MECHANICAL AND STRUCTURAL CONSIDERATIONS
NEW UPPER TIER SPENT FUEL STORAGE RACKS

YANKEE ATOMIC ELECTRIC COMPANY

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FRAMINGHAM, MA 01701

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4.0 MECHANICAL AND STRUCTURAL CONSIDERATIONS

4.1.0 INTRODUCTION

4.1.1 This section contains the description and structural evaluation of new upper tier spent fuel storage racks.

4.1.2 Section 4.2.0 of this document is a summary. Section 4.3.0 includes a physical description of the racks, gratings, rack support structure and a description of the Quality Assurance Program for the rack and grating fabrication. Section 4.4.0 describes the analytical models and the results of the structural analyses for the spent fuel storage racks and grating, and the rack support structure.

4.2.0 SUMMARY

4.2.1 The spent fuel racks are of a welded stainless steel construction containing a neutron absorbing medium of natural boron carbide (B_4C) in an aluminum matrix core clad with 1100 series aluminum. This neutron absorber is marketed under the trade name of Boral. The Boral is sealed within two concentric square stainless steel tubes hereinafter called "Poison Cans". The B-10 areal density of the Boral is 0.0238 g/cm^2. Applicable Federal Regulations, Nuclear Regulatory Commission (NRC) Regulation and the latest industry standards were used as design basis for the structural seismic design of the racks.

4.2.2 The racks will be designed and fabricated to meet the requirements of Yankee Nuclear Power Station (Yankee) specifications and applicable portions of the NRC Regulatory Guides and published standards such as, but not limited to, the following references of Section 4.5.0.

A. April 14, 1978 NRC Position for Review and Acceptance of Spent Fuel Storage and Handling Applications, with modifications of January 18, 1979.

B. Regulatory Guides

1.13 - Design Objectives for Light Water Reactor Spent Fuel Storage Facilities at Nuclear Power Stations

1.29 - Seismic Design Classification

1.61 - Damping Values for Seismic Design of Nuclear Power Plants

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

C. Standard Review Plan

3.7 - Seismic Design

3.8.4 - Other Category I Structures

9.1 - Fuel Storage and Handling

D. Industry Codes and Standards

1. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code Section III, Division 1
2. American Institute of Steel Construction Specification
3. American National Standards Institute, N45.2-1977

4.3.0 DESCRIPTION OF PROPOSED UPPER TIER SPENT FUEL RACKS, GRATING, AND SUPPORT STRUCTURE

4.3.0.1 The proposed rack modules will hang from a network of beams and columns hereinafter called the "support structure" and are designed, such that, the racks will take no vertical load at the base. The racks fit within vertically welded gussets, adjacent modules are therefore separated, thereby eliminating module-to-module contact. The nominal clearance between the modules and the frame gusseting is 1/2 inch (1/4 inch per side). (See Figures 4.3.0-A, -B.)

4.3.0.2 The proposed individual grating elements will rest on the support structure directly below each of the racks within vertically welded gussets. The grating will protect existing standing racks and fuel on the pool floor from a dropped fuel assembly accident. Excessive horizontal swaying of the rack base is limited by the grating. The grating is also used to limit transverse motion of the support structure. The nominal clearance criteria remains the same as stated in Section 4.3.0.1. (See Figure 4.3.0-C.)

4.3.0.3 The support structure will carry 72-1X5 spent fuel storage racks and 72 gratings. The support structure consists of W12 I-Beams utilizing bolted connections. The framework is comprised of a network of beams supported by intermediate columns attached to the pit floor. The side rail beams are bolted to embedments in the pool walls. All materials are Type 304 stainless steel. (See Figures 4.3.0-D, -E and -F.)

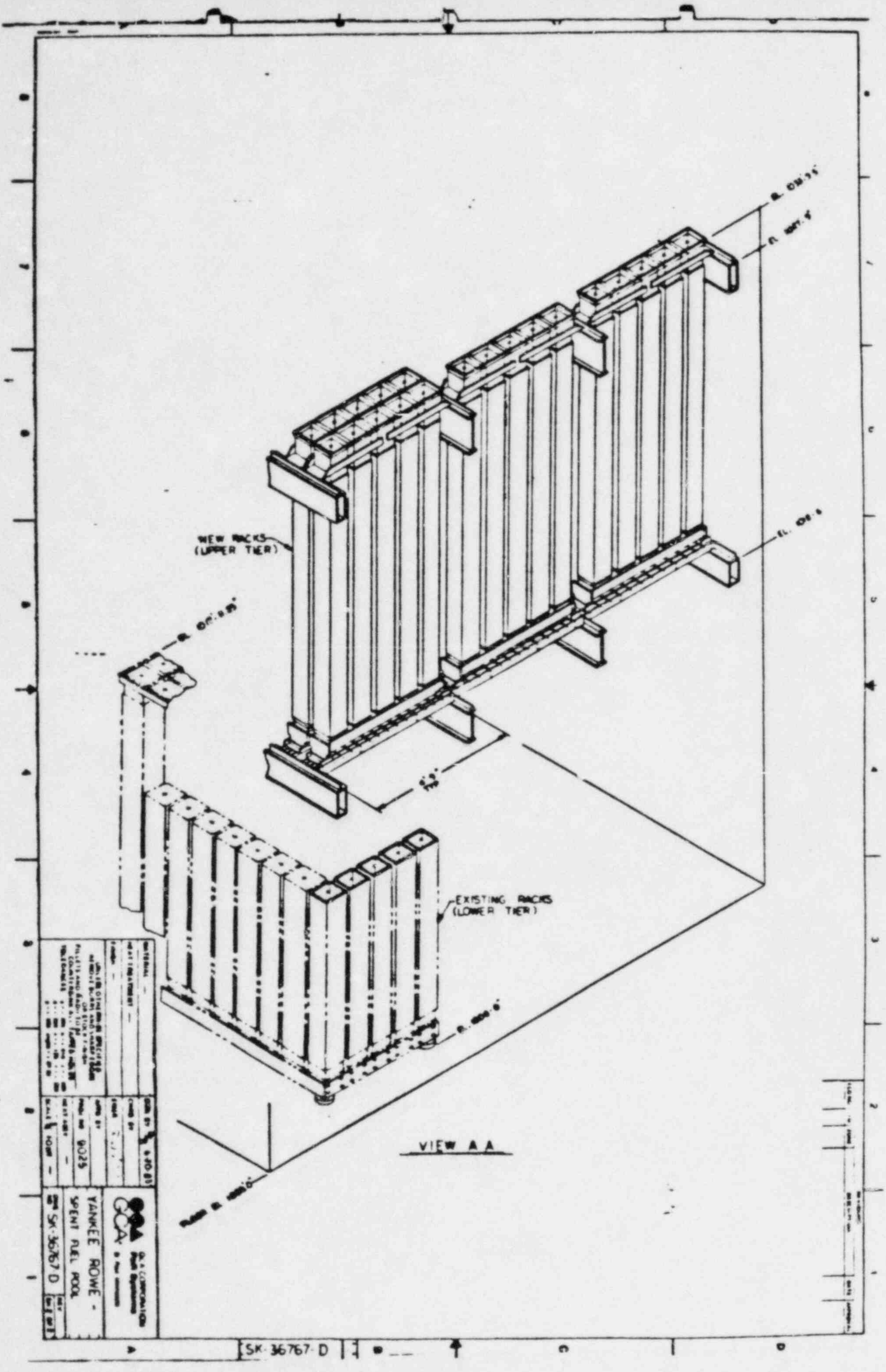
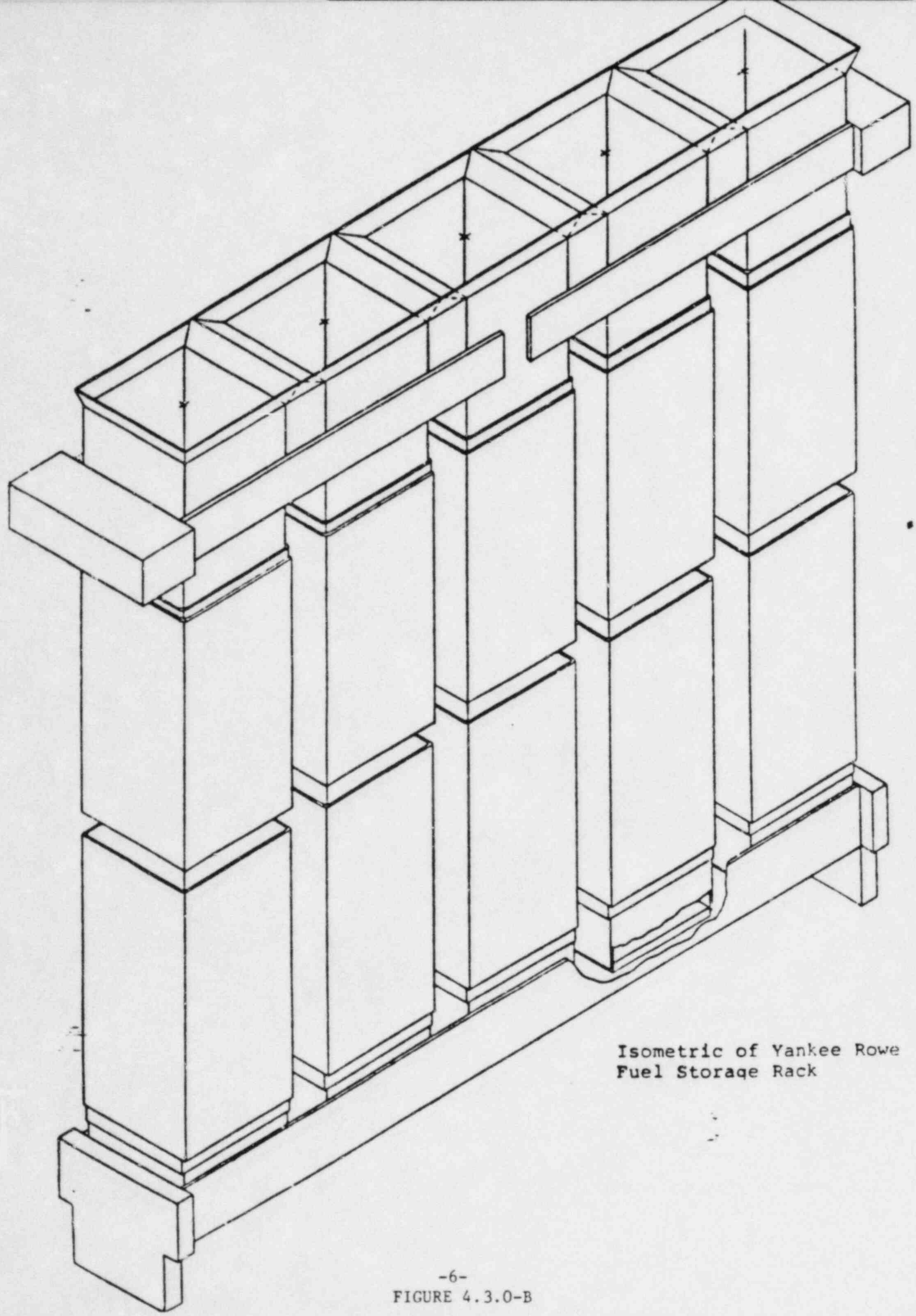

NEW RACKS (UPPER TIER)
EXISTING RACKS (LOWER TIER)
VIEW A A
YANKEE ROWE - SPENT FUEL POOL
9025
SK-36767 D
SK-36767-D

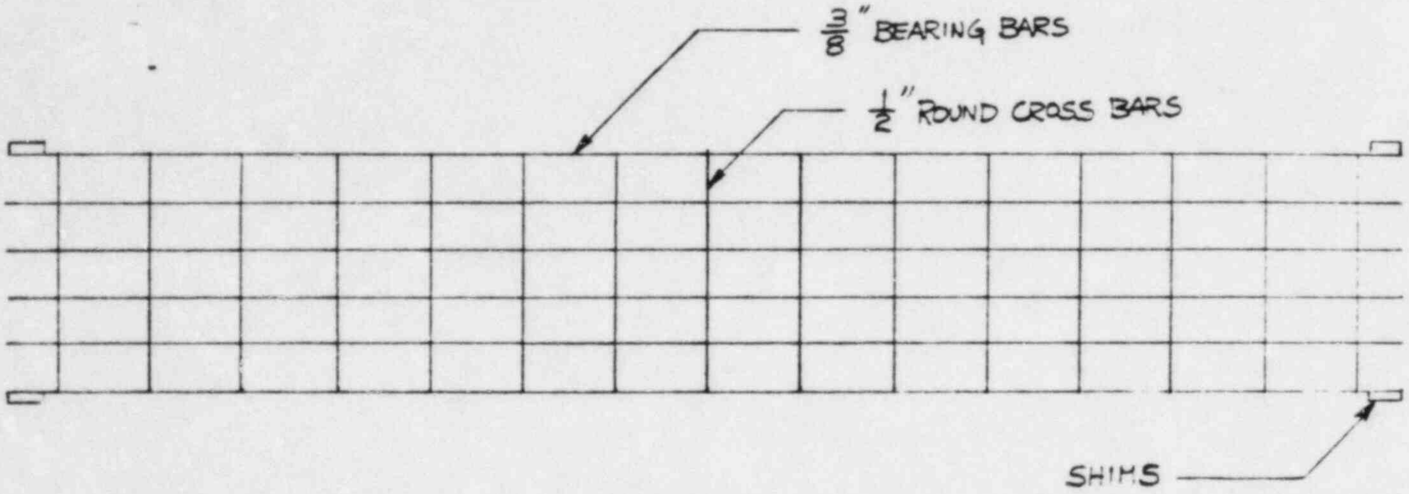
FIGURE 4.3.0-A



Isometric of Yankee Rowe
Fuel Storage Rack

FIGURE 4.3.0-B

GRATING



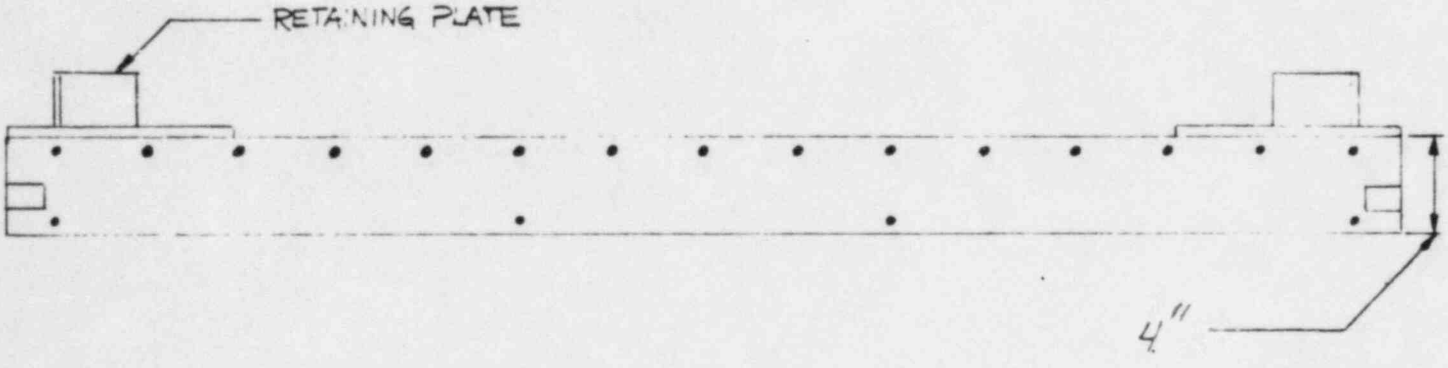


FIGURE 4.3.0-C

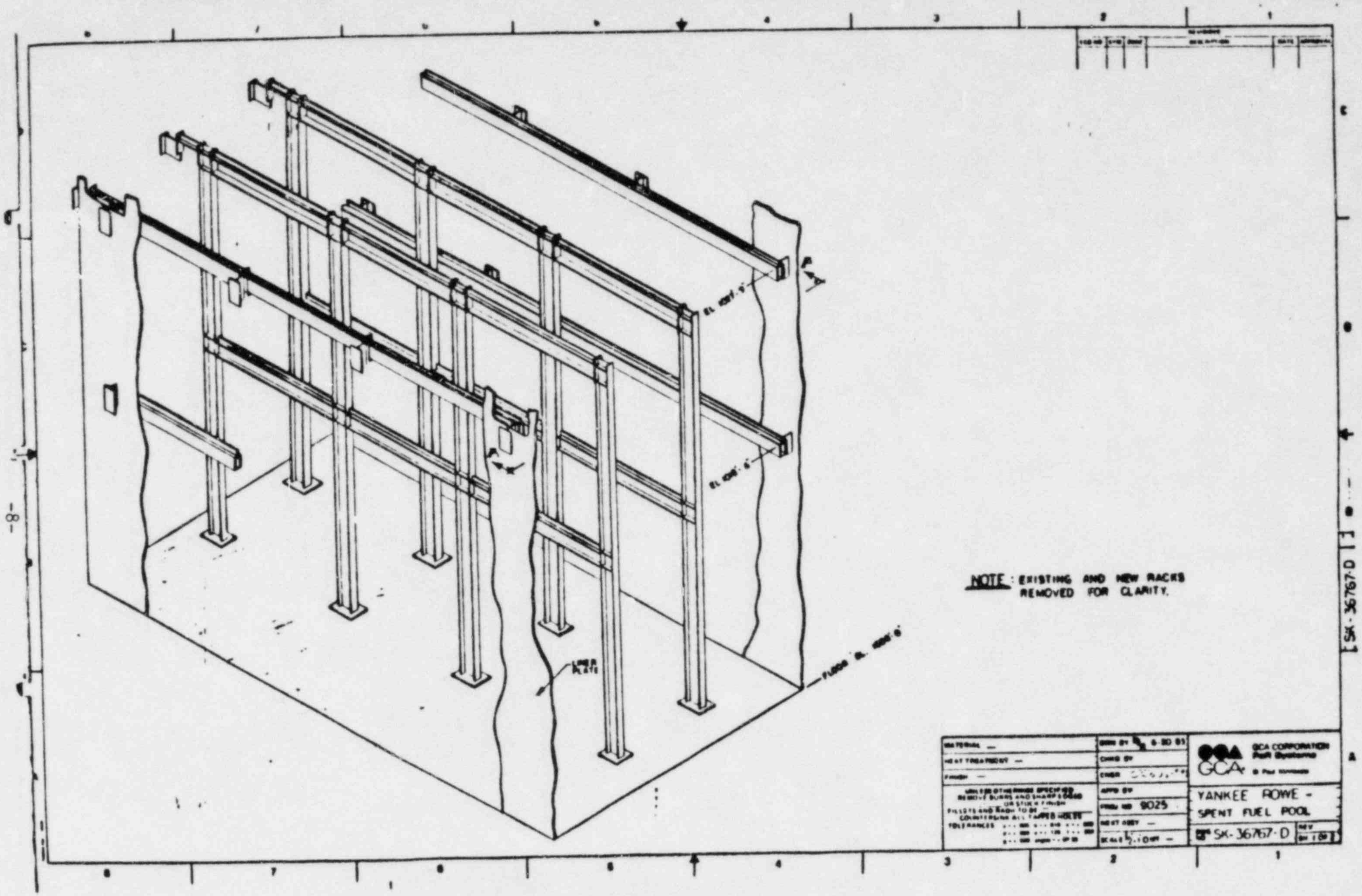

NOTE: EXISTING AND NEW RACKS REMOVED FOR CLARITY.
EL.
EL.
FLOOR EL.
LINER PLATE
MATERIAL —
HEAT TREATMENT —
FINISH —
UNLESS OTHERWISE SPECIFIED REMOVE BURRS AND SHARP EDGES
DRN BY 6-30-83
CHKD BY
ENGR
APPD BY
PROJ NO 9025
NEXT ASSY —
SCALE
GCA CORPORATION
GCA
YANKEE ROWE - SPENT FUEL POOL
SK-36767-D
[SK-36767-D]

FIGURE 4.3.0-D

CROSS SECTIONAL VIEW OF RACK SUPPORT STRUCTURE

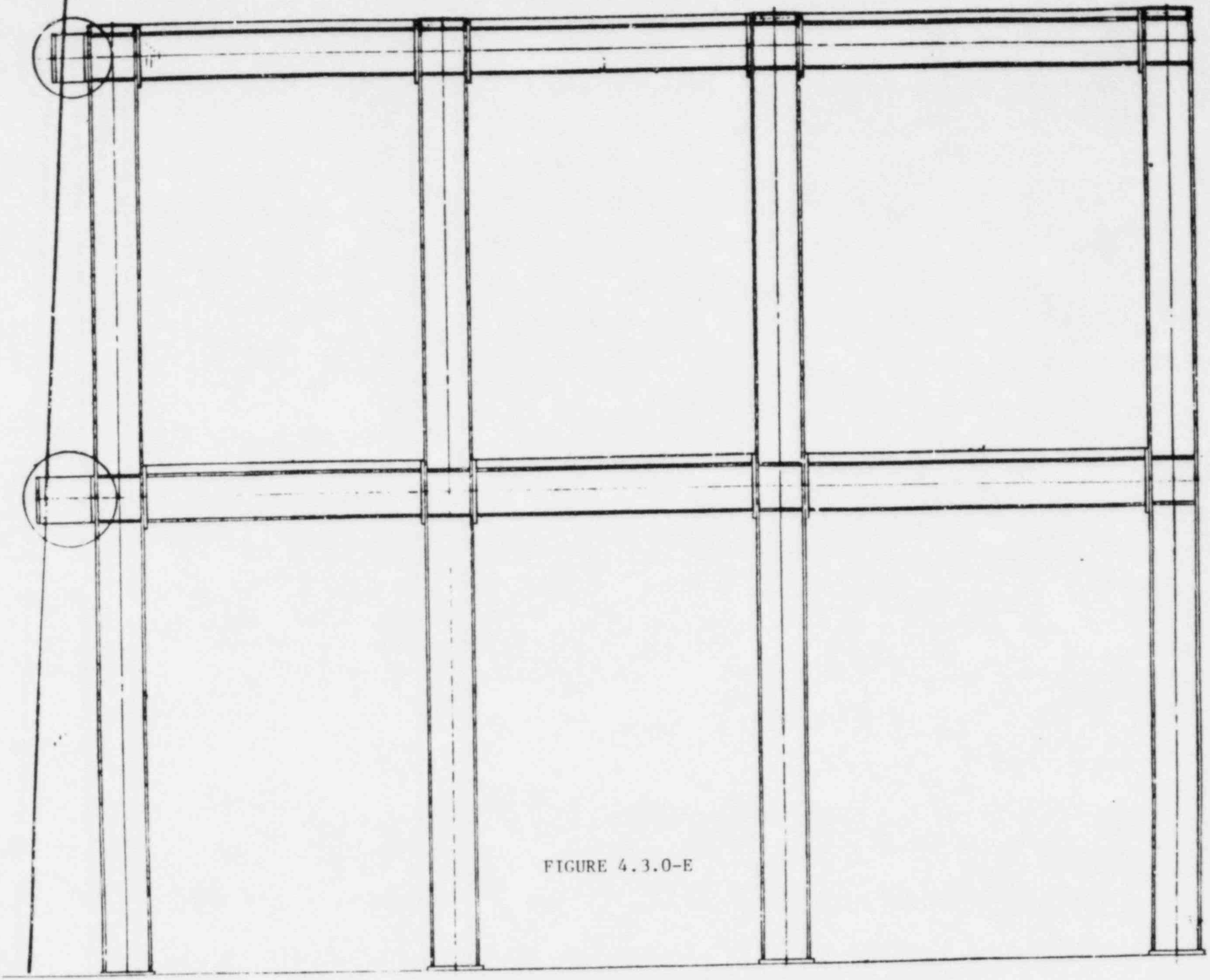
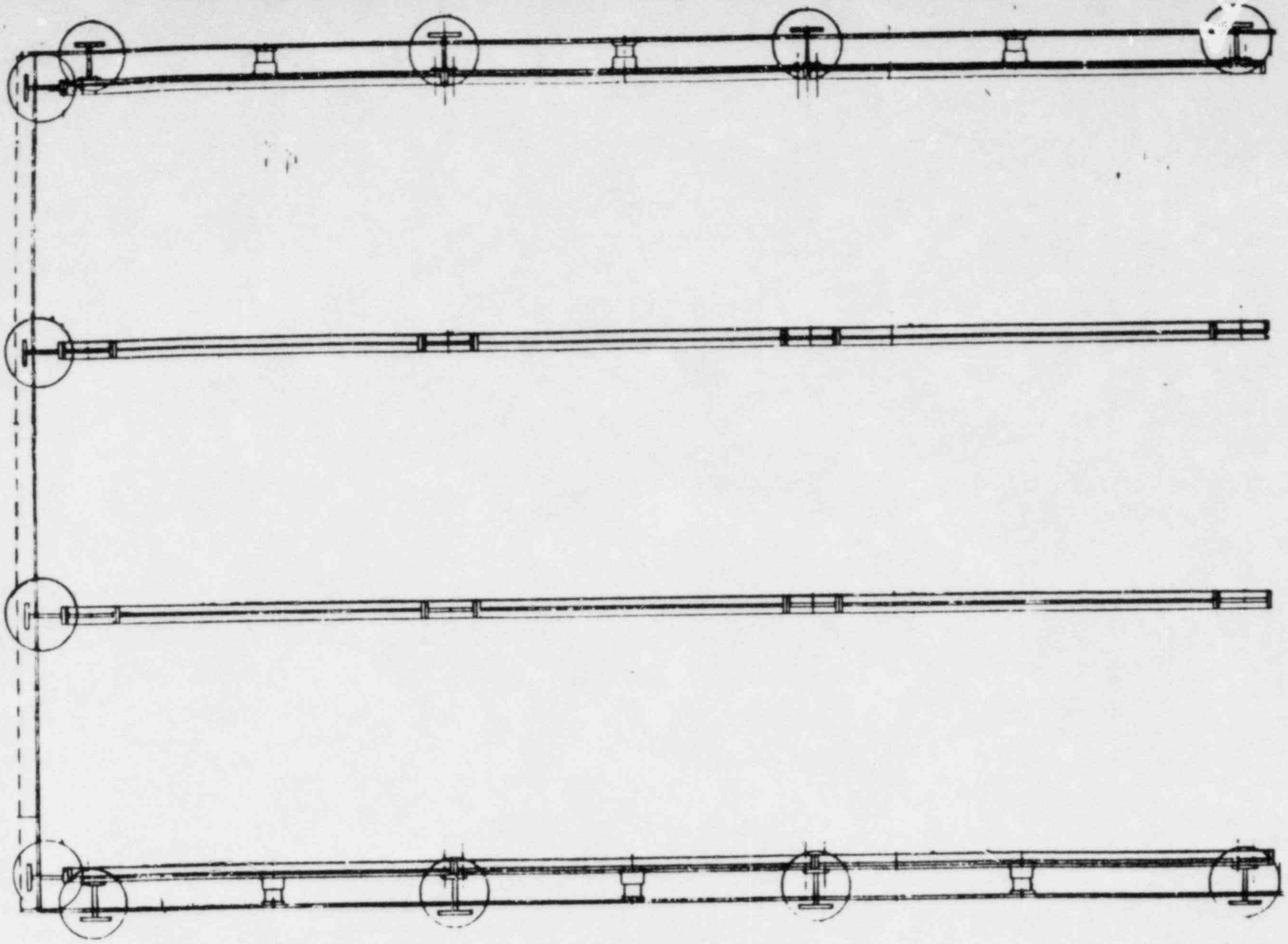


FIGURE 4.3.0-E



FLOOR PLAN – RACK SUPPORT STRUCTURE

FIGURE 4.3.0-F

4.3.1 Module Construction (See Figures 4.3.1-A, 4.3.1-B)

The proposed spent fuel storage racks are a poisoned design. The rack module is composed of poison canisters, a bottom grid, and a partial upper grid with brackets for hanging the racks. Except for the neutron absorber, all rack materials are fabricated from 300-series stainless steel.

4.3.1.1 Poison canisters are die-formed and welded at the top to horizontal perimeter bars. These canisters also provide lead-in surfaces for the fuel.

4.3.1.2 The poison canisters are also welded to horizontal perimeter bars at the bottom with the fuel support surfaces welded to the poison canisters.

The nominal interior square width dimension of the fuel canister will be 8.045 ± .06 inches to accommodate the fuel.

4.3.1.3 Prior to shipment, each poison canister will be checked by a full-length dummy fuel assembly, (7.92 x 7.92, +/-.125 inches) which will account for the combined cross sectional tolerance, straightness, twist, and opening squareness.

4.3.1.4 The poison canister consists of two concentric stainless steel tubes with Boral in the annulus. The outside tube is welded to the inside canister at the top and bottom.

4.3.1.5 The rack utilizes a vented Boral design. This design has been used extensively in spent fuel storage racks for several years. The vented design allows pool water to come in contact with the Boral, thus venting any hydrogen gas generated into the pool water.

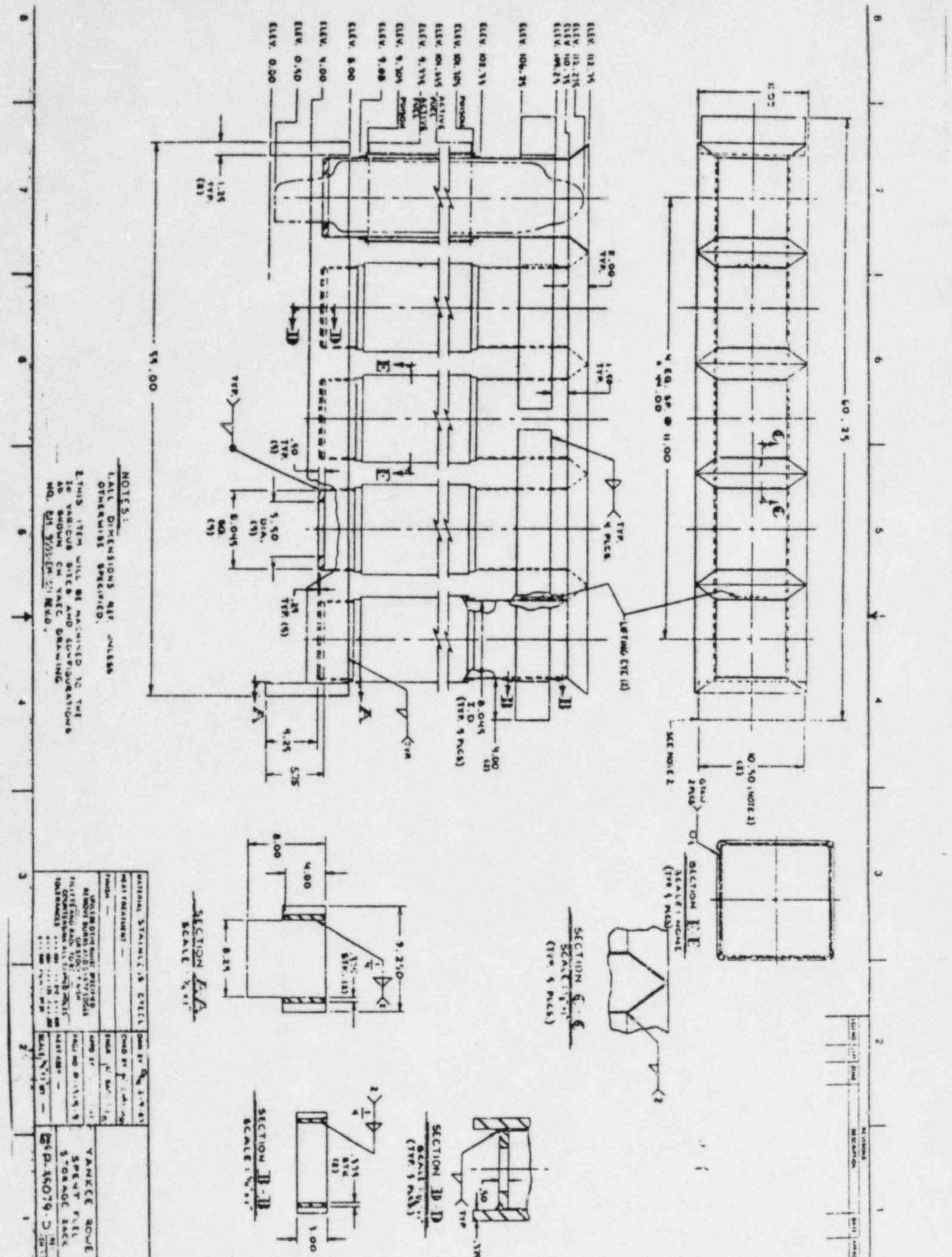

ELEV. 112.75
ELEV. 110.75
ELEV. 108.25
ELEV. 106.25
ELEV. 102.75
POISON
ACTIVE FUEL
ELEV. 9.00
ELEV. 8.00
ELEV. 4.00
ELEV. 0.50
ELEV. 0.00
55.00
60.25
4 EQ. SP. @ 11.00
LIFTING EYE (2)
SEE NOTE 2
10.50 (NOTE 2)
SECTION E-E
SECTION C-C
SECTION A-A
SECTION D-D
SECTION B-B
NOTES:
1. ALL DIMENSIONS REF. UNLESS OTHERWISE SPECIFIED.
2. THIS ITEM WILL BE MACHINED TO THE VARIOUS SIZES AND CONFIGURATIONS AS SHOWN ON YAEC DRAWING
MATERIAL STAINLESS STEEL
YANKEE ROWE - SPENT FUEL STORAGE RACK

FIGURE 4.3.1-A

TYPICAL FUEL ASSEMBLY

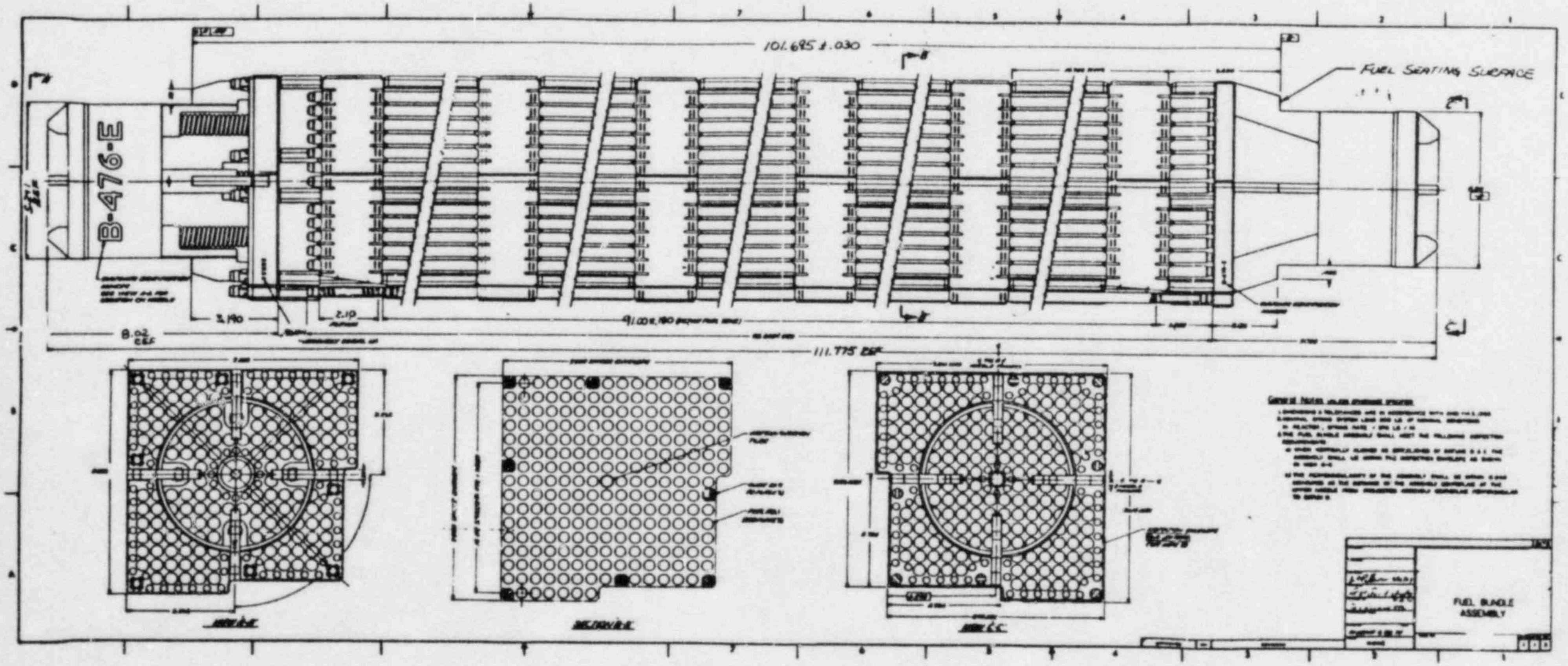


FIGURE 4.3.1-B

4.3.1.6 The Yankee design uses the inner wall can as the structural member. Gas generation will not cause the outer skin to bow since all gases are vented to the pool. The fuel bundle will not become wedged into the can and the Boral will not be mislocated due to gas pressure.

4.3.1.7 Note that only the inside canister tube is used as a structural element. The outer tube will be 0.024 inches thick.

4.3.2 Grating Construction

The proposed gratings are essentially six individual plates held together by inserting cross bars through the plates and welding at selected intersection points.

4.3.2.1 Holes are drilled at 19 locations through all six plates. The plates are held in a special fixture to prevent the plates from becoming misaligned.

4.3.2.2 The cross bars are inserted through the holes and subsequently welded to the plates.

4.3.3 Rack Fabrication

4.3.3.1 The storage racks will be fabricated in accordance with the detail drawings and specifications established during the design phase.

4.3.3.2 All structural welding on the racks will be either gas metal-arc welding [GMAW (MIG)] or gas tungsten arc welding [GTAW (TIG)]. These weld processes give clean spatter-free welds with good penetration and no slag formation. The outer tube will be TIG-welded to the inner canister. The individual cavities will be welded on special fixtures to maintain the required squareness and dimensional tolerances. The module structures will then be welded together using a special fixture to assure that the assembly is square and properly aligned.

4.3.3.3 The racks will be cleaned, completely wrapped with reinforced plastic and skid mounted. The racks will be covered with tarp and shipped by motor freight.

4.3.3.4 All materials used in rack construction are of U.S. origin. The following charts present materials, alloys, and material specifications used in the spent fuel rack module assembly.

Description	ASTM Standard	Alloy
Grid Members	ASTM-A240	304 SS
Inner Canister	ASTM-A240	304 SS
Outer Canister Wrapper	ASTM-A240	304 SS
Boral	ASTM B209 and ASTM C750-80	1100 Alum. and B_4C

4.3.3.5 The following chart describes the weights and dimensions of the rack module.

Module Size	Width (in.)	Length (in.)	Dry Wt. (lbs.) (Empty)
1 x 5	60.25	112.75	1000

4.3.4 Grating Fabrication

4.3.4.1 The grating will be fabricated in accordance with the detail drawing and specifications established during the design phase.

4.3.4.2 All structural welding on the gratings is per the description given in Section 4.3.3.2 of this document. The cross bars are welded to the plates at selected intersection points. The individual plates are held in place using special fixtures to maintain the required squareness and spacing.

4.3.4.3 The gratings will be cleaned and completely wrapped with reinforced plastic. The gratings will be covered with tarp and shipped by motor freight.

4.3.4.4 All materials used in grating construction are of U.S. origin. The following charts present materials, alloys, and material specification used in the grating assembly.

Description	ASTM Standard	Alloy
Bearing Bars	ASTM-A240	304 SS
Cross Bars	ASTM-A276	304 SS

4.3.4.5 The following describes the weights and dimensions of the grating.

Bearing Bars	4.0 x 0.375 x 60.25 (in.)
Cross Bars	9.375 x 0.5 dia. (in.)
Weight	175 (lbs.)

4.3.5 Quality Assurance

4.3.5.1 Materials

ASME or equivalent ASTM materials shall be used in the fabrication of the Spent Fuel Storage Racks.

4.3.5.2 Fabrication and Installation Requirements

All welders and welding procedures shall be qualified in accordance with ASME Section IX.

Tack welds that are incorporated into the final weld shall be, at a minimum, visually examined, and defective tacks removed. All weld filler metals shall meet the chemical and mechanical requirements of the applicable filler metal specifications as noted in ASME Section II, Part C.

The extent and frequency of repairs, and method of inspection of repaired areas shall be in accordance with ASME, Section III, Subsection NF for Class 3 supports.

4.3.5.3 Inspection, Examination and Test Requirements

4.3.5.3.1 General

Examinations, measurements or tests shall be performed for each work operation where necessary to assure quality. Inspection frequency and type shall be, at a minimum, in accordance with ASME Section III, NF for Class 3 supports.

4.3.5.3.2 Dimensional Verifications of Spent Fuel Modules

Each cell of the spent fuel module will be inspected using a dummy fuel bundle sized to assure the minimum required square opening including allowances for squareness, twist, and bow.

Each cell will be inspected to assure that the dummy fuel bundle can be placed vertically in the cell. This will be accomplished by placing the bundle into the cell and moving the top end of the bundle until it is vertical, thereby verifying that a vertical envelope of the proper dimension exists within the cell.

Minimum center-to-center spacing of cells will be inspected by gauging for minimum separation between the walls of adjacent cells. This measurement, done at the tops and bottoms of the cells, determines the spacing of the neutron absorber.

4.3.5.3.3 Neutron Poison Verifications

Procedures for the inspection and testing of the neutron poison material will be required of the supplier for approval by Yankee.

The boron carbide contained in the core of the Boral, shall conform to ASTM C750-80 Type 3 except that: (a) total boron and carbon content allowed is 95% by weight minimum; (b) total boron shall be 70.0 to 79.2%; (c) B-10 isotopic content in the boron shall be 19.45 minimum.

Particle Sizes:

Boron Carbide	-	80-325 Mesh
Through Sieve 50	-	0% Minimum
On Sieve 80	-	10% Maximum
Through Sieve 80-325	-	80% Maximum
Through Sieve 325	-	10% Maximum

Certification of sieve, chemical, and isotopic analysis will be provided for each B_4C lot.

A certificate of conformance shall be furnished for all other raw materials used in Boral. A real density of B_4C shall be verified by chemical analysis or neutron attenuation tests performed on coupons cut from material trimmed from the edges of the Boral sheets. These tests shall be performed on a sampling basis using sample sizes and acceptance criteria for the lots to assure a 95% confidence of the required areal density.

A uniformity test shall be performed on one plate in five hundred. This test consists of taking five coupons from a finished plate and performing the chemical analysis or attenuation test on them. These five coupons are taken along a diagonal of the plate to assure representation of all areas of the plate.

The four edges of all plates will be visually examined for the presence of a full core. All plates not having a full core shall be rejected.

Each piece of Boral sheet will be inspected for damage and for foreign material embedded in the surfaces. Evidence of foreign material in the skin of the Boral is cause for rejection. Scratches are allowed on the skin of the Boral provided the core is not exposed. Boral will be free of peeled skin and surface cracks.

Records for Boral will consist of the following:

1. B_4C test reports
2. Reports of chemical analysis or attenuation tests for each inspection lot
3. Records of plate serial numbers included in the inspection lots
4. Certificate of conformance to product specification and approved procedures

Qualification of nondestructive testing personnel shall be in accordance with SNT-TC-1A as applicable and shall be the responsibility of the supplier, subject to verification by Yankee.

4.3.5.4 Administrative

4.3.5.4.1 General

The supplier shall establish and maintain a Quality Assurance Program prior to the start of fabrication, for the control of quality of equipment supplied or work to be performed, to meet the requirements of 10CFR50 Appendix B, and ANSI N45.2.

The supplier shall implement a method of inspection, identification, marking and traceability of each individual piece of poison material in each cavity, and traceability of each cavity in a spent fuel storage rack.

4.3.5.4.2 Records

The following QA records shall be compiled and forwarded to Yankee at completion of fabrication:

1. Quality Assurance Program;
2. Welding Procedures and Qualifications;
3. NDE Procedures and Qualifications;
4. Cleaning Methods and Procedures;
5. Equipment Acceptance and Shipping Procedures;
6. Personnel Qualifications (welding, testing, etc.);
7. As-Built drawings;
8. Certificates of Compliances to specifications and standards;
9. Certificate of Compliance to ASTM C-750 and B-209 for poison material. Also certification of B_4C density in the core;
10. Inspection, examination, test results and reports;
11. Cavities/poison material traceability maps.

4.4.0 STRUCTURAL ANALYSES

4.4.1 Rack Support Structure Analysis

The rack support structure is analyzed using the NRC Spectrum (OBE) and will demonstrate functionality to NRC Spectrum (SSE) criteria.

4.4.1.1 ANSYS Model

The requirements for modeling the entire structure include 72 (1 x 5) racks, the support structure, the gratings, and the associated non-linear interfaces. This results in an extremely large model with possible computer system difficulties and ANSYS limitations.

Therefore, the approach taken to fully analyze this structure is as follows:

1) Apply the NRC spectrum at the ground level and determine motion applied to the racks. (See Figure 4.4.1-A.)

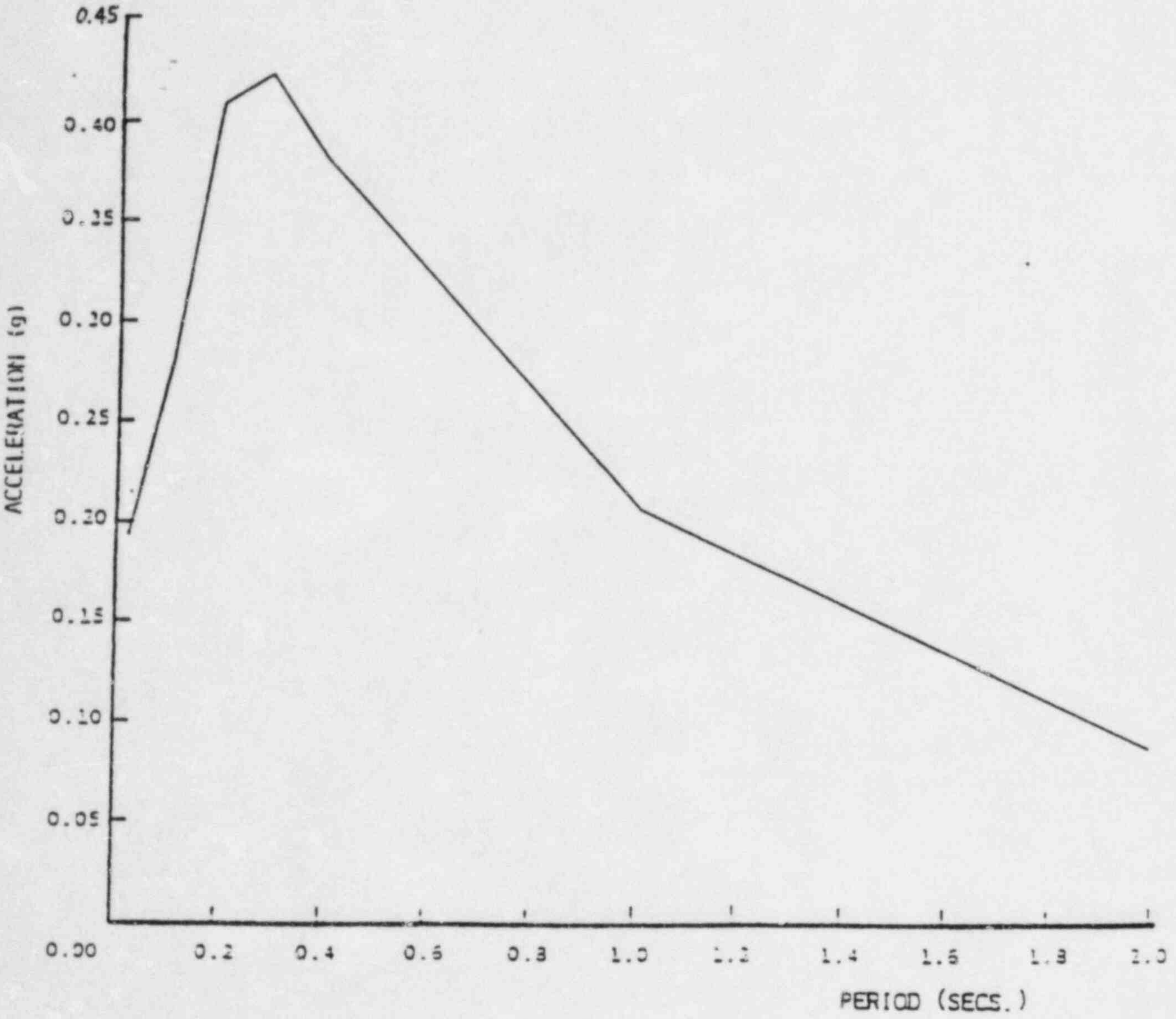
2) Omitting the non-linear interface effects, analyze the transient response of the rack/support structure (time history analysis).

The modified spectrum represents motion imposed on the racks by the support structure as a result of ground motion. The modified transient is developed by modeling the support structure/rack assembly without the non-linear interface elements, retaining all the mass and stiffness characteristics. This approach implies that overall structural response is not substantially affected by such local effects as friction and fuel impact in a single rack.

DESIGN RESPONSE SPECTRUM

NRC SPECTRUM

PGA = 0.19G, DAMPING = 7%



EARTHQUAKE SPECTRA

FIGURE 4.4.1-A

As a result, the overall response can be determined independently, and the resulting motion applied to a non-linear model for a detailed analysis of any particular rack.

4.4.1.1.1 A structural damping of 4% for bolted steel structures is used. No increase in damping is included for water submergence.

4.4.1.1.2 The rack support structure is located below any free surface wave activity. It is concluded that the rack support structure elevation compared to the pool water elevation is such that rigid body motion rather than sloshing loads is applicable to the analysis.

4.4.1.1.3 The digitized time histories are generated artificially using the computer program, SIMQKE, developed under the auspices of the National Science Foundation. The time histories developed for this analysis were chosen per guidelines in the relevant sections of NUREG/CR-1161. The time histories used are shown in Figures 4.4.1-B,-C,-D. The generated time histories have a duration of 12 seconds digitized at intervals of 0.01 seconds.

4.4.1.1.4 All column bases are simple supports. The structure embedments are considered fixed points.

4.4.1.1.5 For clarity, a portion of the ANSYS model is shown in Figures 4.4.1-E,-F and -G. The east and west internal support structure members are identical in geometry as are the side rail beams.

NORTH-SOUTH EXCITATION

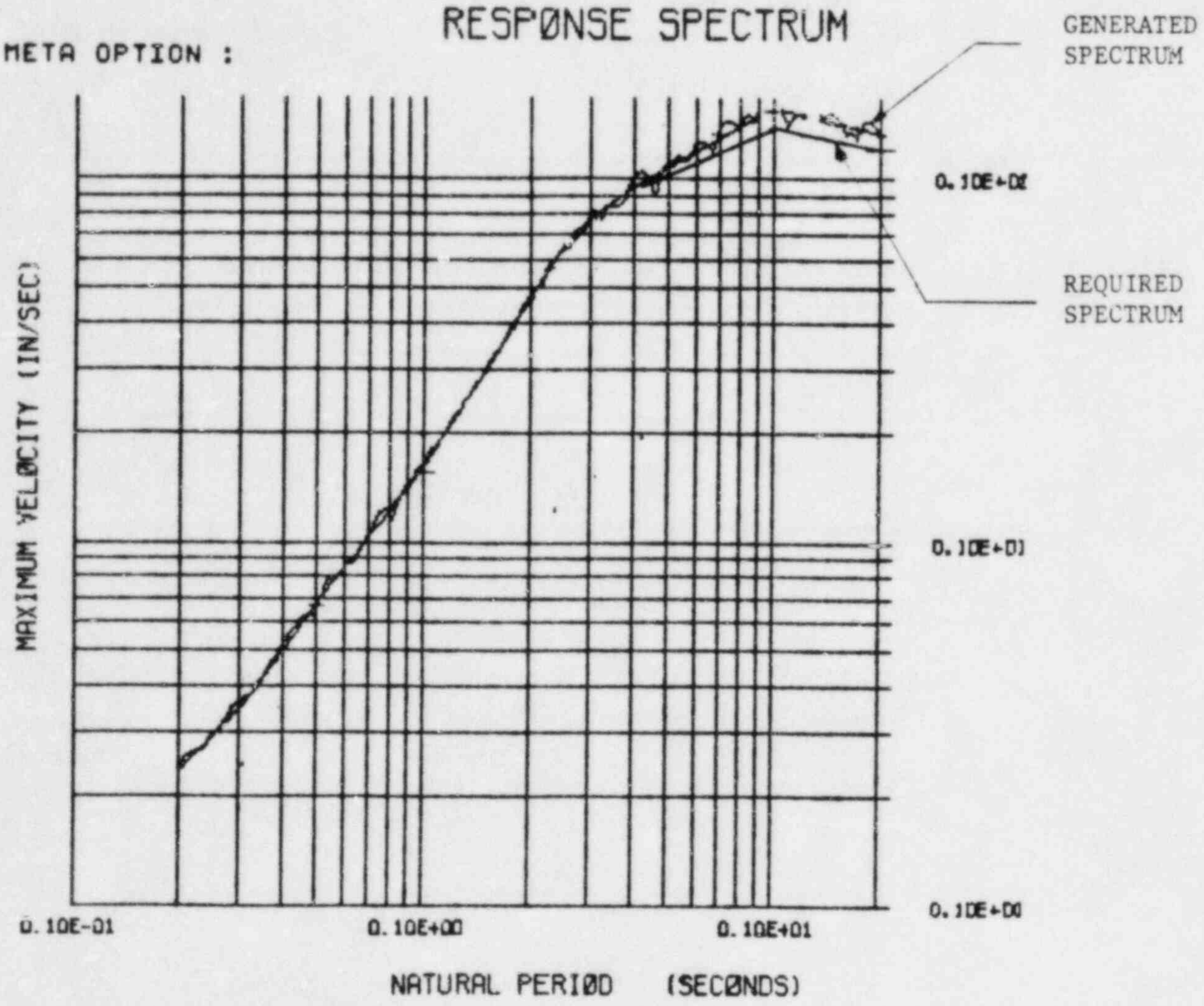


FIGURE 4.4.1-B

EAST-WEST EXCITATION

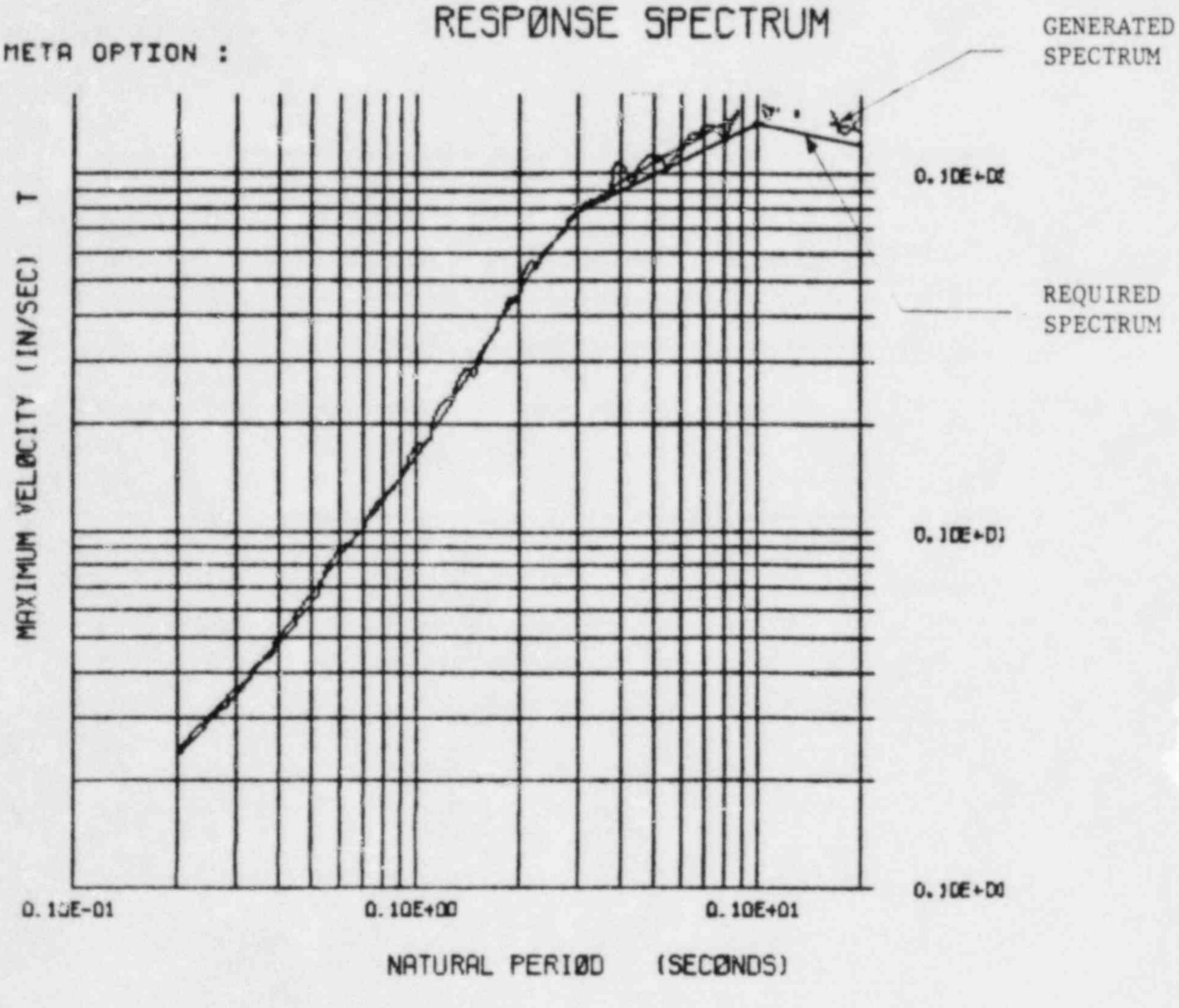


FIGURE 4.4.1-C

VERTICAL EXCITATION

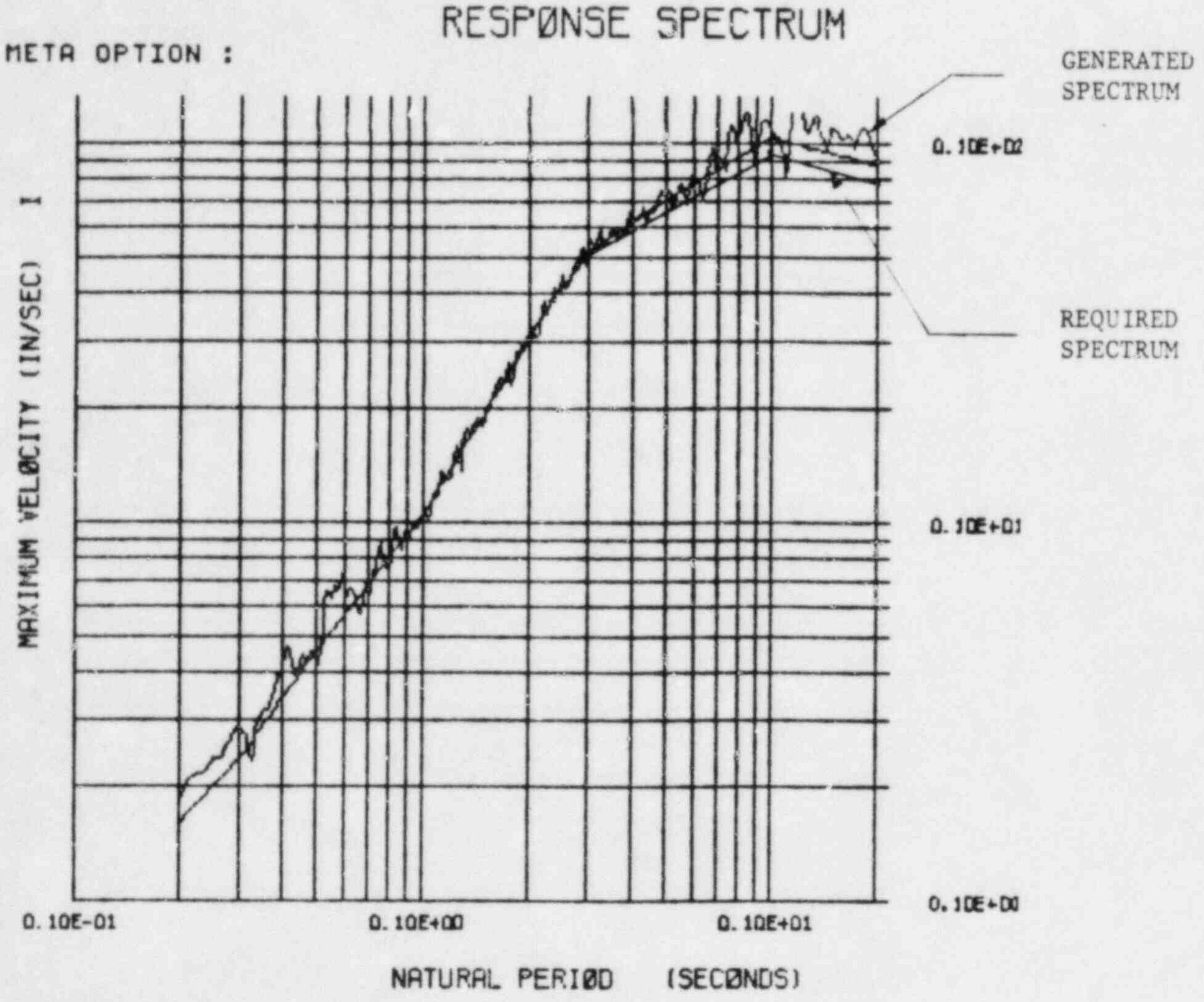


FIGURE 4.4.1-D

EAST INTERNAL FRAME MODEL

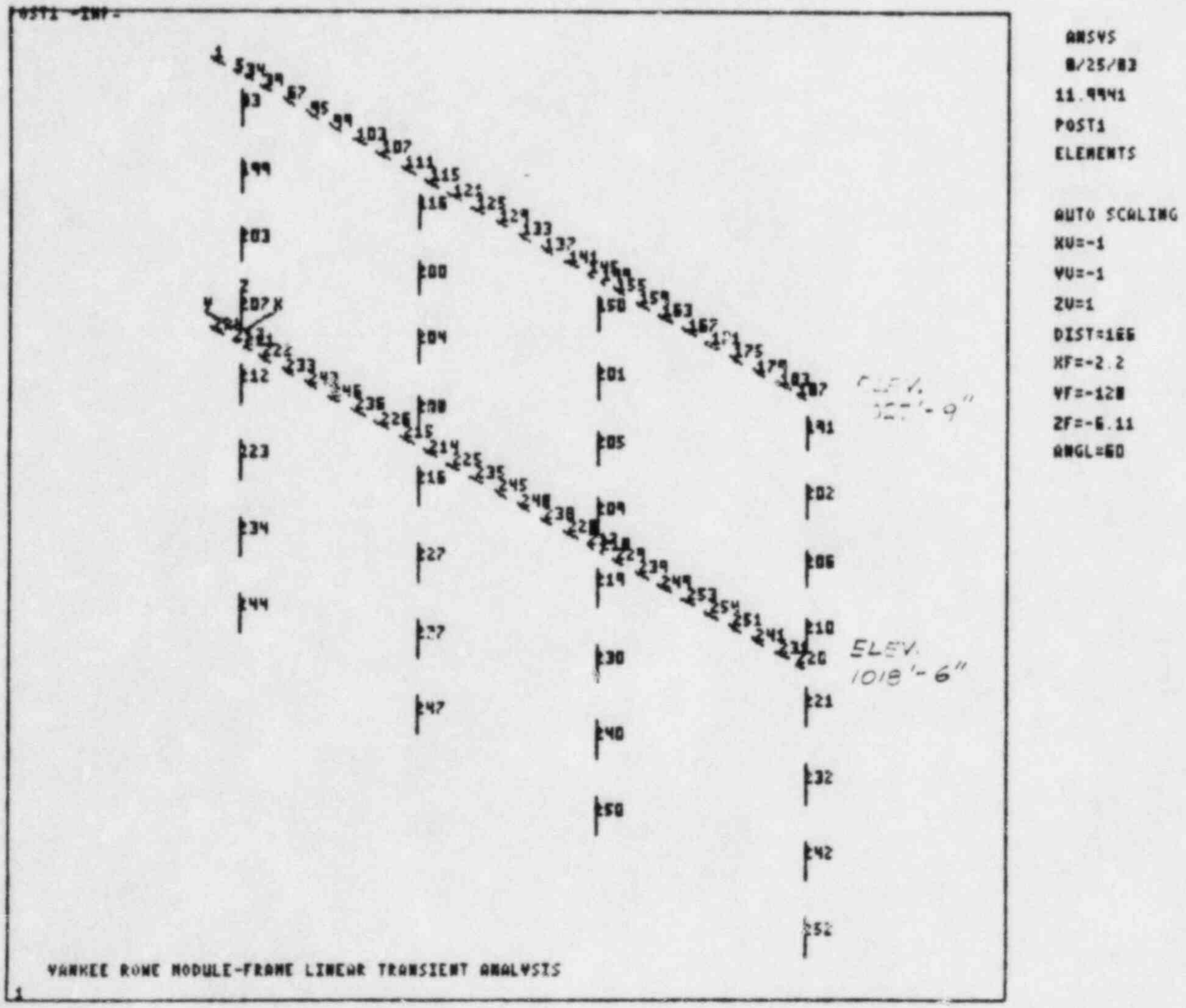


FIGURE 4.4.1-E

WEST INTERNAL FRAME MODEL

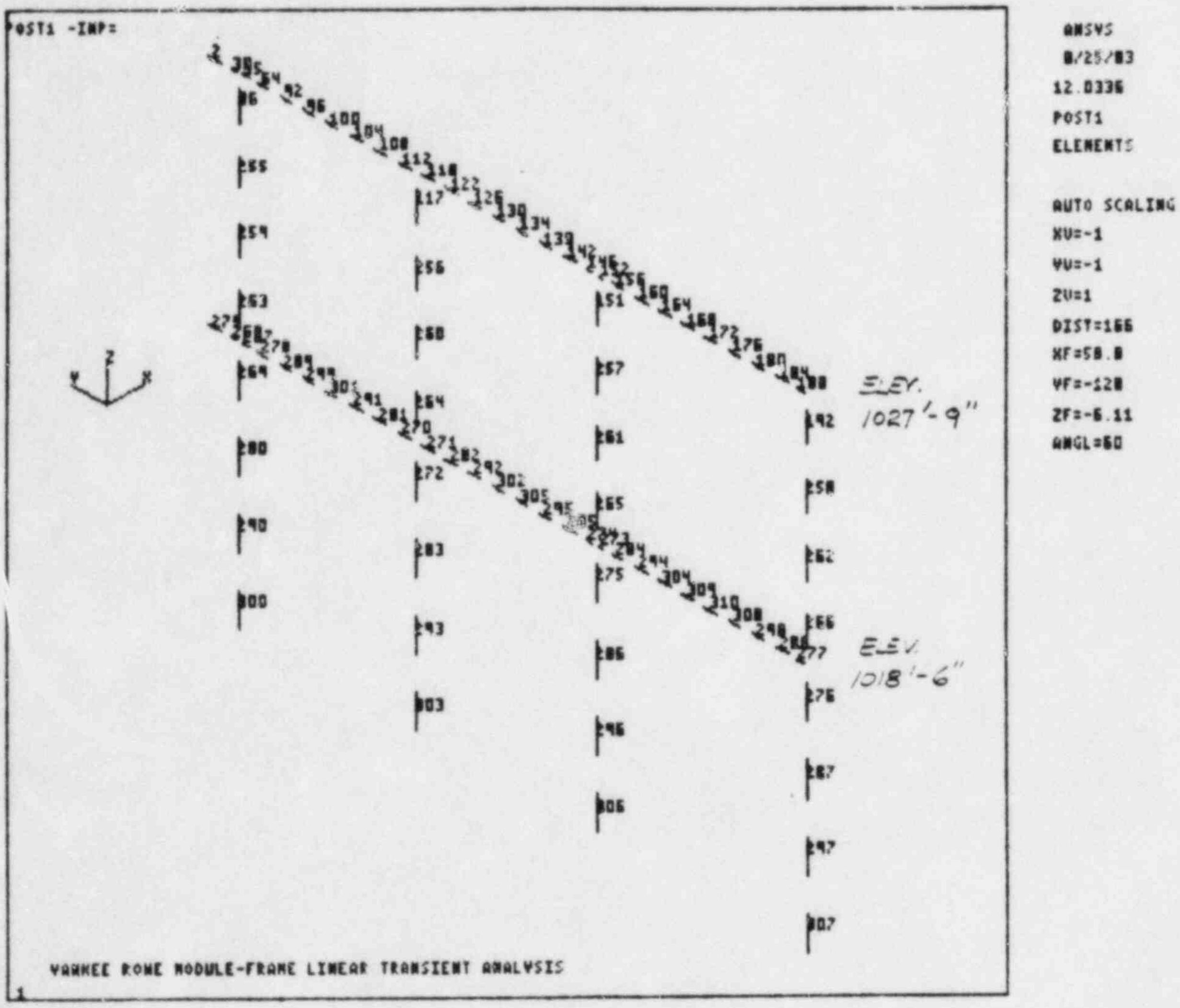


FIGURE 4.4.1-F

WALL BEAM MODEL

ELEV. 1027'-9"

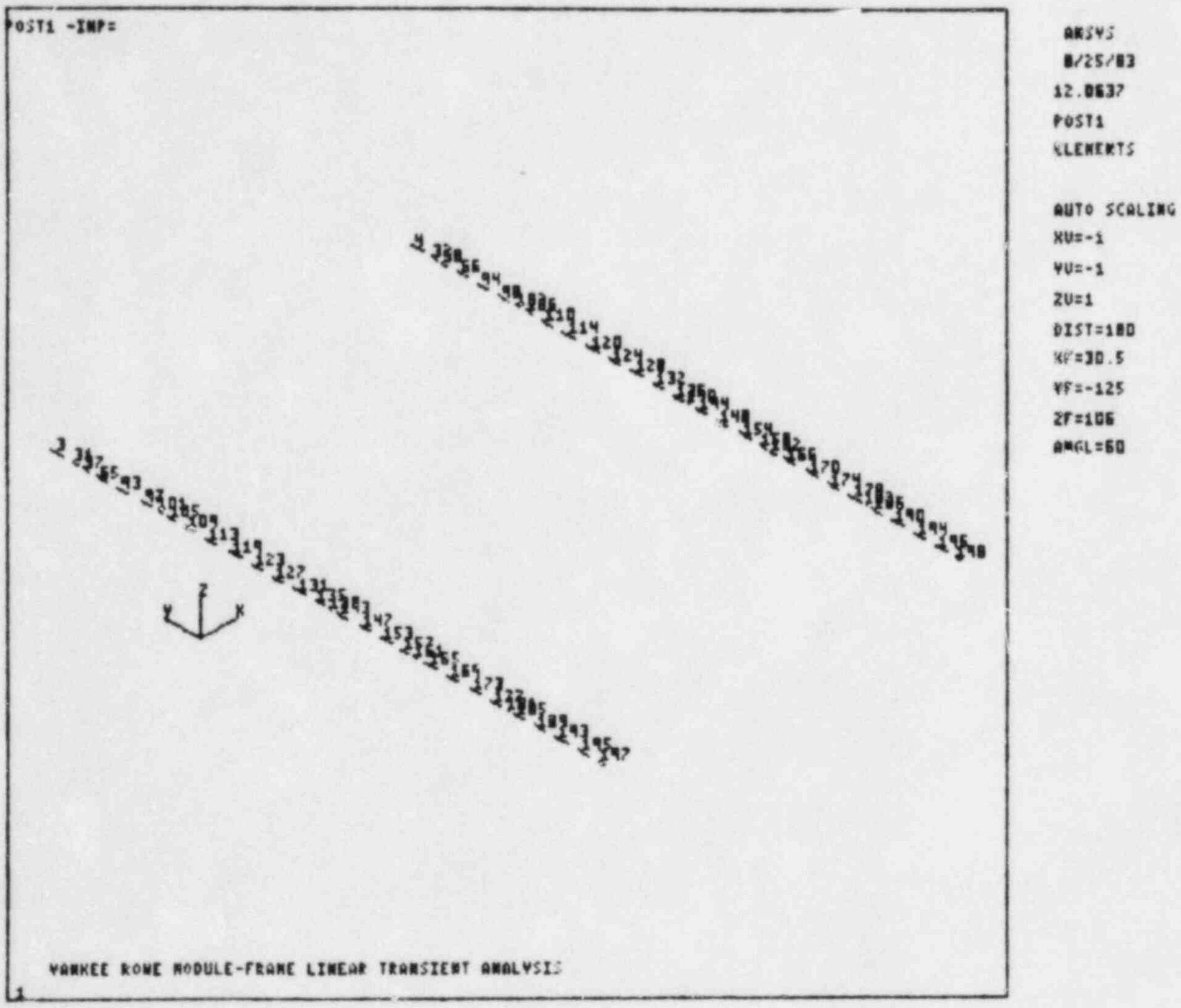


FIGURE 4.4.1-G

4.4.1.2 Results of the Transient Analysis

4.4.1.2.1 The allowable stresses shall be in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Appendix XVII.

4.4.1.2.2 Partially loaded configurations were analyzed since all 72 racks will not be installed prior to Yankee's 1984 outage. The following configurations were analyzed:

1. 1/3 Load Case - 24 (1 x 5) racks located on the south section of the support structure.
2. 2/3 Load Case - 48 (1 x 5) racks comprising the south and middle sections of the support structure.
3. Fully loaded Case - 72 (1 x 5) racks - the maximum load on the support structure.

The above cases include the mass of the individual gratings.

Load Case (3) produced the maximum stresses in the support structure and these are listed in Table 4.4.1-H.

4.4.1.2.3 Sliding at the column bases does not occur since the reaction loads no not exceed the friction forces.

4.4.1.2.4 The allowable stress for bearing on the pool floor is defined by Section 10.16 of the American Concrete Institute. The bearing stresses are determined using the maximum column base force from the linear transient analysis. (See Table 4.4.1-I.)

4.4.1.2.5 All embedments are retained in the pool walls by using rebar rock bolts. The summary of maximum bolt stresses are provided in Table 4.4.1-J.

TABLE 4.4.1-H

RACK SUPPORT STRUCTURE VERSUS ALLOWABLE STRESS

Element Number		Maximum Stress	Allowable Stress	OBE($1.0F_s$) Interaction		SSE($1.6F_s$)[1] Interaction	
1	AXIAL	2,302	15,730	.15		.09	
	BENDING - S.A.	15,924	18,150	.88	- 1.19	.55	- .74
	BENDING - W.A.	3,295	20,625	.16		.10	
2	AXIAL	2,326	15,730	.15		.09	
	BENDING - S.A.	15,874	18,150	.87	- 1.27	.55	- .80
	BENDING - W.A.	5,175	20,625	.25		.16	
106	AXIAL	*	-	-		-	
	BENDING - S.A.	7,276	18,150	.40	- .85	.25	- .53
	BENDING - W.A.	8,090	18,150	.45		.28	
118	AXIAL	1,228	15,830	.08		.05	
	BENDING - S.A.	10,298	18,150	.57	- .81	.35	- .50
	BENDING - W.A.	2,982	18,150	.16		.10	
140	AXIAL	*	-	-		-	
	BENDING - S.A.	9,679	18,150	.53	- 1.02	.33	- .64
	BENDING - W.A.	8,944	18,150	.49		.31	
144	AXIAL	*	-	-		-	
	BENDING - S.A.	8,593	18,150	.47	- .84	.30	- .53
	BENDING - W.A.	6,711	18,150	.37		.23	
149	AXIAL	*	-	-		-	
	BENDING - S.A.	14,362	18,150	.79	- .90	.49	- .56
	BENDING - W.A.	1,997	18,150	.11		.07	

TABLE 4.4.1-H (Cont'd)

RACK SUPPORT STRUCTURE VERSUS ALLOWABLE STRESS

Element Number		Maximum Stress	Allowable Stress	OBE($1.0F_s$) Interaction		SSE($1.6F_s$) Interaction[1]	
150	AXIAL	5,875	7,880	.75		.47	
	BENDING - S.A.	*	-	-		-	
	BENDING - W.A.	*	-	-		-	
152	AXIAL	*	-	-		-	
	BENDING - S.A.	14,216	18,150	.78	- .94	.49	- .59
	BENDING - W.A.	2,831	18,150	.16		.10	
155	AXIAL	*	-	-		-	
	BENDING - S.A.	10,155	18,150	.56	- .71	.35	- .43
	BENDING - W.A.	2,724	18,150	.15		.09	
156	AXIAL	*	-	-		-	
	BENDING - S.A.	10,067	18,150	.55	- .75	.35	- .48
	BENDING - W.A.	3,691	18,150	.20		.13	
171	AXIAL	*	-	-		-	
	BENDING - S.A.	9,600	18,150	.53	- .83	.33	- .52
	BENDING - W.A.	5,527	18,150	.30		.19	
186	AXIAL	*	-	-		-	
	BENDING - S.A.	7,093	18,150	.39	- .91	.24	- .56
	BENDING - W.A.	9,396	18,150	.52		.32	

S.A. - Strong Axis
W.A. - Weak Axis
* - These stresses are less than 1000 psi and were not printed in the output.
1 - Standard Review Plan, Section 3.8.4.II, Load Combinations and Allowable Stress Limits.

TABLE 4.4.1-I

MAXIMUM BEARING STRESS ON CONCRETE

Element Number	Component	Direct Bearing Stress	Allowable Bearing Stress
250	Column	556	1,785
306	Column	553	1,785
110	Side Rail	726	1,785
190	Side Rail	630	1,785

TABLE 4.4.1-J

BOLT STRESS SUMMARY

Element Number	Bolt Type	Maximum Load[1]	Allowable Load[2]
1	Rebar Rock Bolt	6,554	12,500
2	Rebar Rock Bolt	6,577	12,500
106	Rebar Rock Bolt	6,266	12,500
186	Rebar Rock Bolt	5,956	12,500

		Maximum Stress	Allowable Stress
5	Beam Connection - Axial	700	33,000
	- Shear	3,414	13,640
106	Beam Connection - Axial	815	33,000
	- Shear	4,944	13,640
149	Beam Connection - Axial	665	33,000
	- Shear	3,190	13,640
186	Beam Connection - Axial	677	33,000
	- Shear	5,233	13,640

1. The maximum load represents both pullout and shear loads.
2. SEP Topic III-6, Seismic Design Considerations, Staff Guidelines for Seismic Evaluation Criteria for the SEP Group II Plants - Revision 1, September 20, 1982.

4.4.1.3 Summary

In general, the rack support structure member stresses satisfy the allowable stress limit with the exception of three elements using the very conservative assumption of OBE limits for seismicity.

Table 4.4.1-H shows sufficient margin for functionality to SSE limits for all members.

4.4.2 Basis for Analyses - Spent Fuel Racks

The spent fuel storage racks are Seismic Category I equipment as defined in Nuclear Regulatory Commission (NRC) Regulatory Guide 1.13. These racks are designed to withstand the effects of the NRC Spectrum (OBE) and remain functional, in accordance with NRC Regulatory Guide 1.29 and the Code of Federal Regulations, Title 10, Part 50.

4.4.2.1 The structure of the racks is designed to remain functional and to maintain the required spacing between stored fuel assemblies in the event of impact of a fuel bundle dropped on the racks from an elevation of 18 inches (maximum). In this case, local plastic deformation is allowed at the point of impact. The structure of the racks is also analyzed for effects of the impact of a fuel bundle dropped through an empty storage cavity. Failure of a vertical fuel support is allowed in this case. A comparative analysis, with the impact conditions as stated above, is also conducted for a maximum uplift (1,300 lbs.) on a rack due to the refueling crane pulling on a fuel bundle which is stuck. No permanent deformation is allowed in this case.

4.4.2.2 All member and plate stresses for the above conditions are within the factored combination stress limits of Table 4.4.2-1.

4.4.2.3 Load Combinations and Allowable Stresses

The following load combinations result in rack stresses that are within the following stress limits:

TABLE 4.4.2-1

Load Combinations	Stress Limits
1. D + L + T + P	F_s
2. D + L + T + H	F_s
3. D + L + T + E	F_s
4. D + L + T + I	
Condition 1	1.6 F_s
Condition 2	1.6 F_s
Condition 3 (See Note 1)	1.6 F_s
5. D + L + T' + E (See Note 2)	F_s

NOTE: (1) Local failure of fuel support is allowed, however, overall member stress shall be limited to 1.6 F_s.

(2) The load combination has been modified to reflect incorporating only the NRC Spectrum (OBE) as a design basis.

where:

F_s = Normal allowable stress according to Section 4.4.2.4.

D = Dead load of racks including the support framing.

L = Live load due to the weight of fuel assemblies which shall be considered as varying from zero to full load, and loadings corresponding to varying placement of the fuel assemblies in the rack shall be considered so that the most critical loads are obtained.

T = Thermal loads for water temperature equal to 150°F. The minimum water temperature is 40°F.

P = Lifting force of 1,300 pounds applied to the top of rack at any fuel bundle location.

H = Horizontal force of 1,000 pounds applied to the top of rack at any fuel bundle location and at a varying angle from 0° to 45° from the horizontal.

E = Loads and resulting forces and moments generated by the NRC Spectrum (OBE), resulting from ground surface horizontal acceleration and vertical ground surface acceleration acting simultaneously.

T' = Thermal loads for loss-of-coolant condition corresponding to pool surface temperature equal to 212°F.

I = Impact load resulting from the following conditions:

Condition 1 - 18 in. fuel bundle drop above the rack impacting on middle of the top of the rack.

Condition 2 - 18 in. fuel bundle drop above the rack impacting on the corner of the top of the rack.

Condition 3 - 18 in. fuel bundle drop above the racks free falling through an empty cavity and impacting the fuel support surface.

4.4.2.4 Allowable Stresses (For Stainless Steel)

The allowable stresses shall be in accordance with ASME Boiler and Pressure Vessel Code, Section III, Appendix XVII.

Table 4.4.2-2 lists the rack member allowable stresses for the Yankee design.

The one-third increase in allowable stress for an emergency condition is not allowed. The increase in allowable stress is defined by Table 4.4.2-1.

TABLE 4.4.2-2

MEMBER ALLOWABLE STRESSES (ksi)

Component	Stress	F_s @ 150°F	F_s @ 212°F
Can	Axial	16.5	14.82
	Bending	16.5	14.82
Perimeter Bars	Axial	16.5	14.82
	Bending	16.5	14.82
Fuel Seat	Axial	NA	NA
	Bending	20.6	18.53
Welds		21.0	21.0

N/A - Not Applicable

4.4.3 Seismic Analyses - Spent Fuel Storage Racks

A time-history analysis is performed by using the computer program, ANSYS (Engineering Analysis System). ANSYS is documented by a User's Manual, published by Swanson Analyses Systems, Incorporated, Elizabeth, Pennsylvania.

The seismic time-history analysis will be conducted using the extreme coefficients of friction (U) of 0.2 and 0.8. The low coefficient is used to define maximum credible sliding displacement, and the higher coefficient is used to define the worst loading condition.

4.4.3.1 Analysis Methodology

A complete non-linear transient seismic analysis of the entire rack-suppport structure system is not practicable as discussed in Section 4.4.1.1 in greater detail. Therefore, the following approach is adopted:

1) A complete finite element model containing all 72 racks and the support structure is analyzed with non-linear effects omitted.

2) The linear transient results are examined to determine the most severely loaded module.

3) The "worst-case" motion, in the form of transient displacement boundary conditions, is input to a non-linear transient analysis of a single module which includes the effects of sliding friction, fuel rattling, and which allows for the possibility of lifting at the support points.

4) The results of the non-linear transient analysis are used to qualify the module design.

Any discrepancies between the predicted linear response and that noted in the non-linear analysis, such as gap non-linearities affecting the overall structure motion, are accounted for since this stepwise approach permits careful back-checking.

4.4.3.1.1 Thermal effects are addressed using decreased material yield strength corresponding to the actual thermal environment. No fixed end thermal loads occur since the racks and the support structure are both stainless steel.

4.4.3.2 ANSYS Seismic Model

The rack 3-dimensional ANSYS model used to assess non-linear effects of interaction of rack to the support structure and fuel/rack interaction contains non-linear elements to simulate gaps and allow for sliding. The gap boundary conditions are shown in Figure 4.4.3-A.

The rack model consists of plate elements with fuel represented by beam elements. The detailed finite element model is shown in Figure 4.4.3-B.

The model contains the mass and stiffness of all the fuel assemblies and extends the height of the rack. It is pinned at the bottom of the rack and is allowed to impact at the top and middle third points. Gap elements representing the fuel assembly clearance are located at these impact points. The section properties of the fuel assembly are used for this element. This model conservatively assumes that all fuel assemblies are in phase and move together at all times.

4.4.3.2.1 A structural damping of 2% (OBE) for welded steel structures is used. No increase in damping is included for water submergence.

The gap elements
shown also contain
spring-dampers (-⌇-)
but are not shown for
clarity.

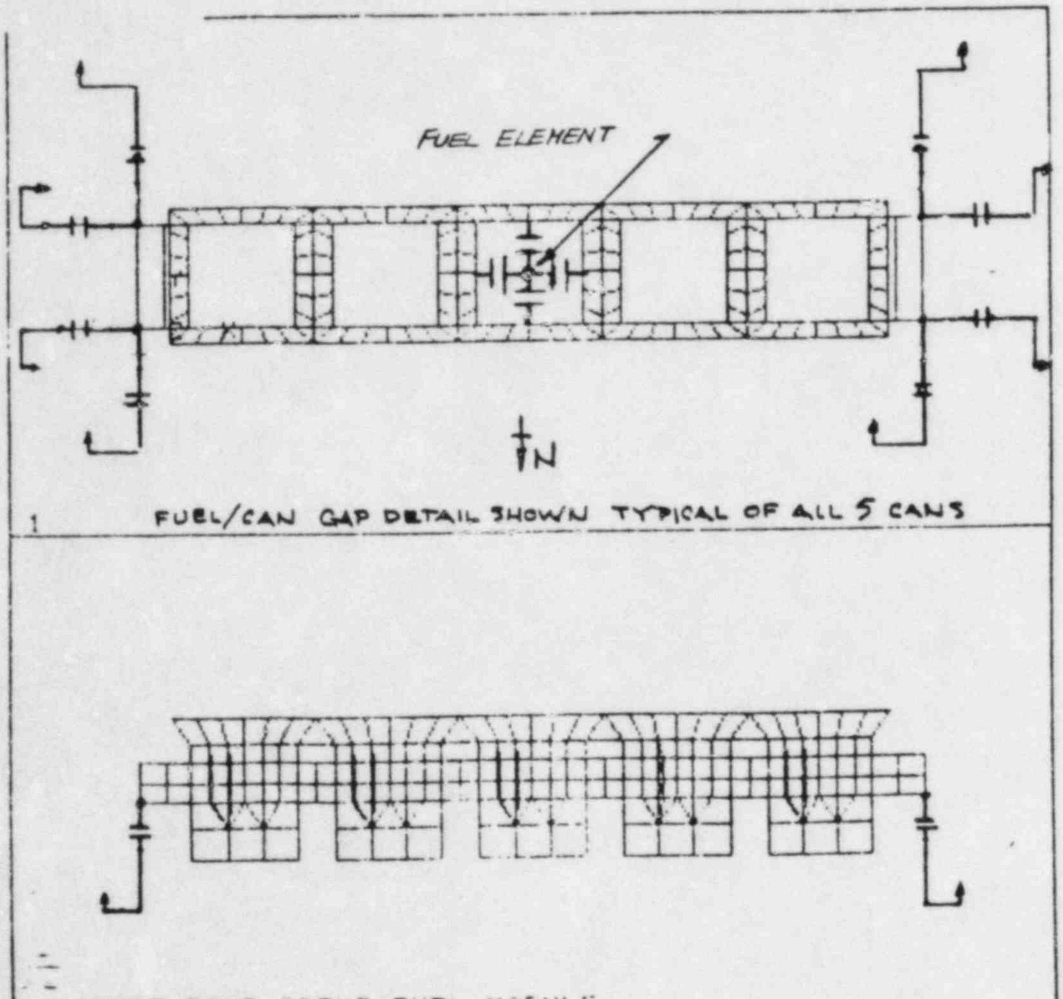


FIGURE 4.4.3-A

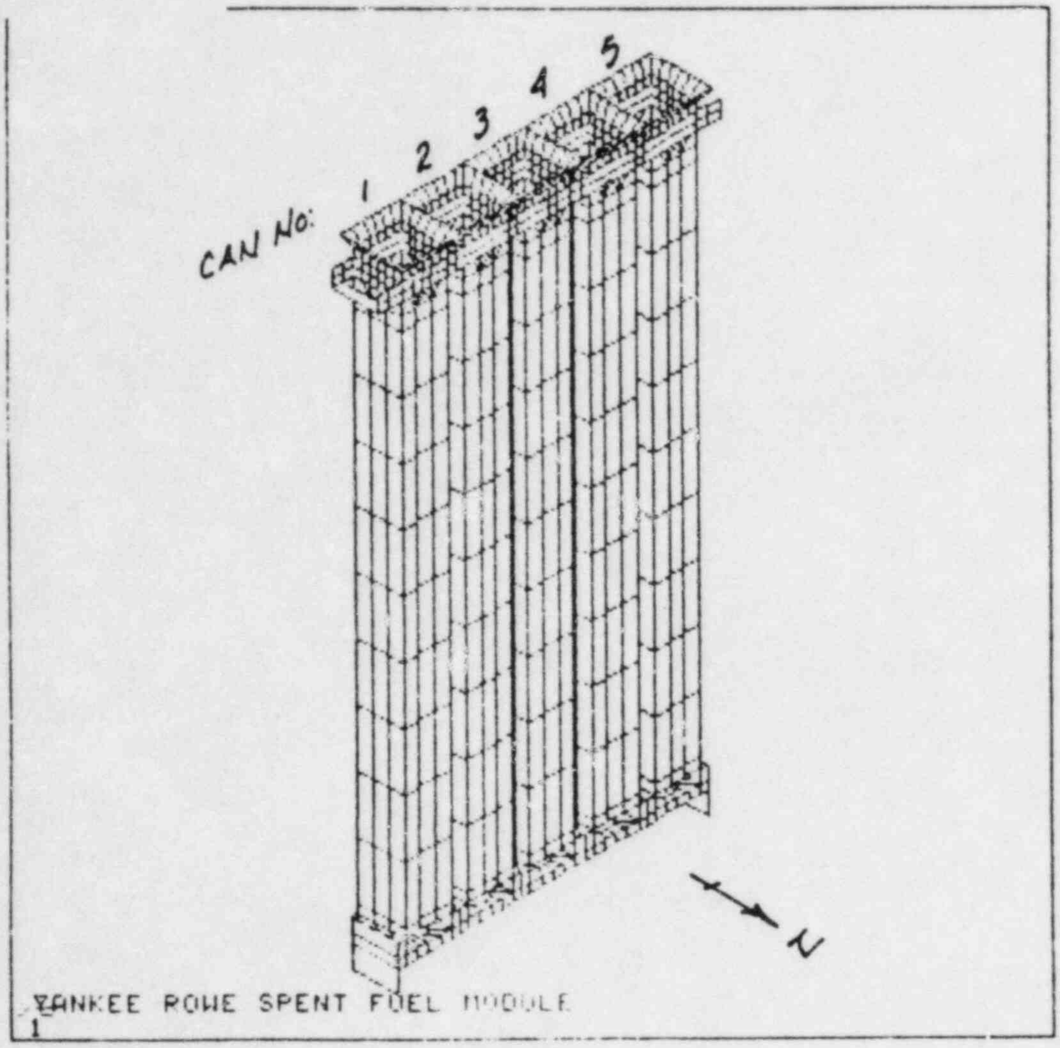


FIGURE 4.4.3-B

4.4.3.2.2 The external hydrodynamic water mass determination is based upon a paper by R. L. Fritz, entitled, "The Effects of Liquids on the Dynamic Motion of Immersed Solids", Journal of Engineering for Industry, February, 1972. All internal water entrapped within the rack envelope is added to the horizontal mass.

4.4.3.2.3 The racks are located below any free wave activity. It is concluded that the rack elevation compared to the pool water elevation is such that rigid body motion rather than sloshing loads is applicable to the rack design.

4.4.3.2.4 The rack model does not include module to module interaction since the racks are separated by welded gussets on top of the beams of the support structure.

4.4.3.2.5 The digitized time histories are generated artificially using the computer program, SIMQKE, as described in Section 4.4.1.1.3.

4.4.3.2.6 The model accounts for in-phase fluid coupling with the pool water by use of the ANSYS fluid dynamic coupling element. This element is used to represent dynamic coupling between two points. The coupling is based on the dynamic response of two points connected by a constrained mass of fluid, as described in the aforementioned paper by R. L. Fritz.

4.4.3.2.7 The transient displacement boundary conditions needed for the non-linear analysis are obtained directly from the results of the linear transient analysis results. The transient loading on each of the 72 modules will be evaluated to determine the most severely loaded module.

4.4.3.2.8 Results of the non-linear time history will provide the time and location of the highest stress.

4.4.3.3 Results of the Non-Linear Rack Analysis

Table 4.4.3-C lists rack stresses versus allowable stresses for the Yankee design.

4.4.3.3.1 The highest stresses are developed at 1.55 seconds into the transient at Canister 5.

4.4.3.3.2 In general, all the member stresses satisfy the stress combination limits and factored allowable stresses of the stress limits in Table 4.4.2-1.

The stresses of 20.8 ksi and 26.2 ksi are very localized stresses in Canister 5 with no permanent distortion occurring. These stresses are well below the material yield point.

TABLE 4.4.3-C

RACK VERSUS ALLOWABLE STRESSES (ksi)

Load Combination	Component	Maximum Stress	Allowable Stress (1.0 F_s)	Allowable Stress (1.6 F_s)
1	Canister	4.3	16.5	
	Fuel Seat	<2.3	20.6	
	Top Perimeter Bar	3.4	16.5	
	Bottom Perimeter Bar	<2.3	16.5	
	Welds:			
	Fuel Seat to Can	<2.	21.0	
	Can to Perimeter Bar	<2.	21.0	
	End Plate Attachment	<2.	21.0	
2	Canister	6.3	16.5	
	Fuel Seat	<3.4	20.6	
	Top Perimeter Bar	5.2	16.5	
	Bottom Perimeter Bar	<3.4	16.5	
	Welds:			
	Fuel Seat to Can	<2.	21.0	
	Can to Perimeter Bar	<2.	21.0	
	End Plate Attachment	<2.	21.0	
3	Canister	20.5	16.5	26.4
	Fuel Seat	26.2	20.6	30.0 (Min. Yield)
	Top Perimeter Bar	15.0	16.5	26.4
	Bottom Perimeter Bar	<8.3	16.5	26.4
	Welds:			
	Fuel Seat to Can	3.0	21.0	
	Can to Perimeter Bar	7.4	21.0	
	End Plate Attachment	15.9	21.0	
4 Condition 1	Canister	18.9		26.4
	Fuel Seat	*		33.0
	Top Perimeter Bar	13.5		26.4
	Bottom Perimeter Bar	*		26.4
	Welds:			
	Fuel Seat to Can	*		33.6
	Can to Perimeter Bar	4.3		33.6
	End Plate Attachment	6.2		33.6
4 Condition 2	Canister	19.1		26.4
	Fuel Seat	*		33.0
	Top Perimeter Bar	9.3		26.4
	Bottom Perimeter Bar	*		26.4
	Welds:			
	Fuel Seat to Can	*		33.6
	Can to Perimeter Bar	2.5		33.6
	End Plate Attachment	3.5		33.6

TABLE 4.4.3-C

RACK VERSUS ALLOWABLE STRESSES (ksi)

Load Combination	Component	Maximum Stress	Allowable Stress (1.0 F_s)	Allowable Stress (1.6 F_s)
4	Canister	26.1		26.4
Condition 3	Fuel Seat	N.A.		N.A.
	Top Perimeter Bar	20.7		26.4
	Bottom Perimeter Bar	20.8		26.4
	Welds:			
	Fuel Seat to Can	N.A.		N.A.
	Can to Perimeter Bar	<2.		33.6
	End Plate Attachment	10.2		33.6
5	Canister	20.5	14.82	23.7
	Fuel Seat	26.2	18.53	29.6
	Top Perimeter Bar	15.0	14.82	23.7
	Bottom Perimeter Bar	<8.3	14.82	23.7
	Welds:			
	Fuel Seat to Can	3.0	21.0	
	Can to Perimeter Bar	7.4	21.0	
	End Plate Attachment	15.9	21.0	

* - These stresses are less than 1.0 KSI and are not printed in the output.
N.A. - Not Applicable.

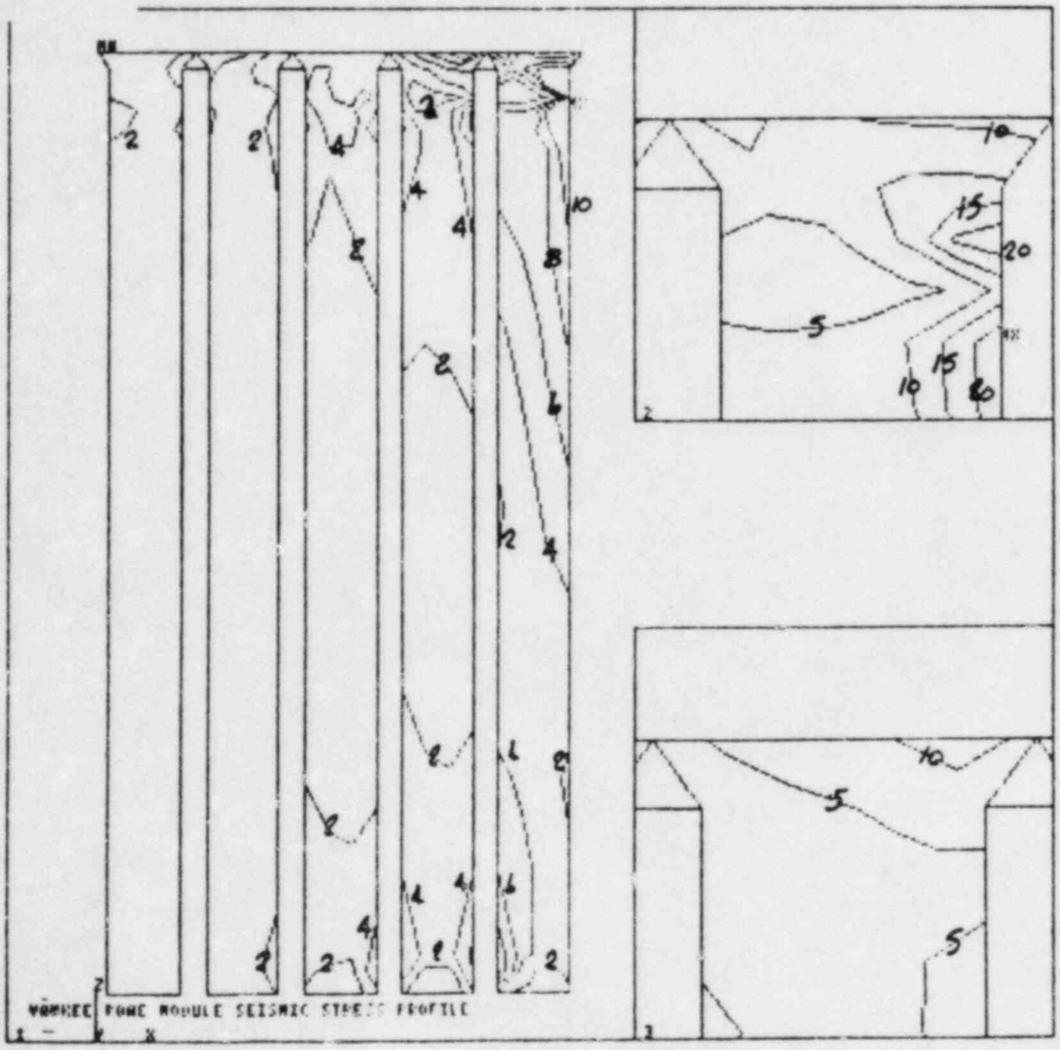


FIGURE 4.4.3-D

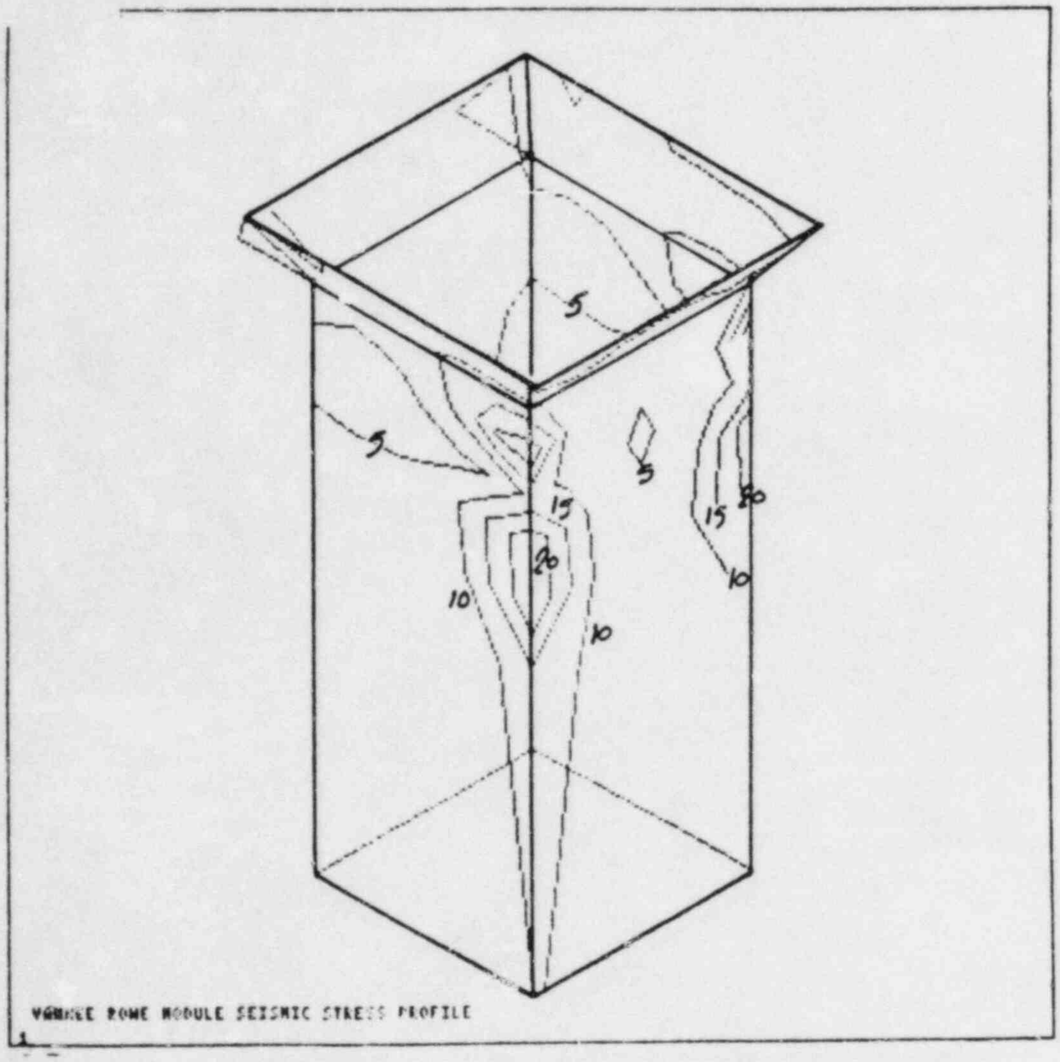

5
5
5
15
20
10
10
15
20
10
YANKEE ROWE MODULE SEISMIC STRESS PROFILE
1

FIGURE 4.4.3-E

4.4.4 Dropped Fuel Bundle Analyses

Analyses were performed to define the equivalent static load for dropped bundle accident conditions 1, 2, and 3 (see paragraph 4.4.2.3).

4.4.4.1 Description of Methods

4.4.4.1.1 The following method was used to define the impact loads. For conditions 1 and 2, the impacting energy was determined to be the potential energy of the fuel bundle. An ANSYS model was used to determine spring rates at various impact locations on the rack. A static impact load was then determined for each of these locations by equating the elastic structural strain energy with the impact energy.

4.4.4.1.2 For condition 3, an unimpeded fuel assembly drop through an empty cavity, an equivalent static load was determined to shear out the bottom fuel support.

4.4.4.1.3 The results for each condition are given below:

Condition	Description	Load-Kips
1	18-inch drop, middle of rack	10.0
2	18-inch drop, middle corner of rack	5.9
3	Drop through empty cavity of rack	16.1

Conditions 1 and 2 are the loads due to vertical impact. Equivalent static loads for different dropped fuel bundle cases were then applied at proper locations to the ANSYS finite element model of the rack and combined with the deadweight vertical load (rack full of fuel). Stresses for each member were such that the ductility ratio was less than 10, and that no deformation would result in an increase in criticality.

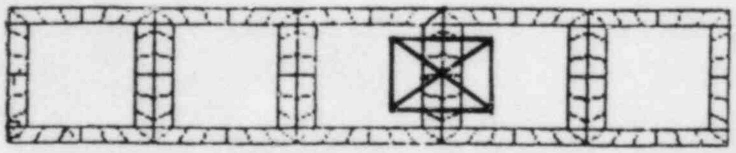
4.4.4.2 Results of Dropped Fuel Bundle Analysis

4.4.4.2.1 Load Condition 1 - 18-Inch Fuel Bundle Drop on Middle of Rack

Maximum Penetration

Maximum penetration occurs when the fuel hits in the middle of the rack. The rack will react elastically up to 10 kips (the load at which significant yielding begins). It will then be inelastic and buckle until the area under the force-deflection curve equals the impact energy. The fuel bundle penetrates about 1.7 inches into the top of can.

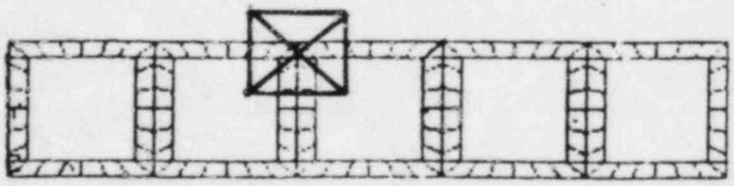
IMPACT AREA



4.4.4.2.2 Load Condition 2 - 18-Inch Fuel Bundle Drop on Corner of Rack Cell

There is no local penetration but the two outer sides of the can will buckle producing a ripple effect on the corner can outer walls. Maximum calculated local deformation in the corner of the can is approximately 2.8 inches.

IMPACT AREA



4.4.4.2.3 Load Condition 3 - Fuel Bundle Drop Through an Empty Cavity

There is no penetration in the rack. The fuel shears out the grid on the bottom of the rack. The load required to shear out the cruciform is the impact load. This load is statically applied to the middle of the bottom grid.

4.4.5 Spent Fuel Rack Grating Design

4.4.5.1 Description

This stainless steel grating is designed to withstand a dropped fuel bundle accident from a distance of 10 feet - 8 inches. The grating will protect the existing freestanding racks and fuel on the pool floor. Since there are no laterally attached cross members in the support structure, the grating is also used to limit transverse motion of the system.

4.4.5.1.1 Structural considerations require that the maximum plastic deflection be limited to 6 inches. This criteria allows the grating to deform without coming into contact with the standing racks.

4.4.5.2 The deflection is found by equating, at maximum deflection, the potential and internal bending strain energies of the system. The analysis assumes a concentrated impact at the center of a simply supported grate. The equations are based on elastic-perfectly plastic criteria which are highly conservative.

4.4.5.2.1 The allowable stresses shall be in accordance with ASME Boiler and Pressure Vessel Code, Section III, Appendix XVII. This is interpreted as being identical with the AISC Steel Construction Manual.

4.4.5.3 Results of Dropped Fuel Bundle on Grating

The maximum shear stress developed for a fuel bundle weight of 820 pounds dropping from a distance of 10 feet - 8 inches above the grating is listed below:

$F_{SHEAR} = 1{,}146 \text{ psi} < F_{ALLOWABLE} = 11{,}000 \text{ psi}$

4.5.0 REFERENCE ABBV

	Description
1. United States Nuclear Regulatory Commission (USNRC)	
a. NRC Regulatory Guide 1.13	Spent Fuel Storage Facility Design Basis, Rev. 1, December 1975
b. NRC Regulatory Guide 1.29	Seismic Design Class, Rev. 2, February 1976
c. NRC Regulatory Guide 1.92	Combination of Modes in Seismic Analysis, Rev. 1, February 1976
d. NRC SRP 3.7	Seismic Design, 1975
e. NRC SRP 3.8.4	Seismic Category I Structures, 1975
f. NRC SRP 9.1.2	Spent Fuel Storage Review Responsibility, 1975
2. Industry Codes and Standards	
a. ASME	Boiler and Pressure Vessel Code Section III, Appendix XVII, and Subsection NF, 1977 Edition (American Society of Mechanical Engineers)
b. AISC	Steel Construction Manual AISC (8th Edition), December, 1980 (American Institute of Steel Constructors)

c. ASTM	ASTM Standards: A240, A276, B209, and C750
d. ANSI N45.2	"Quality Assurance Requirements of Nuclear Power Plants", 1977
e. ANSI N45.2.2	"Packaging and Shipping, Receiving, Storage and Handling of Items for Nuclear Power Plants", 1972
f. ANSI N45.2.10	"Quality Assurance Terms and Definitions", 1973
g. ANSI N18.2	Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants, 1973
h. AWS	Specification D1.1, Rev. 2-77, Structural Welding Code

3. Federal Specifications

10CFR50, Appendix B 1975	Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants
10CFR73.55	Requirements for Physical Protection of Licensing Activities in Nuclear Power Reactors Against Industrial Sabotage
10CFR20	Standards for Protection Against Radiation

4. Compute Programs

ANSYS	Computer Program "Engineering Analysis System", Swanson Analysis Systems, Inc.
SIMQKE	Computer program in which digitized time histories are generated artificially

4.6.0 SPENT FUEL POOL

4.6.1 General

4.6.1.1 The fuel pool is a reinforced concrete structure constructed on dense glacial till. It is of open box form with doubly reinforced walls and basement. The upper tier racks and fuel represent an increase in total weight of the pool of 7%. This increase in weight is well within the static supporting capacity of the pool floor and walls. The storage pool is re-analyzed incorporating simultaneous three-component Yankee Composite Spectrum loads to ensure conformance to the SEP seismic design requirements.

4.6.1.2 The seismic capability of the spent fuel pool in the fully loaded condition is justified.

4.6.2 Structural Assessment of the Upper Building

4.6.2.1 A detailed evaluation of the Fuel Transfer Pit House and Crane Support Structure, and Chute has been performed. These structures were reviewed seismically to the Yankee Composite Spectrum to ensure that nothing can fall into the pool and damage the fuel.

4.6.2.2 The Fuel Transfer Pit House and Crane Support Structural Component are adequate to resist the imposed loading.