PAGE INSERTION GUIDE

Page	Instructions
i	Replace
ii	Replace
2-2	Replace
Figure 2-13	Replace
Figure 2-14	Replace
Figure 2-15	Replace
Figure 2-16	Add
Figure 2-17	Add
4-1 through 4-4	Replace
4-5 through 4-7	Add
Table 4-4	Add
Figure 4-10	Replace
5-2	Replace
13-1	Replace
Response to Questions	Replace All Pages

1265 236

7911050 203

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

1265 238

and 14 feet high. Figures 2-14 and 2-15 provide additional information pertaining to the arrangement plan of the pools.

The module support system consists of a module base plate, four foot pad assemblies, and four support pads. The support pads rest on the pool floor. They are fabricated from 2-inch-thick stainless steel plate, and are 19 inches square in plan and 6 inches high. The 2-inch-thick foot pads rest on the 6-inch-thick support pads to raise the module base plate a minimum of 8 inches above the floor of the fuel pool, allowing sufficient area to clear the existing swing bolts on the pool floor, and to permit natural circulation of cooling water to the modules without taking credit for sources of forced cooling.

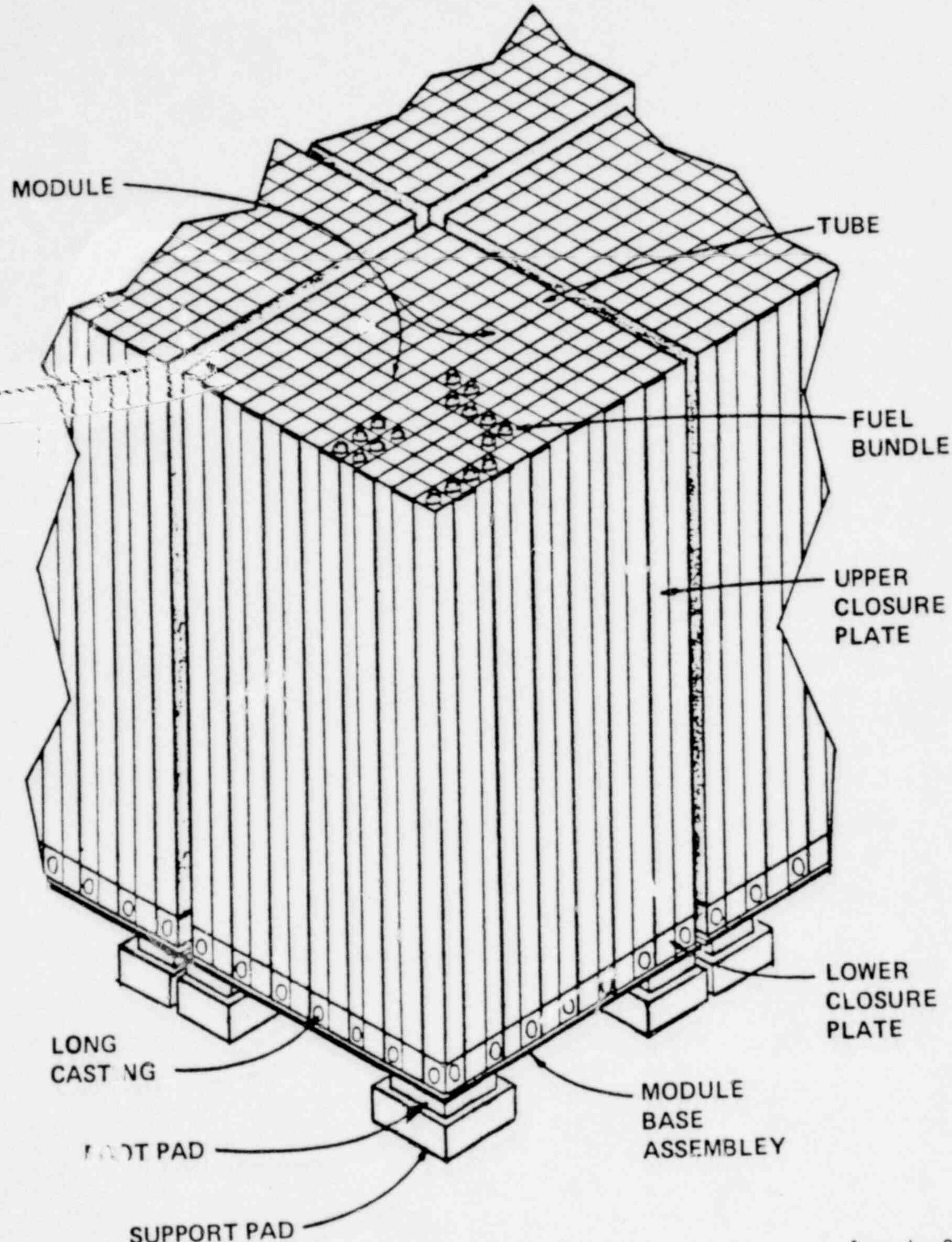
The foot pad assemblies are bolted to the module base plate at each of the four corners. The foot pad assembly consists of a 3/4-inch-thick by either a 12- or 15-inch-diameter plate made from special low-friction material which is 3
pressed into a 1/2-inch-deep circular recess in a 2-inch-thick stainless steel plate. The 2-inch stainless steel plate is 19-3/4 inches square with 10-1/2 inches at 45^{o} cut off one corner to match the module base plate. The foot pad bears on the support pads. These are the only sliding surfaces for the modules.

The module base plate is fabricated from 1-inch-thick stainless steel plate. The long castings and short closure plates on the perimeter of the module are welded to the base plate.

The gap between all modules is a minimum of 2 inches. There are no other gaps in the module construction.

Figure 2-16 and Figure 2-17 illustrate the system descibed above.

1265 239



Amend. 3 10/79

Figure 2-13 Isometric View of Modules

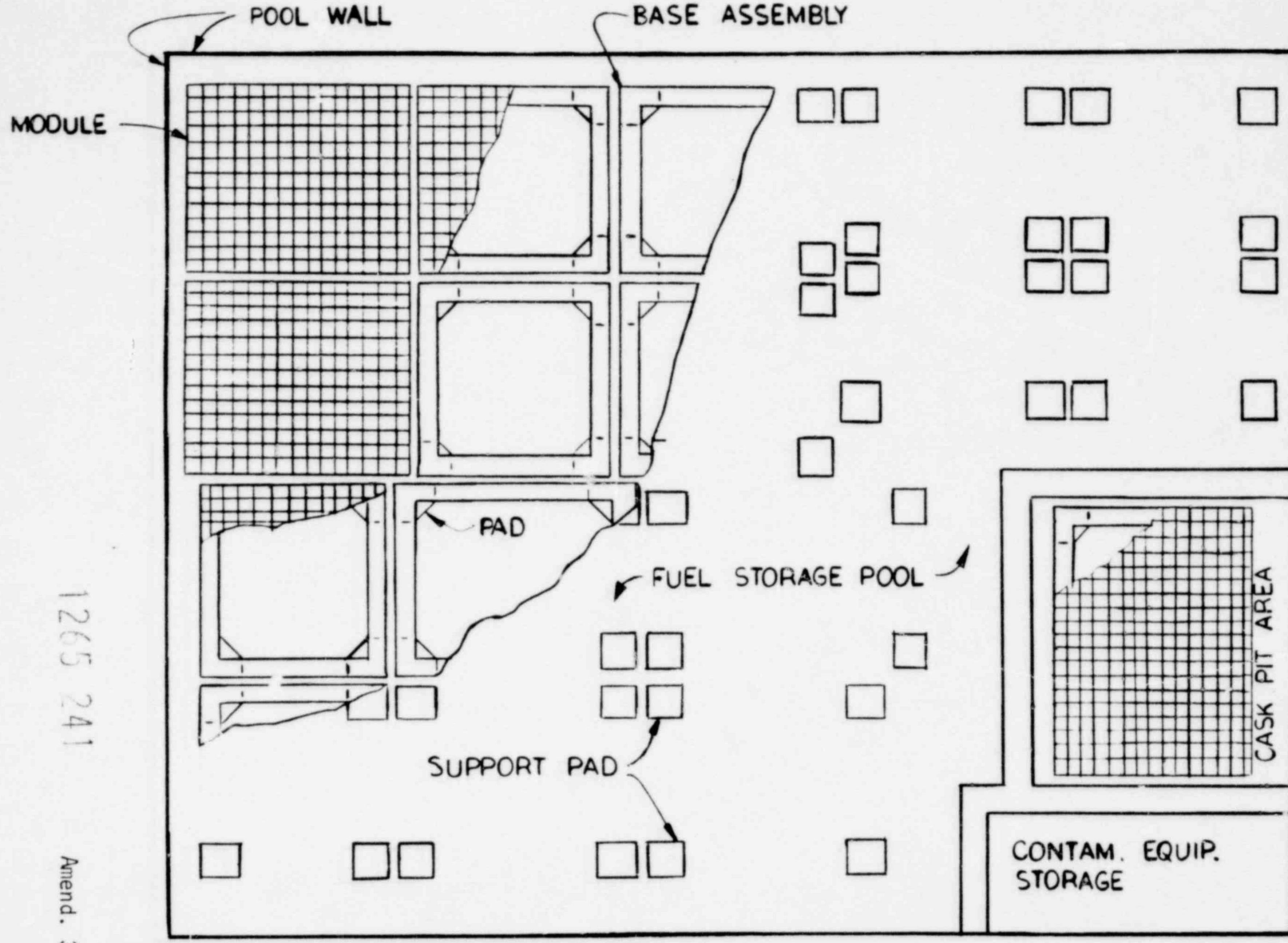


Figure 2-14 Plan of Hatch 1 Spent Fuel Storage Pool, Support Pads and Modules

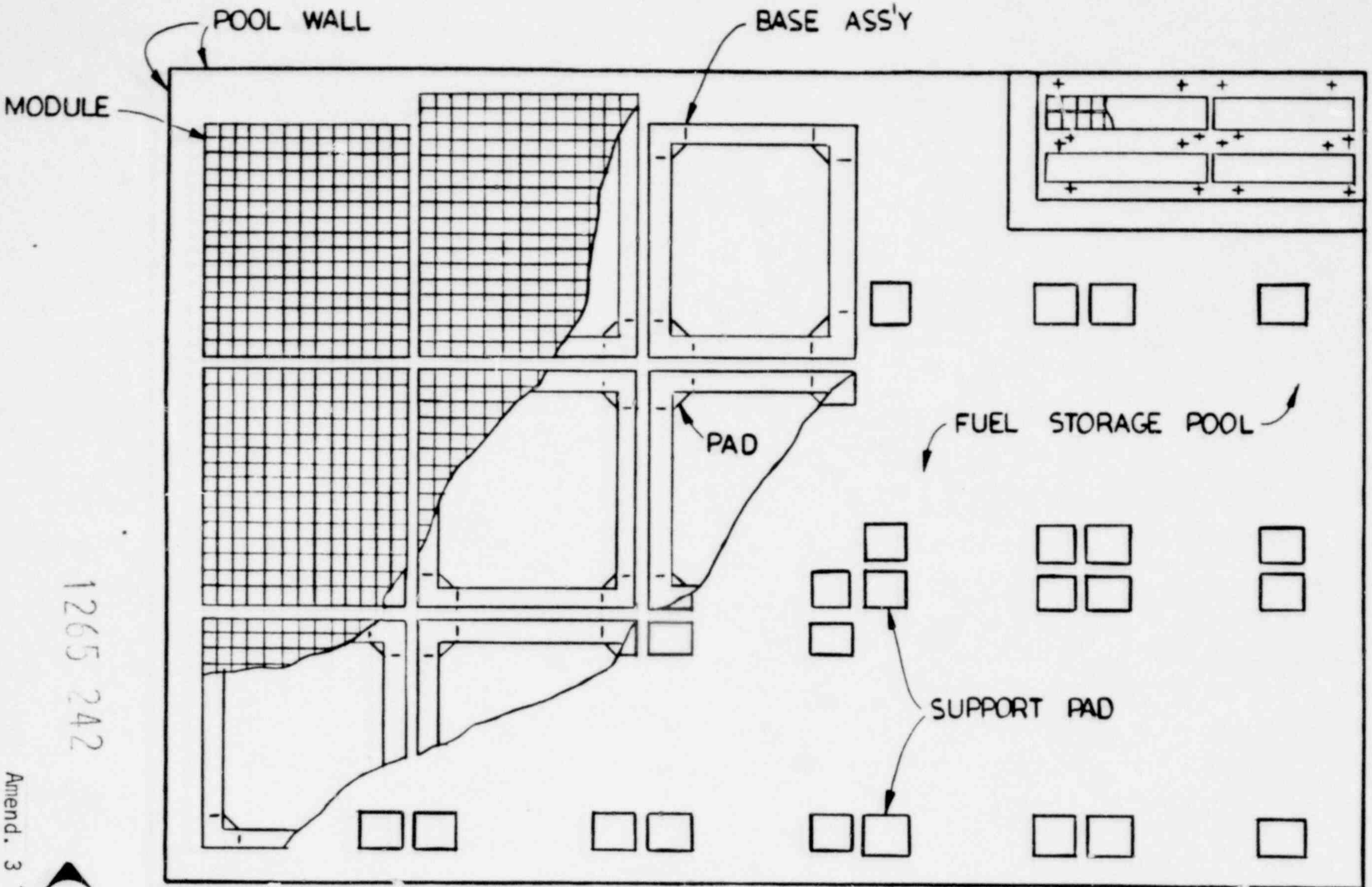


Figure 2-15 Plan of Hatch 2 Spent Fuel Storage Pool, Support Pads and Modules

Amend. 3 10/79

1265 242

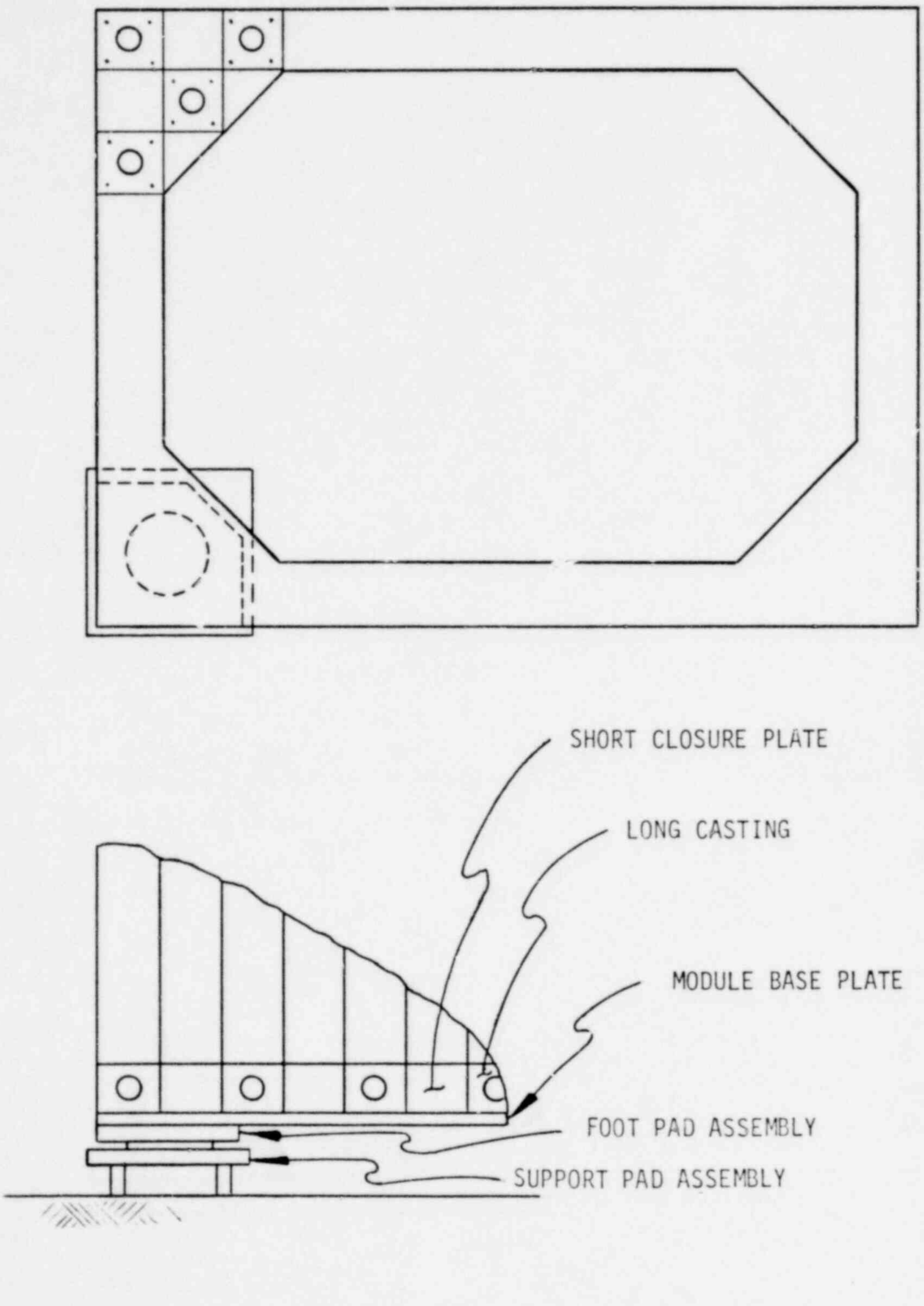


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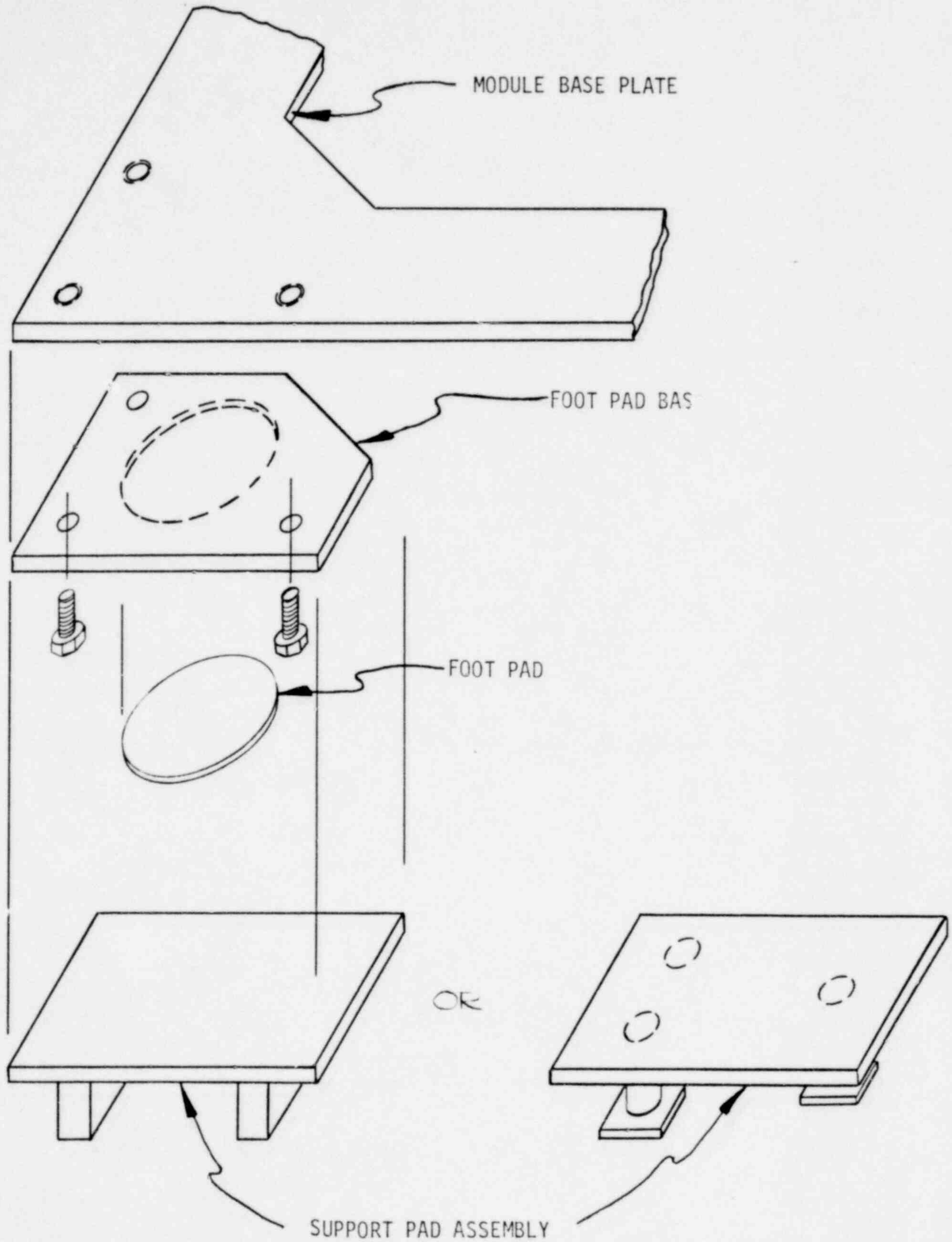
FIGURE 2-16 MODULE SUPPORT SYSTEM

1265 243



Amend. 3 10/79

1265 244

FIGURE 2-17 MODULE SUPPORT SYSTEM DETAIL

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 water in the pool. In addition, ignoring the flexibility of the wall will result in higher hydrodynamic mass. This will result in a lower 3
natural frequency of the module. 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.

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.

In the nonlinear analysis used to calculate the amount of sliding and tilting, a two-node lumped mass model was found to adequately represent 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 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 3 the overturning moment at the base of the module for both the first mode response and rigid body motion. The mass of the bottom of the model was set equal to the difference between the total module mass and the mass at the top. This ensured that the shear force at the base was preserved for rigid body motion. Finally, the stiffness of the structural element was selected to preserve the fundamental frequency of the module. The effects of the corner supports were added to the model by including base springs and the final model was used in the sliding analysis. The horizontal spring represents the stiffness of the support pad and the vertical spring represents 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.

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 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 allowable stresses are given in Table 4-1 based on the following equations.

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

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

In accordance with ASME Section III, Subsection NF, Paragraph NF-3230, thermal stresses are not considered. Furthermore, 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.

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 gradient 3
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 against overturning was also checked and they were found to be stable. Those values are summarized in Table 4-2. 1

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).

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 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. 3

A free fall of a fuel assembly onto the fuel pool liner was evaluated to serve as a basis for concluding that the leaktightness of the fuel pool liner plate is maintained. The evaluation demonstrated that the energy developed by a freely falling fuel assembly from a height extending 27 inches above a module would not cause liner plate perforation (Reference7).

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

Loads that may be carried over the spent fuel pool racks are listed in Table 4-4. The consequences of dropping any of those items onto the spent fuel pool racks are no more severe than those of the fuel assembly 3
drop accident. The provisions employed to prevent movement of heavy objects over the spent fuel assemblies are discussed in Section 11.0

The loads experienced under a stack 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 spent fuel pool structure was re-evaluated based on the increased loads caused by the new high density spent fuel storage racks. A three dimensional finite element model for the spent fuel pool and supporting structure was used for the analysis.

The ACI 349-76 code "Code Requirements of Nuclear Safety Related Concrete Structures" was used as the design basis for the structural re-evaluation. As required by the code, the following is a listing of the primary loads that were considered.

1. The dead weight of the structural elements (D).

2. The live loads acting on the structural elements (L).

3. The hydrostatic load of the water in the pool (F).

4. A three-component OBE seismic load (E_o).

5. A three-component SSE seismic load (E_{ss}). 3

6. A thermal loading based on normal operating conditions (T_o).

7. A thermal loading based on accident conditions (T_a).

The required strength, U, was obtained by using the following loading combinations:

1. $U = 1.4\ (D) + 1.7\ (L) + 1.4\ (F) + 1.7\ (E_o)$

2. $U = (D) + (L) + (E_{ss}) + (T_o)$

3. $U = (D) + (L) + (E_{ss}) + (T_a)$

4. $U = 0.75\ [1.4\ (D) + 1.7\ (L) + 1.4\ (F) + 1.7\ (E_o) + 1.4\ (T_o)]$

The re-evaluation for the Unit 1 spent fuel pool structure showed that the existing structure and liner plate will have adequate capacity to carry the additional loads imposed by the high density spent fuel racks. The allowables established by the ACI 349-76 code are not exceeded. The re-evaluation for Unit 2 will be completed by the middle of November 1979. However, based on Unit 1 results and because of the similarities

between the Unit 1 and 2 structures surrounding their respective spent fuel pools, adequacy of the Unit 2 pool structure will be demonstrated. The outcome of this analysis will be submitted by December 1, 1979. 3

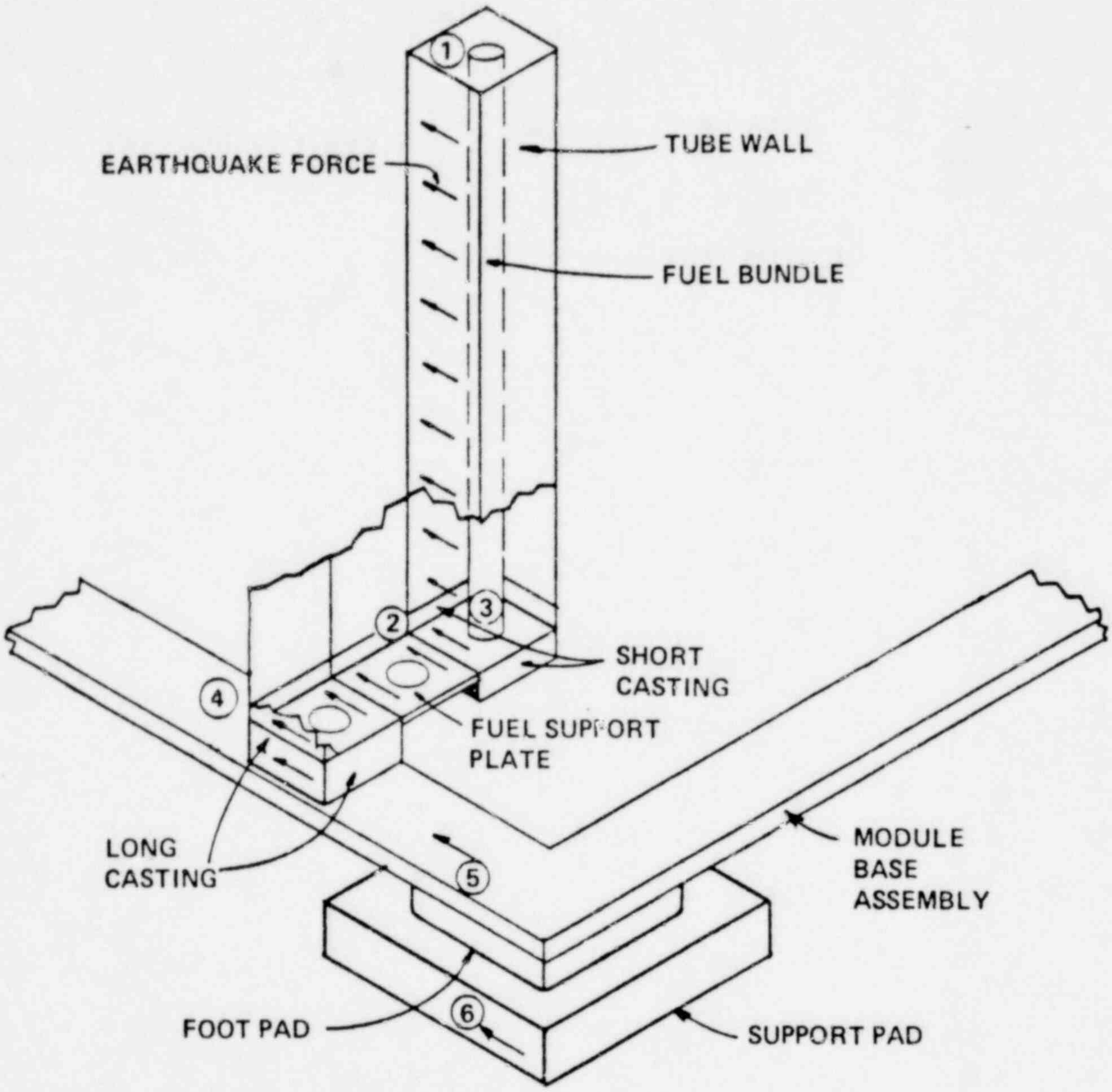
1265 251

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	350
Defective Fuel Cannister	175

3

1265 252



Amend. 3 10/79

Figure 4-10 Path of Earthquake Horizontal Forces in Module

Boral's corrosion resistance is similar to that of standard aluminum sheet. Corrosion data and industrial experience confirm that aluminum and Boral are acceptable (Reference 2) for the proposed 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 3
Boral without stainless "cladding". The stainless "clad" coupons 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).

1265 254

13.0 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

1265 255

RESPONSE TO NRC QUESTIONS

CONTAINED IN THE NRC'S

LETTER OF SEPTEMBER 28, 1979

1265 256

QUESTION 1

Discuss the effects of the increased loads due to the new rack structures on the fuel pool liner and structures.

RESPONSE:

The response has been incorporated into Section 4.3.

1265 257

QUESTION 2

Discuss the effects of the temperature gradient across the rack structure due to thermal differential between a full and an empty cell.

RESPONSE:

The response has been incorporated into Section 4.2.

1265 258

QUESTION 3

Provide the allowable stresses for all loading combinations considered in the rack design. Indicate whether these allowable stresses are in conformance with those allowables stated in "OTP for Review and Acceptance of Spent Fuel Storage and Handling Applications", issued by NRC on April 14, 1978, and later amended on January 18, 1979.

RESPONSE:

The response has been incorporated into Section 4.2.

1265 259

QUESTION 4

In deriving the hydrodynamic virtual mass it was assumed that the modules and the pool walls are rigid bodies. Indicate the reason why the flexibility of these walls may be ignored.

RESPONSE:

The response has been incorporated into Section 4.1.

1265 260

QUESTION 5

For the accident fuel assembly drop condition, describe in detail the assumptions, type of analysis, the ductility ratios and allowable stresses used in the analysis. Provide, also, the basis for concluding that the leak tightness of the fuel pool is maintained.

RESPONSE:

The response has been incorporated into Section 4.2.

1265 261

QUESTION 6

Provide sufficient detail of the base plates, foot pads, the support pads, all gaps of the rack structure and all sliding surfaces of the racks.

RESPONSE:

The response has been incorporated into Section 2.0.

1265 262

QUESTION 7

Discuss the provisions employed to prevent movement of heavy objects over the spent fuel assemblies. Include a description of all items which may be moved over the spent fuel assemblies. State whether the consequences of dropping any of these items into the rack are more severe than the fuel drop accident.

RESPONSE:

The response has been incorporated into Section 4.2.

1265 263

QUESTION 8

During seismic events (horizontal and vertical), part of the fuel bundle inertial forces is transferred directly to the tube wall or the fuel support plate through the clearance gaps. Indicate how these impactive motions have been considered in the analysis along with the effects of fuel storage rack rocking and sliding on the pool floor. Provide the numerical values for these impactive factors (dynamic amplification factors) and justifications.

RESPONSE:

In the seismic analysis and nonlinear analysis of the HDFSS module to calculate the rocking and the sliding motion, the mass of the fuel is included in the mass of the module. This approach is deemed to be conservative because of energy dissipation resulting from fuel bundle rattling motion and the random nature of the fuel storage positions in the storage locations. However, additional analysis is being performed to verify the conservative nature of this approach, and the results are expected to be available by December 31, 1979.

1265 264

QUESTION 9

In the non-linear analysis to calculate the amount of sliding and tilting, a two-node lumped mass model was chosen. Provide more justification and details (sketches and descriptions) of this model.

RESPONSE:

The response has been incorporated into Section 4.1.

1265 265

QUESTION 10

Discuss the service surveillance plans, if any, that you have developed to aasure long-term corrosion protection for the fuel rack system in the pool environment.

RESPONSE:

The response has been incorporated into Section 5.0.

1265 266

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 storage tubes in 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.

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.

1265 267