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John C. Brons
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December 20, 1988
IPN-88-055

U.S. Nuclear Regulatory Commission
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Mail Station P1-137
Washington, D.C. 20555

Subject: Indian Point 3 Nuclear Power Plant
Docket No. 50-286
Spent Fuel Pool Expansion (TAC 68233)

References: 1. Letter to Mr. John C. Brons from Mr. Joseph D. Neighbors, dated September 12, 1988 entitled: "Request For Additional Information Related To The Indian Point 3 Spent Fuel Pool Expansion."

Dear Sir:

Reference 1 requested the Authority to provide additional information regarding the Indian Point 3 (IP-3) spent fuel pool expansion. Attachment I to this letter contains the information requested in Reference 1.

Should you or your staff have any questions regarding this matter, please contact Mr. P. Kokolakis of my staff.

John C. Brons
Executive Vice President
Nuclear Generation

cc: Mr. Joseph D. Neighbors, Senior Project Manager
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PROP DRAWINGS
TO REG FILE

ATTACHMENT I TO IPN-88-055

RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION REGARDING THE INDIAN POINT 3 SPENT FUEL POOL EXPANSION

NEW YORK POWER AUTHORITY
INDIAN POINT 3 NUCLEAR POWER PLANT
DOCKET NO. 50-286
DPR-64

Question I.1

Provide sketches and/or drawings of the pool showing elevations, basemat and pool wall thicknesses, water levels, and safety related components (such as piping) in the pool, and their clearances from the racks.

Response to Question I.1

The attached drawings show the pool elevations, wall thickness, water levels and related components in relation to clearances from the racks. Safety related components in the spent fuel pool consist of water level indicators and inlet and discharge piping for the pool cooling system.

Drawing No.	Title
9321-F-11973 Rev. 8	Fuel Storage Building Plans El. 55' - 0"
9321-F-13013 Rev. 6	Fuel Storage Building Tank Liner - Plate Sh. 1.
9321-F-25143 Rev. 7	Fuel Storage Building General Arrangement - Plans and Elevations
9321-F-25763 Rev. 17	Fuel Storage Building - Auxiliary Coolant System Plans
9321-F-25773 Rev. 14	Fuel Storage Building - Auxiliary Coolant System Sections
9321-F-27243 Rev. 18	Flow Diagram Primary Makeup Water Nuc. Stm. Supply Plt.
9321-F-27513 Rev. 21	Flow Diagram - Auxiliary Coolant System in PAB and FSB - Sheet 2
8721-1 Rev. 3	Plan Arrangement of Spent Fuel Storage Pool, Minimum Pitch-Region 1/Poison Wall - Region 2

Question I.2

Provide information on how the additional weight of maximum density rack (MDR) and impacts on floor and walls under the postulated seismic events are incorporated in the design of the pool structure. Provide information related to pool structure seismic responses due to the proposed reracking, controlling load combinations and stresses at critical structural sections.

Response to Question I.2

As stated in the Spent Fuel Storage Facility Modification Safety Analysis Report (SAR) provided with NYPA's May 9, 1988, letter IPN-88-018 to the NRC, the loads considered in the Spent Fuel Pool Analysis included the additional dead weight of the maximum density racks and their contained fuel assemblies and control rods. The results of the analysis under the postulated seismic events are contained in Table 4-2 of the SAR. As indicated therein, the controlling load combinations are D + L + Ta + E' for shear and 0.75 (1.4D + 1.7L + 1.7 To) for bending. These terms are defined in the SAR. The critical section for shear is located at the mat near the fuel transfer canal and the critical section for bending is located at the wall near the fuel transfer canal. The margin of safety (defined as the allowable minus the actual and then divided by the actual) is 0.08 for shear and 0.12 for bending.

Question I.3

Provide information on the effects of MDR weight on the soil bearing capacity and liquefaction potential.

Response to Question I.3

The pool structure mat is supported directly on solid bedrock with allowable bearing capacity of 50 Kips per sq. ft. per existing design documents. The "Structural Evaluation of the Spent Fuel Storage Building for Storage of U.S. Tool and Die Maximum Density Racks containing 1345 Fuel Assemblies," provided to the NRC by NYPA at the June 8, 1988 meeting, showed that the maximum bearing pressure on the bedrock for the maximum density racks filled with fuel assemblies and control rods is only 17.9 Kips per sq. ft., which is well below the allowable bearing capacity.

The foundation material is classified as solid bedrock per standard engineering classifications. Liquefaction potential of this material is extremely low under the effects of MDR weight and postulated seismic loading conditions.

Question I.4

Provide information on how the integrity of the floor liner plate will be maintained under sliding and impact of rack supports. Consider as-built unevenness of the floor liner plate.

Response to Question I.4

As indicated in the Safety Analysis Report, the analysis for the liner and liner anchors demonstrated the integrity of the floor liner plate, with a minimum safety factor of 4.71 under combined temperature loads, strain induced loads due to the deformation of the floor and maximum horizontal friction forces of the rack supports on the floor from racks filled with fuel assemblies and control rods and with a maximum friction coefficient of 0.8.

As also noted in the Safety Analysis Report, sliding of the maximum density racks is minimal even for a low friction coefficient of 0.2. Rack lift-off is calculated to be extremely low (see response to question II.3) and momentary, which will not cause overturning and impact forces on the floor liner plate are negligible.

The rack supports and pool floor bearing pressure were evaluated in the "Structural Evaluation of the Spent Fuel Storage Building for Storage of U.S. Tool and Die Maximum Density Racks containing 1345 Fuel Assemblies" for the maximum rack reaction results from the non-linear time history analysis of the rack and found to be acceptable.

As-built unevenness of the floor liner plate was previously surveyed and found to be small, e.g. less than 3/4 inch variation in elevation. This unevenness will be accommodated by adjustment during rack installation of the screw pedestals attached to the rack modules. Also, spreader plates will be used to bridge over weld seams on the floor liner plate in areas where weld seams are located under or adjacent to the rack pedestals.

Question II.1

The SSE horizontal time-histories seem to be adequate with respect to the SRP criteria of enveloping. Provide the synthetic time histories corresponding to OBE and show that they meet the SRP enveloping criteria for pertinent damping values.

Response to Question II.1

The Indian Point 3 plant design documents provide the Housner response spectra normalized to 0.15g for DBE (or SSE) earthquakes along E-W and N-S axes for the spent fuel pool. The SSE horizontal time-histories were synthesized from these response spectra over a span of 15.0 seconds at a uniform time interval of 0.01 seconds. In accordance with the Indian Point 3 Final Safety Analysis Report, the OBE time histories for both E-W and N-S axes were obtained by scaling the SSE data by a factor of 2/3rds. These are attached herewith. The design spectra are shown superimposed. As may be noted from these curves, the synthesized time history curves envelope the design spectra, thereby satisfying the SRP enveloping criteria, similar to the SSE curves submitted earlier.

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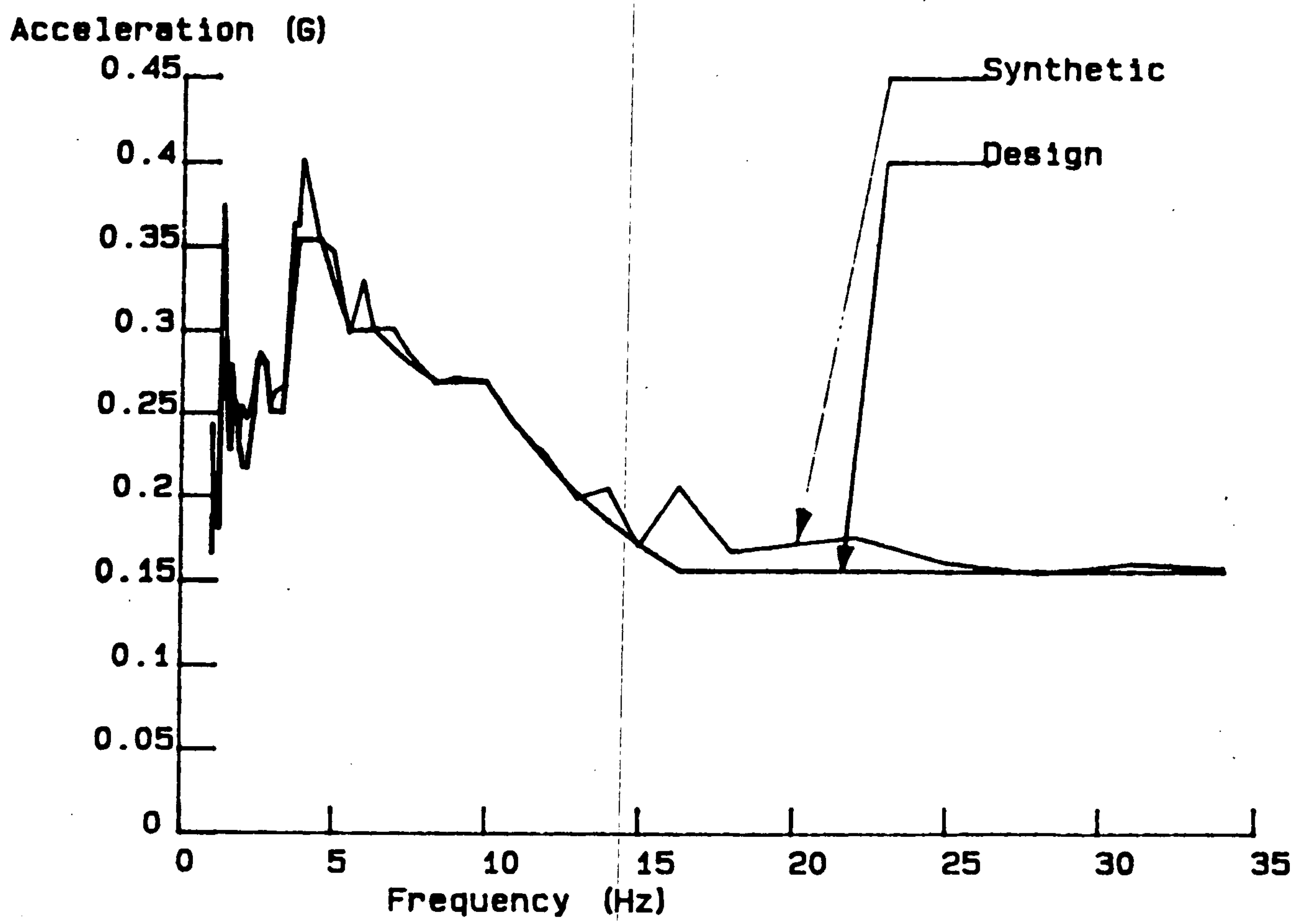

N-S OBE Spectrum Ele 54'-6" Indian Point # 3 (Fig H.1.1. 1% Damping)

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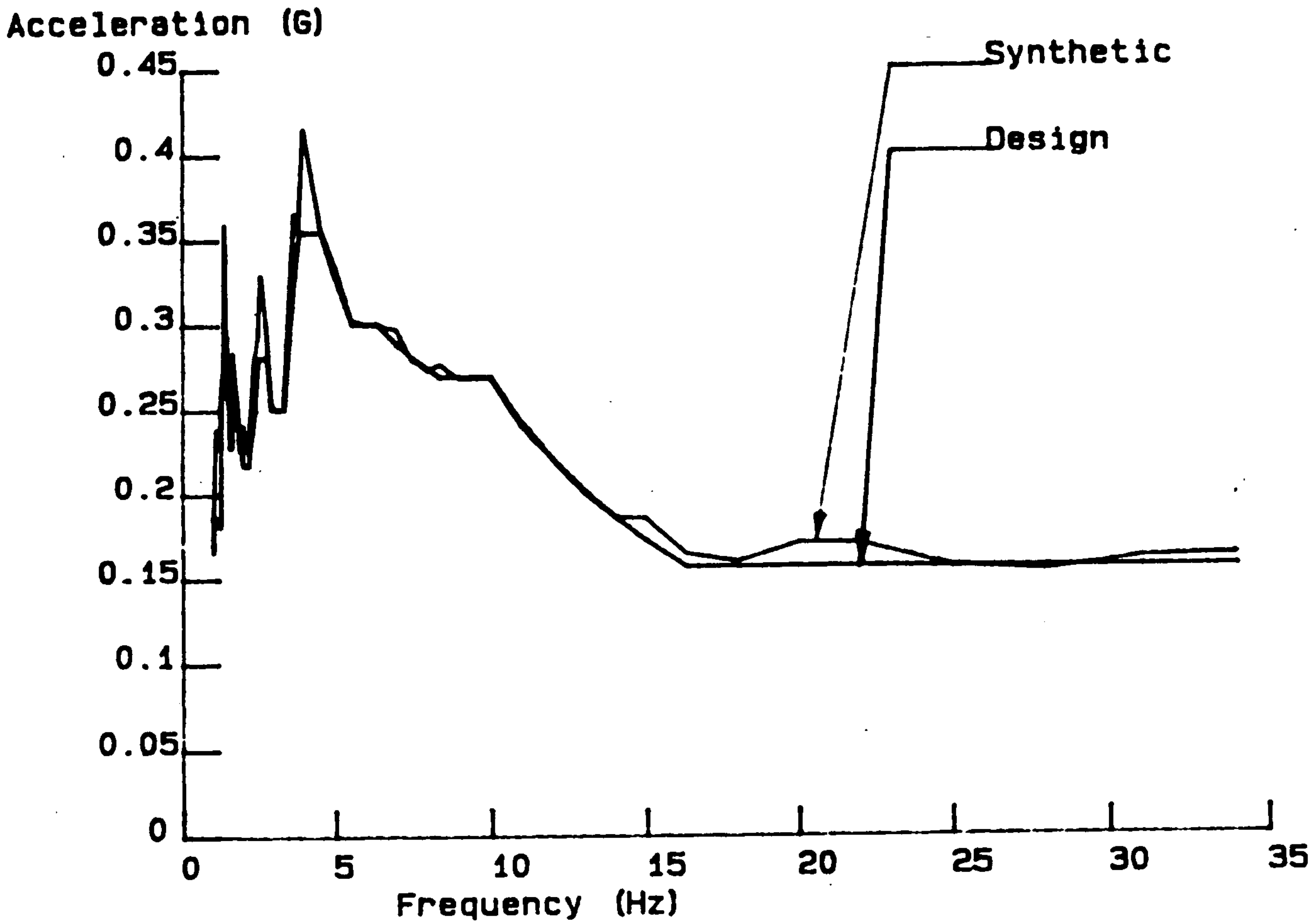

E-W OBE Spectrum Ele 54'-6" Indian Point # 3 (Fig H.3.1, 1% Damping)

Question II.2

Provide justification for using the equivalent static load method for vertical component of earthquake considering the non-linearities and lift-off associated with the analysis.

Response to Question II.2

Vertical seismic analysis was performed using the equivalent static load method as opposed to equivalent static factors method based on the following considerations:

i) Utilizing this methodology does not require the structure to be rigid i.e., having a vertical natural frequency above 33.0 Hertzs in accordance with SRP Section 3.7. The actual vertical natural frequency for the rack was calculated to be 14.6 Hertzs.

ii) Applying a factor of 1.5 to the peak acceleration of the applicable floor response spectra (SRP Section 3.7) would yield more conservative results than the results of dynamic analysis considering all non-linearities. It must be emphasized that the vertical seismic input is not severe enough to cause any of the non-linearities like lift-off in rack response.

However, a subsequent dynamic analysis was performed for the limiting case of 132-cell rack in Region 2 with consolidated fuel during an SSE-event. The analysis considered a combined vertical and horizontal time history input for both N-S and E-W directions. The maximum co-directional response was obtained using the SRSS method. Results were confirmatory and are described below:

Maximum Forces at Base of Rack on Two Pedestals
(Dynamic Analysis)

Direction of Seismic Input	Vertical (lbs.)
N-S (SSE)	136221.5 (F_{vt} N-S)
E-W (SSE)	112852.5 (F_{vt} E-W)

Dead weight (DWT) of 132-cell rack = 423062 lbs.
Submerged weight (S_{wt}) = 368289 lbs.

$$\text{SRSS (vertical)} = S_{wt} + \frac{\sqrt{(F_{vt}\ NS)^2 + (F_{vt}\ EW)^2}}{2}$$

$$= 361040 \text{ lbs.}$$

Response to Question II.2 (Continued)

Maximum Forces at Base of Rack on Two Pedestals
(Equivalent Static Load Method and Dynamic Analysis)

Direction of Seismic Input	Vertical	(lbs.)
N-S (SSE)	127156*	(Fns)
E-W (SSE)	102856*	(Few)
Vertical Equiv. Static Load	112112	(Fvt)
Submerged Weight (Swt)	368289	

* Revised from previous Seismic Analysis Report.

$$\text{SRSS (Vertical)} = \frac{Swt}{2} + \sqrt{(Fns)^2 + (Few)^2 + (Fvt)^2}$$
$$= 382430 \text{ lbs.}$$

Please note that the design basis load (382430 lbs.) on two pedestals by equivalent static load method envelopes the load obtained considering a combined vertical and horizontal time history excitation (361040 lbs.).

Question II.3.

The rack behavior under postulated earthquake will be strongly influenced by the three components of the postulated earthquake. Provide justification to demonstrate that the SRSS method of combination for the responses of the three components of the earthquake is a conservative method for predicting maximum sliding, tilting, twisting, combined displacements and potential impact loads between the racks, and the racks and the walls.

Response to Question II.3.

The rack behavior under the postulated earthquake is strongly influenced by the three components and the most realistic analysis would be to simultaneously provide excitation in both the horizontal directions and the vertical direction. However, the procedure adopted in the present seismic analysis was:

(i) Analysis of each of the horizontal axes independently by time-history method.

(ii) Combining the horizontal axes by SRSS method and

(iii) Algebraic summation with the vertical component, determined by equivalent static method.

This is more conservative than combining with SRSS for all three axes.

Our primary guidance regarding combining loads was provided by the SRP Section 3.7.2 II.6, a & b, "the method for combining the three-dimentional effects is .... by taking the square-root-of-the-sum-of-the-squares (SRSS) of the maximum co-directional responses caused by each of the three components of earthquake motion at a particular point of the structure or of the mathematical model". This applies irrespective of whether the response spectra, time-history or equivalent static load method was used for seismic analysis. In this particular case, as mentioned earlier, time-history method was used for horizontal axes and equivalent static method was used for vertical axis. The SRSS method of combining spatial components is also in agreement with Reg. Guide 1.92 - "Combining Modal Responses and Spatial Components in Seismic Response Analysis."

The SRSS method of combining loads has been demonstrated to be an acceptable method for predicting maximum sliding, tilting, combined displacements and potential impact loads between the racks, and the racks and the walls. Each of these non-linearities involved in the analysis are briefly described below. This is not intended to show the inherent conservatism of SRSS method of combining spatial components over any other method of combining them but that conservatism exists in the design of the IP-3 racks irrespective of the method of analysis.

Sliding and potential impact between the racks and the walls: The racks were allowed to slide (with minimum coefficient of friction between rack pedestal and pool liner = 0.2) to determine the maximum displacement and potential for impact with the pool wall. Cumulative displacements due to five (5) OBE plus one (1) SSE are as follows:

DESCRIPTION	MAXIMUM MOVEMENT AT THE BASE OF RACK (INCHES)	CUMULATIVE DISPLACEMENT 5 (OBE) + 1 (SSE) (INCHES)
132 CELL RACK W/STANDARD FUEL REGION 2	NS-OBE = 0.1280 NS-SSE = 0.3027	0.9427
132 CELL RACK W/ CONSOLIDATED FUEL	NS-OBE = 0.003366 EW-SSE = 0.003480	0.0203
80 CELL RACK W/ STANDARD FUEL REGION 1	NS-OBE = 0.1060 NS-SSE = 0.1454	0.6754
80 CELL RACK W/ CONSOLIDATED FUEL REGION 1	EW-OBE = 0.04512 EW-SSE = 0.08776	0.3134

The minimum gap provided between the pool wall and rack at the south end (Ref. Dwg. UST&D 8721-1) = 4.10 inches. It is concluded, therefore, that no impact between racks and walls will occur.

Sliding and potential impact between racks: Because of the presence of thin film of water between racks, strong hydrodynamic coupling is generated under dynamic situation like, postulated earthquakes. This shall be discussed later in response to Question II.5. It must be stated here that because of this technically well-established criterion, the racks move in-phase; thereby precluding potential impact between them. Yet, to simulate severe out-of-phase movement, the peripheral racks were modeled as stationary walls, to ensure impact. The maximum impact force under this postulated condition produced stresses in the impacted racks well below the allowable stresses (refer to Seismic Analysis Report Section 5).

Additionally, as confirmation that the non-linear behavior of the racks under multi-directional seismic excitation has been enveloped by the design basis analysis, a multi-rack analysis was performed using a combined vertical & N-S time history input. In order to envelop the non-linear behavior of Regions 1 and 2, the input was the limiting rack to rack gap of .125" (Region 2) and the minimum fluid coupling based on 1.5" rack to rack gap (Region 1). Three 80-cell Region 1 racks were analyzed. These are the governing size racks with respect to stability.

Response to Question II.3 (Continued)

The following table shows that no rack to rack impact occurs and that racks move nearly in-phase motion based on the small sliding value of .1238" computed due to the fluid coupling value of 1.5" gap.

MAXIMUM RELATIVE DISPLACEMENT BETWEEN RACKS*

(3 RACKS: CONSOLIDATED, UNCONSOLIDATED & EMPTY)

	0.8 COEFFICIENT OF FRICTION			
	RACK 1	RACK 2	RACK 2	RACK 3
	BOTTOM	TOP	BOTTOM	TOP
DESIGN BASIS N-S AND HORIZ.	.0626	-.1053	.0896	.139
COMBINED N-S HORIZ & VERT	,0785	-.1241	.0881	.1873
	0.2 COEFFICIENT OF FRICTION			
DESIGN BASIS N-S AND HORIZ.	.0714	.0758	.1452	.1427
COMBINED N-S HORIZ. & VERT	-.0371	-.0397	-.1203	-.1238

* The relative displacement is the difference between the absolute displacement of adjacent racks measured at the same elevations (top and bottom rack nodes).
(+) Positive sign indicates adjacent racks moved apart
(-) Negative sign indicates adjacent racks moved closer

Tilting or Tipping: To simulate the worst-case scenario of this non-linearity, the smallest rack filled with standard fuel (80-cell rack in Region 1) without the hydrodynamic coupling with adjacent racks, was subjected to N-S (SSE) and vertical earthquake loading. The maximum distance the pedestals will move vertically off the floor during this seismic event = 0.0014 inches, which is insignificant. (See response to Question II.4)

Twisting This is considered to be a non-concern, since the calculated lift-off height is insignificant, precluding the possibility of rack lifting-off on three pedestals and thereby subjecting the rack to a substantial twisting movement on one pedestal.

Question II.4.

The Seismic Analysis Report and the accompanying papers indicate that numerous computerized analyses were made for single racks and multi-racks. Provide for each analysis case pertinent to Indian Point 3, a summary containing the model, definition of all model parameters (masses, beams, springs, friction elements, fluid coupling coefficients, gaps, etc.), the value of the parameters and the source or method used to develop each parameter. In addition, a summary of the results (forces and displacements) for each analysis case should be presented in a tabular form which would assist in interpreting the rack response (rather than reviewing computer output), permit verification of assumptions made (such as the racks move in phase), and allow comparisons among the different analysis cases.

Response to Question II.4.

The objective of the Seismic Analysis Report was to show that a single rack in isolation, or a multiple number of racks in a group would be structurally stable when subjected to a simulated multi-directional earthquake. For a single rack, analyses were performed to quantify base shear loads, sliding response and tipping response. Non-linear time-history analyses were performed for the two horizontal directions and an equivalent static load analysis was done for the vertical direction.

For multi-rack analysis credit was taken of the presence of liquid between racks and the hydrodynamic coupling generated due to it. The analytical procedure was similar to a single rack. Fig. 1 shows a mathematical model of a rack with multiple cells in it, where ....

REPRESENTS MASS NODES

7	Base (Horizontal)
1-6	Rack (Horizontal)
7-12	Fuel Assembly (Horizontal)
13	Rotary Inertia
14	Vertical Mass of Rack plus Contents

REPRESENTS FLEXIBLE ELEMENTS

1-5	Rack
6-10	Fuel Assembly
11	Horizontal Restraint
12,13	Vertical Supports

REPRESENTS GAP ELEMENTS: Flexibility and local damping between fuel and rack walls

MHrw = Hydrodynamic Mass (rack to wall)
MHrf = Hydrodynamic Mass (rack to fuel)

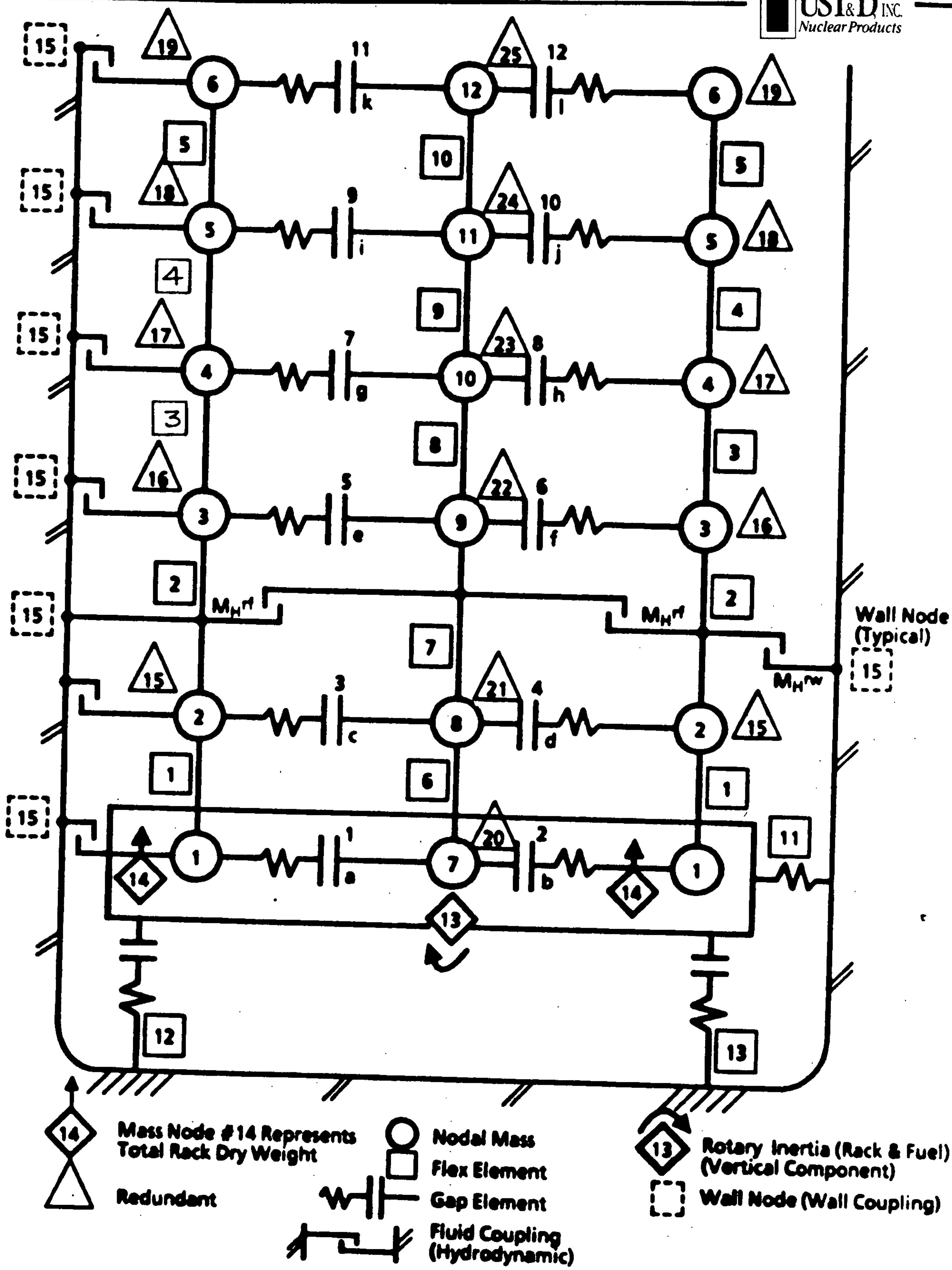

Figure 1

MODEL FOR SEISMIC ANALYSIS

PARAMETERS UTILIZED IN THE MODEL: -

Masses: Masses were calculated from structural dimensions, weights etc. Weight of the thin film of water around each fuel bundle was neglected in the lumped mass, with the exception of consolidated fuel in which case the entrained water was considered.

Beams: Beam-elements connect the lumped-masses of a single cell. As shown in Fig. 1 each has (for example 132 rack unconsolidated fuel, E-W direction) L = 33.08 in and EI = 9.37 E6 lb/in, fuel EI = 3.04 E 3 lb/in. These values were calculated from structural properties of the elements.

Gaps & Springs: Impact between the fuel and the rack cells is modeled by two gap-spring elements at each nodal elevation. The gaps represent the clearance on either side of a fuel assembly placed centrally in the cell.

The spring at each elevation represents the total contact stiffness between the rack and the fuel assemblies. During impact, the fuel assembly grid and cell wall act as springs in series. Therefore, the contact stiffness at each nodal elevation is determined by considering the stiffness of the grid and cell wall acting in series. The rack mass and fuel mass, are each represented as lumped masses at each elevation. Therefore the equivalent contact stiffness, corresponding to all the fuel assemblies and cell locations, is used in the two beam representation of the rack and fuel assemblies system at each elevation. (For example: 132-rack unconsolidated, N-S).

K - 79511 lb/in, GAP = .21 in

Friction Elements: A non-linear element is introduced in the analysis in order to calculate a sliding force at the bottom model based on Coulomb friction. The element is only introduced for sliding cases, where the minimum friction coefficient of .2 is used. A non-linear element is not needed where the friction coefficient of .8 is used because this is the non-sliding case.

Fluid Coupling Coefficient: Effective fluid masses or hydrodynamic masses were calculated for rack to wall (MHrw) and rack to fuel (MHrf) gaps filled with fluid. The primary guidance was provided by the article "The Effect of Liquids on the Dynamic Motion of Immersed Solid" by R.J. Fritz; Transactions of the ASME, 168/ February 1972.

The values of MHrw or MHrf depend upon the gap between the adjacent racks and are indirectly proportional to it.

SUMMARY:

The results are presented for three distinct cases e.g., (i) an isolated rack submerged in water but not in close proximity with any other racks i.e. no hydrodynamic coupling (ii) a single rack with hydrodynamic coupling forces considered between fuel and rack and between individual walls and (iii) multi-rack with adjacent racks full of consolidated fuel, full of unconsolidated fuel and empty.

Response to Question II.4 (Continued)

(i) Isolated Rack With No Hydrodynamic Coupling:

The smallest rack filled with standard fuel, with 0.8 coefficient of friction (non-sliding) in Region 1 was considered. Maximum lift off distance due to N-S plus vertical excitation was 0.0014 inches and maximum lift-off due to E-S plus vertical excitation was .0986". This demonstrates the stability of an isolated rack. Stress evaluation was not performed in accordance with SRP tilting criteria.

(ii) Single Rack With Hydrodynamic Coupling:

This analysis was performed for the math model shown in Fig. 1.

Max. Tensile Stress = 21,810 $\frac{\text{lbs}}{\text{in}^2}$,

This is below the allowable stress.

Max. Sliding (SSE) = 0.3027 inches
Max. Lift-off = 0.01 inches

This shows that the stresses and displacements are acceptable.

(iii) Multi-Rack Analysis: The 3-D model used for this analysis is shown in Fig. 2.

- Racks do not impact as evidenced by:
  initial (as installed) distance between
  Rack 1 & 2 = 0.250 inches
  Rack 2 & 3 = 0.250 inches

  Final displacements (for sliding) between
  Rack 1 & 2 = 0.252 inches
  Rack 2 & 3 = 0.142 inches

- In this case hydrodynamic coupling due to 1 1/2"-gap was utilized for ≤ 1/2" actual installation gap. The racks do move nearly in phase.

- Stresses produced in case of a postulated impact = 1.37 ksi << 2.05 Ksi, buckling stress for typical rack wall material.

The above results represent a limiting case of multi-rack analysis enveloping both Region 1 and 2 racks. This is an extension of the simplified uni-directional multi rack analysis contained in The Seismic Analysis Report (Section V) provided earlier.

MULTI RACK CONNECTIVITY

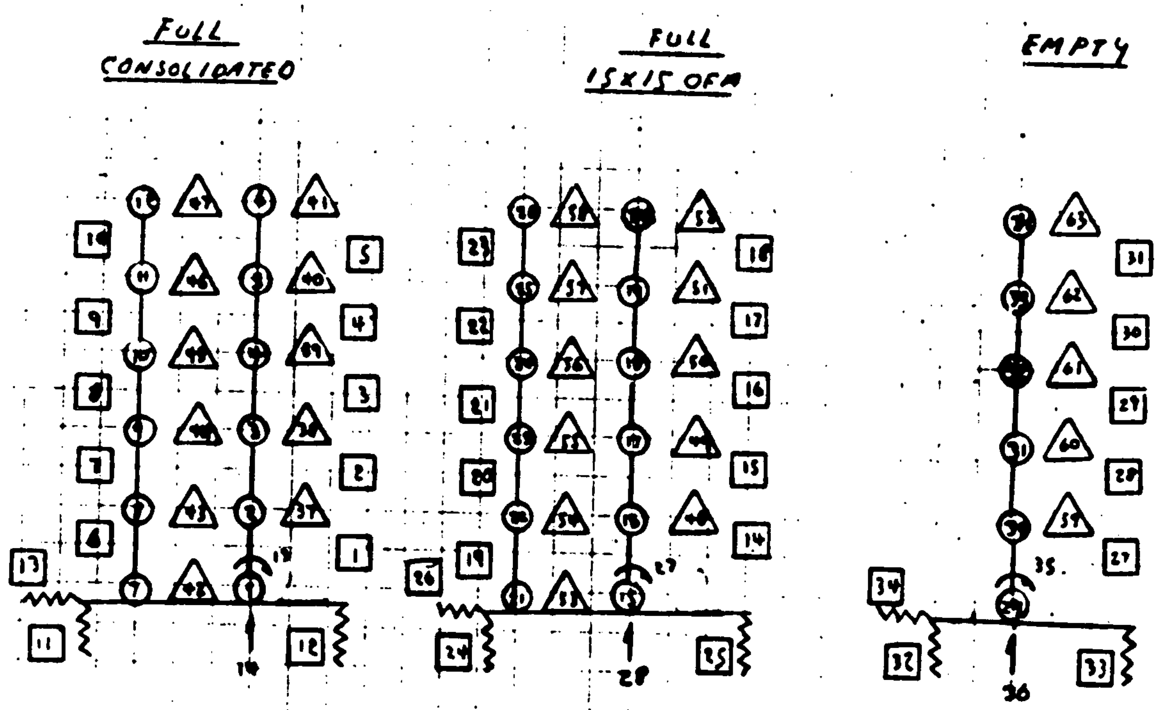

FIGURE No. 2

Question II.5

The following questions deal with the issue of fluid coupling as presented in the Seismic Report, Appendix C (Fluid Structure Coupling of Rectangular Modules).

(a) Are the equations derived in Appendix C used to calculate all the coupling coefficients for fuel to rack, rack to rack and rack to wall? If so, how can this approach, which is based on a rigid rectangular box inside a rigid rectangular pool, simulate the fuel assembly? The fuel assembly does not have a rigid enclosed rectangular boundary but permits fluid flow through the fuel assembly.

(b) Why is flow in the axial (vertical) direction neglected in the formulation?

(c) Justify the use of the equations, if as stated in Appendix C, "the magnitude of the calculated hydrodynamic masses exceed the actual value," and when these values are controlling.

In addition, explain if fluid damping is used in any of the analyses and if so, how was it developed.

Response to Question II.5

(a) The equations are used only for calculating the coupling coefficient between the consolidated fuel canister and the cell wall, where the geometry is the same as that used in Appendix C. Equations for other geometries are shown in the Seismic Analysis Report Sections 4 and 5.

(b) Practically all of the fluid motion, except near the ends is horizontal. Analyses made for similar racks, in which the coupling near the ends was reduced substantially to account for possible axial flow, showed that results were insensitive to this effect.

(c) As in the above response, the loss of hydraulic coupling force due to end effects has been shown to be small and has negligible effect on the calculated results found in the analysis.

In accordance with the SRP Section 3.7, no fluid damping was used in the analysis.

Question III.1

Provide a summary of the calculations indicating the design adequacy of the fuel assembly in the fuel racks, particularly under the calculated impact loads.

Response to Question III.1

Impact forces during a seismic event on all Westinghouse 15 x 15 fuel assembly designs used at IP3 in the racks were calculated as part of the Seismic Analysis. Separate calculations were made for Region 1 and Region 2, each of which determined impact force at six axial points evenly spaced along the fuel assembly.

For Region 1, the highest impact force was 276 lbs. at an elevation of 127.8" above the bottom nozzle. For Region 2, the highest impact force was 230 lbs. at an elevation of 95.9". These forces are several magnitudes less than that required to induce inelastic deformation of fuel assembly components.

Question III.2

When considering the effects of seismic loads, how do the factors of safety for gross sliding and overturning of the racks compare with the acceptance criteria specified in Standard Review Plan Section 3.8.4. Appendix D, paragraph (6).

Response to Question III.2

In accordance with SRP Section 3.8.4, Appendix D, paragraph (6) the factors of safety against sliding and tilting need not be met, provided that it can be shown by detailed non-linear dynamic analyses that the amplitudes of sliding motion are minimal, and impact between adjacent rack modules or between a rack module and the pool walls is prevented, provided that the factors of safety against tilting are within the values permitted by SRP Section 3.8.5, Subsection II.5.

A confirmatory analysis of an isolated 80 cell rack, subjected to a combined horizontal and vertical seismic excitation resulted in a maximum lift-off distance of .0986". The turnover lift-off distance is 44.1". This results in a factor of safety of 447 against overturning. The sliding displacement summary, presented in response to Question II.3 has shown the sliding distances to be minimal.

Question III.3

To understand why thermal load effects on the fuel racks is insignificant, provide your Reference 5 report, "Thermal and Hydraulic Analysis Report, Spent Fuel Storage Pool (8721-00-0104) Rev. No. 1, January 1988."

Response to Question III.3

Enclosed is the above requested report.