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LIST OF ACRONYMS

ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
CCNPP	Calvert Cliffs Nuclear Power Plant
CFR	Code of Federal Regulations
DBE	Design Basis Earthquake
DBT	Design Basis Tornado
DSC	Dry Shielded Canister
HSM	Horizontal Storage Module
ISFSI	Independent Spent Fuel Storage Installation
LNG	Liquified Natural Gas
NRC	Nuclear Regulatory Commission
NUHOMS	Nutech Horizontal Modular Storage®
SER	Safety Evaluation Report

8.0 ACCIDENT ANALYSES – NUHOMS-24P

Analyses of all design events are reported in the Topical Report for the Nutech Horizontal Modular Storage® (NUHOMS)-24P System (Reference 8.1) for the generic NUHOMS-24P Independent Spent Fuel Storage Installation (ISFSI) design as required by American National Standards Institute (ANSI)/American Nuclear Society (ANS) 57.9-1984 (Reference 8.2). The analyses of these design events have been repeated for the Calvert Cliffs site-specific ISFSI design, and the results are reported in this section in the same format as in the Topical Report. The analytical assumptions, methodology, and computer codes used to generate the results in this section are identical to those used in the Topical Report, unless noted otherwise in the text.

This section and Section 12.8 discusses the accident analysis associated with the use of NUHOMS-32P dry shielded canisters (DSCs).

8.1 NORMAL AND OFF-NORMAL OPERATIONS

This section follows the format of the Topical Report (Reference 8.1) and includes the evaluation of Design Basis Type 1 Events (normal operating conditions) as defined in ANSI/ANS 57.9. These events, their bases, and analytical methodology are described in Section 8.1 of the Topical Report. The results of the analyses of these loads on the Calvert Cliffs ISFSI design are discussed in the following subsections.

8.1.1 NORMAL OPERATION STRUCTURAL ANALYSIS

The normal operating loads for the NUHOMS-24P important to safety components are shown in Table 8.1-1 of Reference 8.1. The method of analysis is described in Sections 8.1.1.2 through 8.1.1.9 of Reference 8.1. The material properties are shown in Table 8.1-2 of Reference 8.1. The results of the analyses for the Calvert Cliffs ISFSI components are given in Sections 8.1.1.2 through 8.1.1.9. An additional, comprehensive, structural reanalysis of the NUHOMS-24P DSC was performed and documented in References 8.23 and 8.24.

8.1.1.1 Normal Operation Structural Analysis

The loads applicable to the normal operation structural analysis are described in detail in Section 8.1.1.1 of Reference 8.1. The specific application of these loads to the Calvert Cliffs ISFSI design are described in the following paragraphs.

A. Dead Weight Loads

The Calvert Cliffs NUHOMS component weights (dead weight) are calculated based on the design dimensions and materials. Material densities are the same as those in Reference 8.1.

B. Design Basis Internal Pressure Loads

The DSC internal pressures for normal and off-normal conditions are calculated using maximum ambient temperatures and blowdown pressure conditions. As discussed in Reference 8.1, bounding accident condition pressures are conservatively based on cladding failure of all fuel rods in the DSC. The fission gas release fraction is assumed to be 30%, and all the fill gas is assumed to be released. The fuel rod average burnup is assumed to be 50,000 MWD/MTU. The effects of the postulated accident pressures are described in Section 8.2. Reflood pressure is included as a Service Level D condition, experienced during fuel retrieval, because the DSC will not be re-used after retrieval.

C. Design Basis Thermal Loads

The structural loads due to normal operating condition thermal expansion have been evaluated for a range of ambient temperatures from -3°F to 103°F. These temperatures represent the historical extremes recorded at Patuxent River Naval Air Station, some 10 miles from the ISFSI. The long-term average normal ambient temperature is conservatively assumed to be 70°F, as discussed in Section 8.1.1.C of Reference 8.1.

D. Operational Handling Loads

The significant operational handling load is the sliding transfer of the DSC from the cask to the DSC support rails in the horizontal storage module (HSM). Since the Calvert Cliffs DSC weighs less than that of the generic DSC design, these loads are consistent with those in Section 8.1.1.4.B of Reference 8.1.

E. Design Basis Live Loads

Live loads for the Calvert Cliffs ISFSI are enveloped by the generic live load of 200 lbf/ft^2 used in Section 8.1.1.5.A of Reference 8.1.

8.1.1.2 Dry Shielded Canister Analysis

Stresses were evaluated in the DSC due to:

A. Dead Weight Loads
B. Design Basis Normal Operating Internal Pressure Loads
C. Normal Operating Thermal Loads
D. Normal Operation Handling Loads

The analyses performed for DSCs R001 through R024 are similar to those presented in Section 8.1.1.2 of Reference 8.1 for the generic DSC. The ANSYS analytical model of the DSC shell assembly is used for the analysis of pressure, thermal, and handling loads. Stresses due to normal operating pressures are based on a bounding internal pressure of 10 psig, applied as a uniform load to the inner boundary of the analytical model. Also considered was the external hydrostatic pressure loading on the DSC shell, when the 3/8-inch annulus between the DSC shell and the transfer cask is filled with water. Circumferential shell temperature variations are analyzed using the ANSYS three-dimensional solid shell model.

Dry shielded canisters, starting with R025, employ a modified internal basket assembly design (refer to Section 4.2.3.2). The modified DSC was analyzed using analytical methods comparable to those described for DSCs R001 through R024 above. The modified DSC stresses remain within American Society of Mechanical Engineers (ASME) code allowable stresses (Reference 8.24).

8.1.1.3 Dry Shielded Canister Internal Basket Analysis

The DSC basket analysis was performed for:

A. Dead Weight Loads
B. Thermal Loads

The DSC basket dead weight and thermal analyses for DSCs R001 through R024 were performed according to the methodology described in Section 8.1.1.3 of Reference 8.1 with minor variations. The dead weight stresses for the spacer disk for out-of-plane loads (i.e., DSC in the vertical position) were obtained directly from the ANSYS spacer disk analytical model. The dead weight stresses in the plane of the spacer disk (i.e., DSC in the horizontal position) were obtained by conservatively evaluating the center spacer disk ligament using hand calculations for the combined dead load of 12 fuel assemblies. The thermal analysis of the spacer disk was performed by applying the calculated temperature distribution to the ANSYS analytical model.

Dry shielded canisters, starting with R025, employ a modified internal basket assembly design (refer to Section 4.2.3.2). The modified DSC was analyzed in a manner similar to that described for DSCs R001 through R024 above. The spacer disc maximum out-of-plane stress is much lower for the modified DSC because the guide sleeves are not attached to any spacer disc. The modified DSC spacer disc stresses remain within ASME code allowable stresses (Reference 8.24).

The maximum length of the irradiated spent fuel assemblies is 158.00“ including thermal expansion. The minimum DSC cavity length is 158.24“, including allowance for fabrication tolerances. Using the thermal expansion algorithms in Section 8.1.1.3.B of Reference 8.1, the hot cavity length is 158.47“, allowing at least 0.47“ of clearance between the fuel assembly and the DSC cavity ends.

8.1.1.4 Dry Shielded Canister Support Assembly Analysis

The Calvert Cliffs DSC support assembly consists of WF 8x40 support rail members with WF 8x48 cross members. A 3/4" x 6" rail cover plate runs the full length of the support rail members and extends into the HSM access opening. The support rail members are supported by structural embedments at the HSM front wall and by the cross members at the center and rear of the module.

The Calvert Cliffs DSC support assembly was analyzed using conservative hand calculations. The DSC support assembly is analyzed for the following loads as discussed in Section 8.1.1.4 of Reference 8.1.

A. Dead Weight Loads
B. Normal Operational Handling Loads
C. Thermal Loads

The DSC support assembly and its end connections were analyzed for the normal and off-normal loads. The calculated stresses were small, and the vertical deflections under the transfer cask loading were less than 0.1".

8.1.1.5 Horizontal Storage Module Analysis

The HSM configuration selected for the Calvert Cliffs ISFSI is a 2x6 array. This configuration is within the envelope of possible HSM configurations evaluated in Reference 8.1, which considers a range of HSM array sizes from a single module to a 2x10 array. Similar loads analyses to those described in Reference 8.1 for the generic HSM design have been performed for the Calvert Cliffs HSM design using site-specific parameters. The Calvert Cliffs HSM array was evaluated for the following normal operation loads.

A. Horizontal Storage Module Dead and Live Loads

The HSM dead and live loads were evaluated using the same methodology as discussed in Section 8.1.1.5 of Reference 8.1.

B. Concrete Creep and Shrinkage Loads

Loads due to creep and shrinkage of the concrete were determined by the same methodology described in Section 8.1.1.5 of Reference 8.1.

C. Horizontal Storage Module Thermal Loads

To evaluate the effects of thermal loads on the HSM, heat transfer analyses for a range of ambient temperatures were performed and the limiting thermal gradients and temperature values at various locations in the HSM determined. A description of the heat transfer analyses is provided in Section 8.1.3. Structural analyses of the HSM for the bounding temperatures were performed for the Calvert Cliffs 2x6 array. The analytical approach used is identical to that documented in Reference 8.1.

D. Radiation Effect on HSM Concrete

The effects of radiation on the compressive strength and modulus of elasticity of concrete were examined in Section 8.1.1.5 of Reference 8.1 and determined to be negligible. The integrated neutron and gamma fluxes are slightly greater for the Calvert Cliffs design, but the effect remains insignificant.

E. Horizontal Storage Module Design Analysis

The flexural and shear strength capacities of the HSM concrete sections were calculated using the ultimate strength method of American Concrete Institute (ACI) 349-85 as described in Section 8.1.1.5.E of Reference 8.1. The resulting capacities are reported in Table 8.1-8.

The calculations associated with the HSM walls, roof, and foundation are based on one-way slab design, and the concrete shear capacity used is that given in Equation 11-3 of ACI 349. The design as presented in the calculation has no mixed requirements from different portions of the ACI Code, but is a calculation performed on a consistent set of design criteria. In addition, careful reading of Section 11.8 of ACI 349 and the commentary to the Code reveal that the deep flexural member rules are intended for beams, which are distinct from slabs.

ACI 349, paragraph 11.5.5.1 specifically excludes slabs and footings from the requirement to have a minimum area of shear reinforcement. In addition, the special provisions for slabs and footings (paragraph 11.11) does not require shear reinforcement unless the factored shear force exceeds the shear strength ϕ Vc where Vc = $2\sqrt{f^{'}_{c'}}$ which is the basis for the shear strength determination in the reference calculation. Furthermore, the special provisions for walls (paragraph 11.10) refer to the rules for slabs for shear perpendicular to the plane of the wall, which are the only shear loads of concern for the walls. Shear loads in the plane of the wall are inconsequential as the walls are continuously supported by the foundation slab.

Therefore, the design is adequate and no shear reinforcing is required.

The calculated shear and moment forces, due to dead weight, live loads, creep effects, and normal and off-normal thermal conditions, were well within the capacities of HSM components.

8.1.1.6 Horizontal Storage Module Door Analyses

The HSM access opening for Calvert Cliffs is protected by a door which is similar to that shown in Figure 4.2-5 of Reference 8.1, except that the thickness and materials are different and the door support frame is welded to embedded plates with stud anchors. The Calvert Cliffs HSM access door consists of a 1-3/4“ steel plate, 10-3/4“ of concrete shielding material, and a 1/4” steel cover plate. Steel angle sections are attached to embedded plates in the HSM front wall to form guides to slide the HSM door vertically. The method of analysis for the Calvert Cliffs door and frame assembly is identical to that presented in Section 8.1.1.6 of Reference 8.1.

The maximum calculated bending and shear stresses in the angle are 23.9 ksi and 0.8 ksi, respectively. The maximum allowable bending and shear stresses, as reported in Section 8.1.1.6 of Reference 8.1 [i.e., American Institute of Steel Construction (AISC) 8th Edition], are 24.0 ksi and 14.40 ksi, respectively. The maximum tensile and shear stresses on the embedded anchor studs are 15.8 ksi and 8.8 ksi, respectively. The ACI 349-85 Appendix B allowables for the American Society for Testing and Materials A108 anchor studs are 45.0 ksi for tension and 38.3 ksi for shear. The combined calculated over allowable ratio for tension and shear is 0.58.

8.1.1.7 Heat Shield Analysis

The HSM heat shield and attachment details are identical to those of the generic design except the roof attachment bolts are smaller diameter. The heat shield analysis presented in Section 8.1.1.7 of Reference 8.1 is directly applicable to the Calvert Cliffs design except that maximum heat shield bending stress is 4.4 ksi and the maximum side wall bolt bending stress is 14.6 ksi.

8.1.1.8 Horizontal Storage Module Seismic Restraint for Dry Shielded Canister

Details of the analysis of the Calvert Cliffs DSC seismic restraint design are provided in Section 8.2.3.2. The seismic restraint weighs less than 30 pounds and is not equipped with a handle.

8.1.1.9 Transfer Cask Analysis

The transfer cask was evaluated for normal operating loads as follows:

A. Transfer Cask Dead Weight Loads

As in Section 8.1.1.9 of Reference 8.1, two cask dead weight cases are evaluated. The first is with a fully loaded cask hanging from its lifting trunnions; the second is the loaded cask supported horizontally on its skid.

B. Transfer Cask Normal Handling Loads

The transfer cask handling loads and their method of analysis are described in Section 8.1.1.9 of Reference 8.1. Transfer cask handling stresses are calculated for: (1) the cask supported at the trunnions vertically, horizontally, and tilted; (2) cask transfer operations; and (3) cask loading and unloading at the HSM.

C. Transfer Cask Normal Operation Thermal Loads

Transfer cask thermal loads are calculated using an axisymmetric cask model. A fuel assembly decay heat power of 15.8 kW was applied as a uniform heat flux to the transfer cask inner surfaces. Convection coefficients, applied as surface loads to the cask outer surfaces, are based on simplified equations for heat loss from various surfaces to air. They are: 0.0066 BTU/hr-in^2-°F, for the cylindrical shell; and 0.0051 BTU/hr-in^2-°F through the cask and plates. Two bounding ambient temperature cases are considered, consisting of -3°F and 103°F, representing the site-specific historical extremes. A bounding solar heat flux of 62 BTU/hr-ft^2, is also applied for the hot ambient case.

8.1.2 OFF-NORMAL LOAD STRUCTURAL ANALYSIS

Table 8.1-1a of Reference 8.1 lists the off-normal operating loads for the generic NUHOMS-24P system. No additional loads have been identified for the Calvert Cliffs ISFSI. The off-normal loads discussed include jammed DSC and off-normal thermal loads. The thermal stresses due to off-normal thermal loads were calculated in the same manner as described for the normal operating thermal loads. An additional, comprehensive, structural analysis of the DSC was performed and documented in Reference 8.23.

8.1.2.1 Jammed Dry Shielded Canister During Transfer

A. Postulated Cause of Jammed DSC

If the transfer cask is not accurately aligned with the HSM, the DSC might become bound or jammed during the transfer operation. The maximum tolerable misalignment for the DSC insertion operation is 0.25” as discussed in Section 8.1.2.1 of Reference 8.1.

B. Detection of Jammed DSC

When DSC jamming occurs, the hydraulic pressure in the ram will increase. When the hydraulic pressure corresponds to a force on the DSC of 20,000 lbf, the DSC will be presumed to be jammed. The normal pushing and pulling forces will be limited to 20,000 lbf with a ram system design capability of up to 80,000 lbf.

C. Analysis of Effects and Consequences

The analyses of the DSC under the assumed jamming and binding conditions are discussed in Section 8.1.2.1 of Reference 8.1. In both jammed DSC scenarios considered (axial sticking and binding), the stress on the DSC body is shown to be much less than the ASME code allowable stress at the ram system maximum force of 80,000 lbf. Therefore, plastic deformation of the DSC body will not occur and there is no potential for rupture.

D. Corrective Actions

Two courses of corrective action are open to the system operators. The operator may choose to apply a ram force of up to 80,000 lbf to the DSC without risk of damage to the DSC or other system components, as discussed in

Section 8.1.2.1 of Reference 8.1. This maximum force is limited by the design of the ram system. Such action could be warranted if the DSC encounters a higher than expected sliding friction coefficient, which could result from partial lubricant failure, debris in the cask annulus or on the support rails.

If the DSC is stuck or bound, then the corrective action will be to reverse the ram force and return the DSC to its initial position, either in the cask or in the HSM. The alignment problem then must be corrected and the transfer operation resumed.

8.1.2.2 Off-Normal Thermal Loads Analysis

The off-normal thermal condition for the Calvert Cliffs ISFSI is evaluated at the same historical temperature extremes of -3°F and 103°F as the normal thermal loads. A higher solar heat flux value is used for the evaluation of the loaded HSM and the DSC inside the HSM for the off-normal case, as discussed in Section 8.1.3.

A. Horizontal Storage Module Off-Normal Thermal Analysis

The analysis of the HSM for off-normal thermal loads is performed using the same methodology as for normal thermal loads, as described in Section 8.1.1.5.c. The DSC support assembly is designed with slotted holes as described in Section 8.1.1.4 of Reference 8.1, and therefore the increase in temperature has no effect on the DSC support structure.

B. Dry Shielded Canister Off-Normal Thermal Analysis

The analysis of the DSC and DSC basket, for the DSC inside the HSM, for off-normal thermal loads is performed using the same methodology as for normal thermal loads described in Sections 8.1.1.2 and 8.1.1.3. As previously stated, the off-normal thermal loads for the transfer cask are identical to the normal thermal loads. Therefore, the off-normal thermal loads for the DSC inside the transfer cask are identical to the normal thermal loads for the DSC inside the transfer cask, and are not considered further.

C. Transfer Cask Off-Normal Thermal Loads Analysis

As previously stated, the off-normal thermal loads for the transfer cask are identical to the normal thermal loads. Therefore, the off-normal thermal loads for the transfer cask and are not considered further.

8.1.3 THERMAL HYDRAULIC ANALYSES

For more information see Reference 8.16.

The following evaluations have been performed for the Calvert Cliffs ISFSI:

A. Thermal Analysis of the HSM
B. Thermal Analysis of the DSC in the HSM
C. Thermal Analysis of the DSC in the Transfer Cask

The analytical models of the HSM, the DSC, and the transfer cask are described in Section 8.1.3 of Reference 8.1.

The method described in Reference 8.1 for calculating the effective thermal conductivity of the fuel region was extended to include the Calvert Cliffs spent fuel assemblies. The experimental results at the E-MAD test facility (Reference 8.3) provide data for specific fuel assemblies with given heat generation and various boundary conditions. To determine the effective thermal conductivity of the fuel region, the maximum fuel clad temperature and a circumferentially uniform boundary temperature are required to utilize the analytical expression described in Reference 8.1. The key parameters in the expression are the temperature at the boundary of the fuel assembly and the peak temperature in the assembly that will simulate the parabolic temperature profile in a heat generating slab.

As in Reference 8.1, the temperature distribution in each fuel assembly in the DSC is different due to differing boundary conditions. Therefore, each fuel assembly in the DSC is considered individually. The resulting maximum temperature in each fuel assembly was located, and two perpendicular planes were passed through this point, as shown in Figure 8.1-9(a). Consistent with the basis for the Reference 8.3 results, the temperature on the sides were averaged to convert the non-symmetric temperature profile to an equivalent symmetric profile in each plane as depicted in Figure 8.1-9(b). Using this temperature value for the boundary temperature along with the maximum temperature in the fuel assembly, the effective thermal conductivity of the fuel region for that fuel assembly was determined, using the analytical expression and the method described in Reference 8.1.

Since the effective thermal conductivity is a function of temperature, an iterative analysis was performed. With the effective thermal conductivities for each fuel assembly in the DSC, the HEATING6 computer program (Reference 8.4) was used with the analytical model of the DSC to perform the thermal analysis of the DSC internal basket assembly and spent fuel assembly regions. The resulting calculated temperature profiles for the fuel regions were then used to calculate new values of effective thermal conductivities. This procedure was repeated until convergence was achieved.

The values at the lower end correspond to fuel assemblies located on the outer edge of the DSC. The values at the upper end correspond to fuel assemblies located toward the center of the DSC. The same procedure was used to calculate effective thermal conductivity of the fuel region for normal, off-normal, and accident conditions described in Section 8.1.3.2.

The differences in the effective fuel thermal conductivity (K_{eff}) and the generic NUHOMS-24P design described in Reference 8.1 are due to the extension of the method described in the NUTECH topical report to the Calvert Cliffs fuel assemblies.

The K_{eff} curve in Reference 8.1 is based on the experimental results provided in the spent fuel dry storage testing at the E-MAD facility (Reference 8.3). Experimental results for temperatures at the canister wall and center rod cladding temperatures from a single fuel assembly were used in Reference 8.1 to calculate the K_{eff}. The experimental data at various canister wall temperatures and the corresponding peak cladding temperature for a single fuel assembly was curve fitted to generate the K_{eff} plot in Reference 8.1.

The extension of this method to Calvert Cliffs fuel assemblies is described here. The analytical expression used to calculate the K_{eff} is the same as that described in Reference 8.1. The temperature distribution in each fuel assembly in the DSC is different due to differing boundary conditions. Therefore, K_{eff} for each fuel assembly in the DSC is considered individually.

The fuel assemblies located on the outer edge of the DSC have larger fuel clad temperature to boundary temperature gradients, as compared to fuel assemblies located towards the center of the DSC. The larger gradients result in lower effective thermal conductivities. Similar trends in the temperature gradient were also observed in the measured test results and analytically predicted by the COBRA-SFS computer code as documented in Reference 8.5.

The thermophysical properties of the materials of construction are given in Tables 8.1-5 and 8.1-6 of Reference 8.1. The thermal analyses were performed with the following ambient air temperatures:

A. Normal Conditions

Winter or summer conditions with an ambient temperature range from -3°F (minimum winter), 70°F (lifetime average), and 103°F (maximum summer) were considered. The -3°F and 103°F temperatures represent the historical extreme ambient temperatures recorded at Patuxent River Naval Air Station, some 10 miles from the Calvert Cliffs ISFSI. For the HSM, the vents were assumed to be open and a solar heat load of 82 BTUH/ft^2 is included for the 70°F and 103°F ambient temperature cases. The minimum (winter) and maximum (summer) temperature conditions were assumed to occur for a sufficient period of time such that steady-state conditions were achieved. The lifetime average ambient temperature of the HSM was assumed to be 70°F, as discussed in Section 8.1.1.C of Reference 8.1. For the transfer cask, winter or summer conditions with an ambient temperature range at -3°F (minimum winter) and 103°F (maximum summer) were considered. A solar heat load of 127 BTUH/ft^2 is included for the 103°F ambient case.

B. Off-Normal Condition

Extreme winter or summer conditions with an ambient temperature range of -3°F to 103°F were considered. For the HSM, the vents were assumed to be open. A solar heat flux of 127 BTUH/ft^2 is conservatively included for the 103°F ambient temperature to maximize the HSM roof concrete surface temperatures. This condition is assumed to occur for a sufficient period of time such that steady-state conditions are achieved. The off-normal thermal conditions for the transfer cask are identical to the normal thermal conditions previously described.

C. Accident Condition

An extreme summer condition with an ambient temperature of 103°F was considered. In addition, the HSM vents were assumed to be completely blocked for a period of 48 hours or less. A solar heat flux of 127 BTUH/ft^2 is conservatively included to maximize the HSM concrete temperatures.

8.1.3.1 Thermal Analysis of the Horizontal Storage Module

The HSM thermal analyses were performed for the design basis ambient air temperatures defined in Section 8.1.3. The model is described in Section 8.1.3.1.C of Reference 8.1.

Convection heat transfer from the DSC and HSM surfaces was modeled using a constant air temperature for the axial air gap regions between the DSC and HSM. These temperatures were also used to calculate the heat transfer coefficients for these gap regions.

Maximum temperatures on the DSC outer surfaces and the concrete inner and outer surfaces were calculated for the normal, extreme winter, and extreme summer ambient conditions, and the postulated accident conditions with blocked HSM vents.

8.1.3.2 Thermal Analysis of the Dry Shielded Canister in the Horizontal Storage Module

The DSC and fuel assembly heat transfer analyses with the DSC inside the HSM were performed for the design basis ambient air temperatures defined in Section 8.1.3. The analytical model is described in Section 8.1.3.2.A of Reference 8.1. The cases of interest are those which maximize fuel cladding temperature, so the evaluations are limited to summer ambient conditions as described in Section 8.1.3.1 of Reference 8.1. These temperatures were used to derive the DSC internal pressures. The spacer disk thermal analyses were performed using the analytical model described in Section 8.1.1 of Reference 8.1.

The peak fuel clad temperature limit of 335°C for the Calvert Cliffs NUHOMS design was calculated using fundamentally the same bounding conservative design criteria and analysis methods previously reviewed and approved by the NRC for the NUHOMS-07P and generic NUHOMS-24P designs (References 8.25 and 8.26).

The maximum allowable cladding temperature for long term storage of the spent fuel is based on Zircaloy behavior models developed to predict the behavior of irradiated materials. The primary applicable models are CSFSM models documented in Reference 8.27. This reference provides a simple relationship for calculating the cladding stress given the rod diameter, cladding thickness and internal pressure. The curves in the Reference are then used to determine the acceptable initial storage temperature for the given cladding stress and cooling time. Bounding end of life fission (plus fill) gas pressure was provided by the fuel manufacturer.

Using the above methodology the resulting maximum storage temperature for the design basis fuel to preclude damage of fuel cladding during long term storage was 335°C. The limiting fuel assembly has a maximum burnup of 50 gwd/mthm and cooling time of 12 years to reach 0.66 kW decay heat. The maximum allowable cladding temperature limit for lower burnups and shorter time resulting in 0.66 kW decay heat per assembly are higher than 335°C.

The acceptable peak clad temperature limit for accident conditions for ISFSI storage is the same as the generic NUHOMS-24P design (Reference 8.26). This limit is based on the empirical work presented in Reference 8.27.

8.1.3.3 Thermal Analysis of the Dry Shielded Canister in the Transfer Cask

The thermal analyses for the cases with the DSC inside the transfer cask were performed for the design basis ambient air temperatures defined in Section 8.1.3. The analyses were conducted using the models described in Section 8.1.3.3 of Reference 8.1.

Maximum fuel cladding and DSC shell temperatures and the average helium temperature were calculated for the normal ambient temperature of 70°F, abnormal summer ambient temperature of 103°F, and the postulated accident conditions with blocked HSM vents.

Prior to specifying NS-3 for the transfer cask neutron shield, the manufacturer (Bisco Products) was requested to provide test data to support the behavior of the NS-3 at elevated temperatures. A series of tests were performed on sealed samples of NS-3 to determine the maximum off gas pressure produced by the product at temperatures up to 280°F. The tests were conducted on sealed NS-3 samples to represent the closed neutron shield and the temperature sustained for sufficient time to produce equilibrium. The samples were cycled to room temperature and back to elevated temperature to ensure repeatability of data. At the conclusion of the tests, NS-3 samples were removed and the final hydrogen content measured. This was combined with the measured free water, produced as a result of NS-3 off gassing, to determine the total hydrogen content available for neutron shielding.

The results of these tests showed that the maximum system pressure due to NS-3 off gassing at 280°F was 45 psig. This is less than 50% of the neutron shield safety relief valve set point pressure of 95 psig.

The results of these tests also showed that the hydrogen loss from NS-3 was less than 10% at 280°F. Since the maximum pressure generated due to off gassing at 280°F was less than 50% of the neutron shield safety relief valve set point pressure of 95 psig, this hydrogen is not lost from the neutron shield cavity. The shielding analysis of the Calvert Cliffs NUHOMS design was performed assuming a conservative 10% hydrogen loss from the NS-3.

Differential thermal expansion of the NS-3 is not a problem as the published coefficient of thermal expansion (7.81×10^{-6}) is less than the 9.85×10^{-6} of the neutron shield stainless steel shell and unanticipated stresses will not occur.

The CCNPP cask liner and neutron shield temperatures are higher than those of the generic NUHOMS-24P design because:

1. The solar heat flux used in the generic NUHOMS-24P design for the 100°F ambient case was 62 Btu/hr-ft^2 compared to 127 Btu/hr-ft^2 used for the 103°F ambient case in the CCNPP ISFSI design.

2. The neutron shield in the generic NUHOMS-24P design is a 3.0" ethylene glycol (50/50 mixture) as compared to a 4.0" Bisco NS-3 for the CCNPP ISFSI design. The thermal conductivity of ethylene glycol is considerably higher than that of NS-3.

TABLE 8.1-8
MAXIMUM HORIZONTAL STORAGE MODULE REINFORCED CONCRETE BENDING MOMENTS AND SHEAR FORCES FOR NORMAL AND OFF-NORMAL LOADS

		HSM INTERNAL FORCES					
Structural Section	**Force(a) Component**	**Dead Weight**	**Creep Effects**	**Live Loads**	**Normal Thermal**	**Off-normal Thermal**	**Ultimate(b)(c) Capacity**
Floor Slab	Shear						178
	Moment						1942
Inner Wall	Shear						26.6
	Moment	NOTE: The calculated forces are less than the ultimate capacity.					1027
End Wall	Shear						207
	Moment						1942
Roof Slab	Shear						178
	Moment						1942

For more information see Reference 8.16.

Ultimate Shear Capacity based on ACI 349.85 Section 11.8.3 Equation 11-27 for deep flexural members except for inner wall which is based on Equation 11-28.

(a) Shear values are in kips/ft. Moment values are in inch-kips/ft.

(b) Concrete and reinforcing steel properties were taken at 400°F to conservatively envelope all ambient cases.

(c) Ultimate capacities are reported for a 12” section of HSM using f'_c and f_y values at 400°F.

8.2 ACCIDENTS

This section addresses design events of the third and fourth types as defined by ANSI/ANS 57.9-1984 (Reference 8.2), and other credible accidents consistent with Title 10, Code of Federal Regulations (CFR) Part 72 which could impact the safe operation of the Calvert Cliffs ISFSI. The postulated events identified in Section 8.2 of Reference 8.1 and addressed herein for the Calvert Cliffs ISFSI are:

A. Loss of Air Outlet Shielding
B. Tornado Winds/Tornado Missile
C. Earthquake
D. Flood
E. Transfer Cask Drop
F. Lightning
G. Blockage of Air Inlets and Outlets
H. DSC Leakage
I. Accidental Pressurization of DSC

In addition, two additional Calvert Cliffs site-specific accidents have been identified and addressed. These are:

J. Forest Fire
K. Liquified Natural Gas (LNG) Plant or Pipeline Spill or Explosion

The accidents considered, and the associated components affected by each accident, are summarized in Table 8.2-1.

In the following sections, each accident condition is evaluated for applicability to the Calvert Cliffs ISFSI. For each applicable condition the accident cause, structural, thermal, radiological consequences, and recovery measures required to mitigate the accident are discussed. Where appropriate, resulting accident condition stresses were combined with those of normal operating loads in accordance with the load combination definitions of Section 3.2.5. Load combination results for the HSM, DSC, and transfer cask are discussed in Section 8.2.12. A reanalysis of the effects of all accidents on the DSC structure was performed and documented in Reference 8.23.

Reflood pressure is included as an ASME Service Level D activity but is not identified as an accident.

8.2.1 LOSS OF AIR OUTLET SHIELDING

This postulated accident involves the loss of both air outlet shielding blocks from the top of one HSM. All other components are assumed to be in their normal conditions.

The Calvert Cliffs air outlet shielding blocks are different from those described in Section 8.2.1 of Reference 8.1 in that they are designed to remain in place and withstand all design events including the effects of tornado missiles. Following the occurrence of such an event, the HSM air inlets and outlets will be inspected to confirm their condition. Therefore, this accident event is not applicable to the Calvert Cliffs ISFSI design and no further consideration is required.

8.2.2 TORNADO WINDS/TORNADO MISSILE

8.2.2.1 Cause of Accident

The tornado wind and missile loadings presented in Section 3.2.1 are used as the design basis for this accident condition.

8.2.2.2 Accident Analysis

The applicable parameters of the design basis tornado (DBT) are specified in Section 3.2.1. The DBT parameters specified in Section 3.2.1 are identical to those used in Reference 8.1 in the determination of forces on structures for this accident. The determination of tornado wind and tornado missile forces acting on the HSM was performed for Calvert Cliffs 2x6 module array using the same methodology as that documented in Section 3.2.1 of Reference 8.1. The HSM walls, roof, and foundation are connected by reinforcing steel. The transfer cask is designed for the tornado wind loads and tornado missiles defined in Section 3.2.1.

A. Effect of DBT Wind Pressure Loads on HSM

The effects of DBT wind loads on the HSM were evaluated using the STRUDL finite element model. An analysis was also performed to evaluate the potential for overturning and sliding of the 2x6 module array due to wind and seismic forces. The methodology employed in evaluating the applied and resisting forces and moments is the same as that used in Section 8.2.2.2 of Reference 8.1. The results showed that there was a sufficient margin of safety against the HSM overturning and sliding.

B. Effect of DBT Wind Pressure Loads on Transfer Cask

The transfer cask was evaluated for DBT wind pressures using the same methodology as Section 8.2.2.2 of Reference 8.1. The stabilizing moment of the Calvert Cliffs transfer cask, skid, and trailer, with a combined total weight of 255 kips and a trailer half wheel base of 72", is 1528 k-ft. The overturning moment for the combined projected area of 212 ft^2 and a total height of 147" is 515 k-ft. Therefore, the factor of safety against overturning of the Calvert Cliffs transfer cask is approximately 3.0.

As reported in Section 8.2.2.2 of Reference 8.1, the transfer cask stresses due to DBT wind pressures are small and were not considered further. Since the Calvert Cliffs transfer cask shell and cover plate thicknesses are equal to or greater than those used in the analysis of Reference 8.1, transfer cask stresses due to DBT wind loads are insignificant and do not need to be included in the load combinations.

C. Horizontal Storage Module Missile Impact Analysis

The effects of DBT missile loads on the HSM were evaluated using the same methodology as Section 8.2.2.2 of

Reference 8.1. The computed HSM forces and moments due to tornado missile impact were found to be well within the ultimate capacity.

As discussed in Section 8.2.1, the design of the Calvert Cliffs HSM air outlet shield blocks differs from that documented in Reference 8.1. The Calvert Cliffs air outlet shield blocks have been designed to withstand the effects of tornado generated missile loads, and therefore are not designed to be replaced. The Calvert Cliffs HSM air outlet shield blocks are integrally cast with the HSM concrete. The effects of DBT missile loads on the air outlet shield blocks were evaluated using similar methodology to that for the HSM walls documented in Section 8.2.2.2 of Reference 8.1. The maximum computed shear and moment due to tornado missile impact on the HSM air outlet shield blocks are 3.6 kips/ft and 293 inch-kips/ft, respectively. The corresponding air outlet shield block shear and moment capacities are 11.5 kips/ft and 364 inch-kips/ft, respectively.

D. Transfer Cask Missile Impact Analysis

The transfer cask was analyzed for the effects of the 3,967 lb automobile and 276 lb, 8” diameter, blunt-nosed shell tornado missiles specified for the HSM in Table 3.2-1 of Reference 8.1. The 1” diameter steel spherical missile was not evaluated as there are no critical openings, and the effects of the small sphere are enveloped by the 8” shell missile.

As described in Section 5.1.1, all cask handling outside the Auxiliary Building is performed with the cask secured horizontally on the transfer trailer. Therefore, the analysis was performed for the cask secured in the horizontal position on the support skid. The criteria used to evaluate the adequacy of the transfer cask for tornado generated missiles were stability, penetration resistance, and stress.

The components considered in this evaluation were the transfer cask structural shell and top and bottom cover plates. It was conservatively assumed that the solid neutron shield provides no structural strength or penetration resistance.

1. Stability Analysis

It was conservatively assumed that the missile impacts the uppermost part of the cask. The maximum angle of rotation of the cask/skid/trailer arrangement at impact was calculated as 1.9°, based on the conservation of angular momentum. Tip-over (i.e., instability of the cask/skid/trailer) occurs when the center of gravity of the cask is directly above the point of rotation, which is 35.2° from vertical. The maximum calculated rotation of 1.9° due to missile impact is approximately 5% of that necessary to cause overturning. Therefore, the stability of the cask/skid/trailer arrangement is maintained.

2. Penetration Analysis

Penetration of the cask structural shell by the 276 lb rigid missile was evaluated using two formulas obtained from the listed references. The energy absorbing capacity of the neutron shield material was conservatively ignored for this calculation. The first approach, suggested by Nelms (Reference 8.6), is for a leadbacked shell:

$T = (KE/2.4\ S_u\ D^{1.6})^{0.71}$
$= 0.50“$

Where:

T = Minimum required steel plate or shell thickness to resist penetration
KE = Kinetic energy = $1/2\ mV^2$
m = Mass of missile = 276 lb/g
= 0.715 lb. sec^2/in
V = Velocity of missile
= 2,218 in/sec
S_u = Ultimate strength of cask structural shell
= 70,000 psi
D = Diameter of missile
= 8.0“

The second formula used was developed by the Ballistic Research Laboratory (Reference 8.7):

$T = (KE^{2/3}/672\ D)$
$= 0.52“$

Where:

KE = Kinetic energy = $1/2\ mV^2$
m = Mass of missile
= 8.57 lb sec^2/ft
V = Velocity of missile
= 184.8 ft/sec
D = Diameter of missile
= 8.0”

Both methods produce a consistent result which shows a predicted penetration of 0.5” compared to the minimum structural shell thickness of 1.5“. Therefore, the DBT missile will not penetrate the cask structural shell and the DSC will not be affected by a DBT missile impacting the cask.

3. Stress Analysis

Conservative hand calculations were performed to determine the peak stresses in the cask shell, and the top and bottom cover plates due to DBT missile loads. The calculated stresses were lower than the allowable stresses. The analytical method for each of the load cases shown in this table are briefly described below.

a. Massive Missile Impact: Using the principle of conservation of angular momentum, the total impact forces were calculated at equilibrium. These forces were applied as a live load to the cask structural shell and as a pressure load to the top and bottom cover plates. The analytical method used was the same as that described above for the DBT wind pressure loads.

b. Penetration Resistance Missile: The impact force due to the 8" diameter, 276 lb missile was calculated using the principle of conservation of momentum to be 63.4 kips. Case 9a, Table 31 of Reference 8.8 was used to calculate the membrane and bending stress for the cask shell while Cases 16 and 17, Table 24 of Reference 8.8 were used to calculate the stresses in the top and bottom cover plates, respectively.

8.2.2.3 Accident Dose Consequences

All components of the ISFSI are capable of safely withstanding tornado wind loads and tornado generated missiles. Therefore, there is no accident dose associated with the DBT.

8.2.3 EARTHQUAKE

8.2.3.1 Cause of Accident

As specified in Section 3.2.3, an earthquake is postulated to occur at the Calvert Cliffs ISFSI with peak ground acceleration values of 0.15g horizontal and 0.10g vertical.

8.2.3.2 Accident Analysis

The analytical methods to evaluate earthquake loads for the Calvert Cliffs ISFSI are similar to those documented in Section 8.2.3.2 of Reference 8.1. The HSM and DSC support seismic analyses were performed using the Calvert Cliffs site-specific peak ground accelerations. The DSC and transfer cask are evaluated using the seismic accelerations discussed in Section 8.2.3.2 of Reference 8.1.

A. Dry Shielded Canister Seismic Analysis

1. Dry Shielded Canister Seismic Stress Analysis

The DSC seismic stress analysis for DSCs R001 through R024 was performed using the methodology of Section 8.2.3.2 of Reference 8.1. Seismic accelerations of 1.5g horizontal and 1.0g vertical are used in the evaluation per Reference 8.1.

Dry shielded canisters, starting with R025, employ a modified internal basket assembly design (refer to Section 4.2.3.2). The modified DSC was analyzed using analytical methods comparable to those described for DSCs R001 through R024 above. The modified DSC stresses remain within ASME code allowable stresses (Reference 8.24).

2. Dry Shielded Canister Seismic Stability Analysis

Dry shielded canister lift-off from the DSC support assembly rail during a seismic event was evaluated using the methodology of Section 8.2.3.2 of Reference 8.1 for horizontal and vertical accelerations of 0.41g and 0.26g, respectively. These accelerations correspond to the Regulatory Guide 1.60, Revision 1 peak response values for 7% damping using the Calvert Cliffs peak ground accelerations. The applied and stabilizing moments for the Calvert Cliffs DSC are calculated to be 951 inch-kips and 995 inch-kips, respectively, resulting in a factor of safety against lift-off of 1.05.

B. Horizontal Storage Module Seismic Analysis

1. Horizontal Storage Module Seismic Stress Analysis

The HSM seismic stress analysis was performed using the methodology described in Section 8.2.3.2 of Reference 8.1. A STRUDL finite element model was used to perform the analysis. Seismic accelerations of 0.51g horizontal and 0.33g vertical were used in the analysis. The resulting forces and moments in the HSM were found to be well within the ultimate capacity.

2. Horizontal Storage Module Seismic Stability Evaluation

The stability of the HSM during a seismic event was evaluated using the methodology of Section 8.2.3.2 of Reference 8.1. The Calvert Cliffs 2x6 module array was evaluated for sliding and overturning of the entire array, including the foundation. Accelerations of 0.41g horizontal and 0.26g vertical, which correspond to the peak structural acceleration values from Regulatory Guide 1.60, Revision 1 using the Calvert Cliffs peak ground accelerations, are used in this evaluation. The results showed that there was a sufficient margin of safety against the HSM seismic overturning and sliding.

C. Dry Shielded Canister Support Assembly Seismic Analysis

The DSC support assembly was analyzed for horizontal and vertical seismic accelerations of 0.61g and 0.39g, respectively, which correspond to the Regulatory Guide 1.60, Revision 1 peak structural accelerations for Calvert Cliffs peak ground accelerations, and indicates a multiple mode factor in accordance with NUREG-0800, Revision 1. The evaluation was performed using conservative hand calculations and included the dead weight of the DSC. The maximum calculated axial plus bending stress and shear stress in the wide flange support rails are 17.1 ksi and 11.5 ksi, respectively. The maximum calculated bending stress and shear stress in the wide flange cross member support beams are 22.3 ksi and 13.6 ksi, respectively. These compare with AISC Code allowables of 26.3 ksi for bending and 14.9 ksi for shear. The stresses due to the two horizontal and vertical seismic loads were combined absolutely and included in the load combination results reported in Section 8.2.12.

The use of the multi-mode factor is consistent with the approved NUHOMS topical report. As discussed in Section 8.2.3.2.A(ii) of the topical report, "The factor of 1.5 used in the DSC analysis to account for multi-mode behavior need not be included in the seismic accelerations for this analysis, as the potential for lift off is due to rigid body motion, and no frequency content effects are associated with this action." This analysis approach was accepted by the NRC for the topical report.

D. Transfer Cask Seismic Analysis

As discussed in Section 8.2.3.2 of Reference 8.1, the transfer cask may not be subjected to a horizontal acceleration in excess of 0.40g while standing vertically in the cask washdown pit. The maximum acceleration of the Calvert Cliffs cask washdown pit floor is 0.30g (zero period acceleration), which is within the Reference 8.1 requirements.

The seismic stress analysis for the Calvert Cliffs transfer cask supported by the transport trailer/skid was performed using the same methodology and seismic loads described in Section 8.2.3.2 of Reference 8.1.

8.2.3.3 Accident Dose Consequences

Major components of the Calvert Cliffs ISFSI have been designed and evaluated to withstand the forces generated by the Design Basis Earthquake (DBE). Hence, there are no dose consequences.

8.2.4 FLOOD

As discussed in Section 3.2.2, flood loads are not applicable to the Calvert Cliffs ISFSI.

8.2.5 CASK DROP

A transfer cask drop is any uncontrolled vertical movement resulting in an impact with a large horizontal surface. An uncontrolled vertical movement includes a cask tip-over and the cask falling off of the transfer trailer.

For more information see Reference 8.16.

8.2.5.1 Cause of Accident

This section addresses the structural integrity of the transfer cask, the DSC, and its internals under a postulated transfer cask accident condition. As discussed in Section 8.2.5.1 of Reference 8.1, an actual drop event is not considered credible. However, consistent with the criteria of Reference 8.1, it is postulated that the transfer cask described in Section 4.3 with the DSC inside will be subjected to an end, side, or oblique drop with a maximum height of 80“ onto a thick concrete slab. A drop of greater than 80“ is not considered because (a) transfer inside the Auxiliary Building will be performed using a single-failure-proof crane and (b) the transfer trailer and haul road are designed such that the transfer cask cannot be raised greater than 80“ from the ground.

The transfer cask is transported along an asphalt or concrete paved road which is 16‘ wide and has 7 to 8’ shoulders. The road is approximately 3,300 linear feet with slopes which range from 0% to 3% except for an approximate 50’ length which carries a 5.7% slope. The roadbed is level except for a negligible 1% slope required to create a crown in the road for drainage and a transverse slope at any point along the transportation route of less than 10%. The shoulders are either level with the road or slope up from the road. In those locations where the paved road abuts up to existing blacktop, or concrete paving, the shoulder is discontinued. The shoulder may be paved, gravel or soil and contain typical roadside fixtures, including curbs, fences, guard rails and light poles which do not constitute potential puncture devices for the cask during a drop. The shoulders do not contain items such as light pole pedestals which protrude above the shoulder surface and could represent a potential cask puncture device during a cask drop. For the entire route that the transfer cask is transported there will exist a minimum 8‘ wide zone that is at or above the roadbed elevation.

The transfer trailer braking system is not operable independent of the prime mover. However, failure of the prime mover will cause the trailer braking system to fail-safe, that is "lock tight.”

8.2.5.2 Accident Analysis

The Calvert Cliffs transfer cask and DSC were evaluated for the effects of a drop of 80” onto a hard concrete surface. The maximum computed surface hardness for the Calvert Cliffs Nuclear Power Plant (CCNPP) and the ISFSI was computed based on Reference 8.14, assuming a 3’ thick reinforced concrete slab backed by well compacted sand and/or gravel. Based on the methodology and information provided in Reference 8.14, the target hardness was computed to be 112,000 for the end drop and 33,300 for the side drop. This resulted in maximum decelerations of 51g for the end drop case and 31g for the side drop. The DSC and transfer cask were conservatively designed for the 75g deceleration value discussed in Reference 8.1, which bounds the computed deceleration values for an 80“ drop.

Dry Shielded Canister

The Calvert Cliffs NUHOMS-24P DSC shell was analyzed for an 80“ drop accident using the analytical methods presented in Section 8.2.5.2 of Reference 8.1 for DSCs R001 through R024. An ANSYS model of the DSC shell was used to perform the vertical drop analysis.

The evaluation of the DSC shell for a postulated horizontal drop presented in Reference 8.1 bounds the Calvert Cliffs drop accident. The shell assembly, the top shield plug, and the basket assembly are heavier for the Calvert Cliffs design than the Oconee design, which may have been the basis for the Reference 8.1 analysis. The "end caps," or shield plugs, for the Calvert Cliffs DSC design are thicker than the Oconee design and, therefore, are heavier. However, for the side drop the load is carried in bearing on the inside surface of the transfer cask, i.e. there is no substantial bending mechanism at the end cap/shell juncture for the side drop event. Therefore there will not be significant bending stresses at the end cap/shell juncture as a result of the side drop. The weight of the lead shielding will have a substantial effect on the calculated end drop stresses for bending the shell, which has been evaluated specifically for Calvert Cliffs. The remaining DSC components were evaluated for the horizontal drop case using the same methodology as presented in Section 8.2.5.2 of Reference 8.1 for the Calvert Cliffs specific configuration. This included the consideration of misalignment of fuel assembly spacer grids and DSC spacer discs, where necessary (Reference 8.23).

The DSC basket assembly was analyzed for a vertical drop using an ANSYS model. In DSCs R001 and R024, the guide sleeves are attached to the bottom spacer disc with either clip angles or folded over the welded tabs cut from the guide sleeve wall. The attachments may fail at a deceleration rate of less than the design basis 75g, but in a bounding analysis they were conservatively assumed to remain intact up to 75g. With the attachments remaining intact, the guide sleeve loads are transferred to the spacer disc and support rods.

The integrity of the spacer disc during the postulated vertical drop was evaluated using a very detailed plastic analysis (Reference 8.23). The 1/4 symmetry ANSYS spacer disc model was incrementally loaded with and without guide sleeve masses until the 75g static equivalent drop load was reached. The calculated stresses were below the ASME Level D plastic analysis allowables. In addition, a very detailed plastic analysis was performed for the support rods, which determined that the rods would remain stable well beyond the 75g deceleration.

The expected failure of the guide sleeve to spacer disc welds during a drop accident event are not expected to have any effect on the retrievability of the fuel.

The guide sleeve to bottom spacer disc welds are provided for assembly of the DSC basket and to prevent the guide sleeves from moving during transportation. The lightweight guide sleeves are attached to the bottom spacer disc by four 0.25 in. plug welds or four fillet welds. For the design basis vertical drop load of 75g, the maximum calculated weld stress may exceed the Service Level D fillet weld allowable of 22.4 ksi.

Failure of the welds during a top end drop would result in the guide sleeves moving less than 4” until it impacts the inner cover plate. A bottom drop of the DSC would result in the guide sleeves moving less than .12” before impacting on the bottom cover plate. For the design basis 75g impact, the calculated guide sleeve compressive stress is below the AISC normal allowable compressive stress of 21.4 ksi for a column of these dimensions. Therefore, failure of the welds during a drop accident may result in minor deformation of the guide sleeves but would have no effect on the retrievability of the fuel.

The drop load stresses are all within the applicable Service Level D allowables. The fuel retrievability from the DSC will be assured for the postulated 80” drop accident.

Modified DSC Basket Assembly

Dry shielded canisters starting with R025 employ a modified internal basket assembly design (refer to Section 4.2.3.2). Structural analyses for the major DSC structural elements, including the shell, cover plates, spacer discs and support rods were performed using ANSYS finite element analysis. The modified DSC drop load stresses were determined to be within ASME code allowable stresses (Reference 8.24).

The guide sleeves in the modified DSC design are not attached to the spacer discs and the sleeves may move through the spacer discs openings until bearing occurs against an inner cover plate. In the case of a vertical drop, the only load acting on the guide sleeves in the longitudinal direction is that due to self weight. There is adequate margin against buckling of the guide sleeve. Similarly, for the spacer discs, the only load acting on the spacer discs during a vertical drop is the self weight of the disc. The discs remain elastic throughout the event. No fuel retrieval difficulties will occur due to guide sleeve or spacer disc elastic deflections.

Evaluation of the modified DSC guide sleeve for a horizontal drop conservatively considered a condition where a spent fuel assembly end plate is offset approximately 1” away from the face of the nearest spacer disc. The guide sleeve stresses remain below what is required to pierce the sleeve wall, and therefore, removal of an intact spent fuel assembly will not be prohibited.

The guide sleeves in the modified DSC have two extraction stops (metal tabs) that are mounted to the outside walls of each guide sleeve. The extraction stops are intended to prevent guide sleeve withdrawal in the event any incidental binding should occur during withdrawal of a spent fuel assembly. Extraction forces on the extraction stops have been analyzed. Extraction loads may cause minor dimpling of the guide sleeve, but will not affect the ability to retrieve an intact fuel assembly.

Transfer Cask

The Calvert Cliffs NUHOMS-24P transfer cask was analyzed for the 80” drop height accident (Reference 8.1) using the ANSYS 3-D transfer cask one-half model (Reference 8.33). For the vertical, horizontal, and corner drop orientations, the contacting surface was assumed to be rigid. A static equivalent load of 75g was applied. The internal loading of the DSC was represented as pressure loadings applied to the transfer cask inner surfaces.

The maximum computed decelerations for the transfer cask at the Calvert Cliffs ISFSI are bounded by the design deceleration of 75g. The integrity of fuel assemblies contained within a DSC, following a postulated 75g drop, was analyzed. The analyses consisted of an evaluation of the impact of the drop on all of the fuel assembly components; namely, the fuel rods, guide tubes, spacer grids, retention grid, and upper and lower end fittings. The objectives of evaluation were to determine the impact on safety issues, such as confinement, criticality, thermal response, and retrievability.

Stress intensities were calculated for the fuel rods, guide tubes, lower end fitting (including retention grid) (References 8.34 and 8.35). The ASME code allowables for these components were determined at temperatures that envelop the maximum cladding temperature of 635°F, and were 58.95, 57.96, 57.15 ksi, respectively. The calculated stress values were below the code allowables. Therefore, none of these components would fail following a drop.

The upper end fitting was analyzed for its limiting scenario of an upside-down vertical drop (Reference 8.36). The analysis was based on the consideration of the elastic-plastic material behavior. The acceptance criterion used was the lack of failure, rather than meeting the code minimum stress and strain values. It was determined that the upper end fitting ligaments would not fail, and that at least a factor of 2 margin would be available against ductile tearing. Any deformation of the upper end fitting ligaments would not impact fuel assembly retrievability.

The spacer grids were analyzed (Reference 8.37). The guide sleeve, in which the assembly resides, was assumed perfectly rigid for conservatism. An equivalent static impact force of 75g was used in the analysis to represent the worst case loading experienced by the spacer grids during a DSC accidental horizontal drop. The Zircaloy-4 spacer grid that is part of a spent fuel assembly is expected to be irradiated and thus exhibit a brittle behavior. Nonetheless, both brittle and ductile (un-irradiated) cases were considered in the calculation.

Based on the results of this evaluation, it was determined that major structural damage of the spacer grid would occur from a 75g accidental drop scenario for both ductile and brittle material behavior assumptions. In addition, the perimeter strip would likely fail at the lower levels of the spacer grid and thus allow fuel rods to be relocated from their original grid locations, and create the possibility of one of them getting wedged against the guide sleeve. It was further determined that, with this possibility, an additional pull force of about 220 lbs. would be required for retrieving the fuel assembly from the DSC. The additional required force is within the capacity of the fuel handling machine. Therefore, retrievability of the fuel assembly from the DSC would not be compromised.

The effect of impact of a broken spacer grid fragment, during a horizontal drop, on the fuel rod cladding was investigated (Reference 8.38). Various cladding vs. fragment orientations and edge conditions were considered. The maximum cladding wall stress was found to be less than the allowable stress of 80.5 ksi at 635°F.

The failure of spacer grids was determined also to cause a change in the fuel rod pitch from 0.58 inch to 0.465 inch. The impacts of this change on the criticality and cladding temperature were analyzed. The criticality calculation determined that the effective multiplication factor (k_{eff}) was still less than 0.95 (Reference 8.39). The cladding temperature evaluation determined that the temperature for the reduced rod pitch would be lower than that for the normal rod pitch because of better conductivity of the new arrangement (Reference 8.40).

8.2.5.3 Accident Dose Consequences

The cask drop analyses have shown that transfer cask, DSC, its internal basket assembly, and contained fuel will maintain their structural integrity through a cask drop. For the purpose of demonstrating the safety of the NUHOMS-24P system, it is conservatively assumed that the entire cask solid neutron shield is lost as a result of the design drop accident. This would result in an increase in the cask surface contact dose from 141 mrem/hr to 1126 mrem/hr (References 8.41, 8.42, and 8.43). An on-site worker at an average distance of 15' for the 8-hour recovery time, as discussed in Reference 8.1, would receive an additional dose of 776 mrem (97 mrem/hr x 8 hr).

8.2.6 LIGHTNING

8.2.6.1 Cause of Accident

Lightning striking an HSM and causing an off-normal operating condition is not considered a credible accident given the ISFSI lightning protection system provided. The lightning protection system for the ISFSI is designed in accordance with the Lightning Protection Code (Reference 8.15). This system precludes any damage to an HSM or its contained DSC due to lightning.

8.2.6.2 Accident Analysis

Should lightning strike an HSM, the normal operation of the HSM will not be affected since the current discharged by the lightning will follow the low impedance path to ground provided by the lightning protection system. Therefore, the DSC and HSM will not be damaged by heat or mechanical forces generated by current passing through the higher impedance concrete. Since the HSMs require no equipment for continued operation, the resulting current surge from a lightning strike will not affect the normal operation of the ISFSI.

8.2.6.3 Accident Dose Consequences

Since no off-normal operating condition will develop as a result of lightning striking in the vicinity of the ISFSI, there are no radiological dose consequences.

8.2.7 BLOCKAGE OF AIR INLETS AND OUTLETS

This accident involves the complete and total blockage of all HSM air inlets and outlets for a period of 48 hours.

8.2.7.1 Cause of Accident

Since the ISFSI is located outdoors, HSM air inlets and outlets could potentially be blocked by debris from such unlikely events as tornadoes. Independent Spent Fuel Storage Installation design features such as a perimeter fence and separation of air inlets and outlets reduce the potential for this accident.

8.2.7.2 Accident Analysis

The stresses caused by the additional weight of debris blocking the air inlets and outlets are bounded by the structural consequences of other accidents described in this section (i.e., tornado and earthquake analyses). The thermal consequences of this accident result from heating of the DSC and HSM due to the loss of natural convection cooling.

The thermal analyses to determine the temperature rise for the Calvert Cliffs HSM and DSC components due to blocked vents were performed using the methodology described in Section 8.2.7.2 of Reference 8.1. The calculated pressures in all cases were less than the design basis accident pressure of 50 psig discussed in Reference 8.1. The design basis pressure was considered in the DSC accident pressure evaluation presented in Section 8.2.9.

The thermally-induced stresses for the HSM for the blocked vent case were calculated using the STRUDL analytical model and the methodology discussed in Section 8.2.7.2 of Reference 8.1.

8.2.7.3 Accident Dose Consequences

There are no off-site dose consequences as a result of this accident. The only possible dose increase is related to a recovery operation where the on-site worker could receive an additional 584 mrem (73 mrem/hr x 8 hr) during an estimated 8 hour debris removal period (References 8.41, 8.42, and 8.43).

8.2.8 DRY SHIELDED CANISTER LEAKAGE

For more information see References 8.16 and 8.19.

As described in Section 3.3.2, the DSC is designed to ensure no leakage and the analysis for normal and accident conditions described in Reference 8.1 and this document have shown that there are no credible events which can breach the DSC pressure boundary or fail the double seal welds at each end of the DSC. However, to demonstrate the safety of the NUHOMS-24P system, a total and complete instantaneous leak of a single DSC is postulated, as described in Section 8.2.8 of Reference 8.1.

This postulated accident is the instantaneous release directly to the environment of fission gasses (mainly Kr-85) contained in all the fuel rods in all 24 fuel assemblies. This accident assumes that all fuel rods are ruptured and that concurrent DSC leakage occurs. Nuclide release fractions were obtained using the methodology of ANSI/ANS 5.4-1982. All other components of the storage system remain intact.

The following release mechanisms were evaluated in the manner of SAND80-2124 (Reference 8.28): impact rupture, burst rupture, diffusion, leaching, oxidation, and crud-release. It was concluded that noble gases may escape by diffusion and no other release mechanisms were probable.

Two systems for radionuclide confinement are provided by the NUHOMS-24P system: fuel rod cladding confines the fuel and fission products; and the DSC contains the contents of the fuel assemblies and the crud adherent to the fuel rods. Under normal conditions, both confinement features are intact. If any of the fuel rod cladding fails during storage, the DSC will become pressurized with a mixture of helium (the DSC fill gas) and fission gases. It is noted that the criteria for fuel cladding temperature in storage is established based on a probability of failure of the peak temperature fuel rods of less than 0.5% (PNL-6189) (Reference 8.29). In the postulated accident, the DSC is assumed to be pressurized by failure of 100% of all fuel rods, worst-case fission gas release fractions, and an elevated temperature equal to the worst-case thermal accident conditions. The DSC is designed and shown by structural analysis to withstand this pressure with a substantial margin of safety. Additionally, the DSC closure welds are fully redundant and both are welded and inspected to the standards of the ASME Code. While the release of 100% of the cladding gap fission gas is assumed for the purpose of accident assessment, no mechanistic release path exists.

Diffusion of the noble fission gas through the canister shell is assumed to occur. The release of particulate material would require gross breach of the DSC pressure boundary. Because of the ductile nature of the canister materials, the quality of construction inherent in the ASME Code, and the conservative nature of the design described above, a breach of sufficient size to cause release of radioactive particulate matter is incredible.

Therefore, complete particulate confinement is assumed in the referenced accident analyses.

The OCRWM Database (Reference 8.30) was used as a basis for the gross fuel radionuclide source term. A lengthy list of the nuclides present in one metric ton of heavy metal was extracted from the database and has been attached to this response. The data were obtained using ORIGEN calculations for 8 year cooled, 45,000 MWD/MTU burnup PWR fuel. The values in the "Curies" column should be multiplied by (0.386 MTHM * 24 assemblies/DSC) to obtain the total source term per DSC.

Argon, krypton, and radon are the only noble gases available for release. Kr-85 was determined to be the only significant contributor, as confirmed by Elias and Johnson (Reference 8.31). A release fraction of 2.1% was calculated using the methodology of ANSI/ANS-5.4-1982 (Reference 8.32). One-hundred percent of the "gap activity" was presumed to be available for release into the DSC cavity. Furthermore, the DSC release fraction was assumed to be 100%. The amount of Kr-85 used as a radiological source term for one ruptured DSC was therefore:

$$Q = 7.13E+03\,\frac{Ci}{MTHM}\ x\ 0.386\,\frac{MTHM}{Assy}\ x\ 24\,\frac{Assy}{DSC}\ x\ 0.021$$
$$= 1.39E+03\ Ci$$

Spent Fuel Repository Characteristics Data Base
Developed by: Oak Ridge National Laboratory, Oak Ridge, TN

Type of Reactor: PWR 45,000 Elapsed Decay: 8 years
All isotopes representing: All nuclides

Isotope	Curies	Percentage Of Total
H 3	6.25E+02	0.109 %
BE 10	6.66E-06	0.000 %
C 14	1.69E+00	0.000 %
SI 32	2.57E-07	0.000 %
P 32	2.57E-07	0.000 %
S 35	2.40E-09	0.000 %
CL 36	1.30E-02	0.000 %
AR 39	8.53E-05	0.000 %
AR 42	4.64E-13	0.000 %
K 40	5.90E-09	0.000 %
K 42	4.64E-13	0.000 %
CA 41	2.08E-04	0.000 %
CA 45	1.53E-06	0.000 %
SC 46	1.11E-10	0.000 %
V 50	1.11E-14	0.000 %
MN 54	1.24E+00	0.000 %
FE 55	6.18E+02	0.108 %
FE 59	9.34E-18	0.000 %
CO 58	2.55E-09	0.000 %
CO 60	2.87E+03	0.502 %
NI 59	4.76E+00	0.001 %
NI 63	7.08E+02	0.124 %

Isotope	Curies	Percentage Of Total
ZN 65	2.59E-02	0.000 %
SE 79	5.53E-01	0.000 %
KR 81	7.17E-07	0.000 %
KR 85	7.13E+03	1.247 %
RB 87	2.89E-05	0.000 %
SR 89	2.78E-12	0.000 %
SR 90	7.97E+04	13.934 %
Y 90	7.97E+04	13.934 %
Y 91	8.66E-10	0.000 %
ZR 93	2.61E+00	0.000 %
ZR 95	2.49E-08	0.000 %
NB 93M	1.02E+00	0.000 %
NB 94	1.62E+00	0.000 %
NB 95	5.72E-08	0.000 %
NB 95M	1.85E-10	0.000 %
MO 93	3.20E-02	0.000 %
TC 98	9.47E-06	0.000 %
TC 99	1.70E+01	0.003 %
RU103	6.00E-17	0.000 %
RU106	2.26E+03	0.395 %
RH102	2.75E-01	0.000 %
RH106	2.26E+03	0.395 %
PD107	1.54E-01	0.000 %
AG108	1.27E-03	0.000 %
AG108M	1.43E-02	0.000 %
AG109M	1.57E-02	0.000 %
AG110	2.12E-02	0.000 %
AG110M	1.60E+00	0.000 %
CD109	1.57E-02	0.000 %
CD113M	5.33E+01	0.009 %
CD115M	3.46E-17	0.000 %
IN113M	1.56E-05	0.000 %
IN114M	2.72E-16	0.000 %
IN115	1.57E-11	0.000 %
SN113	1.56E-05	0.000 %
SN119M	1.38E+00	0.000 %
SN121M	8.87E-01	0.000 %
SN123	5.12E-04	0.000 %
SN126	1.04E+00	0.000 %
SB124	4.37E-12	0.000 %
SB125	2.40E+03	0.420 %
SB126	1.45E-01	0.000 %
SB126M	1.04E+00	0.000 %
TE123	5.23E-12	0.000 %
TE123M	1.26E-06	0.000 %
TE125M	5.86E+02	0.102 %
TE127	1.05E-04	0.000 %
TE127M	1.07E-04	0.000 %
I129	4.23E-02	0.000 %

Isotope	Curies	Percentage Of Total
CS134	1.54E+04	2.692 %
CS135	5.66E-01	0.000 %
CS137	1.15E+05	20.105 %
BA137M	1.09E+05	19.056 %
LA138	2.24E-09	0.000 %
CE142	3.67E-05	0.000 %
CE144	7.94E+02	0.139 %
PR144	7.94E+02	0.139 %
PR144M	9.53E+00	0.002 %
ND144	2.18E-09	0.000 %
PM146	1.52E+00	0.000 %
PM147	1.58E+04	2.762 %
PM148M	1.55E-17	0.000 %
SM146	5.16E-07	0.000 %
SM147	5.15E-06	0.000 %
SM148	8.02E-11	0.000 %
SM149	9.82E-13	0.000 %
SM151	4.39E+02	0.077 %
EU150	2.95E-05	0.000 %
EU152	7.51E+00	0.001 %
EU154	8.45E+03	1.477 %
EU155	3.34E+03	0.584 %
GD152	6.06E-13	0.000 %
GD153	1.83E-02	0.000 %
TB160	9.08E-10	0.000 %
HO166M	4.87E-03	0.000 %
TM170	1.29E-08	0.000 %
TM171	8.78E-05	0.000 %
LU176	3.24E-11	0.000 %
LU177	2.83E-09	0.000 %
LU177M	1.23E-08	0.000 %
HF175	2.60E-12	0.000 %
HF181	9.76E-19	0.000 %
HF182	3.74E-07	0.000 %
TA182	1.43E-06	0.000 %
W181	5.24E-08	0.000 %
W185	5.58E-11	0.000 %
W188	3.39E-13	0.000 %
RE187	2.29E-08	0.000 %
RE188	3.42E-13	0.000 %
OS194	1.07E-10	0.000 %
IR192	1.16E-08	0.000 %
IR192M	1.16E-08	0.000 %
IR194	1.07E-10	0.000 %
PT193	1.11E-07	0.000 %
TL206	2.10E-08	0.000 %
TL207	7.99E-06	0.000 %
TL208	1.82E-02	0.000 %
TL209	9.85E-09	0.000 %

Isotope	Curies	Percentage Of Total
PB204	1.72E-16	0.000 %
PB205	2.18E-09	0.000 %
PB209	4.56E-07	0.000 %
PB210	5.05E-08	0.000 %
PB211	8.01E-06	0.000 %
PB212	5.05E-02	0.000 %
PB214	3.75E-07	0.000 %
BI208	3.42E-08	0.000 %
BI210	5.05E-08	0.000 %
BI210M	2.11E-08	0.000 %
BI211	8.01E-06	0.000 %
BI212	5.05E-02	0.000 %
BI213	4.56E-07	0.000 %
BI214	3.75E-07	0.000 %
PO210	5.99E-08	0.000 %
PO211	2.24E-08	0.000 %
PO212	3.24E-02	0.000 %
PO213	4.46E-07	0.000 %
PO214	3.75E-07	0.000 %
PO215	8.01E-06	0.000 %
PO216	5.05E-02	0.000 %
PO218	3.75E-07	0.000 %
AT217	4.56E-07	0.000 %
RN219	8.01E-06	0.000 %
RN220	5.05E-02	0.000 %
RN222	3.75E-07	0.000 %
FR221	4.56E-07	0.000 %
FR223	1.10E-07	0.000 %
RA223	8.01E-06	0.000 %
RA224	5.05E-02	0.000 %
RA225	4.56E-07	0.000 %
RA226	3.75E-07	0.000 %
RA228	7.46E-11	0.000 %
AC225	4.56E-07	0.000 %
AC227	7.99E-06	0.000 %
AC228	7.46E-11	0.000 %
TH227	7.90E-06	0.000 %
TH228	5.04E-02	0.000 %
TH229	4.56E-07	0.000 %
TH230	1.40E-04	0.000 %
TH231	1.85E-02	0.000 %
TH232	1.87E-10	0.000 %
TH234	3.12E-01	0.000 %
PA231	3.27E-05	0.000 %
PA233	4.76E-01	0.000 %
PA234	4.06E-04	0.000 %
PA234M	3.12E-01	0.000 %
U232	5.79E-02	0.000 %
U233	3.68E-05	0.000 %

Isotope	Curies	Percentage Of Total
U234	1.34E+00	0.000 %
U235	1.85E-02	0.000 %
U236	3.52E-01	0.000 %
U237	2.79E+00	0.000 %
U238	3.12E-01	0.000 %
U240	8.44E-07	0.000 %
NP235	6.42E-05	0.000 %
NP236	1.02E-05	0.000 %
NP237	4.76E-01	0.000 %
NP238	7.43E-02	0.000 %
NP239	3.08E+01	0.005 %
NP240M	8.44E-07	0.000 %
PU236	1.60E-01	0.000 %
PU238	4.40E+03	0.769 %
PU239	3.59E+02	0.063 %
PU240	5.80E+02	0.101 %
PU241	1.14E+05	19.930 %
PU242	2.64E+00	0.000 %
PU243	3.51E-07	0.000 %
PU244	8.45E-07	0.000 %
PU246	2.67E-14	0.000 %
AM241	2.01E+03	0.351 %
AM242	1.48E+01	0.003 %
AM242M	1.49E+01	0.003 %
AM243	3.08E+01	0.005 %
AM244	8.46E-11	0.000 %
AM245	1.04E-10	0.000 %
AM246	2.67E-14	0.000 %
CM242	1.26E+01	0.002 %
CM243	3.38E+01	0.006 %
CM244	3.30E+03	0.577 %
CM245	4.23E-01	0.000 %
CM246	1.02E-01	0.000 %
CM247	3.51E-07	0.000 %
CM248	9.75E-07	0.000 %
CM250	1.07E-13	0.000 %
BK249	7.21E-06	0.000 %
BK250	2.84E-11	0.000 %
CF249	1.16E-05	0.000 %
CF250	3.81E-05	0.000 %
CF251	3.50E-07	0.000 %
CF252	8.91E-06	0.000 %
ES254	2.83E-11	0.000 %
Subtotal Curies =	5.73E+05	100.000 %
Total all isotopes =	5.72E+05	

8.2.8.1 Cause of Accident

As described in Section 8.2.8.1 of Reference 8.1, the passive nature of the Calvert Cliffs NUHOMS system and the various design features preclude any credible event that could result in the rupture of all fuel rods concurrent with DSC leakage. However, to demonstrate the safety of the NUHOMS design, this accident assumes that the fuel rods and the DSC pressure boundary are ruptured due to an event of unspecified origin.

8.2.8.2 Accident Analysis

There are no structural or thermal consequences resulting from the DSC leakage accident described above. The radiological consequences of this accident are presented in Section 8.2.8.3.

8.2.8.3 Accident Dose Consequences

Whole body and maximum organ doses are calculated for a hypothetical individual assumed to be present at the nearest controlled area boundary location (with respect to the ISFSI, approximately 3900‘) for the duration of the event. A meteorological dispersion parameter (X/Q) of 3.0×10^{-4} sec/m^3 was used in calculating the maximum potential doses at the 3900‘ controlled area boundary. The resulting calculated doses are 0.1 mrem and 17.8 mrem for the maximum off-site total body and skin doses, respectively. These accident doses are well within the 10 CFR 72.106 limit of 5000 mrem.

8.2.9 ACCIDENTAL PRESSURIZATION OF DRY SHIELDED CANISTER

For more information see Reference 8.16.

This accident addresses the consequences of accidental pressurization of the DSC.

8.2.9.1 Cause of Accident

Internal pressurization of the DSC could result from fuel cladding failure that would release fuel rod fill gas and free fission gas.

8.2.9.2 Accident Analysis

The maximum DSC accident pressurization was calculated assuming that the fuel rod fission gas release fraction is 30%, and that the fuel rod fill gas pressure is 465 psia. The resulting internal DSC pressure was calculated at the Calvert Cliffs maximum ambient temperature of 103°F. The limiting accident for DSC pressurization is the HSM blocked vent case discussed in Section 8.2.7. Under these conditions, the gas temperatures in the DSC will rise to 548°F producing a DSC internal pressure of 49.9 psig (Reference 8.44). The maximum DSC shell local primary membrane stress intensity due to accident pressurization was calculated using 50 psig, the design basis accident pressure discussed in Reference 8.1, and was determined to be below the allowable stress.

The generic NUHOMS-24P Topical Report Section 10.3.1.1, "Spent Fuel Specifications" does not contain a fuel rod fill gas pressure limit. The assumed maximum initial fill gas pressure in the CCNPP fuel rods is 465 psia. This pressure was used only in calculating the number of moles of helium gas available for release from fuel rods into the DSC cavity during accident conditions causing an increase in the DSC internal pressure.

The end-of-life fill gas pressure in the CCNPP fuel rods is used as an input parameter for determining the maximum fuel clad temperature limit for long term dry storage of the spent fuel. The rod pressure used in this calculation was supplied by the fuel manufacturer. It includes the bounding fill gas pressure as well as bounding parameters for fission gas release. The peak fuel clad temperatures are not very sensitive to the end-of-life pressure in the typical range of interest. They are a strong function of burnup and cooling time. Since the analysis bounds all Calvert Cliffs fuels, it is unnecessary to specify all fuel fabrication parameters in this section.

The assumed maximum initial fill gas pressure in the CCNPP fuel rods is 465 psia. This value was provided by the fuel vendor as part of a transmittal of bounding fuel rod fill and fission gas pressures at various burnups. This pressure was used to calculate the quantity of helium gas available for release from fuel rods to the DSC cavity during accident conditions. The maximum partial pressure of fill gas is only 30% for a NUHOMS-24P DSC (Reference 8.44) of the total gas (fission and fill gases from fuel rods, and DSC fill gas) in the DSC and therefore is not a major contributor to the accident DSC internal pressures. Any comparison to fill gas pressures used for other purposes is moot.

The analysis of accidental pressurization of the DSC includes the effect of fuel burnup on internal fuel rod pressure by using the volume of fission gas generated in the fuel rod at the maximum burnup of 50 gwd/mthm. All fuel rods from all the spent fuel assemblies in the DSC are assumed to be ruptured and 100% of fuel rod fill gases and 30% of fission gases are assumed to be released to the DSC cavity. The results of the analysis show that the maximum DSC accident pressures are within the design basis limits.

8.2.9.3 Accident Dose Calculations

Since the maximum DSC accident pressure is within the design basis limits, there are no dose consequences.

8.2.10 FOREST FIRE

For more information see Reference 8.18.

This postulated event involves a forest fire occurring in the woods adjacent to the ISFSI.

8.2.10.1 Cause of Accident

A forest fire is postulated to occur due to a number of reasons, most likely natural causes (e.g., lightning) or man-made (accident or arson).

8.2.10.2 Accident Analysis

The Calvert Cliffs ISFSI was evaluated for a postulated forest fire assumed to occur at a distance of 130‘ from the nearest HSM. The flame front was assumed to be 200‘ long by 100‘ in height burning at an effective flame temperature of 1832°F for a period of 1 hour. The flame emissivity was assumed to be 0.9. Based on these parameters and an initial concrete temperature of 135°F, the maximum calculated HSM surface temperature is ~1475°F. THE resulting elevated temperatures at the surface of the HSM walls due to the postulated forest fire may cause cracking or spalling of the walls. The damage to the wall, based on the HSM wall temperature gradient resulting from the fire, will be limited to a thickness of 4.5” into the wall. The remainder of the wall thickness will remain within ACI 349 temperature limits. Fuel cladding temperature limits will be maintained within the fuel cladding short-term temperature limit. The effect of the surface cracking and spalling will be minimal with respect to the load capacity of the HSM walls. Dry shielded canister internal pressure limits (50 psig) will not be exceeded. The increase in HSM surface dose is from 7 mrem/hr to approximately 21 mrem/hr. This increase is not considered a “significant increase in occupational exposure” for the necessary repair activities. Actions to mitigate the fire and repair the HSMs will ensure that offsite dose consequences will be limited and of short duration and will remain within the limits of 10 CFR 72.106.

8.2.10.3 Accident Dose Consequences

There are no accident dose consequences associated with the postulated forest fire accident.

8.2.11 LIQUIFIED NATURAL GAS PLANT OR PIPELINE SPILL OR EXPLOSION

For more information see References 8.16 and 8.20.

This accident involves a possible LNG spill or explosion at the nearby Cove Point LNG terminal or an associated pipeline.

The Cove Point LNG Terminal is located approximately 4 miles south-southeast of the CCNPP site. The Terminal was built in the seventies and operated for 2 years between 1978 and 1980 before it ceased operation for commercial reasons. Columbia LNG applied for restart approval from the Federal Energy Regulatory Commission (Reference 8.22).

In the summer of 1989, upon learning of Columbia LNG's intention to restart the Cove Point Terminal, Baltimore Gas and Electric Company reviewed previous LNG hazards analyses and related commitments to the Nuclear Regulatory Commission (NRC). At that time, Baltimore Gas and Electric Company decided, as a conservative measure, to perform a new LNG hazards analysis to reflect current regulatory requirements using up-to-date statistical information and state-of-the-art analytical models. Baltimore Gas and Electric Company completed and submitted the new analysis (Reference 8.20).

The new analysis identified those hazards that might be present and that might have potential impact on the CCNPP site and then examined the probability of any of those hazards occurring and the consequences that might result. Finally, it determined the risk to the CCNPP site that could result from these scenarios by combining the probability and consequence of each scenario with the likelihood of various meteorological conditions and the likelihood of ignition. The results of the new analysis confirms the conclusions of the previous analyses that the operation of the Cove Point facility will not present any undue hazards to CCNPP or to the ISFSI located on the same site. The NRC concurred with the conclusions of the new analysis (Reference 8.21).

8.2.12 LOAD COMBINATIONS

The load categories associated with normal operating, off-normal, and accident conditions have been described and analyzed in previous chapters. Evaluation of the load combination for the NUHOMS important to safety components is addressed in this section.

The methodology used in combining normal operating, off-normal, and accident loads and their associated overload factors for various NUHOMS components is presented in Section 8.2.10 of Reference 8.1. The Reference 8.1 fatigue analysis envelopes the Calvert Cliffs NUHOMS system. The load combination analysis results showed that the calculated stresses are less than the code allowables for various load combinations shown in Tables 8.2-8, 8.2-9, 8.2-10, 8.2-12, 8.2-14, 8.2-15, and 8.2-16. The analyses demonstrate that the important to safety components of the Calvert Cliffs ISFSI are adequate to withstand all postulated loading combinations.

Horizontal storage module enveloping load combination results were obtained based on a conservative interpretation of the CCNPP calculation. The forces and moments are taken directly from the STRUDL output presented in the calculation, and the maximum values for each component tabulated. The reported accident thermal moments are equal to the maximum values from the load cases adjusted for the cracked section properties, as described in the calculation package.

To demonstrate the HSM design conservatism, the load combinations were derived by adding the absolute maximums for each member from each contributing load case regardless of sign. The dead loads were increased by 5% and the live load included at 100% as the absolute value is used. In all cases the required capacity was less than the calculated capacity for each member.

The front wall calculation presented in the HSM calculation package was prepared to demonstrate that, under the most conservative assumptions, adequate rebar is provided to carry the loads. A more realistic set of assumptions on the load distribution, span of the members and the applied loads results in calculated shears and moments which are about one-half of those reported in the calculation. Therefore, it is concluded that the front wall is not a critical member.

8.2.13 OTHER EVENT CONSIDERATIONS

8.2.13.1 Storage of Flammable Liquid Fuel

This section addresses the following three issues: (1) does the permanent storage arrangement of the liquid fuel represent a hazard; (2) does a fuel tanker truck, either transferring fuel into the storage tanks or in route to the tanks, create a hazard; and (3) does the standard transfer of liquid fuel into a vehicle, via the pumps, create a hazard? Each of these items will be addressed separately below.

Gasoline (4,000 gal), diesel fuel (4,000 gal), and waste oil (550 gal) are stored in underground storage tanks at the Transportation Facility. Underground storage of flammable and combustible liquids is considered the safest form of storage (National Fire Protection Association Fire Protection Handbook, 16th edition, page 11-36). National Fire Protection Association 30-1987, "Flammable and Combustible Liquid Code," does not require specific separation of underground tanks from structures except for the fill and vent connections. This distance is 5'. These underground tanks do not represent a credible hazard to the spent fuel shipments, especially when the distance from the road is considered.

Gasoline and diesel fuel are delivered to the Transportation Facility via tanker trucks. These tankers carry significant quantities of fuel. The shipments of gasoline and diesel fuel are relatively infrequent. The actual off-loading operation of the tankers takes place at the Transportation Facility. A distance of 25' between the off-loading facility and the nearest unrelated structure is required per NFPA 30-1987 (Section 5-4.4.1). The distance from the Transportation Facility to the normal path of travel of the spent fuel is in excess of 25'. Additionally, the slope of the land is such that a fuel spill or pool fire will flow away from the road. Also, there are plans to stop all tanker trucks, including those which are used to fill the fuel oil tanks for the auxiliary boilers and Emergency Diesel Generators, while spent fuel is being transported.

The normal operation of filling the fuel tanks of vehicles represents a less hazardous subset of the off-loading operation described above. The most important aspect is the slope of the land which will result in a spill flowing away from the road. Additionally, the distance provides adequate spatial separation in the event of a fire or explosion.

TABLE 8.2-1
NUHOMS ACCIDENT LOADING IDENTIFICATION

Accident Load Type	Component Load DSC Shell Assembly	DSC Internal Basket	DSC Support Assembly	HSM	Transfer Cask
Loss of HSM Air Outlet Shielding Blocks		(not applicable to Calvert Cliffs)			
Tornado Wind				X	X
Tornado Missiles				X	X
Earthquake	X	X	X	X	X
Flood		(not applicable to Calvert Cliffs)			
Accidental Cask Drop	X	X			X
Loss of Neutron Shield					X
Lightning				X	
Blockage of HSM Air Inlets and Outlets	X	X	X	X	
DSC Leakage		(radiological consequence only)			
DSC Accident Internal Pressure	X				
Forest Fire				X	
LNG Tank & Pipeline Explosion				X	
Load Combinations	X	X	X	X	X

TABLE 8.2-8
NUHOMS-24P DRY SHIELDED CANISTER ENVELOPING LOAD COMBINATION RESULTS FOR NORMAL AND OFF-NORMAL LOADS

(ASME Service Levels A and B)

DSC COMPONENTS	STRESS TYPE	CONTROLLING[a] LOAD COMBINATION	ALLOWABLE[b][c] STRESS (ksi)
DSC Shell	Primary Membrane	B2	18.7
	Membrane + Bending	B2	28.0
	Primary + Secondary	B2	56.1
Bottom Cover Plate	Primary Membrane	A4	18.7
	Membrane + Bending	B2	28.0
	Primary + Secondary	B2	56.1
Top Pressure Plate	Primary Membrane	A3	18.7
	Membrane + Bending	A3	28.0
	Primary + Secondary	A3	56.1
Top Structural Plate	Primary Membrane	A4	18.7
	Membrane + Bending	A4	28.0
	Primary + Secondary	A4	56.1
Spacer Disk	Primary Membrane	A3/A4	18.7
	Membrane + Bending	A3/A4	28.0
	Primary + Secondary	A3/A4	56.1
Support Rod	Primary Membrane	A3/A4	18.7
	Membrane + Bending	A3/A4	28.0
	Primary + Secondary	A3/A4	56.1

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[a] See Table 3.2-3 for load combination nomenclature.

[b] See Table 3.2-6 of Reference 8.1 for allowable stress criteria. Material properties were obtained from Table 8.1-2 of Reference 8.1 at a design temperature.

[c] Allowables are for stainless steel material at 400°F. Carbon steel material allowables are higher.

TABLE 8.2-9
NUHOMS-24P DRY SHIELDED CANISTER ENVELOPING LOAD COMBINATION RESULTS FOR ACCIDENT LOADS

(ASME Service Level C)

DSC COMPONENTS	STRESS TYPE	CONTROLLING[(a)] LOAD COMBINATION	ALLOWABLE[(b)(c)] STRESS (ksi)
DSC Shell	Primary Membrane	C2	21.6
	Membrane + Bending	C1	32.4
Bottom Cover Plate	Primary Membrane	C2	21.6
	Membrane + Bending	C5	32.4
Top Pressure Plate	Primary Membrane	C2	21.6
	Membrane + Bending	C2	32.4
Top Structural Plate	Primary Membrane	C2	21.6
	Membrane + Bending	C1	32.4
Spacer Disk	Primary Membrane	C1	21.6
	Membrane + Bending	C1	32.4
Support Rod	Primary Membrane	C1	21.6
	Membrane + Bending	C1	32.4

(a) See Table 3.2-3 for load combination nomenclature.

(b) See Table 3.2-6 of Reference 8.1 for allowable stress criteria. Material properties were obtained from Table 8.1-2 of Reference 8.1 at a design temperature.

(c) Allowables are for stainless steel material at 460°F. Carbon steel material allowables are higher.

TABLE 8.2-10
NUHOMS-24P DRY SHIELDED CANISTER ENVELOPING LOAD COMBINATION RESULTS FOR ACCIDENT LOADS

(ASME Service Level D)(c)

DSC COMPONENTS	STRESS TYPE	CONTROLLING(a) LOAD COMBINATION	ALLOWABLE(b) STRESS (ksi)
DSC Shell	Primary Membrane	D2	43.2
	Membrane + Bending	D2	64.0
Bottom Cover Plate	Primary Membrane	D2	43.2
	Membrane + Bending	D2	64.0
Top Pressure Plate	Primary Membrane	D2	43.2
	Membrane + Bending	D2	64.0
Top Structural Plate	Primary Membrane	D2	43.2
	Membrane + Bending	D2	64.0
Spacer Disk	Primary Membrane	D2	44.8(e)
	Membrane + Bending	D2	57.6(e)
Guide Sleeve	Primary Membrane	--	39.4(d)
Support Rods	Primary Membrane	D2	43.2
	Membrane + Bending	D2	64.0
Top End Structural Weld	Primary Membrane + Bending	--	21.6
Bottom End Structural Weld	Primary	--	44.9

For more information see Reference 8.16.

(a) See Table 3.2-3 for load combination nomenclature.

(b) See Table 3.2-6 of Reference 8.1 for allowable stress criteria. Material properties were obtained from Table 8.1-2 of Reference 8.1 at a design temperature.

(c) Allowables are for stainless steel material at 460°F. Carbon steel material allowables are higher.

(d) Allowable stress at 600°F.

(e) Allowable stresses based on plastic analysis.

TABLE 8.2-12
NUHOMS-24P DRY SHIELDED CANISTER SUPPORT ASSEMBLY ENVELOPING LOAD COMBINATION RESULTS

		AISC Allowable Stress		
Component	**Load Combination**	**Axial (ksi)**	**Bending (ksi)**	**Shear (ksi)**
W10x68 Cross Beam	Normal Operation $DW_s + DW_c + HL_f$	14.8	17.6	10.6
	Off-Normal Operation $DW_s + HL_j$	14.8	17.6	10.6
	Accident $DW_s + DW_c + DBE$	22.3	26.3	14.9
WT6x115 Support Rail	Normal Operation $DW_s + DW_c + HL_f$	13.8	17.6	10.6
	Off-Normal Operation $DW_s + HL_j$	13.8	17.6	10.6
	Accident $DW_s + DW_c + DBE$	20.7	26.3	14.9

KEY: DW_s = Dead Weight Support Assembly, HL_j = Off-normal Handling Loads-Jammed, DW_c = Dead Weight Canister, HL_f = Normal Loads Friction, DBE = Seismic Loads

NOTES:
Allowable stresses taken at 600°F to conservatively envelope all ambient temperature cases.
Allowables for $DW_s + DW_c + DBE$ increased by 50% for axial and bending, and by 40% for shear.

TABLE 8.2-14
NUHOMS TRANSFER CASK ENVELOPING LOAD COMBINATION RESULTS FOR NORMAL AND OFF-NORMAL LOADS

(ASME Service Levels A and B)

TRANSFER CASK COMPONENT	STRESS TYPE	CONTROLLING[a] LOAD COMBINATION	ALLOWABLE[b] STRESS (ksi)
Structural Shell	Primary Membrane	A5/B2	21.7
	Membrane + Bending	A5/B2	32.6
	Primary + Secondary	A5/B2	65.1
Top Cover Plate	Primary Membrane	A5/B2	18.7
	Membrane + Bending	A5/B2	28.1
	Primary + Secondary	A5/B2	56.1
Inner Bottom 2" Cover Plate	Primary Membrane	A1	18.7
	Membrane + Bending	A1	28.1
	Primary + Secondary	A1	56.1

(a) See Tables 3.2-4 and 12.3-6 for load combination nomenclature.

(b) See Table 3.2-8 of Reference 8.1 for allowable stress criteria. Material properties were obtained from Table 8.1-2 of Reference 8.1 at a design temperature of 400°F.

TABLE 8.2-15
NUHOMS TRANSFER CASK ENVELOPING LOAD COMBINATION RESULTS FOR ACCIDENT LOADS

(ASME Service Level C)

TRANSFER CASK COMPONENT	STRESS TYPE	CONTROLLING[a] LOAD COMBINATION	STRESS (ksi)	
			CALCULATED	ALLOWABLE[b]
Structural Shell	Primary Membrane	C3	[c]	26.0
	Membrane + Bending	C3	[c]	39.1
Top Cover Plate	Primary Membrane	C2	[c]	22.4
	Membrane + Bending	C2	[c]	33.7
Inner Bottom 2" Cover Plate	Primary Membrane	C2	[c]	22.4
	Membrane + Bending	C2	[c]	33.7

(a) See Tables 3.2-3 and 12.3-6 for load combination nomenclature.

(b) See Table 3.2-8 of Reference 8.1 for allowable stress criteria. Material properties were obtained from Table 8.1-2 of Reference 8.1 at a design temperature of 400°F.

(c) Less than the allowable.

TABLE 8.2-16
NUHOMS TRANSFER CASK ENVELOPING LOAD COMBINATION RESULTS FOR ACCIDENT LOADS

(ASME Service Level D)

TRANSFER CASK COMPONENT	STRESS TYPE	CONTROLLING[a] LOAD COMBINATION	ALLOWABLE[b] STRESS (ksi)
Structural Shell	Primary Membrane	D3	49.0
	Membrane + Bending	D3	70.0
Top Cover Plate	Primary Membrane	D2/D3	44.9
	Membrane + Bending	D3	64.4
Inner Bottom 2" Cover Plate	Primary Membrane	D2/D3	44.9
	Membrane + Bending	D3	64.4

(a) See Tables 3.2-4 and 12.3-6 for load combination nomenclature.

(b) See Table 3.2-8 of Reference 8.1 for allowable stress criteria. Material properties were obtained from Table 8.1-2 of Reference 8.1 at a design temperature of 400°F.

8.3 SITE CHARACTERISTICS AFFECTING SAFETY ANALYSIS

All site characteristics affecting safety analyses presented in this document are noted where they apply.

8.4 REFERENCES

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