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JUL 23 1999

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United States Nuclear Regulatory Commission
ATTENTION: Document Control Desk
Washington, DC 20555

SHEARON HARRIS NUCLEAR POWER PLANT
DOCKET NO. 50-400/LICENSE NO. NPF-63
RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION
REGARDING AMENDMENT REQUEST TO INCREASE FUEL STORAGE
CAPACITY BY PLACING SPENT POOLS 'C' & 'D' IN SERVICE

Dear Sir or Madam:

By letter HNP-98-188, dated December 23, 1998, Carolina Power & Light Company (CP&L) submitted a license amendment request to increase fuel storage capacity at the Harris Nuclear Plant (HNP) by placing spent fuel pools C & D in service. NRC letters dated March 24, 1999 and April 29, 1999 each requested additional information regarding our license amendment application. HNP letters HNP-99-069, dated April 30, 1999 and HNP-99-094, dated June 14, 1999 provided our respective responses.

By letter dated June 16, 1999, the NRC issued a third request for additional information (RAI) regarding our license amendment request to place spent fuel pools C & D in service. Enclosure 1 to this letter provides the HNP responses to each of the questions included within the June 16, 1999 RAI. Enclosures 2 and 3 provide information in support of our responses to the Staff RAI. Please note that Enclosure 3, in its entirety, contains information considered proprietary to Holtec International pursuant to 10 CFR 2.790. In this regard, CP&L requests Enclosure 3 be withheld from public viewing.

The enclosed information is provided as an additional supplement to our December 23, 1998 amendment request and does not change our initial determination that the proposed license amendment represents a no significant hazards consideration.

Please refer any questions regarding the enclosed information to Mr. Steven Edwards at (919) 362-2498.

Sincerely,

Donna B. Alexander

Donna B. Alexander
Manager, Regulatory Affairs
Harris Nuclear Plant

KWS/kws

Enclosures

c:

Mr. J. B. Brady, NRC Senior Resident Inspector (w/Enclosure 1)
Mr. Mel Fry, N.C. DEHNR (w/Enclosure 1)
Mr. R. J. Laufer, NRC Project Manager (w/all Enclosures)
Mr. L. A. Reyes, NRC Regional Administrator - Region II (w/Enclosure 1)

SHEARON HARRIS NUCLEAR POWER PLANT
DOCKET NO. 50-400/LICENSE NO. NPF-63
RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION
REGARDING THE LICENSE AMENDMENT REQUEST TO
INCREASE FUEL STORAGE CAPACITY
BY PLACING SPENT POOLS 'C' & 'D' IN SERVICE

Question 1

With respect to the dynamic fluid-structure interaction analysis using the computer code, DYNARACK, in the Reference, provide the following:

a) Explain how the simple stick model used in the dynamic analyses can represent accurately and realistically the actual highly-complicated nonlinear hydrodynamic fluid-rack structure interactions and behavior of the fuel assemblies and the box-type rack structures. Discuss whether or not a finite element (FE) model with 3-D plate, beam and fluid elements together with appropriate constitutive relationships would be a more realistic, accurate approach to analyze the fluid-structure interactions in contrast to the stick model.

b) Provide the results of any prototype or experimental study that verifies the correct or adequate simulation of the fluid coupling utilized in the numerical analyses for the fuel assemblies, racks and walls. If there is no such experimental study available, provide justification that the current level of the DYNARACK code verification is adequate for engineering application without further experimental verification work

Response to Question 1(a)

As explained in Sections 6.2 and 6.5 of Holtec International Report HI-971760 (Enclosure 6 of the December 23, 1998 submittal), the Whole Pool Multi-Rack (WPMR) model used to predict the dynamic behavior of the storage racks contains elements specifically designed to represent the attributes necessary to simulate rack motions during earthquakes. These elements include non-linear springs to develop the interaction between racks, between racks and walls, and between fuel assemblies and rack internal cell walls. Linear springs having the necessary characteristics to capture the lowest natural frequencies of the ensemble of fuel cells acting as an elastic beam-like structure in extension/compression, two-plane bending, and twisting are used to simulate rack structural elastic action. Hydrodynamic effects within these interstitial spaces are accounted for using Fritz's classical method which relates the fluid kinetic energy in the annulus due to relative motion to an equivalent hydrodynamic mass. Presented below is a historical overview of the fluid coupling effect as applied to the modeling of spent fuel racks in a seismic environment.

The phenomenon of fluid coupling between rectangular planform structures was sparsely investigated until the 1980s. Fritz's classical paper (ca. 1972) was used in the *earliest* version of DYNARACK to model rack-to-surrounding fluid effects in the so-called single rack 3-D

simulation. Enrico Fermi Unit 2 (ca. 1980) and Quad Cities Units 1 and 2 (ca. 1982) were licensed using the Fritz fluid coupling terms embedded in DYNARACK. The Fermi 2 and Quad Cities 1 and 2 submittals were the *first* rerack applications wherein a rack module was analyzed using the 3-D time-history technique. The adoption of a nonlinear time-history approach helped quantify the motion of a rack under a 3-D earthquake event and as a byproduct, also served to demonstrate that solutions using the Response Spectrum Method (which, by definition, presumes a linear structure) can be non-conservative. Practically all rerack licensing submittals since 1980 have utilized the 3-D time-history method. While the nonlinear 3-D time-history method was an improvement over the Response Spectrum (by definition, linear) approach, it nevertheless was limited inasmuch as only one rack could be modeled in any simulation. The analyst had to *assume* the behavior of the adjacent racks. Models, which postulated the behavior of the contiguous racks in the vicinity of the subject rack (rack being analyzed), were developed and deployed in safety analyses. Two most commonly used models were the so-called "opposed phase" model and the "in-phase" model, the former used almost exclusively to predict inter-rack impacts until 1985. Holtec Position Paper WS-115 (proprietary), included in Enclosure 3, provides a summary description of these early single rack 3-D models.

The inadequacy of the single rack models (albeit nonlinear) to predict the response of a grouping of submerged racks arrayed in close proximity became an object of prolonged intervenors' contention in the reracking of PG&E's Diablo Canyon units in 1986-87. Holtec, with assistance from the USNRC, developed a 2-D multi-rack model for the Diablo Canyon racks; this model helped answer intervention issues, permitting PG&E to rerack. USNRC experts testified in support of the veracity of the 2-D multi-rack dynamic models at the ASLB hearings in Pismo Beach, California in June 1987.

The Diablo Canyon intervention prompted Holtec to develop what later came to be known as the 3-D Whole Pool Multi-Rack (WPMR) analysis. A key ingredient in the WPMR analysis is quantification of the hydrodynamic coupling effect that couples the motion of *every* rack with *every* other rack in the pool. In 1987, Dr. Burton Paul (Professor Emeritus, University of Pennsylvania) developed a fluid mechanics formulation using Kelvin's recirculation theorem that provided the fluid coupling matrix (2n x 2n for a pool containing n racks).

As an example, refer to Figure RAI 1.1 (Enclosure 2), where an array of N (N = 16) two-dimensional bodies (each with two degrees of freedom) is illustrated. The dynamic equilibrium equation for the i-th mass in the x-direction can be written as:

$$[m_i + M_{ii}]\ddot{x}_i + \sum_{j=1}^{N}[M_{ij}\ddot{x}_j + N_{ij}\ddot{y}] = Q_{x_i}(t)$$

In the above equation, m_i is the mass of body i (i = 1,2...N), and $\ddot{x}_i$ is the x-direction acceleration vector of body i. M_{ij} and N_{ij} denote the "virtual" mass effects of body j on body i in the two directions of motion. The second derivative of y with respect to time represents the acceleration in the y-direction.

The terms M_{ij} are functions of the shape and size of the bodies (and the container boundary) and, most important, the size of the inter-body gaps. M_{ij} are *analytically* derived coefficients. Q_{xi} represents the so-called Generalized force that may be an amalgam of all externally applied loads on the mass i in the x-direction. The above equilibrium equation for mass i in x-direction translational motions can be written for all degrees of freedom and for all masses. The resulting second order matrix differential equation contains a fully populated mass matrix (in contrast, dynamic equations *without* multi-body fluid coupling will have only diagonal non-zero terms).

The above exposition explains the inclusion of fluid coupling in a multi-body fluid coupled problem using a simplified planar motion case. This explanation provides the building blocks to explain the more complicated formulation needed to simulate freestanding racks. Dr. Paul's formulation is documented in a series of four (Holtec proprietary) reports written for PG&E in 1987, and are included in Enclosure 3. The Paul multi-body fluid coupling theory conservatively assumes the flow of water to be irrotational (inviscid) and assumes that no energy losses (due to form drag, turbulence, etc.) occur. The USNRC personnel reviewed this formulation in the course of their audit of the Diablo Canyon rerack (ca. 1987) and subsequently testified in the ASLB hearings on this matter, as stated above.

While the ASLB, USNRC, and Commission consultants (Brookhaven National Laboratory and Franklin Research Center) all endorsed the Paul multi-body coupling model as an appropriate and conservative construct, the theory was still just a theory. Recognizing this perceptual weakness, Holtec and Northeast Utilities undertook an experimental program in 1988 to benchmark the theory. The experiment consisted of subjecting a scale model of racks (from one to four at one time in the tank) to a two-dimensional excitation on a shake table at a QA qualified laboratory in Waltham, Massachusetts.

The Paul multi-body coupling formulation, coded in QA validated preprocessors to DYNARACK, was compared against the test data (over 100 separate tests were run). The results, documented in Holtec Report HI-88243, were previously provided to the Commission. The experimental benchmark work validated Paul's fluid mechanics model and showed that the theoretical model (which neglects viscosity effects) is consistently bounded by the test data. This experimentally verified multi-body fluid coupling is the central underpinning of the DYNARACK WPMR solution that has been employed in every license application since Chinshan (1989). The DYNARACK 3-D WPMR solution has been found to predict much greater rack displacements and rotations than the previously used 3-D single rack results.

In general, the advance from linearized analyses (response spectrum) in the late 1970s to the single rack 3-D analyses until the mid-1980s and, finally, to the 3-D WPMR analysis in the past eleven years has, at each technology evolution stage, led to some *increase* in the computed rack response. The stresses and displacements computed by the DYNARACK 3-D WPMR analysis for the Shearon Harris racks, in other words, may be larger (and therefore more conservative) than the docketed work on similar instances from 15 years ago. The conservatisms built into the WPMR solution arises from several simplifying assumptions explicitly intended to establish an upper bound on the results, namely:

i. In contrast to the single rack 3-D models, the fluid forces on every rack in the pool consist of the aggregate of fluid coupling effects from *all other* racks located in

the pool. No empirical assumptions on the motion of racks need to be made; the motion of each rack in the pool is a result of the analysis.

ii. The fluid coupling terms are premised on classical fluid mechanics; they are not derived from empirical reasoning. Further, fluid drag and viscosity effects, collectively referred to as "fluid damping," are neglected. In short, while the transfer of fluid kinetic energy to the racks helps accentuate their motion, there is *no* subtraction of energy through damping or other means.

iii. In the Shearon Harris rack simulations, the dynamic model for the fuel assemblies in a rack assumes that *all* fuel assemblies within a rack move in unison. Work in quantifying the effect of discordant rattling of fuel assemblies within a rack in other licensing applications by Holtec has shown that the "unified motion" assumption exaggerates the rack response by 25% to 60%, depending on the rack geometry details and earthquake harmonics.

iv. The rack-to-rack and rack-to-wall gaps are taken as the *initial* nominal values. During the earthquake, these gaps will in fact change through the time-history duration. Strictly speaking, the fluid coupling matrix should be recomputed at each time-step with the concomitant gap distribution. The inversion of the mass matrix at each time-step (there are over four million time-steps in a typical WPMR run) would, even today, mandate use of a supercomputer. Fortunately, neglect of this so-called nonlinear fluid coupling effect is a conservative assumption. This fact is rigorously proven in a peer reviewed paper by Drs. Soler and Singh entitled "Dynamic Coupling in a Closely Spaced Two-Body System Vibrating in a Liquid Medium: The Case of Fuel Racks," published in 1982. The only docket where recourse to the nonlinear fluid coupling was deemed essential was Vogtle Unit 2 (in 1988) where the margin inherent in the nonlinear fluid effect, published in the above mentioned paper, was reaffirmed.

Nonlinear fluid coupling effects due to the use of current gaps at each time instant are not employed in this present application which imputes over 15% margin (in Holtec's analysts' estimate) in the computed rack response.

In summary, the WPMR analysis utilizes a fluid coupling formulation that is theoretically derived (without empiricism) and experimentally validated. The assumptions built in the DYNARACK formulation are aimed to demonstrably exaggerate the response of all racks in the pool simulated in one comprehensive model.

A further elaboration of the details of the structural model used for the spent fuel racks and a mathematical explanation of the manner in which fluid coupling is considered in the solution is provided below.

DYNARACK, developed in the late 1970s and continuously updated since that time to incorporate technology advances such as multi-body fluid coupling, is a Code based on the Component Element Method (CEM). The chief merit of the CEM is its ability to simulate friction, impact, and other nonlinear dynamic events with accuracy. The high-density racks

designed by Holtec International are ideally tailored for the CEM-based Code because of their honeycomb construction (HCC). Through the interconnection of the boxes, the HCC rack essentially simulates a multi-flange beam. The beam characteristics of the rack (including shear, flexure, and torsion effects) are appropriately modeled in DYNARACK using the classical CEM "beam spring." However, the rack is not rendered into a "stick" model, as implied by the staff's RAI. Rather, each rack is modeled as a prismatic 3-D structure with support pedestal locations and the fuel assembly aggregate locations set to coincide with their respective center of gravity axes. The rattling between the fuel and storage cells is simulated in exactly the same manner as it would be experienced in nature; namely, impact at any of the four facing walls followed by rebound and impact at the opposite wall. Similarly, the rack pedestals can lift off or slide as the instantaneous dynamic equilibrium would dictate throughout the seismic event. The rack structure can undergo overturning, bending, twist, and other dynamic motion modes as determined by the interaction between the seismic (inertia) impact, friction, and fluid coupling forces. Hydrodynamic loads, which can be quite significant, are included in a comprehensive manner, as we explain in more detail below.

As explained above, the fluid coupling effect renders the mass matrix into a fully populated matrix. Modeling the fuel rack as a multi-degree of freedom structure, the following key considerations are significant:

i. Over 70% of the mass of the loaded rack consist of fuel assemblies, which are unattached to the rack, and resemble a loose bundle of slender thin-walled tubes (high mass, low frequency).

ii. In honeycomb construction (HCC) racks, as shown in a 1984 ASME paper, the rack behaves like a stiff elongated box beam (End Connected Construction racks, built 20 years ago and now obsolescent, behave as a beam and bar assemblage).

Since the Shearon Harris racks under inertial loading have overall structural characteristics of a multi-flange beam, it is computationally impractical to model such a structure as a plate assemblage. The DYNARACK dynamic model preserves the numerical stability of the physical problem by representing the rack structure by an equivalent flexural and shear resisting "component element" (in the terminology of the Component Element Method).

A detailed discussion of the formation of the fluid mass matrix is presented below.

The problem to be investigated is shown in Figure RAI 1.1 (Enclosure 2), which shows an orthogonal array of sixteen rectangles which represent a unit depth of the sixteen spent fuel racks in the Shearon Harris Spent Fuel Pool. The rectangles are surrounded by narrow fluid filled channels whose width is much smaller than the characteristic length or width of any of the racks. The spent fuel pool walls are shown enclosing the entire array of racks.

The dimensions of the channels are such that an assumption of uni-directional fluid flow in a channel is an engineering assumption consistent with classical fluid mechanics principles.

We consider that each rectangular body (fuel rack) has horizontal velocity components U and V parallel to the x and y axes, and that the channels are parallel to either the x or y axes. The pool walls are also assumed to move.

We conservatively assume that the channels are filled with an inviscid, incompressible fluid. Due to a seismic event, the pool walls and the spent fuel racks are subject to inertia forces that induce motion to the rectangular racks and to the wall. This motion causes the channel widths to depart from their initial nominal values and causes flow to occur in each of the channels. Because all of the channels are connected, the equations of classical fluid mechanics can be used to establish the fluid velocity (and hence, the fluid kinetic energy) in terms of the motion of the spent fuel racks.

For the case in question, there are 40 channels of fluid identified. Figure RAI 1.2 (Enclosure 2) shows a typical rack (box) with four adjacent boxes and fluid and box velocities identified. The condition of vanishing circulation around the box may be expressed as

$$\Gamma = \oint_C v_s ds = 0$$

or

$$\int_{-a/2}^{a/2} (u_B - u_T) d\xi + \int_{-b/2}^{b/2} (v_R - v_L) d\eta = 0$$

where the subscripts (L, R, B, T) refer to the left, right, bottom, and top channels, respectively; ξ,η are local axes parallel to x and y, and u, v are velocities parallel to ξ, η.

Continuity within each channel gives an equation for the fluid velocity as

$$w = w_m - \left(\frac{\dot{h}}{h}\right) s$$

where w represents the velocity along the axis of a channel, w_m represents the mean velocity in the channel, s is either ξ or η, and $\dot{h}$ is the rate of increase of channel width. For example,

$$\dot{h}_R = U_R - U$$

From Figure RAI 1.2 (Enclosure 2), four equations for u_B, u_T, v_R, and v_L in terms of the respective mean channel velocities, can be developed so that the circulation equation becomes

$$a\,(U_{Bm} - U_{Tm}) + b\,(v_{Rm} - v_{Lm}) = 0$$

One such circulation equation exists for each spent fuel rack rectangle. We see that the velocity in any channel is determined in terms of the adjacent rack velocities if we can determine the mean fluid velocity in each of the 40 channels. Circulation gives 16 equations. The remaining equations are obtained by enforcing continuity at each junction as shown in Figure RAI 1.3 (Enclosure 2). Enforcing continuity at each of the 25 junctions gives 25 equations of the general form.

$$\Sigma h \sigma w \frac{1}{2} \Sigma L \dot{h}$$

where w is the mid-length mean velocity in a connecting channel of length L and $\dot{h}$ is the relative normal velocity at which the walls open. The summation covers all channels that meet at the node in question. The sign indicator $\sigma = \pm 1$ is associated with flow from a channel either into or out of a junction.

Therefore, there are a total of 25 + 16 = 41 equations which can be formally written; one circulation equation, however, is not independent of the others and reflect the fact that the sum total of the 25 circulation equations must also equal zero, representing circulation around a path enclosing all racks. Thus, there are exactly 40 independent algebraic equations to determine the 40 unknown mean velocities in this configuration.

Once the velocities are determined in terms of the rack motion, the kinetic energy can be written and the fluid mass matrix identified using the Holtec QA-validated pre-processor program CHANBP6. The fluid mass matrix is subsequently apportioned between the upper and lower portions of the actual rack in a manner consistent with the assumed rack deformation shape as a function of height in each of the two horizontal directions. This operation is performed by the Holtec QA-validated pre-processor code VMCHANGE. Finally, structural mass effects and the hydrodynamic effect from fluid within the narrow annulus in each cell containing a fuel assembly between fuel and cell wall is incorporated using the Holtec QA-validated pre-processor code MULTI122.

The initial inter-rack and rack-to-wall gaps are illustrated in Figure RAI 1.2 (Enclosure 2). These gaps, which directly figure in the computation of fluid mass effects in fluid coupling matrix, are assumed to apply for the entire duration of the earthquake. In reality, the gaps change throughout the seismic event and a rigorous analysis would require that the mass matrix be recomputed at every time-step. Besides being numerically impractical, such refinement in the solution would reduce the conservatism in the computed results, as previously discussed.

The time variations in the inter-rack and rack-to-wall gaps are, however, tracked for the duration of the earthquake. Closure of any gap at any location results in activation of the compression gap spring at that location. The loads registered in the gap spring quantify the collision force at that location. The fuel-to-storage cell rattling forces and rack pedestal-to-pool liner impact forces (in the event of pedestal lift-off) are typical examples of collision forces that are ubiquitous in rack seismic simulations. The nonlinear contact springs in DYNARACK simulate these "varying gap" events during seismic events using an unconditionally convergent algorithm.

In summary, the Whole Pool Multi-Rack (WPMR) analysis is a geometrically nonlinear formulation in all respects (lift-off, sliding, friction, impact, etc.), except in the computation of the fluid coupling matrix, which is based on the nominal (initial) inter-body gaps.

The modeling technique used (i.e. representation of the fuel rack and contained fuel by elastic beams and appropriate lumped masses) was chosen based on the application Codes, Standards and Specifications given in Section IV (2) of the NRC guidance on spent fuel pool modifications entitled, "Review and Acceptance of Spent Fuel Storage and Handling Applications," dated April 14, 1978. This reference states that "Design...may be performed based upon the AISC specification or Subsection NF requirements of Section III of the ASME B&PV Code for Class 3 component supports." The rack modeling technique is consistent with the linear support beam-element type members covered by these codes.

It is recognized that finite element models could also be developed using plate and fluid elements, which may also provide satisfactory simulated behavior for a single rack. However, there is no known commercial finite element code which can treat multi-body fluid interaction correctly and sufficiently so as to account for near and far field fluid effects involving many bodies (racks) in a closed pool. It is for this reason that the global dynamic analysis uses the formulation specifically developed and contained within DYNARACK.

Response to Question 1(b)

Holtec Report HI-88243 by Dr. Burton Paul provides a comparison of DYNARACK fluid coupling formulation with over 100 experiments carried out in an independent laboratory under a 10CFR50 Appendix B program. These tests were performed with the sole purpose of validating the multi-body fluid coupling formulation based on Kelvin's recirculation theorem in classical fluid mechanics. These experiments, to our knowledge, are the only multi-body fluid coupling tests conducted and recorded under a rigorous QA program. The participating bodies used in the tests were carefully scaled to simulate rectangular planform fuel racks. The tests were run on a wide range of seismic frequencies to sort out effects of spurious effects such as sloshing in the tank, and to establish that the fluid coupling matrix is independent of the frequency content of the impressed loading. The University of Akron tests performed some testing under the sponsorship of the predecessor company of U.S. Tool & Die, Inc. However, these tests were performed in the time when racks were still being analyzed using the Response Spectrum Method. We note that a theoretical model developed by Scavuzzo (Scavuzzo, R.J., et al. "Dynamics Fluid Structure Coupling of Rectangular Modules in Rectangular Pools," ASME Publications PVP-39, 1979, pp. 77-87) is *exactly* that used in the Holtec WPMR analysis when the Holtec mass matrix is reduced to a single rectangular solid block surrounded by four rigid (pool) walls. That is, the work by Scavuzzo is a special case of a Holtec WPMR analysis for a spent fuel pool containing a single spent fuel rack.

The Holtec WPMR fluid mass matrix for many racks in the pool is obtained by applying the same classical principles of fluid continuity, momentum balance, and circulation, to a case of many rectangular bodies in the pool with multi-connected narrow fluid channels.

The experimental work performed by Scavuzzo, et al., does not attempt to model a free standing rack since many rack structures of that vintage were not free-standing. The experimental test is

equivalent to a single spring-mass-damper subject to a forced harmonic oscillation while submerged. If one accepts the fact that the fluid model used by Scavuzzo is a limiting case of the more general Holtec formulation, then the good agreement of theory with experiment for the single "rack" modeled experimentally serves as additional confirmation that the Holtec theoretical hydrodynamic mass model, which is identical to the Scavuzzo model (for a simple rack) is reproducible by experiment.

We have utilized the data supplied by Scavuzzo to simulate the experiment using the pre-processor CHANBP6 and the solver DYNARACK. The results of this comparison have been incorporated into the Holtec validation manual for DYNARACK (HI-91700) as an additional confirmation of the fluid coupling methodology. This validation manual, along with additional supporting documentation and discussions, was presented to the NRC in April, 1992 under dockets 50-315 and 50-316 for the D.C. Cook station and also was submitted in the licensing for re-racking of the Waterford 3 spent fuel pool. The submittal for Waterford contained the evaluation of the Scavuzzo theory and experiment, and demonstrated that the WPMR general formulation was in agreement with the experimental work presented in ASME Publication PVP-39, 1979, "Dynamics Fluid Structure Coupling of Rectangular Modules in Rectangular Pools."

Question 2

Demonstrate that the artificial seismic time histories used in the analyses satisfy the power spectral density (PSD) requirement of Standard Review Plan (SRP) Section 3.7.1.

Response to Question 2

Holtec Report HI-971702 provides the details of the development of the time histories used for the Shearon Harris spent fuel pool from the design basis Response Spectra. Figures RAI 2.1 through 2.6 (Enclosure 2), reproduced from the aforementioned report, demonstrate the required enveloping of the target PSD over the frequency range important to spent fuel racks (3-7 Hz) by the PSD regenerated from the developed time histories.

Question 3

Provide the physical dimensions of the racks, gaps between the racks, and the gaps between the racks and the walls.

Response to Question 3

The requested dimensional data is included in the Holtec Licensing Report, HI-971760, submitted as Enclosure 6 to the December 23, 1998 license amendment request. Pages 1-9, 1-10, and pages 2-17 through 2-20 from the Holtec report provide this requested information.

Question 4

Your analysis results show that there are rack-to-pool wall and rack-to-rack impacts. Indicate whether you are planning to install a support system to minimize displacement and impact force between the rack-to-pool wall and rack-to-rack.

Response to Question 4

The high-density racks for Shearon Harris are designed for installation as freestanding structures. There are no rack-to-pool wall impacts predicted by any of the WPMR simulations performed for the Shearon Harris spent fuel pool. There are, however, some rack-to-rack impacts that occur during the seismic simulations.

Impact during seismic events is a natural corollary of a freestanding structure. At minimum, during seismic events, the fuel assemblies rattle inside the storage cavity and rack pedestals' compression forces change with time. Pedestal lift-off and impact are also more of a rule than an exception. Rack-to-rack impact is also observed in a significant number of cases. None of these impact forces would lead to an adverse effect on safety if their magnitudes are conservatively quantified and if their consequences to the rack structure are carefully examined. The Shearon Harris racks have been subjected to an exhaustive set of dynamic and stress analyses to ensure that the safety conclusions are accurate. Where rack-to-rack impacts occur, there is no effect on the structure in the region of active fuel; the effects from the impact forces are accounted for in the subsequent dynamic response of the rack. Consequently, the magnitudes of the impact forces suggest that there is no need to add any type of rack support system.

Question 5

With respect to the spent fuel pool (SFP) structural analysis using the STARDYNE computer code presented in the Reference:

a) Provide a plan view of the SFP and physical dimensions of the reinforced concrete slab and walls, liner plate and liner anchorage.

b) Provide the mesh used in the analysis.

c) Describe the boundary conditions used, and indicate them in the mesh.

d) Provide the material properties used in the analysis.

e) Describe the applied loading conditions including the magnitudes, and indicate their locations in the mesh.

f) Explain how the interface between the liner and concrete slab is modeled, and also, how the liner anchors are modeled. Provide the basis for using such modeling with respect to how they accurately represent the real structural behavior.

g) Provide the calculated governing factors of safety in a tabular form for the axial, shear, bending and combined stress conditions.

Response to Question 5(a)

Harris Nuclear Plant (HNP) drawings CAR-2168-G-117, 118, 119, 120, and 122 along with HNP drawings CAR-2167-G-1876, 1877, 1878, and 1879 provide the requested dimensional information for the Spent Fuel Pools (see Enclosure 2).

Response to Question 5(b)

The pre-processing capabilities of the STARDYNE computer code are used to develop the 3-D finite-element model. The STARDYNE finite-element model contains 13353 nodes, 3564 solid type finite-elements, 7991 plate type finite-elements and 24 hydro-dynamic masses. Figure 4 from Holtec Report HI-981868 (see Enclosure 2) depicts an isometric view of the three-dimensional finite element model without the water and concentrated masses (racks, cask, etc.). Figure 5, also taken from Holtec Report HI-981868, shows a 3-D longitudinal section through the finite-element (see Enclosure 2).

The on-grade mat, completely modeled from solid type finite-elements, is shown in Figure 6. The vertical reinforced concrete structure (walls) located parallel to the global X and Y directions of the model are depicted in enclosed Figures 7 and 8. These elements are constructed by employing plate type finite-elements which account for the shear deformation that is an important factor in the structural investigation of thick plates. Figures 6, 7, and 8 are also taken from Holtec Report HI-981868 and included in Enclosure 2.

Response to Question 5(c)

To simulate the interaction between the modeled region and the rest of the Fuel Handling Building a number of boundary restraints were imposed upon the described finite-element model. All nodes located at the ground level elevation 206'-0" (the model Z coordinate -120") are fixed. Additionally, in order to simulate the structural continuity of the overall mat, the nodes located at the periphery of the concrete mat, between elevations 206'-0" and 216'-0", are restrained from moving in all three directions. The nodes located at the contact between the walls and the mat are constrained against rotations.

All nodes located on column line 43 (the model X=-984"), which represents the Fuel Handling Building East-West axis of symmetry, are constrained appropriately to ensure preservation of symmetry.

The nodes associated with the masses used to describe the hydro-dynamic behavior of the water during a seismic event are constrained to move in only one direction (X or Y horizontal direction only).

Response to Question 5(d)

The behavior of the reinforced concrete in the structural elements (walls, slabs and mat) is considered elastic and isotropic. The elastic characteristics of the concrete are independent of the reinforcement contained in each structural element for the case when the un-cracked cross-section is assumed. This assumption is valid for all load cases with the exception of the thermal loads, where for a more realistic description of the reinforced concrete cross-section behavior cracking of the concrete is assumed. The elastic characteristics for the concrete and reinforcement used in this calculation are summarized in Table 2 (see Enclosure 2). To simulate the variation and the degree of cracking patterns, the concrete Young's Modulus was reduced to reflect the scenario where all tension is carried only by the available reinforcement. Table 3 (see Enclosure 2) contains the elastic isotropic material properties and the reduced elastic modulus (E_{crack}) pertinent to each one of the structural elements used in the finite-element model. As shown in Table 3, some locations not subject to exposure to the fuel pool water do not suffer cracking under thermal loads as there is no significant thermal gradient in these regions.

Response to Question 5(e)

For this numerical investigation, only four of the load categories described in NUREG-0800 Standard Review Plan are applicable. They are: dead loads (D), live loads (L), thermal loads (operating - T_o and accident - T_a) and seismically induced loads (OBE - E and SSE – E').

Dead Loads - (D)

The dead loads acting on the Harris Spent Fuel Pools C and D concrete structures consist of the self weight of the concrete structure, fully loaded racks, spent fuel cask, and the existing reinforced concrete upper structure of the Fuel Handling Building resting on the pool walls. All the loads contained in this category are statically applied loads. The magnitude of the loads used in the analysis are summarized below:

* Dead weight of the modeled concrete structure is calculated considering a density of 150 lb/ft^3;

* Dead weight of maximum density rack modules in Pools C and D. The loads are concentrated at the pedestals and cumulatively applied at the nearest corresponding slab nodes as concentrated weights.

* Dead maximum weight of fully loaded cask is estimated to be 250,000 lb. The weight of the cask is also distributed as concentrated weights at its slab tributary nodes. The racks, cask and upper structure loads are summarized in Table 4 (Enclosure 2);

* Dead weight of Fuel Handling Building reinforced concrete upper structure considered at 150 lb/ft^3. The weights are equally distributed as concentrated weights at the nodes located along the corresponding supporting walls;

* Hydro-static water pressures vary linearly along the height of the walls. The considered water density is 62.00 lb/ft^3, a value which corresponds to 100 degrees F, since the operating pool temperature is expected to be in this range with a maximum normal temperature of 140 degrees F. The vertical variation of the hydro-static pressure is shown in Table 5 (see Enclosure 2).

Live Loads - (L)

The only live loads considered in this numerical investigation are the live loads related to the Cask Handling Crane (CHC), the Auxiliary Crane (AC) and the Spent Fuel Handling Machine (SFHM), consider as follows:

* The 2.050E+05 lb weight for the Cask Handling Crane (CHC), considered to be located in a stationary position over the East-West center line of Spent Fuel Pool D having a lifting capacity of 3.000E+05 lb. The crane has four (4) wheels on each truck.

* The 3.500E+04 lb weight for the Spent Fuel Handling Machine (SFHM) which has a lifting capacity of 2.000E+03 lb. The SFHM has four (4) wheels and is considered to be located in stationary position on the East-West center-line of Spent Fuel C.

* The Auxiliary Crane is modeled at the same position as the SFHM with a dead weight of 6.000E+04 lb and a lifting capacity of 2.000E+04 lb. This crane has four (4) wheels.

The loads, calculated from the equipment lifting capacities, are multiplied by an impact factor of 1.25. The live loads used in the analysis are tabulated in Table 6 (see Enclosure 2).

Thermal Load - T_o, T_a

Two thermal loading conditions, normal operating (T_o) and accident (T_a), are evaluated.
The maximum normal bulk water temperature for partial discharge operating condition (T_o) in the Spent Fuel Pools C and D is considered to be 140 degrees F. During a loss-of-cooling accident, the pool water temperature (T_a) could reach the boiling point (212 °F). The temperature existing in all other rooms and adjacent areas is considered to be constant at 60 °F. The ambient temperature outside of the analyzed structures is considered to be 0 °F.

The temperatures on each side of the wall or slab are determined using a one-dimensional steady-state heat transfer. The results from the heat transfer analyses are then used as inputs in the numerical analysis of the concrete structure and are reported for both scenarios in Table 7 (see Enclosure 2).

Seismic Induced Loads - (E, E')

Two levels of seismic events were considered in the numerical analysis: the operating basis earthquake (OBE) and the safe shut down earthquake (SSE). The inertial loads generated for OBE and SSE are noted as E and E', respectively.

A. Structural Seismic Loads - (Es, Es')

Inertial loads of the reinforced structure are computed using the Response Spectrum method by considering a simultaneous application of the plant design basis three-dimensional acceleration spectra of the seismic event applied at the ground level.

B. Hydro-dynamic Loads - (Ew, Ew')

The impulsive and convective hydro-dynamic forces, which act on the surfaces of the reinforced concrete walls, develop as the pool water is accelerated by the horizontal components of the ground accelerations during a seismic event. The upper portion of the water mass exhibits sloshing motion during the seismic excitation. These pool water oscillation effects are modeled using a spring-mass system, developed in compliance with the guidelines established in TID 7024. The lower portion of the water acts as if it is a solid mass in rigid contact with the walls. The dynamic model of the water is shown in Figures 9 and 10 (see Enclosure 2). The vertical movement of the water mass, generated by the vertical component of the ground acceleration, also induces time dependent wall and floor pressures. This component of the hydro-dynamic load is conservatively modeled as an equivalent static pressure by multiplying the hydro-static water pressure by the value corresponding with the ZPA vertical spectral acceleration. The ZPA value is used because the vertical frequency of the pool floors is higher then 33.0 Hz.

All forces resulting from the water movement, due to the three-dimensional seismic acceleration are calculated for both OBE (Ew) and SSE (Ew') seismic events.

C. Rack Dynamic Load - (Er, Er')

In order to assess the effect of the motion of the submerged, fully loaded racks due to the seismic excitation of the pool concrete structure, the dynamic model that includes the concentrated nodal weights simulating the existence of the array of racks was used to compute the rack reactive forces acting on the pool floor. The fluid coupling maximum pressure acting on the wall surfaces is obtained from the rack dynamic analyses and applied as an uniformly distributed pressure. The rack to wall hydro-dynamic coupling pressures are listed in Table 8 (see Enclosure 2).

Load Combinations

The loads described in the above sections are grouped in thirteen (13) individual load cases and shown in Table 9 (see Enclosure 2). These various individual load cases are combined in accordance with the NUREG-0800 Standard Review Plan requirements with the intent to obtain the most critical stress fields for the investigated reinforced concrete structural elements. This process results in the following thirteen (13) load combinations. The load combination matrix is shown in Table 10 (see Enclosure 2). The load combinations for "Service Load Conditions" and "Factored Load Conditions" are provided in Enclosure 6, Section 8.4.3, of the December 23, 1998 submittal.

Response to Question 5(f)

The liner and the liner slab interface are not part of the global model of the spent fuel pool used for structural analysis. Liner evaluation is carried out in a separate analysis where the frictional loading from the rack pedestals (obtained from the rack dynamic analyses) is used as an input to a model of the liner. The in-plane stresses in the liner, induced by this loading, are computed and evaluated for their fatigue and liner buckling implications. The liner weld seams nearest to the highest loaded portion of the liner plate are evaluated for safety against rupture of the weld.

Response to Question 5(g)

In general, the acceptability of the reinforced concrete cross-section should be judged with reference to two important limit states: the strength ultimate load (usually the most important) and the service load. For both limit states, the reinforced concrete cross-section is well defined when the Axial Force-Bending Moment Interaction Diagram and the Shear Capacity is evaluated. For practical purposes, the diagram may be defined by four points (P_o - compression capacity, P_b and M_b - the balanced point, M_o - pure bending capacity and T_o - pure tension capacity) and a linear variation between them. In the present calculation, only the assessment of the strength ultimate load interaction diagram and shear capacity are determined in accordance with ACI-318-95.

The structural evaluation focused on the eight reinforced concrete walls and two slabs associated with Spent Fuel Pools C and D located in the north end of the Fuel Handling Building. The axial forces, bending moments and shear forces are computed using a 3-D finite-element model and the capabilities of STARDYNE computer code. The reinforced concrete cross-sectional capacities are evaluated and used to obtain the safety margins of the structural elements.

Tables 12 through 21 (Enclosure 2) contain the minimum safety factors obtained from the numerical investigation for each one of the eight walls and two slabs. Table 22 (Enclosure 2) summarizes the calculated safety factors.

Question 6

What is the maximum bulk pool temperature at a full core off-load during a refueling outage? If the temperature exceeds 150 °F, provide the following:

a) ACI Code 349 limits the concrete temperature to 150 °F for normal operation or any other long-term period. Provide technical justifications for exceeding 150 °F.

b) Describe the details of the SFP structural analysis including the material properties (i.e., modulus of elasticity, shear modulus, Poisson's ratio, yield stress and strain, ultimate stress and strain, compressive strength) used in the analysis for the reinforced concrete slab and walls, and liner plate, welds and anchorages in the analysis.

Response to Question 6

The maximum bulk pool temperature resulting from a full core offload during a refueling outage is limited to less than or equal to 137 °F, as stated in HNP FSAR Section 9.1.3.

Question 7

Discuss the quality assurance and inspection programs to preclude installation of any irregular or distorted racks, and to confirm the actual fuel rack gap configurations with respect to the gaps assumed in the DYNARACK analyses after installation of the racks.

Response to Question 7

Following rack construction, all racks cells are drag tested using a free path inspection gage (dummy fuel assembly) to ensure that fuel assemblies can be inserted into and withdrawn from the storage cells without damage. Any cells that do not pass this test are reworked and then re-tested until the cell passes.

Receipt inspection procedures ensure that each rack is in full compliance with the provisions of the December 23, 1998 submittal and Holtec International's 10CFR50 Appendix B program. Upon receipt, racks are first inspected for any damage potentially caused by the shipping or handling processes. The racks are also inspected for any scratches, dents, or signs of environmental exposure.

After the racks are set in the spent fuel pool, the rack gaps are checked at various locations along each side of the rack at the rack top. Long handled measuring tools and an underwater camera are used for this evolution. If the gaps are within the tolerances assumed in the analysis and allowed by the pool layout drawings, then the rack is acceptable. If the gaps are not acceptable, the rack is re-lifted and re-positioned.

Question 8

Describe the plan and procedure for the post operating basis earthquake inspection of fuel rack gaps and configurations.

Response to Question 8

Since the fuel racks are free standing structures, the inter-body spacings (rack gaps) after a seismic event may change from the as-installed values. HNP procedure AOP-021 (*Seismic Disturbances*) prescribes actions to be taken following a seismic event and includes general inspection guidelines for the Fuel Handling Building and facility areas. AOP-021 will be revised to require post-seismic event verification of rack gaps as required to ensure continued compliance with the plant licensing basis. If the gaps are found to be greater than or equal to 75% of the as-installed values, then the revised configuration will be accepted without further modification. If the gaps are found to be less than 75% of the as-installed values, then the racks

will either be re-evaluated to determine acceptability of the rack gaps and module layout configuration or the racks will be re-positioned to achieve the pre-seismic event gaps and configuration.

Question 9

Describe how the liner plates are attached to the channels embedded in the concrete slab.

Response to Question 9

As shown on HNP drawing 2168-G-117, Section AH (see Enclosure 2), the liner floor plate is attached to a 1-1/2" x 1-1/2" stainless steel backing bar utilizing a 3/16" full penetration groove weld. The backing bar is attached to the slab through the use of ½" diameter x 1-5/8" anchor studs. Additionally, the liner plate is attached to the edges of embedded plates as detailed on Section CU of enclosed HNP drawing 2168-G-117 also using a 3/16" full penetration groove weld. The only channel that is embedded in the concrete slab are those around the outer wall of the pools. The liner plate does not attach to these channels. The sole purpose of the channels is leak collection.

Question 10

Provide the locations of the leak chase systems with respect to the locations of the racks and pedestals.

Response to Question 10

As shown on HNP drawings 2168-G-118, -119, and -122 (see Enclosure 2), the leak chase system corresponds to the location of the liner seams. Enclosed Holtec rack layout drawings 1994 (for pool C) and 1993 (for pool D) show the leak chases and their location with respect to the rack pedestals. The bearing pad analysis is carried out assuming that a leak chase is located directly under the pedestal transmitting the largest vertical load to the liner. Average bearing pressures in the concrete are demonstrated to be below the allowables set forth in the ACI 318 Code.

Question 11

Describe the method of leak detection in the fuel pool structure. How are leaks monitored? Is there any existing leakage?

Response to Question 11

As shown on HNP drawing 2168-G-117, Section AK (see enclosure 2), the liner is attached to a backing bar with a full penetration groove weld. On each side of the backing bar, a filler material was poured with and then removed from the concrete to form a 1" x ¾" concrete channel. Also, a filler material was poured with and then removed from the concrete in the area behind the liner plate to form a 1/8" gap. The embedded channels as well as the floor backing bars have been divided into zones by the use of plates. These plates are welded to the embedded bars and channels such that the water would be directed toward a specific zone, and thus a leak in a specific area could be detected. The design of the leak detection is such that if a liner plate or seam began to leak, the water would flow behind the plate within the 1/8" gap. The water would then proceed over to the vertical seam, whereby it would fall down to the embedded channel located at the wall/floor intersection. A potential floor leak would run horizontal and drain into the embedded channel. The channels would then funnel any leakage to drain lines which are located on the 216' elevation of the Fuel Handling Building.

Leaks are monitored under site procedure OMM-016, Operator Logs, which delineates four leak detection zones. Each leak detection zone is checked on a monthly basis. The chart shown below is a graphical month-by-month illustration of fuel pool liner leakage for calendar year 1999 through the 10th of July.