NUCLEAR ENERGY SERVICES, INC.

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Attachment 2

LICENSING SUBMITTAL REPORT

FOR

CALVERT CLIFFS UNIT #1 NUCLEAR PLANT

HIGH DENSITY SPENT FUEL STORAGE RACKS

PREPARED UNDER PROJECT 5134

FOR THE

BALTIMORE GAS & ELECTRIC COMPANY

NUCLEAR ENERGY SERVICES, INC.
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1. DESIGN BASES

The high density spent fuel storage racks are designed to provide 840 fuel storage locations in the Calvert Cliffs Unit No. 1 spent fuel pool and to maintain the stored fuel, having an equivalent uranium enrichment of 4.1 weight percent U-235 in UO_2, in a safe, coolable, and subcritical configuration during normal and abnormal conditions.

2. STORAGE RACK ARRANGEMENT

The arrangement of the storage racks in the Calvert Cliffs Unit No. 1 fuel storage pool is shown in Figure 2-1. From this figure it can be seen that the fuel storage pool will have six storage racks with a 10 x 10 array of fuel storage locations and three storage racks with an 8 x 10 array of fuel storage locations.

3. STORAGE RACK DESCRIPTION

Each storage rack consists of a welded assembly of fuel storage cells spaced 9.75 inches on center. Each storage cell is a double wall Type 304-L stainless steel square box with an inner dimension of 8.56 inches. The double wall construction provides four compartments in which poison elements are placed. The poison elements are centrally positioned on each side of the storage cell at an elevation corresponding to the active fuel region of a fuel assembly located within the cell. The top opening of each storage cell is flared to facilitate insertion of a fuel assembly; the bottom member of the storage cell provides the level support surface required for the fuel assembly and contains a cooling flow orifice.

Storage racks consist of assemblies of 2 x 2 modular cell units. A modular cell unit is a square array of four storage cells described above. Each 10 x 10 rack contains twenty five 2 x 2 modular cell units and each 8 x 10 rack contains twenty 2 x 2 modular cell units. Figure 3-1 shows a typical modular cell unit and a schematic drawing of a 10 x 10 storage rack structure.

Within each storage rack continuous spacer beams are provided at the middle and top of the storage cells to ensure that the required pitch (9.75 inches) is maintained between storage cells in both directions (North/South and East/West) under lateral load conditions.

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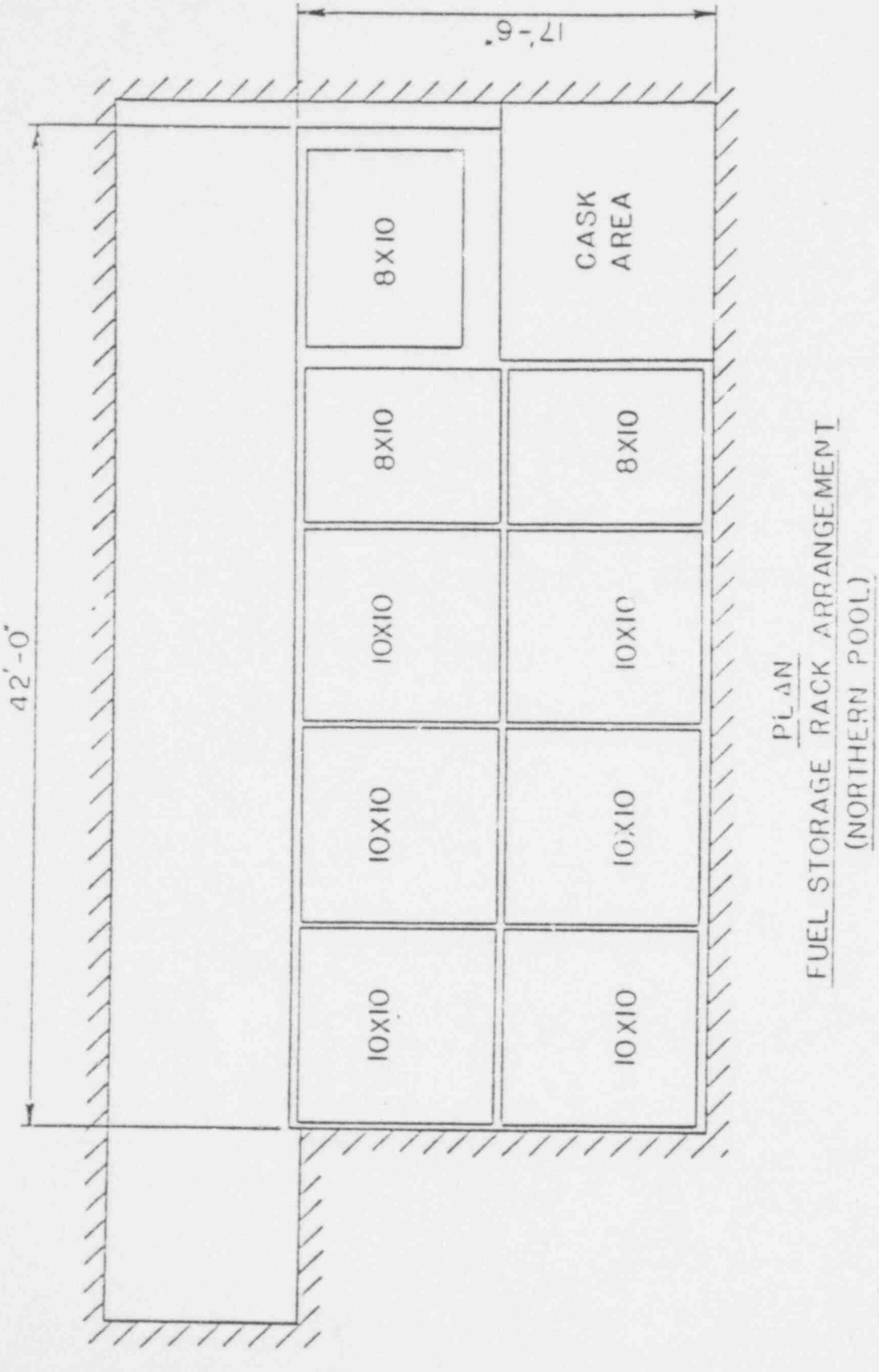

FIGURE 2-1

SPENT FUEL STORAGE RACK ARRANGEMENT PLAN

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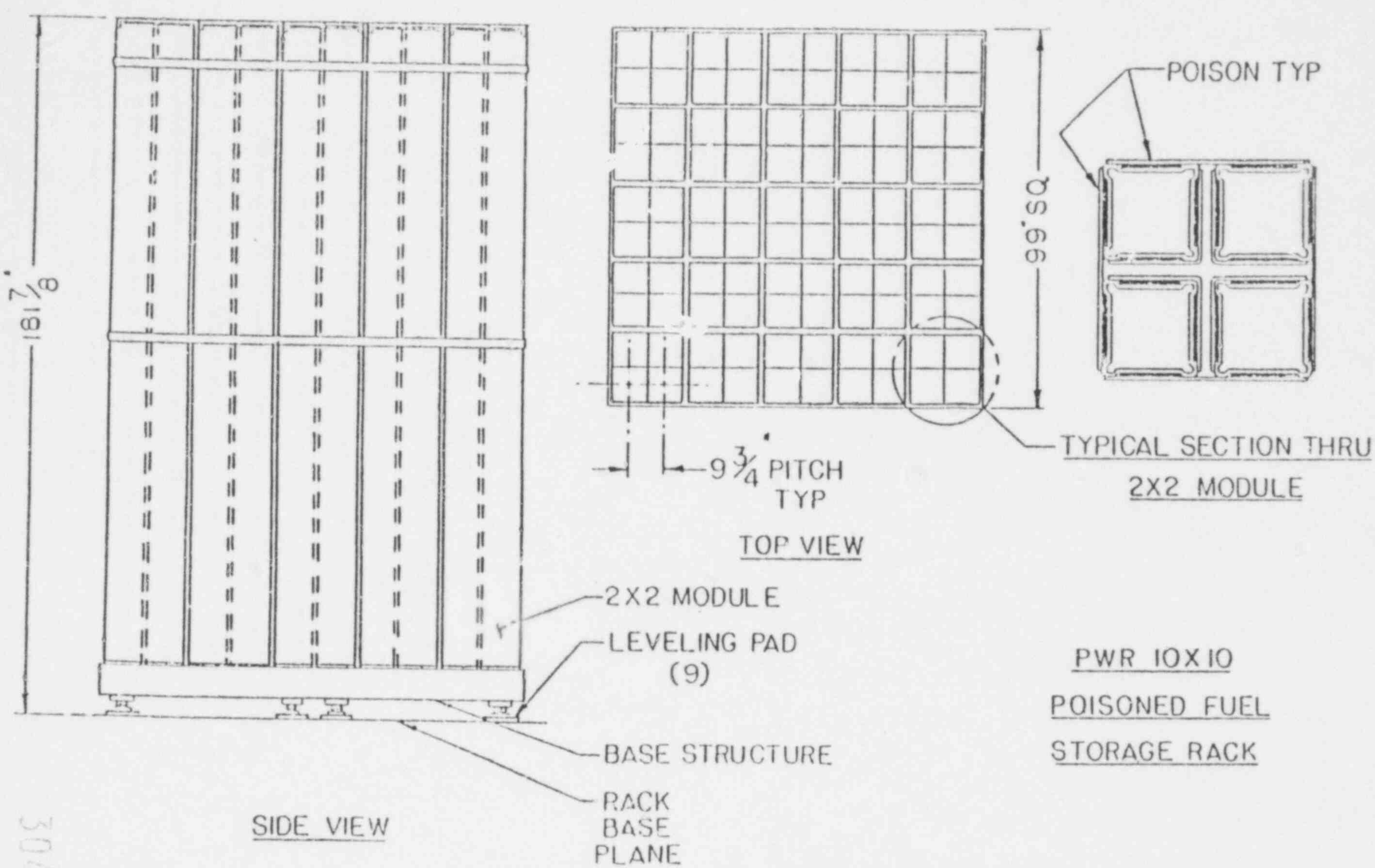

FIGURE 3-1

SPENT FUEL STORAGE RACK SCHEMATIC (10 x 10)

The spacer beams which are intermittantly welded to the storage cells also maintain the vertical alignment of the cells. Support pads attached to the bottom of the rack base raise the rack above the pool floor to the height required to provide an adequately sized cooling water supply plenum (for natural circulation). Each support pad contains a remotely adjustable jack screw to permit the rack to be leveled following wet installation.

The storage racks are positioned on the pool floor so that adequate clearances are provided between racks and between the racks and pool structure to avoid impacting of the sliding racks during seismic events. The horizontal seismic loads transmitted from the rack structure to the pool floor are only those associated with friction between the rack structure and the pool liner. The vertical deadweight and seismic loads are transmitted directly to the pool floor by the support feet.

The fuel storage racks are primarily fabricated from Type 304L stainless steel with 17-4PH stainless steel used for the supporting jack screws. The poison material consists of a B_4C composite material fabricated by Carborundum Company. Tests have been completed to verify the compatibility of the poison material with the pool water environment, including the anticipated radiation fluence and thermal conditions. All materials used in the storage racks are fully compatible with the anticipated Calvert Cliffs pool water environment.

4. STORAGE RACK EVALUATION

4.1 Nuclear Analysis

A detailed nuclear analysis was performed to demonstrate that for all anticipated normal and abnormal configurations of fuel assemblies within the fuel storage racks, the k_{eff} of the system is below 0.95. Certain conservative assumptions about the fuel assemblies and racks were used in the calculations and these assumptions are described in Section 4.1.1.

The principal calculational method used for the criticality analyses was diffusion theory using HAMMER and EXTERMINATOR. Verification calculations were done by using KENO, a Monte Carlo code. A description of the calculational method and codes is presented in Section 4.1.3, together with a description of a benchmark of the diffusion theory method.

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4.1.1 Design Criterion and Assumptions

The criticality design criterion established for the Calvert Cliffs Unit No. 1 spent fuel racks is that the multiplication constant (k_{eff}) shall be less then 0.95 for all normal and abnormal configurations as confirmed by KENO.

The following conservative assumptions were used in the criticality calculations performed to verify the adequacy of the rack design:

1. Stored fuel will be fresh and of a specified enrichment greater than or equal to that of any fuel available (4.1 w/o).

2. The reference configuration contained an infinite array of storage locations spaced 9.75 x 9.75 inches on centers. Obviously the array is not infinite, but finite.

3. The absorption of the fuel assembly spacers was ignored.

4. Any burnable poisons in the fuel assemblies were ignored.

5. The vertical buckling was ignored, i.e., the fuel assemblies are considered to be infinitely long.

6. Any soluble poison in the pool water was ignored.

4.1.2 Configurations Analyzed

The various configurations of fuel within racks that are possible are classed as either normal or abnormal configurations. Normal configurations result from the placement of fuel within racks and the variation in rack dimensions permitted in fabrication. Abnormal configurations are typically results of accidents or malfunctions such as seismic events, malfunction of the fuel pool cooling system, etc.

Normal Configurations

The normal configurations analyzed were a reference configuration at the nominal conditions, an eccentric fuel positioning configuration, and variations in fuel assembly fabrication tolerances, fuel rack pitch, cell wall thickness, and rack poison concentration. A KENO analysis of the reference configuration was made to establish a diffusion to Monte Carlo bias.

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Analysis of Normal Cases

1. Reference Configuration

The reference configuration consisted of an infinite array of 304L stainless steel square storage cells with nominal dimensions: 9.75 inch pitch, 0.60 inch inner and outer cell wall thickness, 8.56 inch inner cell dimension and .060 inch poison thickness with 0.015 gms/cm^2 of B^{10}. Each storage cell contained a centrally located fresh 14 x 14 Combustion Engineering fuel assembly, with an average enrichment of 4.1 w/o. The water temperature within the rack was 68°F.

2. Eccentric Fuel Positioning Configuration

It is possible for a fuel assembly not to be positioned centrally within a storage cell because of the clearance allowed between the assembly and the cell wall. This clearance is nominally 0.221 inches on each side of the fuel assembly. Calculations have been performed to determine the effect of eccentrically located fuel. In these calculations it was assumed that four fuel assemblies were diagonally displaced within their storage cells as close as possible towards each other.

3. Fuel Assembly Fabrication Tolerance

The important fuel assembly parameter determining k_{eff} is the ratio of the amount of U^{235} to that of water. The amount of U^{235} per assembly is controlled to within a few tenths of a percent by weighing pellet stacks as the fuel is built and by using a known enrichment. The fuel assembly parameters which determine the volume of water in an assembly are the clad O.D. and the fuel rod pitch. These parameters are closely controlled to typically within $\pm$ 0.4 percent. The effects of these fuel assembly tolerances on k_{eff} have been determined to be negligible on the basis of simple k_{∞} cell calculations.

4. Fuel Rack Pitch Variation

Calculations were performed to determine the sensitivity of k_{eff} to changes in pitch, the center-to-center spacing between storage cells. The pitch was varied 0.125 inch above and below the nominal value. The criticality configuration was similar to that of the reference configuration except for the obvious change in center-to-center spacing.

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5. Cell Wall Thickness Variation

The base case wall thickness was 0.060 inches for each of the stainless steel sheets forming the cell walls. This thickness was varied up to 0.070 inches and down to 0.050 inches to determine the effect on k_{eff}.

6. Poison Concentration Variation

The poison slabs contain a nominal concentration of 0.015 gms/cm^2 of B^{10}. This concentration was varied ± 10% to determine the sensitivity of k_{eff} to variations in this parameter.

7. "Worst Case" Normal Configuration

The "worst case" normal configuration considers the effect of eccentric fuel assembly positioning, the minimum average pitch (center-to-center spacing) permitted by fabrication, the minimum wall thickness and the minimum poison concentration.

Abnormal Configurations

The abnormal configurations analyzed were single storage cell displacement, fuel handling incident, pool temperature variation and rack deformations due to a fuel assembly drop incident, a heavy object drop incident, or a seismic incident.

Analysis of Abnormal Cases

1. Single Storage Cell Displacement

Displacement of a single storage cell within the array is precluded by the welded construction and the presence of structure between cells. Therefore the effect of such a displacement was taken to be zero.

2. Fuel Handling Incident

Accidental placement of fuel between the fuel racks or the racks and pool wall will be prevented by structural material. It is, however, conceivable that an assembly could be laid across the top of a fuel rack. In this case, the distance between the tops of the stored fuel and the bottom of the misplaced fuel will be greater than 25 inches, a distance which according to calculations effectively "decouples" the two groups of fuel. No increase in k_{eff} will result from this incident.

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3. Pool Temperature Variation

Calculations were performed to determine the sensitivity of k_{eff} for the reference configuration to variations in the spent fuel pool temperature. The pool temperature was varied from 39°F, where water density is a maximum, to 250°F, the approximate boiling point of water near the bottom of the fuel rack.

4. Fuel Drop Incident

The maximum height through which a fuel assembly can be dropped onto the fuel storage racks is limited. The dropped fuel assembly will most likely impact the tops of the fuel storage rack cells. Because of the fuel rack design, damage will be limited to the upper 6 to 8 inches of the storage cells. Since the active fuel region is about 18 inches below this area, no significant change in fuel/cell geometry will occur. However, it is possible for a dropped fuel assembly to enter a cell cleanly and impact directly on the fuel stored in the cell. The effect of this type of fuel drop incident was evaluated from a criticality viewpoint by assuming that the stored assembly would be compressed axially.

A calculation based on an axial compression of 2 feet yielded a 0.06 decrease in k_{oo} of the fuel cell. It has been concluded, therefore, that this incident would reduce k_{eff} and need not be considered further in this analysis.

5. Heavy Object Drop

In the unlikely event that a heavy object is dropped on the storage rack with sufficient impact to cause structural deformation, it has been concluded that k_{eff} will decrease. The basis for this conclusion is that the principal effect of dropping a heavy object will be to squeeze water from the rack. Both in the case of compacted fuel and voided pool water, depletion of water leads to a decrease in k_{eff}.

It would not be possible for a dropped heavy object to eject the poison material from the rack; the crushing effect of the heavy object could only act to compress the fuel and poison together.

6. Seismic Incident

Seismic analyses have determined that during an SSE the pitch between two adjacent fuel assemblies could narrow locally by as much as 0.005 inches, due to oscillations about nodal points determined by structural members locating the cells within the racks.

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However, at the same time, the local pitch at other locations is greater by the same amount, with the net effect that although the pitch may vary locally, the average pitch is unaffected. In the event that the entire rack is displaced by a seismic event, the average pitch will also be unaffected.

It is concluded, therefore, that if the fuel assemblies deflect independently in random directions or move together in a single direction, the average pitch between assemblies and, consequently, the k_{eff} are unaffected.

7. "Worst Case" Abnormal Configuration

The "worst case" abnormal configuration considers the effect of the most adverse abnormal condition in combination with the "worst case" normal configuration.

4.1.3 Calculational Methods

Code Descriptions

The HAMMER Code

HAMMER (see Reference 1) is a multigroup integral transport theory code which is used to calculate lattice cell cross sections for diffusion theory codes. This code has been extensively benchmarked against D_2O and light water moderated lattices with good results.

The EXTERMINATOR Code

EXTERMINATOR (see Reference 2) is a 2-D multigroup diffusion theory code used with input from HAMMER to calculate k_{eff} values.

The KENO IV Code

KENO IV is a 3-D multigroup Monte Carlo criticality code used to determine k_{eff} (see Reference 3).

Benchmark Calculations for Diffusion Theory and Monte Carlo Methods

Both HAMMER and EXTERMINATOR were used by NES as versions available at Combustion Engineering at Windsor Locks, Connecticut. The combination has been benchmarked against a cold critical experiment performed at the LaCrosse Boiling Water Reactor with excellent results (see Reference 4).

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The calculated k_{eff} differed from the experimental value by only 0.0017. A similar benchmark has been performed for KENO-IV using 16 group Hansen-Roach cross sections, resulting in a k_{eff} which differed from the experimental value by only 0.001.

Details on the calculational methods, codes and input/output data are presented in Reference 5.

4.1.4 Results of Analysis

Normal Configurations

Results for normal configurations can be summarized as follows:

		k_{eff} or Δk_{eff}
1.	Reference Configuration	0.9246
2.	Minimum Cell Pitch	0.0046
3.	Minimum Poison Concentration	0.0050
4.	Cell Wall Thickness Tolerance	0.0008

No allowance for fuel enrichment variation was required since the fuel on which the calculations were based is of the highest enrichment considered. The Δk due to eccentric location of fuel within cells was determined to be negative and therefore was not included.

The effects of these normal variations were combined statistically as follows:

$$\Delta k_{eff} = \sqrt{(.0046)^2 + (.0050)^2 + (.0008)^2} = \pm 0.0068.$$

Abnormal Configurations

The "worst case" abnormal configuration combines the change in k_{eff} due to the occurence of the most adverse abnormal condition with the k_{eff} value associated with the "worst case" normal configuration. However, since none of the abnormal conditions gives a positive Δk, the "worst case" abnormal condition is simply equal to the "worst case" normal condition.

Monte Carlo Reference Configuration Calculation

KENO-IV, a Monte Carlo code, was used to calculate k_{eff} for the reference configuration in order to check diffusion theory results.

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The k_{eff} value obtained with KENO is 0.9314. This value differs from the diffusion theory reference k_{eff} by +0.0068.

Calculational Uncertainty

A calculational uncertainty of 0.01 Δk_{eff} was conservatively assumed and combined statistically with the uncertainties due to normal variations to provide the following upper limit of uncertainty for normal configurations:

$$\Delta k_{eff} = \sqrt{(0.0068)^2 + (0.01)^2} = \pm\ 0.0121$$

Maximum K_{eff} Value

The upper limit for the "worst abnormal" configuration results from taking the normal configuration at the upper limit of its uncertainty and adding the Δk_{eff} values for the worst abnormal configuration and for the calculational bias between diffusion theory and Monte Carlo theory.

0.9246	Reference Configuration
0.0121	Upper Limit of Uncertainty for Normal Configuration
0.0000	"Worst Case" Abnormal Configuration
0.0068	Monte Carlo/Diffusion Theory Bias
0.9435	

Thus the upper limit for the k_{eff} including the effects of normal and abnormal variation, uncertainties, and difference between codes is 0.9435; it is concluded, therefore, that the Calvert Cliffs high density fuel storage racks when loaded with the specified fuel are safe from a criticality standpoint.

4.2 Thermal Hydraulics

4.2.1 Method of Analysis and Assumptions

In the NES rack design the crossflow of water between adjacent fuel assemblies is prevented by the stainless steel cells in the fuel rack. The effect is such that each of the fuel assemblies becomes isolated and, therefore, sits in its own thermal chimney.

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The chief thermal-hydraulic concern is the possibility of local boiling due to flow starvation in some cells of the rack matrix as a result of excessive pressure losses in the natural circulation loops established in the spent fuel pool.

The adequacy of natural circulation flow to cool the spent fuel assemblies in the rack matrix was verified by establishing, for the worst row of assemblies, a thermal-hydraulic balance between the driving head produced by decay heat generation and the pressure losses existing in the natural circulation flow path. The pool itself was modeled as a large volume with a bulk water temperature unaffected by local disturbances. Pressure losses in the downcomers, in the rack inlet plenum, and along the fuel assemblies were explicitly considered in the analysis. The effect of an assembly lying horizontally across the top of the racks was also considered. Cross-flows in the rack inlet plenum area have been conservatively neglected.

A ten bundle (fuel assembly and its surrounding fuel rack cell) was selected as the worst row of assemblies since it represents the greatest distance between any fuel assembly and the nearest downcomer area. The assemblies in the ten bundle model were part of a freshly discharged batch. The rack inlet plenum, which acts as a manifold to the bundles in the model, was assumed to consist of a discrete channel bounded by the floor and the bottom of rack cans. This representation neglects the crossflows that would be expected in an open channel.

A bulk fuel pool temperature of 150°F was assumed in the analysis. Bundle decay heat was calculated from APCSB 9-2 assuming infinite irradiation and a cooling time of 4 days. Reactor power is 2700 MWt with 217 assemblies in the core.

The detailed thermal-hydraulic calculations are presented in Reference 6.

4.2.2 Results of Analysis

The thermal-hydraulic calculations indicated that even with the most conservative assumptions, the natural circulation in the spent fuel pool is adequate to preclude local boiling by a substantial margin. The maximum temperature increase in the assembly with a minimum flow is 45.8°F which would result in an outlet temperature of 195.8°F.

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An assembly lying horizontally on top of the racks would increase the temperature increase to 51.3°F with a resultant outlet temperature of 201.3°F, which is still substantially less than the 238°F saturation temperature at the top of the racks.

These results are exceedingly conservative in that the heat generation assumed in the analysis is equivalent to a core hot spot linear heat generation rate of 17 kw/ft.

The pool configuration and the natural circulation patterns indicate that the pool water bulk temperature will maintain an acceptable temperature distribution.

4.3 Structural and Seismic Analysis

The Calvert Cliffs Nuclear Plant Unit #1 high density spent fuel storage racks have been designed to meet the requirements for Seismic Category I structures. Detailed structural and seismic analyses of the high density storage racks have been performed to verify the adequacy of the design to withstand the loadings encountered during installation, normal operation, the severe and extreme environmental conditions of the Operating Basis and Design Basis Earthquakes and the abnormal loading conditions of an accidental fuel assembly drop event.

4.3.1 Loads and Load Combinations

The following load cases and load combinations have been considered in the analysis in accordance with the requirements of the UNSRC Standard Review Plan, Section 3.8.4 (Reference 7).

Load Case 1 - Dead Weight of Rack, D + L (Normal Load)

Under normal operating conditions, the rack is subjected to the dead weight loading of the rack structure itself plus the loads resulting from the storage cells and fuel assemblies stored in the cells.

Load Case 2 - Dead Weight of Rack Plus 1 G. Vertical Installation Load, D + I.L. (Normal Load)

During installation the rack is subjected to the loading resulting from its own structural weight, weight of empty storage cells, plus a 1 G. vertical load resulting from a suddenly applied crane load.

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Load Case 3 - Dead Weight of Rack Plus Uplifting Load, (D + U.L.) (Abnormal Load)

The possibility of the fuel handling bridge fuel hoist grapple getting hooked on a fuel storage cell was considered. The axial upward force considered for this load case was 1,000 pounds.

Load Case 4 - Operating Basis Earthquake, E (Severe Environmental Load)

The rack, fuel assemblies, and virtual water mass react to the simultaneous loading of the horizontal and vertical components of the seismic response acceleration spectra specified for the Operating Basis Earthquake in the Calvert Cliffs Unit 1 Fuel Storage Rack Specifications (Reference 8) and presented in Figure 4-1 and 4-2. The effects of fuel assembly impact during a seismic event were taken into account.

Load Case 5 - Design Basis Earthquake, E' (Extreme Environmental Load)

S... as Load Case 4 except that the seismic response acceleration spectra corresponding to the Design Basis Earthquake was used in the analysis (Figure 4-1 and 4-2).

Load Case 6 - Assembly Drop Impact Load, F.D. (Abnormal Load)

The possibility of dropping a fuel assembly on the rack from the highest possible elevation during spent fuel handling was considered. A 1300 pound weight (fuel assembly) was postulated to drop on the rack from a height of 24 inches above the top of the rack. Three cases were considered: 1) a direct drop on the top of a 2 x 2 module, 2) a subsequent tipping of the assembly onto the surrounding storage cans, 3) a straight drop through the storage cell and impact onto the rack base grid structure.

Thermal Loading, T (Normal Load)

The stresses and reaction loads due to thermal loadings are insignificant since clearances are provided to allow unrestrained growth of the racks for the maximum pool temperature of 150°F.

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SPECTRUM RESPONSE

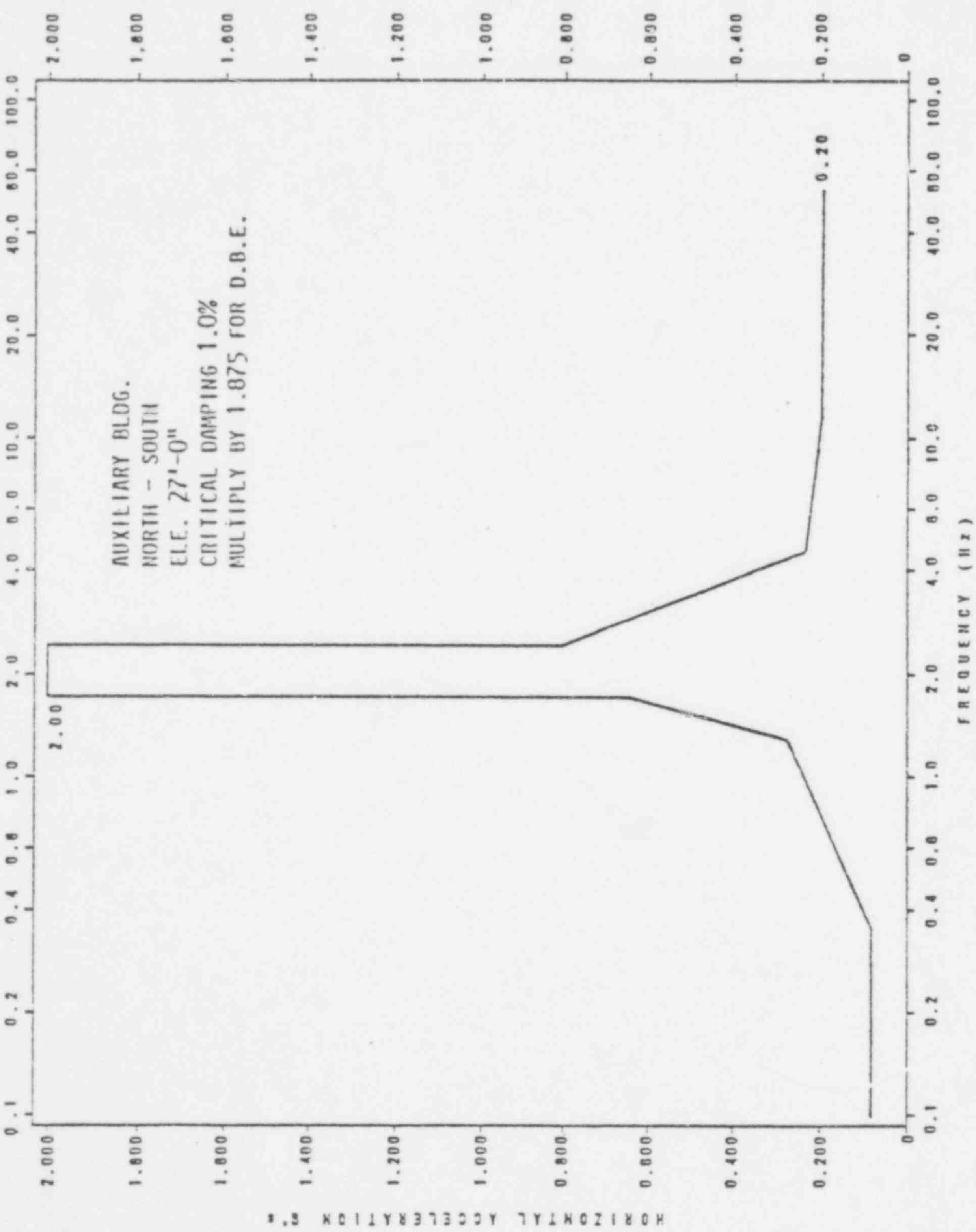

FIGURE 4-1

HORIZONTAL SEISMIC RESPONSE ACCELERATION SPECTRA - OPERATING BASIS EARTHQUAKE

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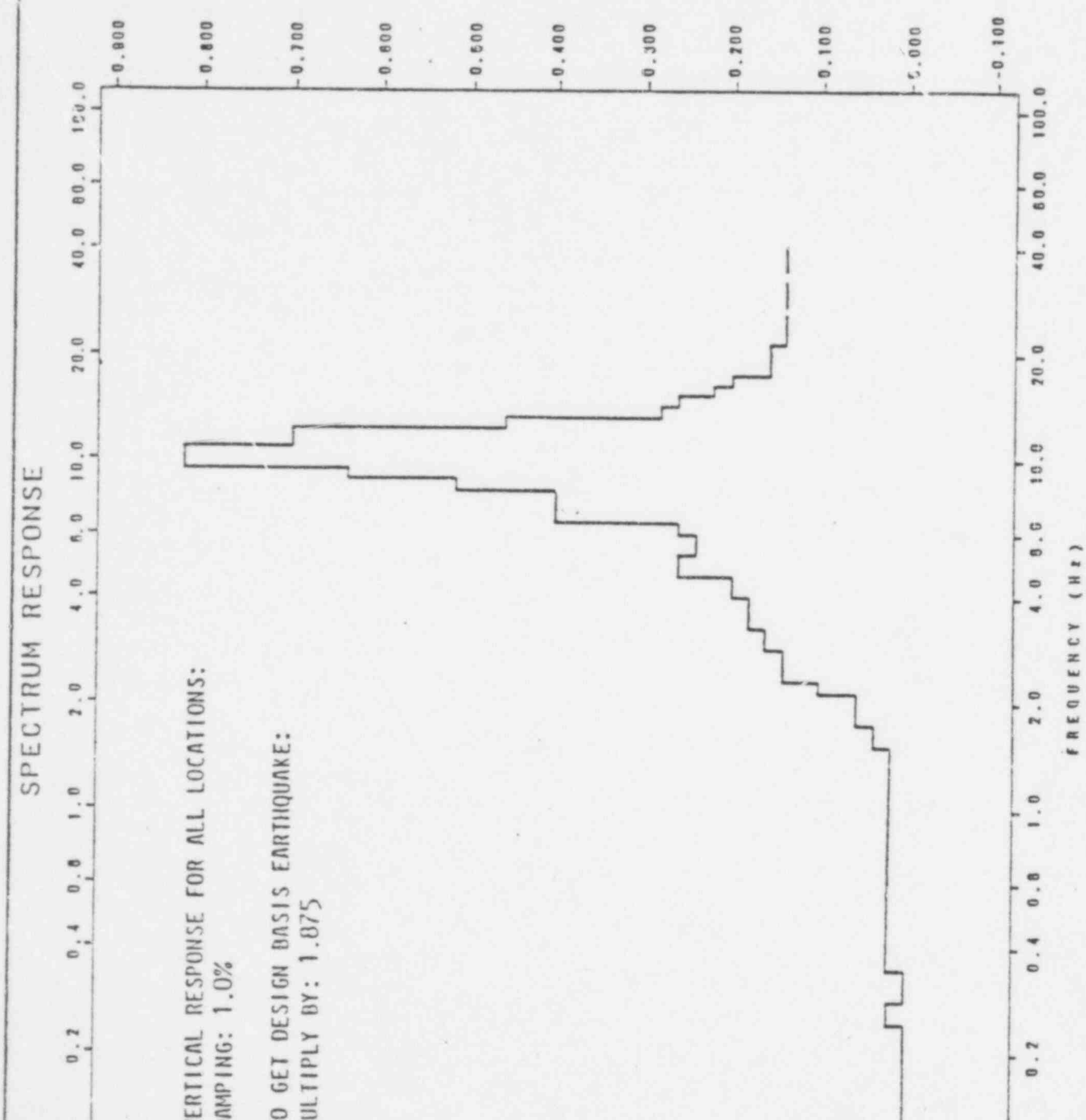

FIGURE 4-2

VERTICAL SEISMIC RESPONSE ACCELERATION SPECTRA - OPERATING BASIS EARTHQUAKE

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Load Combinations

For service load conditions, the following load combinations were considered using elastic working stress design methods of ASME Section III, Sub Section NF, Class 2, 1977 Edition (Reference 9):

(1) D + L	(1a) D + L + T
(2) D + I.L	
(3) D + L + E	(3a) D + L + T + E

For factored load conditions, the following load combinations were considered using elastic working stress design methods of ASME Section III, Sub Section NF, Class 2, 1977 Edition.

(4) D + L + T + E'
(5) D + L + U.L
(6) D + L + T + F.D

4.3.2 Design and Analysis Methods

Static, dynamic and stress analyses were performed using finite element methods. An individual fuel storage rack was mathematically modeled as a finite element structure consisting of discrete three-dimensional elastic beam and plate elements interconnected at a finite number of nodal points. Stiffness characteristics of the structural members were related to the plate thickness, cross sectional area, effective shear area and moment of inertia of the element sections.

Appropriate support connections were provided at the support feet for both static and dynamic analysis. Six degrees of freedom (three translations and three rotations) were permitted at each nodal point.

For the static dead weight and live load analysis, the distributed masses of the structural elements, storage cells and fuel elements are lumped at the system nodal points. Similarly, for Load Case 2, rack installation and removal analysis, the distributed masses of the structural elements and the cells were lumped at the system nodal points. The effect of suddenly applied crane load was considered by applying a 1 G vertical load in addition to the dead weight loading. For Load Case 3, a net vertical uplift load of 1,000 pounds was applied at the worst location of the storage rack.

For the horizontal and vertical seismic analyses, the following mathematical models were developed:

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2 x 2 Modular Cell Unit Model

This model was a detailed three-dimensional finite element model of an equivalent 2 x 2 module on the storage rack base structure. It was used in determining the natural frequency and seismic response (displacement, velocity, acceleration, member forces and stresses) of the 2 x 2 module.

10 x 10 Rack Model

This model consisted of twenty five single mass cantilever beams (representing twenty five 2 x 2 modules) rigidly attached to the rack base structure and attached to each other at the top by spacer bars. Each single mass cantilever beam has the same dynamic (frequency) characteristics as a 2 x 2 module. This model was used in calculating the maximum stresses in the rack base structure and the reaction loads and stresses in the rack support feet. The distributed masses corresponding to the fuel assembly storage cells, poison elements and contained plus hydrodynamic mass were lumped at appropriate nodal points. The hydrodynamic mass calculations were based on recommendations given in References 10 and 11. The horizontal and vertical weights were distributed such that the resulting lumped mass multi-degree-of-freedom model best represents the dynamic characteristics of the fuel storage rack. The seismic analyses were performed for the fully loaded racks only since this loading condition results in lower frequency, higher seismic accelerations, higher stresses and reaction loads.

The eigenvalues (natural frequencies) and the eigenvectors (mode shapes) for each of the natural modes of vibration were calculated using the Lanczos Modal Extraction Methods. The Seismic Response Analyses were performed by the response spectrum modal superposition methods of dynamic analysis, using the Calvert Cliffs Unit #1 Spectrum Response Curves (Figures 4-1 and 4-2). Individual modal response of the system were combined in accordance with Section 1.2.1 of Regulatory Guide 1.92 (Reference 12). The maximum response of the system for each of the three orthogonal spatial components (two horizontal and one vertical) of an earthquake were combined on a square root of the sums of square (SRSS) bases (Regulatory Guide 1.92).

Computer Code

The static, seismic and stress analyses for the fuel storage racks were performed utilizing the STARDYNE computer code (Reference 13). Details of the mathematical model, input and calculated data are presented in Reference 14.

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Water Sloshing Effects

The sloshing effects of water on the fuel racks have been evaluated using the analytical methods given in USAEC's TID 7024 "Nuclear Reactors and Earthquakes" (Reference 15).

Fuel Assembly Impact Loads

Clearances are provided between fuel assemblies and the storage cells to avoid interferences during fuel storage and removal operations. The storage cell/fuel assembly clearance or gap could result in the impacting of the fuel assembly and the storage cell during a seismic event. The Calvert Cliffs Unit 1 fuel storage racks have been analyzed using the linear response spectrum modal superposition methods of dynamic analysis. In these seismic analyses, the effect of impacting masses has been conservatively accounted for by imposing the following assumptions:

1. Each storage cell contains a fuel assembly.

2. All fuel assemblies simultaneously impact the storage cells.

3. The effect of fuel assembly impact is a two-fold increase in the seismic inertia loadings produced by the impacting fuel assemblies mass.

4. The impact and seismic inertia loads of the impacting masses are added to the seismic inertia loads of the non-impacting masses.

Accidental Fuel Assembly Drop Analysis

Linear and non-linear analysis techniques using energy balance methods were used to evaluate the structural damage resulting from a fuel assembly drop onto the rack.

4.3.3 Structural Acceptance Criteria

The following allowable stress limits constitute the structural acceptance criteria used for each of the loading combinations presented in Section 4.3.1.

Load Combinations	Limit
1, 2, 3	S
1a, 3a	1.5S
4, 5	1.6S

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Load Combinations	Limit
6	*

Where S is the required section strength based on the elastic design methods and the allowable stresses defined in ASME: "ASME Boiler and Pressure Vessel Code an American National Standard", ANSI/ASME BPV-III, Sub Section N F, Class 2, 1977 Edition.

* The acceptance criteria for Load Case 6, the accidental fuel assembly drop on the rack is that the resulting impact will not adversely affect the overall structural integrity of the rack the leak-tightness integrity of the fuel pool floor and liner plate and that the deformation of the impacted storage cells will not adversely affect the value of k_{eff} or the ability to cool adjacent fuel elements.

4.3.4 Results of Analysis

The results of the seismic and structural analysis indicate that the deflections and/or stresses in the rack structure resulting from the loadings associated with the normal and abnormal conditions are within allowable deflection and stress limits for Seismic Category I structures.

The maximum calculated stress in the fuel rack structure is a bending stress of 11.82 ksi (24.43 ksi allowable), which occurs in an exterior support beam. The maximum calculated stress in a fuel rack support leg is a bending stress of 65.52 ksi (121.26 ksi allowable). These maximum stresses result from the maximum DBE seismic loading. The fundamental frequency of vibration of the fuel storage rack is 5.387 cps.

Sloshing of pool water in a seismic event will have insignificant effects on the fuel storage racks.

The analysis of the accidental fuel assembly drop condition indicates acceptable local structural damage to the storage cells with no buckling or collapse, and no puncturing of the stainless steel liner. Therefore, no significant changes in the value of k_{eff} will occur and the leak tightness of the fuel pool will be maintained.

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It is concluded that the design of the Calvert Cliffs Unit 1 high density fuel storage racks is adequate to withstand the loadings of normal and abnormal conditions.

4.4 Sliding Analysis

4.4.1 Method of Analysis

The Calvert Cliffs Nuclear Plant Unit No. 1 High Density Spent Fuel Storage Racks have been designed to meet the requirements for Seismic Category 1 structures. Detailed non-linear time history seismic analyses have been performed to evaluate the maximum sliding of the storage racks and to determine the maximum frictional resistance load transmitted by the storage racks to the pool floor liner plate during the Design Basis Earthquake (DBE).

The fuel rack was mathematically modeled as a multi-degree-of-freedom finite element structure incorporating the stiffness characteristics of the storage rack and fuel assemblies, and the structural non-linearities that exist at the fuel assembly/storage cell interface and the storage rack leveling pad/pool floor interface. The hydrodynamic effect of the spent fuel pool water and the effect of fuel assembly impact have been included in the analyses.

The non-linear time history seismic analyses have been performed by step-by-step integration techniques (Houbolt method - Reference 16), using the ANSYS computer program (Reference 17). The details of these seismic analyses are contained in Reference 18.

4.4.2 Results of Analysis

The results of the non-linear time history seismic analysis indicate that during a DBE seismic event, the maximum sliding of an individual storage rack is approximately 0.85 inches (conservatively assuming a low coefficient of friction of 0.20). Therefore, the gaps provided between storage racks (3 inches minimum) and between storage racks and pool walls (1.25 inches minimum) are sufficient to preclude racks impacting each other or the pool structure.

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The maximum horizontal frictional resistance load transmitted by the storage rack to the pool floor liner is 182,600 pounds. The maximum frictional resistance load for an individual rack support foot is 30,430 pounds. This data assumes that the coefficient of friction is sufficiently high to prevent sliding.

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