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WOODY, C. O. Florida Power & Light Co.
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SUBJECT: Forwards response to 870820 request for addl info re 870612 application for amend to License DPR-67, authorizing replacement of spent fuel pool racks. W/nine proprietary oversize drawings. Encls withheld.

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L-87-422

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555

Gentlemen:

Re: St. Lucie Unit 1
Docket No. 50-335
Spent Fuel Pool Rerack - Design and Analysis

By letter L-87-245, dated June 12, 1987, Florida Power & Light Company (FPL) submitted a proposed license amendment to permit replacement of the spent fuel pool racks at St. Lucie Unit 1 to ensure that sufficient future capacity exists for storage of spent fuel.

By letter dated August 20, 1987 (E. G. Tourigny to C. O. Woody) the NRC Staff requested additional information in the area of the spent fuel pool rack description, design and analysis it needed to continue its review of this proposed license amendment.

Attached is FPL's partial response to this request. As identified in the Attachment, FPL will respond to certain portions of this request in the near future. This phased response has been found acceptable by the NRC Staff.

If additional information is required, please contact us.

Very truly yours,

C. O. Woody
Group Vice President
Nuclear Energy

COW/EJW/gp

Attachment

cc: Dr. J. Nelson Grace, Regional Administrator, Region II, USNRC
Senior Resident Inspector, USNRC, St. Lucie Plant

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1987 OCT 26 A 9:59

USNRC-DS

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Nuclear Energy

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cc: Dr. J. Nelson Grace, Regional Administrator, Region II, USNRC
Senior Resident Inspector, USNRC, St. Lucie Plant

A001
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ATTACHMENT

RESPONSES TO NRC LETTER

DATED AUGUST 20, 1987

(E. G. Tourigny to C. O. Woody)

QUESTION #1 Description of the Spent Fuel Pool and Racks

Question 1a - Provide typical fuel rack design drawings which indicate all weld details.

Response 1a - Region 1 and Region 2 fuel rack designs are represented pictorially in Figures JPE-LR-87-043-1 and JPE-LR-87-043-2. The attached Joseph Oat Corporation drawings, D-8286 Rev 1 and D-8288 Rev 1, show all design details for a typical fuel rack module.

Question 1b - Provide a typical fuel assembly drawing indicating details of rack interface areas.

Response 1b - Attached Tables 1 and 2 present detailed information regarding the three types of fuel assemblies intended for storage in the new spent fuel racks. These fuel assemblies are shown in the St Lucie Unit 1 FSAR Figure 4.2-3, 18 and 19, and the St Lucie Unit 2 FSAR Figure 4.2-6. The assembly when stored in a spent fuel rack storage cell rests on the lower end fitting. During a seismic event, lateral contact between the fuel assembly and the storage cell wall may occur at one or more of the spacer grid assemblies. These items are shown in the figure included with Table 1.

Question 1c - Provide detailed fuel pool drawings which show the liner weld seams, the leak detection system channels, and any modifications.

Response 1c - The attached Figure JPE-LR-87-043-3 shows the general arrangement and wall thickness of the spent fuel pool. The attached Ebasco Services Inc. drawings 8770-G-830 sheet 1 Rev 4, sheet 2 Rev 2 and sheet 3 Rev 4 show all the design details for the St Lucie Unit 1 spent fuel pool. Drawing 8770-G-830 sheet 4 Rev 0 shows 1-1/4 inch base plates which were added to the pool floor at the time of the last rerack.

Additional 1-1/4 inch base plates are required to be placed on the pool floor to accommodate the new spent fuel racks. See response to Question 1d for additional discussion.

Liner weld seams are located on Sheet 1, Fuel Pool Liner Plan, Sections A, B and C and Sheet 2, Section G. Leak detection channels are provided behind all weld seams. Details are shown on 8770-G-830 Sheet 3, Coordinates D11 to D17.

QUESTION #1 Description of the Spent Fuel Pool and Racks (continued)

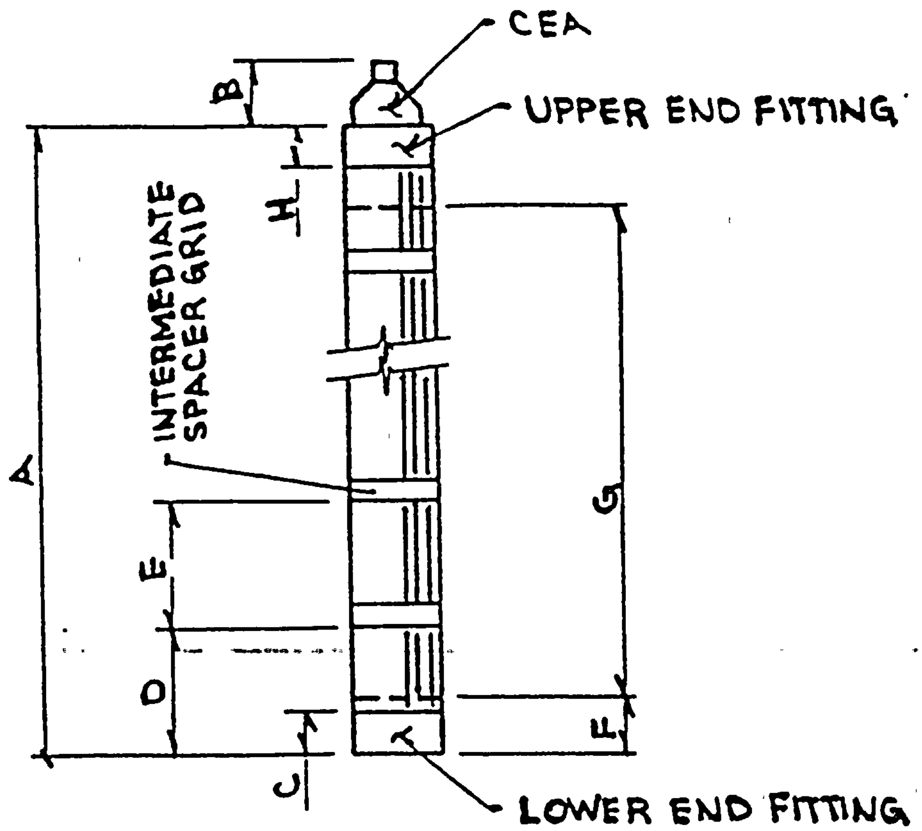
Question 1d - Will any shim plates be used between the rack feet and the pool floor?

Response 1d - The design of the new spent fuel racks does not call for the use of shim plates. Level adjustment is achieved through variable height support legs accessible from the pool surface using long-handled tools. Additional 1-1/4 inch base plates are provided as shown on Joseph Oat Corp drawing E-8281 Rev 2 for those areas of the pool floor where the rack support legs are located which do not already have 1-1/4 inch base plates. These new base plates will not be attached to the pool floor.

Question 1e - Are there any structural restraints to prevent the racks from sliding into the cask area?

Response 1e - There are no structural restraints around the cask area. A structural steel wall separates the cask area from the rest of the spent fuel pool. This wall is shown on Ebasco Services Inc. drawings 8770-G-830 Sheet 1 Rev 4, Sections A and D, and Sheet 2 Rev 2, Section F. The analysis of the spent fuel racks demonstrates that this wall is sufficiently distant from the racks such that rack-to-wall impact does not occur during a seismic event. Consequently, the wall was not analyzed for this condition.

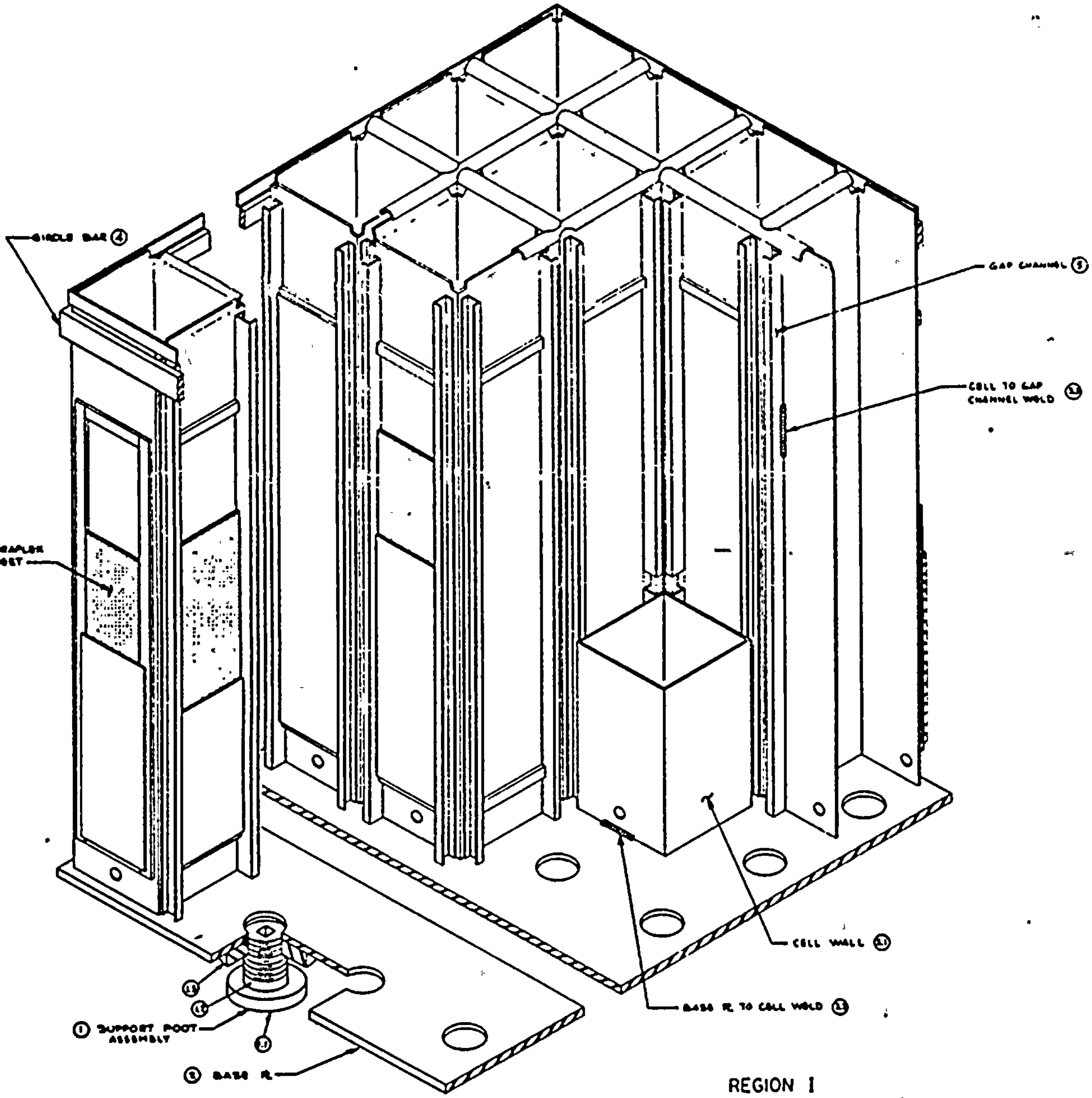
TABLE 1



DIMENSION/DESCRIPTION	ST LUCIE 1 CE 14x14	ST LUCIE 1 EXXON 14x14	ST LUCIE 2 CE 16x16
A - Fuel Assembly Length	157.241	157.24	158.1
B - CEA Projection	7.7	7.7	11.1
C - Lower End Fitting Height	3.312	2.677	3.8
D - Location of Lower Spacer Grid	13.25	16.137	4.1
E - Spacing of Intermediate Grids	18.86	18.86	15.8
F - Location of Bottom of Active Fuel	4.250	3.137	4.7
G - Active Fuel Length	136.70	136.70	136.70
H - Upper End Fitting Height	5.773	6.38	6.8

TABLE 2

CHARACTERISTIC/DESCRIPTION	ST LUCIE 1 CE 14x14	ST LUCIE 1 EXXON 14x14	ST LUCIE 2 CE 16x16
1. Fuel Rods			
Length (in)	146.963	146.50	146.49
Pitch (in)	0.577	0.577	0.506
Number	176	176	236
Active Length (in)	136.70	136.70	136.70
O.D. (in)	0.440	0.440	0.382
Wall Thickness (in)	0.03	0.031	0.025
Material	ZR-4	ZR-4	ZR-4
Weight (lbs)	6.88	6.91	5.17
2. Guide Tubes			
Number	5	5	5
O.D. (in)	1.115	1.115	0.980
Wall Thickness (in)	0.040	0.040	0.040
Material	ZR-4	ZR-4	ZR-4
3. Intermediate Spacer Grids			
Number	8	9	9
Material	ZR-4	ZR-4	ZR-4
Envelope (in square)	8.115	8.105	8.230
4. End Fittings			
Envelope (in square)	8.110	8.110	8.134
5. Fuel Assembly Weight			
w/o CEA (lbs)	1280	1280	1303
w/CEA (lbs)	1361	1361	1384
6. Peaking Factors			
Radial	1.67	1.67	1.75
Axial	1.32	1.32	1.35

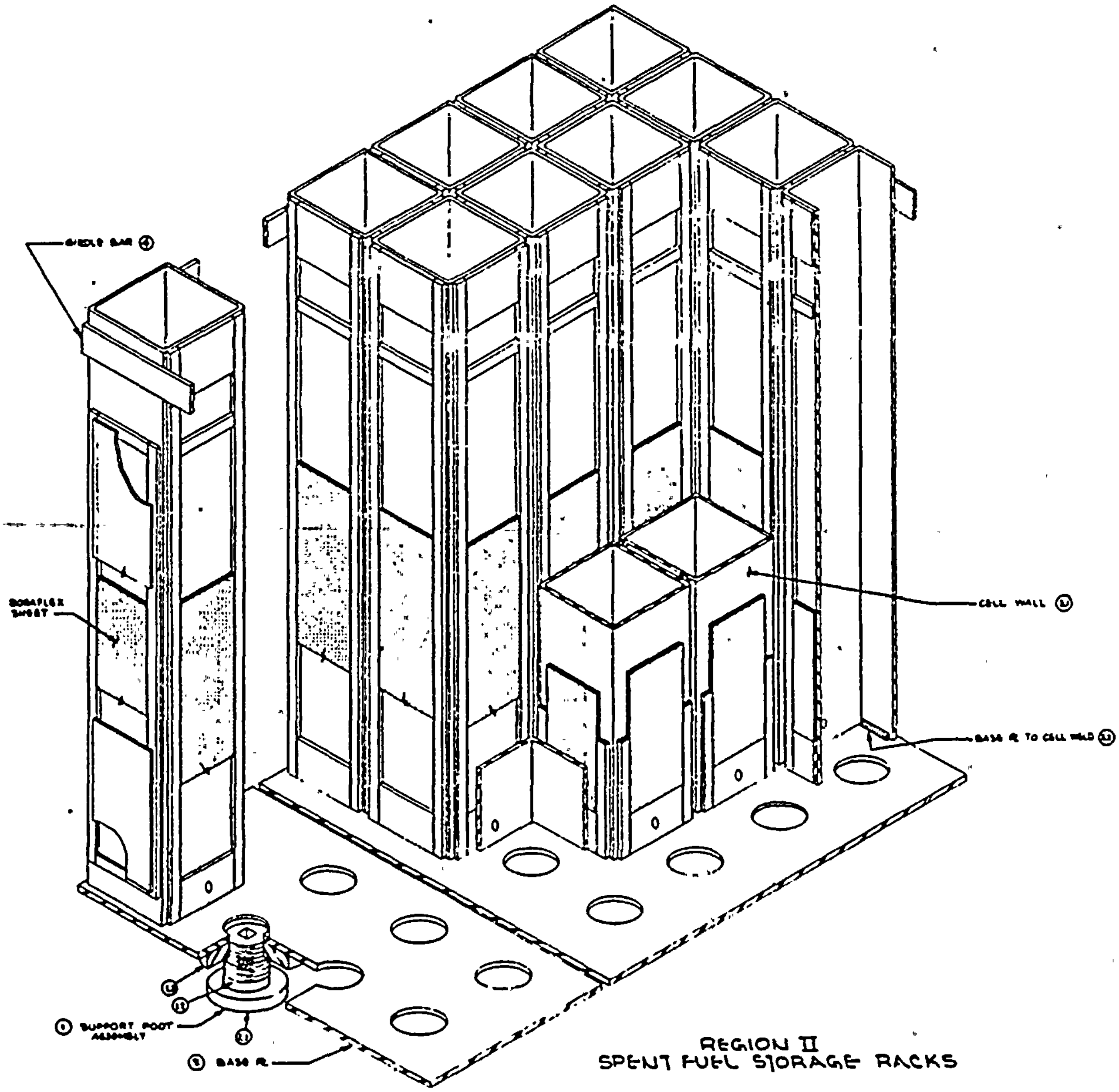


REGION I
SPENT FUEL STORAGE RACKS

FLORIDA POWER & LIGHT COMPANY
ST. LUCIE PLANT UNIT 1

REGION I FUEL RACK DESIGN

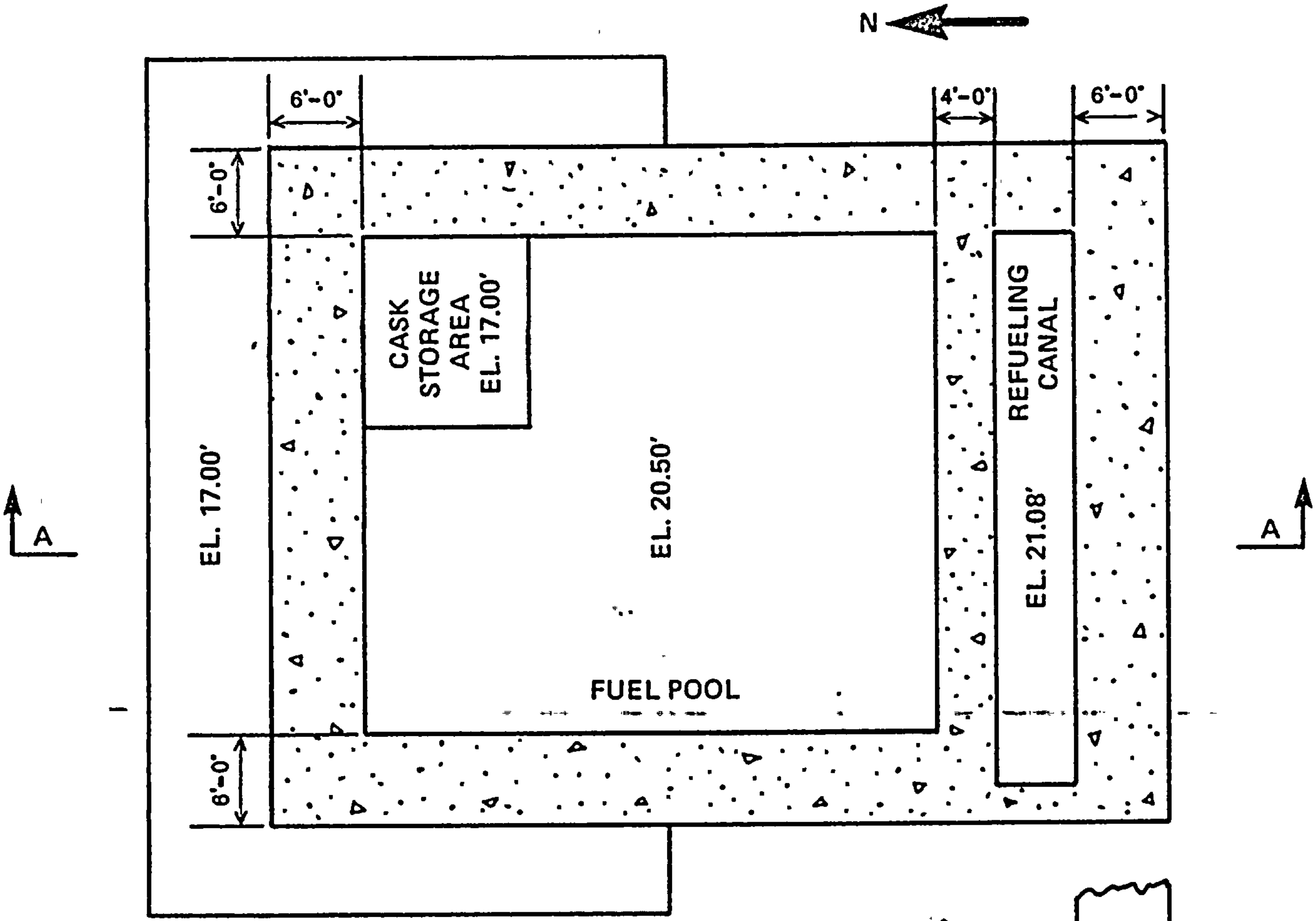
FIGURE JPE-LR-87-043-1



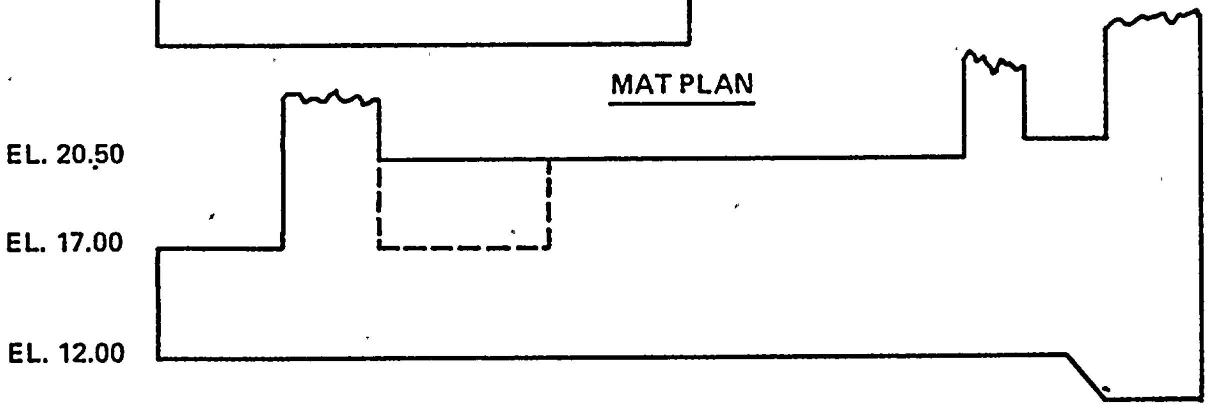
FLORIDA POWER & LIGHT COMPANY
ST. LUCIE PLANT UNIT 1

REGION II FUEL RACK DESIGN

FIGURE JPE-LR-87-043-2



MAT PLAN



SECTION A-A

FLORIDA POWER & LIGHT COMPANY
ST. LUCIE PLANT UNIT 1

GENERAL ARRANGEMENT
OF SPENT FUEL POOL

FIGURE JPE-LR-87-043-3

QUESTION #2 Seismic and Impact Loads

Question 2a - Provide a detailed description of the methodology and analytical models used to generate the new floor response spectra shown in Figure 4.9.

Response 2a - The analytical model of the Fuel Handling Building (St Lucie Unit 1 FSAR, Subsection 3.7.2.1.1(a)and Figure 3.7-9) is represented by a cantilever beam with masses lumped at selected elevations simulating weights of floors, walls, columns and major equipment. The cantilever beam connecting these lumped masses is assumed weightless and elastic representing the stiffness of the walls. The foundation mat supporting the cantilever beam is considered as a rigid body and is supported by rotational and translational springs simulating soil-structure interaction.

For the horizontal direction, two models were used corresponding to the N-S (long) and E-W (short) directions of the building. Each model consists of a cantilever beam with three lumped masses.

For the vertical direction, a mathematical model was developed using the same lumped mass principles. However, since the focus of interest for this case is the middle of a floor bay or at column-floor junctures, appendages representing floor bay behavior are added to the cantilever beam resulting in a more complex model.

The increased mass at the base mat resulting from the increase in the fuel rack weight increases the weight and the weight moment of inertia of the mat. (See FSAR Table 3.7-5). Properties as shown in this table for horizontal model mass points 1, 2, and 3, and vertical model mass points 1, 2, 3, 4 and 5 will not change. Other input data including geometry, material properties, structural damping, and soil spring constants are the same as used for the original analysis of the Fuel Handling Building.

The new response spectra curves were generated using the method described in FSAR Subsection 3.7.1.2.3, which was used in the original dynamic analysis of the Fuel Handling Building.

QUESTION #2 Seismic and Impact Loads (continued)

Response 2a (continued) - Minimum and maximum fuel rack weights were considered in the analysis, corresponding to the empty and full conditions of the racks. Increasing fuel rack weight tends to increase the weight moment of inertia of the mat and hence the horizontal responses. Decreasing fuel rack weight decreases the mass of the mat and hence tends to increase the vertical responses. Three ground motion acceleration records (as used in the original plant design) were used as input. These six combinations of parameters result in six response spectra curves, which were then broadened $\pm$ 20% and enveloped into one curve which envelopes the full spectrum of rack loading conditions. Six such curves were developed, two (OBE and SSE) for each direction (NS, EW, vertical), as shown in Figure 4-9 in the licensing submittal.

Question 2b - Provide a detailed description of the methodology used to generate the pool floor time histories.

Response 2b - The methodology used by the computer program for artificial motion generation is based on the fact that any periodic function can be expressed as a sum of sinusoidal waves, i.e.

$$X(t) = a_n \sin(w_n t + P_n) \qquad (1)$$

Where a_n, w_n and P_n are respectively the amplitude, frequency and phase angle of the n-th contributing sinusoid. A random number generator is utilized to generate an array of phase angles with uniform likelihood in the range between 0 and 360 degrees. The amplitude a_n are related to the one side spectral density function $S(w_n)$ by the relationship

$$a_n = \text{SQRT}\ (2\ S(w_n) Dw_n) \qquad (2)$$

where Dw_n represents an increment of w_n

The transient character of the earthquake is simulated by multiplying the steady state motion expressed by Eq(1) by a deterministic envelope function as described in the report, "Simulated Earthquake Motions Compatible with Prescribed Response Spectra" by D Gaspirino and E H Vanmarcke, MIT Report No R76-4 (January 1976).

The program utilizes an iteration approach whereby the calculated response produced by the simulated seismic excitation is compared with the "target" response spectrum, and the amplitudes a_n are modified at each iteration step so as to obtain the best agreement at certain control frequencies specified by the user.

QUESTION #2 Seismic and Impact Loads (continued)

Question 2c - Provide a comparison of the response spectra for the pool floor motion shown in Figures 4-12, 13, 14, with the corresponding design response spectra of Figure 4-9.

Response 2c - The attached Figures JPE-LR-87-43-4, 5 and 6 provide a comparison of the design response spectra with the calculated response spectra corresponding to the artificially generated time histories. For clarity, velocity response spectra rather than acceleration response spectra are presented, as velocity spectra will accentuate the differences in the lower frequency range.

The plots demonstrate that the calculated curves closely envelope the design curves.

Question 2d - Have impacts between fuel racks and the pool walls been considered? Do the walls have sufficient margin to accommodate these loads?

Response 2d - The potential for rack-to-wall impact has been considered in the fuel rack models. Impact springs are included in the model at both the base plate level and at the girdle bar level on all four sides of the rack being modelled to account for this potential. The true rack-to-wall spacing (less the projection of the girdle bar or base plate, as applicable) is input as a clear gap between the rack structure and the spring. The maximum calculated rack displacement under the analyzed design conditions is 1.82 inches, which is less than the actual rack-to-wall spacing (minimum 4 inches). Therefore, analysis of the pool walls for impact loading was not required.

To obtain additional confidence that the racks will not impact the walls, the behavior of a two-dimensional multiple rack model under the seismic condition will be evaluated. See response to Question 3g for additional discussion.

FSAR TABLE 3.7-5

FUEL HANDLING BUILDING PROPERTIES
HORIZONTAL MODEL

Mass No.	A(N-S) (ft^4)	I(N-S) (ft^4)	A(E-W) (ft^2)	I(E-W) (ft^4)	W (k)
1	251.0	859,000	212.0	187,000	3,510.0
2	932.0	1,728,000	877.5	527,000	3,639.0
3	984.0	1,834,000	921.5	531,000	14,103.0
Base		*7,580,000		*1,025,000	6,846.0

* Weight Moment of Inertia ($k\text{-}sec^2\text{-}ft$)

N-S Long Direction of Structure

E-W Short Direction of Structure

VERTICAL MODEL

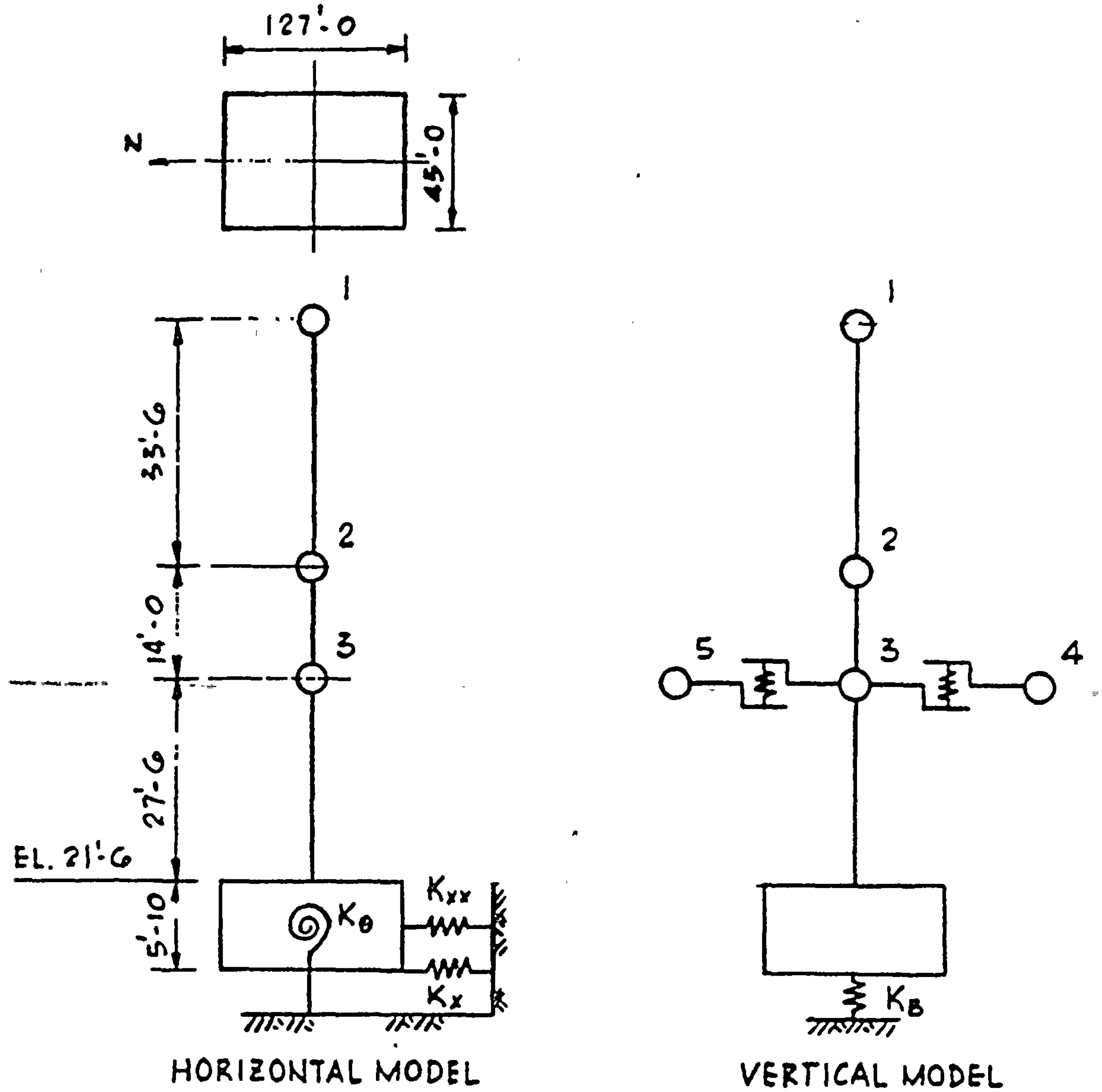
Mass No.	W (k)	S (k/ft)
1	3,510.0	5,950,000
2	3,639.0	54,000,000
3	12,500.0	25,600,000
4	180.0	98,000
5	248.0	33,300
Base	6,846.0	

Design Concrete Strength $f_c^1 = 3,000$ psi

Young's Modulus $E_c = 422,000$ ksf

Poisson's Ratio $\mu = 0.17$

Shear Modulus $G_c = 180,000$ ksf



FLORIDA POWER & LIGHT COMPANY

ST. LUCIE PLANT

FUEL HANDLING BUILDING MATHEMATICAL MODELS

FSAR FIGURE 3.7-9

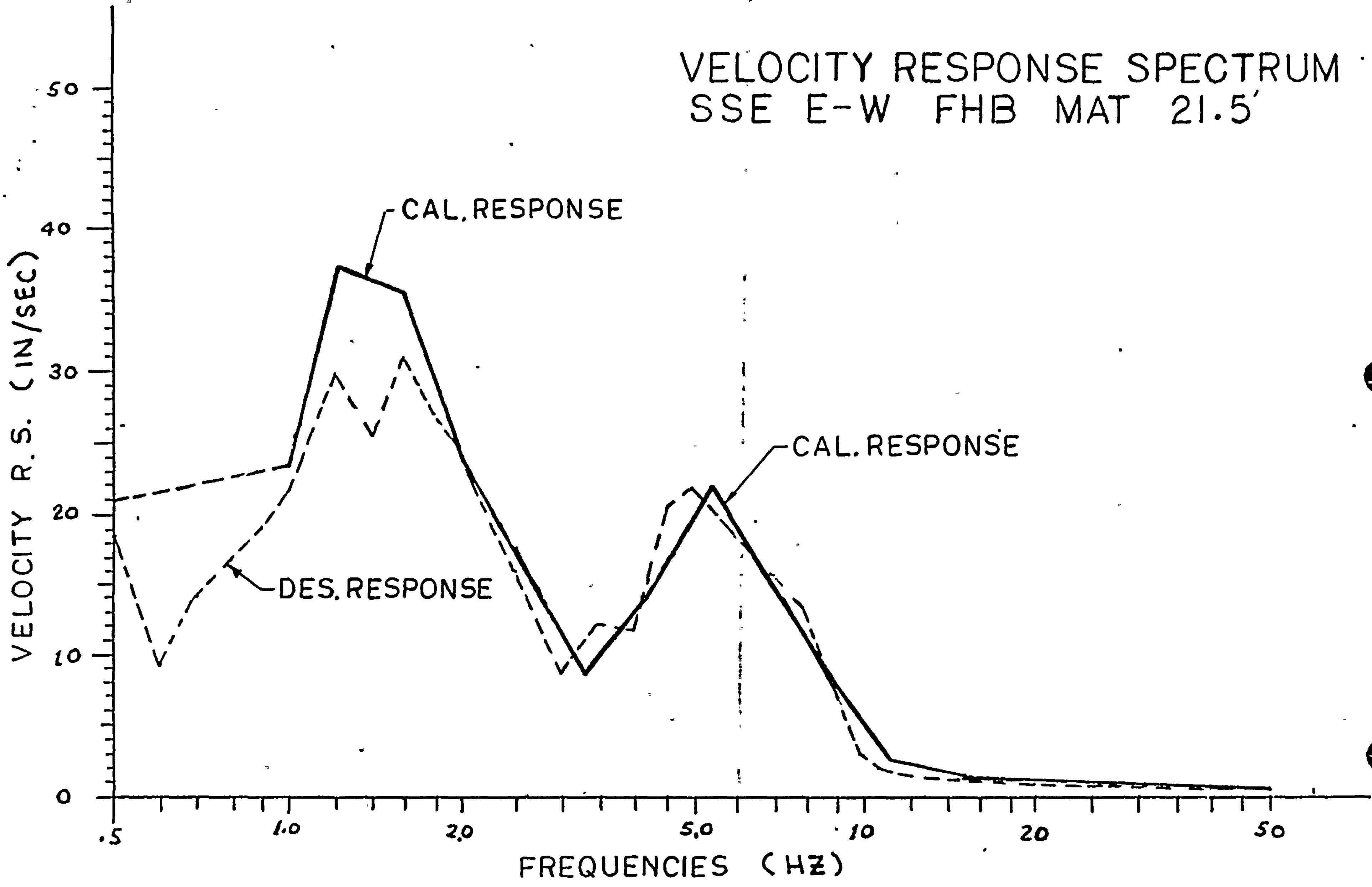


FIGURE JPE-LR-87-043-4

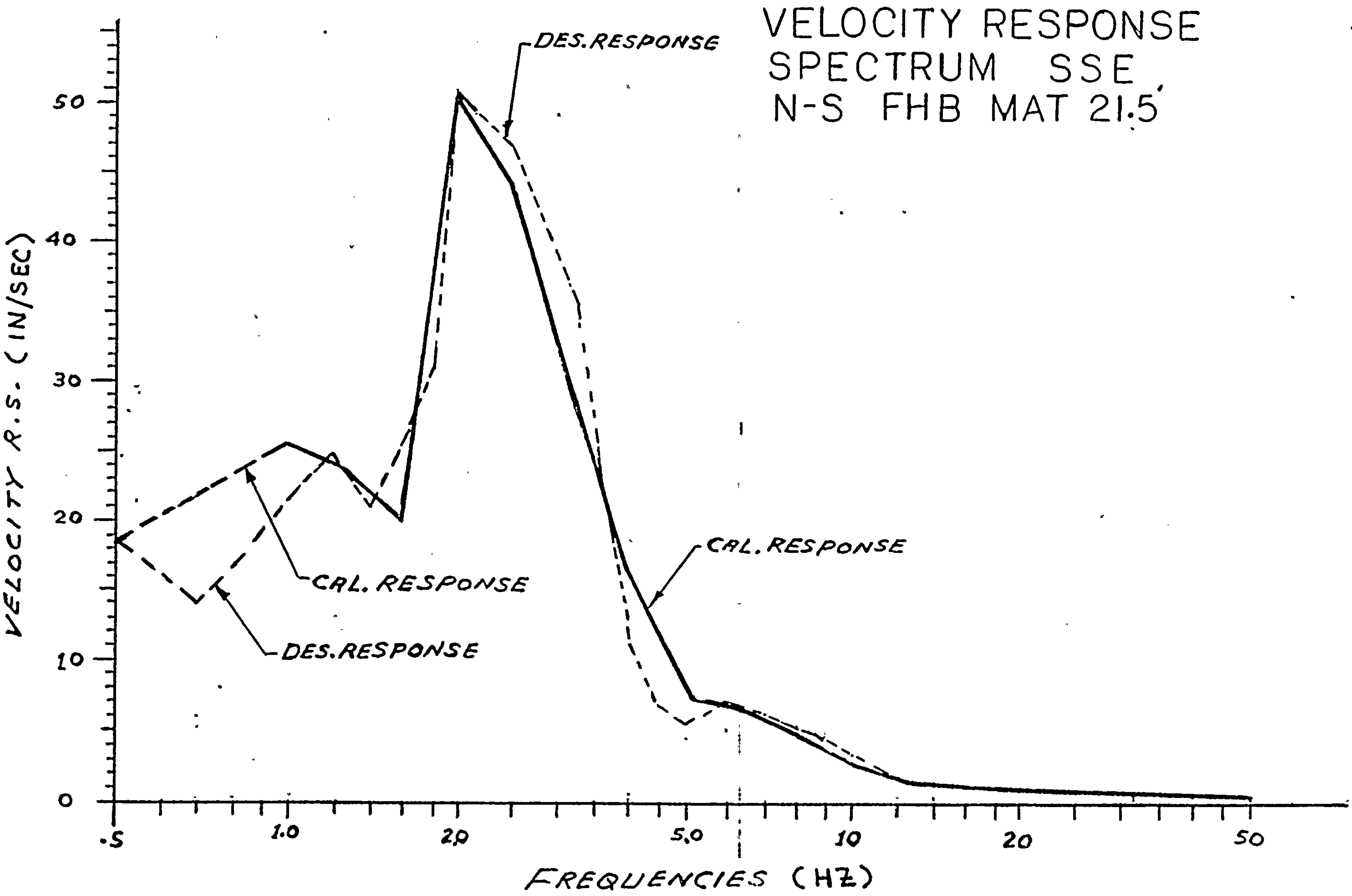


FIGURE JPE-LR-87-043-5

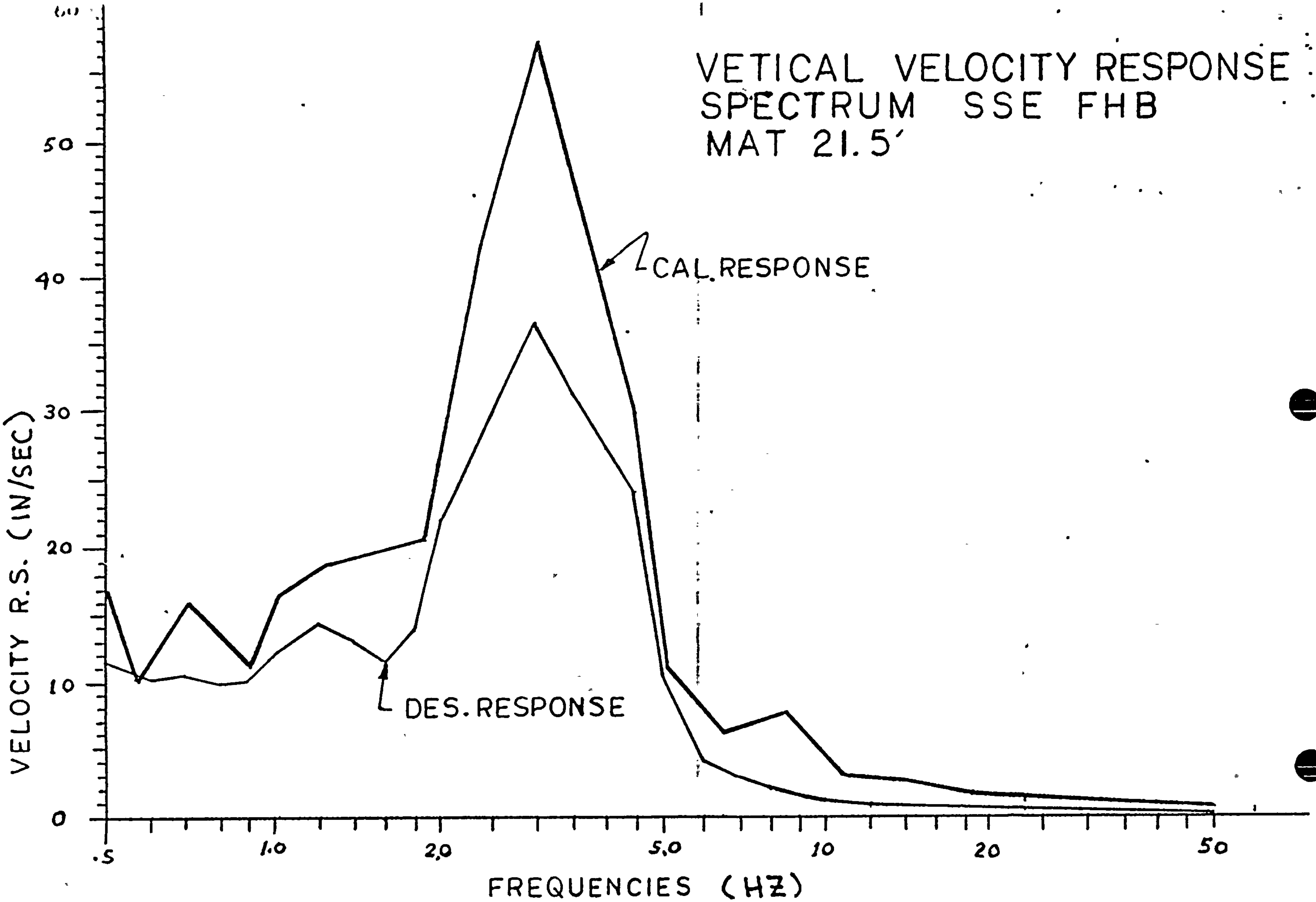


FIGURE JPE-LR-87-043-6

QUESTION #3 <u>Design and Analysis Procedures</u>

Question 3a - Provide a list of values of modeling parameters used in the fuel rack analysis including:

- Inter-rack impact element properties
- Rack/fuel impact element properties
- Support foot properties
- Friction element properties
- Mass of rack and fuel
- Dimensions
- Gaps between racks and wall, racks and fuel, and rack to rack
- Fluid coupling coefficients

Response 3a - Table 3.1a summarizes the property values used in the simulations. The following nomenclature is used in the table:

K_I - fuel assembly-to-cell wall impact spring rate
K_w - rack-to-rack or rack-to-wall impact spring rate
K_f - friction spring rate (active prior to sliding)
K_R - spring rate representive of rotational resistance between liner and support leg
K_d - support leg axial spring rate
h - length of support leg
H - height of rack above base plate

The weight and dimensions of the racks studied are given as follows:

cells	rack weight(lb)	fuel weight(lb)	LX(in)	LY(in)
8x13	19800	260,000	71*	116
9x10	29800	225,000	90	100
9x12	22300	270,000	80	107

LX, LY are the planform dimensions assumed for each rack.

Fluid coupling coefficients are calculated internally during the simulation.

---

* This dimension is smaller than actual value to reflect cut-out.

QUESTION #3 Design and Analysis Procedures (continued)

TABLE 3.1a
Property Value

Rack Module	H1	B2	G1*
K_I (#/in)	$.359 \times 10^6$	$.310 \times 10^6$	$.372 \times 10^6$***
K_w (#/in)	$.1 \times 10^7$	$.1 \times 10^7$	$.1 \times 10^7$**
K_f (#/in)	$.221 \times 10^{10}$	$.221 \times 10^{10}$	$.221 \times 10^{10}$
K_d (#/in)	$.112 \times 10^7$	$.109 \times 10^7$	$.123 \times 10^7$
K_R ($\frac{\text{\#in}}{\text{rad}}$)	$.567 \times 10^8$	$.567 \times 10^8$	$.567 \times 10^8$
h (in)	6.125	6.125	6.125
H (in)	169	169	169

* 6 support feet (.1875" initial gap on 2 of 6 supports)
** Where 2 racks are adjacent, gap between base plates = .625"; gap between girdle bars = .375"
*** Nominal gap between cell wall and fuel assembly = .125"

Question 3b - Provide the calculations which defined the key modeling parameters.

Response 3b - Manual calculation of the key modeling parameters was not required since these parameters are internally calculated by a preprocessing program which has been validated according to Holtec's Quality Assurance Procedures. Based on user input of overall rack dimensions, cell size, thickness of cell walls, etc., the preprocessor calculates all inertias, spring rates, etc. and provides, as output, a data file which is directly used by the DYNARACK transient analysis code.

QUESTION #3 Design and Analysis Procedures (continued)

Question 3c - Do the spring stiffnesses used in the fuel rack model represent calculated values? If not, provide justification.

Response 3c - For the single rack models used in the St Lucie analysis, the spring rates used represent calculated values with the exception of rack-to-rack impact springs at the upper girdle bars. The values used for all external impact springs are 1×10^6 #/in. Calculations have shown that this value is reasonable for the base plate-to-base plate impact, but is significantly larger than what may be expected at the upper girdle bars. Since the design basis analysis model assumes adjacent racks to execute 180° out-of-phase motions with respect to the rack under analysis, overestimating the impact spring constant results in an overestimate of the peak impact load.

Question 3d - Provide justification for the assumption that the motion of a fuel rack can be represented by a rigid six degree of freedom structure.

Response 3d - The use of a six degree of freedom (DOF) model for the rack is based on natural frequency considerations of a rack gridwork in water. For a typical rack, the lowest natural frequency due to elastic deformation is 32 Hz, which is well above the expected forcing frequency of the seismic input (5-8 Hz). Thus, the rack behavior may be considered as that of a rigid body, whose motion is completely described by a 6 DOF model.

The natural frequency value of 32 Hz was calculated for the G1 rack assuming that it is vibrating about its weak plane of symmetry in the first mode of a cantilever. All water contained in the rack is assumed to vibrate with the rack. The fuel in the rack is assumed to vibrate independently as a series of rattling masses and does not contribute to the natural frequency of the rack.

QUESTION #3 Design and Analysis Procedures (continued)

Question 3e - Provide the natural frequencies of the fuel racks in both the vertical and horizontal (rocking) directions. Consider variations in geometry, fluid immersion, and fuel load conditions.

Response 3e - The fuel rack model is not a linear model. All of the "spring" elements used are non-linear in that they are either gap elements or friction elements. As such, there is no real definition of a "natural frequency" which is appropriate to the model. The computer simulation does not make use of any "mode shapes" or "natural frequencies" as part of the solution methodology. Nevertheless, a calculation can be made of a "bouncing frequency" associated with vertical motions of the rack with the support springs considered as linear springs. For the G1 rack we obtain:

$$f = 5.92n^{1/2}\ \text{Hz}$$

where n is the number of feet involved during a vertical impact with the ground. For bouncing on four feet (purely vertical), f = 11.84 Hz. For rocking alternately on two feet, f = 8.37 Hz.

The bouncing frequency is also calculated for the G1 rack. All locations are assumed to be filled with fuel and the fuel in the rack is assumed to be attached to the rack base. The virtual mass of water equal to the volume displaced by a solid (imaginary) rack parallelopiped is also assumed to be added to the rack inertia.

Question 3f - Were rack modules B2, G1, and H1 the only racks analyzed as indicated in Table 4-10? On what basis were these racks selected?

Response 3f - Modules B2, G1, H1 are the racks analyzed to show that structural integrity is maintained during a seismic event. These racks were chosen on the following bases:

B2 - representative of region 1 configuration (the largest region 1 rack); this rack is adjacent to two walls.

G1 - a large region 2 rack near the cask area; this rack has 6 feet, 2 of which (nearest the cask area) have an initial gap and are designed to come into contact with the floor only when rocking is sufficient to close the gap. The eccentric placement of its main support legs causes this rack to be relatively more prone to rocking, thus resulting in potentially higher stresses than a more conventional region 2 rack. The relatively unique configuration of this rack thus makes it a logical candidate for analysis.

H1 - This is a region 2 rack with a cut-out and one additional support foot. For conservatism, the rack was considered to have 104 cells loaded with fuel, but used a planform for analysis that was less stable than the planform actually present. The uniqueness of this rack required that it be analyzed.

QUESTION #3 Design and Analysis Procedures (continued)

Question 3g - Provide justification for using a single rack model of a fuel rack. How are multiple rack effects accounted for in the analysis?

Response 3g - The single rack analysis permits construction of a highly detailed model of the 3-D non-linear behavior not feasible with a multi-rack model. The methodology includes the following three conservative assumptions for rack analysis to account for the presence of multiple racks.

- Each adjacent rack module was assumed to move in a manner equal and opposite (out of phase) to the rack module being analyzed. This conservative assumption results in an overestimate of rack-to-rack impact force and was incorporated in the model by utilizing a reference plane midway between adjacent racks as the location of the interrack impact springs.

- The fluid coupling coefficients were based on the conservative assumption that adjacent rows of racks are spaced further away from the rack being analyzed than is actually the case. This reduces the "cross coupling effect" of adjacent rows of racks and results in higher displacements and forces.

- The rack-to rack impact spring rates were set at a value significantly higher than the expected calculated value so as to produce an upper bound on rack-to-rack impact forces.

An analysis of a two-dimensional multiple rack model will be performed to determine the extent of rack displacement under a seismic event.

The analysis will treat the east-west rack array near the south wall containing modules A1, A2, B1 and B2. The fluid coupling gaps in the north side will be assumed to be 4 inches, and at the south side 4.5 inches. The fluid coupling gaps at the east and west wall locations will be the actual gaps; however, the rack-to-wall impact gap clearance will be assumed to be 3-1/4 inches. CE 14x14 fuel assemblies are assumed to be in every storage location. The fuel-to-cell hydraulic coupling coefficients will be reduced to 50% of the "blunt body" value.

The rack-to-rack impact gap is 3/8 inch. The total spring rate at the girdle bar and baseplate locations are $1x10^6$ and $2x10^6$ lb/inch, respectively.

Two runs for friction coefficients of 0.2 and 0.8 will be made. Results of the analysis will be provided when available.

QUESTION #3 Design and Analysis Procedures (continued)

Question 3h - Provide a description of the DYNARACK program and sample outputs. Discuss how the program was verified.

Response 3h - The computer code DYNARACK is a dynamic simulation program based on the component element method of analysis described in the text "The Component Element Methods in Dynamics" by S Levy and J P D Wilkinson, McGraw Hill (1976).

The solution of the rack dynamics problem using DYNARACK entails the following three steps:

(i) Develop a structural characterization of the rack-fuel assembly structure in terms of lumped masses, non-linear springs (including friction and stop elements), fluid coupling elements, and appropriate provisions for three dimensional kinetic degrees-of-freedom.

(ii) Assuming conservatively prescribed motions for neighboring racks and fluid effects, write equations for the kinetic energies of the rack proper, the assembly of fuel assemblies, and the entrained and coupling fluid energies.

(iii) Utilize Lagrange's formulation to assemble the displacement coupled second order differential equations in the prescribed generalized coordinates. These simultaneous equations are solved by a uniformly converging method of numerical quadrature. The input to DYNARACK consists of information about the rack, and information about the relationship of each spring extension to the various degrees-of-freedom used in the simulation.

Both DYNAHIS and DYNARACK are based on the solution for non-linear structures under time history inputs. DYNARACK, however, has many more capabilities and refinements that the older code, DYNAHIS, does not possess. In particular, the following features of DYNARACK distinguish it from DYNAHIS:

(i) DYNARACK includes "cross coupling" fluid effects (which DYNAHIS does not).

(ii) DYNARACK includes non-linear hydrodynamic coupling terms between cell wall and fuel assemblies. DYNAHIS model is quite approximate in this respect.

QUESTION #3 Design and Analysis Procedures (continued)

Response 3h - (continued) (iii) DYNARACK has capability for multi-rack analysis (DYNAHIS does not).

(iv) DYNARACK has 16 DOF (DYNAHIS had only eight)

(v) DYNARACK is coupled with a Q.A. validated data file generation code. DYNAHIS is not.

Verification of the DYNARACK program is carried out in accordance with Quality Assurance Procedures following 10 CFR 50, Appendix B. Validation of DYNARACK results involves: (1) comparison with analytical solutions and with numerical solutions obtained from other computer codes (DYNARACK has been validated against all test cases which were originally used to validate DYNAHIS); and (2) manual calcuation of mass matrix terms and comparison with results determined internally by DYNARACK.

Question 3i - Provide additional information on how fluid coupling effects are incorporated into the equations of motion. Provide justification for using fluid coupling coefficients based on small displacements and constant gaps for both fuel-to-cell and rack-to-rack coupling.

Response 3i - Fluid coupling effects are incorporated into the governing equations by a proper accounting of the kinetic energy of the fluid trapped in the region between fuel assemblies and cell walls, and in the region between racks or between racks and walls. Based on an assumed motion of the walls enclosing a fluid region, satisfaction of continuity permits development of expressions for fluid velocity in the region in terms of spatial coordinates, and in terms of the velocity degrees-of-freedom of the adjacent structures (rack and/or fuel assemblies). The development of these velocity expressions for the fluid is based on the methods outlined in Refs [1] and [2], below. Having satisfied continuity by developing appropriate fluid velocities in terms of the degrees-of-freedom of the adjacent structures, the contribution of the fluid motion, induced by structure motion, to the system kinetic energy, is easily constructed. Formation of the appropriate Lagrange's equations automatically yield the correct fluid contributions to the system equations.

[1] R J Fritz, "The Effects of Liquids on the Dynamic Motion of Immersed Solids", Journal of Engineering for Industry, ASME, Feb., 1972 pp 167-172.

[2] "The Component Element Method in Dynamics", S Levy and J P D Wilkinson, McGraw Hill, 1976.

QUESTION #3 Design and Analysis Procedures (continued)

Response 3i - (continued) Fritz consistently makes the small deflection assumption in his work, but the approach of determining fluid velocities to satisfy continuity and subsequently forming system kinetic energy is not limited to small deformations. It can be shown that the contribution of the fluid leads to terms in the mass matrix and to terms which can be considered as non-linear springs. If small deflections are considered, only the mass matrix terms appear and the terms have constant coefficients. If rack/fuel motions are assumed large compared to the gap spacing, then both mass matrix and spring terms appear. Previous studies have shown that inclusion of the large deformation terms lead to a lowering of the structural response (see Ref [3]). Therefore, our neglect of the non-linear spring like terms arising from the fluid effects is conservative.

[3] "Dynamic Coupling in a Closely Spaced Two-Body System Vibrating in a Liquid Medium": "The Case of Fuel Racks", K P Singh and A I Soler, 3rd International Conference on Nuclear Power Safety, Keswick, England, May 1982.

Question 3j - Did the fuel-to-wall fluid coupling coefficients consider the flow area through the fuel assemblies? If not, provide calculations demonstrating the conservatism of the model.

Response 3j - The PWR fuel assemblies used in the St Lucie Unit 1 reactor typically contain 176 fuel rods in a 14 x 14 array. The fuel rods are 0.440 inches in diameter arranged in a square lattice with a pitch of 0.577 inches. Therefore, the gap between the adjacent fuel rods is less than 3/16 inch (0.137 inches nominal). The cross-sectional dimension of the rod array is 8.115 inches square. Since the storage cell opening cross-sectional dimension is 8.65 inches, the net lateral spacing between the fuel assembly and the storage cell is 0.535 inches. The lateral movement of the fuel assembly in the storage cell causes the water to flow past the assembly. Since the flow between the narrow channels formed by the array of rods involves repeated changes in the flow cross-section of width from 0.137 inches to 0.577 inches - a fourfold change in transverse flow area - the hydraulic pressure losses through the channels are an order of magnitude greater than what the fluid encounters flowing through the assembly/cell wall gap around the array periphery. The hydraulic pressure loss due to flow through these narrow covergent/divergent channels is an important mechanism for energy loss from the vibrating rack system. However, in the conservative approach used to model fluid coupling, no such flow, and therefore, no such loss occurs; all the fluid is assumed to flow in the assembly/cell wall space around the array periphery.

QUESTION #3 Design and Analysis Procedures (continued)

Question 3k - How was structural damping incorporated into the fuel rack model? Describe method and list specific elements in which damping is included.

Response 3k - No structural damping is used in DYNARACK. The damping imposed on the fuel rack model is impact damping applied to all gap elements. A viscous damping matrix [C] is constructed where

$$[C] = [K]B$$

[K] is the stiffness matrix associated with all non-linear gap elements. B is given as

$$B = 2p/w$$

Where p is the ratio of actual damping to critical damping, and w is the forcing frequency (rad/sec) at which this ratio is presumed to occur. The fuel rack model consists of masses, friction spring elements, and gap (impact) elements. Structural damping is associated only with the gap elements and is active only when the gaps are closed. For the St Lucie analyses, B = 6.4×10^{-4} in all runs which is equivalent to p = .02 at a frequency of 10 Hz. Since the dominant forcing frequency of the seismic input is in the neighborhood of 5 Hz, the value of B used is conservative in that it will predict less damping than is actually present in the real structure.

Question 31 - Provide justification for assuming the same friction coefficient for both static and sliding rack conditions.

Response 31 - The bounding values of 0.2 and 0.8 used in the analysis envelope both the static and sliding conditions and separate analyses are performed at both extremes to simulate the worst cases for translational and rotational motion and rack stress. Justification for using the same value in a given analysis is found in the fact that there is only a small difference between the sliding and static values for a given condition.

QUESTION #3 <u>Design and Analysis Procedures</u> (continued)

Question 3m - Provide justification for modeling the fuel assemblies as independent rattling masses.

Response 3m - The fuel assemblies are modeled as five uncoupled lumped masses spaced uniformly along the vertical length of the fuel rack. Since the fuel assembly has a natural frequency much lower than the rack, the effects of coupling the masses is insignificant and do not affect conclusions concerning structural integrity.

Question 3n - Discuss the basis for selection of the fuel to cell impact spring elevations. Are these the only locations where fuel to cell impacts are anticipated?

Response 3n - Fuel is modeled as five lumped masses free to move in the horizontal plane at Z=0, .25H, .5H, .75H and H where H is the height of the rack above the base plate. Actual fuel-rack impacts, if they occur, will occur at the locations of any spacer grids for the rod bundle, and certainly at the top of the rack. The choice of impact locations in the dynamic model is such as to balance the modeling of the fuel as a uniform mass distribution with the actual location of potential impact locations.