NUCLEAR ENERGY SERVICES, INC.

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.
DANBURY, CONNECTICUT 06810

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1. DESIGN BASES

The high density spent fuel storage racks are designed to provide 830 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 10x10 array of fuel storage locations, two storage racks with an 8x10 array of fuel storage locations and one storage rack with a 7x10 array of fuel storage locations.

3. STORAGE RACK DESCRIPTION

Each storage rack consists of a welded assembly of fuel storage cells spaced 10-3/32 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.

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Storage racks consists of assemblies of 2x2 and 2x3 modular cell units. A modular cell unit is a square array of four or six storage cells described above. Each 10x10 rack contains twenty-five 2x2 modular cell units, each 8x10 rack contains twenty 2x2 modular cell units and the 7x10 rack contains ten 2x2 modular cell units and five 2x3 modular cell units. Figure 3-1 shows a typical modular cell unit and a schematic drawing of a 10x10 storage rack structure.

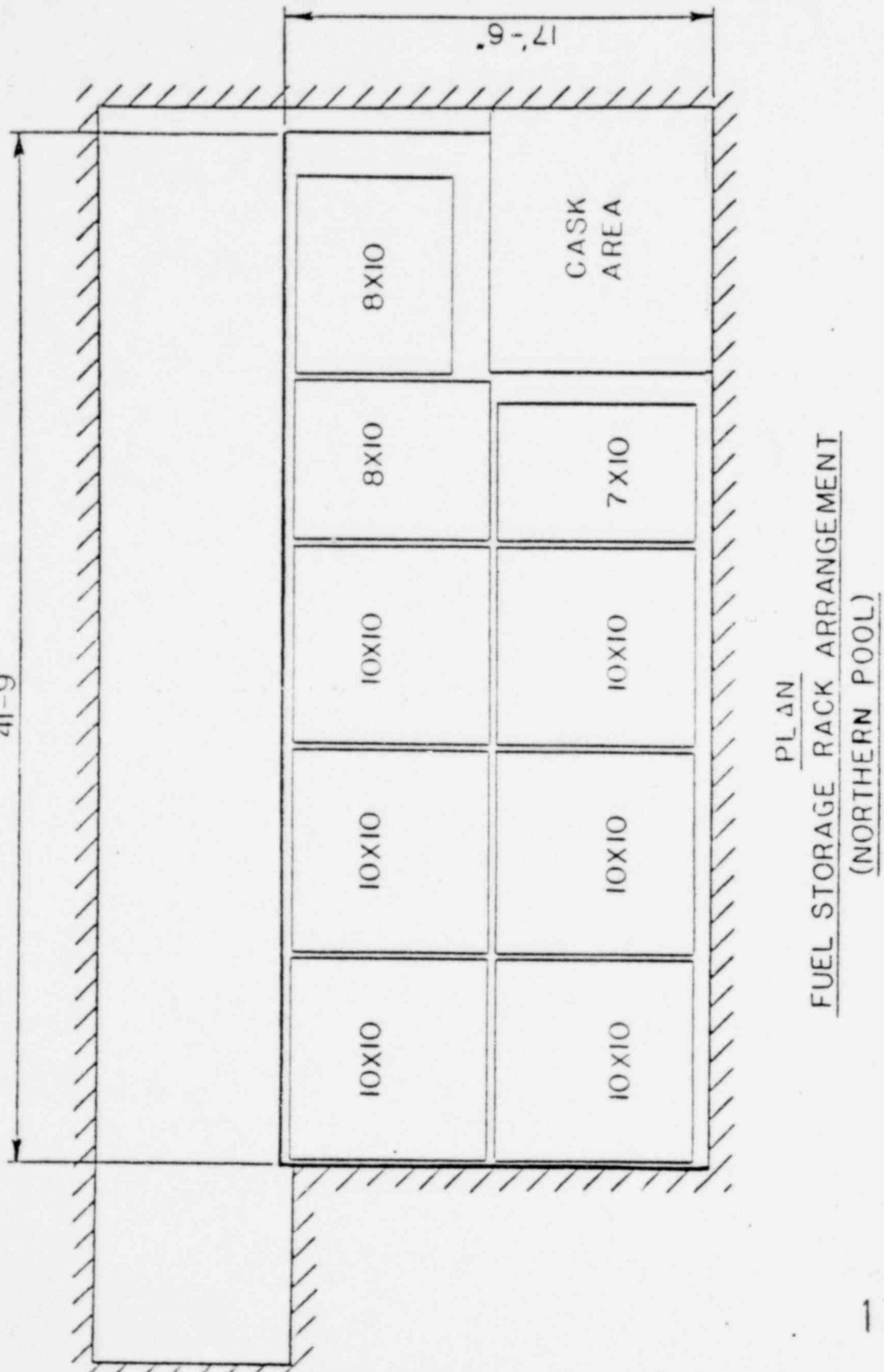

FIGURE 2-1

SPENT FUEL STORAGE RACK ARRANGEMENT PLAN

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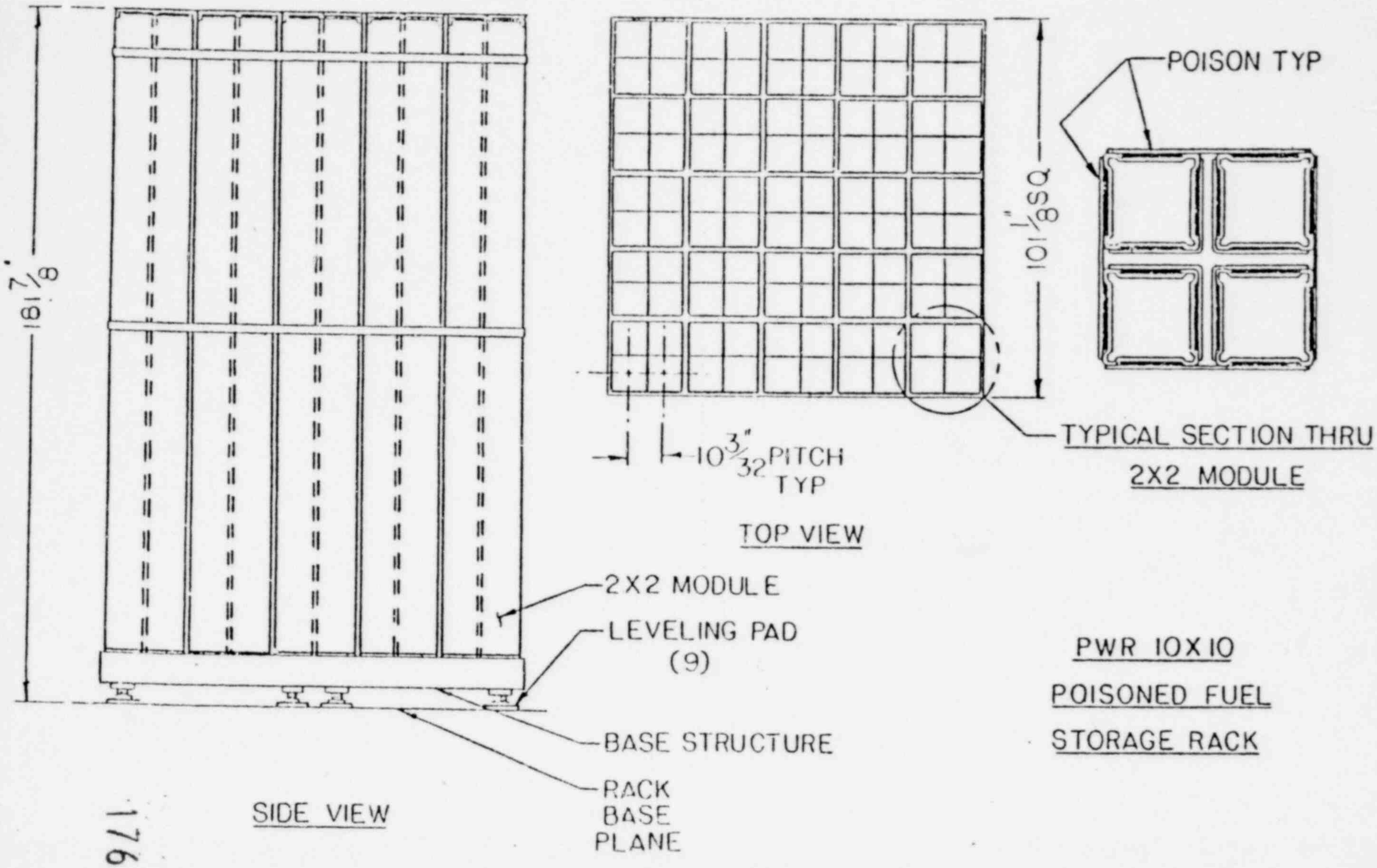

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FIGURE 3-1

SPENT FUEL STORAGE RACK SCHEMATIC (10 x 10)

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

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 or dry 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 304-L stainless steel with 17-4 PH 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.

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4. NUCLEAR ANALYSIS

4.1 CALCULATIONAL METHODS

A detailed nuclear analysis has been performed for the NES designed fuel storage racks for the Calvert Cliffs Unit No.1 Nuclear Plant. This analysis demonstrates that, for all anticipated normal and abnormal configurations of fuel assemblies within the fuel storage racks, the k_{eff} of the system is less than the criticality criterion of 0.95 for 4.1 w/o, 14x14 Combustion Engineering fuel assemblies. Certain conservative assumptions about the fuel assemblies and racks have been used in the calculations.

Both normal and abnormal configurations were considered in the analysis. The reference configuration consists of a square array, infinite in lateral extent, of storage cells spaced 10-3/32 inches on centers. Each storage location contains one centrally located 14x14 Combustion Engineering fuel assembly. Poison sheets containing boron in the form of B_4C are located in the walls of the storage cells to provide criticality control. This reference configuration provides a base of comparison relative to which effects of normal and abnormal variations have been measured. Normal configurations include: eccentrically positioned fuel, fuel enrichment variation, dimensional and material variations permitted by fabrication tolerances, and variation in the density of the boron in the poison slabs. Effects due to finite B_4C particle sizes were also considered. Abnormal configurations include: pitch variation due to seismic events, spent fuel pool temperature variations and fuel handling accidents such as misplaced fuel assemblies.

For the reference configuration, the k_{eff} was determined from a three-dimensional Monte Carlo calculation using KENO IV (Ref. 1) with two sets of cross sections: the 16 group Hansen-Roach cross section set and the 123 group cross section set. Check calculations of the reference configuration as well as the parametric studies were performed with two-dimensional diffusion theory using HAMMER (Ref. 2) and EXTERMINATOR (Ref. 3). In both the Monte Carlo and diffusion theory methods, an infinite array of fuel assemblies loaded in spent fuel storage locations was represented by use of appropriate boundary conditions. An infinite array is used for two reasons: an infinite array has a conservatively higher value of k_{eff} and the problem can be suitably represented by a repeating portion of the array.

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4.2 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 than 0.95 for all normal and abnormal configurations as determined by Monte Carlo calculations.

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

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

2. The reference configuration contains an infinite square array of storage locations spaced 10-3/32 inches on centers. This is conservative because the array is not infinite, but finite.

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

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

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

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

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4.3 RESULTS OF ANALYSIS

4.3.1 K_{eff} Values for Normal Configurations

(1) Reference Configuration

The reference configuration consists of an infinite array of storage cells having nominal dimensions each containing a fresh 14x14 Combustion Engineering fuel assembly centrally located within the storage cell. The water temperature within the rack is 68°F.

The k_{eff} determined by KENO IV using the 16 group cross section set was 0.8859 with an uncertainty of $\pm$0.0055 at the 95% confidence level. The k_{eff} determined by means of KENO IV using 123 groups was 0.9201 which when combined with the bias of -0.0200 determined from benchmarking gives a k_{eff} of 0.9001. The higher of these two KENO values, 0.9001, is chosen for conservatism.

(2) Eccentric 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 effects of eccentrically located fuel. In these calculations it was assumed that four fuel assemblies were diagonally displaced within their storage cells as far as possible towards each other. This Δk was determined to be -0.0075.

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(3) Fuel Assembly 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%. The effects of these fuel assembly tolerances on k_{eff} have been determined to be negligible on the basis of simple k_{∞} cell calculations. Consequently, fuel assembly tolerances were not considered further in this analysis.

(4) Fuel Design Variation

Calculations were performed to determine the sensitivity of k_{eff} to variations of fuel enrichment from the base enrichment of 4.1 w/o. The criticality configuration used for these calculations was that of the reference configuration with the exception of fuel enrichment, which was varied from 4.1 w/o to 3.9 w/o. Since the reference configuration was based on the maximum enrichment, and therefore produced the highest k_{eff}, this parametric study was made for information only.

(5) 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 criticality configuration was similar to that of the reference configuration except for the obvious change in center-to-center spacing. The mechanical design of the fuel rack is such that the average pitch between boxes is maintained by structural members at 10-3/32 $\pm$1/32 inches. The change in k_{eff} for a decrease in average pitch of 1/32 inch is +0.0062.

(6) Fuel Rack Cell Wall Thickness Variation

The base case wall thickness was 0.060 inch for each of the stainless steel sheets forming the cell walls. The material used for the wall will have a thickness tolerance of $^{+0.006}_{-0.000}$ inches and the Δk for this variation is +0.0008.

(7) Poison Content Variation

The B^{10} poison concentration specified for the Calvert Cliffs racks is 0.024 gm/cm^2. Experiments have shown that this poison material experiences a loss of B_4C during radiation exposure equivalent to 40 years residence in the spent fuel pool. The loss of B_4C reduces the B^{10} concentration by an average value of 15%, with the maximum reduction in B^{10} concentration experienced by any single test sample being 19.2%. The reference configuration k_{eff} is based on a B^{10} concentration of 0.020 gm/cm^2. A parametric study was made to determine the effect of k_{eff} if the poison concentration is varied from the reference value of 0.020 gm/cm^2. The results of this study showed that if the B^{10} concentration is 0.01939 gm/cm^2 (representing the maximum B^{10} loss of 19.2% compared to the reference 0.020 gm/cm^2) the Δk value is +0.0015.

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(8) Effect of Discrete B_4C Particle Size

Calculations were performed with KENO in which the B_4C particles in the poison sheets were represented as spheres of fixed diameter, regularly spaced throughout the sheet. The diameters studied were: 0.020 inch, 0.010 inch and zero (homogeneous). For the 0.020 inch case, an increase of about 2% Δk was found compared with the homogeneous case. However, for the 0.010 inch case, the increase in k was zero within the uncertainty of the KENO calculation. Since 50% of the particles are smaller than 0.008 inch and 90% are smaller than 0.010 inch the Δk due to finite particle size is taken as zero.

(9) "Worst Case" Normal Configuration

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

Results for normal configuration can be summarized as follows:

		K_{eff} or $+\Delta K_{eff}$
1.	Reference Configuration	0.9001
2.	Eccentric Positioning	0.0000 (negative)
3.	Fuel Assembly Tolerance	0.0000 (negligible)
4.	Enrichment Variation	0.0000
5.	Minimum Cell Pitch	0.0062
6.	Cell Wall Thickness	0.0008
7.	Minimum Poison Concentration	0.0015
8.	B_4C Particle Size Effect	0.0000 (negligible)
9.	Statistical Uncertainty in KENO	0.0055

The effects of the above normal variations are combined statistically as follows:

$$\Delta k_{eff} = (0.0062^2 + 0.0008^2 + 0.0015^2 + 0.0055^2)^{1/2} = 0.0085$$

The result for the "worst case" normal configuration is thus 0.9086.

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4.3.2 K_{eff} Values for Abnormal Configurations

(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 is 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.

(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 maximum, to 250°F, the approximate boiling point of water near the bottom of the fuel rack. Results show that the rack has a negative temperature coefficient with the highest k_{eff} occuring at the nominal 68°F temperature.

(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.

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A calculation based on an axial compression of 2 feet yielded a 0.06 decrease in k_{∞} 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. However, at the same time, the local pitch at other locations is greater by the same amount. Thus, the net effect, although the pitch may vary locally, is that 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.

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(7) "Worst Case" Abnormal Configuration

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.

		K_{eff}
1.	Worst Case Normal Configuration	0.9086
2.	Most Adverse Abnormal Configuration	0.0000
3.	Final k_{eff} for "worst abnormal" configuration.	0.9086

Details on calculational methods, codes and input/output data are presented in Reference 4.

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5. THERMAL HYDRAULICS

5.1 METHOD OF ANALYSIS AND ASSUMPTIONS

In the NES rack design the cross-flow 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.

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 cross-flows 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.

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The detailed thermal-hydraulic calculations are presented in Reference 5.

5.2 RESULTS OF ANALYSIS

The thermal-hydraulic calculations indicate 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 55.6°F which would result in an outlet temperature of 205.6°F.

An assembly lying horizontally on top of the racks would increase the temperature increase to 60.7°F with a resultant outlet temperature of 210.7°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. It should be noted that the maximum assembly outlet temperatures of 205.6°F and 210.7°F reported above for normal maximum operation and accident conditions respectively are unlikely to occur in the pool, as they are the result of highly conservative assumptions postulated to establish a calculational boundary. In the analysis, the major portion of the total pressure drop in the natural circulation loop is caused by the selection of the narrowest gap in the pool as the sole flow path to the bottom plenum from the water above trhe racks. The expected mode of natural circulation is for the coolant to reach the bottom plenum via least-resistant flow paths, such as the cask area, and the large cask wall downcomer, all of which have been neglected in the analysis.

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

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6. STRUCTURAL AND SEISMIC 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 I structures. Detailed structural and seismic analyses of the high density storage rcks 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.

6.1 LOADS AND LOAD COMBINATIONS

The following load cases and load combinations have been considered in the analysis in accordance with the requirements of USNRC Standard Review Plan, Section 3.8.4 (Reference 6).

Load Case 1 - Deadweight of Rack, D + L (Normal Load)
Under normal operating conditions, the rack is subjected to the deadweight loading of the rack structure itself plus the loads resulting from the storage cells and fuel assemblies stored in the cells.

Load Case 2 - Deadweight Of Rack Plus 1G. 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 1G. vertical load resulting from a suddenly applied crane load.

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Load Case 3 - Deadweight 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 7) and presented in Figure 6-1 and 6-2. The effects of fuel assembly impact during a seismic event are taken into account.

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

Same as Load Case 4 except that the seismic response acceleration spectra corresponding to the Design Basis Earthquake was used in the analysis (Figure 6-1 and 6-2).

Load Case 6 - Assembly Drop Impact Load, D.L. (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 2x2 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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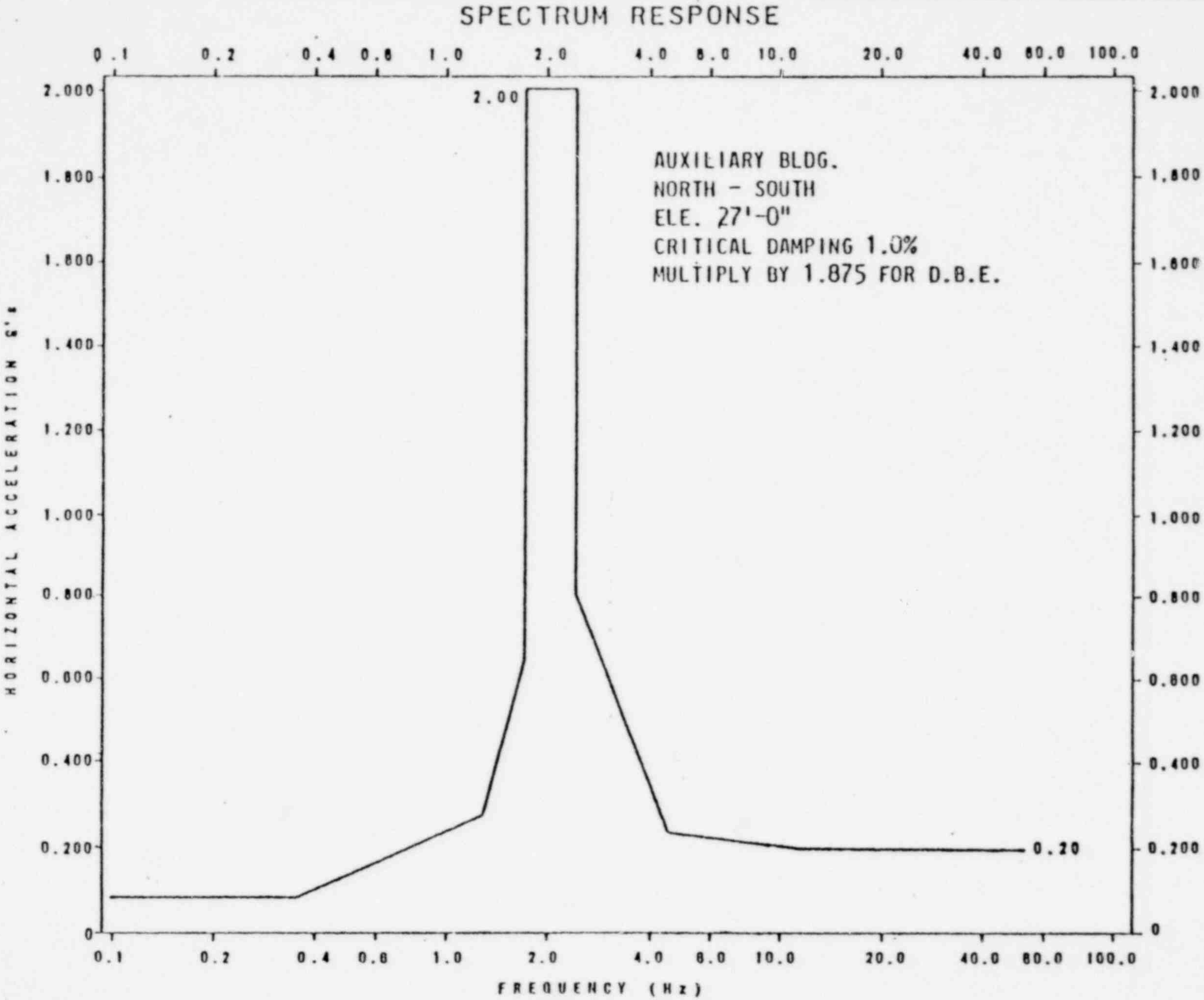

FIGURE 6-1

HORIZONTAL SEISMIC RESPONSE ACCELERATION SPECTRA - OPERATING BASIS EARTHQUAKE

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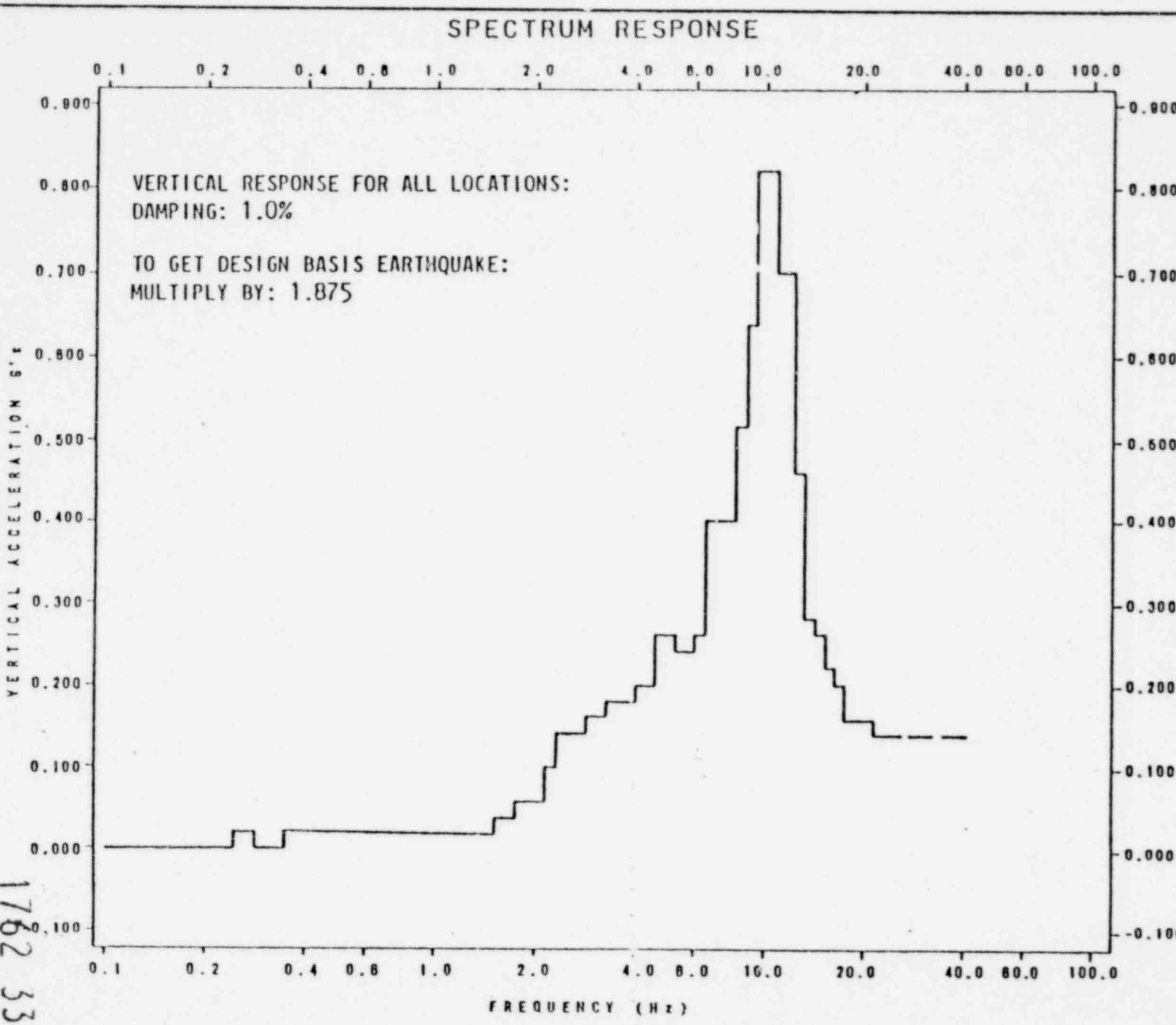

FIGURE 6-2

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 (Ref. 8):

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

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

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

6.2 DESIGN AND ANALYSIS METHODS

A 10x10 rack has been analyzed in detail. This rack conservatively represents the controlling structural case since it has the longer beam span and will be loaded by greater seismic loads than the smaller racks. The dynamic (frequency) characteristic of the rack is essentially controlled by the dynamic characteristics of its component 2x2 or 2x3 modular cell units. Although the fundamental frequency of the 2x3 modular cell unit is higher than that of the 2x2 modular cell units, the design seismic spectra is such that the lateral seismic G loading for the 2x2 and 2x3 modular cell units will be essentially similar.

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.

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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 deadweight 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 1G vertical load in addition to the deadweight 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:

<u>2x2 Modular Cell Unit Model</u>

This model was a detailed three-dimensional finite element model of an equivalent 2x2 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 2x2 module.

<u>10x10 Rack Model</u>

This model consisted of twenty-five single mass cantilever beams (representing twenty-five 2x2 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 2x2 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 9 and 10. 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

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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 calcualted 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 No.1 Spectrum Response Curves (Figures 6-1 and 6-2). Individual modal response of the system were combined in accordance with Section 1.2.1 of Regulatory Guide 1.92 (Ref. 11). The maximum response of the system for each of the three orthogonal spatial componetns (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).

Compute Code

The static, seismic and stress analyses for the fuel storage racks were performed utilizing the STARDYNE computer code (Ref. 12). Details of the mathematical model, input and calculated data are presented in Reference 13.

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" (Ref. 14).

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 No.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.

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(3) The effect of fuel assembly impact is a two-fold increase in the seisimc 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.

6.3 STRUCTURAL ACCEPTANCE CRITERIA

The following allowable stress limits constitute the structural acceptance criteria used for each of the loading combinations presented in Section 6.1.

Load Combinations	Limit*
1, 2, 3	S
1a, 3a	1.5S
4, 5	1.6S
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 NF, Class 2, 1977 Edition.

** The acceptance criteria for Load Case 6, the accidental spent 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 ability to cool adjacent fuel elements.

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6.4 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). Thses 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 strucutral 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.

It is concluded that the design of the Calvert Cliffs Unit No.1 high density fuel storage racks is adequate to withstand the loadings of normal and abnormal conditions.

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7. SLIDING ANALYSIS

7.1 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 I 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 full assemblies, and the strucutral 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, Ref. 15), using the ANSYS computer program (Ref. 16). The details of these seismic analyses are contained in Reference 17.

7.2 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 inch (conservatively assuming a low coefficient of friction of 0.20). Therefore, the gaps provided between storage racks (2 inches minimum) and between storage racks and pool walls (1 inch 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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REVISION LOG

REV. NO.	DATE	PAGE NO.	DESCRIPTION	APPROVAL
1	12-13-79		See CRA No. 1147	RAM 12-14-79 △1
			Since this CRA contains extensive changes	
			to report 81A0564, the use of a triangle/	
			revision number adjacent to the revised	
			area (per 80A9003, item 8.1.3) was not	
			meaningful and therefore omitted.	

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