Appendix A

TECHNICAL EVALUATION REPORT

EVALUATION OF SPENT FUEL RACKS STRUCTURAL ANALYSIS

FLORIDA POWER AND LIGHT COMPANY

ST. LUCIE GENERATING STATION UNIT 2

NRC DOCKET NO. 50-389 FRC PROJECT C5506

NRC TAC NO. 54463 FRC ASSIGNMENT 26

NRC CONTRACT NO. NRC-03-81-130 FRC TASK 528

Prepared by

Franklin Research Center
20th and Race Street
Philadelphia, PA 19103

FRC Group Leader: R. C. Herrick

Prepared for

Nuclear Regulatory Commission
Washington, D.C. 20555

Lead NRC Engineer: S. B. Kim

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ARVIN/CALSPAN
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Prepared by:	Reviewed by:	Approved by:
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Date: 9-19-1984	Date: 9-19-84	Date: 9-19-84

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FOREWORD

This Technical Evaluation Report was prepared by Franklin Research Center under a contract with the U.S. Nuclear Regulatory Commission (Office of Nuclear Reactor Regulation, Division of Operating Reactors) for technical assistance in support of NRC operating reactor licensing actions. The technical evaluation was conducted in accordance with criteria established by the NRC.

The following staff of the Franklin Research Center contributed to the technical preparation of this report: Maurice Darwish, R. Clyde Herrick, Vincent K. Luk, and Balar S. Dhillon (consultant).

1. INTRODUCTION

1.1 PURPOSE OF THE REVIEW

This technical evaluation report (TER) covers an independent review of the Florida Power and Light Company's licensing report [1] on high-density spent fuel racks for St. Lucie Generating Station Unit 2 with respect to the evaluation of the spent fuel racks' structural analyses, the fuel racks' design, and the pool's structural analysis. The objective of this review was to determine the structural adequacy of the Licensee's high-density spent fuel racks and spent fuel pool.

1.2 GENERIC BACKGROUND

Many licensees have entered into a program of introducing modified fuel racks to their spent fuel pools that will accept higher density loadings of spent fuel in order to provide additional storage capacity. However, before the higher density racks may be used, the licensees are required to submit rigorous analysis or experimental data verifying that the structural design of the fuel rack is adequate and that the spent fuel pool structure can accommodate the increased loads.

The analysis is complicated by the fact that the fuel racks are fully immersed in the spent fuel pool. During a seismic event, the water in the pool, as well as the rack structure, will be set in motion resulting in fluid-structure interaction. The hydrodynamic coupling between the fuel assemblies and the rack cells, as well as between adjacent racks, plays a significant role in affecting the dynamic behavior of the racks. In addition, the racks are free-standing. Since the racks are not anchored to the pool floor or the pool walls, the motion of the racks during a seismic event is governed by the static/dynamic friction between the rack's mounting feet and the pool floor, and by the hydrodynamic coupling to adjacent racks and the pool walls.

Accordingly, this report covers the review and evaluation of analyses submitted for the St. Lucie Generating Station Unit 2 by the Licensee, wherein the structural analysis of the spent fuel racks under seismic loadings is of primary concern due to the nonlinearity of gap elements and static/dynamic friction, as well as fluid-structure interaction. In addition to the evaluation of the dynamic structural analysis for seismic loadings, the design of the spent fuel racks and the analysis of the spent fuel pool structure under the increased fuel load are reviewed.

2. ACCEPTANCE CRITERIA

2.1 APPLICABLE CRITERIA

The criteria and guidelines used to determine the adequacy of the high-density spent fuel racks and pool structures are provided in the following documents:

- OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications, U.S. Nuclear Regulatory Commission, January 18, 1979 [2]

- Standard Review Plan, NUREG-0800, U.S. Nuclear Regulatory Commission

  Section 3.7, Seismic Design
  Section 3.8.4, Other Category I Structures
  Appendix D to Section 3.8.4, Technical Position on Spent Fuel Pool Racks
  Section 9.1, Fuel Storage and Handling

- ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers

  Section III, Subsection NF, Component Supports
  Subsection NB, Typical Design Rules

- Regulatory Guides, U.S. Nuclear Regulatory Commission

  1.29 - Seismic Design Classification

  1.60 - Design Response Spectra for Seismic Design of Nuclear Power Plants

  1.61 - Damping Values for Seismic Design of Nuclear Power Plants

  1.92 - Combining Modal Responses and Spatial Components in Seismic Response Analysis

  1.124 - Design Limits and Loading Combinations for Class 1 Linear-Type Component Types

- Other Industry Codes and Standards

  American National Standards Institute, N210-76

  American Society of Civil Engineers, Suggested Specification for Structures of Aluminum Alloys 6061-T6 and 6067-T6.

2.2 PRINCIPAL ACCEPTANCE CRITERIA

The principal acceptance criteria for the evaluation of the spent fuel racks' structural analysis for St. Lucie Unit 2 are set forth by the NRC's OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications (OT Position Paper) [2]. Section IV of the document describes the mechanical, material, and structural considerations for the fuel racks and their analysis.

The main safety function of the spent fuel pool and the fuel racks, as stated in that document, is "to maintain the spent fuel assemblies in a safe configuration through all environmental and abnormal loadings, such as earthquake, and impact due to spent fuel cask drop, drop of a spent fuel assembly, or drop of any other heavy object during routine spent fuel handling."

Specific applicable codes and standards are defined as follows:

> "Construction materials should conform to Section III, Subsection NF of the ASME* Code. All materials should be selected to be compatible with the fuel pool environment to minimize corrosion and galvanic effects.
>
> Design, fabrication, and installation of spent fuel racks of stainless steel materials 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. Once a code is chosen its provisions must be followed in entirety. When the AISC specification procedures are adopted, the yield stress values for stainless steel base metal may be obtained from the Section III of the ASME B&PV Code, and the design stresses defined in the AISC specifications as percentages of the yield stress may be used. Permissible stresses for stainless steel welds used in accordance with the AISC Code may be obtained from Table NF-3292.1-1 of ASME Section III Code."

Criteria for seismic and impact loads are provided by Section IV-3 of the OT Position Paper, which requires the following:

- o Seismic excitation along three orthogonal directions should be imposed simultaneously.

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* American Society of Mechanical Engineers Boiler and Pressure Vessel Codes, Latest Edition.

** American Institute of Steel Construction, Latest Edition.

- o The peak response from each direction should be combined by the square root of the sum of the squares. If response spectra are available for vertical and horizontal directions only, the same horizontal response spectra may be applied along the other horizontal direction.

- o Increased damping of fuel racks due to submergence in the spent fuel pool is not acceptable without applicable test data and/or detailed analytical results.

- o Local impact of a fuel assembly within a spent fuel rack cell should be considered.

Temperature gradients and mechanical load combinations are to be considered in accordance with Section IV-4 of the OT Position Paper.

The structural acceptance criteria are provided by Section IV-6 of the OT Position Paper. For sliding, tilting, and rack impact during seismic events, Section IV-6 of the OT Position Paper provides the following:

"For impact loading the ductility ratios utilized to absorb kinetic energy in the tensile, flexural, compressive, and shearing modes should be quantified. When considering the effects of seismic loads, factors of safety against gross sliding and overturning of racks and rack modules under all probable service conditions shall be in accordance with the Section 3.8.5.II-5 of the Standard Review Plan. This position on factors of safety against sliding and tilting need not be met provided any one of the following conditions is met:

(a) it can be shown by detailed nonlinear dynamic analyses that the amplitudes of sliding motion are minimal, and impact between adjacent rack modules or between a rack module and the pool walls is prevented provided that the factors of safety against tilting are within the values permitted by Section 3.8.5.II.5 of the Standard Review Plan

(b) it can be shown that any sliding and tilting motion will be contained within suitable geometric constraints such as thermal clearances, and that any impact due to the clearances is incorporated."

3. TECHNICAL REVIEW

3.1 SEISMIC ANALYSIS AND MATHEMATICAL MODELING OF SPENT FUEL RACK MODULES

The submerged spent fuel rack modules exhibit highly nonlinear structural behavior under seismic excitation. The sources of nonlinearity can generally be categorized by the following:

a. The impact between fuel assembly and fuel cell - Standing inside a fuel cell, the fuel assembly repeatedly impacts the four inside walls of the cell under earthquake loadings. These impacts are nonlinear in nature and when compounded with the hydrodynamic coupling effect will significantly affect the dynamic responses of the modules in seismic events.

b. Rack sliding on the pool liner - The modules are free-standing on the pool liner, i.e., they are neither anchored to the pool liner nor attached to the pool wall. Consequently, the modules are restrained horizontal by virtue of the frictional forces at the interface between the module base and the pool liner. The module will slide when these frictional forces are not large enough to overcome the horizontal seismic loads.

All fuel rack modules at St. Lucie Unit 2 have nearly square horizontal cross sections [1]. Modules of this design geometry generally behave in three-dimensional fashion under earthquake loadings. Hence, the modules will exhibit three-dimensional nonlinear structural behavior in seismic events, and all seismic analyses of modules should therefore focus on characterizing this behavior.

The layout of the spent fuel pool at St. Lucie Unit 2 is shown in Figure 1. The pool is divided into Regions I and II. Region I is the high-enrichment core off-load region. In Region I, the fuel assemblies are stored in every other location in a checkerboard configuration (see Figure 1). Cell blocking devices are inserted in the unused cavities to prevent inadvertent insertion of fuel into these locations. The modules in Region II are used to store irradiated fuel below specific reactivity levels. Cell blocking devices are placed in every fourth cavity in this region.

The Licensee performed the seismic analysis on the 8 x 11 module. Two finite element models were used to carry out the seismic analysis.

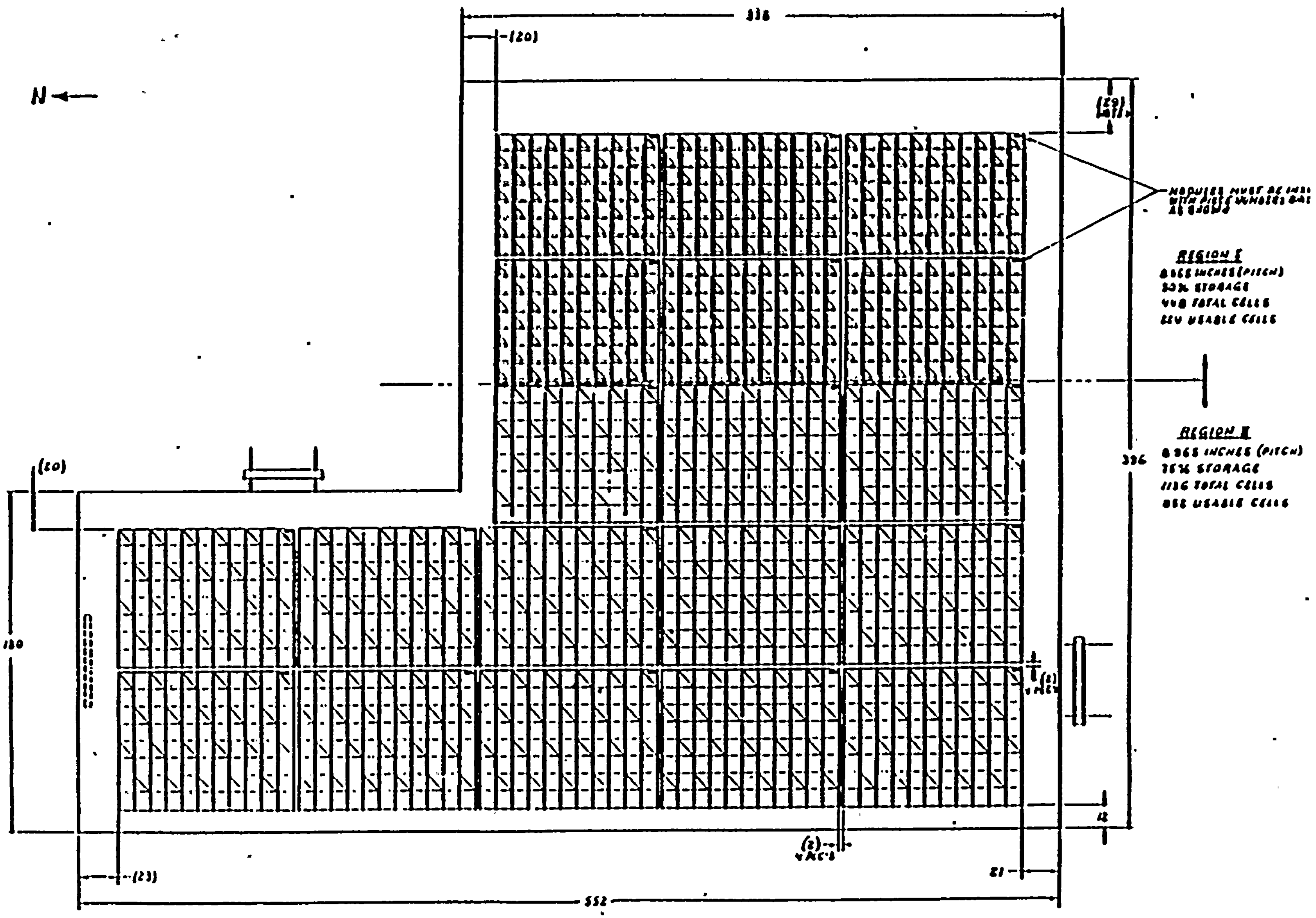

Figure 1. Spent Fuel Pool Layout

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The SAP IV model, a linear three-dimensional model of the module shown in Figure 2, served two purposes: (1) to generate the dynamic characteristics of the module structure in air and (2) to serve as a stress model to identify maximum stresses and their locations. The dynamic analyses (time history and response spectrum) of the module were conducted by the CESHOCK model which is a two-dimensional representation of an individual fuel cell shown in Figure 3. This is a nonlinear model with equivalent dynamic characteristics (natural frequencies and mode shapes) derived from the SAP IV model.

The seismic analysis was performed for both the OBE and the SSE conditions. The seismic loadings in terms of time history accelerations are different for the OBE and the SSE conditions as well as the north-south and the east-west directions. Linear response spectrum methods were used for the analysis in the vertical direction. The horizontal seismic responses of the modules were determined by nonlinear time history analyses. The structural damping value used in the seismic analysis was 4% for the SSE condition and 2% for the OBE condition.

The description and evaluation of the two models are addressed in detail in Sections 3.2 and 3.3. Section 3.4 focuses on discussion of the stress results and the procedure of their derivations.

3.2 EVALUATION OF THE SAP IV FINITE ELEMENT MODEL

3.2.1 Description of the Model

A linear three-dimensional model was developed to simulate the major structural characteristics of an unloaded module in air. The SAP IV computer code [3] was used to generate this model. The walls of fuel cells were simulated by plate elements and beam elements were used to represent the fuel support bars. A computer plot of the model is shown in Figure 2.

3.2.2 Dual Purposes of the Model

The SAP IV model served two purposes:

1. to determine the dynamic characteristics of an empty dry module. The natural frequencies and model shapes derived from this model were

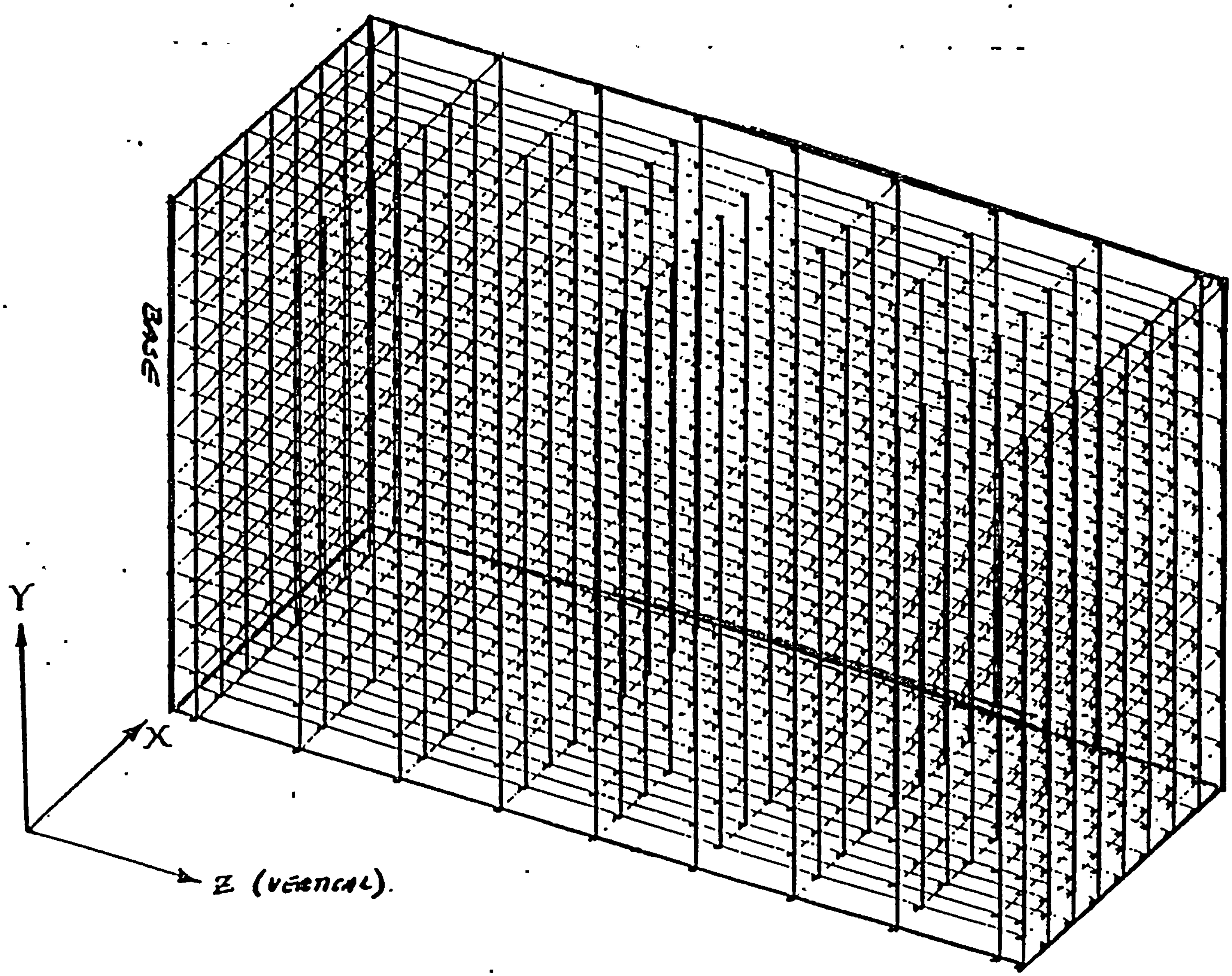

Figure 2. Plot of the SAP IV Finite Element Model

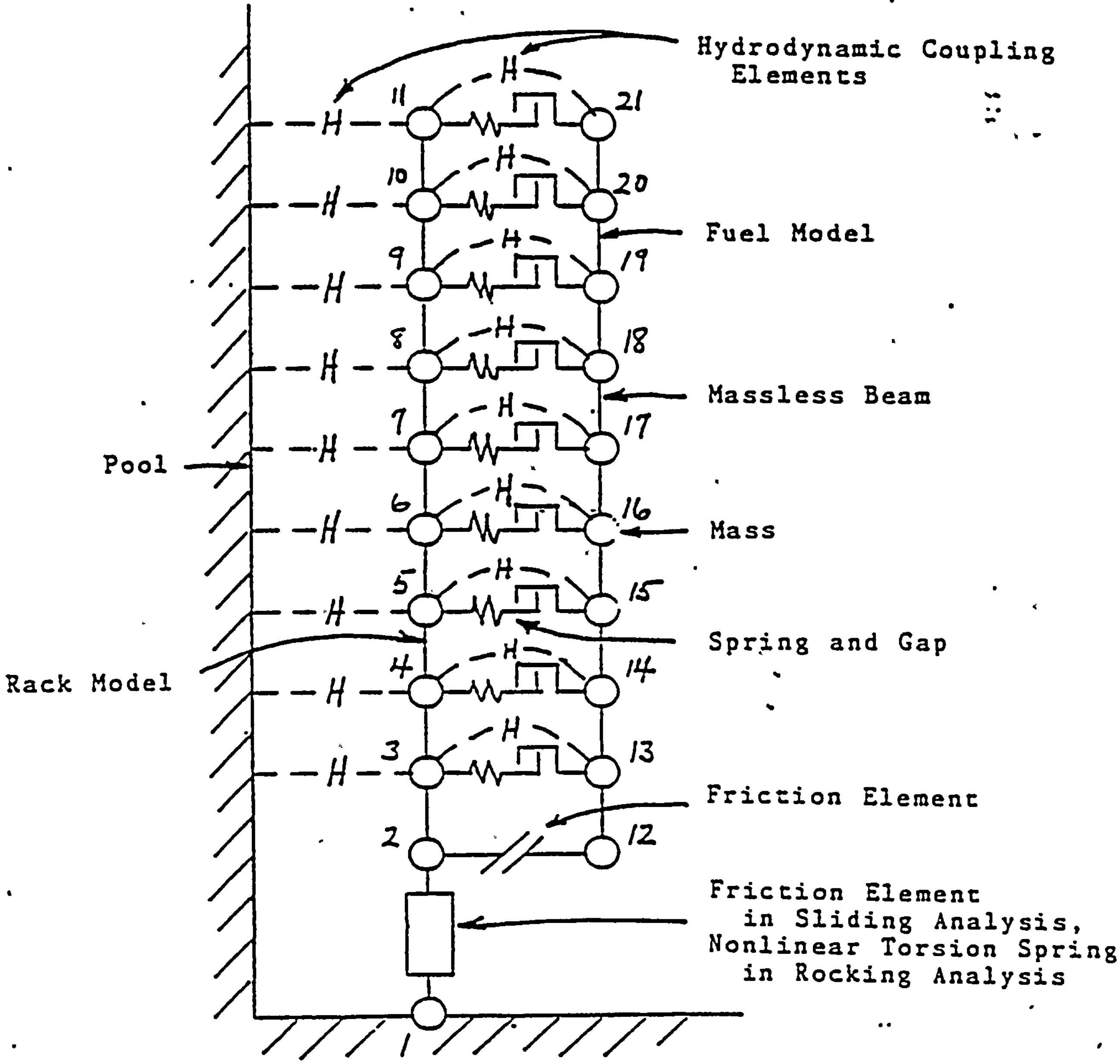

Figure 3. CESHOCK Model of an Individual Fuel Cell

incorporated into the CESHOCK model which was used to simulate a loaded fuel cell submerged in water.

2. to be used as a stress model to calculate the stress distribution on the module structure. The resulting loads from the CESHOCK model were incorporated into this model through the application of horizontal and vertical load factors which will be discussed in detail in Section 3.4.

3.3 EVALUATION OF THE CESHOCK MODEL

3.3.1 Description of the Model

A nonlinear two-dimensional model was developed to simulate the major structural characteristics of an individual fuel cell within a submerged rack assembly. The model was designed in accordance with the CESHOCK code [1]. The dynamic characteristics of the module in terms of natural frequencies and mode shapes derived from the SAP IV Model were incorporated into this model.

A schematic description of the CESHOCK model is shown in Figure 3. The masses of the fuel cells and fuel assemblies were discretized in the CESHOCK model [4]. The spent fuel pool was represented by node 1. Mass nodes 2 through 11 were used to represent the fuel cells. These mass nodes were linked by flexible elements. Similar arrangements were made to simulate the fuel assemblies by mass nodes 12 through 21. The hydrodynamic couplings between the fuel cells and fuel assemblies as well as the module and pool wall were designated by element H. Nonlinear gap-spring elements were used to represent the possibility of impacting between the fuel cells and fuel assemblies. A friction element coupled the base of the fuel assemblies to the module. The coupling element at the interface between the base of module and the pool liner represented a friction element in a sliding analysis and a nonlinear torsion spring in a rocking analysis. The possibility of the module lifting the pool liner was not included in this model because the Licensee claimed that its seismic analysis indicated no liftoff for a fully loaded module [5].

Separate CESHOCK models were developed for normal and consolidated fuel storage. Appropriate values for fuel assembly weight, beam stiffness, hydrodynamic coupling mases, gap, and impact spring stiffness were used in each case. Different models were also used for seismic loadings in the north-south and the east-west directions because the dynamic characteristics of the module structure are not the same in these directions.

Linear response spectrum methods were used for the vertical direction because the module structure is very stiff in this direction. In the horizontal directions, the module is much more flexible and exhibits nonlinear structural behavior due to impact between fuel cells and fuel assemblies and sliding at the interface between module base and pool liner. Therefore, nonlinear time history analyses were engaged to calculate the horizontal seismic responses of the module.

3.3.2 Assumptions Used in the Analysis

The following assumptions were used in the seismic analysis of the CESHOCK model:

a. A structural damping value of 4% was used for the SSE condition and 2% for the OBE event.

b. The value of fuel assembly damping used in the analysis is significantly less than that measured by test.

c. Each module was assumed to be 100% loaded with fuel assemblies, but actual loading was between 50 and 75% for normal storage.

d. Stresses were computed assuming that the module base was totally fixed to the pool liner and not allowed to slide.

e. Peak broadening was done in accordance with Reg. Guide 1.122.

f. Adjacent modules were assumed to vibrate in phase with each other.

3.3.3 Hydrodynamic Coupling Between Fluid and Module Structure

In the CESHOCK models, the hydrodynamic coupling was specified between the fuel cell and the fuel assembly, and between the module and the pool wall. A potential theory (incompressible invicid theory) was employed, using simple two-dimensional models of the structures coupled by the fluid, to estimate the hydrodynamic virtual mass terms based on the model configurations. The three-dimensional end effects were then accounted for by modifying the calculated hydrodynamic mass terms.

A finite element analysis, using the ADDMASS computer code (a Combustion Engineering proprietary code), was used to establish the hydrodynamic coupling elements. The ADDMASS code was based principally on the work presented in Reference 6.

3.3.4 Seismic Loading

The seismic input used for the analyses of the module consisted of the vertical response spectrum and the horizontal acceleration time histories corresponding to the pool liner elevation at St. Lucie Unit 2. At the meeting on August 16, 1984 at Combustion Engineering, Inc., the Licensee stated that there are distinct OBE and SSE horizontal acceleration time histories and the seismic loading is much more severe in the north-south direction.

3.3.5 Solution Stability and Integration Time Steps

The CESHOCK code numerically integrates the equations of motion using the Runge-Kutta-Gill technique [4]. The initial integration time step in the analysis, calculated by the CESHOCK code, was one-twentieth of the period of the highest individual mass-spring frequency in the model. During the computer execution of the analysis, the time step was continually checked and adjusted by the code as a function of the rate of change of the linear and the angular accelerations. The time step was held within the bounds of one-fifth to twice the initial time step. With this procedure for selecting the integration time step, the Licensee claimed that the seismic analysis produced a stable and converged solution [4], continuing a long history of stable solutions.

At a meeting, the Licensee stated [5] that the confidence in the solution of their analysis was based on approximately 15 years of experience at Combination Engineering using the CESHOCK code for the seismic analyses of spent fuel racks, reactor internals, fuel, and other complex nonlinear dynamic problems.

3.3.6 Friction at the Interface Between Module Base and Pool Liner

The friction at the interface between the module base and the pool liner was addressed in two ways. In the first approach, the module was not permitted to slide relative to the pool liner. In this case, the coefficient of friction was assumed extremely high to model the possibility of adhesion between the module base and the pool liner. This fixed-based model was used to provide conservative base shear loads for both the module and the pool liner.

In the second approach, a sliding-base model was used. In this model, a friction element which connected the module base to the pool liner was a slip-stick friction element with a velocity dependent coefficient of friction. A static coefficient of friction of 0.55 was used until the relative velocity of the module base with respect to the pool liner exceeded 2.5 in/sec, then the dynamic coefficient of friction of 0.28 became activated [4]. The friction values were based on the textbook, "Friction and Wear of Materials," by Ernest Rabinowicz, data from Combustion Engineering laboratory tests, and data obtained through a technical exchange agreement with Kraftwerk Union (KWU) of West Germany. The sliding-base models were used to determine the maximum relative sliding displacement between the module base and the pool liner.

3.3.7 Liftoff Analysis

The Licensee stated, based on the analysis results, that a fully loaded module did not lift off the pool liner for the conditions postulated, but liftoff could occur in the case of a partially loaded rack [5]. Detailed analysis performed by the Licensee indicated that loads resulting from the tipping and subsequent impact of a partially loaded module were bounded by the maximum loads of the fully loaded module.

3.3.8 Displacement Results

The Licensee performed a series of analyses to study the relative displacements between the module base and the pool liner. For the non-sliding cases, analyses were performed for the fully loaded, partially loaded, and empty modules. A fully loaded and an empty modules were also examined for the sliding case. The combined maximum relative displacement of 1.88 in was found in the non-sliding case when two adjacent modules, one partially loaded and the other empty, moved towards each other [5]. This is a rather conservative result because it was assumed that the two adjacent modules vibrated totally out of phase and their maximum tipping displacements occurred at the same time during the earthquake. The nominal inter-module gap is 2.0 in (see Figure 1), which is greater than the maximum displacement of 1.88 in. Hence, no impact between adjacent modules appears to be possible in a seismic event.

3.4 EVALUATION OF THE STRESS MODEL

3.4.1 Load Multiplication Factors

A one-G response spectrum load was applied in each of the three orthogonal directions to the three-dimensioned SAP IV stress model. The component stresses derived from this procedure were multiplied by load factors determined from the results of the CESHOCK model. The horizontal load factor is defined as the ratio of the maximum horizontal shear load derived from the CESHOCK model nonlinear time history analysis to the horizontal empty module load from the SAP IV model. Likewise, the vertical load factor is defined as the ratio of the maximum vertical load determined from the CESHOCK model response spectrum analysis to the vertical empty module load from the SAP IV module.

Typical load factors are tabulated as follows [5]:

Normal Storage	OBE	SSE
Maximum Horizontal	7.7	10.0
Maximum Vertical	12.0	13.2
Consolidated Storage		
Maximum Horizontal	5.7	10.5
Maximum Vertical	17.3	19.0

These load factors are seemingly high because they represent ratios of loads from fully loaded modules to those from empty ones. Typically, the ratio of a loaded cell weight to an empty cell weight is about a factor of 10 [5].

It must be noted that, although the Licensee employs load factors representing the transfer of vertical and horizontal base loadings from the two-dimensional CESHOCK nonlinear analysis to the linear three-dimensional stress analysis, no base moment load factor is employed. Thus, the analysis method presented by the Licensee is valid only for the cases where liftoff does not occur. Without the base moment load factor, the mounting foot impact loads and resulting impact moments cannot be transmitted to the stress model.

Since liftoff did not occur in the racks analyzed by the Licensee, the loadings and resulting stresses are acceptable.

3.4.2 Stress Results and Allowables

The component stress on each element resulting from the application of each directional load was combined by the square root of the sum of the squares method. The resulting stresses are compared below to the stress allowables in accordance with the rules of the ASME Boiler & Pressure Vessel Code, Section III, Subsection NF, Paragraphs 3220 and 3230 [4].

Maximum Stress Intensities Found in the Modules

	Design (psi)	Allowable (psi)	Margin of Safety (%)
Normal Operating Condition (OBE)			
Primary Membrane (Pm)	19,713	20,000	1.5
Primary Membrane and Bending (Pm & Pb)	29,670	30,000	1.1
Primary and Secondary (Pm & Pb & Pe)	45,020	60,000	33.3
Faulted Condition (SSE):			
Primary Membrane (Pm)	28,056	30,000	6.9
Primary Membrane and Bending (Pm & Pb)	33.262	45,000	35.3

Maximum Stresses Found in the Fuel Support Bars

	Design (psi)	Allowable (psi)	Margin of Safety (%)
Faulted Conditon (SSE):			
Bending Stress	4,930	33,000	569.4
Shear Stress	414	22,000	5214.0

The above stress results are all for the consolidated storage except the primary membrane and bending stress intensity during normal operating condition, which is for the normal storage.

The maximum stresses were found at the plate elements of the fuel cell wall at an elevation near the fuel lower end fitting and support bar interface [5]. The maximum stress points were clustered near the module/liner support points (see Figure 4).

The margin of safety for the worst case is as low as 1.1%. The Licensee stated that the analysis results are acceptable because of the conservative assumptions made in the analysis (see Subsection 3.3.2).

Although the analysis method is not satisfactory for general application where liftoff does occur because of the omission of a moment load factor applied to the stress model from the non-liner model, the review and evaluation indicated that the stress analysis is acceptable because liftoff does not occur in these cases.

Maximum stress intensities found in the canisters:

Normal Operation & OBE

P_m = 19,713 psi

$P_m + P_b$ = 29,670 psi

$P_m + P_b + P_e$ = 45,020 psi

Faulted:

P_m = 28,056 psi

$P_m + P_b$ = 33,262 psi

Bending Stress: Faulted = 4,9

Shear Stress: Faulted 414 psi

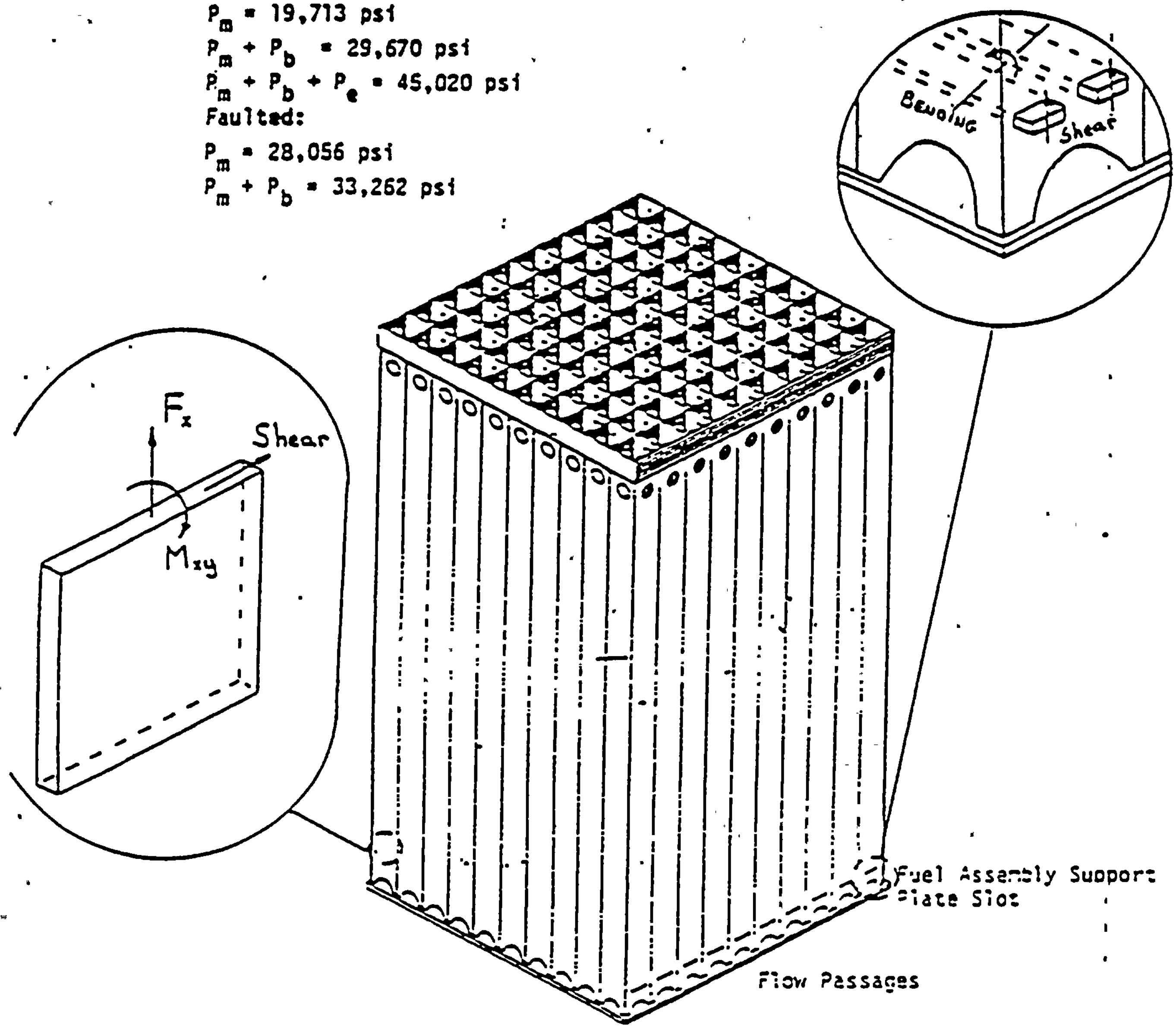

Figure 4. Maximum Stress Location in the Module

3.5 REVIEW OF SPENT FUEL POOL STRUCTURAL ANALYSIS

3.5.1 Spent Fuel Pool Floor Analysis

The spent fuel pool at St. Lucie Unit 2 is a reinforced concrete plate structure integrated with walls to the remainder of the fuel handling building. The spent fuel pool walls are lined with stainless steel. The Licensee presented an analysis to demonstrate the structural integrity of the spent fuel pool for the postulated loading conditions for the new high-density racks.

3.5.2 Analysis Procedure

The dynamic analysis of the fuel handling building was performed using lumped mass mathematical models. Separate models were used for seismic loadings in the vertical and the two horizontal directions. Detailed information on this dynamic analysis is contained in FSAR Section 3.7.2

The spent fuel pool structure was analyzed for loadings associated with the higher density fuel storage by a three-dimensional finite element model consisting of plate and rigid bar elements. The model was developed in accordance with the STARDYNE computer code. In the thermal analysis, the design temperatures inside and outside the building were input into the model. The thermal analysis was based on the uncracked sections and the resulting forces and moments were then reduced to represent the cracking of the section.

The increased fuel rack loads were specified in Section 4.3 of Reference 1. The analysis was performed for the loading combinations listed in FSAR Section 3.8.4.

3.5.3 Summary of Pool Floor Analysis Results

With respect to a question regarding the response amplifications under OBE, SSE, and rack impact loads, the Licensee provided the following:

> "Detail information on the dynamic analysis of the Fuel Handling Building is contained in FSAR Section 3.7.2. FSAR Tables 3.7-31 through 3.7-33 provides the structural responses of the building under a SSE event.

Attached Tables 1 and 2 provides the structural responses of the building under an OBE event.

The fuel rack impact loads on the fuel pool floor from the tipping of the fuel rack module are not significant compared to the total vertical seismic plus deadweight load used to evaluate local concrete stresses under the rack legs. The analysis has shown that the racks tip enough to transfer loads from four pads to two pads, but do not significantly lift from the floor."

In response to a question on the possibility of high localized stresses in the concrete beneath the rack legs caused by impact loading, the Licensee provided the following:

"The maximum ultimate vertical load (based on the loading in Section 4.3 of the Spent Fuel Rerack Safety Analysis Report) on one rack leg bearing pad is 294.3^K. The maximum bearing stress of 3.26ksi is less than the allowable bearing stress of 4.76ksi as specified in ACI 318-77 paragraph 10.16.12.

The fuel rack impact loads on the fuel pool floor from the tipping of the fuel rack module are not significant compared to the total vertical seismic plus deadweight load used to evaluate local concrete stresses under the rack legs. The analysis has shown that the racks tip enough to transfer loads from four pads to two pads, but do not significantly lift off from the floor."

With respect to the thermal analyses of the pool, the Licensee was questioned whether the analysis was based on cracked or uncracked sections. The Licensee responded as follows:

"In the thermal analysis of the FHB, a 3-dimensional finite element model of the building was constructed based on uncracked sections. Figure 4 (see response 1) is a portion of our 3-dimensional model. The design temperatures inside and outside the building were input into the finite element model. STARDYNE was used to perform the thermal analyses. The resulting forces/moments are reduced by the ration $\frac{lcr}{lunc}$ where lcr = cracked section and lunc = uncracked section. These design forces/moments are then used in various load combinations (see FSAR Section 3.8.4) in the design of the building. The reduction of the thermally induced forces/moments by the ratio $\frac{lcr}{lunc}$ was reviewed and found acceptable by the NRC during the July 1981 St. Lucie Unit 2 Structural Audit in connection with the Reactor Building Exterior Shield Wall design."

The review of the structural analysis indicated that the spent fuel pool was satisfactory under the increased mass of higher density fuel storage.

3.6 REVIEW OF THE SPENT FUEL POOL RERACK DESIGN

3.6.1 Cask Drop

In Section 5.3.1.1 [1], the Licensee stated that:

"The construction of the fuel handling building, the design of the cask handling crane and the travel limit switch interlock circuitry are such that the spent fuel cask cannot transverse over the spent fuel in the spent fuel pool."

It was concluded that, because the cask travel passage is not in the area of the spent fuel pool, therefore it is not possible to damage the fuel racks due to a cask drop accident.

3.6.2 Overhead Crane

As mentioned in 5.3.1.2 [1], no crane capable of carrying heavy loads can move into the area of the spent fuel pool. Also, the crane hook is prevented from approaching the spent fuel pool. Thus, in the event of a cask drop, where dropping is limited to a vertical orientation by the design of the cask yoke, the cask drops onto the walls separating the spent fuel pool and the cask storage pool. However, in this accident, the interior wall will fall back into the cask storage pool. It is concluded that there is no failure mode in which the cask will fall over the separating walls into the fuel pool.

3.6.3 Accidental Fuel Assembly Drop

In Section 5.3.1.1 [1], the Licensee stated that:

"The possibility of fuel handling accident is remote because of the interlocks and administrative controls and physical limitations imposed on the fuel loading operations.

Notwithstanding the above, the fuel handling accident is assumed to occur as a consequence of a failure of the fuel asembly lifitng mechanism resulting in the dropping of a raised fuel assembly onto the spent fuel pool."

In response to questions regarding the consequences of an accidental fuel drop through a cell of the spent fuel rack from a point 3 feet above the fuel rack, the Licensee provided the following:

"The fuel drop accident was evaluated to determine the effect of a dropped assembly on the functional and structural integrity of the racks. The analysis indicated that the impact of a fuel assembly on the support bars caused plastic deformation of the support bars and the fuel cell wall supporting the bars. For conservatism it was assumed that further displacement of the bars occurs, resulting in the fuel and support bars potentially resting on the pool floor. Neither functional nor structural integrity of the racks was impaired.

Impact on the fuel pool liner was not analyzed; however, a dummy fuel assembly was dropped during gaging of the St. Lucie 2 racks. This drop, which occurred in air as opposed to water, resulted in some deformation of the support bars, but did not impact the fuel pool liner. This supports the assumption that a dropped fuel assembly will deform the support structure but not result in impact to the fuel pool liner."

4. CONCLUSIONS

Based upon the review and evaluation, the following conclusions were reached:

- Although the methodology for nonlinear rack displacement analysis and linear rack stress analysis is not satisfactory for general rack stress analysis application where liftoff does occur, the stress analysis presented by the Licensee is, nevertheless, acceptable because the Licensee showed that liftoff did not occur.

- The structural analysis of the spent fuel pool structure was found to be acceptable and to indicate that the spent fuel pool is satisfactory for the higher density fuel loadings.

- Although an accidental drop of a fuel assembly from above the spent fuel rack and through the cell of the rack was found to damage only that cell of the rack, the Licensee stated that an actual drop of a dummy fuel assembly did not damage the liner of the spent fuel pool.

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