Edwin I. Hatch Nuclear Plant, Units 1 and 2
Spent Fuel Pool Modification

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November 1979

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4.0 MECHANICAL AND STRUCTURAL CONSIDERATIONS

The high density fuel storage system (HDFSS) module has been analyzed for both operating basis earthquake (OBE) and safe shutdown earthquake (SSE) conditions. A detailed stress analysis was then performed to check the design adequacy of the module against calculated loads. Results indicated that the HDFSS module design is adequate for the postulated combined loading conditions.

4.1 Seismic Analysis

The HDFSS module has been analyzed for both OBE and SSE conditions. Critical damping ratios of 2 percent were used in the analysis for the SSE condition and 1 percent for the OBE condition. The design floor acceleration response spectra are given in Figures 4-1 through 4-6. These spectra are based on Hatch 2 which bounds the spectra for Hatch 1. Combination of the modal response and the effect of the three components of an earthquake will be performed in accordance with the applicable provisions of US NRC Regulatory Guide 1.92.

The seismic analysis was performed in several steps. First, the hydrodynamic effect, which represents the inertial properties of the fluid surrounding the submerged modules, was calculated to obtain the hydrodynamic virtual mass terms based on the module and pool configuration. Three-dimensional end effects and leakage between modules are accounted for by modifying the calculated hydrodynamic mass.

Figures 4-7 and 4-8 show the plan view of the two-dimensional model of
the modules and pool used in the hydrodynamic virtual mass analysis.
The model consisted of two rigid bodies: the modules and the pool
walls. The walls are considered rigid because their substantial
thickness makes them considerably stiffer than the module and the 3
water in the pool. The distance between the modules and the walls
of the pool is very large compared to the magnitude of the deflection
of the module walls and the pool walls during a seismic event. Con- 4
sequently, the assumption that both bodies are rigid does not signifi-
cantly affect the hydrodynamic mass contribution. In addition, ignor-
ing the flexibility of the wall will result in higher hydrodynamic
mass. This will result in a lower natural frequency of the module. 3
Because of the shape of the floor spectra, underestimating the natural
frequency of the module provides a conservative estimate of stresses
and displacement of the module. Water finite elements fill the spaces
in between the walls and the modules. The total mass matrix of each
module for the analysis is equal to its structural mass matrix plus
the hydrodynamic mass matrix. Conservative structural damping values
of 1 percent for the OBE and 2 percent for the SSE are applied without
any added damping from fluid effects.

The WATER-01 computer program, GE-proprietary, was used to determine the hydrodynamic mass of one rectangular body inside another rectangular body. This program has been design reviewed and meets NRC-QA requirements. The methodology in calculating hydrodynamic mass has been presented in Reference 1.

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Second, the derived total mass of the module was used to perform dynamic analysis for the OBE and SSE. As seen in Figure 4-9, for a typical 13 x 13 module, when the added-mass terms from the hydrodynamic mass effect were included, the fixed base frequency decreased.

Third, both finite-element and lumped-mass models of a module were then developed to provide a basis for selecting simplified module models to be used in the module and support system analysis and module sliding analysis. The finite-element model also was used to obtain the distribution of shear forces in the module plate elements.

Fourth, an eleven-node lumped-mass model was then developed by lumping the tributary module mass to the corresponding node point and initially selecting the stiffness properties based on beam theory. The stiffness properties of this model were based on matching the natural frequencies of the finite element model.

The model is represented as a triangle with three masses. This model
preserves the overturning and tilting moment of the rectangularly
shaped module. A rectangular model with more mass node would not pro- 4
duce higher effects. Thus, there would be no difference in results if
a rectangular model was used.

In the nonlinear analysis used to calculate the amount of sliding and
tilting, a two-node lumped-mass model was found to adequately re-
present the module and support system analyses, since the response of
the module support system was shown to be primarily first mode and
rigid body motion and both the first mode and rigid body dynamic 3
properties could be simulated. The lumped mass at the top of the
two-mass model was selected so that the base shear force of the first
mode was preserved. The height of the model was selected to preserve
the overturning moment at the base of the module for both the first
mode response and rigid body motion. The summation of the two lower
masses and the upper mass used in the model equals the total mass of 4
the module. The distance of the two lower masses was selected to pre-
serve the mass moment of inertia of the module This ensured that the
shear force at the base was preserved for rigid body motion. Finally, 3
the stiffness of the structural element was selected to preserve the
fundamental frequency of the module. The effects of the corner sup-
ports were added to the model by including base springs and the final
model was used in the sliding analysis. The horizontal spring repre-
sents the stiffness of the support pad and the vertical spring repre-
sents the stiffness of the fuel support plate, the foot pad, and the
support pad

The mechanism for controlling the shear force in each module is the limiting of the coefficient of friction between the module and the support pad by the selection of a non-galling, corrosion-resistant material with a low coefficient of friction to be used as the module foot pads which are in contact with the stainless-steel support pads. The range of friction coefficient for the selected materials was found to be between 0.145 and 0.203. The friction coefficient between the stainless-steel support pads and the stainless-steel liner is at least

0.349. This difference insures that sliding will occur between the foot pad and the support pad, and not between the support pad and the floor liner (References 8 and 9). | 4

The sliding analysis was done using the two-dimensional, non-linear DRAIN-2D and SEISM computer codes. DRAIN-2D was originally developed at the University of California at Berkeley; SEISM was developed by GE. Both computer codes have been design reviewed and meet NRC-QA requirements. Sliding and overturning of the module were studied for the SSE and OBE conditions. All of the modules were found to be stable under the worst postulated seismic loading conditions, and the minimum 2-inch clearance between modules precludes contact during a seismic event.

4.2 Stress Analysis

The HDFSS module has been designed to meet Seismic Category I requirements. Structural integrity of the rack has been demonstrated for the load combinations below using linear elastic design methods.

Analysis was based upon the criteria and assumptions contained in the following documents:

a. ASME Boiler and Pressure Vessel Code Section III, Subsection NF.

b. USNRC, Regulatory Guide 1.92, Combining Modal Responses and Spatial Components in Seismic Response Analysis.

c. Hatch 2 Final Safety Analysis Report, Seismic Design Criteria.

OBE - Operating Basis Earthquake

SSE - Safe Shutdown Earthquake

d. Light-Gage Cold-Formed Steel Design Manual, 1961 Edition, American Iron and Steel Institute.

Acceptance criteria were based on:

a. Normal and upset (OBE) Appendix XVII, ASME, Section III.

b. Faulted (SSE) Paragraph F-1370, ASME Section III, Appendix F.

c. Local buckling stresses in the spent fuel storage tubes were calculated according to "Light-Gage Cold-Formed Steel Design Manual" of American Iron and Steel Institute in lieu of Appendix XVII, ASME, Section III, because of its applicability to these light-gage tubes. Only the strength of the outer wall thickness of 0.090 inch nominal is considered in the stress calculations.

The applied loads to the rack are:

a. Dead loads which are weight of rack and fuel assemblies, and hydrostatic loads.

b. Live loads - effect of lifting an empty rack during installation.

c. Thermal loads - the uniform thermal expansion caused by pool temperature changes from the pool water and stored fuel.

d. Seismic forces of OBE and SSE.

e. Accidental drop of a fuel assembly from the maximum possible height.

f. Postulated stuck fuel assembly causing an upward force of 1000 pounds.

The load combinations considered in the rack design are:

a. Live loads.

b. Dead loads plus OBE.

c. Dead loads plus SSE.

d. Dead loads plus fuel drop.

The allowable stresses for each loading combination follow ASME Boiler
and Pressure Vessel Code Section III, Subsection NF, per "Operating
Technical Position for Review and Acceptance of Spent Fuel Storage and
Handling Applications". Only an elastic analysis was considered. The 3
two controlling loading combination equations were found to be D + L +
OBE and D + L + SSE. D + L + T_a + SSE was also considered to check
for elastic buckling per ASME Section III, Subsection NF. The allow-
able stresses are given in Table 4-1 based on the following equations,
and they are consistent with the requirements specified in Regulatory 4
Guide 1.124.

Stress Type	D+L + OBE	D+L + SEE
Tension (w/o pin hole)	0.6 Sy	
(w/pin hole)	0.45 Sy	
Shear	0.4 Sy	Increased by $1.2 \frac{Sy}{F_t}$ 3
Bending Stress	0.66 Sy	
Bearing	0.9 Sy	

Note: Sy and F_t are specified minimum yield strength and allowable tensile stress, respectively.

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Thermal loads were not included in combinations because the design of the rack makes them negligible; i.e., the rack is not attached to the structure and is free to expand or contract under pool temperature changes. Assuming the boundaries of the module are completely fixed and the module is not allowed to expand, the maximum thermal stress between loaded and unloaded cells is less than 6,400 psi. This is well within the allowable compressive stress in the tube wall. Furthermore, according to ASME Section III, Subsection NF, Paragraph NF-3230, Appendix XVII Article F-1370, thermal stresses need not be considered 4
in the stress calculation but only in the buckling analysis for the SSE condition. This is consistent with industrial practice for piping stress analysis where thermal stress is treated as secondary stress. Therefore, under the cooling water flow conditions in the modules, the heat rise in the wall of a loaded storage tube caused by gamma heating is no more than 5°F and the maximum water temperature rise from bottom to top of a storage tube is 19°F. Thus, the maximum temperature grad- 3
ient between a loaded and an empty cell is no more than 24°F, as is explained in Section 8.5. Temperature-induced stresses are not additive from module to module because each module is independent of the others.

Stress analyses were done for both OBE and SSE conditions, based upon the shears and moments developed in the finite-element dynamic analysis of the seismic response. These values were compared with allowable stresses referenced in ASME Section III, Subsection NF (Table 4-1). Values given in Table 4-1 are based on the maximum stresses calculated for all module sizes. Additional analyses were then performed to determine the dynamic frequencies, earthquake loading reactions, and maximum amount of sliding. The stability of the modules 1
against overturning was also checked and they were found to be stable. Those values are summarized in Table 4-2.

The force path in the module caused by a horizontal earthquake is shown schematically in Figure 4-10. This figure shows the path of the horizontally induced earthquake fuel element inertial forces from the fuel element to the module support pads. Part of the fuel bundle inertial forces induced by the motion of the module are transferred either through the water or directly to the tube walls perpendicular to the direction of motion (Point 1 in Figure 4-10). These walls then transfer the forces to the side tube walls, which carry the forces down the walls and into the fuel support plates (Point 2). The portion of the fuel bundle load which is not transferred to the fuel tube walls is transferred directly to the fuel support plate at the point where the lower end fitting of the fuel bundle is supported vertically (Point 3). The fuel support plates, acting as a relatively rigid diaphragm, transfer the in-plane shear forces to the long casting which then transfers the shear forces to the module base assembly plate (Point 4). The forces are carried in the module base assembly (Point 5) until they are ultimately transferred to the foot pad and to the support pad and the pool slab (Point 6).

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The vertical forces caused by earthquake and gravity loads become axial forces in the foot pads. The critical location for the compression forces from the foot pads is in the long castings and tubes directly above the foot pads. For stress analysis purpose, these compression forces are considered to be resisted by four fuel tubes sitting directly above the support pad.

Fuel assembly drop accidents were analyzed using analytical methods in accordance with the "Operating Technical Position for Review and Acceptance of Spent Fuel Storage and Handling Applications". In estimating local damages in the module, the maximum strain energy resulting from plastic deformation is equated to the maximum potential energy of the fuel. Energy dissipation attributable to the viscosity 3
of the water and plastic deformation of the fuel bundle was ignored for conservative results. The stainless steel for the module is assumed to exhibit a bi-linear hysteresis relationship, with yield stress and ultimate stress as the two control points. The results are summarized in Table 4-3.

Also evaluated was the damaging effect of a fuel bundle drop through an empty storage position along the outer rows of the module, imparting the base frame. It was determined that the fuel bundle will not possess enough energy to perforate the 1-inch thick base frame. The resulting configuration of the module will be adequate to maintain the fuel in a safe condition. This case is less critical than the cases discussed in Table 4-3.

The loads that may be carried over the spent fuel pool are listed in Table 4-4. A free fall of these loads onto the fuel pool liner plate and storage racks was evaluated. It was determined that a fuel assembly drop causes the most damaging effect due to its weight and geometrical configuration. Also, none of the other loads can be lifted to a position higher than that of a fuel assembly above the liner plate and storage racks. Regarding the integrity of the liner plate, the evalu- 4
ation demonstrated that the energy developed by a freely falling fuel assembly would not cause perforation (Reference 7). A free falling fuel assembly dropping from a height extending 27 inches above the height of a module with 0 ft/sec initial velocity is calculated to have a final velocity of 26.5 ft/sec when it comes in contact with the slab liner plate after traveling through the water. The required steel plate thickness to just perforate, based on this velocity, is less than the liner plate thickness that is provided for the pool slab. The presence of concrete below the liner plate was conservatively neglected in the computation. Regarding the integrity of the fuel and storage racks, the consequences of dropping any of the items listed in Table 4-4 are no more severe than that of the fuel assembly drop accidents summarized in Table 4-3. The provisions employed to prevent movement of heavy objects over the spent fuel pool are discussed in Section 11.0.

The HDFSS design does not require any different fuel handling procedures from those discussed in the Unit 1 and Unit 2 FSAR. 3

The loads experienced under a stuck fuel assembly condition are less than those calculated for the seismic condition and have therefore not been included as a load combination.

4.3 Effects of Increased Loads on the Fuel Pool Liner and Structures

The effects of increased loads on the fuel pool structure are being reevaluated using a three-dimensional finite element model. The NRC site visit (November 1, 1979) comments will be incorporated in the analysis. The results of the analysis will be submitted by the end of January 1980. 4

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TABLE 4-4
Items That May Be Moved Over The Spent Fuel Pool Racks

Item	Approximate Weight (lb)
Fuel Assembly (Including Channel)	725
Channel	75
Control Rod	235
Fuel Sipping Equipment	85
Defective Fuel Cannister	175

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Boral's corrosion resistance is similar to that of standard aluminum sheet. Corrosion data and industrial experience confirm that aluminum and Boral are acceptable (References 2, 10, 11, and 12) for the proposed 4
application. Although experience indicates that it is unnecessary, an inservice test program will be conducted, consisting of periodic examination of surveillance samples which will be suspended underwater in the fuel storage pool. These samples consist of two types; the first being 8-inch x 8-inch coupons of Boral plate with stainless steel sheet formed to both sides, and the second consisting of 6-inch square samples of Boral without stainless "cladding". The stainless "clad" coupons 3
have two sides open to permit water access. Sufficient samples are included to permit destructive examination of a sample on inspection intervals of 1 to 5 years over the life of the facility.

Pool water quality will be maintained as specified in the Hatch 2 FSAR, Section 9.1.3.2.4. No changes to water quality are expected as a result of the planned modification to the spent fuel storage capacity (see Section 10-1 of the Radiological Evaluation).

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Phase V — Decontamination of old racks--This work is expected to require one man at a time operating a hydro-lazer or other decontamination equipment approximately 15 feet from the contaminated rack. This is estimated to require 1 hr/rack.

Phase VI — Support pad installation for new racks--This work will require a four-man team working above the pool. There are 29 support pads to set plus an elevation survey of these pads to be done to check levels. Allowing 2 hours per support pa plus 8 hours for the survey results in a total of 264 man ours.

Phase VII — Installation of new racks--This work may be done gradually over a period of time since all racks are not required immediately and because of delivery schedule limitations. 2
However, to install all 17 racks, allowing 6 hours of above pool work per rack using a four-man team, results in approximately 408 manhours.

Table 6-1 is a breakdown of the man-rem exposures estimated for each phase of the work as described above. Measurements taken over the Unit 1 spent fuel pool during refueling operations have shown that dose rates normally do not exceed 2.0 mrem/hour with a maximum of 3.0 mrem/hour while handling fuel assemblies. The exposure estimates assume all personnel involved in the change-out work to be continuously exposed to the maximum 3 mrem/hour field. Decontamination work on the old racks is assumed to require exposure to a 50 mrem/ hour field. This estimate assumes divers will not be required. However, divers may be required to disassemble the swing bolts and seismic restraints associated with the existing racks. It is estimated that this could require 3 to 4 manhours of underwater work and add 4
approximately 0.09 to 0.1 man-rem to the total occupational exposure for the rerack effort.

If the Hatch 2 spent fuel pool should become contaminated prior to its modification, this would have essentially no effect on the above estimate which is for Hatch 1 only. Very little exposure is estimated for the Hatch 2 work assuming an uncontaminated pool (i.e., less than 2
five man-rem). If the pool becomes contaminated before reracking, techniques similar to those envisioned for Unit 1 might be required and similar exposures may be received.

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10.7 Disposal of Present Spent Fuel Racks

There are at present 42 aluminum racks in the Unit 1 pool and 56 in Unit 2. Each rack weighs about one ton. Presently, there is no fuel stored in the Unit 2 spent fuel pool. The racks removed from Unit 2 will be prepared and stored in the warehouse for future sale or use. The racks and seismic restraints from the Unit 1 pool will be decontaminated, crated, and shipped offsite to a licensed burial location. This represents an estimated volume of 10,000 cubic feet of contaminated materials. 2
A reasonable effort will be made to limit personnel exposures to as low as reasonably achievable during this work.

A study is currently underway to determine the feasibility and cost effectiveness for volume reduction of the old racks. If this option is chosen it could add approximately 0.1 to 3.0 man-rem to the total 4
occupational exposure for the rerack effort depending on the method of volume reduction used.

10.8 Impact on Radioactive Effluents

The spent fuel pool has its own filter/demineralizer system, and under normal circumstances the spent fuel pool water is not transferred to the liquid radwaste system. Therefore, no increase in liquid effluents from the plant is anticipated as a result of the proposed pool modifications.

The spent fuel pool leakage collection system is comprised of embedded stainless steel channels behind the stainless steel liner plate, which provide interconnected drainage paths for the pool walls and slab. The leak off connections from the channels drain through open funnels into drain lines, as shown in Unit 2 FSAR Figure 9.1-4, that direct the flow to the reactor building dirty radwaste sumps located in the southwest and southeast corner rooms. The sumps, pumps, level instrumentation and system operation are discussed in the Unit 2 FSAR Sections 9.3.3.2 and 2
9.3.3.3. Liner leaks can be visually observed at the open funnels and can be monitored by observing the frequency and duration of the sump pump runs. Presence of large leaks would be annunciated in the control room by level switches on the sumps. The design features described above for Unit 2 are applicable for Unit 1.

In addition, abnormal spent fuel pool water level alarms are provided in the control room. Level switches are also provided on the skimmer surge tanks which will initiate alarms for high, low, and low-low surge tank levels. A low level alarm can be an indication of a leak in the system.

There has not been any leakage from the spent fuel pool in the past on Unit 1; however, should leakage occur, it can be detected through an increase of the make up water, a visual inspection of the liner leak off connections, and/or unusual frequency of operation of the sump pumps.

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13.0 NOTES AND REFERENCES

Notes:

1. For the purposes of this report the term "fuel bundle" will imply configuration either with or without flow channels unless the term "fuel assembly" is specifically and distinctly intended.

2. Boral is a product of Brooks and Perkins, Inc., consisting of a layer of boron carbide-aluminum (B_4C-Al) matrix bonded between two layers of aluminum.

References:

1. L. K. Liu, "Seismic Analysis of the Boiling Water Reactor," Symposium on Seismic Analysis of Pressure Vessel and Piping Component, First National Congress on Pressure Vessel and Piping, San Francisco, California, May 1975.

2. U.S. NRC Safety Evaluation for Yankee Rowe, dated December 29, 1976, Page 4, Structural and Material Considerations.

3. C. M. Kang and E. C. Hanson, ENDF/B-IV Benchmark Analysis with Full Spectrum Three-Dimensional Monte Carlo Models, ANS Meeting, November 1977.

4. M. J. Bell, "ORIGEN Code - The ORNL Isotope Generation and Depletion," ORNL-4628.

5. N. Eickelpasch and R. Hock, "Fission Product Release After Reactor Shutdown," IAEA-SN-178/19.

6. Letter from W. E. Ehrensperger, Georgia Power Company, to U. S. Nuclear Regulatory Commission, dated July 24, 1978.

7. BC-TOP-9A, Revision 2, September 1974. 3

8. W. C. Wheadon, "Friction Test of Graphite Base Materials Sliding Against Type 304 Stainless Steel Plates", GE report No. C5445-TR-02, dated April 19, 1979. (Proprietary)

9. E. Rabinowicz, "Friction Coefficient Value for A High Density Fuel Storage System", GE Report VPF No. V5455, dated January 3, 1978.

10. U. E. Wolff, "Boral From Long-Term Exposures at BNL and Brooks & Perkins", GE Report No. 78-212-0079, dated December 14, 1978. 4

11. Brooks & Perkins Report, "The Suitability of Brooks & Perkins Spent Fuel Storage Module For Use in BWR Storage Pool", Report No. 577.

12. A. J. Jacobs, "Boral Corrosion Test: 2022-Hour Results", GE Report No. 77-688-120, dated December 15, 1977. (Proprietary)

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QUESTION 11

Discuss the possibility of swelling (inward and outward) in the cell containing the boral composite due to off gasing generating pressure and discuss the provisions employed to prevent such swelling or the provision employed such that withdrawal of the fuel assembly is insured.

RESPONSE:

Swelling of the inner wall (only) of the storage tubes in the water was first observed in the storage modules following their submergence in the Monticello fuel pool. The swelling was caused by the accumulation of gas between the inner and outer walls of the stainless steel storage tube as a result of water in-leakage and subsequent generation of hydrogen gas during the passivation of the aluminum surface of the Boral. The leak must be in the lower one third of the storage tube in order to cause tube inner wall deformation.

When submerged in the pool, a storage tube in a module is subjected to an outside hydraulic pressure difference of 5.7 psi between the top tube weld and the bottom tube weld. The inner wall of the storage tube is significantly thinner than the outer tube wall and a leak in the lower part of a tube will allow the trapped gases to swell the inner wall (at about 3 psi) before the gases can be forced out the leak. To prevent this occurrence, the four corners of each tube are left unwelded at the top and at the bottom.

Water is allowed to leak into each tube, passivating the aluminum surface of the Boral, and the generated gases are allowed to vent out the upper end of the tubes, precluding any significant buildup of gas pressure. Corrosion programs have demonstrated that the long-term corrosion rates for Boral in demineralized pool water will not affect the 40-year life of the storage modules (References 2, 10, 11 and 12). 4

Modules fabricated from these tubes have been installed underwater at Monticello and at Browns Ferry and have been under test in the GE Morris storage basin since October 1978, with no measurable change in dimensions. It has been demonstrated that because of the significantly thinner inner wall, swelling, if it should occur, will affect only the inside of a tube. Fuel stored in spaces on the outside of a swollen tube could always be removed in the unlikely event of a buildup of gas inside a tube. The outer tube wall could then be drilled or punched remotely to relieve the swelling of the inner wall. 4

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