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Docket No. 50-397

June 1, 1979
G02-79-113

Director
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington D.C. 20555

Attention: Mr. S. A. Varga, Chief
Branch No. 4
Division of Project Management

Subject: WPPSS NUCLEAR PROJECT NO. 2
SUBMITTAL OF EXPANDED CHUGGING REPORT

Dear Mr. Varga:

Enclosed are five (5) copies of the following report:

> Burns and Roe, Inc., "Chugging Loads - Improved Definition and Application Methodology to Mark II Containments - Technical Report"

The above report comprises Attachment 1 of our submittal.

This report provides a detailed description of the mathematical models introduced in the Burns and Roe, Inc. report titled, "Chugging Loads - Improved Definition and Application Methodology to Mark II Containments - Summary Report", submitted to the NRC for review on March 30, 1979.

Portions of the report are proprietary to Burns and Roe, Inc., and General Electric. Accordingly, those portions (5 copies) are being submitted separately as Attachment 2 with the appropriate application and affidavit as required per 10CFR 2.790.

NONE 1/10

The Supply System would like an opportunity to meet with the NRC's technical staff and consultants to discuss any comments or questions regarding the two chugging load reports. Our preference for such a meeting would be in mid-July or at your earliest convenience thereafter.

Very truly yours,

D L Renberger

D. L. RENBERGER
Assistant Director - Technology

DLR:TRM:ct

Enclosures

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D. L. RENBERGER, Being first duly sworn, deposes and says: That he is the Assistant Director, Technology, for the WASHINGTON PUBLIC POWER SUPPLY SYSTEM, the applicant herein; that he is authorized to submit the foregoing on behalf of said applicant; that he has read the foregoing and knows the contents thereof; and believes the same to be true to the best of his knowledge.

DATED June 1, 1979

D L Renberger
D. L. RENBERGER

On this day personally appeared before me D. L. RENBERGER to me known to be the individual who executed the foregoing instrument and acknowledged that he signed the same as his free act and deed for the uses and purposes therein mentioned.

GIVEN under my hand and seal this 1st day of June, 1979.

Shirley A. Reese
Notary Public in and for the State
of Washington
Residing at Kennewick

CHUGGING LOADS - IMPROVED DEFINITION AND
APPLICATION METHODOLOGY TO MARK II CONTAINMENTS

TECHNICAL REPORT

prepared by

BURNS AND ROE, INC.

for application to

WASHINGTON PUBLIC POWER SUPPLY SYSTEM

NUCLEAR PROJECT NO. 2

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NOTICE

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LIST OF SYMBOLS

f, Ω, ω_i	Frequency
$Y(f)$	Output in the frequency domain
$T(f)$, $H(\Omega)$	Transfer function
$h(t)$	Impulse response function
t	Time variable
$X(f)$	Input in the frequency domain
$x(t)$	Input in the time domain
$y(t)$	Output in the time domain
t_d	Time duration of the impulse
m	Mode number
f_m	Frequency of the m^{th} mode
L	Length
c_s	Sound wave velocity in steam
c_w	Sound wave velocity in water
H_w	Height of water column
H_{eff}	Effective height of water column
p	Pressure
C	Sound wave velocity in fluid
ρ_w	Mass density of water
n	Normal direction
$\ddot{U}_n$	Normal acceleration
Δt	Time step
$\underline{r}$	Position vector
$\underset{\sim}{P}(\underline{r},t)$	Vector of input pressures
$\underset{\sim}{P}_o(\underline{r})$	Spatial distribution of input pressures
$P(t)$	Temporal distribution of input pressures
$\underset{\sim}{R}(\underline{r},t)$	Output vector
X_{ij}	Tensor of spectral pressures

LIST OF SYMBOLS (continued)

N_f	Number of frequencies
N_c	Number of samples
d_2	Smirnov-Kolmogorov test indicator parameter
μ	Population mean
σ	Population standard deviation
p_e	Probability level
$\underset{\sim}{P}_2(\Omega)$	Total pressure
$\underset{\sim}{P}_i(\Omega)$	Incident pressure
$\underset{\sim}{M}_a(\Omega)$	Hydrodynamic masses
$\underset{\sim}{\ddot{U}}(\Omega)$	Acceleration in frequency domain
$\underset{\sim}{M}_s$	Structural mass
$\underset{\sim}{C}_s$	Structural damping
$\underset{\sim}{K}_s$	Structural stiffness
$\underset{\sim}{\ddot{U}}_s$	Structural acceleration
$\underset{\sim}{\dot{U}}_s$	Structural velocity
$\underset{\sim}{U}_s$	Structural displacement
$\underset{\sim}{T}$	Transformation matrix
$\underset{\sim}{K}(\Omega)$	Frequency dependent stiffness matrix
L_j	Strength of vents in the θ-direction
$\underset{\sim}{X}(\theta)$	Response at angle = θ, due to one row of vents
$\underset{\sim}{U}(\theta)$	Response at angle = θ, due to multivents excitation

1.0 INTRODUCTION

The purpose of this report is to present an improved chugging load definition developed for specific application to WNP-2, a boiling water reactor plant of Mark II configuration with a steel containment structure. The reactor building response to this load also is included.

1.1 The Chugging Phenomenon

The phenomena and resulting loads which occur in a Mark II containment following a LOCA event are discussed in the DFFR (Reference [1], Sections 2 and 4). Near the end of a LOCA, at low steam mass flow rates through the downcomer vents, the condensation at the steam-water interface becomes unstable. During this unstable steam condensation process known as chugging*, impulsive forcing signals are released in a relatively random fashion, both in terms of intensity and time of occurrence, to the suppression pool in the vicinity of downcomer vent exits. The forcing signals travel through the water of the suppression pool and upon reaching the pool boundaries act as pressure loads on the wetted perimeter of the wetwell. The containment structure and the reactor building will respond when acted upon by these pressure loads.

1.2 The 4T Facility and Associated LOCA/Chugging Tests

The experimental data base used to obtain the chugging load definition was developed in the General Electric Temporary Tall Tank Test (4T) facility, [4, 5], schematically shown in Figure 1-1. The 4T tests simulated LOCA events postulated for Mark II containment design. The 4T facility approximates

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* For a description of the chugging phenomenon see [2, 3].

a unit-cell* of a full-scale Mark II containment with respect to the parameters listed in Table 1-1. As indicated in Table 1-1 the downcomer vent length in the 4T facility is different from the vent lengths in a Mark II containment but this difference is properly accounted for by preserving the strength of the impulsive load derived at vent exit from 4T data when transferring it to Mark II vent exits (see Sections 4 and 5 of this report).

The tests performed in the 4T facility also duplicated Mark II plant conditions with respect to wetwell atmospheric pressurization (wetwell overpressure) and the range of initial pool temperatures expected during postulated LOCA events.

1.3 Present Chugging Load Definition

The present chugging load design specification developed by the Mark II Owners Group for application to Mark II containments is based on direct application of pressure traces measured on the boundary of the General Electric 4T test facility to the wetted perimeter of Mark II containments.

The two methods of application of 4T data to Mark II containments, identified in DFFR, [1], are:

Method 1: the "bounding" load approach, [6], and

Method 2: the "hydrodynamic multi-vent analytical model" approach, [2].

Method 1 does not account for differences between the 4T test facility and the Mark II containments with respect

* A unit-cell is composed of a single vent with the afferent drywell atmospheric volume, wetwell atmospheric volume and suppression pool.

to vent length (vent acoustics), single vent versus multi-vent geometry, and flexibility of pool boundaries (fluid-structure interaction effects). In order to account for these differences it is necessary to develop a chugging load definition at the "source", i.e., at vent exits.

Method 2 is in development stages and may not be finalized and confirmed in time to meet WNP-2 schedule needs. Since proper application of this method also requires that chugging load be defined at the "source", i.e., at vent exits, this method requires further development, beyond the description summary of [2].

Because of the schedule requirements for WNP-2, and in view of the concerns discussed above in relation to the present chugging load design specification, an improved and realistic chugging load definition was developed for specific application to WNP-2.

1.4 Improved Chugging Load Definition and Application Methodology to Mark II Containments

The improved definition is derived to bound results of pressure-suppression tests conducted for the Mark II Owners at the General Electric 4T test facility, [4, 5].

The successive steps implemented in developing this improved definition are shown in the flow chart of Figure 1-2. First, the 4T test results (recorded boundary pressure traces) were analyzed in order to identify the characteristics of the chugging load and the main components of the 4T system affected by this load. Second, an analytical model of the 4T system was developed. This model adequately accounts for the main 4T components identified in Step I as being excited

by the chugging load. Third, the 4T analytical model obtained in Step II was utilized to develop a bounding chugging load definition at the "source", i.e., at vent exit. When applied at vent exit in the 4T system this source load results in calculated boundary pressures which bound those measured during the 4T tests. Since this source load is independent from the properties of the 4T system and depends only on the chugging phenomenon itself (4T pressure-suppression tests were conducted at conditions representative of Mark II containment conditions expected during postulated LOCA events) it can be directly applied to vent exits in a Mark II containment. This is illustrated in Figure 1-3. The method of analysis of Mark II containment structures subjected to chugging loads is presented in Section 5 of this report. As described there, the method accounts for the plant specific parameters that govern the response, i.e., length of downcomer vents, 3-D multi-vent suppression pool geometry, the vent-water-structure interaction effects, as well as the inertial, stiffness and damping characteristics of the structure. Computational tools (3-D finite element hydroelastic computer codes, operating in the frequency domain) were developed and used for the analysis of WNP-2, thus allowing the concerns associated with the previous methods regarding fluid-structure interaction (FSI) effects (i.e., the interaction between the suppression pool and its structural boundaries) and, more specifically the interaction between the vents, the suppression pool and the structure to be addressed.

It is believed that the new approach represents a more accurate yet conservative estimation of containment structure/ reactor building responses to chugging loads.

2.0 CHUGGING DATA BASE

A total of some 600 chugs* were identified by General Electric in the entire 4T data base. From this total, a restricted group of 137 chugs was selected by General Electric in order to establish a conservative data base for a probabilistic application in connection with the multivent hydrodynamic model [1, 4], and these data were made available to the Mark II architect-engineers via a digital computer tape, [7]. As described in [4, 6], these chugs occurred at two test conditions (24-inch vent, 70°F pool, and 20-inch vent, 150°F pool) noted to have similar probability distributions of maximum positive pressure amplitude but extending to higher values than for any other test conditions (the chug amplitude probability distributions show a higher probability of large amplitude chugs and the highest amplitude chugs belonged to this group). Pressure traces recorded at 4T bottom center during these 137 chugging events were used to obtain a single-vent chugging load design specification for application to Mark II containment design, as described in the following sections of this report. In addition, pressure traces recorded at seven different locations of the 4T wetted perimeter (bottom center, wall at vent exit elevation, etc.) during 8 representative chugging events selected by General Electric also were made available and used by Burns and Roe, Inc. to verify some of the assumptions used in developing the 4T analytical model. The pressure time-history associated with each chug extends over a period of 0.768 seconds and is digitized at 0.001 second intervals.

* A chug (or chugging event) is represented by the pressure time-history recorded at the 4T tank boundary. Chugging events were selected with the aid of a computer, scanning the 4T tank boundary pressure traces recorded continuously during tests. A chugging event was identified whenever the variation in the 4T bottom center pressure exceeded 4 psi or the vent tip acceleration exceeded 2 g.

2.1 Characteristics of the 4T Chugs

A study of the 137 4T bottom center pressure traces was conducted in the time and frequency domains with the intent of identifying the presence of any dominant characteristics. The time domain study was performed by comparing the plots of the pressure time histories and the frequency domain study was accomplished by comparing the plots of the Fourier amplitude spectra of the pressure time histories.

2.1.1 Temporal Characteristics

A study of the pressure time histories indicates that they are not unique. The majority of the recorded pressure traces are lightly damped wave forms with multiple frequency structure as illustrated in Figure 2-1*, while a few traces exhibit a stronger damped wave form as shown in Figure 2-2. The peak amplitudes of the pressure traces vary considerably from trace to trace.

2.1.2 Frequency Characteristics

A study of the Fourier amplitude spectra of the 137 recorded pressure traces indicates some regular features as well as some irregular characteristics.

The predominant frequencies of the 137 chugs studied belong to a discrete set identified at approximately 5, 12, 22, 30, 37 and 46 Hz. The term "approximate" is used because slight variations of these frequencies also were observed.

---

* For identification purposes the chugs are numbered sequentially in the same order as they were stored on the computer tape received from General Electric Company, [7].

The Fourier amplitude spectra of the chugs shown in Figure 2-1 are displayed in Figure 2-3. It is of importance to note that the relative contributions of each of these dominant frequencies vary at random from chug to chug (see Figure 2-3). Also, the very sharp peaks exhibited in these spectra are characteristic of undamped system behavior.

The Fourier amplitude spectra of the pressure traces of Figure 2-2 exhibiting a damped behavior are displayed in Figure 2-4 and indicate the presence of another dominant peak in the frequency range of 18 - 30 Hz; this wide-banded peak is indicative of greater damping at this frequency. Again, we note the variability of this frequency (in the range mentioned above) as well as of its amplitude from chug to chug.

2.1.3 Random Trends in 4T Chugs

The rather regular frequency pattern discussed in 2.1.2 indicates that the 4T system subjected to chugging loads could be approximated by a linear analytical (hydroelastic) model. However, the variability observed in the chugging traces as noted in 2.1.1 and 2.1.2 above, is indicative of the random nature of the phenomenon and requires that the improved chugging load definition be statistically derived. In summary, the variability observed in the chug traces are:

- the amplitude at a particular dominant frequency is different for different chugs (see Figures 2-3 and 2-4);
- there are slight variations in the dominant frequencies between the different pressure traces (see Figures 2-3 and 2-4);

- the peak pressures are different for different chugs (see Figures 2-1 and 2-2).

These observed variations may be attributed to:

- changes in vent air-steam mixture properties during blowdown;
- changes in water properties, due to air and/or steam injection into the pool during blowdown;
- changes in detailed conditions at vent-pool interface during unstable steam condensation.

Consequently, it appears rational to account for these changes when developing the improved chugging load definition from 4T test data and, furthermore, when analyzing the Mark II containments subjected to chugging loads.

2.1.4 Impulsive Nature of Chugging Load

The study in the frequency domain has identified trends in the frequency content of the 4T facility response (bottom pressure traces) to chugging which are indicative of the impulsive nature of this loading. To explain this, consider a linear dynamic system, such as the 4T facility. As illustrated in Figure 2-5, the input-output (or excitation-response) relation for a linear dynamic system in the frequency domain may be expressed as, [10]:

$$Y(f) = T(f) \times X(f);$$

where $T(f)$ is the transfer function, a characteristic of the linear system which displays the system's natural frequencies and their relative importance, and $X(f)$ and $Y(f)$ are the Fourier transforms of the excitation, $x(t)$, and the response, $y(t)$, respectively.

In view of this relation, the Fourier transform of the output, Y(f), will exhibit the characteristics of the excitation, X(f). In order to identify these characteristics let us consider the Fourier transform pairs, [10], displayed in Figure 2-6 for rectangular and triangular simple impulses of duration T and for an inverted triangular impulse of total duration 2T. A comparative examination of the skylines of the Fourier spectra of some of the recorded traces, for example pressure traces #25, #26 and #36 displayed in Figures 2-7, 2-3(c) and 2-8, respectively, and of the Fourier transform pairs displayed in Figure 2-6 indicates the impulsive nature of the chugging load.

See PROPRIETARY SUPPLEMENT P

2.2 Analytical Study of the 4T Chugging Traces

In order to develop an analytical model which will adequately represent the behavior of the 4T system during chugging, it is necessary to identify the dominant frequencies observed in the 4T data. The 4T system consists of four major components: the vent, the pool, the steel tank and the supporting foundation. The various dominant frequencies observed in the 4T data result from the excitation of various components of the 4T system. What follows is a discussion of the component frequencies, their contribution to the Fourier amplitude spectra of recorded pressure traces, and possible coupling effects between components.

2.2.1 Frequency Contributions of the Vent

If the steam in the vent is assumed to be a one-dimensional acoustic medium, with a pressure-free boundary at the drywell end, and a rigid boundary at the wetwell end, (i.e., at vent exit), the natural frequencies of the steam inside the vent can be expressed as:

$$f_m = \left(\frac{2m-1}{4L}\right) c_s, \quad m = 1,2,3... \qquad (2-1)$$

where f_m is the natural frequency associated with the m^{th} mode, expressed in Hz, c_s is the velocity of sound propagation in steam in ft/sec, L is the vent length in ft and m is the mode number.

With the vent length at L = 94 ft and assuming saturated steam with c_s = 1600 ft/sec, the first few frequencies of the 4T vent can be calculated using equation (2-1). A comparison between these calculated frequencies and the frequencies actually observed in the 4T traces is shown in Table 2-1. The agreement is quite good. This leads to the conclusion that the steam in the vent behaves essentially as a 1-D linear acoustic medium which has an important contribution to the 4T response, and hence, it should be included in the analytical model of the 4T system.

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* The natural frequencies of the steam or air-steam mixture contained in the vent and assumed an acoustic medium are referred to as vent acoustic frequencies.

See PROPRIETARY SUPPLEMENT

P

See PROPRIETARY SUPPLEMENT P

2.2.2 Frequency Contribution of the Water-Tank-Support System

The origin of the wide band frequency peak observed in some of the 4T traces in the range of 18 to 30 Hz is discussed in this section. This wide band frequency peak is believed to reflect the coupled dynamic behavior of the water-tank-support system. The frequency characteristics of each of the individual components will be discussed first, followed by a discussion of the coupled effects together with a discussion of 4T results.

i <u>Water Pool</u>

If the 4T tank is considered to be a rigid vessel filled with water up to a depth H_w, it can be shown that the natural frequencies of the water pool, assuming axisymmetric behavior, are given by equation (2-2):

$$f_m = \left(\frac{2m-1}{4H_w}\right) c_w, \quad m = 1,2,3... \qquad (2-2)$$

where f_m is the natural frequency associated with the m^{th} r-independent axisymmetric mode (r being radial coordinate), expressed by Hz, c_w is the velocity of sound wave propagation in water, and m is the mode number.

If the presence of the vent (assumed a rigid-wall pipe) is accounted for, the natural frequency associated with the fundamental (m = 1) r-independent axisymmetric mode, may be approximated with equation (2-3).

$$f_1 \simeq \frac{c_w}{4H_{eff.}} ; \qquad (2\text{-}3)$$

where $H_{eff.}$ is the effective depth of water which depends on the boundary conditions assumed at the steam-water interface at vent exit (Reference 11). If the interface is assumed to be rigid, i.e., the component of fluid velocity normal to the interface boundary is zero, (von Neumann boundary condition) $H_{eff.}$ approximately equals the total depth of water (23 ft) in the tank. If, on the other hand, the hydrodynamic pressure is specified to be zero at the interface (Dirichlet boundary condition), $H_{eff.}$ is found to be approximately equal to the distance between the vent exit and the bottom of the tank (12 ft). The fundamental frequency (m = 1, c_w = 5000 ft/sec) for the two cases is, respectively:

$$\left. f_1 \right]_{H_{eff.} = 23'} \simeq 54 \text{ Hz}$$

and

$$\left. f_1 \right]_{H_{eff.} = 12'} \simeq 104 \text{ Hz}$$

The true value, however, is in between these two results. In view of this sensitivity of pool water fundamental frequencies to specified boundary conditions at vent-water interface at vent exit, it is important that the analytical models of either the 4T system or Mark II containments be capable of ensuring a compatible boundary condition at the vent-water interface.

ii Steel Tank

The calculated fundamental axisymmetric frequency of the bottom plate of the 4T tank, with and without water, is (Reference [11]):

	Frequency (Hz)	
	Fixed End Support	Hinged End Support
Dry Bottom Plate	236	115
Bottom Plate with 23 ft column of water	73	36

The actual frequency should fall between the values corresponding to hinged end support conditions. As indicated in Section 3 the hinged end support assumption is more accurate.

The calculated fundamental axisymmetric breathing mode frequency of the cylindrical shell (wall) of the 4T tank, with and without water, is (Reference [11, 12]):

	Frequency (Hz)
Dry Cylindrical Shell	800
Cylindrical Shell with water	60

As noted earlier in Section 2.1.2 the dominant frequency of the damped 4T traces is in the range of 18 to 30 Hz. Consequently, the frequency of the bottom plate (~36 Hz), which is well separated from the frequency of the shell (~60 Hz), will be the governing frequency of the actual coupled systems, while the cylindrical shell frequency will have a secondary effect in the response of the tank over the frequency range of interest.

iii <u>4T Supports</u>

A schematic representation of the piles and pile cap system that supports the 4T tank is shown in Figure 2-9. The calculated vertical fundamental frequency of this support system is approximately 42 Hz.

iv <u>Frequency Characteristics of the Coupled Water-Tank-Support System and its Correlation with 4T Response</u>

Since the natural frequencies of the water pool, 4T bottom plate and 4T support are of the same order of magnitude, these three 4T system components will behave as a coupled dynamic system. Calculation of the frequency characteristics of the coupled system is a rather complex problem which requires a water pool (compressible fluid) - tank structure - support interaction analysis (see Section 3).

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This leads to the conclusion that the wide band peak in 18 to 30 Hz range observed in some of the 4T pressure traces results from excitation of the coupled water-structure-support system.

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2.2.3 Damping Characteristics

As noted earlier in 2.1.1 and 2.1.2 the pressure traces exhibit two distinct types of damping behavior:

- the narrow bank (sharp) frequency peaks corresponding to the vent acoustic frequencies indicate that there is very little or no damping in the vent; and
- the wide band frequency peaks (18 - 30 Hz) corresponding to the water-tank-support system indicate the presence of significant damping.

The sources of energy dissipation in the 4T system may be classified into two categories:

- dissipation in the acoustic fluid media (steam and water);

- dissipation in the tank structure and the supporting system.

Due to low viscosity of both the steam and water the energy dissipation in the first category will be insignificant. This is consistent with the earlier observation that pressure traces characterized by lightly damped wave forms with multiple frequency structure are associated with the vent acoustic modes. The stronger damped behavior of some of the pressure traces which exhibit a dominant frequency in the range of 18 - 30 Hz may be attributed to the second category of energy dissipation mechanism. This observation is consistent with the estimate (see 2.2.2) that the coupled water-tank-support system has a fundamental frequency of approximately 23.8 Hz.

3.0 ANALYTICAL MODEL AND PARAMETRIC STUDIES OF 4T SYSTEM

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As discussed in Section 2.0 the chugging load is impulsive in nature and, in order to study it, it requires a rather detailed analytical model of the 4T system. The analytical model must include the important components of the 4T system: the vent, the water pool, the tank structure and its supports, and must adequately account for the coupling between these components. In this section, an analytical model of the 4T system developed to satisfy these requirements is presented, the dynamic characteristics of the 4T system are discussed, and a comparison between recorded pressure traces and pressure traces calculated using an impulsive chugging load applied at the "source" is presented.

3.1 Analytical Model of the 4T System

3.1.1 Mathematical Formulation

The analytical model of the 4T system (see Figure 3-1) includes the following main components:

- the steam in the vent,
- the water pool,
- the 4T wetwell tank* structure, and
- the 4T wetwell tank* supports (concrete footing on piles).

The steam in the vent and the water in the pool behave essentially as acoustic fluids whose dynamic pressure, p, satisfies the linearized wave equation (3-1):

$$\nabla^2 p = \frac{1}{c^2} \frac{\partial^2 p}{\partial t^2} ; \qquad (3\text{-}1)$$

where: ∇^2 is Laplace's differential operator, c is the velocity of sound propagation in fluid and $\frac{\partial^2}{\partial t^2}$ is the second derivative with respect to time. Since the ratio between the vent cross-sectional area and its length is small, the steam in the vent was modeled as a 1-D acoustic fluid. The water in the suppression pool was modeled as a 2-D (axi-symmetric) acoustic fluid.

The steel tank was modeled as a linearly elastic structure consisting of a thin ring-stiffened cylindrical shell and a bottom circular thin plate. The governing equations of motion for the tank structure are not detailed here for brevity but may be found in texts on dynamics of plates

* In the remainder of this report, the 4T wetwell tank will be referred to as the 4T tank, for simplicity.

and shells (see for example Reference [13], pp 287-394).

The tank support (concrete footing and supporting piles) was represented by equivalent linear springs and dashpots, and the weight of the piles and pile cap (concrete footing) was accounted for by an equivalent lumped mass.

The boundary and interface conditions specified are discussed below.

- At the drywell end of the vent the dynamic pressure in the steam was set at zero, thus uncoupling the drywell from the remainder of the 4T system. This boundary condition is appropriate since the drywell volume is large in comparison with the vent volume and, as a result, the drywell presence is equivalent to that of an infinite reservoir.

- At the steam-water interface, i.e., at the suppression pool end of the vent, the chugging load was specified as an impulsive forcing function and thereafter pressures and velocities in steam and water were maintained equal, thus adequately addressing the steam-water coupling effects. The pressure loading applied at the steam-water interface to simulate the chugging event is considered impulsive in nature (see Section 2.1.4) and treated as an initial value problem as described in Section 3.1.3.

- At the free surface of the water pool, the dynamic pressure was specified to be zero.

- At the water-tank interface, the normal components of velocities in water and of the tank shell were maintained equal at all times, thus maintaining compatibility between the water pool and the tank structure,

i.e., adequately addressing the fluid-structure interaction effects. The equivalent equation is:

$$\frac{\partial p}{\partial n} = - \rho_w \ddot{U}_n ; \qquad (3-2)$$

where n indicates the direction normal to the interface, ρ_w is the mass density of water, $\ddot{U}_n$ is the normal component of acceleration of a particle on the tank shell and $\frac{\partial}{\partial n}$ is the normal derivative.

- The vent surface bounding the steam was assumed to be rigid.
- The two acoustic fluids (steam and water) and the tank structure were assumed to be at rest initially.

3.1.2 Finite Element Solution

The coupled steam-water-structure equations are solved using finite element techniques. The computer program NASTRAN [14] is used to obtain the numerical solution. The finite element model of the 4T system is shown in Figure 3-2. The steam in the vent and the water pool are modeled with a set of cylindrical (axisymmetric) acoustic fluid elements. The cylindrical wall shell and the circular bottom plate of the 4T tank are modeled with a set of quadrilateral plate elements. The tank support (concrete footing and piles) is represented by an equivalent mass-spring-dashpot system. Since the finite element model used is a coupled model consisting of vent, water, tank and the tank supports, the compatibility conditions at the water-tank interface and at the steam-water interface are always satisfied.

Appendix 3-1 describes in more details the finite element equations used in the NASTRAN program. The dynamic equations are solved numerically using the modified Newmark-β method, [15]. The choice of the time step for numerical integration depends on the maximum frequency of interest. The Fourier amplitude spectra of recorded pressure traces indicate that the contribution of the frequencies above 150 Hz is negligible. Thus, a time integration of $\Delta t = 0.0005$ sec. was considered adequate.

3.1.3 Treatment of Chugging Source Load

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3.2 Parametric Studies of the System

Having developed an analytical model for the 4T system, its dynamic behavior under chugging loads can now be studied. Parametric studies were performed in order to assess the importance of various system components, (vent, water, tank structure and supports) in determining the system response, as well as to assess the sensitivity of the system response to assumed properties.

3.2.1 Effect of Vent

To study the effect of the vent on the dynamic behavior of the 4T system, two cases were considered (see Figure 3-4). In both cases the flexibility of the tank boundary (cylindrical shell and circular bottom plate) were modeled. In Case 1 the vent-water interface and the supporting pile system were assumed to be rigid. In Case 2, a column of steam inside the 97 ft. long vent was modeled together with the pool to represent a coupled steam-water-structure system, and the supporting pile system was assumed to be rigid. Figures 3-5 and 3-6 display the transfer functions of pressure between the steam-water interface and the bottom center of the 4T tank for Case 1 and Case 2, respectively. As can be seen from Figure 3-5, the transfer function for Case 1 is characteristic of a highly damped system having a single predominant wide-band peak at the frequency of approximately 42.0 Hz, which corresponds to the fundamental water-structure interaction mode (see Section 2.2.2-ii). The transfer function for Case 2 (see Figure 3-6), however, exhibits multiple narrow

band peaks with varying magnitude. The presence of the undamped vent acoustic modes is quite conspicuous and the spacing between the vent acoustic modes at frequencies higher than the fundamental water-structure interaction frequency is not constant, an indication of coupling between the steam in the vent and the water in the pool. It is of interest to note that envelope of the peak of Figure 3-6 resembles the shape of the transfer function shown in Figure 3-5.

3.2.2 Effect of Flexibility of the Bottom Plate and of the Supporting Pile System

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3.2.3 Sensitivity to Assumed Fluid Properties

The sensitivity of the 4T system response to the assumed steam and water properties is studied in this section. The sensitivity of the 4T system transfer function to the assumed sound wave velocity in the steam, c_s, can be observed by comparing Figures 3-6 and 3-15 which correspond to

c_s = 1600 ft/sec and c_s = 950 ft/sec, respectively. Although the envelopes of the peaks of the two transfer functions are quite similar in shape, the distribution of the individual peaks and their relative magnitudes are quite different for the two cases.

The effects of the assumed sound wave velocities in water, c_w, were studied next. Figure 3-16 shows the Fourier amplitude spectrum of the bottom center pressure resulting from application of a triangular pressure pulse of unit amplitude and 0.01 seconds duration at the vent exit for an assumed C_w = 4800 ft/sec and Figure 3-17 shows the same amplitude spectrum corresponding to c_w = 2400 ft/sec.

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3.2.4 Summary of 4T Analytical Studies

Based on the results of the preceding studies, the important conclusions regarding the dynamic behavior of the analytical model of the 4T system may be summarized as follows:

- the dynamic coupling between the vent and the water-structure system is important and must be accounted for when specifying the chugging load;
- the 4T model is sensitive to the assumed velocity of sound propagation in steam (c_s), and is relatively insensitive to the assumed sound wave velocity in water (c_w);
- the water structure interaction effect is important and must be considered in the load definition;

- The effect of the flexibility of the piles support system on the 4T model response depends on the spatial distribution of the chugging load. The response is insensitive to the piles support system flexibility if the load is specified over the steam-water interface at vent exit. However, the reverse is true if the load is specified within the water pool at some depth below the vent exit.

3.3 Analytical Simulation of 4T Response

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5.0 WNP-2 REACTOR BUILDING RESPONSES TO CHUGGING LOAD

The specification for the single vent design load was developed and presented in Section 4.0. The response of WNP-2 reactor building can now be evaluated by applying this chugging load at vent exits of the WNP-2 containment. In order to obtain the WNP-2 reactor building responses to chugging load, it is necessary to develop an analytical model of the reactor building and of the vents-pool system. As can be seen from Figures 1-1 and 5-1, there are a number of differences between the 4T system and the WNP-2 containment, e.g.:

- The single vent 4T geometry and the associated chugging load are axisymmetric whereas the multi-vent geometry and the resulting chugging load in the WNP-2 containment are three dimensional;

- The vent length is different in the two systems (4T and the WNP-2 containment).

It should also be recognized that, due to the random nature of the chugging load with respect to the time of occurrence, all the vents in the WNP-2 containment may not chug in phase thereby producing some nonsymmetric loading.

In view of the above, it is necessary to develop an analytical model of the WNP-2 containment that will account for the three dimensional nature of the problem as well as for the coupling between the major components of the WNP-2 containment, i.e., the steam in the vents, the water in the pool, the reactor building structure, and the supporting

foundation. An analytical model that adequately satisfies these requirements was developed and is discussed below, the design conditions for the WNP-2 containment are presented, and, finally, the WNP-2 reactor building responses (floor response spectra) to chugging loads are presented in this section.

5.1 THEORETICAL BACKGROUND

The finite element method has been used to model both the reactor building and the three dimensional behavior of the vents-water system in the WNP-2 wetwell. The chugging load definition derived in Section 4.0 is assumed applied at the steam-water interface. The details of the analytical development of the finite element approach used in WNP-2 response prediction are provided in Appendix 5-1.

The finite element treatment used in WNP-2 response prediction for chugging load is somewhat different from that used for the 4T system. In the case of the 4T system, the solution was obtained in one step. This was feasible since the 4T system is axisymmetric and its dynamic modeling requires a relatively smaller number of degrees of freedom.

However, for the WNP-2 containment, because the vents-water system is three dimensional, a relatively large number of degrees of freedom is required to adequately model its dynamic behavior. Hence, a two-step solution approach has been implemented for the WNP-2 analysis. This two-step approach not only ensures adequate representation of all major components of the WNP-2 system as well as their coupling, but also enables one to take advantage of the axisymmetric configuration

of the containment structure (further extrapolated to the entire reactor building) thereby reducing significantly the computational effort.

5.1.1 TWO-STEP APPROACH

In the two-step approach, first the three dimensional vents-water system is analyzed for the specified chugging load using the finite element technique described in Appendix 5-1. In the frequency domain, the Fourier transform, $\underset{\sim}{P}_2(\Omega)$, of the total dynamic pressure, $\underset{\sim}{p}_2(t)$, developing at the water-structure interface can be expressed as (see Appendix 5-1):

$$\underset{\sim}{P}_2(\Omega) = \underset{\sim}{P}_i(\Omega) + \underset{\sim}{M}_a(\Omega)\ \ddot{\underset{\sim}{U}}(\Omega) \qquad (5\text{-}1)$$

where $\underset{\sim}{P}_i(\Omega)$ is a vector containing the Fourier transform of the incident pressure developed at water-structure interface for the specified chugging load if the interface is assumed to be rigid, $\underset{\sim}{M}_a(\Omega)$ is a frequency dependent matrix representing the hydrodynamic (added mass) effects, $\ddot{\underset{\sim}{U}}(\Omega)$ is the Fourier transform of the structural accelerations at the water-structure interface and Ω is the frequency of excitation. Equation (5-1) represents the linear fluid-structure interaction phenomenon in the frequency domain. The first step of the two-step approach is then to evaluate the elements of the vectors $\underset{\sim}{P}_i(\Omega)$ and $\underset{\sim}{M}_a(\Omega)$ for a number of frequencies in the frequency range of interest. It is of interest to note that the added mass matrix $\underset{\sim}{M}_a(\Omega)$ becomes frequency dependent for compressible fluid and depends on the spatial distribution of the chugging load (see Appendix 5-1). Thus, the effect of fluid-structure interaction depends not only on the compressibility of the fluid, but also on the spatial distribution of

assumed chugging load; this is another reason underlying the importance of dynamic coupling between the steam in the vents and the rest of the WNP-2 containment system: water in suppression pool, containment structure, foundation support, etc.

Having determined $\underset{\sim}{M}_a(\Omega)$ and $\underset{\sim}{P}_i(\Omega)$, the building response is evaluated next. The dynamic equilibrium equation of the structure subjected to hydrodynamic pressures, $\underset{\sim}{p}_2(t)$, can be written as:

$$\underset{\sim}{M}_s \ddot{\underset{\sim}{U}}_s(t) + \underset{\sim}{C}_s \dot{\underset{\sim}{U}}_s(t) + \underset{\sim}{K}_s \underset{\sim}{U}_s(t) = - \underset{\sim}{T} \underset{\sim}{p}_2(t) \qquad (5-2)$$

where $\ddot{\underset{\sim}{U}}_s(t)$, $\dot{\underset{\sim}{U}}_s(t)$ and $\underset{\sim}{U}_s(t)$ are respectively the structural accelerations, velocities and displacements, $\underset{\sim}{M}_s$, $\underset{\sim}{C}_s$, and $\underset{\sim}{K}_s$ are respectively the structural mass, damping and stiffness matrices and $\underset{\sim}{T}$ is a transformation matrix containing 1 and 0 which accounts for the differences in the dimensions between the load vector and the response vectors. With the use of Equation (5-1) and noting that $\ddot{\underset{\sim}{U}} = \underset{\sim}{T}^T \ddot{\underset{\sim}{U}}_s$, the frequency domain representation of Equation (5-2) takes the form:

$$\underset{\sim}{K}(\Omega) \underset{\sim}{U}_s(\Omega) = - \underset{\sim}{T} P_i(\Omega) \qquad (5-3)$$

where $\underset{\sim}{U}_s(\Omega)$ is the Fourier transform of the structural response and $\underset{\sim}{K}(\Omega)$ is the dynamic stiffness matrix obtained from the relation:

$$\underset{\sim}{K}(\Omega) = -\Omega^2(\underset{\sim}{M}_s + \underset{\sim}{T} \underset{\sim}{M}_a \underset{\sim}{T}^T) + i\Omega \underset{\sim}{C}_s + \underset{\sim}{K}_s \qquad (5-4)$$

where $i = \sqrt{-1}$ and Ω is the frequency of excitation.

The structural displacement, $\underset{\sim}{U}_s(t)$, is then obtained by solving Equation (5-3) and performing an inverse Fourier transform. Having obtained $\underset{\sim}{U}_s(t)$ it is relatively straightforward to evaluate the other response measures, such as accelerations and velocities.

5.1.2 TREATMENT OF MULTIPLE VENTS

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5.2 DESIGN CONDITIONS FOR WNP-2 CONTAINMENT

A cross-sectional view of the WNP-2 containment is shown in Figure 5-1 and a plan-view of the wetwell at the elevation of vent exits is shown in Figure 5-2. Since chugging occurs at the tail-end of a postulated loss of coolant accident (LOCA) event, when conditions within containment (drywell, wetwell and connecting vents) are expected to be rather uniform, it is reasonable to apply the same impulsive forcing signal at all vent exits. In view of the large number of vents and the random character of the chugging phenomenon, it is reasonable to specify a design level load that corresponds to a statistical statement of 50% probability of non-exceedance limit and 97.7% confidence level. Simultaneous application (in phase) of the forcing signals at vent exits is a conservative assumption considering the random nature of the load with respect to the time of occurrence. In view of the randomness associated with the chugging load, it is recognized that a nominal nonsymmetric effect may occur in Mark II containments. The degree of this imbalance is yet unknown. However, for practical design purposes, this nonsymmetric behavior is accounted for by assuming that at exits of a set of 3 radially located downcomers at one side of the containment, the impulsive forcing signal is at a level of 84.1% probability of non-exceedance limit. This loading condition is schematically shown in Figure 5-4.

5.3 WNP-2 RESULTS

The WNP-2 reactor building was analyzed for the loading conditions defined in Section 5.2. An equivalent axisymmetric finite element model for the reactor building, schematically represented in Figure 5-5, was developed for this purpose. This model includes all the significant reactor building components: the mat, the primary containment stiffened steel shell, the reactor pressure vessel (RPV) and its support pedestal, the sacrificial shield wall, the drywell floor with supporting columns, the secondary containment and the remainder of the reactor building (walls, floors and roof). The model also incorporates the supporting foundation material.

In order to be consistent with the load definition of Section 4.0, the building was analyzed assuming that the properties of the steam in the vents and the water in the pool may vary in the ranges specified in Section 4.0. The resulting floor response spectra curves were then developed. The envelope floor response spectra (with the peaks spread by ±15%) corresponding to 0.5%, 1%, 2% and 4% damping values are plotted for selected locations (foundation mat at primary containment vessel, RPV pedestal at vessel support elevation, sacrificial shield wall at stabilizer truss level and containment vessel at mid-submergence depth) in Figures 5-6 through 5-9. These responses are generally lower and different from those calculated when using the present "bounding" chugging load definition of reference [1].

For comparison purposes, floor response spectra corresponding to 0.5% damping are plotted in Figures 5-10 through 5-13 for both the improved and "bounding" load definitions.

5.4 CONCLUDING REMARKS

The design conditions and the analytical procedures for computing the response of WNP-2 containment structure subjected to the improved chugging load, have been developed and are presented in this section. The method of analysis is consistent with that used for the 4T tank and adequately addresses the plant specific concerns. WNP-2 containment structure responses to improved chugging load were calculated. These responses are generally lower and different from those calculated when using the present "bounding" chugging load definition.

6.0 SUMMARY AND CONCLUSIONS

An improved single vent design load specification has been developed for chugging using the full scale single vent test data base [4,5]. These tests were performed in a test facility representative of a Mark II single vent/unit cell geometry and plant/containment conditions expected during postulated LOCA events. The improved load specification recognizes the impulsive nature of the load and, realistically, assumes that the load is imparted to the vent/suppression pool coupled system over the steam-water interface, at vent exits. This load specification also accounts for variations in properties of steam-air vent mixture and suppression pool water, evidenced in 4T data and expected in a Mark II containment during LOCA conditions. The improved chugging load is defined at the "source", independent of the 4T test facility specific properties/characteristics, thus making it possible to apply it directly to vent exits in the Mark II containment. In view of the established random character of the chugging phenomenon, a design level load is defined for Mark II application at the desired/required probability of non-exceedance limit and confidence level; a statistical statement of 50% non-exceedance at 97.7% confidence is adequate for such a design application because of the large number of vents in a Mark II containment and the randomness of the load.

The improved chugging load definition was developed with the aid of an analytical model of the 4T test facility. When subjected to an impulsive loading applied at the steam-water interface this model was able to simulate the important trends observed in the recorded traces.

A computational methodology was developed and utilized to obtain the WNP-2 containment response to chugging. The method is based on finite element discretization of the containment (coupled vents-pool-structure-supports system).

The response of the containment system was obtained in the frequency domain, in two steps:

- first, frequency dependent hydrodynamic (added) masses and frequency dependent incident pressures are obtained for the wetted perimeter of the containment structure, and,

- second, the dynamic responses of the structure, whose inertial properties are modified by addition of hydrodynamic masses to represent contained fluid effects, are obtained in the frequency domain subjecting the structure to the incident pressure loading.

When extrapolating the single vent design load specification to loading conditions for Mark II containments the following realistic and conservative assumptions are made:

- the impulsive design level load is assumed to be applied simultaneously (i.e., in phase) at all vent exits; this assumption could be relaxed in the future, if required;

- the expected nominal non-symmetric loading component is addressed by conservatively assuming that a stronger impulse (corresponding to 84.1% non-exceedance limit at 97.7% confidence level) is applied simultaneously at three vent exits, located along the same containment radius at one side of the containment.

The definition and the application methodology to Mark II containments adequately address the concerns identified with chugging loads:

- FSI effects are accounted for when reducing the 4T data;

- conservatism is used when interpreting the 4T data and in establishing the single vent design load specification;

- the chugging load is defined at the "source", independent of the 4T test facility characteristics, thus making possible direct extrapolation to vent exits in Mark II containments and, as a result, allowing for adequate determination of relative vents and pool acoustic participation in the incident pressure wave in a Mark II geometry;

- FSI effects are accounted for when analyzing Mark II containments for chugging loads; and

- conservatism is used in extrapolating the single vent design load specification to load conditions used in Mark II containment design.

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Table 1-1

Comparison of 4T Facility and Mark II Containments

Scaling Parameter	4T Facility				Mark II Range	WPPSS-NP#2
	24-in. Downcomer		20-in. Downcomer			
	2½-in. Venturi	3-in. Venturi	2½-in. Venturi	3-in. Venturi		
Break Area/Drywell Free Volume (ft^{-1})	$1.80x10^{-5}$	$2.50x10^{-5}$	$1.80x10^{-5}$	$2.50x10^{-5}$	N/A	$1.59x10^{-5}$; $1.94x10^{-5}$ (See Note (a))
Break Area per Vent (ft^2)	0.0341	0.0491	0.0341	0.0491	N/A	0.0315; 0.0384 (See Note (a))
Break Area/Vent Area	0.0116	0.0167	0.0169	0.0243	N/A	0.0106; 0.0129 (See Note (a))
Break Area/Pool Area	$9.97x10^{-4}$	$14.35x10^{-4}$	$9.70x10^{-4}$	$13.96x10^{-4}$	N/A	$7.11x10^{-4}$; $8.67x10^{-4}$ (See Note (a))
Vent Diameter, in.	24	24	20	20	24-28 (Note (b))	24-28 (Note (b))
Vent Length, ft.	← 96 →				N/A	45.25
Drywell Volume per Vent (ft^3)	$1.892x10^3$	$1.892x10^3$	$1.892x10^3$	$1.892x10^3$	$(1.800-2.700)x10^3$	$1.980x10^3$
Drywell Volume/Vent Area (ft)	642	642	936	936	575-914	663

Notes: (a) - First value due to DBA recirculation line; second value due to DBA steam line.

(b) - 28-inch downcomers have 10-inch relief valve piping located concentrically within the downcomer, for a portion of the downcomer length.

Table 1-1 (Continued)

Comparison of 4T Facility and Mark II Containments

Scaling Parameter	4T Facility: 24-in. Downcomer, 2½-in. Venturi	4T Facility: 24-in. Downcomer, 3-in. Venturi	4T Facility: 20-in. Downcomer, 2½-in. Venturi	4T Facility: 20-in. Downcomer, 3-in. Venturi	Mark II Range	WPPSS-NP#2
Pool Area per Vent (ft^2)	34.21	34.21	35.17	35.17	36.8-60.0	44.3
Pool Area/Vent Area	11.60	11.60	17.40	17.40	12-20	14.84
Clearance; Downcomer to Pool Bottom (ft)	← 12.0 →				8.3-18.0	10.9-19.1
Vent Submergence (ft)	← 9.0, 11.0, and 13.5 →				8.8-13.5	12
Clearance; Pool Surface to Ceiling (ft)	← 31.5, 29.5, and 27.0 →				22.7-37.0	31.1
Overall Height (ft)	← 52.5 →				45.4-62.0	51-62

TABLE 2-1 - FREQUENCIES OBSERVED IN THE 4T TANK VS. CALCULATED FREQUENCIES

OBSERVED FREQUENCY	CALCULATED FREQUENCY	COMMENTS
5.0	4.3	Observed in Most Traces
12.0	12.8	Observed in Most Traces
22.0	21.3	Observed in Fewer Traces
30.0	29.8	Observed in Fewer Traces
37.0	38.3	Observed in Fewer Traces
46.0	46.8	Observed in Fewer Traces

See PROPRIETARY SUPPLEMENT

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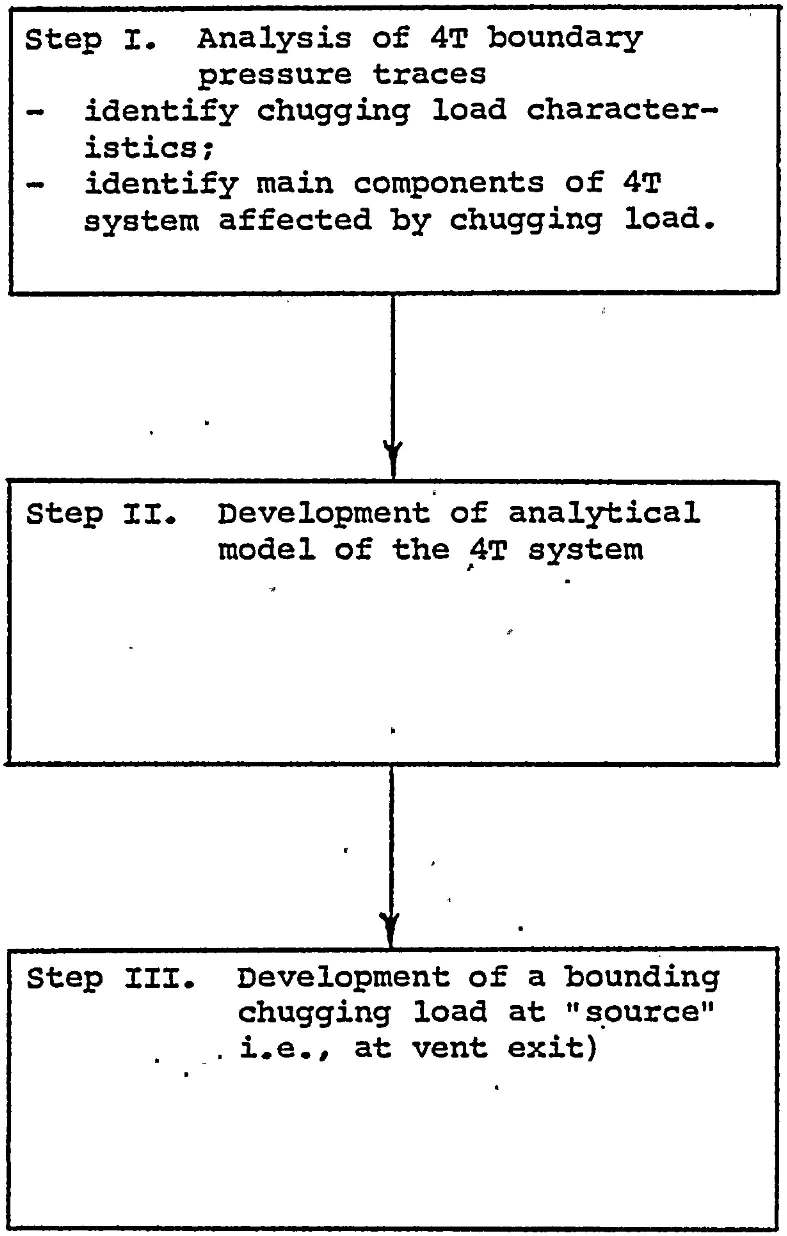
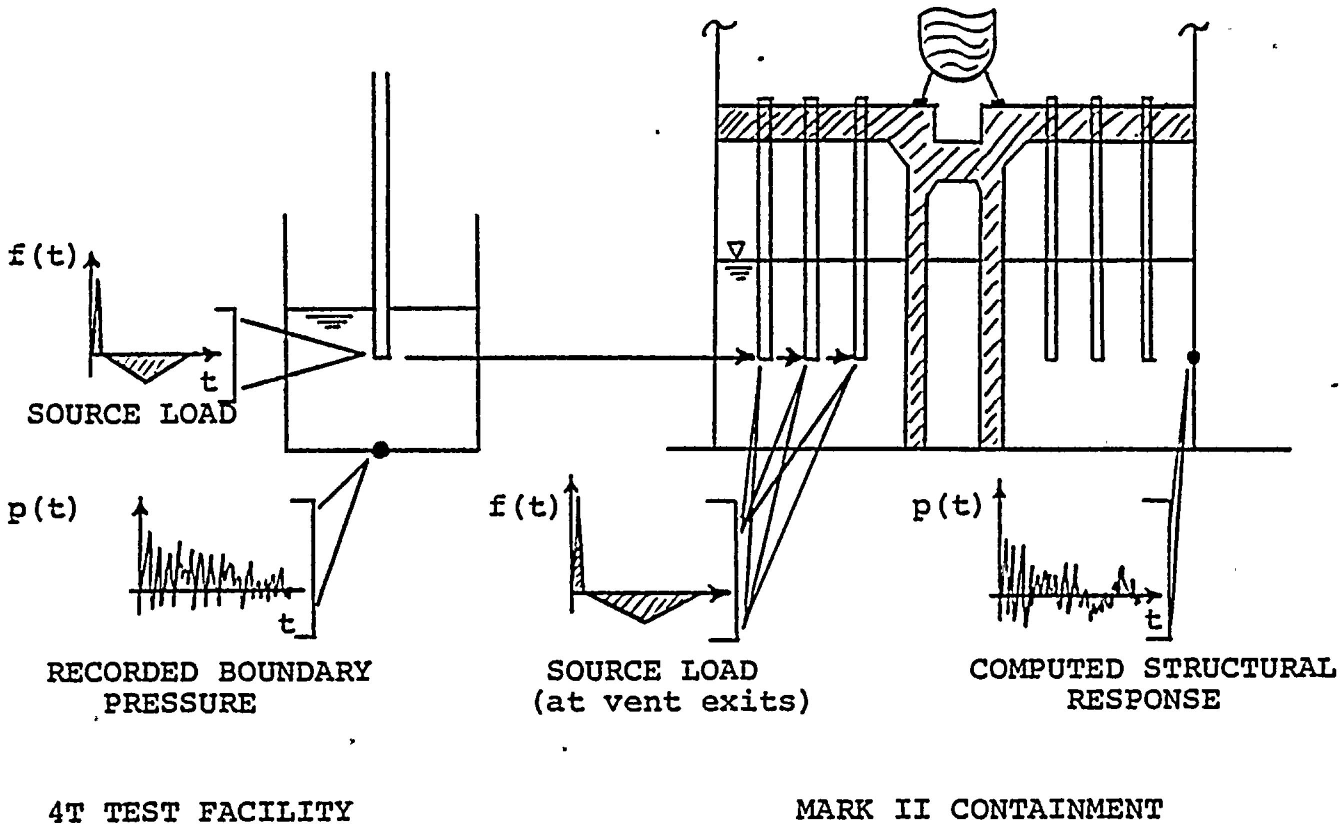
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	SCHEMATIC OF THE 4-T TEST FACILITY	FIGURE 1-1



WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	DEVELOPMENT OF IMPROVED CHUGGING LOAD - FLOW CHART	FIGURE 1-2



WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	IMPROVED CHUGGING LOAD-APPLICATION METHODOLOGY TO MARK II CONTAINMENTS	FIGURE 1-3

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF 4T BOTTOM CENTER PRESSURE TRACE #11	FIGURE 2-1(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF 4T BOTTOM CENTER PRESSURE TRACE #20	FIGURE 2-1(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF 4T BOTTOM CENTER PRESSURE TRACE #26	FIGURE 2-1(C)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF 4T BOTTOM CENTER PRESSURE TRACE #101	FIGURE 2-1(D)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF 4T BOTTOM CENTER PRESSURE TRACE #14	FIGURE 2-2(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF 4T BOTTOM CENTER PRESSURE TRACE #17	FIGURE 2-2(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF 4T BOTTOM CENTER PRESSURE TRACE #22	FIGURE 2-2(C)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF 4T BOTTOM CENTER PRESSURE TRACE #30	FIGURE 2-2(D)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #11	FIGURE 2-3(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #20	FIGURE 2-3(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #26	FIGURE 2-3(C)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #101	FIGURE 2-3(D)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #14	FIGURE 2-4(A)

See PROPRIETARY SUPPLEMENT

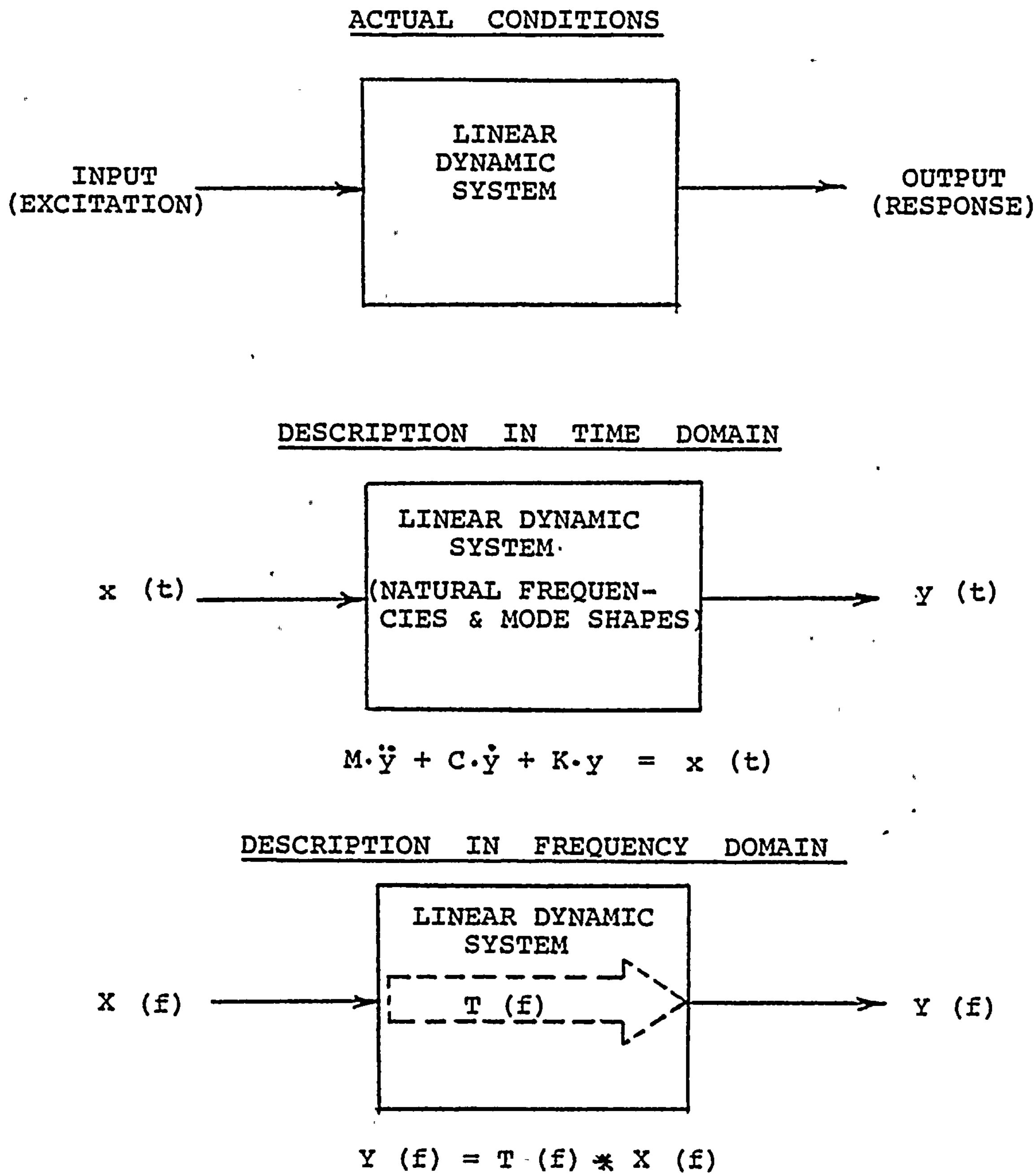
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2.	FOURIER SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #17	FIGURE 2-4(B)

See PROPRIETARY SUPPLEMENT

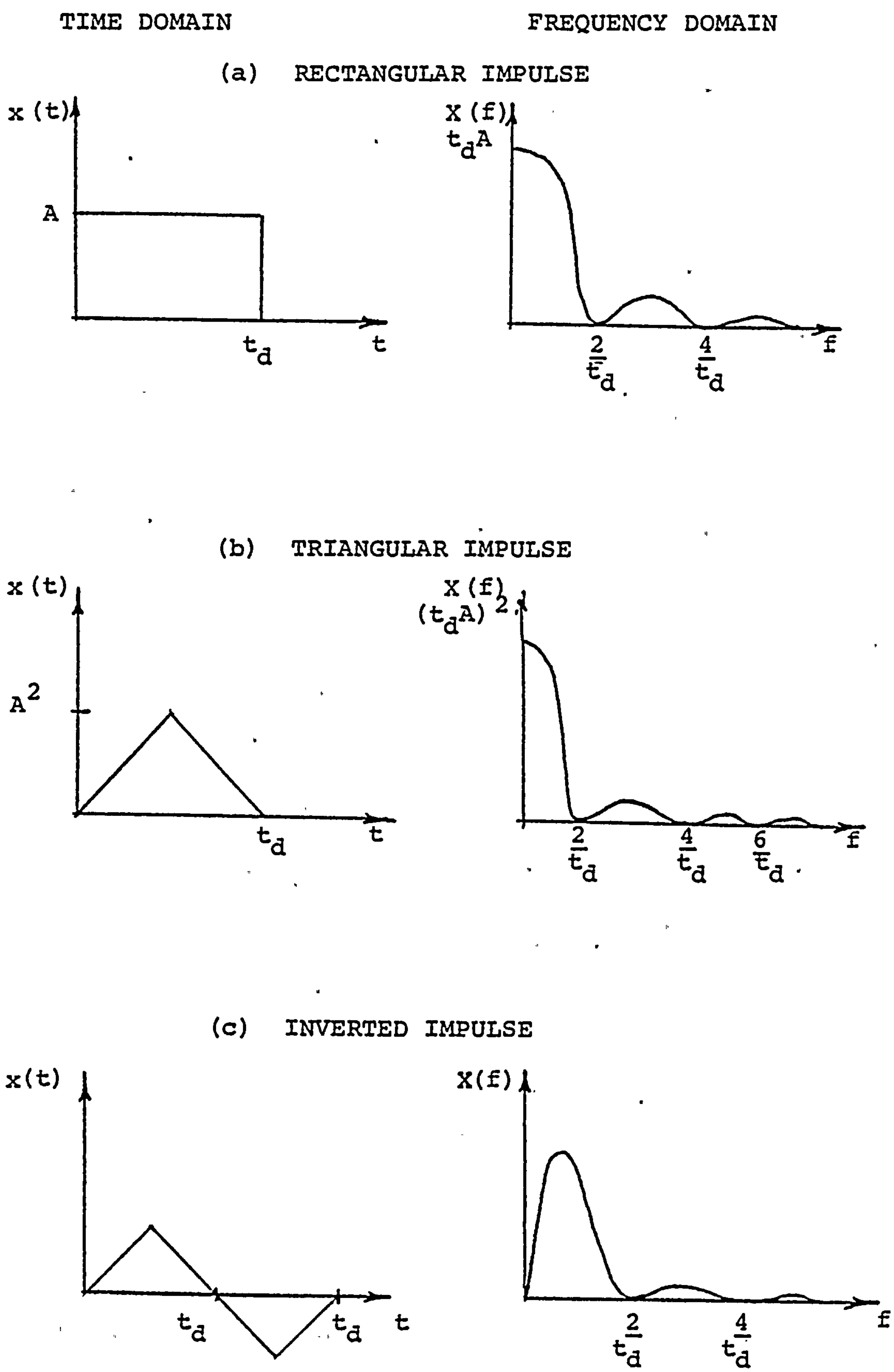
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #22	FIGURE 2-4(C)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #30	FIGURE 2-4(D)



WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME DOMAIN/FREQUENCY DOMAIN STUDIES	FIGURE 2-5



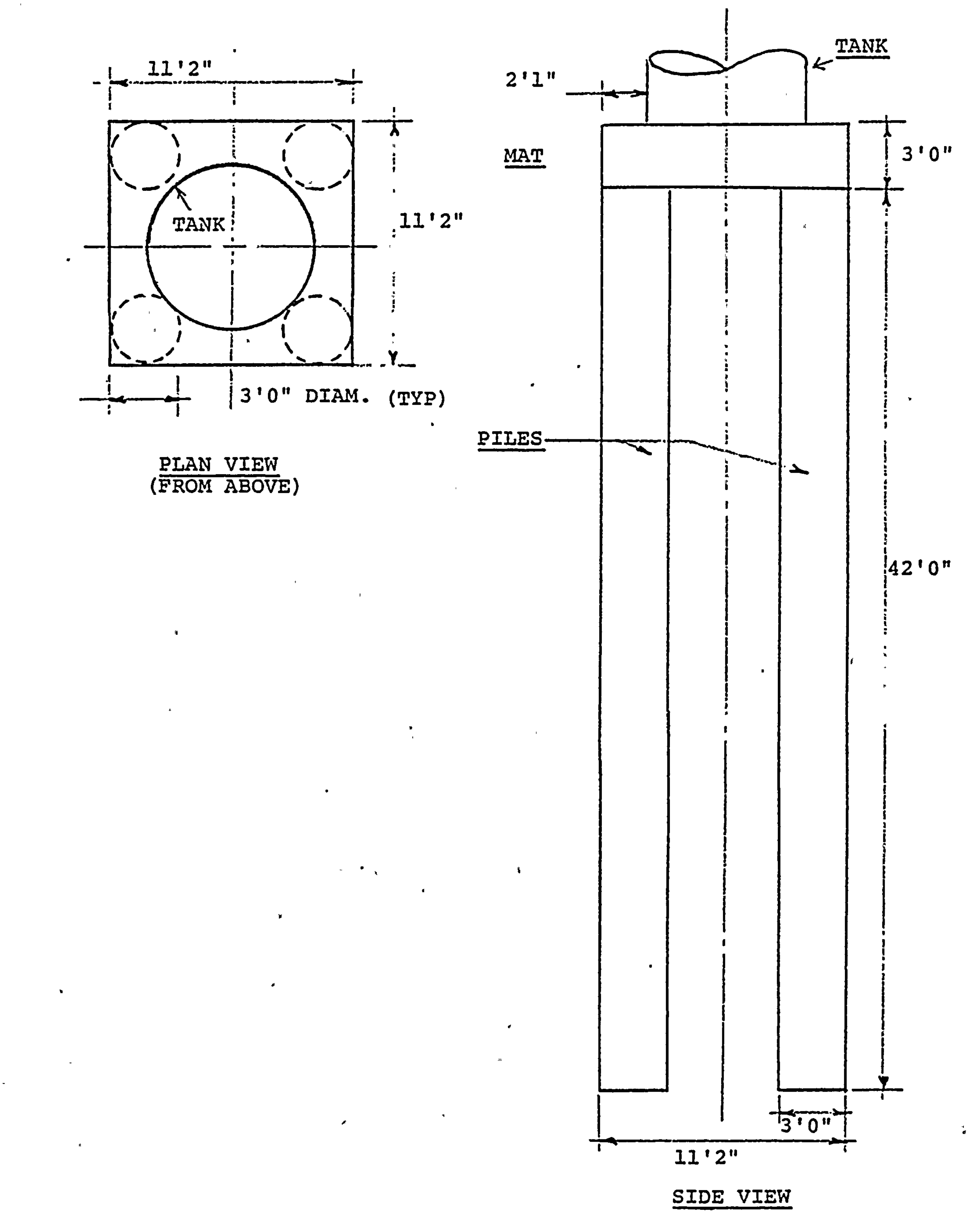
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER TRANSFORM PAIRS	FIGURE 2-6

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #25	FIGURE 2-7

See PROPRIETARY SUPPLEMENT

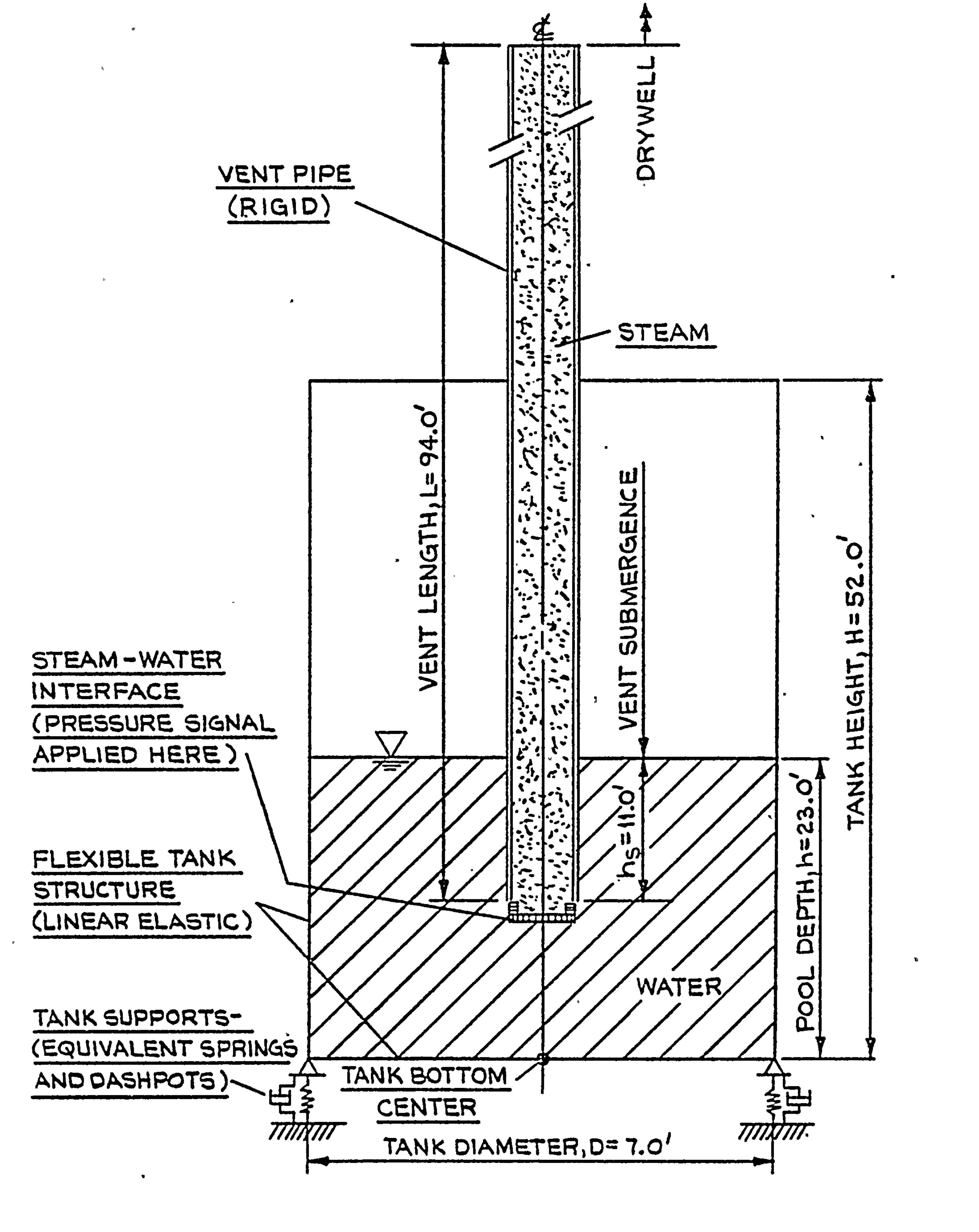
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #36	FIGURE 2-8



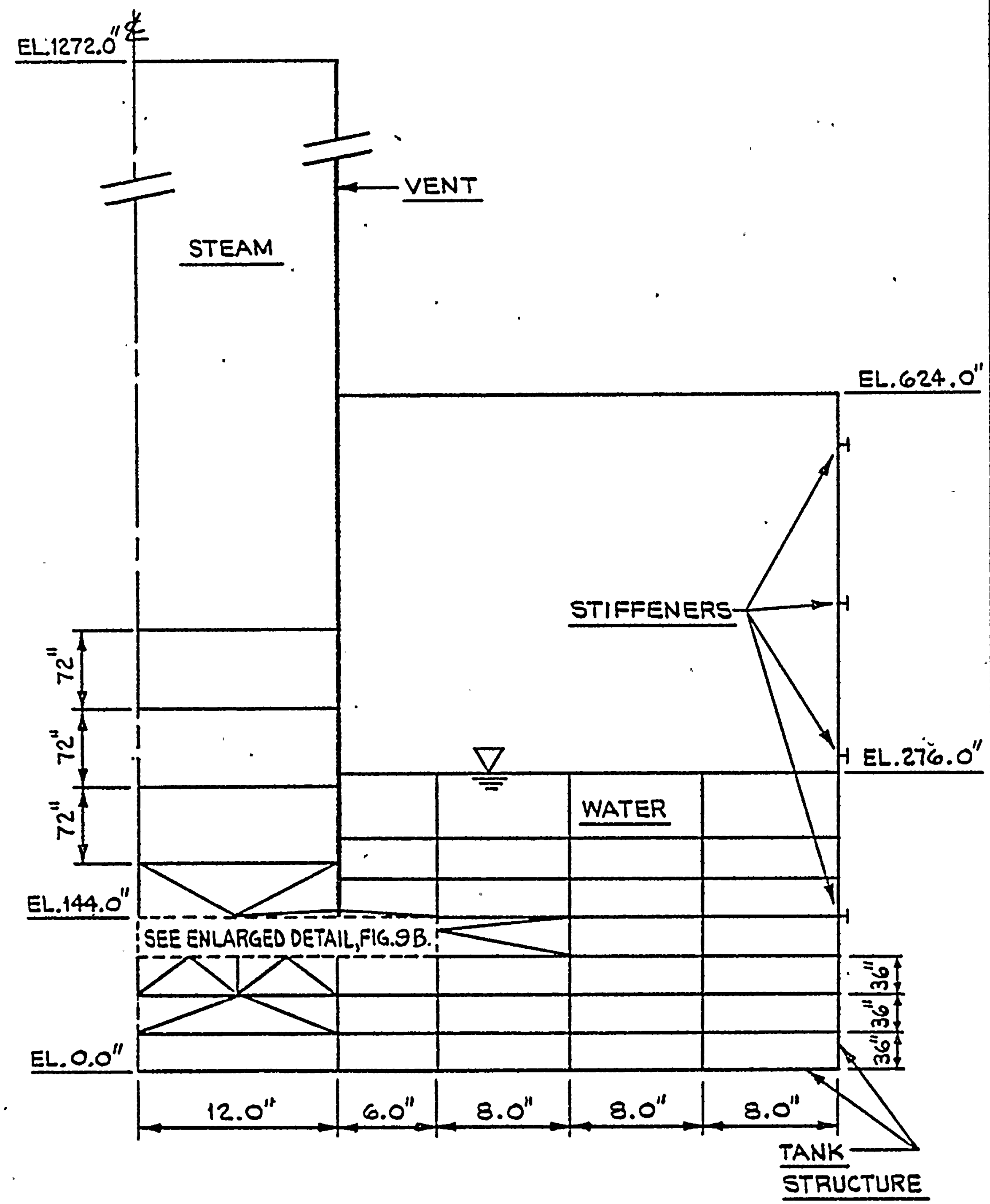
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	SCHEMATIC OF PILE & PILE CAP SYSTEM SUPPORTING 4T.TANK	FIGURE 2-9

See PROPRIETARY SUPPLEMENT

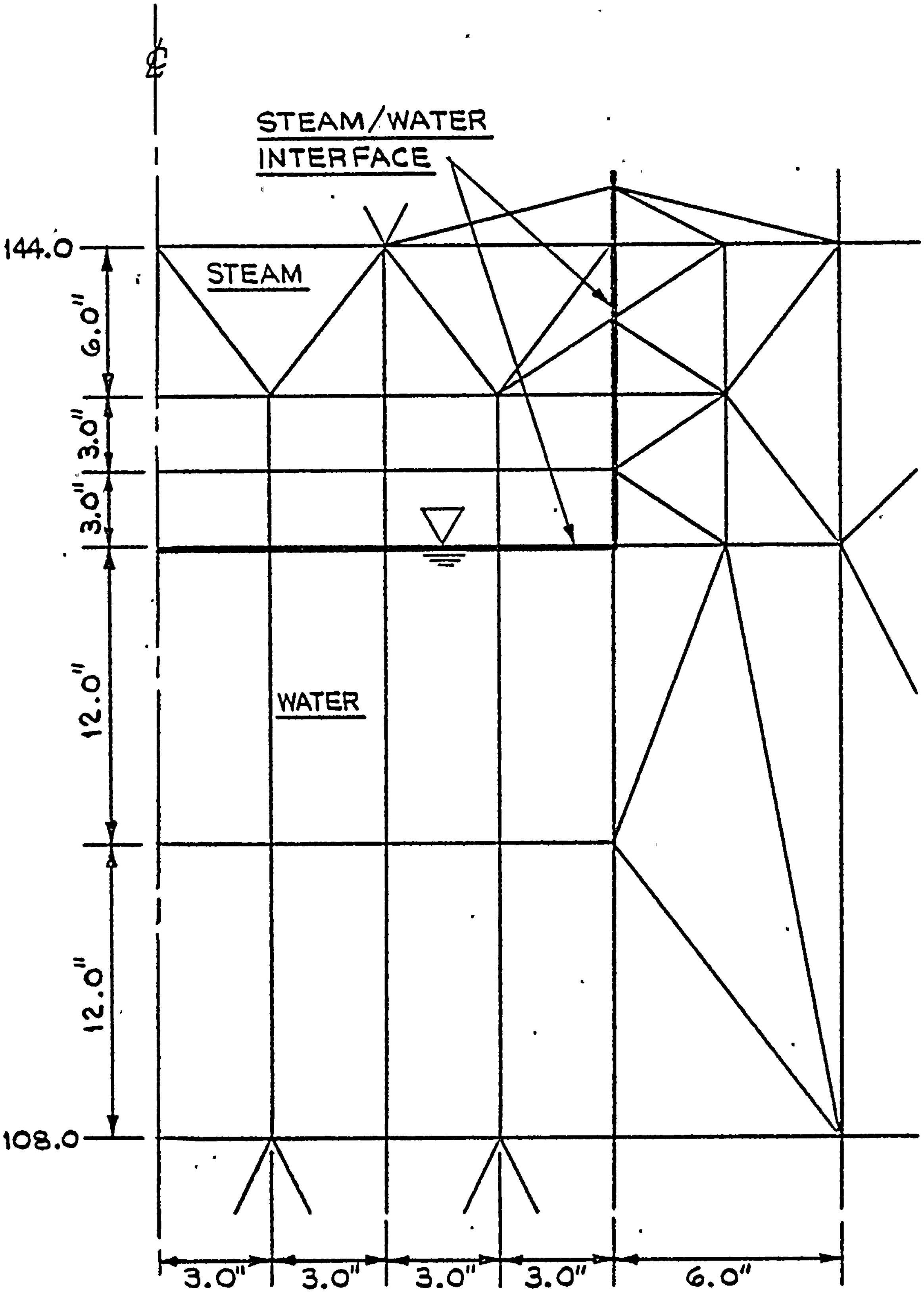
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	THREE D.O.F. SYSTEM REPRESENTING 4-T TANK	FIGURE 2-10



WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	MATHEMATICAL MODEL OF 4T TANK (REDUCED MODEL)	FIGURE 3-1



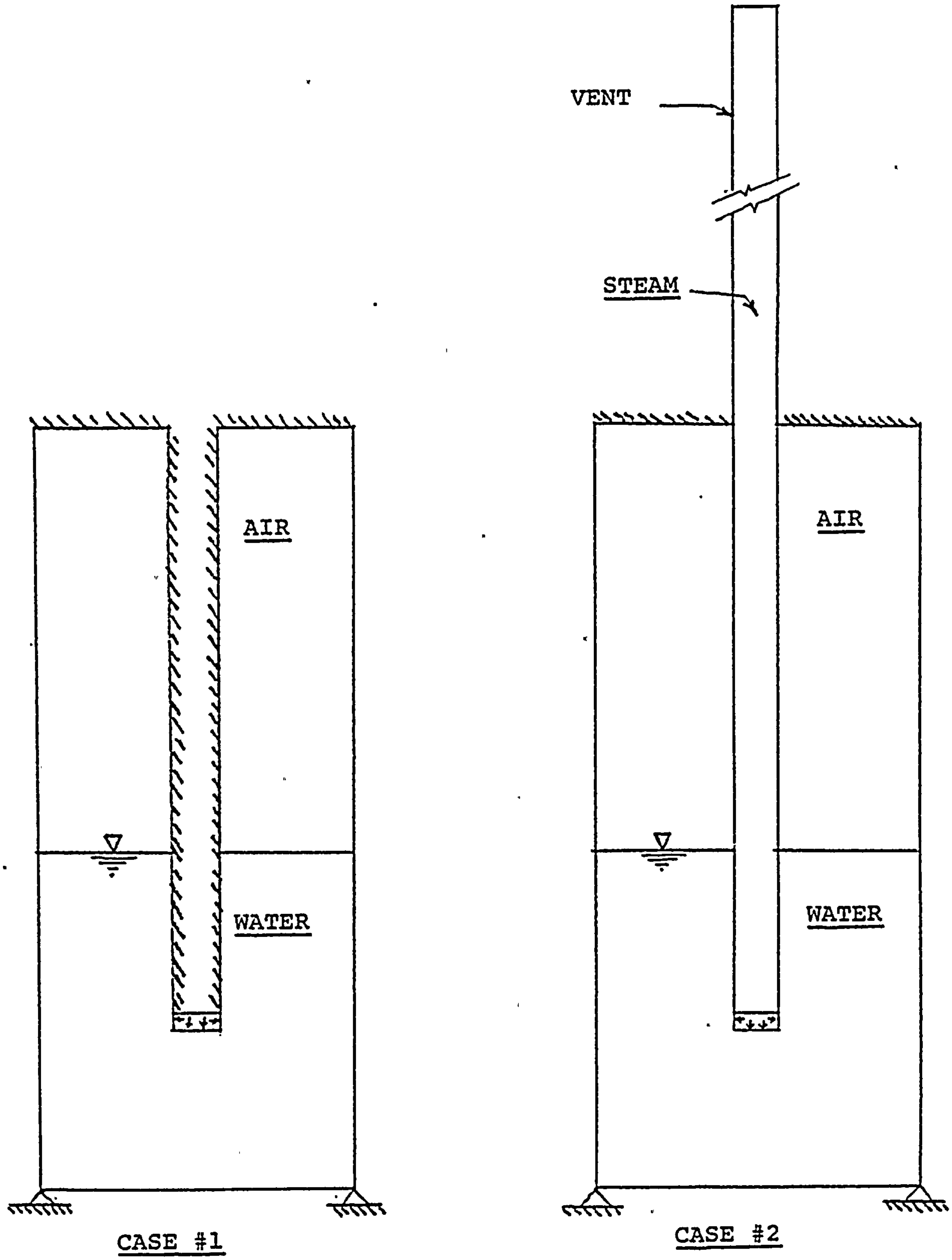
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FINITE ELEMENT MESH - 4T TANK	FIGURE 3-2(A)



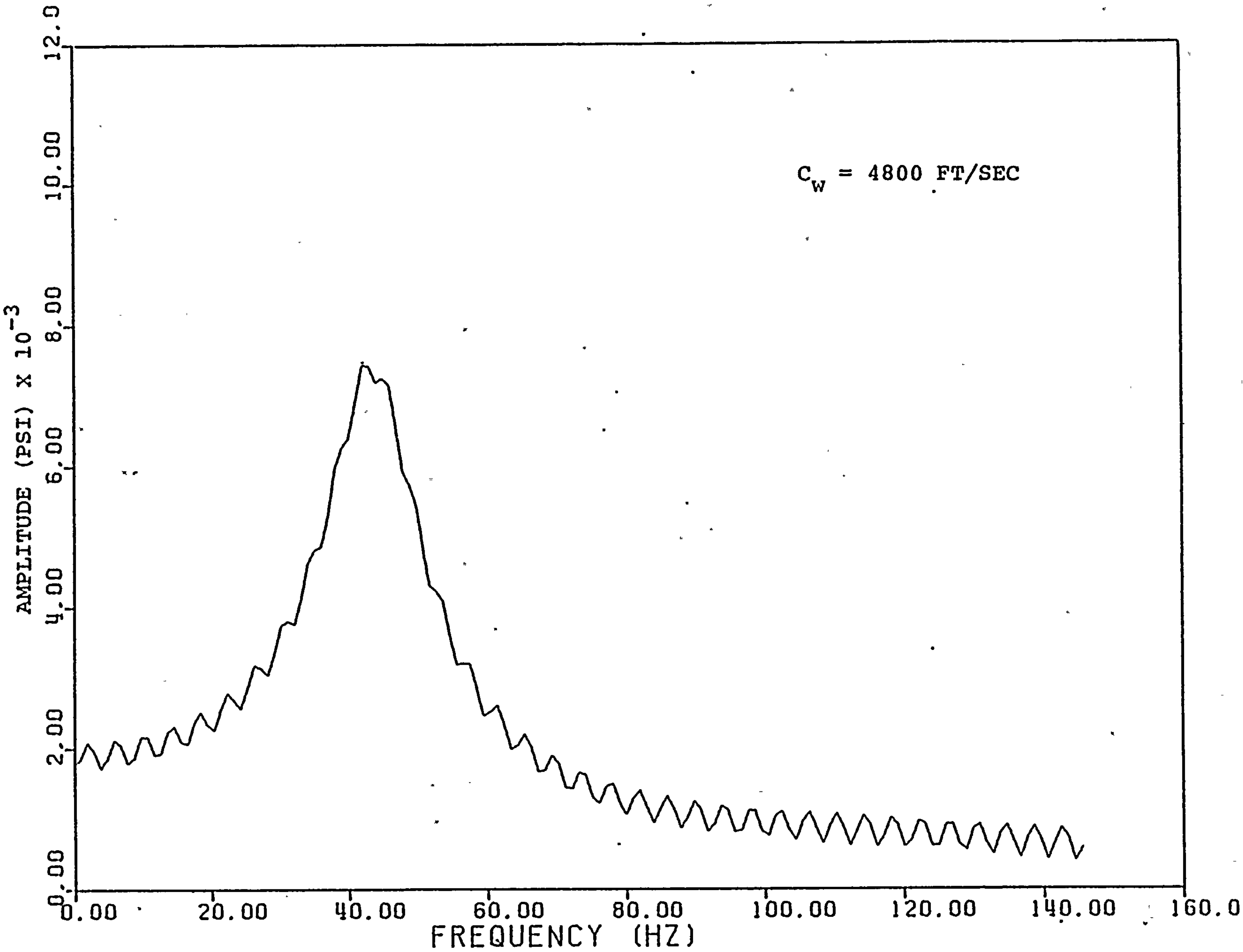
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FINITE ELEMENT MESH - 4T TANK DETAIL AT STEAM-WATER INTERFACE	FIGURE 3-2(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TREATMENT OF CHUGGING SOURCE LOAD	FIGURE 3-3



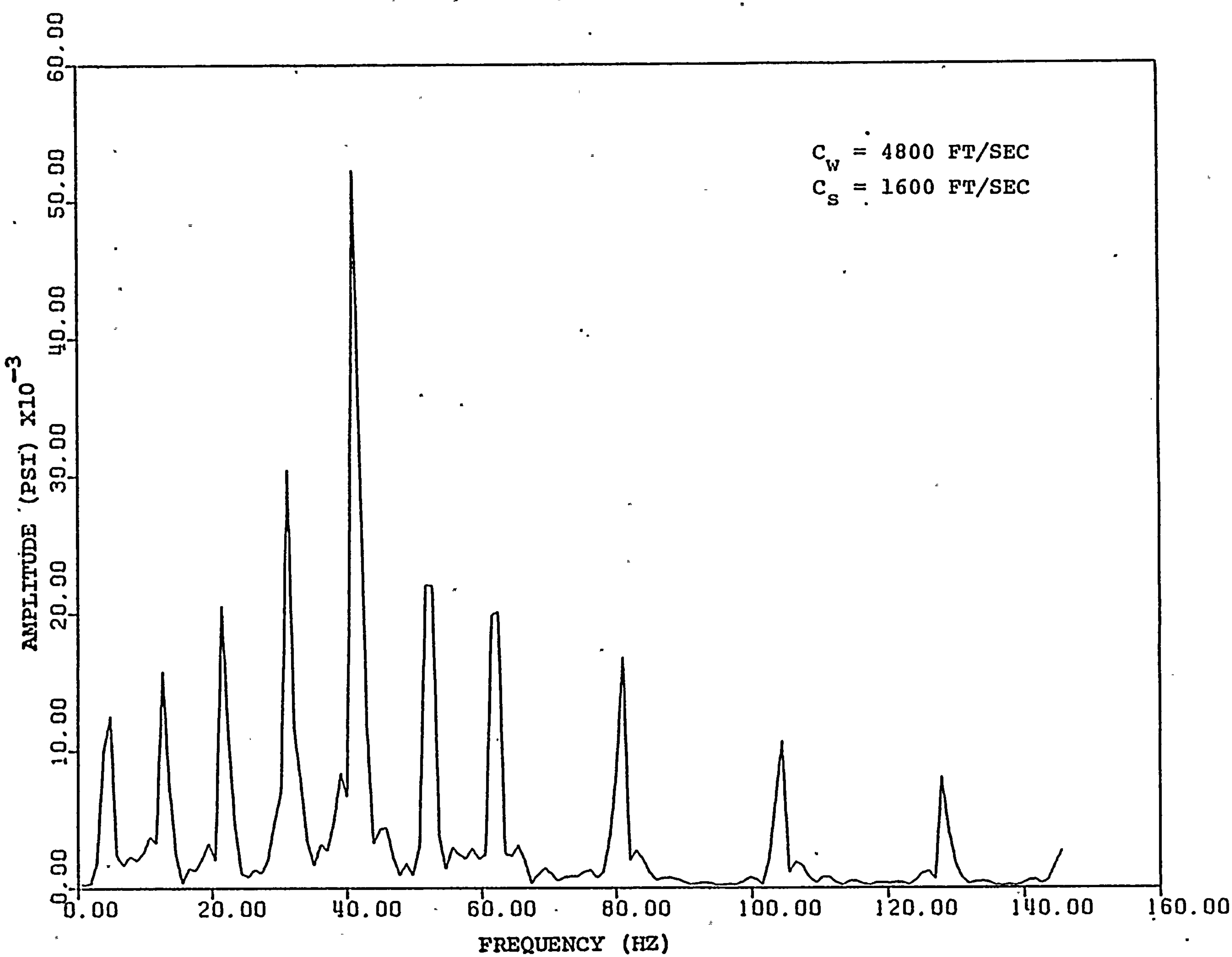
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	EFFECT OF VENT ON DYNAMIC BEHAVIOR - CASES STUDIED	FIGURE 3-4



WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2.

TRANSFER FUNCTION - VENT EXIT TO BOTTOM CENTER OF 4T TANK

FIGURE 3-5



WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

TRANSFER FUNCTION - VENT EXIT TO BOTTOM CENTER OF TANK

FIGURE 3-6

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	EFFECTS OF RIGIDITY OF BOTTOM PLATE AND SUPPORTING PILES-CASES STUDIED	FIGURE 3-7

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF BOTTOM CENTER PRESSURE DUE TO A .010 SEC. IMPULSE (FLEX. BOTTOM - NO SOIL)	FIGURE 3-8(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF BOTTOM CENTER PRESSURE DUE TO A .010 SEC. IMPULSE (FLEXIBLE BOTTOM - RIGID SUPPORT)	FIGURE 3-8(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF BOTTOM CENTER PRESSURE DUE TO A .010 SEC. IMPULSE (RIGID BOTTOM - NO SOIL)	FIGURE 3-9(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF BOTTOM CENTER PRESSURE DUE TO A .010 SEC. IMPULSE (RIGID BOTTOM - RIGID SUPPORT)	FIGURE 3-9(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF BOTTOM CENTER PRESSURE DUE TO A .010 SEC. IMPULSE (FLEX. BOTTOM - WITH SOIL)	FIGURE 3-10(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF BOTTOM CENTER PRESSURE DUE TO A .010 SEC. IMPULSE (FLEXIBLE BOTTOM - FLEXIBLE SUPPORT)	FIGURE 3-10(B

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF BOTTOM CENTER PRESSURE DUE TO A .010 SEC. IMPULSE (RIGID BOTTOM - WITH SOIL)	FIGURE 3-11(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2.	FOURIER SPECTRUM OF BOTTOM CENTER PRESSURE DUE TO A .010 SEC. IMPULSE (RIGID BOTTOM - FLEXIBLE SUPPORT)	FIGURE 3-11(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	SCHEMATIC PRESENTATION OF THE IN-FLUID PRESSURE LOADING	FIGURE 3-12

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TRANSFER FUNCTION-IN-FLUID LOADING TO BOTTOM CENTER - RIGID SUPPORT	FIGURE 3-13

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TRANSFER FUNCTION-IN-FLUID LOADING TO BOTTOM CENTER - FLEXIBLE SUPPORT	FIGURE 3-14

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TRANSFER FUNCTION - VENT EXIT TO BOTTOM CENTER	FIGURE 3-15

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF BOTTOM CENTER PRESSURE DUE TO A .010 SEC. IMPULSE	FIGURE 3-16

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF BOTTOM CENTER PRESSURE DUE TO A .010 SEC. IMPULSE	FIGURE 3-17

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF PRESSURE CALCULATED AT.4T BOTTOM CENTER	FIGURE 3-18(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF PRESSURE CALCULATED AT 4T BOTTOM CENTER	FIGURE 3-18(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF PRESSURE CALCULATED AT .4T BOTTOM CENTER	FIGURE 3-19(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF PRESSURE CALCULATED AT 4T BOTTOM CENTER	FIGURE 3-19(B

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	4T TANK - CASE CONSIDERED TO STUDY DAMPED CHUGS	FIGURE 3-20

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	TIME HISTORY OF PRESSURE CALCULATED AT .4T BOTTOM CENTER	FIGURE 3-21(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FOURIER SPECTRUM OF PRESSURE CALCULATED AT 4T BOTTOM CENTER	FIGURE 3-21(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	RESPONSE SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #20	FIGURE 4-1

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	RESPONSE SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #25	FIGURE 4-2

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	RESPONSE SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #26	FIGURE 4-3

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	RESPONSE SPECTRUM OF 4T BOTTOM CENTER PRESSURE TRACE #30	FIGURE 4-4

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	VARIATION OF THE STATISTIC, d_2, WITH FREQUENCY	FIGURE 4-5

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	DESIGN LEVEL RESPONSE SPECTRA	FIGURE 4-6

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	DESIGN LEVEL RESPONSE SPECTRA	FIGURE 4-7

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	DESIGN LEVEL RESPONSE SPECTRA	FIGURE 4-8

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	DESIGN LEVEL RESPONSE SPECTRA	FIGURE 4-9

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	FLOW CHART OF THE PROPOSED METHOD	FIGURE 4-10

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	DESIGN LOAD AT SOURCE	FIGURE 4-11

See PROPRIETARY SUPPLEMENT

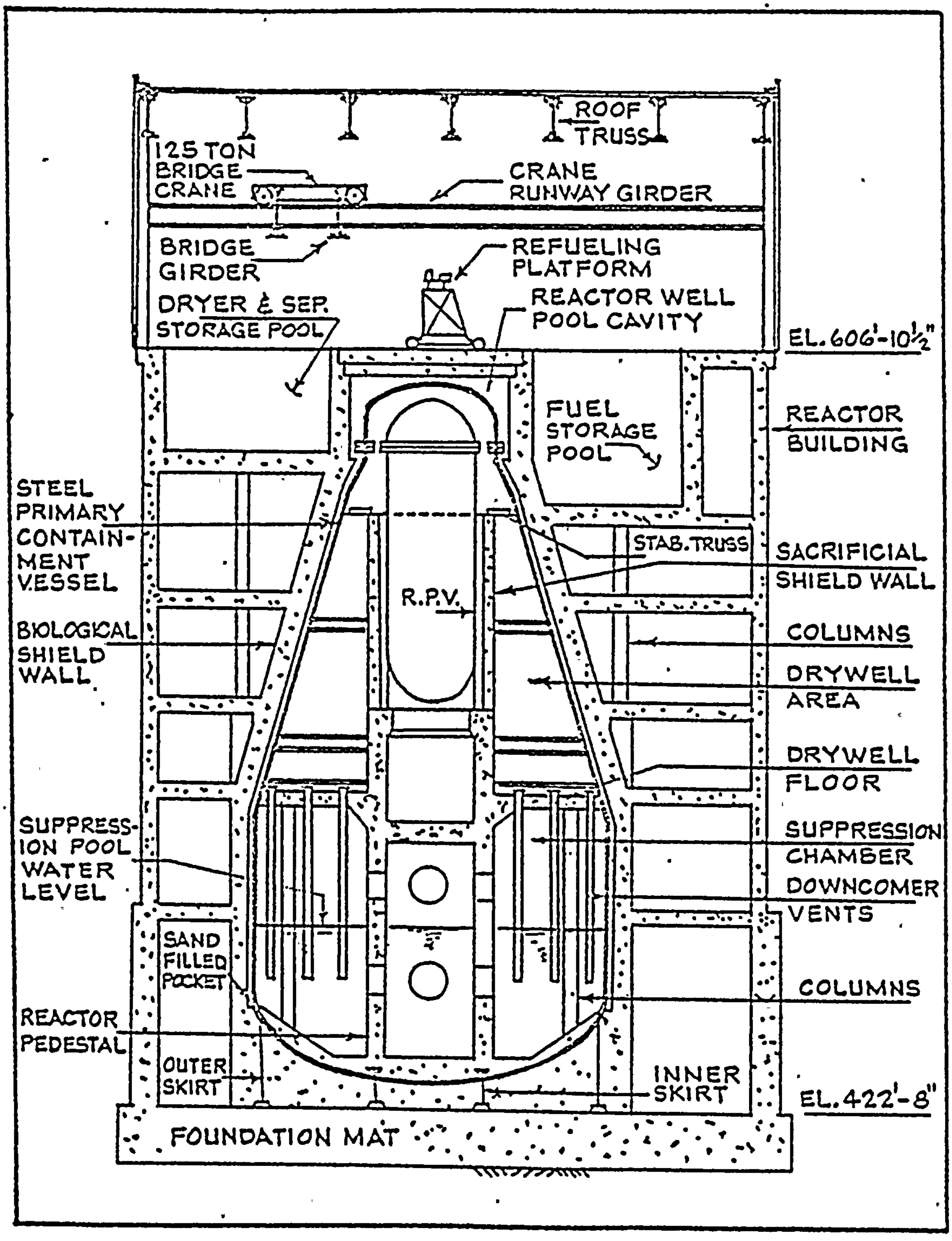
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	RESPONSE SPECTRUM OF 4T BOTTOM CENTER PRESSURE (50%, 97.7%)	FIGURE 4-12

See PROPRIETARY SUPPLEMENT

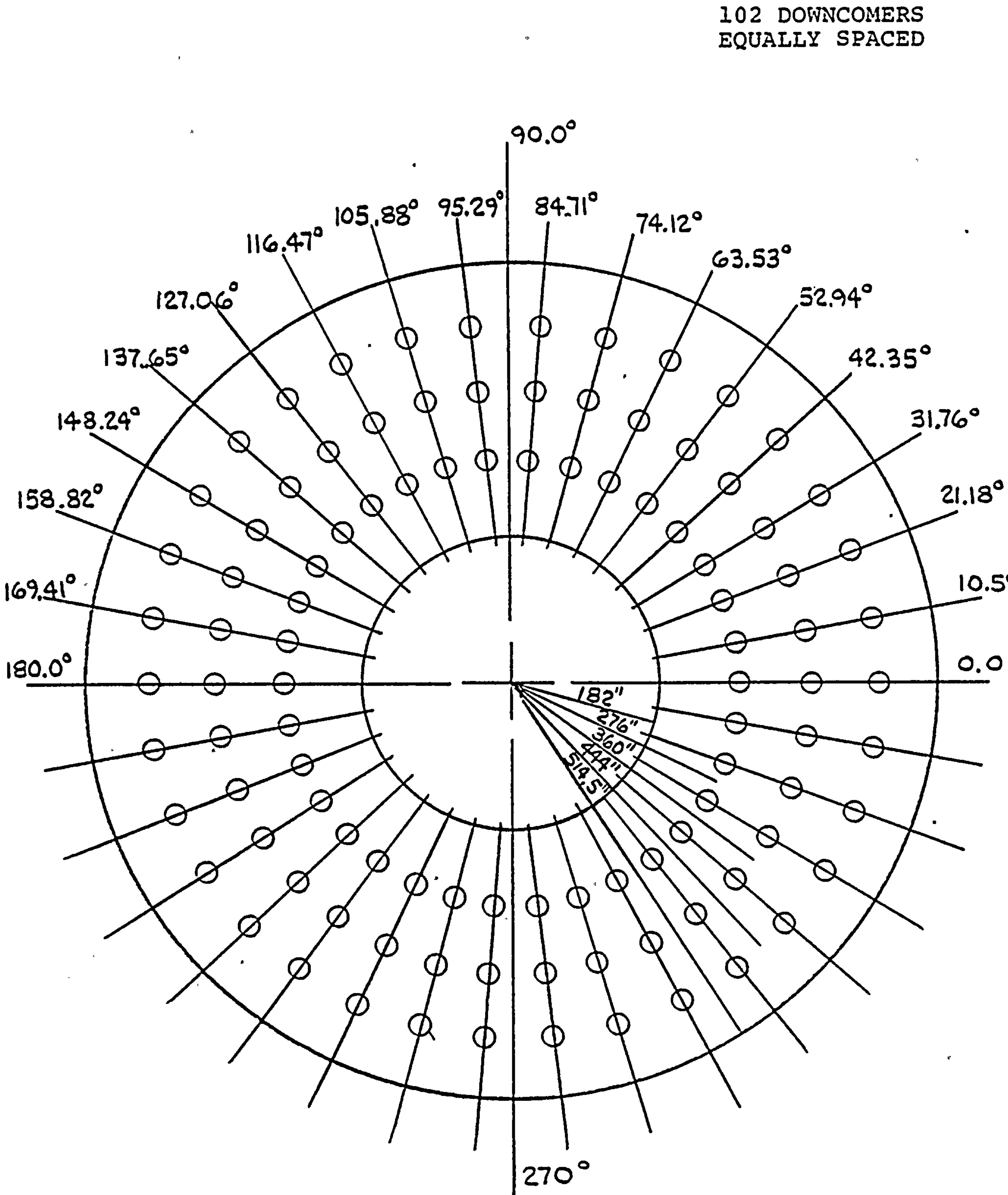
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	RESPONSE SPECTRUM OF 4T BOTTOM CENTER PRESSURE (84.1%, 97.7%)	FIGURE 4-13

See PROPRIETARY SUPPLEMENT

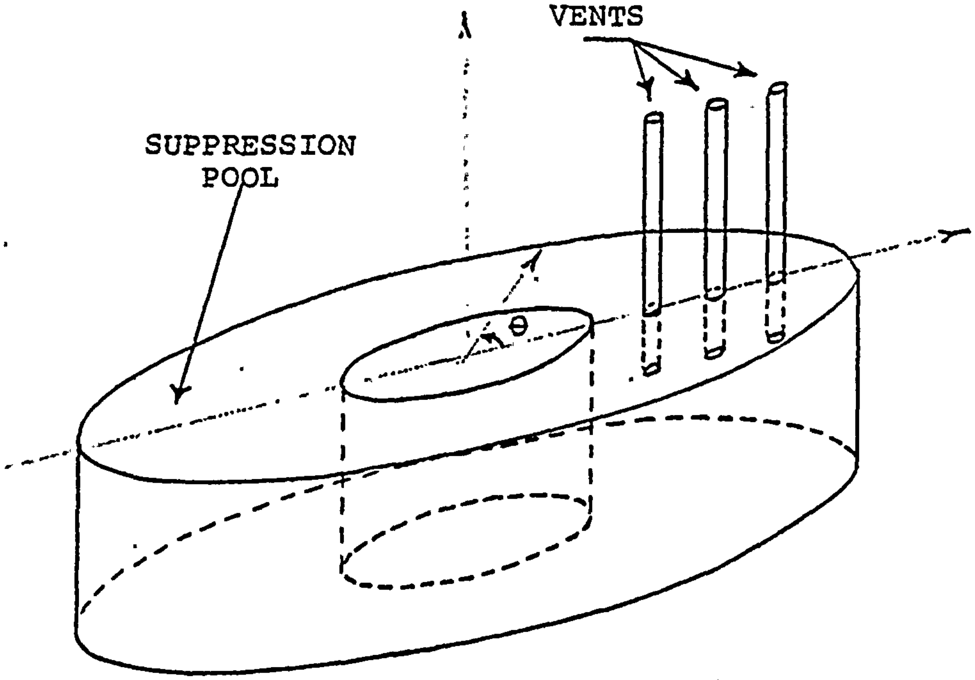
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	RESPONSE SPECTRUM OF 4T BOTTOM CENTER PRESSURE (97.7%, 97.7%)	FIGURE 4-14



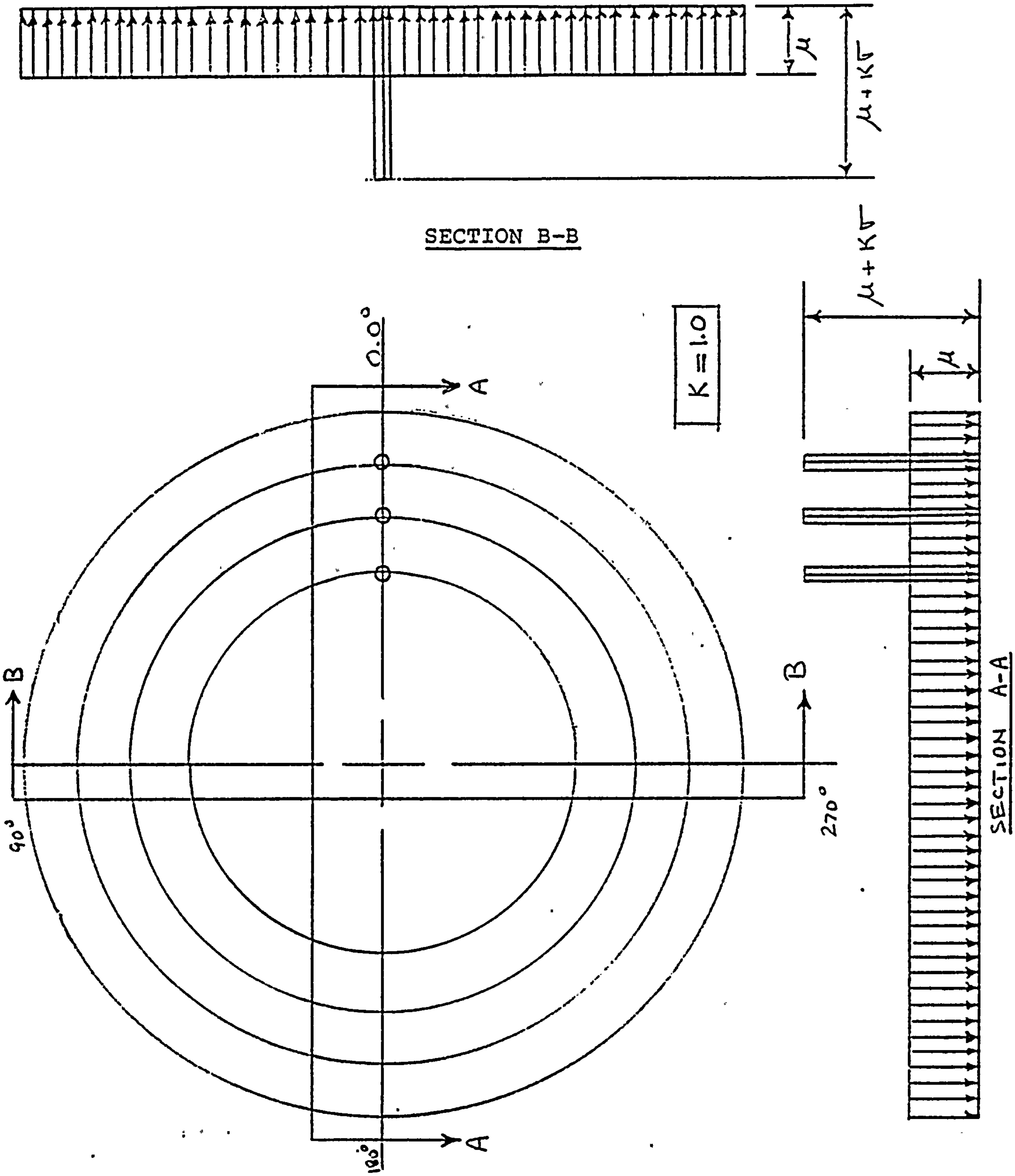
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	GENERAL CROSS-SECTION OF REACTOR BUILDING	FIGURE 5-1



WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	WETWELL PLAN VIEW AT ELEVATION OF DOWNCOMER EXITS	FIGURE 5-2

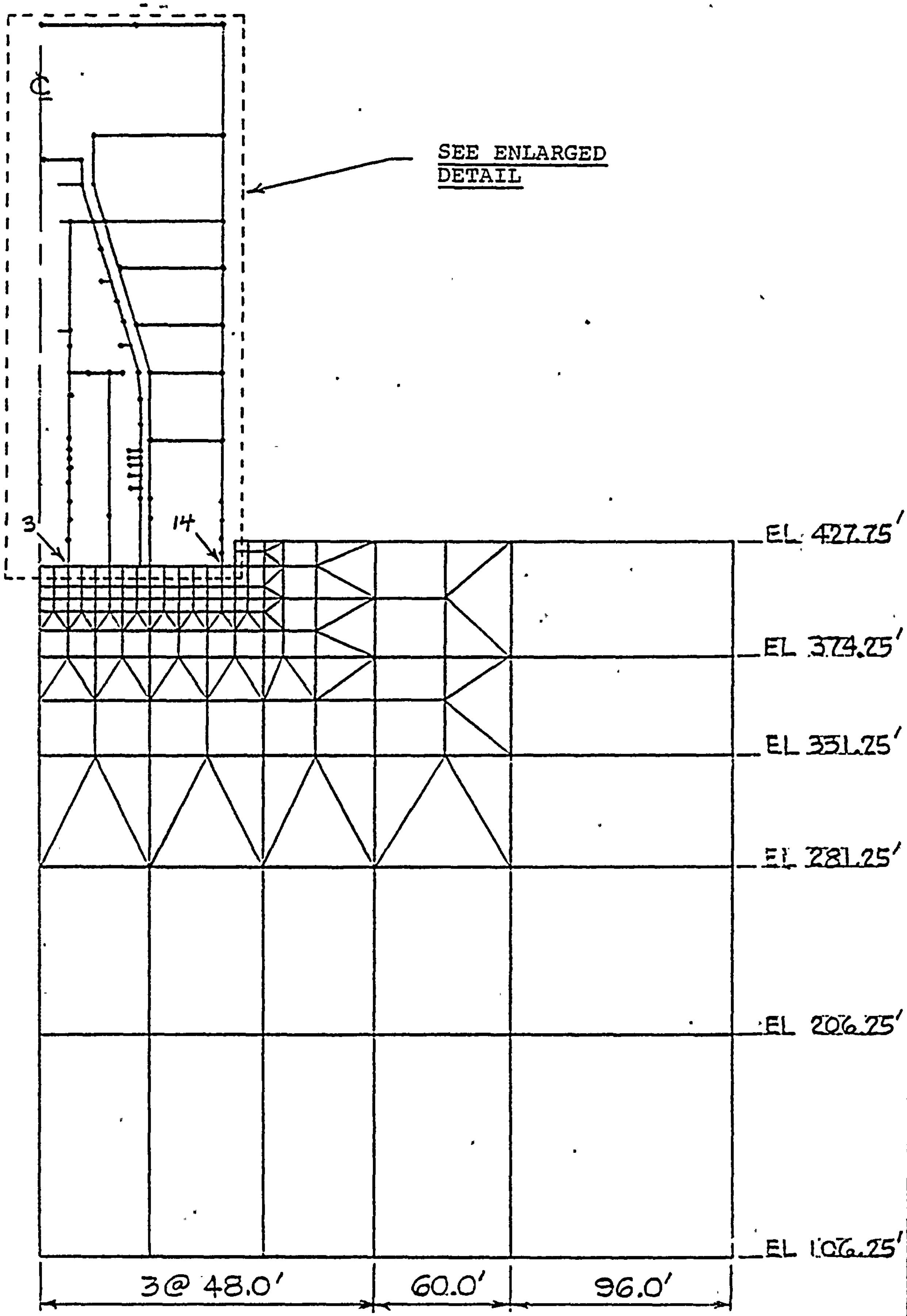


WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	MODEL OF SUPPRESSION POOL WITH ONE ROW OF VENTS	FIGURE 5-3

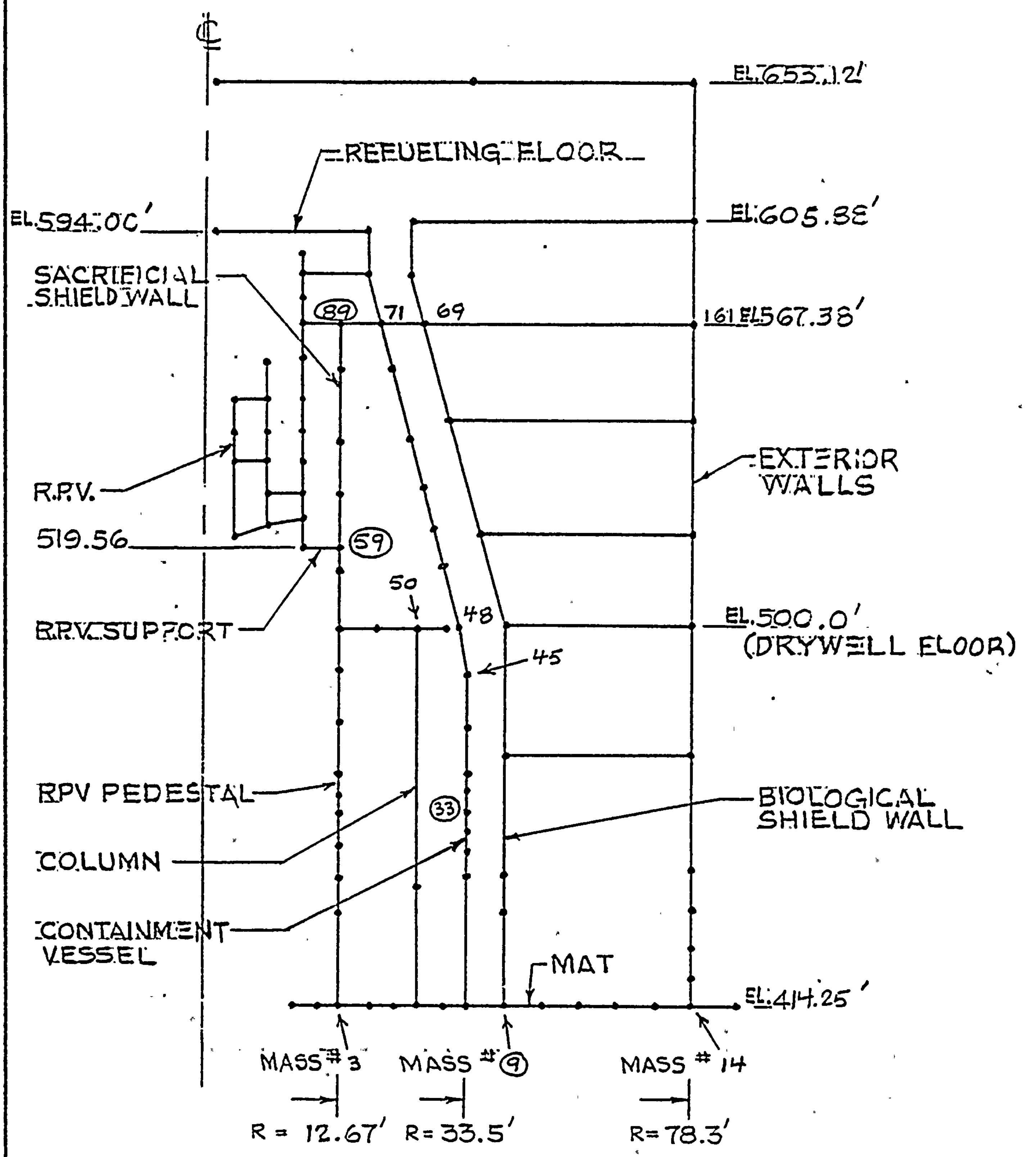


PLAN

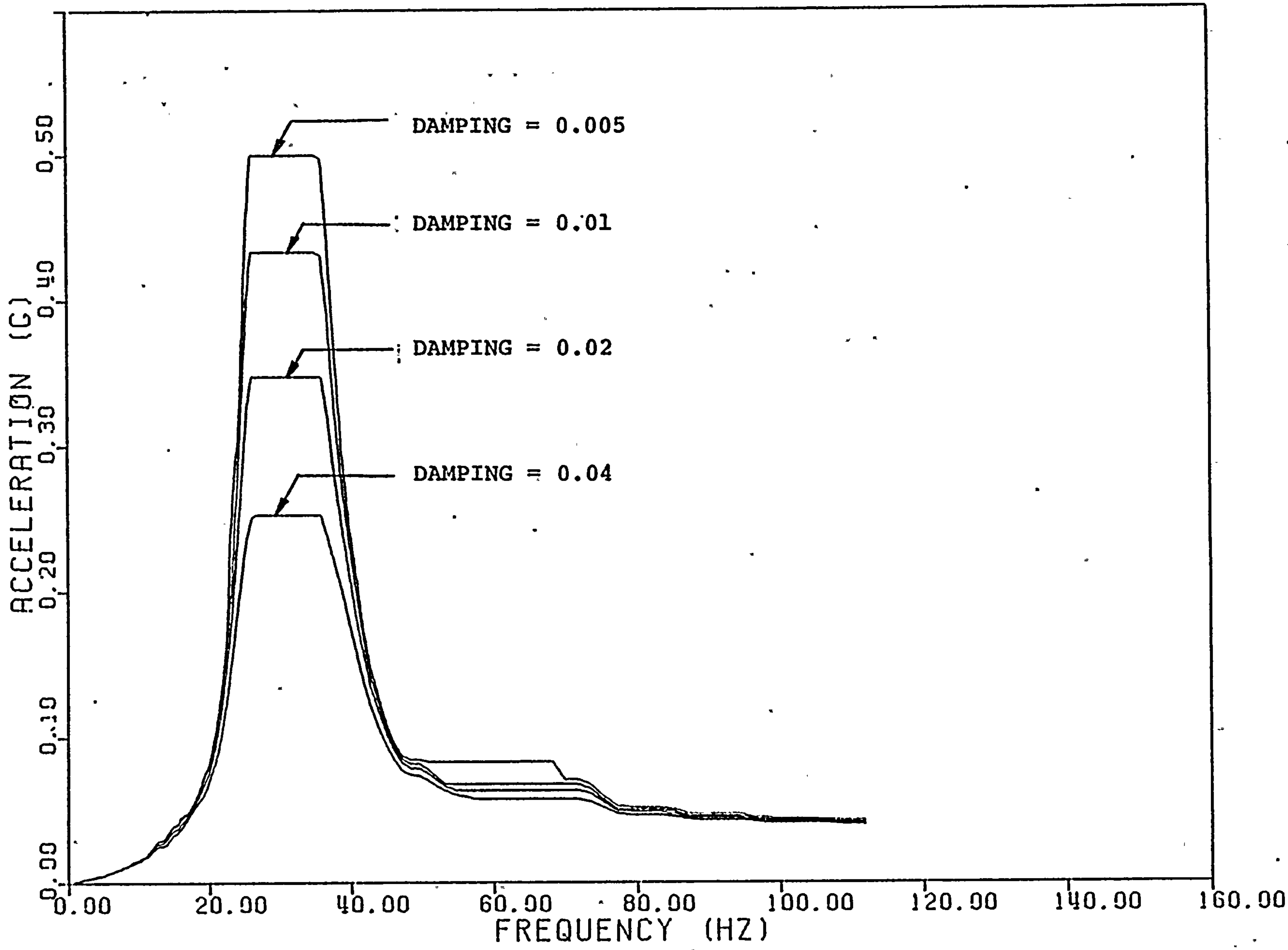
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	MAINLY SYMMETRICAL LOADING CONDITION	FIGURE 5-4



WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	AXISYMMETRIC MODEL OF THE REACTOR BUILDING AND SOIL FOUNDATION	FIGURE 5-5(A)



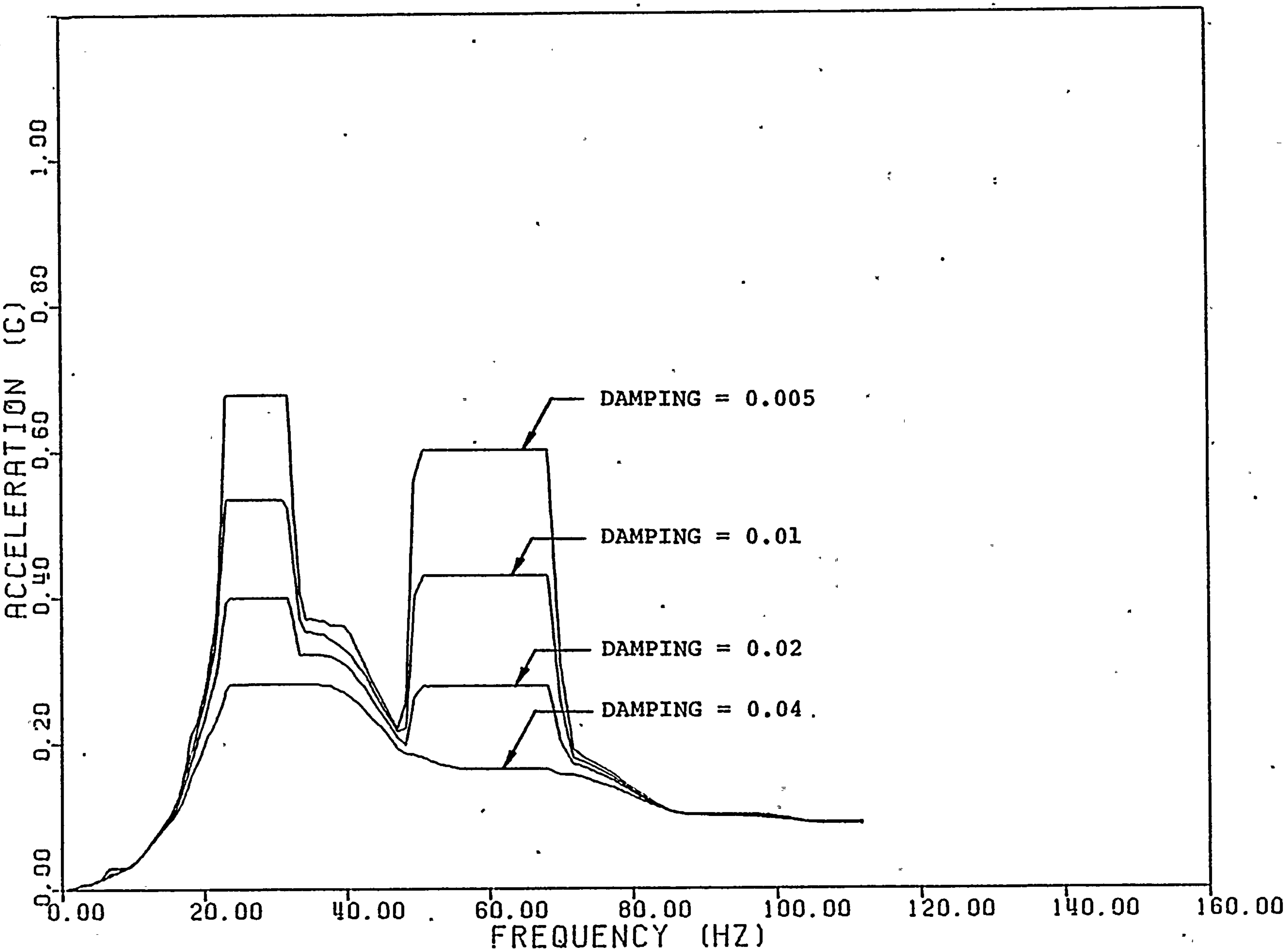
WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	ENLARGED DETAIL - AXISYMMETRIC MODEL OF THE REACTOR BUILDING	FIGURE 5-5(B)



WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

MASS #9-MAT AT CONTAINMENT VESSEL
HORIZONTAL RESPONSE

FIGURE
5-6(A)



WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

MASS #9-MAT AT CONTAINMENT VESSEL
VERTICAL RESPONSE

FIGURE
5-6(B)

WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

MASS #59-RPV SUPPORT
HORIZONTAL RESPONSE

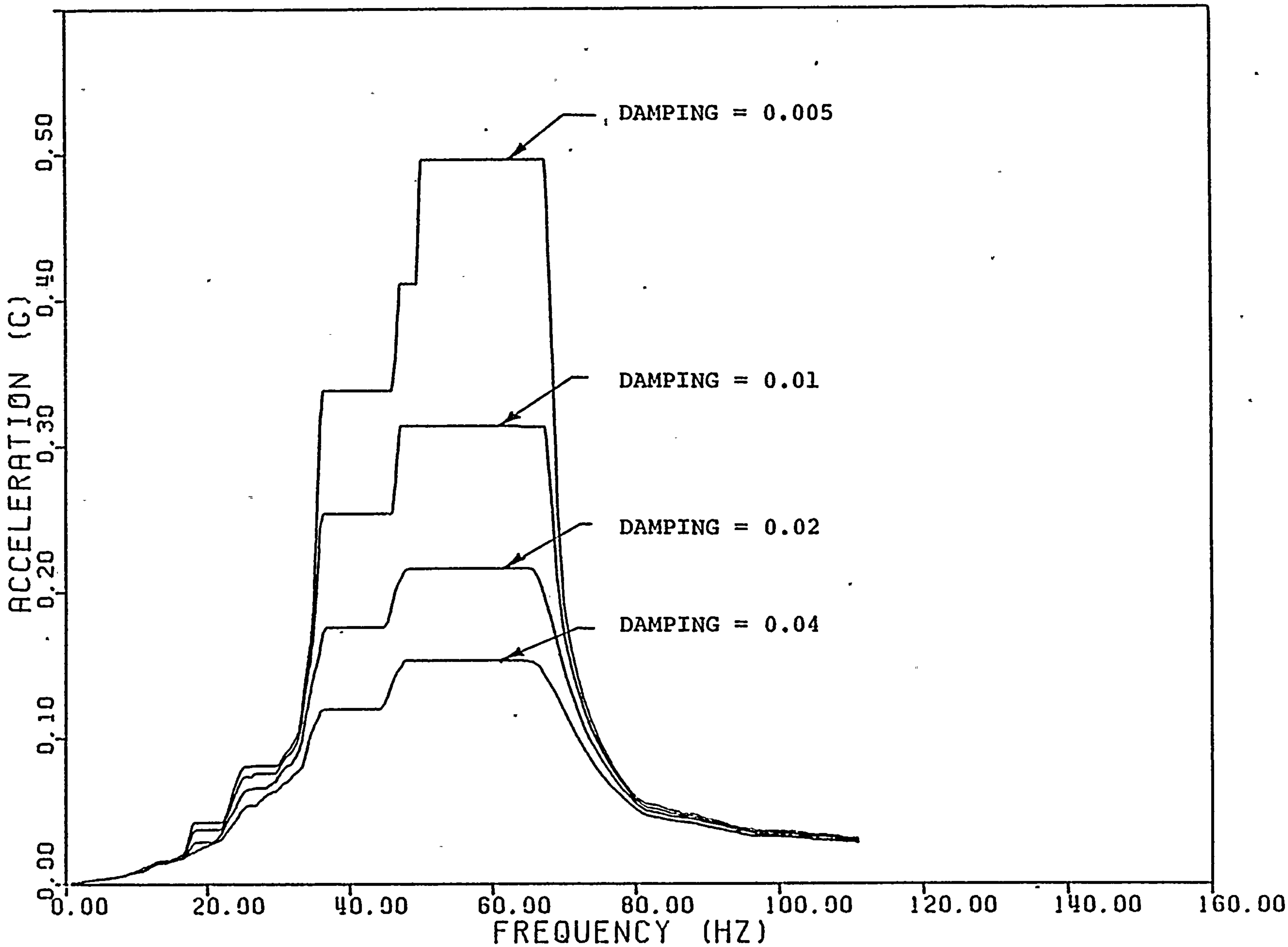


FIGURE 5-7(A)

WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

MASS #59-RPV SUPPORT
VERTICAL RESPONSE

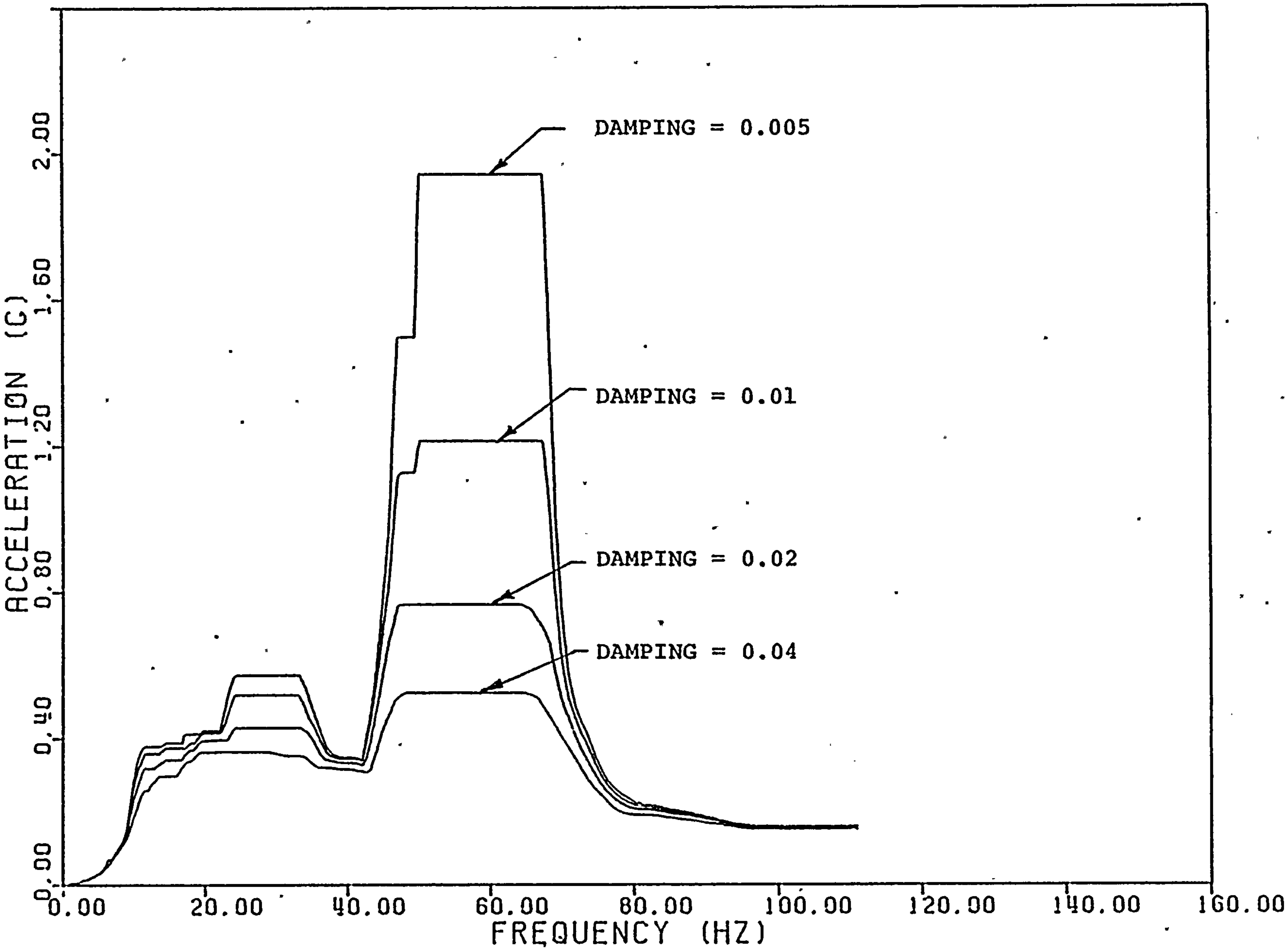


FIGURE
5-7(B)

WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

MASS #89-SACRIFICIAL WALL AT STABILIZER LEVEL HORIZONTAL RESPONSE

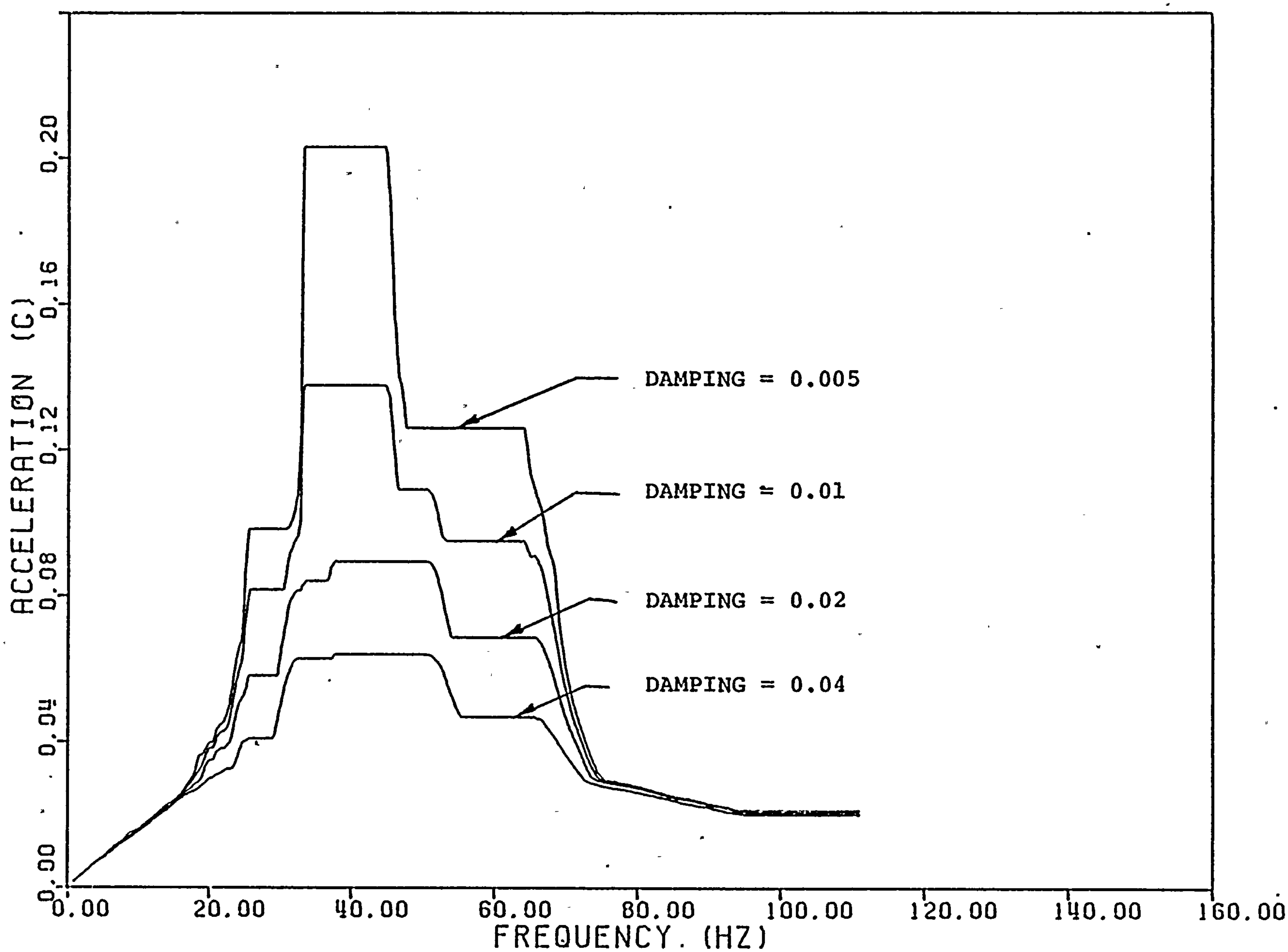
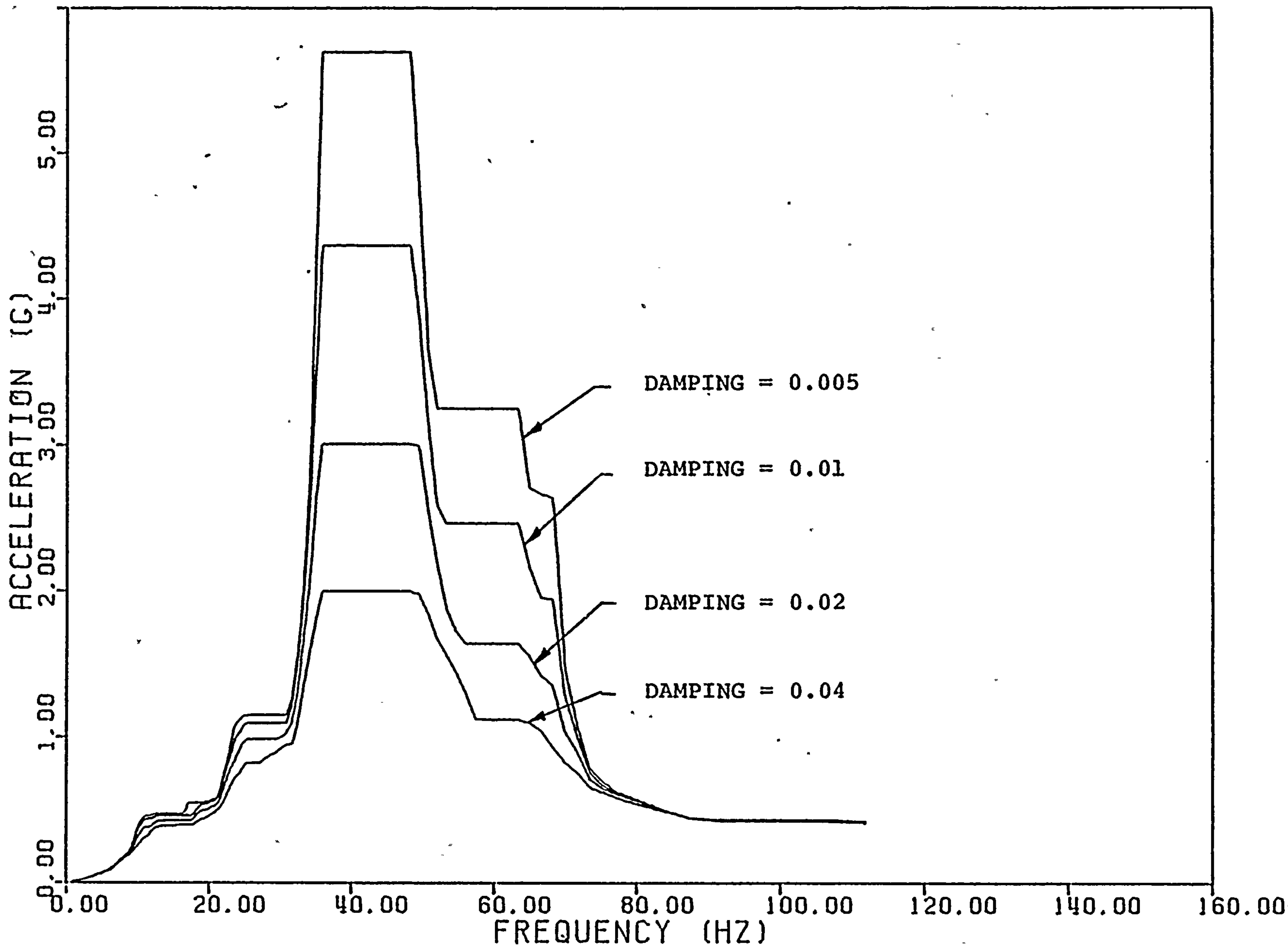


FIGURE 5-8(A)

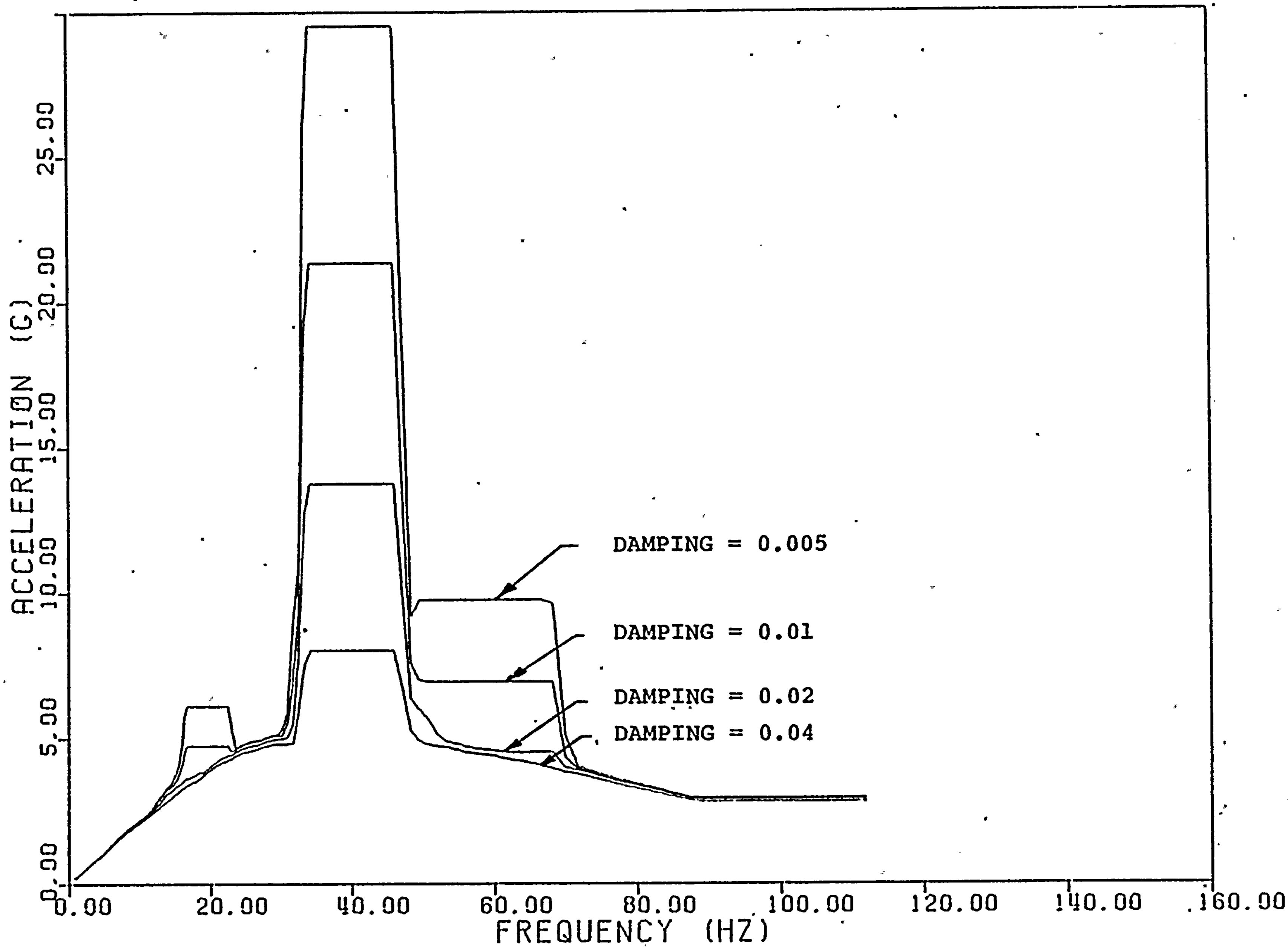
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

MASS #89-SACRIFICIAL WALL AT
STABILIZER LEVEL
VERTICAL RESPONSE

FIGURE
5-8(B)

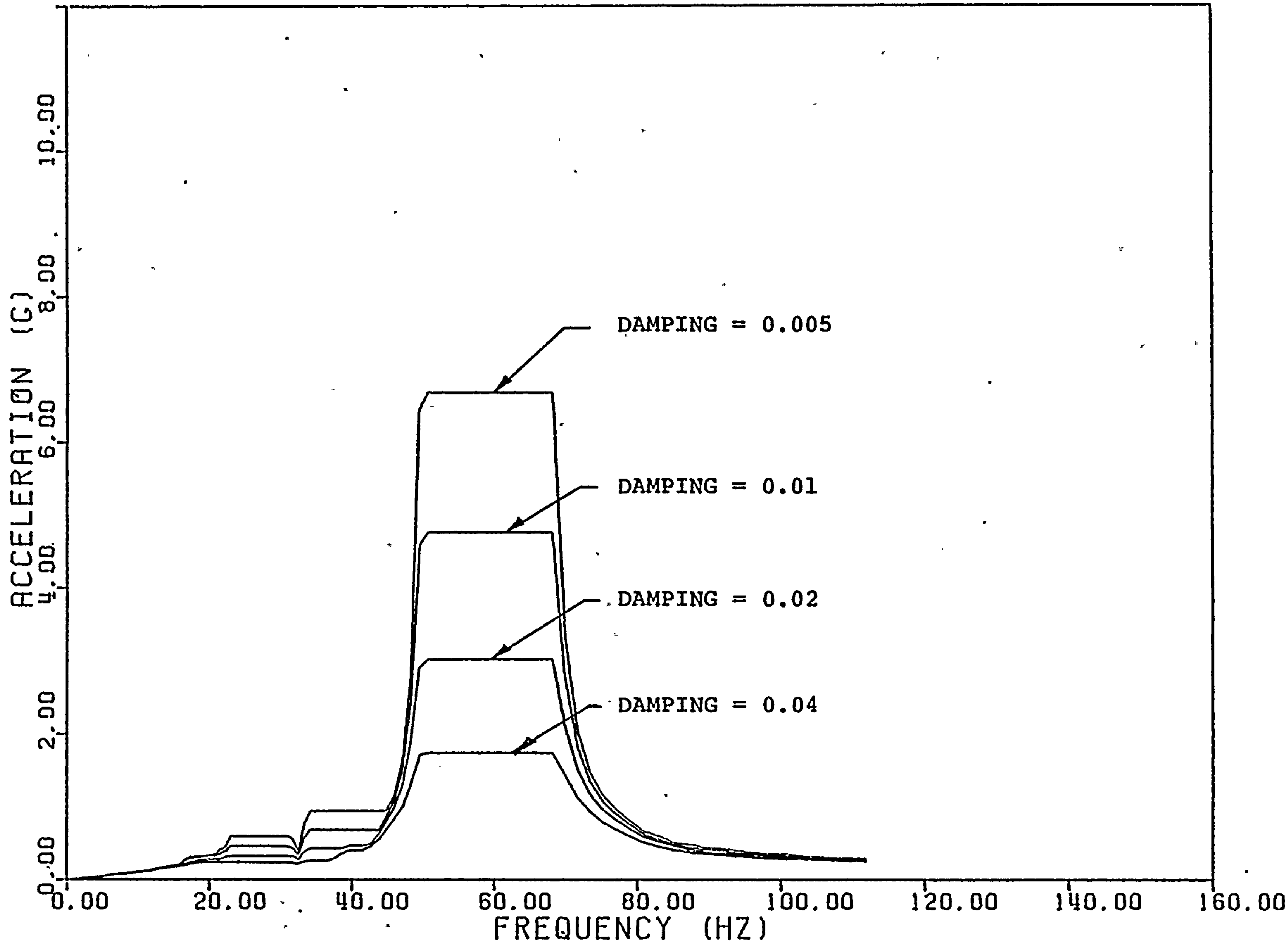


WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2



MASS #33-CONTAINMENT VESSEL AT POINT OF MAXIMUM RESPONSE HORIZONTAL RESPONSE

FIGURE 5-9(A)



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MASS #33-CONTAINMENT VESSEL AT POINT OF MAXIMUM RESPONSE VERTICAL RESPONSE

FIGURE 5-9(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	MASS #9-MAT AT CONTAINMENT VESSEL COMPARISON: IMPROVED VS "BOUNDING" LOAD - HORIZONTAL RESPONSE	FIGURE 5-10(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	MASS #9-MAT AT CONTAINMENT VESSEL COMPARISON: IMPROVED VS "BOUNDING" LOAD - VERTICAL RESPONSE	FIGURE 5-10(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	MASS #59-RPV SUPPORT COMPARISON: IMPROVED VS "BOUNDING" LOAD - HORIZONTAL RESPONSE	FIGURE 5-11(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	MASS #59-RPV SUPPORT COMPARISON: IMPROVED VS "BOUNDING" LOAD - VERTICAL RESPONSE	FIGURE 5-11(B)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	MASS #89-SACRIFICIAL WALL AT STABILIZER LEVEL-COMPARISON:IMPROVED VS "BOUNDING"LEVEL-HORIZONTAL RESPONSE	FIGURE 5-12(A)

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	MASS #89-SACRIFICIAL WALL AT STABILIZER LEVEL-COMPARISON:IMPROVED VS"BOUNDING"LOAD-VERTICAL RESPONSE	FIGURE 5-12(B

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	MASS#33-CONTAINMENT VESSEL AT POINT OF MAXIMUM RESPONSE-COMPARISON: IMPROVED VS "BOUNDING" LOAD HORIZONTAL RESPONSE	FIGURE 5-13(A

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	MASS#33-CONTAINMENT VESSEL AT POINT OF MAXIMUM RESPONSE - COMPARISON: IMPROVED VS "BOUNDING" LOAD VERTICAL RESPONSE	FIGURE 5-13(B)

See PROPRIETARY SUPPLEMENT

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WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	PROPERTIES OF THE 2 D.O.F. SYSTEM	FIGURE 2-A

See PROPRIETARY SUPPLEMENT

See PROPRIETARY SUPPLEMENT

WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	COUPLED AND UNCOUPLED VENT/WATER SYSTEM	FIGURE 2-B

APPENDIX 3-1

SUMMARY OF FLUID-STRUCTURE INTERACTION EQUATIONS IN "NASTRAN"

The equation of motion of irrotational linear inviscid fluid is

$$\frac{1}{B}\ddot{p} - \frac{1}{\rho}\nabla^2 p = 0$$

where p is the hydrodynamic pressure, ρ is the mass density and B is the bulk's modulus. It can be shown that this equation can be approximated by a linear algebraic equation, using the finite elements technique. The linear algebraic equations are

$$\underset{\sim}{M}\,\ddot{\underset{\sim}{P}} + \underset{\sim}{K}\,\underset{\sim}{P} = \underset{\sim}{I}$$

where $\underset{\sim}{P}$ is the vector of pressures at different nodal points. M is an equivalent "mass" matrix with the elements

$$M_{ij} = \frac{\partial^2 T}{\partial p_i \partial p_j}$$

T = Equivalent kinetic energy for a fluid element.

$$= \int_{(Vol)} \frac{1}{2B} \cdot (\dot{p})^2 \; d\,(Vol)$$

The elements of the stiffness matrix $\underset{\sim}{K}$ are

$$K_{ij} = \frac{\partial^2 U}{\partial p_i \ \partial p_j}$$

U = Equivalent potential energy for a fluid element

$$= \int_{Vol} \frac{1}{2\rho} \vec{\nabla} p \cdot \vec{\nabla} p \ \ d \ \ (Vol)$$

I = Vector of generalized forces imparted to the fluid.

$$= \underset{\sim}{R} \ \underset{\sim}{\ddot{U}}$$

$\underset{\sim}{\ddot{U}}$ = Boundary accelerations

$\underset{\sim}{R}$ = Appropriate transformation matrix.

The hydrodynamic forces on the structure can be shown to be

$$\underset{\sim}{F} = \underset{\sim}{A} \ \underset{\sim}{P}^b$$

where

$$\underset{\sim}{A} = - \underset{\sim}{R}^T$$

$\underset{\sim}{P}^b$ = Fluid pressures at the fluid-structure interface.

This force vector is applied then to the wet structure perimeter, in order to insure the compatibility between the fluid and the structure.

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WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	ACTUAL PRESSURE DISTRIBUTION VS. NORMAL DISTRIBUTION	FIGURE 4-A

See PROPRIETARY SUPPLEMENT

APPENDIX 5-1

THEORETICAL BACKGROUND OF 3-D HYDRODYNAMIC FLUID-STRUCTURE INTERACTION

1. Equations of Motion

Consider a compressible, inviscid fluid, with a hydrodynamic pressure of P, the equation of motion of this fluid could be written in cartesian coordinates, as Ref.[19]

$$\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} + \frac{\partial^2 P}{\partial z^2} = \frac{1}{C^2}\frac{\partial^2 P}{\partial t^2} \qquad \text{(A1)}$$

with the boundary conditions:

$P(x,y,z,t) = 0$ (1-a) at the free surface

$\frac{\partial P}{\partial n} = -\rho \ddot{U}_n$ (1-b) at the fluid-structure interface

$P(x,y,z,t) = \tilde{P}(x,y,z,t)$ (1-c) at any interior fluid point with specified pressure time history, such as a bubble interface.

Where

C = Sound Wave Velocity in the fluid

n = Normal direction to the fluid-structure interface

$\ddot{U}_n$ = Normal acceleration of the fluid-structure interface

ρ = Mass density of the fluid

Equation (A1) could be written as

$$\nabla^2 P = \frac{1}{C^2}\frac{\partial^2 P}{\partial t^2} \qquad \text{(A2)}$$

where $\vec{\nabla} = \frac{\partial}{\partial x}\vec{i} + \frac{\partial}{\partial y}\vec{j} + \frac{\partial}{\partial z}\vec{k}$

$\nabla^2 = \vec{\nabla} \cdot \vec{\nabla}$

$\vec{i}, \vec{j}, \vec{k}$ are the unit vectors in the x, y, z directions, respectively.

If we consider a function x, and its variation δx, it could be shown, [Reference 20], that equation (A2) is the variation of the function x, such that

$\delta x = 0$, and

$$\delta x = \delta \int_V \left(\nabla^2 p + \frac{1}{c^2} \left(\frac{\partial \dot{p}}{\partial t}\right)^2 \right) d\ \text{Vol.} - \int_s \delta p (\vec{\nabla} p) \cdot \vec{ds} \qquad \text{(A3)}$$

where s is the boundary surface with specified normal acceleration (pressure gradient).

Equations (A1) to (A3) can be generalized to have a set of initial pressures

$p_o = p_o(x, y, z, 0)$.

2. Finite Elements Discretization

Equation (A3), with its different boundary and initial conditions is solved using the finite elements technique, [Reference 20]. Fig. 1 shows a three-dimensional arbitrary element with eight nodes.

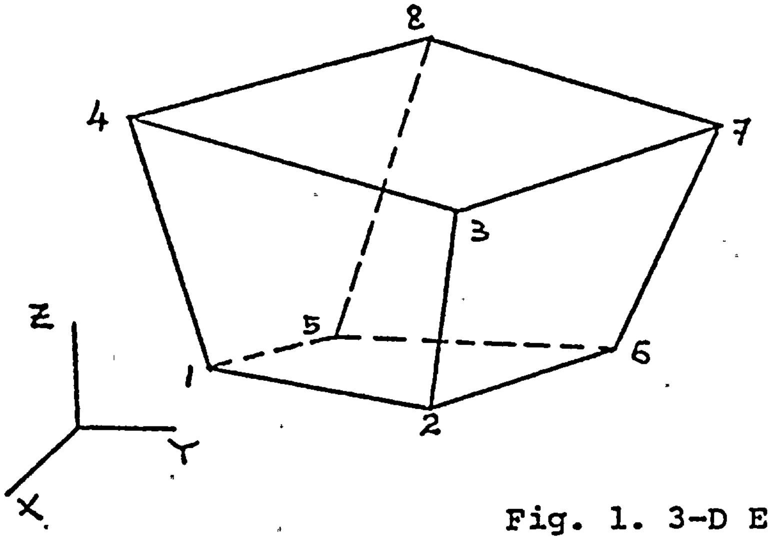
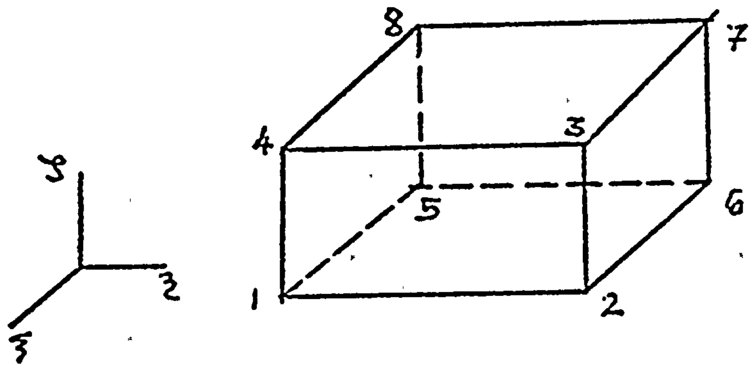


Fig. 1. 3-D Element

A linear expansion of the pressures will be assumed. These expansions will be derived first for a parallelopiped shape, Fig. 2,



then a conformal transformation will be made. The pressure distribution is expressed as:

$$P = \underset{\sim}{\Phi}\, \underset{\sim}{P}^{n}$$

P_1 = Vector containing the nodal pressures

$$\underset{\sim}{\Phi}^{T} = \frac{1}{8} \times \begin{bmatrix} (1-\xi)(1-\eta)(1-\zeta) \\ (1-\xi)(1+\eta)(1-\zeta) \\ \cdot \\ \cdot \\ \cdot \\ (1+\xi)(1-\eta)(1+\zeta) \end{bmatrix}, \text{ Reference[21]}$$

Then the variation δx could be expressed as:

$$\delta x = \delta \underset{\sim}{P}^{nT} \left[\int_{Vol.} \{ \underset{\sim}{\Phi}^{T},_x \underset{\sim}{\Phi},_x + \underset{\sim}{\Phi}^{T},_y \underset{\sim}{\Phi},_y + \underset{\sim}{\Phi}^{T},_z \underset{\sim}{\Phi},_z \} \right.$$

$$\left. x dVol. \right] \underset{\sim}{P}^{n} + \delta P^{nT} \left[\frac{1}{c^2} \int_{Vol} \underset{\sim}{\Phi}^{T} \underset{\sim}{\Phi}\, dVol \right] \frac{\partial^2 \underset{\sim}{P}^n}{\partial t^2}$$

$$- \delta \underset{\sim}{P}^{nT} \left[\int_{S} \underset{\sim}{\Phi}^{*T} \underset{\sim}{\Phi}^{*} ds \right] \ddot{\underset{\sim}{U}}_n \qquad \text{(A4)}$$

where

$$\Phi,_x = \frac{\partial \Phi}{\partial x}, \text{ etc.}$$

$$\underset{\sim}{\Phi}^{*} = \bar{\underset{\sim}{A}}\, \underset{\sim}{\Phi}$$

$\bar{A}$ = Transformation diagonal matrix with 1.0 and 0. in the leading diagonal to account for the transformation from the volume expansion to the surface expansion, Reference A3.

Equation (A4) could be simplified as:

$$\underset{\sim}{K}^{e} \underset{\sim}{P}^{n} + \underset{\sim}{M}^{e} \frac{\partial^2 \underset{\sim}{P}^n}{\partial t^2} = \underset{\sim}{F}^{e} \ddot{\underset{\sim}{U}}_n$$

Where superscript "e" stands for each element, and:

$$\underset{\sim}{K}^{e} = \int_{Vol} (\underset{\sim}{\Phi},_x^{T} \Phi,_x + \underset{\sim}{\Phi},_y^{T} \underset{\sim}{\Phi},_y + \underset{\sim}{\Phi},_z^{T} \underset{\sim}{\Phi},_z)\, d\, Vol.$$

$$\underset{\sim}{M}^{e} = \frac{1}{c^2} \int_{Vol.} \Phi^{T} \Phi\, d\, Vol.$$

$$\underset{\sim}{F}^{e} = \int_{S} \underset{\sim}{\Phi}^{T*} \underset{\sim}{\Phi}^{*} ds$$

The global equation of the whole system could be obtained by assembling all the element matrices and vectors. This equation is

$$\underset{\sim}{K}\,\underset{\sim}{P} + \underset{\sim}{M}\,\ddot{\underset{\sim}{P}} = \underset{\sim}{F}\,\ddot{\underset{\sim}{U}}_n \qquad \text{(A5)}$$

with initial pressures $\underset{\sim}{P}_o = \underset{\sim}{P}\ (t=0)$ and specified pressure time histories $\overline{\underset{\sim}{P}}(t)$.

3. Frequency Domain Decomposition

In order to solve the fluid-structure system, it is necessary to operate on equation (A5) in the frequency domain. Taking the Fourier Transform of equation (A5), we get, [Reference 18].

$$\underset{\sim}{K}\,\underset{\sim}{P} + \underset{\sim}{M}\,(-\Omega^2 \underset{\sim}{P} - i\Omega \underset{\sim}{P}_o) = \underset{\sim}{F}\,(\mathcal{F}(\ddot{\underset{\sim}{U}}_n)) \qquad \text{(A6)}$$

with

$$\underset{\sim}{P} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} \overline{\underset{\sim}{P}} \exp(-i\Omega t)\,dt$$

$\mathcal{F}(\ddot{\underset{\sim}{U}}_n)$ = Fourier transform of $\ddot{\underset{\sim}{U}}_n$

$i = \sqrt{-1}$

Ω = Frequency of excitation

Equation (A6) could be simplified as

$$(\underset{\sim}{K} - \Omega^2 \underset{\sim}{M})\,\underset{\sim}{P} = \underset{\sim}{F}(\mathcal{F}(\ddot{U}_n)) + i\Omega \underset{\sim}{M}\,\underset{\sim}{P}_o \qquad \text{(A7)}$$

with specified pressures $\bar{\bar{P}}$, where

$$\underset{\sim}{\bar{\bar{P}}} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} \bar{P}(t) \exp(-i\Omega t)\, dt \tag{A8}$$

From (A7), the equation of motion becomes

$$\underset{\sim}{A}\,\underset{\sim}{P} = \underset{\sim}{F}(\mathcal{F}(\ddot{\underset{\sim}{U}}_n)) + \underset{\sim}{F}_o \tag{A9}$$

where

$$\underset{\sim}{F}_o = i\Omega \underset{\sim}{M}\,\underset{\sim}{P}_o$$

$$\underset{\sim}{A} = \underset{\sim}{K} - \Omega^2 \underset{\sim}{M}$$

Equation (9) should be modified to account for prescribed pressured P. From Reference 22, the final equation of motion becomes:

$$\underset{\sim}{B}\,\underset{\sim}{P} = \underset{\sim}{F}(\mathcal{F}(\ddot{\underset{\sim}{U}}_n)) + \underset{\sim}{F}_o + \underset{\sim}{C}\,\underset{\sim}{\bar{\bar{P}}} \tag{A10}$$

where $\underset{\sim}{B} = \underset{\sim}{T}_1 \underset{\sim}{A}$

$$\underset{\sim}{C} = \underset{\sim}{T}_2 \underset{\sim}{A}_2$$

Details of $\underset{\sim}{T}_1$ and $\underset{\sim}{T}_2$ could be found in Reference 22. It should be noticed that matrices $\underset{\sim}{B}$, $\underset{\sim}{F}_o$ and $\underset{\sim}{C}$ are frequency dependent.

4. Evaluation of Added Masses and Incident Pressures

The pressure vector P could be decomposed so that

$$\underset{\sim}{P}^T = [\underset{\sim}{P}_1^T \,\vdots\, \underset{\sim}{P}_2^T]$$

where nodes with subscript of $_1$ denote the inner fluid nodes, and those with subscript of $_2$ denote the structural interface.

Equation (A10) becomes

$$\underset{\sim}{M}_{11}\underset{\sim}{P}_1 + \underset{\sim}{M}_{12}\underset{\sim}{P}_2 = \underset{\sim}{F}_1\,(\mathcal{F}(\ddot{\underset{\sim}{U}}_n)) + \underset{\sim}{F}_{o1} + \underset{\sim}{C}_1\,\underset{\sim}{\overline{\overline{P}}} \qquad \text{(A11)}$$

$$\underset{\sim}{M}_{21}\underset{\sim}{P}_1 + \underset{\sim}{M}_{22}\underset{\sim}{P}_2 = \underset{\sim}{F}_2\,(\mathcal{F}(\ddot{\underset{\sim}{U}}_n)) + \underset{\sim}{F}_{o2} + \underset{\sim}{C}_2\,\underset{\sim}{\overline{\overline{P}}} \qquad \text{(A12)}$$

Eliminating P_1 from the two equations, we get

$$\underset{\sim}{M}_{21}\left\{\underset{\sim}{M}_{11}^{-1}\,(\underset{\sim}{F}_1\,(\mathcal{F}(\ddot{\underset{\sim}{U}}_n)) + \underset{\sim}{F}_{o1} + \underset{\sim}{C}_1\,\underset{\sim}{\overline{\overline{P}}})\right. + (\underset{\sim}{M}_{22}-\underset{\sim}{M}_{21}\underset{\sim}{M}_{11}^{-1}\underset{\sim}{M}_{12})\,\underset{\sim}{P}_2$$

$$= \underset{\sim}{F}_2(\mathcal{F}(\ddot{\underset{\sim}{U}}_n)) + \underset{\sim}{F}_{o2} + \underset{\sim}{C}_2\,\underset{\sim}{\overline{\overline{P}}} \qquad \text{(A13)}$$

$$\underset{\sim}{D}\,\underset{\sim}{P}_2 = \underset{\sim}{D}_1\,(\mathcal{F}(\ddot{\underset{\sim}{U}}_n)) + \underset{\sim}{D}_o + \underset{\sim}{D}_2\,\underset{\sim}{\overline{\overline{P}}} \qquad \text{(A14)}$$

where

$$\underset{\sim}{D} = \underset{\sim}{M}_{22} - \underset{\sim}{M}_{21}\,\underset{\sim}{M}_{11}^{-1}\,\underset{\sim}{M}_{12}$$

$$\underset{\sim}{D}_1 = \underset{\sim}{F}_2 - \underset{\sim}{M}_{21}\,\underset{\sim}{M}_{11}^{-1}\,\underset{\sim}{F}_1 \qquad \text{(A15)}$$

$$\underset{\sim}{D}_o = \underset{\sim}{F}_{o2} - \underset{\sim}{M}_{21}\,\underset{\sim}{M}_{11}\,\underset{\sim}{F}_{o1}$$

$$\underset{\sim}{D}_2 = \underset{\sim}{C}_2 - \underset{\sim}{M}_{21}\,\underset{\sim}{M}_{11}^{-1}\,\underset{\sim}{C}_1$$

Pre-multiplying equation (A14) by D^{-1}, we get

$$\underset{\sim}{P}_2 = [\underset{\sim}{AM}]\,(\mathcal{F}(\ddot{\underset{\sim}{U}}_n)) + \underset{\sim}{E}_o + \underset{\sim}{E}_2 \qquad \text{(A16)}$$

with

$$[\underset{\sim}{AM}] = \underset{\sim}{D}^{-1}\underset{\sim}{D}_1$$

$$\underset{\sim}{E}_o = \underset{\sim}{D}^{-1}\underset{\sim}{D}_o \qquad \text{(A17)}$$

$$\underset{\sim}{E}_2 = \underset{\sim}{D}^{-1}\underset{\sim}{D}_2\underset{\sim}{\overline{\overline{P}}}$$

The matrix $[\underset{\sim}{AM}]$ represents the matrix of coefficients which relates the accelerations of the structural interface with the hydrodynamic pressures on the structure, it is known as the fluid added mass matrix and it is frequency dependent. The vectors $\underset{\sim}{E}_o$ and $\underset{\sim}{E}_2$ are frequency dependent pressure vectors, they present the hydrodynamic pressures on the structural interface due to an initial pressure and specified internal pressures, respectively, if the surrounding structure was rigid.

5. Evaluation of the Structural Response

The dynamic equilibrium equation of the structures subjected to hydrodynamic pressures $\underset{\sim}{P}_2$ is:

$$\underset{\sim}{M}_s \ddot{\underset{\sim}{U}}_s + \underset{\sim}{K}\,\underset{\sim}{U}_s = -\underset{\sim}{T}\tilde{\underset{\sim}{P}}_2 \qquad \text{(A17)}$$

where

$$\tilde{\underset{\sim}{P}}_2 = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} \underset{\sim}{P}_2 \exp(i\Omega t)\, d\Omega \qquad \text{(A18)}$$

$\underset{\sim}{T}$ = Appropriate transformation matrix

$\underset{\sim}{U}_s, \dot{\underset{\sim}{U}}_s, \ddot{\underset{\sim}{U}}_s$ = Structural displacements, velocities and accelerations, respectively

$\underset{\sim}{M}_s$ = Structural mass matrix

$\underset{\sim}{K}$ = Structural stiffness matrix

From equation (A16), (A17) and (A18), it could be shown that

the equation of motion of the structure in the frequency domain becomes

$$(-\Omega^2(\underset{\sim}{M}_s + \underset{\sim}{T}\ \underset{\sim}{AM}\ \underset{\sim}{T}^T) + \underset{\sim}{K})\ \underset{\sim}{U}_s^{\Omega} = \underset{\sim}{T}\ \underset{\sim}{E}_o + \underset{\sim}{T}\ \underset{\sim}{E}_2 \qquad \text{(A19)}$$

Where

$$\underset{\sim}{U}_s^{\Omega} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} \underset{\sim}{U}_s \exp\ (-i\Omega t)\ dt$$

Solving equation (19) for $\underset{\sim}{U}_s^{\Omega}$, then performing an inverse Fourier transform operation we get the structural displacements $\underset{\sim}{U}_s$.

WPPSS NUCLEAR PROJECT NO. 2

PROPRIETARY INFORMATION

WASHINGTON PUBLIC POWER SUPPLY SYSTEM

GENERAL ELECTRIC COMPANY

AFFIDAVIT

I, Glenn G. Sherwood, being duly sworn, depose and state as follows:

1. I am Manager of Safety and Licensing, General Electric Company, and have been delegated the function of reviewing the information described in paragraph 2 which is sought to be withheld and have been authorized to apply for its withholding.

2. The information sought to be withheld consists of the following figures as filed with the NRC as part of the WPPSS Nuclear Project Number 2 Final Safety Analysis Report (WNP-2 FSAR):

   A. Offgas System Technology (Table 11.3-3 and Figure 11.3-2).

3. In designating material as proprietary, General Electric utilizes the definition of proprietary information and trade secrets set forth in the American Law Institute's Restatement Of Torts, Section 757. This definition provides:

   "A trade secret may consist of any formula, pattern, device or compilation of information which is used in one's business and which gives him an opportunity to obtain an advantage over competitors who do not know or use it.... A substantial element of secrecy must exist, so that, except by the use of improper means, there would be difficulty in acquiring information.... Some factors to be considered in determining whether given information is one's trade secret are: (1) the extent to which the information is known outside of his business; (2) the extent to which it is known by employees and others involved in his business; (3) the extent of measures taken by him to guard the secrecy of the information; (4) the value of the information to him and to his competitors; (5) the amount of effort or money expended by him in developing the information; (6) the ease or difficulty with which the information could be properly acquired or duplicated by others."

4. Some examples of categories of information which fit into the definition of proprietary information are:

   a. Information that discloses a process, method or apparatus where prevention of its use by General Electric's competitors without license from General Electric constitutes a competitive economic advantage over other companies;

b. Information consisting of supporting data and analyses, including test data, relative to a process, method or apparatus, the application of which provide a competitive economic advantage, e.g., by optimization or improved marketability;

c. Information which if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality or licensing of a similar product;

d. Information which reveals cost or price information, production capacities, budget levels or commercial strategies of General Electric, its customers or suppliers;

e. Information which reveals aspects of past, present or future General Electric customer-funded development plans and programs of potential commercial value to General Electric;

f. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection;

g. Information which General Electric must treat as proprietary according to agreements with other parties.

5. In addition to proprietary treatment given to material meeting the standards enumerated above, General Electric customarily maintains in confidence preliminary and draft material which has not been subject to complete proprietary, technical and editorial review. This practice is based on the fact that draft documents often do not appropriately reflect all aspects of a problem, may contain tentative conclusions and may contain errors that can be corrected during normal review and approval procedures. Also, until the final document is completed it may not be possible to make any definitive determination as to its proprietary nature. General Electric is not generally willing to release such a document to the general public in such a preliminary form. Such documents are, however, on occasion furnished to the NRC staff on a confidential basis because it is General Electric's belief that it is in the public interest for the staff to be promptly furnished with significant or potentially significant information. Furnishing the document on a confidential basis pending completion of General Electric's internal review permits early acquaintance of the staff with the information while protecting General Electric's potential proprietary position and permitting General Electric to insure the public documents are technically accurate and correct.

6. Initial approval of proprietary treatment of a document is made by the Subsection Manager of the originating component, the man most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within the Company is limited on a "need to know" basis and such documents at all times are clearly identified as proprietary.

7. The procedure for approval of external release of such a document is review by the Section Manager, Project Manager, Principal Scientist or other equivalent authority, by the Section Manager of the cognizant Marketing function (or his delegate) and by the Legal Operation for technical content, competitive effect and determination of the accuracy of the proprietary designation in accordance with the standards enumerated above. Disclosures outside General Electric are generally limited to regulatory bodies, customers and potential customers and their agents, suppliers and licensees only in accordance with appropriate regulatory provisions or proprietary agreements.

8. The document mentioned in paragraph 2 above has been evaluated in accordance with the above criteria and procedures and has been found to contain information which is proprietary and which is customarily held in confidence by General Electric.

9. The information in the WNP-2 FSAR, considered proprietary to General Electric, consists of Offgas System Technology.

10. The information, to the best of my knowledge and belief, has consistently been held in confidence by the General Electric Company, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties have been made pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence.

11. Public disclosure of the information sought to be withheld is likely to cause substantial harm to the competitive position of the General Electric Company and deprive or reduce the availability of profit-making opportunities for the following reasons:

    A. Offgas System Technology

        1. The cost of developing the proprietary information in the Table and Drawing mentioned in paragraph 2A above, as detailed in Table I, exceeds $2,146,000.

        2. We believe the difficulty of obtaining information, such as the above represents, is substantial; as our engineering would have to be duplicated in large part.

        3. Our competitors are CTI-Nuclear, Ebasco, Suntac, CVI, Stone and Webster, Air Products & Chemicals, Linde, Airco, AEG*, Hitachi*, Toshiba*.

            *Indicates GE licensees who can obtain the information from GE, but have to pay for it, and are allowed and do bid in competition with GE under the license.

        4. Commercial advantage to the competitors include cost savings if the information were free, and thus with reduced write-off could underbid GE. Also sales advantage would be gained by ability to sell against GE features instead of on their own systems merit alone.

GENERAL ELECTRIC COMPANY
PROPRIETARY
INFORMATION

5. GE competitive position as supplier of about 80% of the BWR plant offgas system would be harmed to the extent described above.

6. The nature of the damage would be loss of cost advantage from engineering development involved and potential serious inroads in future sales of GE offgas systems.

7. The information contained in the offgas system drawing and process data table is not available from commercial sources and has been protected by GE proprietary stamps and handling for some years.

Glenn G. Sherwood, being duly sworn, deposes and says that he has read the foregoing affidavit and the matters stated therein are true and correct to the best of his knowledge, information, and belief.

Executed at San Jose, California, this 10th day of March, 1978.

Glenn G. Sherwood
General Electric Company

STATE OF CALIFORNIA) ss:
COUNTY OF SANTA CLARA)

Subscribed and sworn before me this 10th day of March 1978

OFFICIAL SEAL
J. PATRICIA MASTERS
NOTARY PUBLIC - CALIFORNIA
SANTA CLARA COUNTY
My comm. expires DEC 9, 1979

NOTARY PUBLIC IN AND FOR
SAID COUNTY AND STATE

rm/105L

OFFICIAL SEAL
J. PATRICIA MASTERS
NOTARY PUBLIC - CALIFORNIA
SANTA CLARA COUNTY
My comm. expires DEC 9, 1979

TABLE I

APPROXIMATE EXPENDITURES FOR THE DEVELOPMENT OF PROPRIETARY GAS SYSTEM INFORMATION IN WNP-2 FSAR

1.	Cost of Offgas System Technology and Development (1968 to 1973)	
a.	German Licensing Cost and Consultation	$ 6,000
b.	Design Study (5 man years)	150,000
c.	Development Support (15 man years)	600,000
	Test Equipment	900,000
d.	Design Development, System and Equipment (15 man years)	450,000
e.	Startup Special Test - Verification of Design Performance	
	Equipment	25,000
	Labor	15,000
	Total Approximate Cost	$2,146,000

rm/105L5

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INFORMATION

TABLE 11.3-3

PROCESS DATA FOR THE OFF-GAS (RECHAR) SYSTEM

Off Gas System - Low Temp.
FCF 239X689AD (N64-1020)

761E918AD
Revision 3

DESIGN BASIS:

100,000 μc/sec modified gas ($\lambda^{0.4}$) mixture after 30 minutes.
$0^{o}F$ charcoal temperature.
30 std cu ft ($60^{o}F$, 1ATM)/min air flow at normal operation.

NOTES:

1. Compressed air used for pre-startup and system purging only. Supply air to be oil free, derived from a non-oil lubricated compressor.
2. Use bypass only for initial plant startup and during period of low fuel leakage.
3. Cascaded drains-no FWD pumping. Condensate shutoff pressure ∿215 PSIG: Design pressure 250 PSIG.
4. Nuclear steam used for normal operation and startup. Size off gas condesner for 105% steam flow.
5. N-16 and 0-19 contents are 1.7×10^{8} and 1.4×10^{6} μc/sec respectively at the reactor nozzle.
6. Charcoal adsorber bed system differential pressure at normal and startup based on 2 parallel adsorber trains each with 4 adsorbers, and each adsorber 4.0' diameter x 19' packed bed with 8 - 14 mesh charcoal.
7. Ejector to be provided to perform against 7.0 PSIG back pressure at cited startup air rate to assure process flexibility. Sub-system differential pressure to be maintained as shown in data sheets.
8. Holdup pipe to be designed for turbulent flow with 10 minute delay of bulk gas at design basis normal flow rate.
9. Supporting document no. 1 shall be used with & form a part of this process data. If there are any conflicts between the process diagram and this process data, the process data shall govern.
10. A total of 2,100 gallons required for making new solution. New solution required less than once every 5 years. At that time the required delivery capacity for refilling the glycol tank is the cited startup flow rate.
11. Water to be removed is about 100 pounds and the reactivation time is about 12 hours.

SUPPORTING DOCUMENTS:

1. Off gas system low temp. process diagram - - - - - - - - - - - - - 761E918.

STREAM NUMBER	1	2	3	4	5	6
STREAM DESCRIPTION	DISCH. FROM INTERMEDIATE STAGE OF SJAE	STEAM DILUTED OFF GAS	PREHEATER DISCHARGE	RECOMBINER DISCHARGE	CONDENSER DISCHARGE	CONDENSER CONDENSATE
NORMAL OPERATION						
Flow Rate, Pounds Per Hour						
Air	138	138	138	138	138	- - -
Hydrogen (Radiolytic Only)	42.9	42.9	42.9	0.01	0.01	- - -
Oxygen (Radiolytic Only)	344	344	344	0.08	0.08	- - -
Water (Or Glycol Solution)	~119	9,319	9,319	9,705.8	14.3	9,691.5
Total -	644	9,844	9,844	9,844	152.4	9,691.5
Flow Rate, Gallons/Minute	- - -	- - -	- - -	- - -	- - -	19.4
Radioactivity μc/sec						
Rare Gases, Krypton & Xenon	$\sim1.27 \times 10^6$	$\sim1.27 \times 10^6$	$\sim1.27 \times 10^6$	$\sim1.27 \times 10^6$	$\sim1.27 \times 10^6$	Negl.
Nitrogen-13 (Note 5)	3.3×10^3	3.3×10^3	3.3×10^3	3.3×10^3	3.3×10^3	Negl.
Temperature, Degrees F.	- - -	~228	350	~830	130	~130
Pressure, PSIA (Note 7)		16.8	16.4	15.9	15.55	15.55
STARTUP OPERATION						
Flow Rate, Pounds/Hour						
Air	1,150.0	1,150.0	1,150.0	1,150.0	1,150.0	- - -
Hydrogen (Radiolytic)	2.1	2.1	2.1	0.08	0.08	- - -
Oxygen	17.2	17.2	17.2	0.64	0.64	- - -
Water	~133	9,333	9,333	9,351.6	90.9	9,260.7
Total -	1,302.2	10,502.3	10,502.3	10,502.3	1,241.6	9,260.7
Temperature, Degrees F	- - -	~228	350	374	130	~130
Pressure, PSIA (Note 7)	- - -	20.8	20.55	20.05	19.7	19.7

STREAM NUMBER	7	8	9	10	11	12
STREAM DESCRIPTION	HOLD-UP PIPE DISCHARGE (NOTE 8)	GLYCOL SOLUTION INLET	GLYCOL SOLUTION DISCHARGE	COOLER CONDENSATE	MOISTURE SEPARATOR DISCHARGE	DRYER DISCHARGE
NORMAL OPERATION						
Flow Rate, Pounds Per Hour						
Air	138	- - -	- - -	- - -	138	138
Hydrogen (Radiolytic Only)	0.01	- - -	- - -	- - -	0.01	0.01
Oxygen (Radiolytic Only)	0.08	- - -	- - -	- - -	0.08	0.08
Water (Or Glycol Solution)	14.3	33,250	33,250	13.5	0.82	0.003
Total -	152.4	33,250	33,250	13.5	138.9	138.1
Flow Rate, Gallons/Minute	- - -	65	65	0.027	- - -	- - -
Radioactivity, μc/sec						
Rare Gases, Krypton & Xenon	$\sim 1.90 \times 10^5$	- - -	- - -	Negl.	$\sim 1.90 \times 10^5$	$\sim 1.90 \times 10^5$
Nitrogen-13 (Note 5)	$\sim 1.7 \times 10^3$	- - -	- - -	Negl.	$\sim 1.7 \times 10^3$	$\sim 1.7 \times 10^3$
Temperature, Degrees F.	∿130	35	36	∿45	45	90
Pressure, PSIA (Note 7)	15.53	95	85	- - -	15.52	15.41
STARTUP OPERATION						
Flow Rate, Pounds/Hour						
Air	1,150	- - -	- - -	- - -	1,150	1,150
Hydrogen (Radiolytic)	0.08	- - -	- - -	- - -	0.08	0.08
Oxygen	0.064	- - -	- - -	- - -	0.64	0.64
Water	90.9	33,250	33,250	85.3	5.6	0.021
Total -	1,244.7	33,250	33,250	85.3	1,156.3	1,150.7
Temperature, Degrees F	∿130	35	40	45	45	90
Pressure, PSIA (Note 7)	19.2	95	85	19.14	18.92	18.3

STREAM NUMBER	13	14	15	22
STREAM DESCRIPTION	CHARCOAL BED FEED	CHARCOAL BED DISCHARGE	BYPASS (NOTE 2)	REFIGERATION AIR
NORMAL OPERATION				
Flow Rate, Pounds Per Hour				
Air	138	138	138	18300
Hydrogen (Radiolytic Only)	0.01	0.01	0.01	- - -
Oxygen (Radiolytic Only)	0.08	0.08	0.08	- - -
Water (Or Glycol Solution)	0.003	0.003	0.003	- - -
Total -	138.1	138.1	138.1	18300
Flow Rate, Gallons/Minute	- - -	- - -	- - -	4000 SCFM (Total for 2 Coolers)
Radioactivity, μc/sec				
Rare Gases, Krypton & Xenon	$\sim 1.90 \times 10^5$	50	(Note 2)	- - -
Nitrogen-13 (Note 5)	1.7×10^3	Negl.	(Note 2)	- - -
Temperature, Degrees F.	-3	0	90	-7
Pressure, PSIA (Note 7)	15.4 (Note 6)	14.8	14.8	- - -
STARTUP OPERATION				
Flow Rate, Pounds/Hour				
Air	1,150	1,150	1,150	~36600
Hydrogen (Radiolytic)	0.08	0.08	0.08	- - -
Oxygen	0.64	0.64	0.64	- - -
Water	0.021	0.021	0.021	- - -
Total -	1,150.7	1,150.7	1,150.7	~36600
Temperature, Degrees F	3	3	90	-7
Pressure, PSIA (Note 7)	17.9 (Note 6)	15.0	15.0	- - -

STREAM NUMBER	16	17	18	19	20	21
STREAM DESCRIPTION	DRYER CHILLER DISCHARGE	REGENERATION BLOWER DISCHARGE	DRYER HEATER DISCHARGE	DRYER DISCHARGE	GLYCOL INLET	GLYCOL DISCHARGE
<u>REGENERATION OPERATION</u>						
Flow Rate, Pounds Per Hour						
Air	736	736	736	736	- - -	- - -
Hydrogen (Radiolytic Only)	0.05	0.05	0.05	0.05	- - -	- - -
Oxygen (Radiolytic Only)	0.41	0.41	0.41	0.41	- - -	- - -
Water (OR Glycol Solutiion)	~3.2	~3.2	~3.2	5~130 (Note 11)	33,250	33,250
Total -	740	740	740	740~870	33,250	33,250
Flow Rate, Gallons/Minute	- - -	- - -	- - -	- - -	65	65
Temperature, Degrees F	45	45	425	45~425	35	37
Pressure, PSIA (Note 7)	21.0	21.7	21.6	21.3	- - -	- - -

UTILITY STREAM NUMBER	1	2	3	4	5	6
STREAM DESCRIPTION	DILUTION STEAM (NOTE 4)	AIR BLEED (NOTE 1)	PREHEATER STEAM (NOTE 4)	REACTOR CONDENSATE	DILUTION CONDENSATE	COOLING WATER
NORMAL OPERATION						
Flow Rate, Pounds Per Hour						
Air	---	28	---	---	---	---
Hydrogen (Radiolytic Only)	---	---	---	---	---	---
Oxygen (Radiolytic Only)	---	---	---	---	---	---
Water (Or Glycol Solution)	9,200	---	742	14.3×10^6	---	35,000
Total -	9,200	28	742	14.3×10^6	---	35,000
Flow Rate, Gallons/Minute	---	---	---	3.2×10^4	---	70
Radioactivity, μc/sec						
Rare Gases, Krypton & Xenon	---	---	---	---	---	---
Nitrogen-13 (Note 5)	---	---	---	---	---	---
Temperature, Degrees F	338	70	460	108.7	---	110
Pressure, PSIA (Note 7)	114.7	25 (Supply Pressure)	265	193 (Note 3)	---	~65
STARTUP OPERATION						
Flow Rate, Pounds/Hour						
Air	---	276	---	---	(Note 10)	---
Hydrogen (Radiolytic)	---	---	---	---	---	---
Oxygen (Radiolytic)	---	---	---	---	---	---
Water	9,200	---	753	5.48×10^6	25,000	52,500
Total -	9,200	276	753	5.48×10^6	25,000	52,500
Temperature, Degrees F.	338	70	406	~110	~85	105
Pressure, PSIA (Note 9)	114.7	25	265	176	~45	~65

LINE SIZING SUMMARY

P&ID LINE NO.	ESTIMATED NOMINAL PIPE DIAMETER (INCHES)	ALLOWABLE EQUIVALENT PIPE LENGTH (FEET)	
1	16	500	
2	1 1/2	200	
3	16	50	
4	16	100	
5	TO BE SIZED BY AE		
6	6	100	
7	14	400[1]	
8	4	10	
9	3	200	
10	3	200	
11	3	200	
12	3	200	
13	4	10	
14	4	50	
15	6	400	
16	6	100	
17	6		
18	6	100	
19	6		
20	4		
21	4		TOTAL FOR
22	4	200	ALL LINES/TRAIN
23	4		
24	- -	- -	
25	- -	- -	
26	6	100	
27	6	100	
28	4	50	
29	6	1000	
30	4	100	
33	6	100	
37	3	200	
38	3	200	
39	3	200	
40	3	200	
41	3	200	
42	3	50	
43	3	50	
44	4	50	
45	3	20	

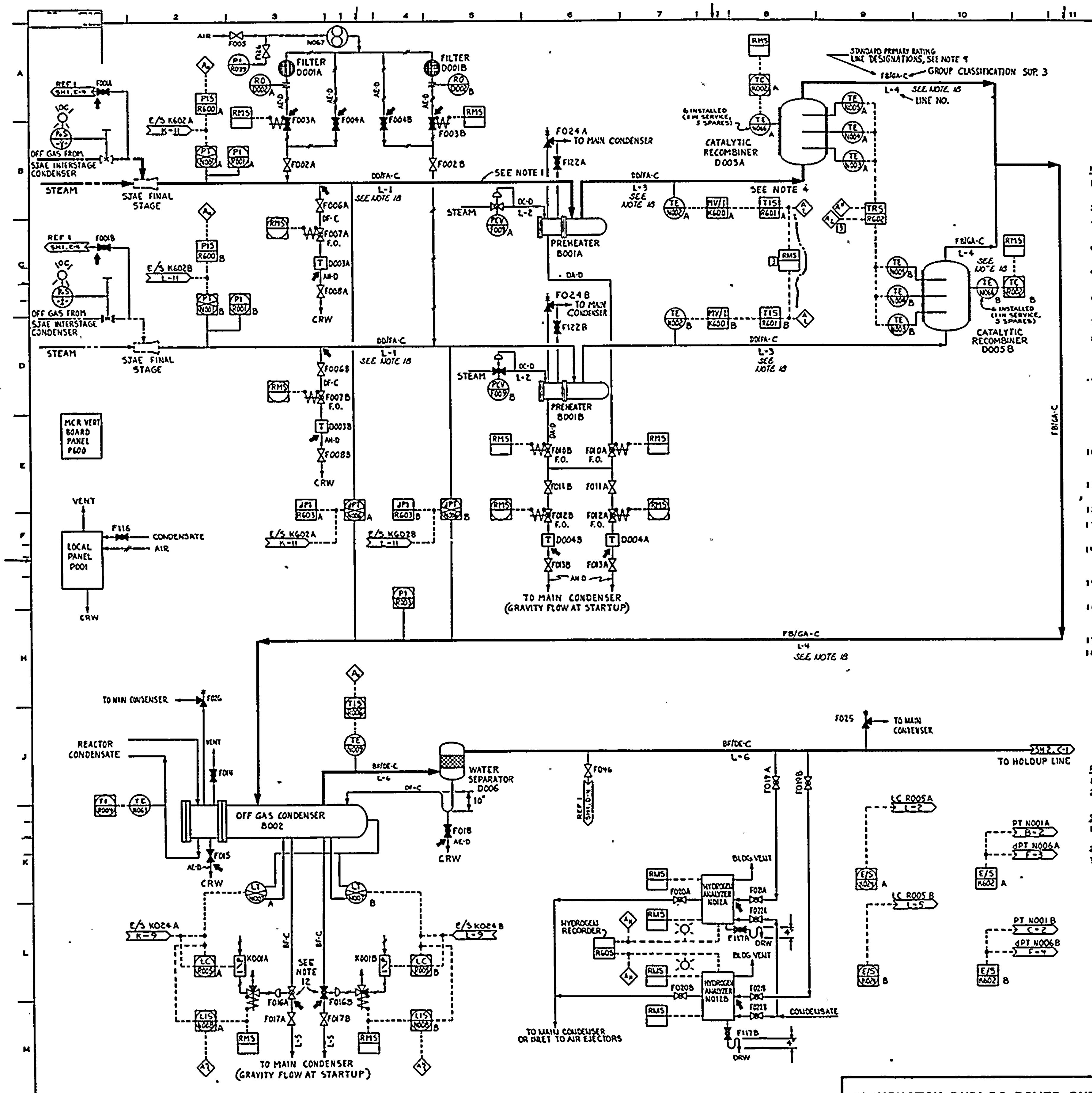
1 ACTUAL LENGTH

NOTE:

EXCEPT FOR ACTUAL LENGTH CITED, THIS LINE SIZING COMPLETES A TRAIL PRESSURE DROP BALANCE FOR THE SYSTEM. CONCERNING DEVIATIONS IN CONSTRUCTION, SEE NOTE 7 PAGE 1.

EQUIPMENT DESIGN CONDITION SUMMARY

PART NO.	ITEM	PROCESS GAS SIDE Δ P AT 250 SCFM (PSI)	EQUIPMENT DESIGN PRESSURE (PSIG)		EQUIPMENT DESIGN TEMPERATURE (°F)	
			SHELL	TUBE	SHELL	TUBE
N64-B001	PREHEATER	0.15	350	1000	450	575
N64-D005	CATALYTIC RECOMBINER	0.47	350		900	
			SHELL	TUBE	SHELL	TUBE
N64-B002	OFF GAS CONDENSER	0.30	350	250	900	150
N64-D006	WATER SEPARATOR	0.044	350		250	
			SHELL	TUBE	SHELL	TUBE
N64-B010	COOLER CONDENSER	0.11	350	100	32/150	32/150
N64-D010	MOISTURE SEPARATOR	0.044	350		32/150	
N64-D011	PREFILTER	0.14(DIRTY)	350		-50/150	
N64-D030	DESICCANT DRYER (WITH DESICCANT-D033)	0.22(INCLUDES VALVES Z002-8 & Z002-15 & LINE L-16)	350		32/500	
N64-B011	GAS COOLER	0.22	1050		-50/250	
N64-D012,D013, D014,D015	CHARCOAL ADSORBERS (WITH ACTIVATED CARBON-D021)	2.50/4 BED TRAIN	350		-50/250	
N64-D016	AFTER FILTER	0.14(DIRTY)	350		-50/150	



PROPRIETARY INFORMATION NOTICE

NOTES:

1. INSULATED PIPING FROM STEAM JET AIR EJECTORS UP TO OFF GAS CONDENSER & FROM COOLER CONDENSER TO CHARCOAL VAULT.
2. PREFILTERS TO BE LOCATED CLOSE TO CHARCOAL ADSORBERS.
3. MOISTURE SEPARATORS CAN BE INTEGRAL PARTS OF COOLER CONDENSERS.
4. PIPE FROM AIR EJECTOR TO BE SLOPED SO CONDENSATE CAN BE DRAINED AND NOT ENTER RECOMBINER.
5. AFTER VALVE CLOSES IT SHALL REMAIN CLOSED UNTIL RESET BY MANUAL SWITCH.
6. SMOKE INJECTION EQUIP. OF STANDBY GAS TREATMENT SYS TO BE USED FOR FILTER TESTING. (USE HANSEN COUPLINGS).
7. INSULATE ALL GLYCOL TRANSFER LINES.
8.
9. THOSE LINES WITH TWO PRESSURE-TEMPERATURE INTEGRITY CLASSIFICATIONS SHALL CONFORM TO THE LOWER CLASSIFICATION IN STRAIGHT PIPE RUNS & SHALL CONFORM TO THE HIGHER CLASSIFICATION AT ALL STRAIGHT RUN ENDS. A STRAIGHT RUN END INCLUDES BENDS. VALVES AND ANY DISCONTINUITY REDUCING THE DIAMETER 5% OR MORE. THE END SHALL INCLUDE THE LAST TEN FEET OF LINE TO SUCH END OR DISCONTINUITY.
10. THE HOLD-UP PIPE SHALL BE SIZED TO PRODUCE TURBULENT FLOW UNDER THE NORMAL OPERATING CONDITIONS LISTED IN THE PROCESS DATA.
11. ALL VENTS, DRAINS & INSTRUMENT LINES ARE 1" UNLESS OTHERWISE SPECIFIED. GAS SAMPLE LINES ARE 1/4".
12. THESE VALVES TO BE LOCATED PHYSICALLY CLOSE TO THE MAIN CONDENSER TO MINIMIZE THE EFFECT OF FLASHING.
13.
14. OPERATED VALVES ARE SHOWN IN THEIR POSITION FOR NORMAL OPERATION, AS OPPOSED TO "SHELF" OR "FAILED" POSITION. VALVES WILL FAIL CLOSED UNLESS OTHERWISE NOTED
15. PUMPS SHALL HAVE RUNNING LIGHTS AND OPERATED VALVES SHALL HAVE POSITION INDICATING LIGHTS LOCATED WITH THE RMS.
16. VAULT COOLERS & PIPING WILL BE SLOPED TO DRAIN MOISTURE OUT THE DRAIN ON THE INLET LINE. (DRAIN TO BE LOCATED OUTSIDE THE REFRIGERATED VAULT).
17. LINES TO SLOPE TOWARDS FILTER DRAINS.
18. IF L/D RATIO OF THIS LINE <7.0, DECREASED DESIGN PRESSURE PERMITS USE OF SCH. 40 PIPING AND 600 LB. ANSI-RATED FLANGES.

REFERENCE DOCUMENTS:	MPL ITEM NO.
1. PROC RAD MON SYS IED	D17-1010
2. REGENERATOR PUR PART DWG	N64-Z002

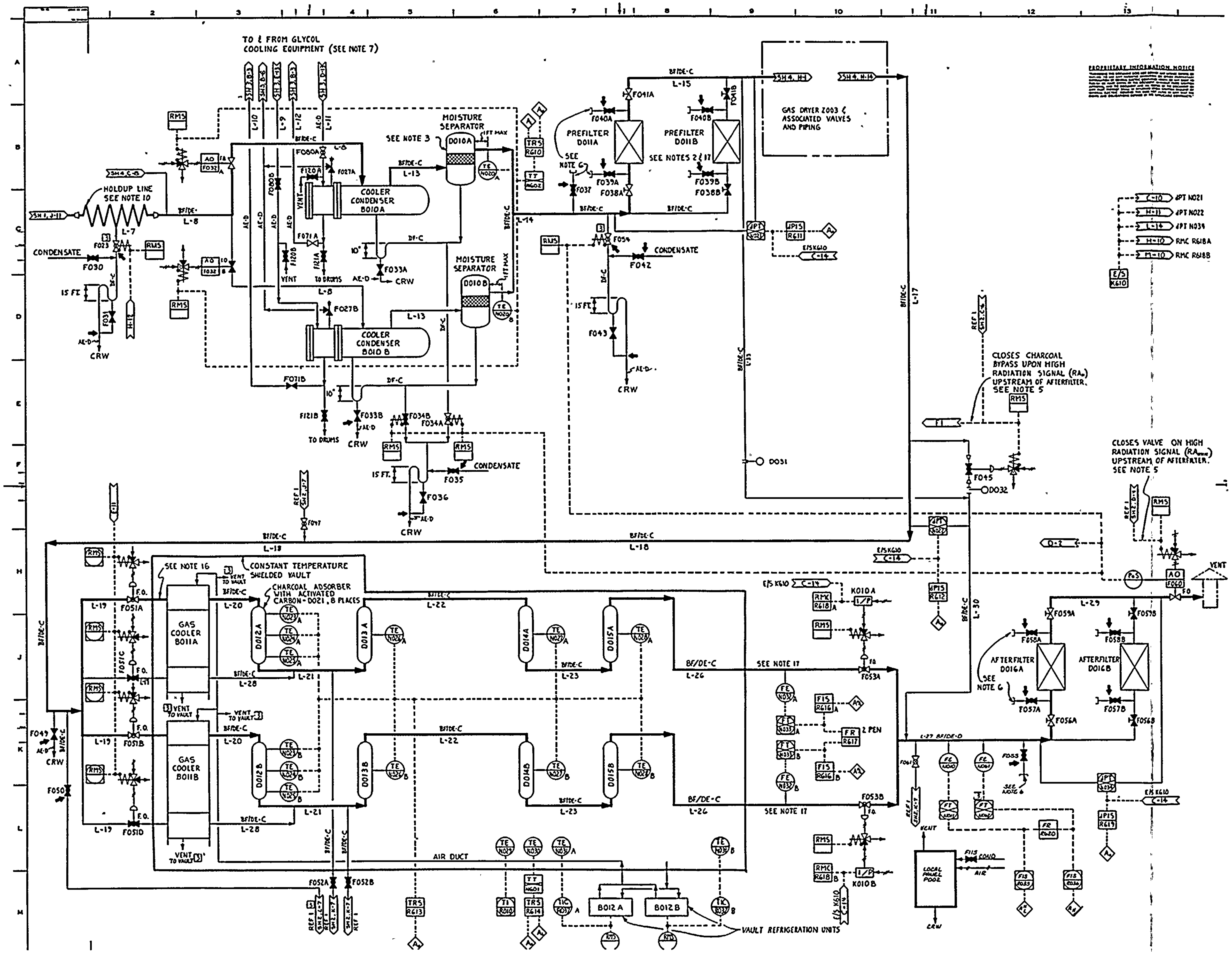
SUPPORTING DOCUMENTS:

1. PRESS. INTEGRITY OF PIPING EQUIP. PRESSURE RATING - - - A62-4030
2. PIPING & INSTRUMENT SYMBOLS - - - A42-1010
3. GROUP CLASSIFICATION - - - A62-1010

WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

OFF GAS SYSTEM-LOW TEMPERATURE

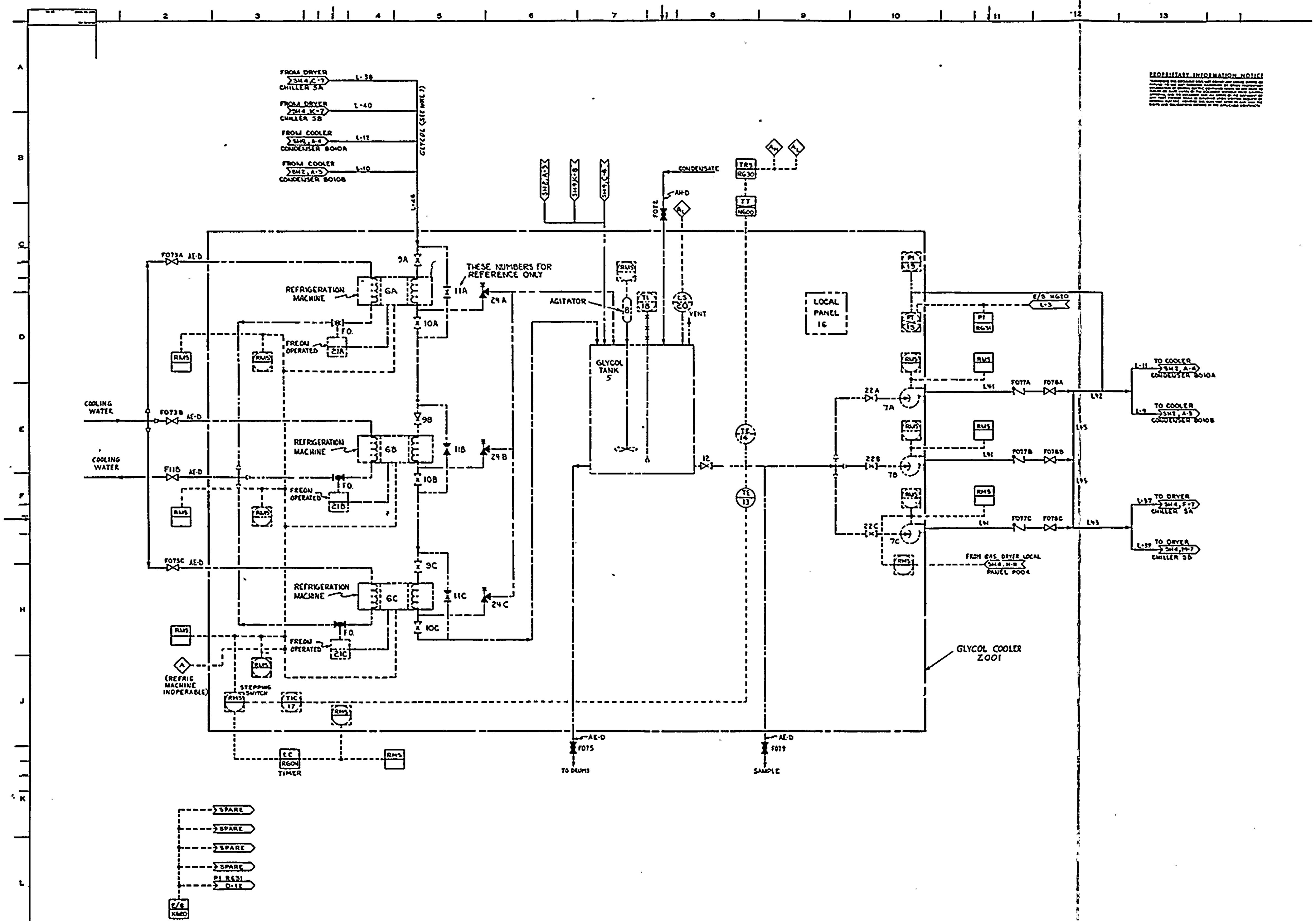
FIGURE 11.3-2a



WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

OFF GAS SYSTEM-LOW TEMPERATURE

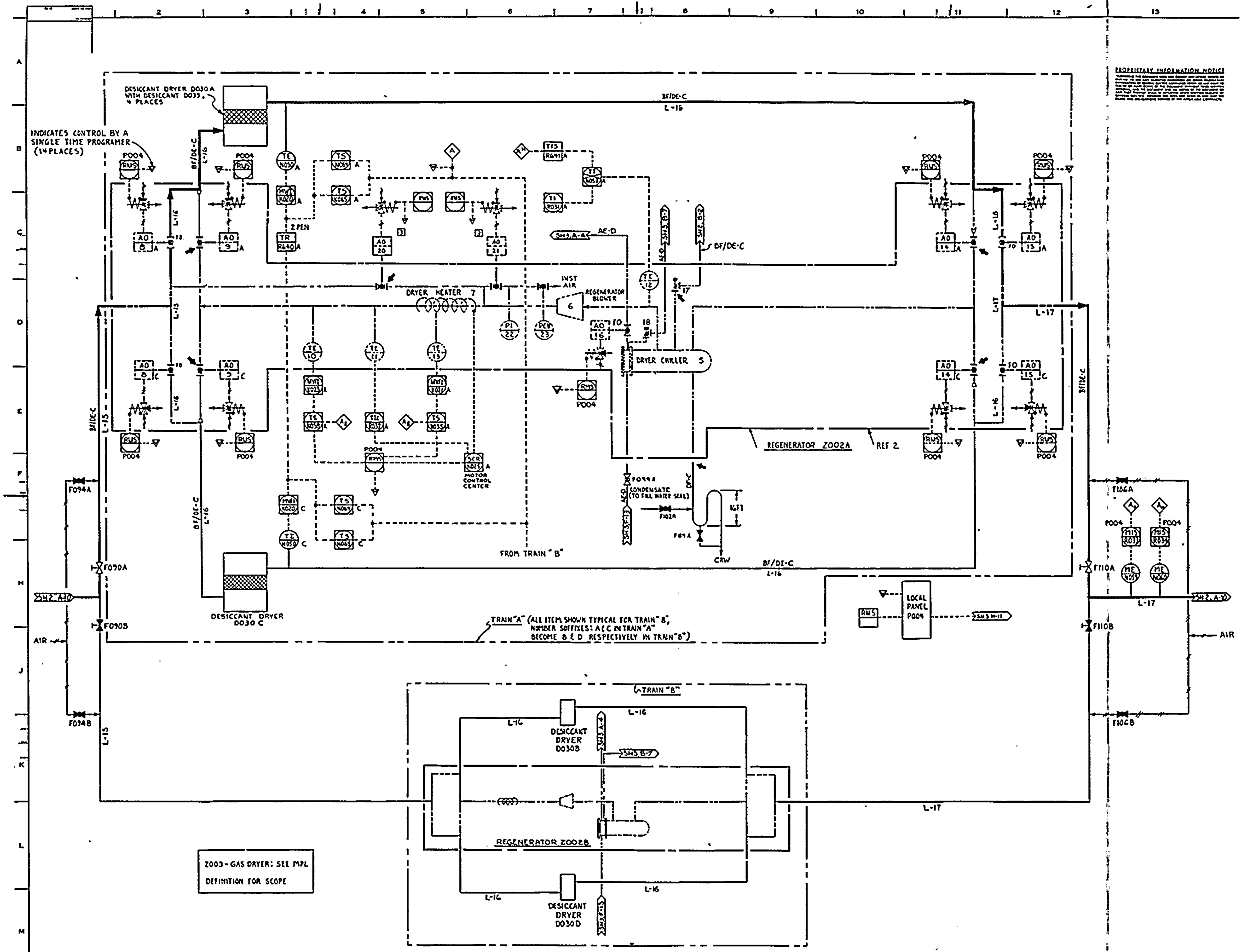
FIGURE 11.3-2b



WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

OFF GAS SYSTEM-LOW TEMPERATURE

FIGURE 11.3-2c



WASHINGTON PUBLIC POWER SUPPLY SYSTEM NUCLEAR PROJECT NO. 2	OFF GAS SYSTEM-LOW TEMPERATURE	FIGURE 11.3-2d

NS = NOT SHOWN

ITEM NO. N64-	ZONE LOCATION
B001A	SH 1,C-6
B001B	D-6
B002	K-3
B010A	SH 2,C-5
B010B	D-5
B011A	J-2
B011B	K-2
B012A	H-7
B012B	H-8
D001A	SH 1,A-3
D001B	A-5
D002A	A-3
D002B	A-5
D003A	C-3
D003B	E-3
D004A	F-6
D004B	F-6
D005A	B-8
D005B	C-10
D006	J-5
D010A	SH 2,B-6
D010B	D-6
D011A	B-7
D011B	B-9
D012A	J-3
D012B	K-3
D013A	J-4
D013B	K-4
D014A	J-6
D014B	K-6
D015A	J-7
D015B	K-7
D016A	J-12
D016B	J-13
D021	SH 2,J-3
D030A	SH 4,B-3
D030B	J-7
D030C	H-3
D030D	L-7
D031	SH 2,F-9
D032	SH 2,F-11
D033	SH 4,B-2
F001A	SH 1,A-1
F001B	C-1
F002A	B-3
F002B	B-5
F003A	A-3
F003B	A-5
F004A	A-4
F004B	A-4
F005	A-3
F006A	B-3
F006B	D-3
F007A	C-3
F007B	D-3
F008A	C-3
F008B	E-3
F009A	B-5
F009B	D-5
F010A	E-6
F010B	E-6
F011A	E-6
F011B	E-6
F012A	F-7
F012B	F-7
F013A	F-6
F013B	F-6
F014	J-2
F015	K-2
F016A	L-3
F016B	L-3

ITEM NO. N64-	ZONE LOCATION
F017A	SH 1,H-3
F017B	H-3
F018	K-5
F019A	J-8
F019B	J-8
F020A	K-7
F020B	L-7
F021A	K-8
F021B	L-8
F022A	L-8
F022B	H-8
F023	SH 2,C-2
F024A	SH 1,C-5
F024B	D-5
F025	J-9
F026	H-2
F027A	SH 2,B-4
F027B	D-4
F030	C-1
F031	D-1
F032A	B-3
F032B	C-3
F033A	C-5
F033B	E-4
F034A	E-5
F034B	E-5
F035	F-5
F036	F-5
F037	B-7
F038A	B-8
F038B	B-9
F039A	B-7
F039B	B-8
F040A	B-7
F040B	B-8
F041A	A-8
F041B	A-9
F042	C-8
F043	D-7
F045	F-12
F046	SH 1,J-6
F047	SH 2,F-4
F049	K-1
F050	L-1
F051A	H-2
F051B	K-2
F051C	J-2
F051D	L-2
F052A	H-4
F052B	H-4
F053A	J-10
F053B	L-10
F054	C-7
F055	K-12
F056A	K-12
F056B	K13
F057A	J-12
F057B	J-13
F058A	J-12
F058B	J-13
F059A	H-12
F059B	H-13
F060	H-14
F061	K-11
F071A	SH 2,C-4
F071B	SH 2,E-4
F072	SH 3,C-8
F073A	C-2
F073B	E-2
F073C	H-2
F075	J-6
F077A	SH 3,E-11
F077B	E-11
F077C	F-11
F078A	E-12
F078B	E-12
F078C	F-12
F079	J-9
F080A	SH 2,B-4
F080B	SH 2,B-3
F090A	SH 4,H-1
F090B	H-1
F094A	F-1
F094B	J-1

ITEM NO. N64-	ZONE LOCATION
F099A	SH 4, F-7
F099B	NS
F102A	SH 4, F-8
F102B	NS
F106A	SH 4, F-13
F106B	SH 4, J-13
F110A	SH 4, H-13
F110B	SH 4, H-13
F115	SH 2, L-12
F116	SH 1, F-1
F117A	SH 1, L-8
F117B	SH 1, H-8
F118	SH 3, F-2
F119A	SH 4, F-8
F119B	NS
F120A	SH 2, B-4
F120B	C-4
F121A	C-4
F121B	E-4
F122A	SH 1,B-6
F122B	SH 1,D-6
F126	SH1, A- 3
K001A	SH 1, L-3
K001B	SH 1, L-4
K010A	SH 2, H-10
K010B	SH 2, L-10
K020A	SH 4, C-3
K020B	NS
K020C	F-3
K020D	NS
K021A	E-5
K021B	NS
K023A	E-4
K023B	NS
K024A&B	SH 1, K-9&L-9
K025A	SH 4, F-6
K025B	NS
K600A	SH 1, B-8
K600B	SH 1, C-8
K602A&B	SH 1, K-10&L-10
K610	SH 2, C-13
K620	SH 3, L-2
N001A	SH 1, B-2
N001B	C-2
N002A	B-7
N002B	C-7
N003A	B-9
N003B	D-9
N004A	B-9
N004B	C-9
N005A	A-9
N005B	C-9
N006A	E-4
N006B	E-5
N007A	K-3
N007B	K-4
N008A	H-2
N008B	H-4

ITEM NO. N64-	ZONE LOCATION
N009	SH 1,J-4
N010	SH 2 K-11
N011	L-11
N012A	SH 1, K-8
N012B	L-8
N020A&B	SH 2,B-6& D-6
N021	C-9
N022	F-11
N023A	H-4
N023B	K-4
N024A	J-4
N024B	K-4
N025A	J-4
N025B	L-4
N026A	J-5
N026B	K-5
N027A	J-7
N027B	K-7
N028A	J-8
N028B	K-8
N029	L-6
N030	L-6
N031A&B	L-7&L-9
N032A	J-9
N032B	K-9
N033A	K-9
N033B	K-9
N034	K-13
N050A	SH 4,B-3
N050B	NS
N050C	H-3
N050D	NS
N053A	B-7
N053B	NS
N055A	E-5
N055B	NS
N058A	E-4
N058B	NS
N059	H-13
N060	H-13
N061	SH 2, K-12
N062	L-12
N063	SH 1,J-2
N064A&C	SH 4,B-4&F-4
N064B&D	NS
N065A&C	C-4&H-4
N065B&D	NS
N066A&B	SH 1, A-8&C-10
N067	SH 1, A-4
N600	SH 3, C-8
N601	SH 2, M-6
N602	SH 2, B-7
P001	SH 1, F-1
P002	SH 2, L-11
P004	SH 4, H-11
P600	SH 1, E-1
R001A	SH 1,B-3
R001B	C-3
R002A	A-8
R002B	C-11
R003	F-4
R004	J-1
R005A	L-2
R005B	L-4
R006	H-4
R010	SH 2,M-6
R031A	SH 4,C-6
R031B	NS
R032A	E-4
R032B	NS
R033	F-13
R034	F-13
R035	SH 2,M-12
R036	SH 2,M-12
R037A&B	SH 2,M-7&M-9
R039	SH 1, A-3
R600A&B	SH 1, A-2 & C-2
R601A	B-8
R601B	D-8
R602	B-9
R603A	E-3
R603B	E-4
R604	SH 3, K-3
R605	SH 1,L-6

ITEM NO N64-	ZONE LOCATION
R610	SH 2,B-6
R611	C-9
R612	H-11
R613	H-5
R614	H-6
R616A	J-10
R616B	K-10
R617	K-10
R618A	H-10
R618B	L-10
R619	L-13
R620	SH 2,L-2
R630	SH 3,B-8
R631	SH 3,D-11
R640A	SH 4,C-3
R640B	NS
R641A	SH 4,B-6
R641B	NS
Z001	SHEET 3
Z002A & B	SHEET 4
Z003	SH 4,L-3

PROPRIETARY INFORMATION NOTICE

WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

OFF GAS SYSTEM-LOW TEMPERATURE

FIGURE 11.3-2e