations are to the same as those for normal condition dose rates.

12.2.15.4 Extreme Environmental Temperature Corrective Action

There are no consequences of this accident that require corrective action.

Table 12.2.1

ACCIDENT EVENTS AND THEIR PROBABILITY OF OCCURRENCE

	Event	Probability of Occurrence	Subsection Where Addressed	Comments
1.	**HI-TRAC VW Transfer Cask Handling Accident**	**Non-Credible**	**12.2.1**	**This FSAR mandates the use of single-failure-proof lifting devices for handling loaded HI-TRAC VWs within the Part 72 jurisdictional boundary.**
2.	**HI-STORM FW Overpack Handling Accident**	**Non-Credible**	**12.2.2**	**This FSAR mandates the use of single-failure-proof lifting devices for handling loaded HI-STORM FWs within the Part 72 jurisdictional boundary.**
3.	**HI-STORM FW Non-Mechanistic Tip-Over**	**Non-Credible**	**12.2.3**	**The HI-STORM FW tip-over event is more properly referred to as a "non-mechanistic" tip-over, meaning that no physical loading considered in this FSAR leads to a tip-over event.**
4.	**Fire**	**Very small probability but credible**	**12.2.4**	**Although there are no ignition sources in the ISFSI area, combustible material (motive fuel) is present. Therefore, the potential of a fire event cannot be ruled out categorically.**
5.	**Partial Blockage of MPC Basket Vent Holes**	**Non-Credible**	**12.2.5**	**An impactive event may jolt the stored fuel and cause its crud to fall off. However, as explained in Subsection 12.2.5, there is no realistic mechanism for the blockage of the flow holes.**
6.	**Tornado**	**Credible**	**12.2.6**	**Because a HI-STORM FW ISFSI can be deployed in any state within the U.S., the potential of a tornado event at a generic ISFSI must be considered.**
7.	**Flood**	**Credible**	**12.2.7**	**Flood, like tornado, must be categorized as a credible event at a generic ISFSI site.**
8.	**Earthquake**	**Credible**	**12.2.8**	**The Design Basis Earthquake for an ISFSI is a specified event for a nuclear facility.**

Table 12.2.1

ACCIDENT EVENTS AND THEIR PROBABILITY OF OCCURRENCE

	Event	Probability of Occurrence	Subsection Where Addressed	Comments
9.	100% Fuel Rod Rupture	Non-Credible	12.2.9	"100% rod rupture" is a non-mechanistic event; no specific loading event has been identified to cause 100% rod rupture.
10.	Confinement Boundary Leakage	Non-Credible	12.2.10	The Confinement Boundary has been determined to be invulnerable to leakage in Chapter 7.
11.	Explosion	Credible	12.2.11	Explosion of gasoline is a credible event at an ISFSI.
12.	Lightning	Credible	12.2.12	Lightning is a small probability event at any ISFSI, hence, it cannot be deemed non-credible.
13.	100% Blockage of Air Inlets	Non-Credible	12.2.13	Because the air openings are along the circumference of the cask, and surveillance is at very short intervals (see Technical Specification), the assumption of blockage of all openings has no mechanistic basis.
14.	Burial Under Debris	Credible	12.2.14	Burial of a loaded system under a debris cannot be generically ruled out because a nuclear plant site may (ever so minimally) susceptible to a large adverse environment event such as a tsunami or an avalanche.
15.	Extreme Environmental Temperature	Credible	12.2.15	In certain desert areas in the country a temperature spike that reaches the accident temperature limit (Table 2.2.2) cannot be ruled out. Such areas have not been declared unfit at a nuclear plant site by the USNRC and therefore, must be factored in defining generic accident events.

12.3 OTHER EVENTS

This section addresses the MPC reflood event which is placed in the category of "other events" since it cannot be categorized as an off-normal or accident event. The MPC reflood event occurs if an ISFSI owner needs to return the fuel in a loaded canister to wet storage in the plant's fuel pool. The MPC reflood event is presented in Subsection 9.4.3 in connection with the preparation for the MPC unloading operation. The reflooding of a loaded MPC with water results in a change to the environment around the fuel from a gaseous (low heat transfer medium) to aqueous (high heat transfer medium). This implies the generation of thermal stresses in the fuel cladding and potential for loss of cladding integrity.

The safety analysis of the reflood event in Subsection 3.4.4 focuses on the effect of strains (due to reflooding) on the integrity of the cladding. This safety analysis, which uses an appropriate thermal/structural model as well as evaluations in Subsection 4.5.5, forms the basis for the instructions in the MPC reflood procedures provided in Subsection 9.4.3. For a complete evaluation of the effects of the MPC reflood event on the MPC and spent nuclear fuel, the postulated cause of the event, monitoring of the event, analysis of the event effects and consequences, corrective actions, and radiological impact from the event are presented in this section similar to the systematic evaluations presented for design basis off-normal and postulated accident condition events in the preceding sections.

The results of the evaluations performed herein demonstrate that the HI-STORM FW System can withstand the effects of MPC reflood and remain in compliance with the applicable acceptance criteria. In particular, the integrity of the fuel cladding shall be preserved. The following subsections contain the evaluation of the effects of the MPC reflood event on the MPC and spent nuclear fuel that demonstrates that the requirements of 10CFR72.122 are satisfied, and that the corresponding radiation doses continue to meet the requirements of 10CFR72.104(a) and 10CFR20.

12.3.1 MPC Reflood

MPC reflood is performed during the preparation for the unloading operations as described in Subsection 9.4.3. The MPC is flooded with water at a controlled rate as specified in Subsection 4.5.5 with the MPC vent port open such that the generation of steam from flashing of water is not excessive and the pressure within the MPC remains below its normal condition internal design pressure. Although past industry experience generally supports cooldown of cask internals and fuel from hot storage conditions by a direct introduction of water into the canister space (as specified in Subsection 9.4.3) a structural evaluation has been performed to ensure fuel cladding integrity and is provided in Paragraph 3.4.4.1.

12.3.1.1 Postulated Cause of MPC Reflood

Likely causes to perform MPC reflood include those associated with required actions for certain limiting conditions for operation (LCO) (as specified in Appendix A of the Technical Specifications) to unload fuel assemblies from the MPC. A reflood operation may also be carried out at the plant owner's volition to return the fuel to wet storage as a voluntary act.

12.3.1.2 Monitoring of MPC Reflood

MPC reflooding is monitored at frequent intervals by the surveillance of MPC pressure as required by SR 3.1.3.1 to Specification 3.1.3 (Appendix A of the Technical Specifications). An indication of MPC pressurization at or above normal condition MPC internal design pressure established in Section 2.2 requires the immediate action to stop reflooding operations until the MPC cavity pressure is below the required limit. See LCO 3.1.3 and the associated basis in Chapter 13 for more information.

12.3.1.3 Analysis of Effects and Consequences of MPC Reflood

i. Structural

<u>MPC Enclosure Vessel Integrity:</u> The MPC water reflood rate specified in Subsection 4.5.5, the essential reflooding control procedure steps established in Subsection 9.4.3, and the surveillance instructions in SR 3.1.3.1 Specification 3.1.3 (Appendix A of the Technical Specifications) ensure that the MPC is maintained below the normal condition pressure limit and well below MPC off-normal and accident condition pressure limits set down in Section 2.2, thus ensuring large margins of safety and no harmful effect on the MPC enclosure vessel integrity.

<u>Fuel Cladding Integrity:</u> The structural evaluation in Paragraph 3.4.4.1 ensures that the fuel cladding integrity is preserved during the reflood event.

<u>Other Structural Related Considerations:</u> MPC reflooding is performed under a specified maximum water injection rate and below normal condition MPC internal design pressure. The pressures and temperatures are therefore compatible with design limits of existing MPC ancillaries and standard connections such as RVOAs. Maintaining the pressure and temperature parameters well below the design basis values for the ancillaries ensures that failure of components and appurtenances during the reflooding operation is unlikely. Therefore, no credible mechanism for risk to the plant staff or general public from radiological release due to the reflood operation can be identified.

ii. Thermal

A thermal evaluation is provided in Subsection 4.5.5 to specify the maximum water reflood rate. The maximum calculated water reflood rate will prevent MPC over-pressurization and fuel cladding damage.

iii. Shielding

There is no adverse effect on the shielding performance of the system as a result of the MPC reflood event. The shielding performance of the MPC is indeed enhanced by the flooding of its contents.

iv. Criticality

There is no adverse effect on the criticality control of the system as a result of this planned plant event. The essential procedure steps in Chapter 9 and surveillance SR 3.3.1.1 to Specification 3.3.1 (Appendix A of the Technical Specifications) ensure that the water used to reflood the MPC will have the minimum required soluble boron concentration. The generation and escape of steam from the MPC will increase (not lower) the soluble boron concentration.

v. Confinement

During the reflood operation, the MPC confinement function is inoperative (and supplanted by the part 50 facility) as the canister is connected to the plant's fluid accumulation system and the source of water (such as the fuel pool). The reflooding operation, however, does not degrade the confinement capability of the MPC because the internal pressures and temperatures are procedurally controlled to remain well within the design limits.

vi. Radiation Protection

As there is no adverse effect on the shielding or confinement functions, there is no adverse effect on occupational or public exposures as a result of this MPC reflood event. The vent port steam is delivered to the radwaste gas facility of the plant in accordance with the specified procedure in Subsection 9.4.3.

Based on this evaluation, it is concluded that MPC reflood has no adverse effects or consequences on the safety or operability of the HI-STORM FW System.

12.3.1.4 Corrective Action for MPC Reflood

See Specification 3.1.3 (Appendix A of the Technical Specifications) on MPC Cavity Reflooding and Specification 3.3.1 (Appendix A of the Technical Specifications) on Boron Concentration.

12.3.1.5 Radiological Impact of MPC Reflood

The event has no radiological impact because the plant's confinement barrier and shielding infrastructure are unaffected and the operation relies on no new system for the control of effluents.

12.4 REFERENCES

Currently no references listed.