Oct. 16, 1984

Docket No. 50-389

Mr. J. W. Williams, Jr.
Vice President
Nuclear Energy Department
Florida Power & Light Company
P. O. Box 14000
Juno Beach, Florida 33408

Dear Mr. Williams:

The Commission has issued the enclosed Amendment No. 7 to Facility Operating License No. NPF-16 for the St. Lucie Plant, Unit No. 2. The amendment adds a license condition and changes the Technical Specifications in response to your application dated March 13, 1984.

The amendment revises the Technical Specifications and authorizes you to increase the storage capacity of the spent fuel pool from 675 to 1076 fuel assemblies.

On the basis of our review, it has been concluded that a license condition be added to preclude you from storing extended burnup fuel (greater than 38,000 Mw-days/Metric ton) in the modified pool until a new analysis is submitted and approved that addresses the potential for larger gap releases for the extended burnup fuel.

A copy of the related Safety Evaluation is also enclosed. The notice of issuance will be included in the Commission's next regular monthly Federal Register notice.

The Environmental Assessment related to this action was transmitted to you on . The Notice of Issuance of Environmental Assessment and Finding of No Significant Impact was published in the Federal Register on October 15, 1984 (49 FR 40234).

Sincerely,

/s/

Donald E. Sells, Project Manager
Operating Reactors Branch #3
Division of Licensing

Enclosures:
1. Amendment No. 7 to NPF-16
2. Safety Evaluation

cc w/enclosures
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Power Plant Siting Section
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County Administrator
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Clearinghouse
Office of Planning & Budget
Executive Office of the Governor
The Capitol Building
Tallahassee, Florida 32301

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

FLORIDA POWER & LIGHT COMPANY, ET AL.

DOCKET NO. 50-389

ST. LUCIE PLANT UNIT NO. 2

AMENDMENT TO FACILITY OPERATING LICENSE

Amendment No. 7
License No. NPF-16

1. The Nuclear Regulatory Commission (the Commission) has found that:

   A. The application for amendment by Florida Power & Light Company, et al., (the licensee) dated March 13, 1984, complies with the standards and requirements of the Atomic Energy Act of 1954, as amended (the Act) and the Commission's rules and regulations set forth in 10 CFR Chapter I;

   B. The facility will operate in conformity with the application, the provisions of the Act, and the rules and regulations of the Commission;

   C. There is reasonable assurance (i) that the activities authorized by this amendment can be conducted without endangering the health and safety of the public, and (ii) that such activities will be conducted in compliance with the Commission's regulations;

   D. The issuance of this amendment will not be inimical to the common defense and security or to the health and safety of the public; and

   E. The issuance of this amendment is in accordance with 10 CFR Part 51 of the Commission's regulations and all applicable requirements have been satisfied.

2. Accordingly, Facility Operating License No. NPF-16 is amended by changes to the Technical Specifications as indicated in the Attachment to this license amendment, by amending paragraph 2.C.2, and by adding a new paragraph 2.C.(19) to read as follows:

    2. Technical Specifications

    The Technical Specifications contained in Appendices A and B, as revised through Amendment No. 7 , are hereby incorporated in the license. The licensee shall operate the facility in accordance with the Technical Specifications.

    (19) Prior to storing extended burnup fuel in the modified spent fuel pool (greater than 38,000 Mw-days/Metric ton) the licensee must submit and obtain approval of a new analysis that addresses the potential of large gap releases for the extended burnup fuel.

3. This license amendment is effective as of the date of its issuance.

FOR THE NUCLEAR REGULATORY COMMISSION

James R. Miller, Chief
Operating Reactors Branch #3
Division of Licensing

Attachment:
Changes to the Technical
Specifications

Date of Issuance: October 16, 1984

ATTACHMENT TO LICENSE AMENDMENT NO. 7

FACILITY OPERATING LICENSE NO. NPR-16

DOCKET NO. 50-389

Remove and replace the following pages of the Appendix A Technical Specifications with the enclosed pages. The revised pages are identified by amendment number and contain vertical lines indicating the area of change. The corresponding overleaf pages are provided to maintain document completeness.

Remove	Insert
5-4	5-4
--	5-4a (new)

5.3 REACTOR CORE

FUEL ASSEMBLIES

5.3.1 The reactor core shall contain 217 fuel assemblies with each fuel assembly containing 236 fuel rods clad with Zircaloy-4. Each fuel rod shall have a nominal active fuel length of 136.7 inches and contain a maximum total weight of 1698.5 grams uranium. The initial core loading shall have a maximum enrichment of 2.73 weight percent U-235. Reload fuel shall be similar in physical design to the initial core loading and shall have a maximum enrichment of 3.70 weight percent U-235.

CONTROL ELEMENT ASSEMBLIES

5.3.2 The reactor core shall contain 83 full-length control element assemblies and no part-length control element assemblies.

5.4 REACTOR COOLANT SYSTEM

DESIGN PRESSURE AND TEMPERATURE

5.4.1 The Reactor Coolant System is designed and shall be maintained:

a. In accordance with the code requirements specified in Section 5.2 of the FSAR with allowance for normal degradation pursuant of the applicable Surveillance Requirements,

b. For a pressure of 2485 psig, and

c. For a temperature of 650°F, except for the pressurizer which is 700°F.

VOLUME

5.4.2 The total water and steam volume of the reactor coolant system is 10,931 ± 275 cubic feet at a nominal T_{avg} of 572°F.

5.5 METEOROLOGICAL TOWER LOCATION

5.5.1 The meteorological tower shall be located as shown on Figure 5.1-1.

5.6 FUEL STORAGE

CRITICALITY

5.6.1

a. The spent fuel storage racks are designed and shall be maintained with:

   1. A k_{eff} equivalent to less than or equal to 0.95 when flooded with unborated water, which includes a conservative allowance of 0.024 Δk_{eff} for Total Uncertainty.
   2. A nominal 8.96 inch center-to-center distance between fuel assemblies placed in the storage racks.
   3. A boron concentration greater than or equal to 1720 ppm.

   Region I can be used to store fuel which has a U-235 enrichment less than or equal to 4.5 weight percent. Region II can be used to store fuel which has achieved sufficient burnup such that storage in Region I is not required. The initial enrichment vs. burnup requirements of Figure 5.6-1 shall be met prior to storage of fuel assemblies in Region II.

b. The new fuel storage racks are designed for dry storage of unirradiated fuel assemblies having a U-235 enrichment less than or equal to 4.5 weight percent, while maintaining a k_{eff} of less than or equal to 0.98 under the most reactive condition.

DRAINAGE

5.6.2 The spent fuel storage pool is designed and shall be maintained to prevent inadvertent draining of the pool below elevation 56 feet.

CAPACITY

5.6.3 The spent fuel storage pool is designed and shall be maintained with a storage capacity limited to no more than 1076 fuel assemblies.

5.7 COMPONENT CYCLIC OR TRANSIENT LIMITS

5.7.1 The components identified in Table 5.7-1 are designed and shall be maintained within the cyclic or transient limits of Table 5.7-1.

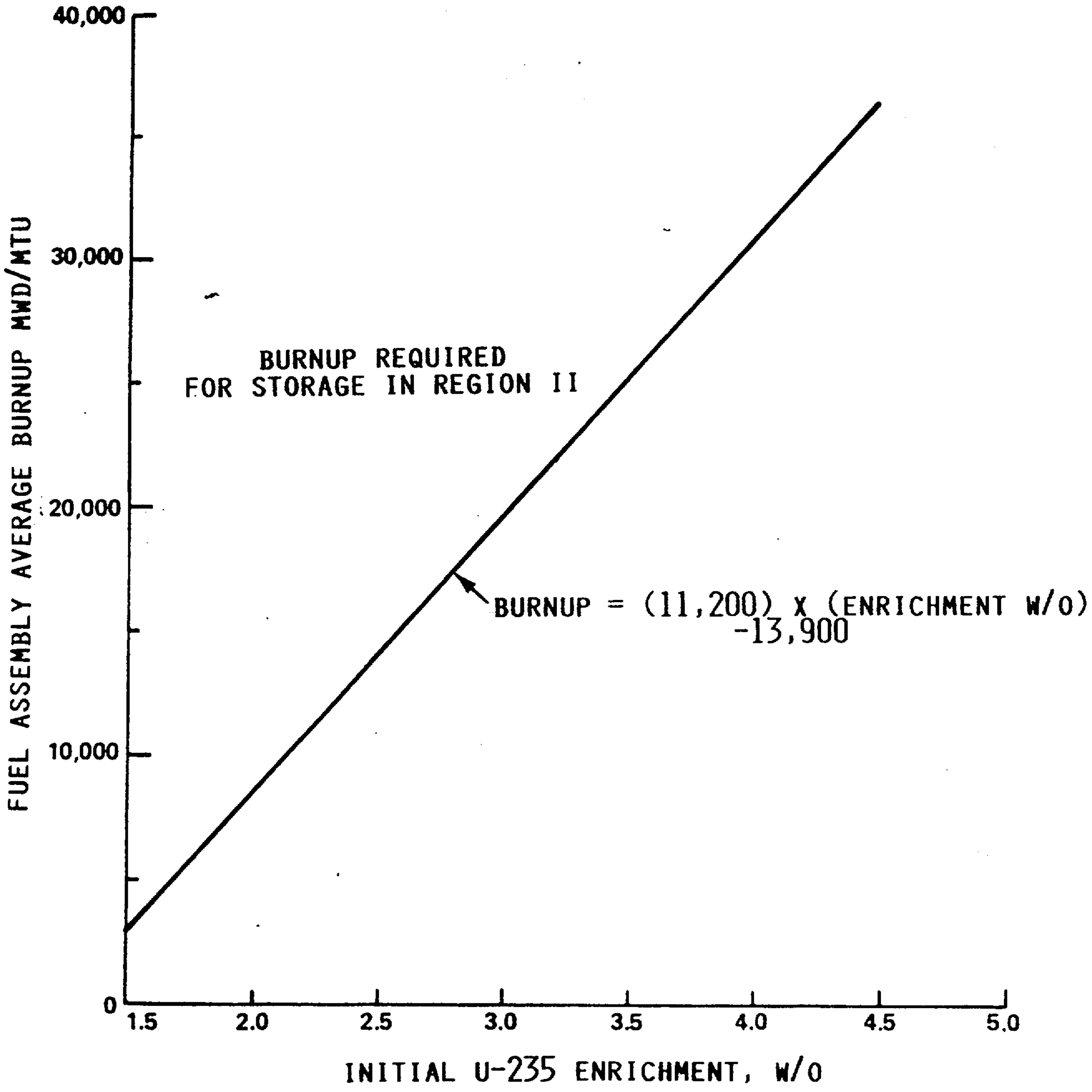

FIGURE 5.6-1

INITIAL ENRICHMENT VS
BURNUP REQUIREMENTS FOR STORAGE OF
FUEL ASSEMBLIES IN REGION II

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

SUPPORTING AMENDMENT NO. 7

TO FACILITY OPERATING LICENSE NO. NPF-16

FLORIDA POWER AND LIGHT COMPANY, ET AL.

ST. LUCIE PLANT, UNIT NO. 2

DOCKET NO. 50-389

1.0 INTRODUCTION

By letter dated March 13, 1984, Florida Power and Light Company (FP&L) submitted an application to increase the storage capacity of the spent fuel pool (SFP) by replacing the existing racks with new storage racks. By letter dated August 29, 1984, FP&L provided additional clarification in response to the NRC staff's requests. This is the first rerack for St. Lucie Plant, Unit No. 2.

The proposed amendment would authorize the licensee to increase the current capacity by installing high density racks to bring the capacity up to 1076 cells. With the 300 presently available cells, St. Lucie 2 would lose the full core reserve storage capability after the second refueling in 1986. With 675 cells, allowed by the current license, the reserve storage capability would be lost in 1992. The new spent fuel storage racks would have a usable storage capacity of 1076 cells, extending the full core reserve storage capability until 1998 when a federal depository should be available for spent fuel [Nuclear Waste Policy Act of 1982, Section 302(a)(5)].

2.0 DISCUSSION AND EVALUATION

2.1 Criticality Considerations

Florida Power and Light Company (FP&L) has requested approval to modify the spent fuel storage racks at St. Lucie 2. At present, there is one spent fuel pool at St. Lucie 2 with existing racks that have a capacity of 300 storage cells. FP&L contracted with Combustion Engineering (CE) for new spent fuel storage racks that allow for more dense storage of spent fuel. These new racks will replace the existing racks and have a usable storage capacity of 1076 cells. CE is responsible for the design and fabrication of the new spent fuel storage racks and providing engineering assistance in reviewing the spent fuel pool cooling system. Ebasco Services, Inc. is responsible for reviewing building structural analysis and accident evaluation.

Region I of the two region spent fuel pool contains four 7x11 modules and two 7x10 modules. However, in order to achieve a sufficient center-to-center spacing between fuel assemblies, only one-half of these cells (224) will be available for fuel assembly storage. The remaining unused cells will contain blocking devices to preclude fuel assembly storage. Region I will, therefore, be a checkerboard configuration. Fuel similar to the CE 14x14 or 16x16 design with U-235 enrichments up to 4.5 weight percent may be stored in Region I.

Region II contains one 8x19 module and twelve 8x11 modules. Fuel is stored in three out of four locations with cell blocking devices in each unused cell. Therefore, 852 cells will be available for storage. Region II is used to store fuel that has experienced sufficient burnup such that storage in Region I is not required.

2.1.1 Analysis Methods

The criticality aspects of the storage of the CE design fuel from St. Lucie Unit 2 in the spent fuel storage pool are analyzed using the DOT-2W two-dimensional discrete ordinates transport theory code with s_n order 6 for reactivity determination. Four energy-group neutron cross sections are calculated by the CEPAK lattice code with correction factors to account for heterogeneous lattice effects calculated by the NUTEST two-dimensional integral transport theory code.

FP&L has provided qualification of the CE calculation model and methods used in spent fuel storage rack analyses. Based on the results of a series of UO_2 critical experiments, a calculational uncertainty of 0.00714 at the 95/95 confidence level and a calculational bias of +.00138 were obtained. In addition, calculations were performed to evaluate the effects of mechanical tolerances, off-center placement of fuel assemblies, and temperature changes on the rack reactivity. These uncertainties, which are at least 95/95 confidence level, result in a value of 0.0184 for Region I and 0.0115 for Region II when combined statistically. The overall uncertainties are, therefore, 0.024 and 0.017 for Regions I and II, respectively.

Section 4.3 of the St. Lucie 2 FSAR illustrates the good agreement obtained between measured plutonium isotopic concentrations and values predicted with CEPAK.

2.1.2 Spent Fuel Storage Rack Analysis

The spent fuel racks have a nominal center-to-center spacing between adjacent storage cells of 8.965 inches and a nominal stainless steel wall thickness of 0.135 inches. The design analysis assumed a nominal pool temperature of 98.6°F and the storage cell arrays were assumed to be infinite in lateral extent and in length.

The calculated multiplication factor (K_{eff}) for the Region I checkerboard configuration is 0.942 including the previously mentioned uncertainties and calculational biases. An enrichment of 4.5 weight percent U-235 was assumed for Region I.

For Region II, a family of curves of k_{eff} versus burnup for a range of enrichments is generated. These resulting values of k_{eff} include the calculational uncertainties and biases (net value of +0.0172 in k_{eff}) previously described. The curves are then used to define the minimum burnup for fuel of a given initial enrichment which will result in a k_{eff} of 0.95 when Region II is fully loaded with fuel assemblies of this type. These burnup/enrichment data points are then used to plot the curve of burnup versus initial fuel enrichment to be included in the St. Lucie 2 Technical Specifications. Since these calculations assumed an assembly average burnup, a burnup bias of 1900 MWD/MTU was applied to the figure to conservatively account for the most adverse axial burnup distribution.

2.1.3 Abnormal and Accident Conditions

Postulated accidents such as the dropping of a fuel assembly on top of the racks, dropping of other objects into the spent fuel pool, deformation and relative position of racks due to tornado or earthquake, and loss of one spent fuel pool cooling pump were considered and do not violate our acceptance criterion of 0.95. For these accidents, the assumption is made that it is not necessary to assume concurrently two unlikely independent events to ensure protection against a criticality accident (double contingency principle). Therefore, the assumption of the minimum boron concentration in the spent fuel pool required by the Technical Specifications (1720 ppm) ensures that k_{eff} is no greater than 0.95 for these accidents.

2.1.4 Conclusions

The staff concludes that the proposed storage racks meet the requirements of General Design Criterion 62 as regards criticality. This conclusion is based on the following considerations:

1. Acceptable calculation methods that have been verified by comparison with experiment have been used.
2. Conservative assumptions have been made about the enrichment of the fuel to be stored and the pool conditions.
3. Credible accidents have been considered.
4. Suitable uncertainties have been considered in arriving at the final value of the multiplication factor.
5. The final effective multiplication factor value meets our acceptance criterion.

The staff has also concluded that the modifications to the St. Lucie 2 Technical Specifications are acceptable to allow operation with the proposed expansion of spent fuel pool storage capacity.

2.2 SPENT FUEL POOL COOLING AND MAKEUP

The increase in the total decay heat load resulting from the expansion will amount to only a few percent of the total heat load due to the longer decay times of the oldest fuel assemblies. The licensee therefore concluded that the existing spent fuel cooling capability could adequately remove the additional decay heat without exceeding the pool water temperature presented in Standard Review Plan Section 9.1.3. Information was also provided to demonstrate that the available source of makeup water provides adequate assurance that the fuel would not become uncovered in the event all pool cooling was lost.

2.2.1 Spent Fuel Storage Pool

The St. Lucie 2 spent fuel facility is housed in the Fuel Handling Building adjacent to the reactor Containment Building. It consists of the storage pool, the spent fuel cask loading pit and the transfer canal. These three areas within the Fuel Handling Building are connected by waterproof gates that are normally closed except at those times when radioactive material is moved from one area to another, e.g., during refueling of the reactor and loading the spent fuel shipping cask. The storage pool is L-shaped with the longest dimensions, 33' x 46', and contains water to a depth of 38'-6". The storage pool, canal and pit are lined with stainless steel liner plates. A leak detection system is provided on the concrete side of the liner to detect and collect any pool water that leaks through the liner plate welds. The 23 feet of water above the top of the spent fuel assemblies acts as a transparent shielding and cooling medium.

2.2.2 Decay Heat Loads

The licensee's calculated spent fuel discharge heat load to the pool, which was determined in accordance with the Branch Technical Position ASB 9-2, "Residual Decay Energy for Light Water Reactors for Long Term Cooling", and the Standard Review Plan Section 9.1.3, "Spent Fuel Pool Cooling and Cleanup System", indicates that the expected maximum normal heat load following the last refueling is 16.9 MBTU/Hr. This heat load results in a maximum bulk pool temperature of less than 137°F. The expected maximum abnormal heat load following a full core discharge is 31.7 MBTU/Hr. This abnormal heat load results in a maximum bulk pool temperature of less than 150°F with both cooling trains operating. Assuming the loss of all cooling, boiling would occur after 9.0 hours for the normal heat load condition and after 2.9 hours for the maximum heat load condition. This results in a boil off rate of 35.6 and 66.3 gpm, respectively. This provides reasonable time to initiate makeup to the spent fuel pool.

2.2.3 Spent Fuel Pool Cooling System

The cooling portion of the Fuel Pool System is a closed loop system consisting of two half-capacity fuel pool pumps and two full-capacity fuel pool heat exchangers, where the full capacity condition corresponds to the design condition of a full core placed in the spent fuel pool seven days after reactor shutdown, in addition to the decay heat from seven previous annual batches, the most recent of which has been cooling for 90 days. The fuel pool water is drawn from the fuel pool near the surface as required and is circulated by fuel pool pumps through one of the fuel pool heat exchangers where heat is rejected to the Component Cooling Water System. From the outlet of the fuel pool heat exchanger, the cooled fuel pool water is returned to the bottom of the fuel pool via a distribution header. This spray header allows for overall pool circulation. The cooling system is controlled manually from a local control panel. Control room alarms for high fuel pool temperature, high and low water level in the fuel pool, low fuel pool pump discharge pressure, overload of fuel pool cooling and fuel pool purification pump motors and high radiation in the fuel pool area are provided to alert the operator to abnormal circumstances.

The major chemical concerns for the fuel pool are boron reactivity worth, radioactivity, and optical clarity. Proper boron reactivity worth is maintained by adding water to the pool at the prescribed refueling concentration. Soluble and insoluble radioactivity in the water is controlled by the fuel pool purification circuit while gaseous and airborne radioactivity is controlled by area ventilation systems. The purification system is normally run on an intermittent basis as required to maintain the fuel pool water purity and clarity permitting underwater operations for discharge of spent fuel, bundle inspection and visual observation for these planned maneuvers. Crud carried into the pool on spent fuel usually settles to the bottom of the pool and can be removed by the pool purification loop, or via special underwater vacuum cleaning equipment connected to an external filter. With the exception of that time after fuel bundle movement when crud is sloughed off and clouds the water, optical clarity is maintained through purification system operation.

Various samples are taken periodically from local sample points off the purification loop (fuel pool filter inlet, filter outlet/fuel pool ion exchanger inlet and the ion exchanger outlet) to meet the chemistry objectives. Wet chemistry techniques are used to analyze key parameters. These parameters include pH, ammonia and lithium for monitoring proper system operating condition and for minimizing corrosion, boron for maintaining proper boron reactivity worth and chloride and fluoride for monitoring ion exchanger performance.

2.2.4 Storage Racks

The spent fuel storage racks are fabricated with 304 stainless steel having a maximum carbon content of 0.065%. The racks are monolithic honeycomb structures with square fuel storage locations. Each storage location is formed by welding stainless steel sections along the intersecting seams, permitting the assembled cavities to become the load bearing structure, as well as framing the storage cell enclosures. Each module is free standing and seismically qualified without mechanical dependence on neighboring modules or pool walls. This feature enables remote installation (or removal if required for pool maintenance) with minimal effort. Reinforcing plates at the upper peripheral edges provide the required strength for handling.

Stainless steel bars, which are inserted horizontally through the rectangular slots in the lower region of the module, support the fuel assemblies. These support bars, when welded in place, support an entire row of fuel assemblies. Semicircular passages at the bottom of every cell wall allow cooling water to flow to all cells. The size of the openings precludes blockage by any crud accumulations.

Loading of the fuel racks is facilitated via a movable lead-in funnel assembly containing four lead-in devices. The openings of the funnel assembly are symmetrical and the assembly sits on top of the rack module.

The module wall thickness is 0.135 inch 304 stainless steel. The L-inserts are 0.188 inches thick. L-inserts are used only in Region I and cell blocks are used in both Regions I and II. The cell blocks for Region II are removable and are similar to those for Region I. The nominal pitch of the spent fuel racks is uniform throughout the 19 modules to be contained in the spent fuel pool. This pitch is 8.96 inches center-to-center in both horizontal directions.

Region I is located within 6 modules and comprises a total of 448 cells. Region I is the high-enrichment, core off-load region. The fuel assemblies are to be stored in every other location in a checkerboard configuration. The checkerboard arrangement mades 50% of the Region I storage capacity initially avialable for storage of fuel with high fissile concentrations. The unused cells are fitted with cell blocking devices to prevent inadvertent insertion of fuel into these locations.

Region I is designed for a total of 224 usable cells for enrichments up to and including 4.5 w/o U-235. The cells in Region I contain an L-insert. The L-shaped stainless inserts lock into the storage cell using a spring locking mechanism on the upper end. This locking mechanism snaps into one of the holes in the four surrounding cell walls. These L-shaped 304 stainless inserts are neutron absorbers.

Region II consists of a total of 1136 cells. Within Region II, fuel assemblies are stored in 75% of the total cells for an initial available storage capacity of 852 cells. Cell blocking devices are used to preclude placement of fuel assemblies into every fourth cell, which remains empty and provides a flux trap for reactivity control.

The spent fuel racks have been designed for direct bearing onto the spent fuel pool floor. A 10" support plate under the peripheral cells provides the bearing surface for the racks. Fuel rack module leveling is accomplished by placing 10" square stainless steel shims between the support plates and the fuel pool liner.

2.2.5 Makeup Water

Redundant spent fuel pool water level and temperature devices alarm in the control room should a loss of fuel pool cooling occur. Two permanent fuel pool inventory makeup systems are provided. The fuel pool purification pump draws water from the refueling water tank (RWT) at a flow capacity of 150 gpm. In addition, the primary water pumps, with suction from the primary water tanks, provide makeup to the fuel pool at 100 gpm. These makeup systems are designed as non-safety-related and designated nonseismic. In addition to these permanent makeup systems, water inventory sources (e.g. city water storage tank, condensate storage tank, demineralized water tank, Steam Generator Blowdown System Monitor Tanks and St. Lucie Unit 1 primary water storage and refueling water storage tanks), in excess of three million gallons are available onsite which could be utilized for fuel pool makeup. These additional water sources could supply fuel pool makeup for more than 40 days at the maximum water boil-off rate without any makeup to these sources.

A seismic Category I backup system is also available for fuel pool makeup. A hose connection is provided on each seismic intake cooling water header. A seismic standpipe is provided in the Fuel Handling Building from grade to the operating deck elevation. The Intake Cooling Water System via the hose connections can provide flow in excess of 61.6 gpm for an indefinite period of time.

The seismic standpipe backup system would introduce salt water to the fuel pool. The salt water does not affect the integrity of the spent fuel pool leakage barrier. The rate of corrosion of the stainless steel liner is dependent on the oxygen content of the water. At boiling temperatures, the oxygen content of water is extremely low thereby greatly reducing the stress corrosion.

Sea water does not result in unacceptable corrosion of the Zircaloy-4 fuel cladding or structural components. It is unlikely that any localized corrosion cracking can result in a loss of structural integrity of these components. Should sea water be introduced to the fuel pool, fuel elements would be inspected.

2.2.6 Conclusions

Based the staff review of the proposed spent fuel pool expansion program for St. Lucie 2, the staff concludes the following:

1. The calculated maximum normal and abnormal heat loads have been properly determined and are acceptable.

2. The existing spent fuel pool cooling capability can maintain the fuel pool water temperature for the maximum normal and abnormal heat loads within the limits indicated in the criteria of SRP Section 9.1.3.

3. The design for the new storage racks provides adequate flow paths permitting sufficient flow for fuel cooling to preclude local boiling.

Therefore, the proposed spent fuel pool expansion is acceptable.

2.3 INSTALLATION OF RACKS AND LOAD HANDLING

There is no spent fuel in the St. Lucie 2 spent fuel pool at the present time. Therefore, no special administrative controls or procedures will be necessary to provide radiation protection. Standard construction techniques and procedures will be utilizied during installation to ensure worker safety and compliance with guidelines from the manufacturer.

Based on the above, the staff concludes that the installation of the new racks will be accomplished with reasonable assurance that a load drop accident will not occur and, therefore, the installation of the new racks is acceptable in this regard.

2.4 STRUCTURAL DESIGN

The structural aspects of the proposed modification are based on a review performed by the staff's consultant, Franklin Research Center (FRC). The FRC Technical Evaluation Report TER-C5506-528 is appended to this Safety Evaluation as an appendix.

2.4.1 Description of the Spent Fuel Pool and Racks

The high density rack modules for long term fuel storage are located in the spent fuel pool of the Fuel Handling Building. The spent fuel pool is a steel lined reinforced concrete tank structure that provides space for spent fuel racks and the storage of spent fuel.

The spent fuel racks are fabricated from 304 stainless steel that is 0.135 inches thick. Each cell is formed by welding along the intersecting seams which enables the assembled cells to become a free-standing module that is seismically qualified without depending on neighboring modules or the fuel pool walls for support.

2.4.2 Applicable Codes, Standards and Specifications

Load combinations and acceptance criteria were compared with those found in the "Staff Position for Review and Acceptance of Spent Fuel Storage and Handling Applications" dated April 14, 1978, and amended January 18, 1979. The existing concrete pool structure was evaluated for the new loads in accordance with the requirements of NUREG-0800, Standard Review Plan Section 3.8.4 and the St. Lucie 2 FSAR.

2.4.3 Loads and Load Combinations

Loads and load combinations for the racks and the pool structure were reviewed and found to be in agreement with the applicable portions of the NRC position and the SRP.

2.4.4 Seismic Loads

Seismic loads for the rack design are based on the original design floor acceleration response spectra calculated for the plant at the licensing stage. The seismic loads were applied to the model in all three orthogonal directions. Damping values for the seismic analysis for the racks were taken as 2 percent for OBE and 4 percent for SSE. Rack/fuel bundle interactions were considered in the structural analysis.

2.4.5 Design and Analysis Procedures

a. Design and Analysis of the Racks

A non-linear time-history analysis of the rack module model was performed. The model included mass, spring, damping, and gap elements and accounts for sliding, tipping and potential rack-to-rack interaction in order to determine stresses and strains within the racks. A three dimensional finite element model was used to determine a final stress in the rack modules. This finite element model was also used to generate an equivalent stiffness for the simplified two dimensional non-linear dynamic model.

Calculated stresses for the rack components were found to be well within allowable limits. The racks were found to have adequate margins against tipping and impacting. An analysis was conducted to assess the potential effects of a dropped fuel assembly on the racks and results were considered satisfactory.

An analysis was conducted to assess the potential effects of a stuck fuel assembly causing an uplift load on the racks and a corresponding downward load on the lifting device as well as a tension in the fuel assembly. Resulting stresses were found to be within acceptance limits.

b. Analysis of the Pool Structure

The St. Lucie 2 fuel pool is a reinforced concrete structure. The slab, beams and walls are reinforced to meet all FSAR criteria. The existing structures were analyzed for the modified fuel rack seismic loads using a conventional lumped mass mathematical model. A finite element model was used to calculate final stresses. Original plant response spectra and damping values were used in consideration of the seismic loadings. Design criteria, including loading combinations and allowable stresses, are in compliance with St. Lucie 2 FSAR Section 3.8.4. Consequently, the existing spent fuel pool structure has been determined to safely support the loads generated by the new fuel racks.

2.4.6 Conclusion

Based on the above, the staff concludes that the proposed rack installation will satisfy the requirements of 10 CFR Part 50, Appendix A (GDC 2, 4, 61 and 62), as applicable to structures.

2.5 MATERIALS

The proposed spent fuel storage racks are fabricated of Type 304 stainless steel with a maximum carbon content of 0.065%, which is used for all structural components. Each fuel assembly is stored in an individual cell of square cross section, designed to accommodate storing both the 14x14 design fuel from St. Lucie 1 and the 16x16 fuel from St. Lucie 2. Criticality is controlled by three methods used together: stainless steel cell blocks prevent fuel element storage in one half of the cells in Region I and one fourth of the cells in Region II, limiting the initial capacity of the racks to 1076 fuel assemblies; "L" inserts of stainless steel are inserted into each cell in Region I to provide additional neutron absorption; and a technical specification amendment is proposed requiring a minimum of 1720 ppm boron as boric acid must be present in the spent fuel pool water. Fuel assemblies with low burnup can be stored only in Region I.

The licensee has stated that the new storage racks will be fabricated in accordance with NRC regulations and regulatory guides for materials and quality assurance, the ASME Boiler and Pressure Vessel Code Section III - NP, and ASTM and ANSI standards.

2.5.1 Evaluation

The modified spent fuel pool storage racks will be fabricated of materials possessing good compatibility with the borated water chemistry of the spent fuel pool. The corrosion rate of Type 304 stainless steel in this water is low and unmeasurable. No instances of corrosion of this material in spent fuel pools containing boric acid have been observed (Ref. 1). The Technical Specification requirement for a minimum of 1720 ppm boron as boric acid does not affect the compatibility of the materials with the environment, since a normal boron concentration of 2000 ppm as boric acid is used in many spent fuel pools at pressurized water reactor sites (Ref. 1). The Codes and Standards used in fabricating and inspecting the proposed new fuel storage racks should ensure their integrity and minimize the likelihood that any stress corrosion cracking will occur during service.

2.5.2 Conclusion

Based on the above, the staff concludes that the corrosion that will occur in the modified spent fuel pool will be of little significance during the remaining life of the unit. Components of the spent fuel storage pool are constructed of alloys that are known to have a low galvanic differential potential and that have performed well in spent fuel pools at other pressurized water reactor sites where the water chemistry is maintained at comparable standards. The staff finds that no significant corrosion should occur in the proposed spent fuel storage racks for a period well in excess of the design life of the facility. Further, since there is no significant change in either the materials or water chemistry associated with this reracking amendment, the conclusions in the original SER are not changed by it.

Therefore, the staff concludes that the compatibility of the materials and coolant used in the spent fuel storage pool is adequate based on tests, data, and actual service experience in operating reactors and that the selection of appropriate materials by the licensee meets the requirements of 10 CFR Part 50, Appendix A, Criterion 62, because of the capability to prevent criticality by maintaining structural integrity of components, and is acceptable.

2.5.3 References

1. J. R. Weeks, "Corrosion of Materials in Spent Fuel Storage Pools," BNL-NUREG-23021, July 1977.

2.6 SPENT FUEL POOL CLEANUP SYSTEM

The clarity and purity of the water in the fuel pool, refueling cavity and refueling water tank are maintained by the purification portion of the fuel pool system. The purification loop consists of a fuel pool purification pump, fuel pool filter, fuel pool purification pump suction strainer, fuel pool ion exchanger, fuel pool skimmer, fuel pool ion exchanger strainer, associated valves, and piping. Purification is conducted on an intermittent basis as required by the fuel pool water conditions. Most of the purification flow is drawn directly from the bottom of the fuel pool while a small fraction of the purification flow is drawn through the fuel pool skimmer to remove surface debris. During purification operations, the capability exists for taking suction at three different levels within the pool to prevent stratification. A strainer is provided in the purification line to the fuel pool purification pump suction to remove particulate matter before the fuel pool water is pumped through the fuel pool filter and the fuel pool ion exchanger. The fuel pool water is circulated by the fuel pool purification pump through the fuel pool filter, which removes particulates larger than five micron size, then through the fuel pool ion exchanger to remove ionic material, and finally through a "Y" type fuel pool strainer.

Connections to the refueling water tank provide makeup to the fuel pool through the purification loop. In addition to purifying the fuel pool water, the refueling water tank and the refueling transfer canal are cleaned through connections to the purification loop.

The staff expects only a small increase in radioactivity and other contaminants to be released to the pool water as a result of the proposed modification and concludes that the spent fuel pool cleanup system is adequate for the proposed modifications and will continue to keep the concentrations of radioactivity and other contaminants in the pool water to acceptably low levels.

2.7 OCCUPATIONAL RADIATION EXPOSURE

The staff has reviewed the licensee's plan for the removal and disposal of the low density racks and the installation of the high density racks with respect to occupational radiation exposure. Since the SFP for St. Lucie 2 has never had spent fuel stored in it and is currently dry, clean and uncontaminated, there will be no additional radiation exposure to workers due to the SFP modification. Therefore, the staff concludes that SFP modification exposure to workers is as low as is reasonably achievable (ALARA) and acceptable.

The staff has estimated the increment in onsite occupational dose resulting from the proposed increase in stored fuel assemblies at St. Lucie 2 on the basis of information supplied by the licensee and by utilizing relevant assumptions for occupancy times and for dose rates in the spent fuel pool area from radionuclide concentrations in the SFP water. The spent fuel assemblies themselves contribute a negligible amount to dose rates in the pool areas because of the depth of water shielding the fuel. Based on present and projected operations in the spent fuel pool area, the staff estimates that the proposed modification should add less than one percent to the total annual occupational radiation dose at the unit. This small increase in radiation dose in the SFP area should not affect the licensee's ability to maintain individual occupational doses to ALARA levels and within the limits of 10 CFR Part 20. Therefore, the staff concludes that storing additional fuel in the St. Lucie 2 SFP will not result in any significant increase in doses received by workers.

2.8 RADIOACTIVE WASTE TREATMENT

St. Lucie 2 contains radioactive waste treatment systems designed to collect and process the gaseous, liquid, and solid wastes that might contain radioactive material. The radioactive waste treatment systems were evaluated in the Safety Evaluation Report, dated October 1981, in support of the issuance of Operating License No. NPF-16 and in supplements thereto. There will be no change in the radioactive waste treatment systems or in the conclusions given regarding the evaluation of these systems because of the proposed spent fuel pool rerack.

2.8.1 Conclusions

The staff evaluation of the radiological considerations supports the conclusion that the proposed installation of new spent fuel storage racks at St. Lucie 2 is acceptable because the conclusions of the evaluation of the radioactive waste treatment systems, as found in the St. Lucie 2 Safety Evaluation Report, are unchanged by the installation of new spent fuel storage racks.

2.9 RADIOLOGICAL CONSEQUENCES OF ACCIDENTS INVOLVING POSTULATED MECHANICAL DAMAGE TO SPENT FUEL

The staff has reviewed the FP&L submittal for the expansion of the storage capacity of the Spent Fuel Pool (SFP) at St. Lucie 2. The review was conducted according to the guidance of Standard Review Plan 15.7.4, NUREG-0612, and NUREG-0554 with respect to accident assumptions.

2.9.1 Cask Drop Accident

The SER Issued in October 1981 states "With respect to the fuel cask drop accident, the cask handling crane and the travel limit switch interlock circuitry are designed to preclude the spent fuel cask from traversing over the spent fuel pool. The maximum potential drop of a spent fuel cask is about 43 feet just outside the fuel handling building. Accordingly, it was assumed that the cask becomes disengaged from the crane and falls 43 feet upon a [sic] unyielding surface, resulting in the damage of all ten irradiated fuel assemblies and the instantaneous release of the associated radioactivity to the atmosphere from ground level. Our calculated doses are shown in Table 15.3." Based on the licensee's March 13, 1984 submittal and the SER review, the staff concludes that the operating license SER cask drop evaluation remains unchanged.

2.9.2 Fuel Handling Accident

For the fuel handling accident, it is assumed that a fuel assembly is dropped by the refueling crane into the reactor core or spent fuel pool. The licensee has proposed to expand the storage capacity of the SFP from 300 spent fuel assemblies to 1076 assemblies that requires a re-evaluation of the fuel handling accident presented in the SER issued in October 1981. The new high density racks will be installed prior to the first refueling outage; the spent fuel pool contains no spent fuel at this time. The proposed spent fuel pool modification does not increase radiological consequences of fuel handling accidents considered in the staff SER of October 1981, since this accident would still result in, at most, release of the gap activity of one fuel assembly due to the limitation on available impact kinetic energy.

2.9.3 Conclusion

The above accident evaluations are based on the recommended design basis assumptions in Standard Review Plans 15.7.4 and 15.7.5 and Regulatory Guide 1.25. However, the licensee is proposing to store extended burnup fuel (45,000 Mw-days/Metric ton) in the rerack spent fuel pool that may result in larger gap releases than were assumed in the analysis submitted. Therefore, it is concluded that the licensee proceed with the SFP modification, and that a licensing condition be placed on the SFP so that the licensee cannot store extended burnup fuel (greater than 38,000 Mw-days/Metric ton) in the modified pool until a new analysis is submitted and approved that addresses the potential for larger gap releases for the extended burnup fuel.

3.0 Conclusions

In conclusion, the staff finds the proposed changes to the St. Lucie 2 Technical Specifications to be acceptable and, based on the considerations discussed above, that (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, and (2) such activities will be conducted in compliance with the Commission's regulations and the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

Date: October 16, 1984

Attachment: Technical Evaluation Report prepared by Franklin Research Center

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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

NRC TAC NO. 54463

NRC CONTRACT NO. NRC-03-81-130

FRC PROJECT C5506

FRC ASSIGNMENT 26

FRC TASK 528

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Washington, D.C. 20555

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September 19, 1984

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Franklin Research Center

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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

CONTENTS

CONTENTS (Cont.)

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:

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

- o 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

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

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

- o 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

- o 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:

- 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.

- 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.
- 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.
- 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.

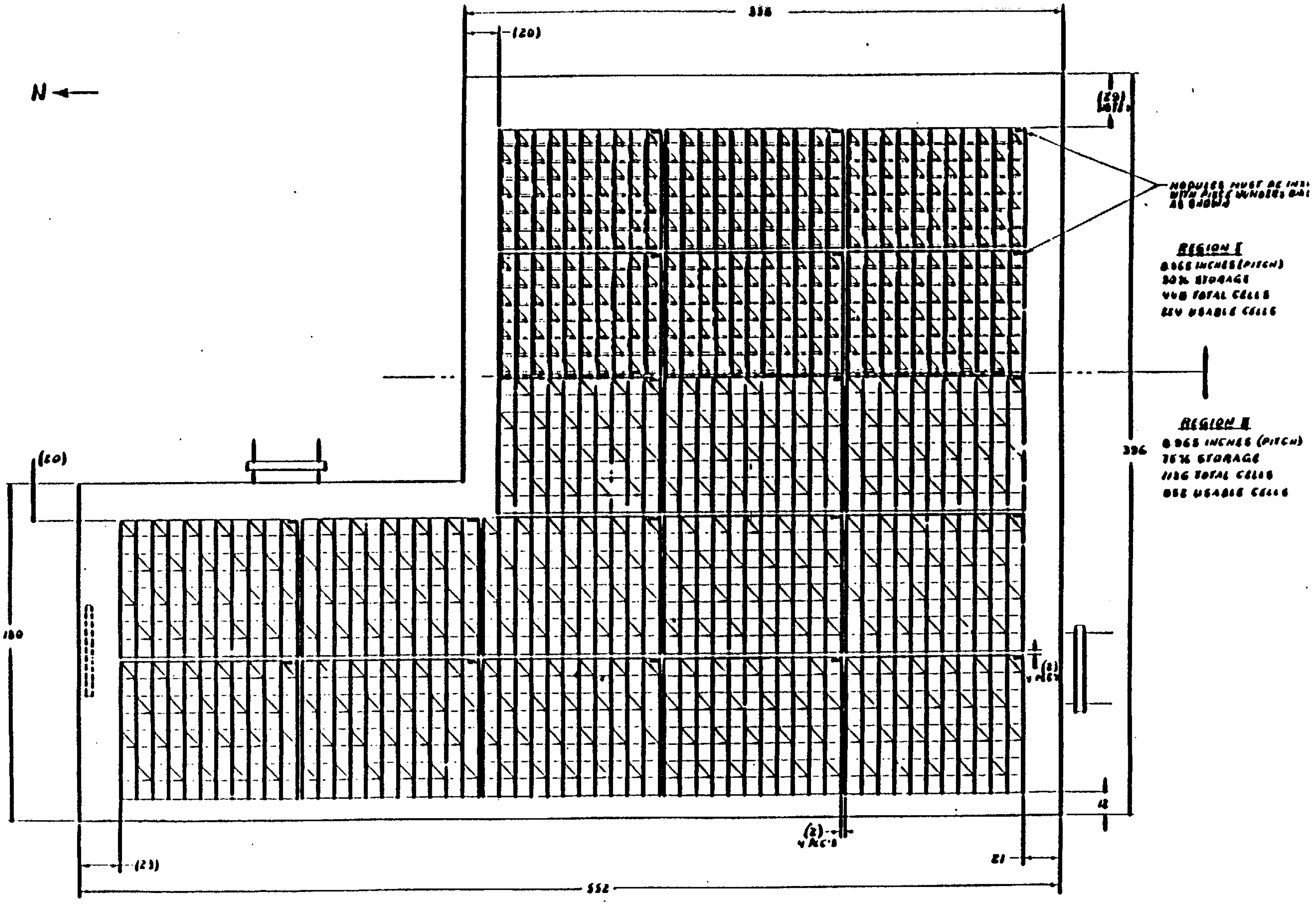

Figure 1. Spent Fuel Pool Layout

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

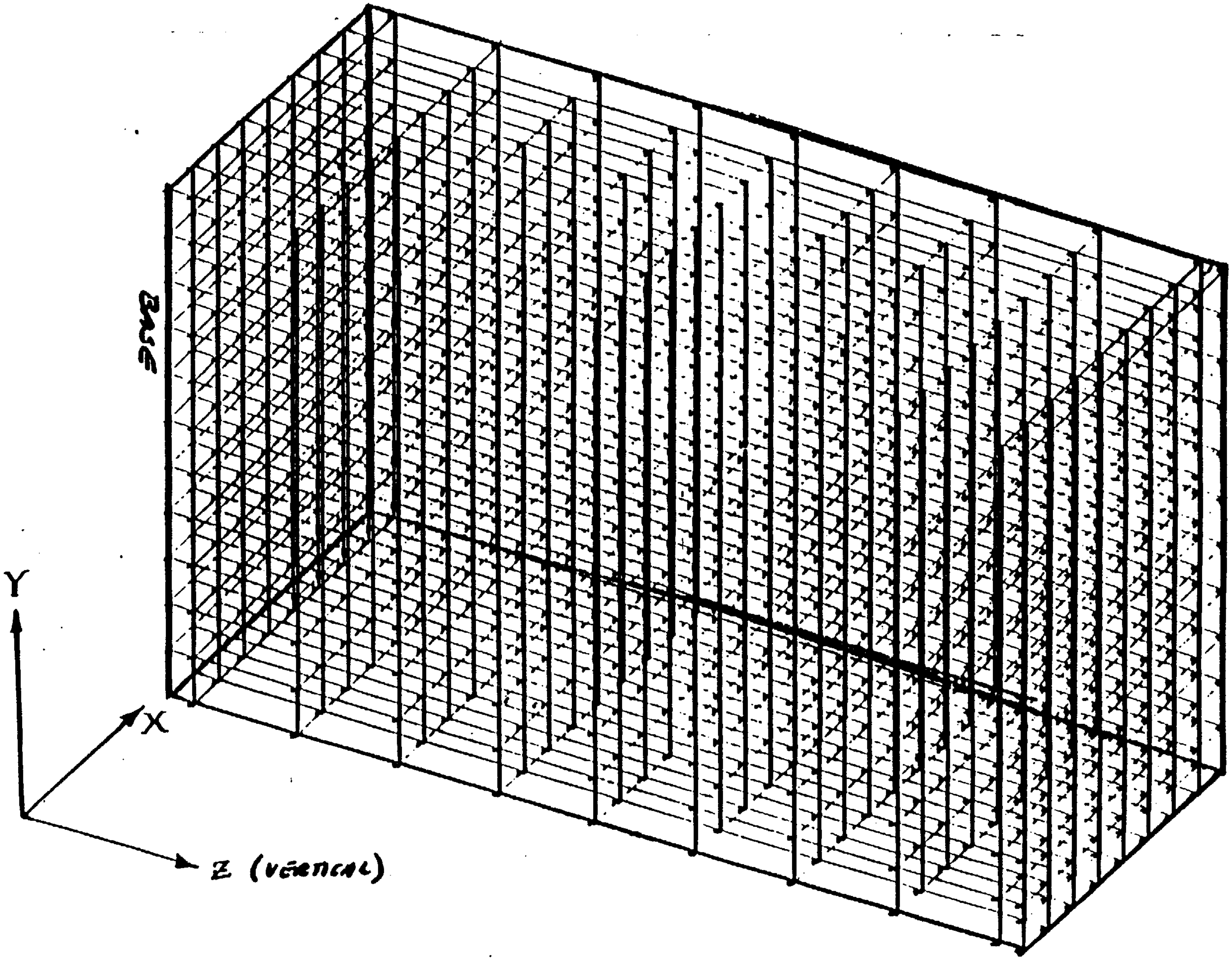

Figure 2. Plot of the SAP IV Finite Element Model

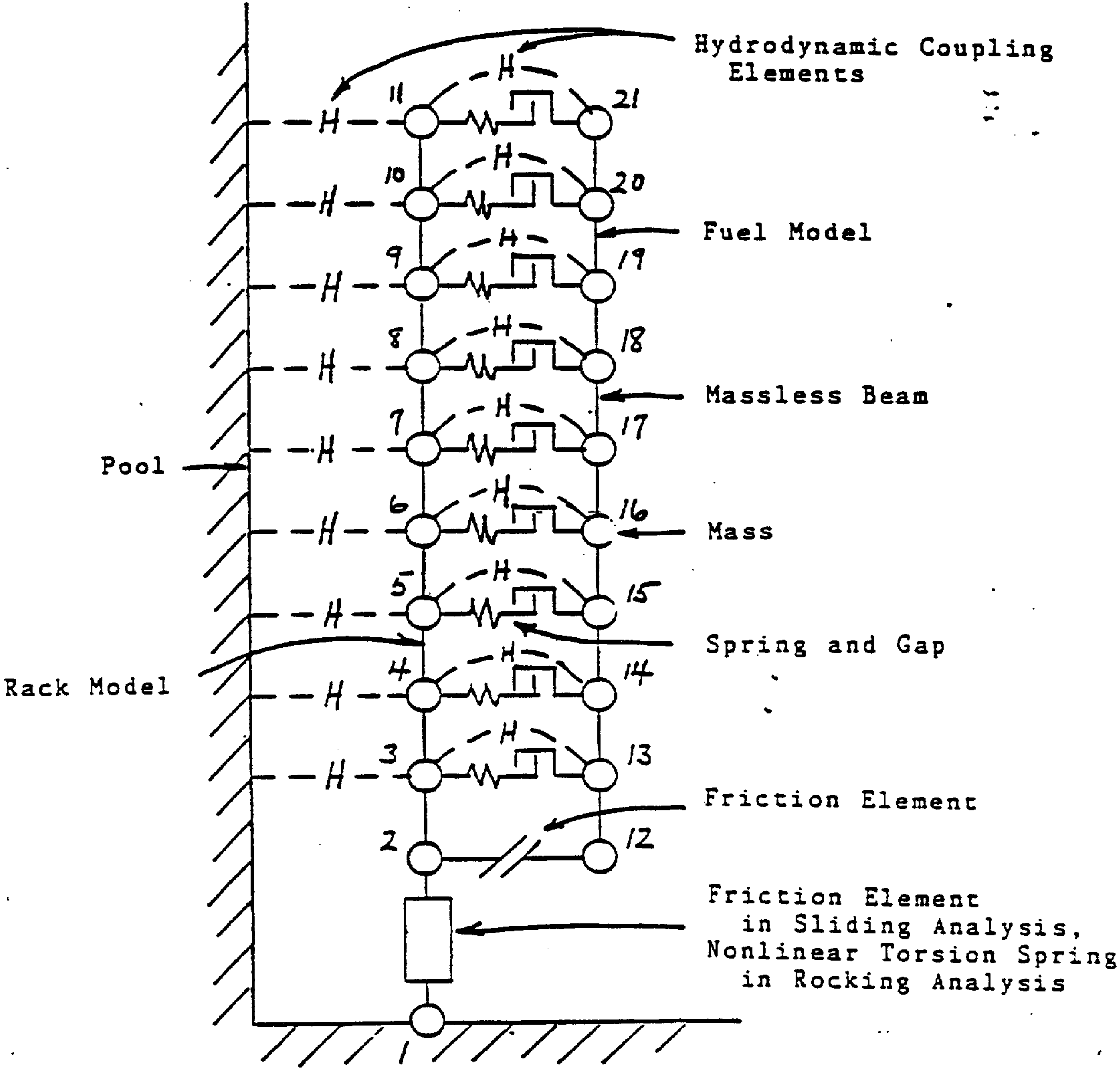

Figure 3. CESHOCK Model of an Individual Fuel Cell

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

[illegible]

Bending Stress: Faulted = 4,9

Shear Stress: Faulted 414 psi

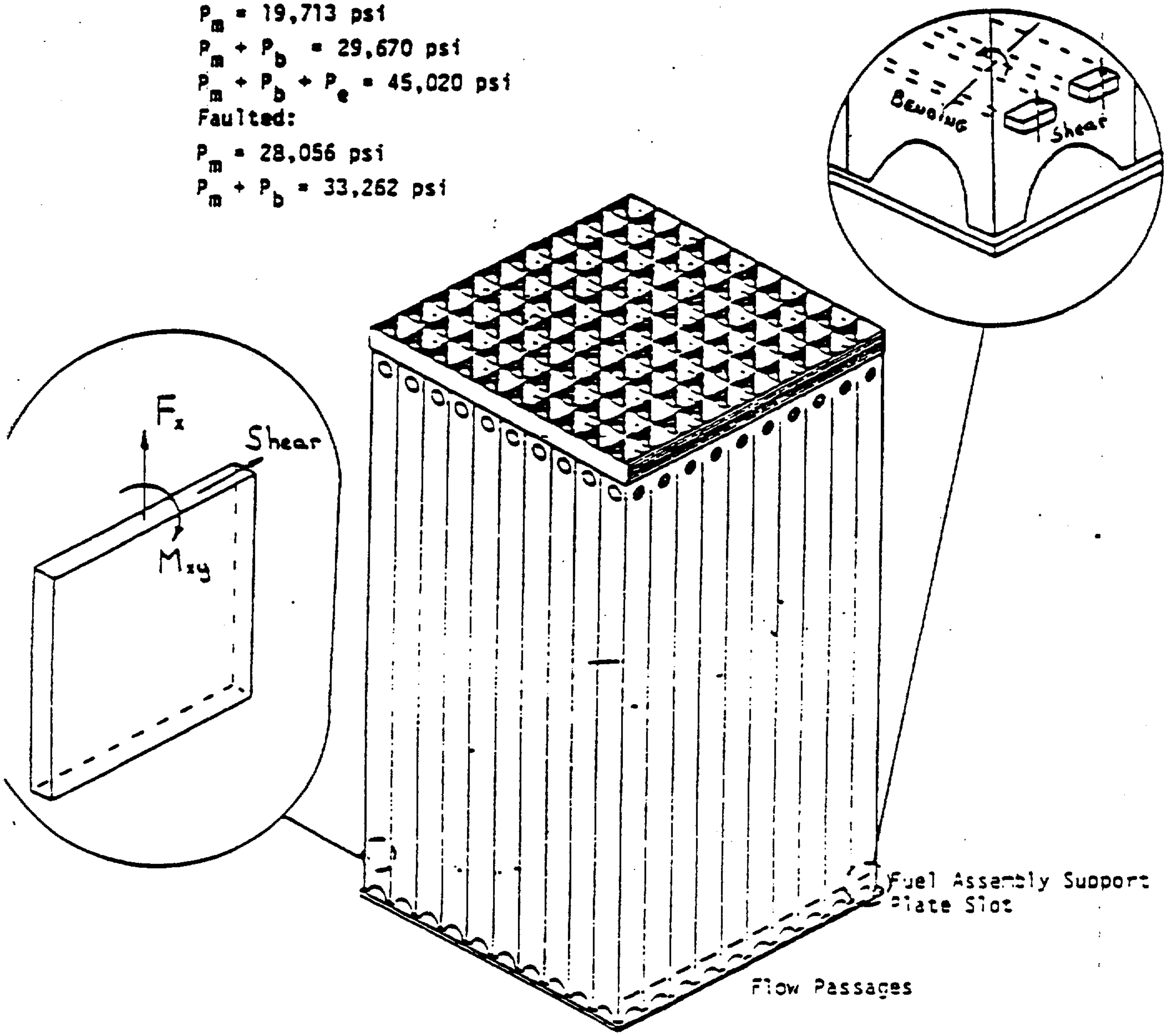

Figure 4. Maximum Stress Location in the Module

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.

5. REFERENCES

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