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MARK I CONTAINMENT PROGRAM COMPARISON OF GE AND EPRI TORUS LOAD TEST RESULTS

TASK NUMBER 5.10

NUCLEAR SERVICES CORPORATION

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ABSTRACT

In this report comparisons of subscale pool swell test results from the General Electric 1/4 Scale two dimensional (2D) Test Facility and the Electric Power Research Institute 1/12 Scale three dimensional (3D) Test Facility are presented. The parameters compared include maximum upload, maximum download and peak pressure distribution. These comparisons lead to the conclusion that the 2D test facility yields maximum uploads and downloads which equal or exceed those measured in the 3D facility within the range of Mark I drywell pressurization rates.

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1. INTRODUCTION

This report presents a comparison of pool swell test results from the General Electric (GE) 1/4 Scale two dimensional (2D) (Ref. 1) and the Electric Power Research Institute (EPRI) 1/12 Scale three dimensional (3D) (Ref. 2) test facilities. Both facilities were modeled after the Browns Ferry containment design. Test results from the facilities are presented in full-scale values to identify the degree of consistency and to evaluate any differences in the data that might exist between the 3D and the 2D test facilities.

The Mark I GE 1/4 Scale pool swell tests were conducted under the Long Term Program Task 5.5. Hydrodynamic scaling relationships for pool swell were validated in Subtask 5.5.1 by direct comparison of 1/4 Scale data with results from GE's Twelfth Scale Test Facility. Both facilities model an average cell* of the Browns Ferry torus and are considered 2D models. Both include a 7.5° segment of the torus encompassing one pair of downcomers. The facilities are equivalent geometrically, but not in scale.

Similar subscale investigations of Mark I pool swell hydrodynamic loads have been conducted by EPRI. The EPRI facility is a 1/11.7 scale (referred to as 1/12 scale) straight cylindrical section, which is equivalent to a 90° segment of a Mark I torus, containing twelve pairs of downcomers. This is considered a 3D model.

The comparison of test results considered in this report includes the magnitude of measured torus loads in the GE 1/4 Scale and the EPRI 1/12 scale facilities, and the resulting 3D/2D load factors and load sensitivities to drywell pressurization rate. The report also includes a description of the test facilities and their data

* An average cell is defined as the axial centerline distance in a torus bay divided by the total number of downcomer pairs in the bay.

acquisition systems, a check of each facility's conformance to the prototype plant configuration and a summary of test conditions for each facility.

2. SUMMARY

Comparisons of pool swell test results from the GE 1/4 Scale 2D and EPRI 1/12 Scale 3D test facilities are presented in this report. Test results from the two subscale facilities are presented in full-scale values to identify the degree of consistency and to evaluate any differences in measured loads that may exist between them. For the comparison, the load data was converted to force per unit area.

From this study it was found that the peak download per unit area for the facilities had an approximately linear correlation with the drywell pressurization rate ($\dot{P}$). However, the relationship between the peak upload per unit area and the drywell pressurization rate was not linear for either the GE or EPRI data. The uploads peaked out between 50 and 70 psi/sec and then decreased with an increase of the $\dot{P}$.

The data base used in this study was selected so that the driving conditions and the initial test conditions used in the test facilities were the same, or nearly the same, when scaled to full-scale values. For the GE 1/4 Scale, test data were taken for full ΔP, 40 in. submergence at four different drywell pressurization rates (14.8, 29, 56, 98 psi/sec). For the EPRI 1/12 scale facility, test data were taken for the full ΔP, 40 in. downcomer submergence at 28, 58.1, 90 psi/sec $\dot{P}$ values. All test series numbers used in this report from each facility are identified in corresponding tables in Section 4.

A comparison of the 1/4 Scale 2D data with the EPRI 1/12 Scale 3D data reveals that the peak downloads and uploads per unit area of the two facilities show very good agreement at the "medium" drywell pressurization rate of 56 psi/sec. The highest drywell pressurization rate for BWR 3, 4 and 5 in Mark I containments ranges from 46.1 to 74.7 psi per second. At 28 psi/sec ("low" drywell pressurization rate), the EPRI 3D peak download and upload were lower than the GE 1/4 Scale 2D loads. At 90 psi/sec ("high" pressurization rate) the 3D peak download was lower than that of the 2D load and the 3D peak upload was slightly higher than the 2D upload.

The radial (azimuthal) pressure distribution under the downcomer vents for the 1/4 Scale tests lies in between the 1/12 Scale radial pressure distribution at planes X/L=0 (under main vent pipe) and X/L=0.90 (under downcomer vents) where X/L is defined in Figure 4-13.

3. FACILITIES AND DATA ACQUISITION SYSTEMS

Key features of the facility designs and data acquisition systems used in the two subscale test programs are presented and compared in this section.

3.1 Comparison of Facility Designs

Facility designs of the GE 1/4 Scale and the EPRI 1/12 Scale test facilities are compared, with each parameter scaled to the full-scale value. The scaling relationships are given in Appendix A. Results of the comparison are presented in Table 3-1.

The fundamental frequencies given in Table 3-1 correspond to the lowest vertical frequency of the facilities. They indicate that the facility structures have approximately the same vertical stiffness.

3.2 Comparison of Data Acquisition Systems

The sensor locations used for the GE 1/4 Scale torus load measurements are given in Figure 3-1 (Ref. 1). A list of the instrumentation including type of measurement, range, sampling rate and filter settings are given in Tables 3-2 and 3-3.

Table 3-4 and Figure 3-2 (Ref. 2) describe the instrumentation and sensor locations used in the EPRI test facility.

As indicated in Table 3-2, the sampling rate and filter frequency for the GE 1/4 Scale torus load measurements were 500 samples per second and 300 Hz for the pressure transducers, respectively,

except for the vent differential pressure transducer and the upstream air temperature thermocouple, in which the filter frequency was 100 Hz. For the torus and vent header load cells, the sampling rate and filter frequency were 1,000 and 2,500 samples per second and 300 and 1,000 Hz, respectively. For the torus and vent header accelerometers, the corresponding sampling rate and filter frequency were 1,000 and 2,500 samples per second and 300 and 1,000 Hz, respectively. As indicated in Table 3-4, the sampling rate and filter frequency for the EPRI 1/12 Scale facility were 1000 samples per second and 2,000 Hz, respectively, for load cells and accelerometers. For the pressure transducers, the sampling rate was 1,000 samples per second.

TABLE 3-1

COMPARISON OF FACILITY DESIGNS AND HYDRODYNAMIC CONDITIONS FOR WHICH DATA IS PRESENTED

	GE 2-D		EPRI 3-D	
	1/4-SCALE	FULL-SCALE	1/11.7-SCALE	FULL-SCALE
1. Downcomer Water Submergence, in.	10 Nom.	40	3.42 Nom.	40
2. Torus I.D., ft.	7.75	31.0	2.65	31.0
3. Total Torus Wetwell Air Volume, ft^3	42.7	2,733	21.03	33,954 (2,742)*
4. Projected Pool Area at Water Level, ft^2 (Minus Vent Downcomer Outside Areas)	13.66	218.56	18.33	2,509 (202.6)*
5. Projected Torus Area at Equator, ft^2 (Minus Vent Downcomer Outside Areas)	13.69	219.04	19.72	2,699 (218.0)*
6. Total Vent Area (Based on Downcomer I.D.), ft^2	0.36	5.76	0.53	72.55 (5.86)*
7. Vent Header O.D., in.	15.0	60.0	5.0	58.5
8. Distance from Water Level to Bottom of Vent Header, in.	13.14	52.56	4.57	53.47
9. $\frac{\text{Pool Area at Water Level}}{\text{Vent Area}}$	37.94	37.94	37.20	37.20
10. $\frac{\text{Torus Air Volume}}{\text{Torus Projected Area}}$, ft	3.12	12.48	1.075	12.58
11. Torus Shell Thickness, in.**	0.25	1.00	---	---
12. Wetwell length, in.	21.8	87.2	91.52	1,079.8
13. fL/D, Vent Resistance****	20.3	5.08	67.04	5.73
14. Orifice Location	DOWNCOMER MAIN VENT	---	DOWNCOMER	---
15. Type of Test Initiation	QUICK OPENING VALVE	---	RUPTURE DISK	---
16. Torus Fundamental Vertical Frequency, Hz***	51	25	79	23

*Equivalent 7.5° - Sector Value

**Stiffness also dependent on webs

***Lowest vertical frequency

****Tests also conducted in both facilities to evaluate sensitivity to fL/D and orifice placement

Table 3-2

1/4 SCALE TEST INSTRUMENTATION

Reference Number	Measurement	Transducer Range	Sample Rate (Hz)	Filter Frequency (Hz)	Transducer Manufacturer
1	Orifice Upstream Pressure	0-100 psia	500	300	Sensometrics
2	Drywell Pressure	0-50 psia	500	300	" "
3	Drywell Pressure	0-50 psia	500	300	" "
4	Torus Air Pressure	0-50 psia	500	300	" "
5	Torus Air Pressure	0-50 psia	500	300	" "
6	Vent Differential Pressure	0-10 psia	500	100	Sensotec
7	Upstream Air Temperature	0-500 °F	500	100	Aerotherm
8	Downcomer Pressure	0-50 psia	500	300	Sensometrics
9	Torus Water Pressure 180°	0-50 psia	500	300	" "
10	Torus Water Pressure 180°	0-50 psia	500	300	"
11	Torus Water Pressure 195°	0-50 psia	500	300	" "
12	Torus Water Pressure 195°	0-50 psia	500	300	" "
13	Torus Water Pressure 210°	0-50 psia	500	300	" "
14	Torus Water Pressure 210°	0-50 psia	500	300	" "
15	Torus Water Pressure 225°	0-50 psia	500	300	" "
16	Torus Water Pressure 225°	0-50 psia	500	300	" "
17	Torus Water Pressure 240°	0-50 psia	500	300	" "
18	Torus Water Pressure 240°	0-50 psia	500	300	" "
19	Torus Load Cell	25,000 lbf	1000	300	Interface
20	Torus Vertical Acceleration	± 1g*	1000	300	Endevco
21	Vent Header Load Cell	10,000 lbf	2500	1000	Interface
22	Vent Header Acceleration	± 10g*	2500	1000	Endevco
23	Vent Header Acceleration	± 10g*	2500	1000	Endevco

*Piezo-electric accelerometers, with an adjustable range.

Table 3-3

1/4 SCALE ACCELEROMETER SPECIFICATIONS

VENT HEADER

Acceleration Range	± 10g
Natural Frequency	> 10,000 Hz (undamped accelerometer)
Frequency Response	1 Hz to 3,000 Hz (±5%)
Resolution	0.002g
Noise (including amplifier)	0.1g
Type	piezo - electric

TORUS

Acceleration Range	± 1.0g
Natural Frequency	> 1,000 Hz (undamped accelerometer)
Frequency Response	1 Hz to 1,000 Hz (±5%)
Resolution	0.01g
Noise (including amplifier)	0.01g
Type	piezo - electric

TABLE 3-4

EPRI MARK I

1/12 SCALE INSTRUMENTED TESTS

Instrument Channel No.**	Instrument Identification	Type of Measurement	Location	Instrument Range	Filter
1	p1	p	Vent pipe plane: 186°	0-200 psi	
2	p3	p	Vent pipe plane: 240°		
3	p20	p	Vent pipe plane: 250°		
4	p21	p	Vent pipe plane: 260°		
5	p22	p	Vent pipe plane: 270°		
6	p8	p	Downcomer plane: 186°		
7	p10	p	Downcomer plane: 240°		
8	p11	p	Downcomer plane: 250°		
9	p12	p	Downcomer plane: 260°		
10	p23	p	Downcomer plane: 270°		
11	p5	p	Unit cell axis: x/L = 0.33		
12	p6	p	Unit cell axis: x/L = 0.52		
13	p18	p	Wetwell airspace: 350°		
14	Pulse	V			
15	Drywell	Sp	Drywell	± 25 psid	2kHz
16	TLC	L	Ringheader load cells	± 25,000 lbf	
17	BLC	L	Torus load cells	± 5,000 lbf	
18	Temperature probe	T	Right vent pipe		
19	---				
20	$\ddot{y}_1$	A	Bottom spar at load cell 3	± 250g	2kHz
21	$\ddot{y}_2$	A	Top spar at load cell 4	± 250g	"
22	p17	p	Downcomer 3 exit	0-200 psi	
23	p2	p	Vent pipe plane: 210°		
24	p9	p	Downcomer plane: 210°		
25	p8	Sp	Supply tank*		
26	---				
27	---				
28	Pulse	V			

p = pressure, piezoelectric
Sp = pressure, strain gage
V = voltage step
L = load
T = temperature
A = acceleration

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*The supply tank pressure transducer was added during the four tests in which the drywell was charged from a pressurized supply tank.

** A/D Rate is 1,000S/S for all channels

TEST INSTRUMENTATION (Series 5.5.3-1)

Pressure Transducer

Accelerometer

Load Cell

Differential Pressure Transducer

Thermocouple

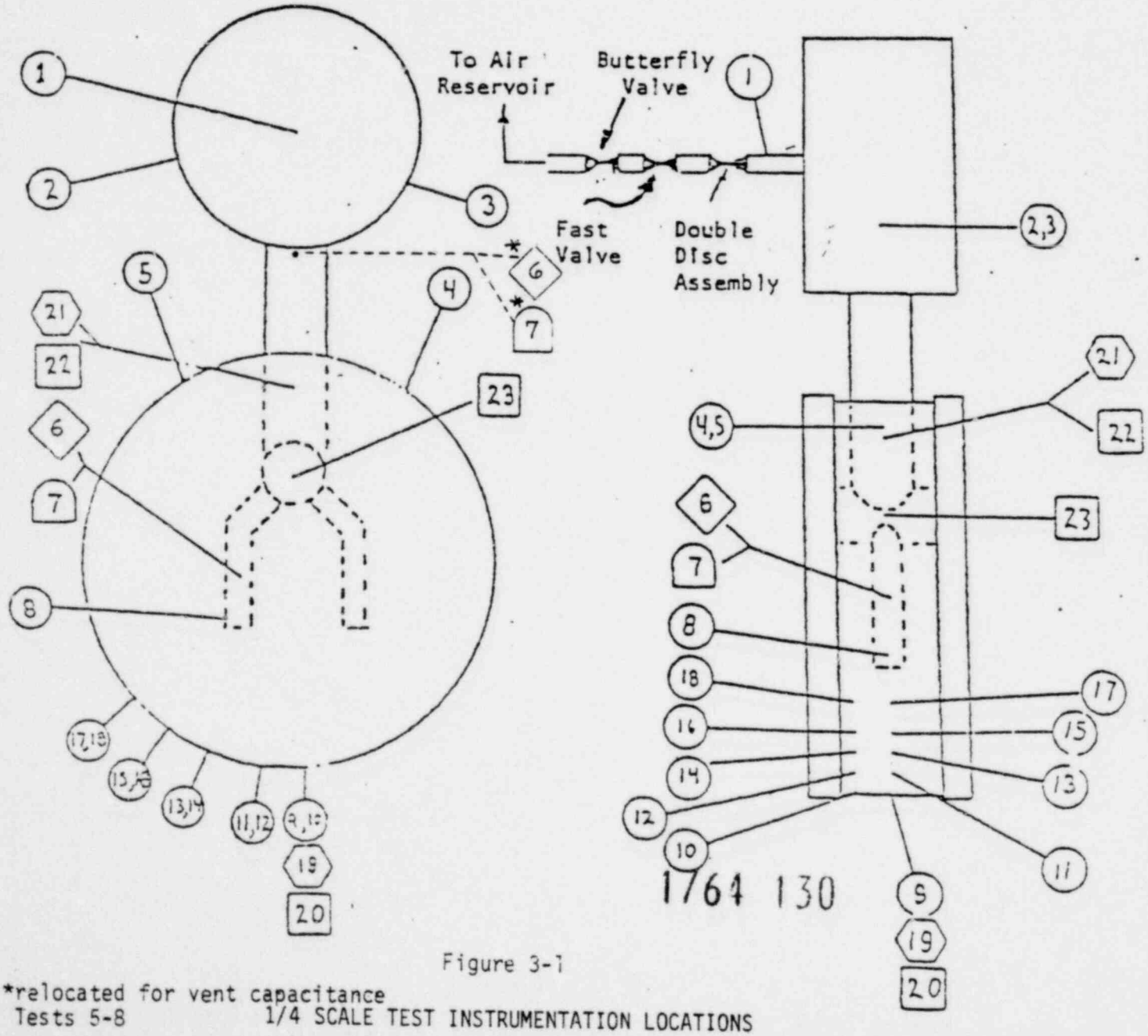
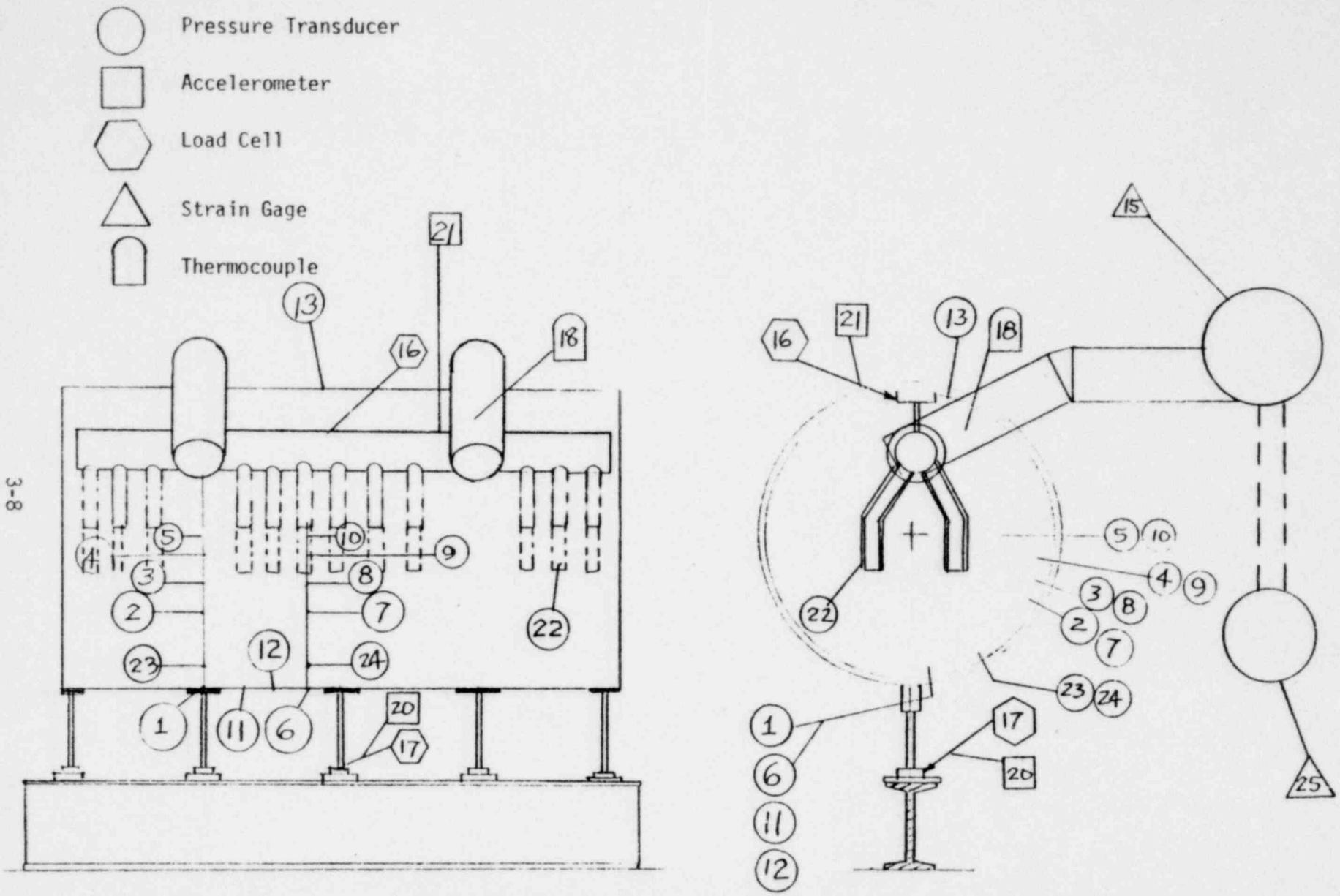


Figure 3-1

*relocated for vent capacitance Tests 5-8

1/4 SCALE TEST INSTRUMENTATION LOCATIONS



EPRI 1/12 SCALE FACILITY INSTRUMENTATION LOCATIONS

Figure 3-2

4. TEST DATA EVALUATION

The comparisons of the vertical loads (maximum downloads and maximum uploads) per unit area on the torus between the facilities are given in this section. Appendix A provides basic parametric scaling factors between sub-and full-scale parameters. All test conditions and results are presented in full-scale values, unless noted.

4.1 Data Base

The data base for these comparisons has been obtained from References 1, 2, and 3. All load data was given in units of force. To allow comparison of loads between 2D and 3D facilities, the data was converted to force per unit area by dividing by the torus projected area.

Reference to "corrected" or "uncorrected" data in the following discussions indicate the presence or absence of inertial corrections to measured forces. Load cell values have been corrected by the structure mass times the measured facility acceleration to account for facility inertia and to provide a comparison with the torus pressure integral. The torus pressure integral which defines the total force applied to the torus wall (an accelerating boundary) during the test can be adjusted by the water mass times the total acceleration to account for water inertia. For peak download water mass correction of the pressure integral defines download applied to a non-accelerating torus boundary. The reported 1/12 Scale torus pressure integral data includes a correction of water inertia throughout the transient; however, very little connection was observed at peak upload. The 1/4 Scale torus pressure integrals were calculated both with and without correction for water inertia. As with the 1/12 Scale data,

very little difference was observed between corrected and uncorrected pressure integrals at peak upload. However, because of high frequency noise content in the 1/4 Scale torus accelerometer and because water inertia correction is not required at peak upload, the peak digital values of the uncorrected torus pressure integral were reported for the 1/4 Scale upload.

4.1.1 GE 1/4 Scale Data

This section presents the 1/4 Scale test results used in the comparisons. Initial wetwell pressures for all tests were 14.7 psia. Tables 4-1 through 4-4 contain data for the 40 in. downcomer submergence with full initial pressure difference (40 in. of water) between the drywell and the wetwell. Surfactant was added to the wetwell water. Surfactant (Kodak Photo-Flow) has been shown to remove surface air bubbles experienced under vacuum test conditions. Air bubble removal reduces the download oscillation recorded by pressure transducers (Ref. 4). Struts were placed to stiffen the test facility side windows to reduce non-prototypic download oscillations. Initial drywell pressurization rates were 14.8, 29.0 (low), 56.0 (medium), and 98.0 psi/sec (high).

Figures 4-1 through 4-5 show the sensitivity of peak downforces per unit area and peak upforces per unit area with respect to drywell pressurization rates. From the data it may be concluded that the peak download per unit area varies almost linearly with the drywell pressurization rate whereas the peak upload increases to a maximum and then decreases with further increase of $\dot{P}$.

4.1.2 EPRI 1/12 Scale Data

Test results from EPRI 1/12 Scale tests are given in Table 4-5. All data have been obtained from pressure integrals corrected for inertial forces. The initial drywell pressurization rates were 28.0, 58.1, and 90.0 psi/sec for the low, medium and high $\dot{P}_{dw}$, respectively. The downcomer submergence was 40 in. and initial wetwell pressure was 14.7 psia. No surfactant was added to the wetwell water, however, repeated blowdowns were executed to remove the surface air bubbles.

The variations of peak downloads per unit area and maximum uploads per unit area with respect to drywell pressurization rates are given in Figures 4-6 and 4-7, respectively. It is noted that again the peak download per unit area increases approximately linearly with drywell pressurization rate.

4.2 Test Data Comparison

In this section data comparisons are made for the two different test facilities.

4.2.1 1/4 Scale (2D) vs. 1/12 Scale (3D)

Comparisons between the 2D 1/4 Scale and 3D 1/12 Scale results are given in Table 4-6. All peak forces per unit area are shown in the form of (mean value $\pm$ one standard deviation). Values have been adjusted where necessary to provide a common $\dot{P}$ base for direct comparisons. It is noted that both the peak downloads and uploads per unit area match very closely at medium $\dot{P}_{dw}$.

Figure 4-8 is a composite plot of Figures 4-2 and 4-6. It compares the peak downforces per unit area between the 1/4 Scale and the 1/12 Scale facilities. Figure 4-9 compares the peak upforces per unit area between the same two facilities.

The 3D/2D load factors shown in Figure 4-10 was obtained by taking the ratio of 1/12 Scale results to those of 1/4 Scale results given in Figures 4-8 and 4-9. Since all plants under consideration have $\dot{P}<75$ psi/sec, the 3D/2D load factor is approximately equal to 1.0.

Figure 4-11 compares typical load transients from both scaled test facilities. The 1/12 Scale curve was scaled up to 1/4 Scale for direct comparison. The general shapes of load transients are very similar. Both traces show one or more download peaks. The time when the peak download and peak upload for both facilities occurred is almost identical.

4.2.2 Peak Pressure Distributions in Facilities

The peak pressure distributions, both in radial and axial directions, are discussed in this section. Table 4-7 summarizes the radial (azimuthal) pressure distribution during peak download for the 1/4 Scale full ΔP tests with $\dot{P}_{dw}$ =56.0 psi/sec. Table 4-8 provides the peak pressure distribution data for the EPRI 1/12 Scale full ΔP tests with $\dot{P}_{dw}$ = 58.1 psi/sec.

Figure 4-12 gives the azimuthal pressure distribution between the 1/4 Scale and the EPRI 1/12 Scale tests under full ΔP condition. The axial pressure distribution at the EPRI facility torus bottom is given in Figure 4-13.

The angular distributions for 1/12 Scale are taken at two planes with x/L = 0.0 and 0.90, where x is the distance from the centerline of the nearest vent-pipe to the point of interest and L is half the distance between two vent-pipes. The downcomers are located at x/L = 0.36, 0.63, and 0.90, respectively. The axial distribution is taken at the bottom of the torus (186°).

TABLE 4-1

1/4 Scale Test Results
($\dot{P}dw$ = 14.8 psi/sec, Full ΔP, 40" Submergence)

Test No.	GS17	GS18	GS19	GS20	Mean	Std. Dev.
Peak Downforce						
Pressure Integral (psi)						*
Pressure Integral Corrected (psi)						
Load Cell Corrected (psi)						
Peak Upforce						
Pressure Integral (psi)						
Load Cell Corrected (psi)						

*Proprietary information deleted

TABLE 4-2

1/4 Scale Test Results
($\dot{P}dw$ = 29.0 psi/sec, full ΔP, 40" Submergence)

Test No.	GS21	GS22	GS23	GS24	Mean	Std. Dev.
Peak Downforce						
Pressure Integral (psi)						*
Pressure Integral Corrected (psi)						
Load Cell Corrected (psi)						
Peak Upforce						
Pressure Integral (psi)						
Load Cell Corrected (psi)						

*Proprietary information deleted

TABLE 4-3

1/4 Scale Test Results
($\dot{P}dw$ = 56.0 psi/sec, Full ΔP, 40" Submergence)

Test No.	GS1	GS2	GS3	GS4	Mean	Std. Dev.
Peak Downforce						
Pressure Integral (psi)						
Pressure Integral Corrected (psi)						
Load Cell Corrected (psi)						
Peak Upforce						
Pressure Integral (psi)						
Load Cell Corrected (psi)						

*

*Proprietary information deleted.

TABLE 4-4

1/4 Scale Test Results
($\dot{P}dw$ = 98.0 psi/sec Full ΔP, 40" Submergence)

Test No.	GS25	GS26	GS27	GS28	Mean	Std. Dev.
Peak Downforce						
Pressure Integral (psi)						*
Pressure Integral Corrected (psi)						
Load Cell Corrected (psi)						
Peak Upforce						
Pressure Integral (psi)						
Load Cell Corrected (psi)						

*Proprietary information deleted.

TABLE 4-5

1/12 Scale Test Results

($\dot{P}dw$ = 28.0 psi/sec)

Test No.	162	163	164	165	Mean	Std. Dev.
Peak Download per unit area,* (psi)	2.25	1.94	1.78	2.14	2.02	0.21
Peak Upload per unit area,* (psi)	1.54	1.24	1.24	1.49	1.38	0.16

($\dot{P}dw$ = 58.1 psi/sec)

Test No.	149	150	151	152	Mean	Std. Dev.
Peak Download per unit area,* (psi)	3.67	3.52	3.83	3.83	3.72	0.15
Peak Upload per unit area,* (psi)	1.95	1.95	1.90	1.85	1.92	0.05

($\dot{P}dw$ = 90.0 psi/sec)

Test No.	190	191	192	193	Mean	Std. Dev.
Peak Download per unit area,* (psi)	5.11	4.90	5.05	4.86	4.98	0.12
Peak Upload per unit area,* (psi)	1.85	1.59	1.95	1.65	1.76	0.16

* Pressure integral corrected, full ΔP.

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TABLE 4-6

COMPARISON BETWEEN 1/4 SCALE (2D) AND 1/12 SCALE (3D)

	Low Pdw		Medium Pdw		High Pdw	
	1/4, 2D	1/12, 3D	1/4, 2D	1/12, 3D	1/4, 2D	1/12, 3D
DRIVING CONDITIONS						
Initial drywell pressure, psia	14.7		14.7		14.7	
Downcomer submergence, in.	40.0		40.0		40.0	
Pressure differential, in. of water	40.0		40.0		40.0	
Drywell pressurization rate, psi/sec	28.0		56.0		90.0	
LOADS AND LOAD FACTORS*						
Peak download per unit area, psi (pressure-integral corrected)	2.28 ± 0.07	2.02 ± 0.21	3.70 ± 0.12	3.62 ± 0.15	5.05 ± 0.08	4.98 ± 0.12
Peak upload per unit area, psi (pressure-integral)**	1.78 ± 0.09	1.38 ± 0.16	1.96 ± 0.08	1.91 ± 0.05	1.64 ± 0.14	1.76 ± 0.16

*The loads listed in Tables 4-2 through 4-5 have been adjusted to the common P indicated.

**1/4 Scale values are uploads uncorrected and 1/12 Scale upload values are corrected (see Section 4.1).

TABLE 4-7

AZIMUTHAL PEAK PRESSURE DISTRIBUTION -- 1/4 SCALE

$\dot{P}dw$ = 56.0 psi/sec, DOWNCOMER SUBMERGENCE = 40", FULL ΔP

ANGLE, DEGREE	TEST NO.	GS1	GS2	GS3	GS4	MEAN	STD. DEV.
180°							
195°							
210°							
225°							
240°							

*

*Proprietary information deleted.

TABLE 4-8

PEAK PRESSURE DISTRIBUTION -- 1/12 SCALE

$\dot{P}dw$ = 58.1 psi/sec, DOWNCOMER SUBMERGENCE = 40", FULL ΔP

Transducer	Location		Test No.	149	150	151	152	Mean	Std. Dev.
	x/L	Degree							
P1	0.0	186°		4.10	4.68	4.45	4.10	4.33	0.29
P3	0.0	240°		2.69	3.63	3.04	3.28	3.16	0.39
P5	0.36	186°		4.21	4.68	4.45	4.56	4.48	0.20
P6	0.55	186°		4.68	4.91	4.80	4.91	4.83	0.11
P8	0.90	186°		5.27	5.15	5.38	5.50	5.32	0.15
P10	0.90	240°		3.16	3.39	3.39	3.51	3.36	0.15

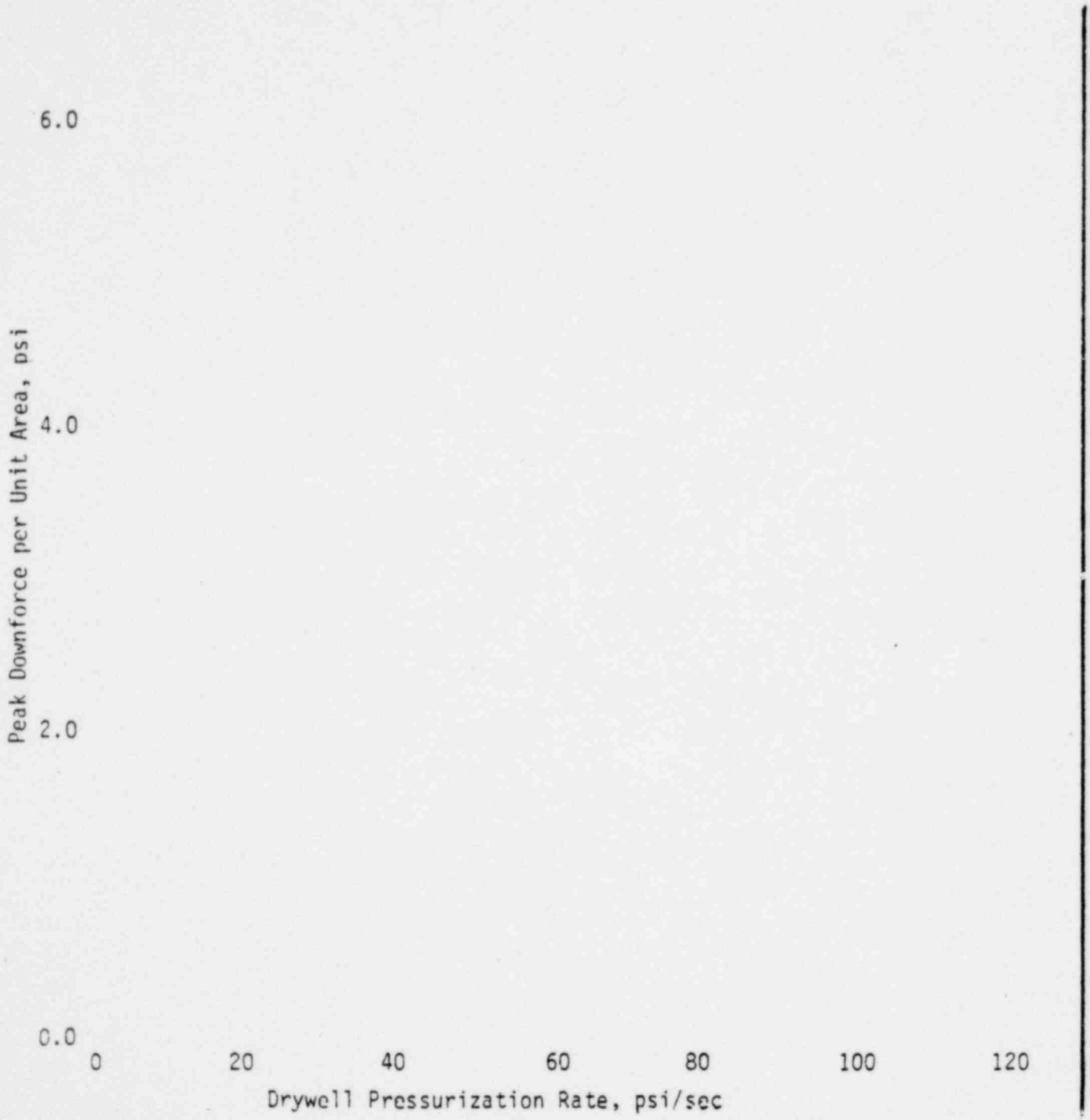

FIGURE 4-1. 1/4 Scale Test Results Peak Downforce per Unit Area, Pressure Integral Uncorrected vs. Drywell Pressurization Rate (Full ΔP, 40" Submergence)

*Proprietary information deleted

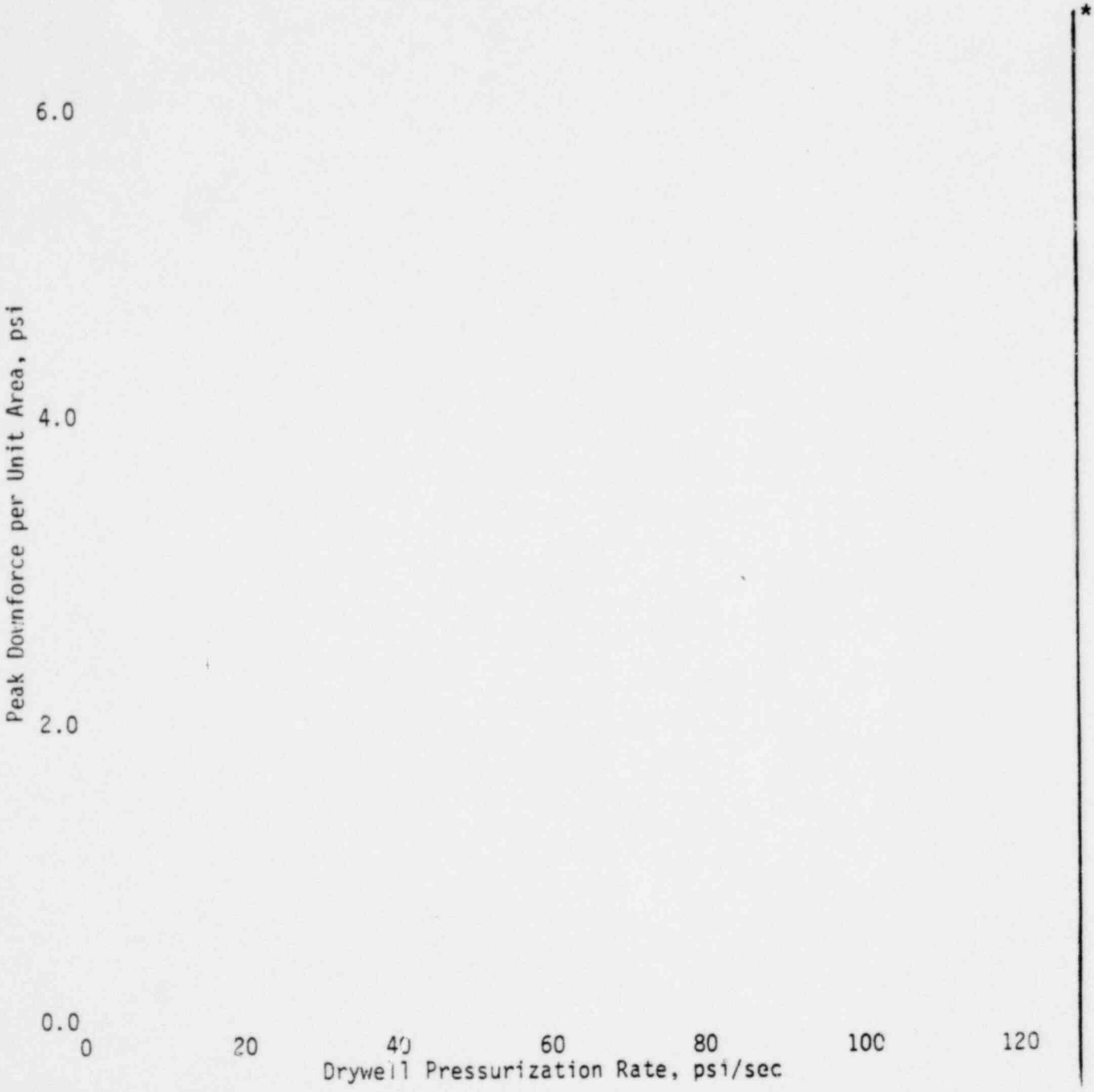

FIGURE 4-2. 1/4 Scale Test Results Peak Downforce Per Unit Area, Pressure Integral Corrected vs. Drywell Pressurization Rate (Full ΔP, 40" Submergence)

*Proprietary information deleted

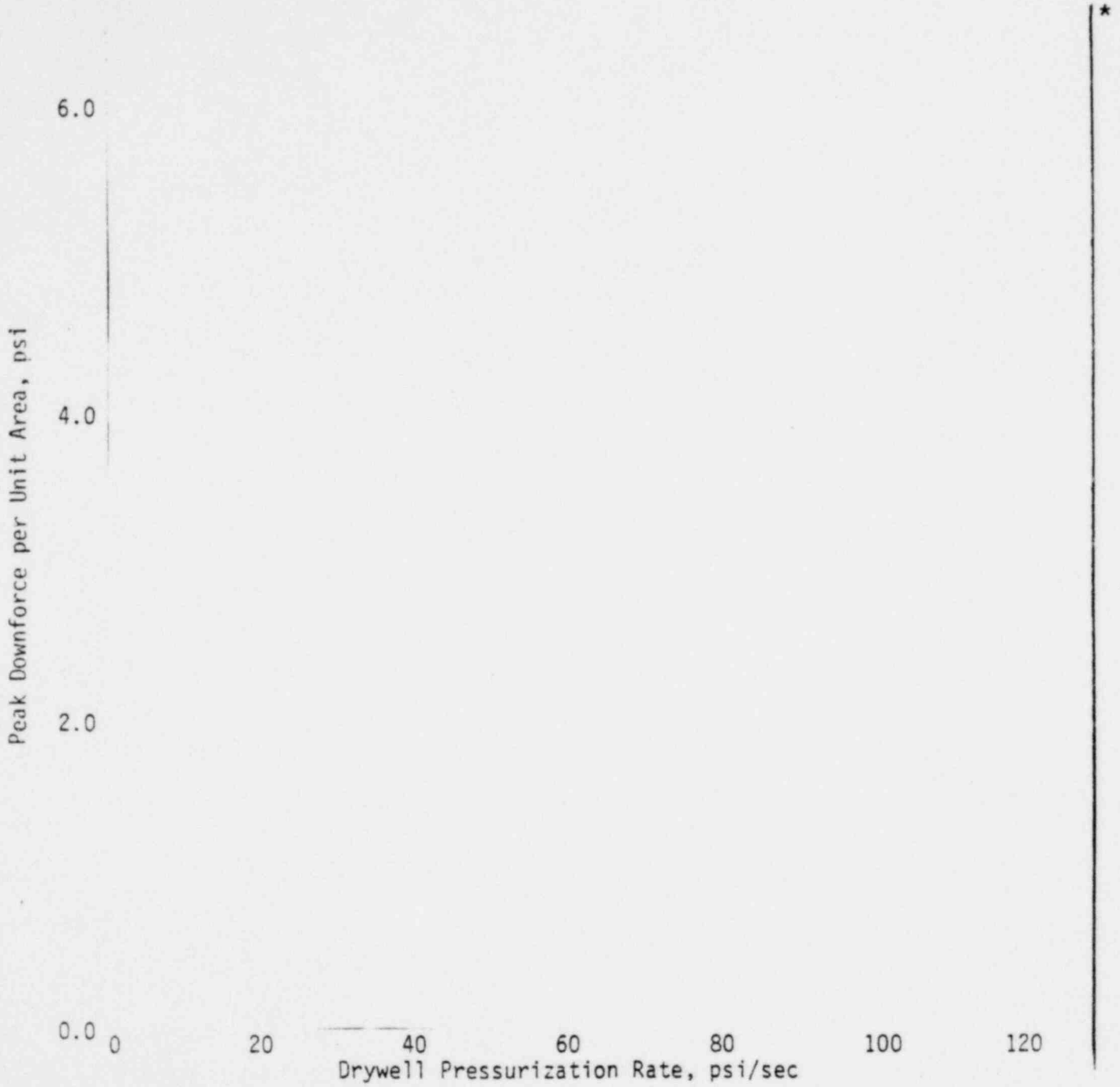

FIGURE 4-3. 1/4 Scale Test Results Peak Downforce Per Unit Area, Load Cell Corrected vs Drywell Pressurization Rate (Full ΔP, 40" Downcomer Submergence)

*Proprietary information deleted

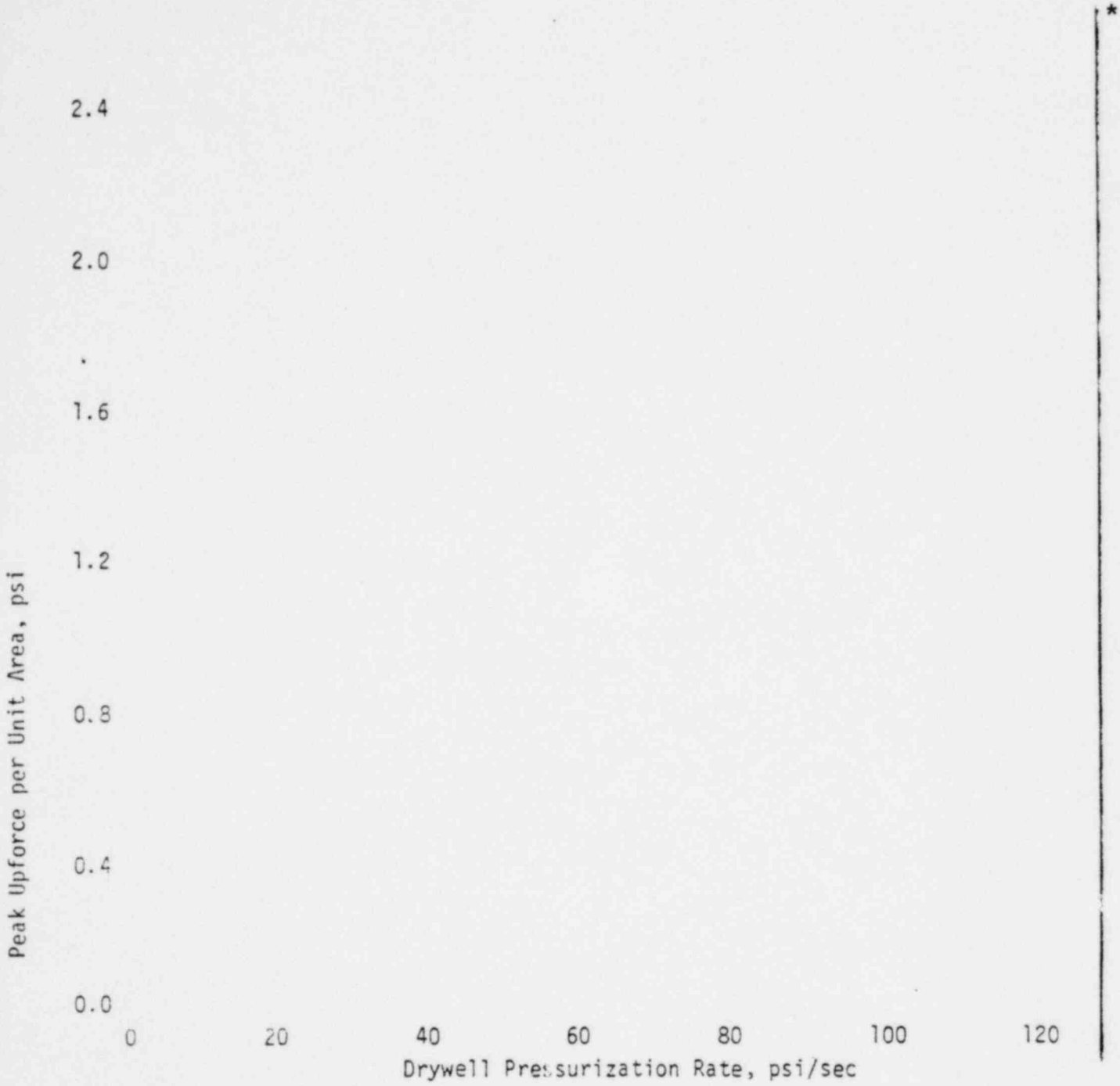

Figure 4-4 1/4 Scale Test Results
Peak Upforce per Unit Area, Pressure Integral
Uncorrected vs. Drywell Pressurization Rate
(Full ΔP, 40" Downcomer Submergence)

*Proprietary information deleted

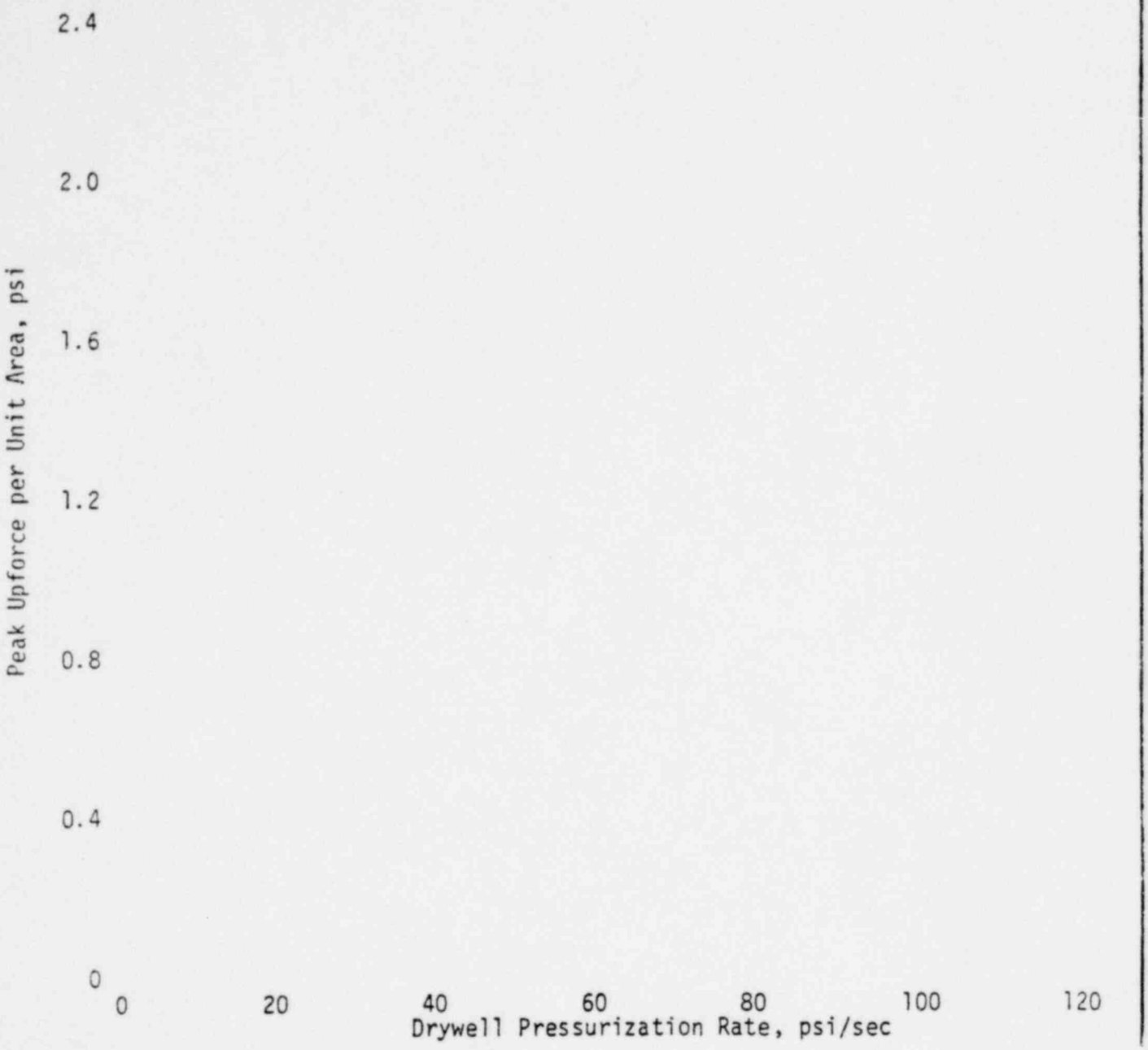

Figure 4-5 1/4 Scale Test Results
Peak Upforce per Unit Area, Load Cell
Corrected vs. Drywell Pressurization Rate
(Full ΔP, 40" Downcomer Submergence)

*Proprietary information deleted

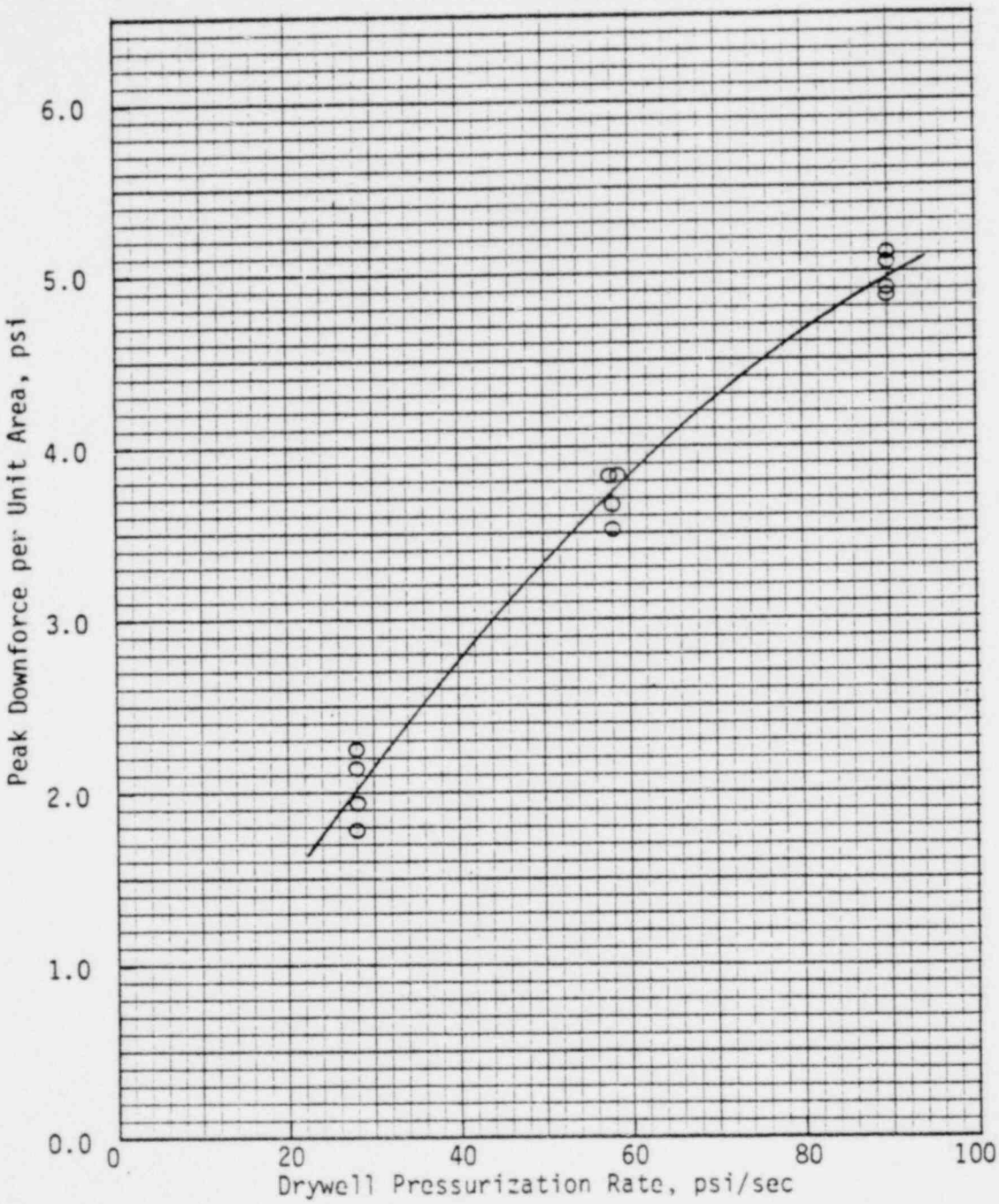

FIGURE 4-6. 1/12 Scale Test Results
Peak Downforce per Unit Area vs.
Drywell Pressurization Rate
(Full ΔP, 40" Submergence)

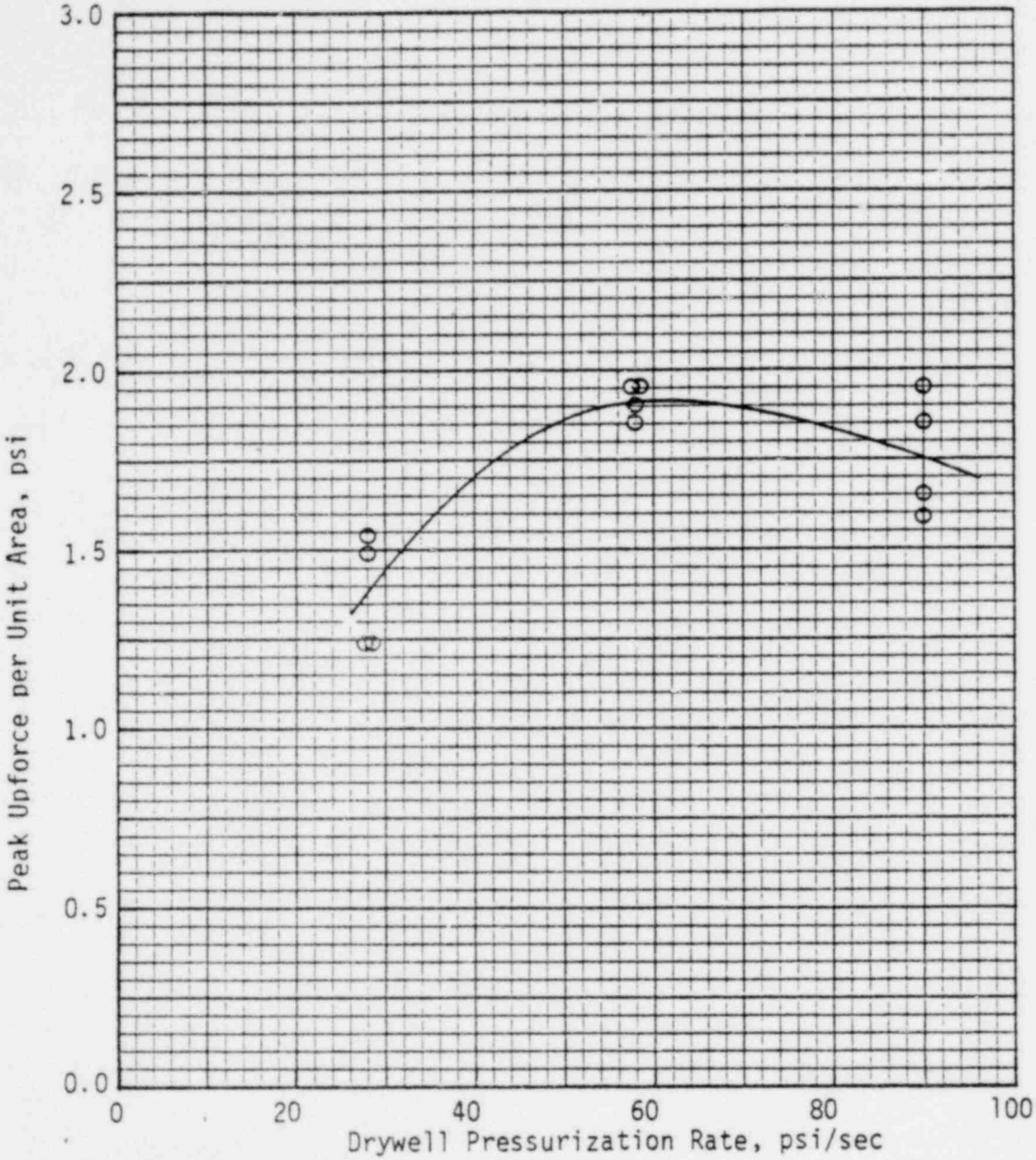

FIGURE 4-7. 1/12 Scale Test Results
Peak Upforce per Unit Area vs.
Drywell Pressurization Rate
(Full ΔP, 40" Submergence)

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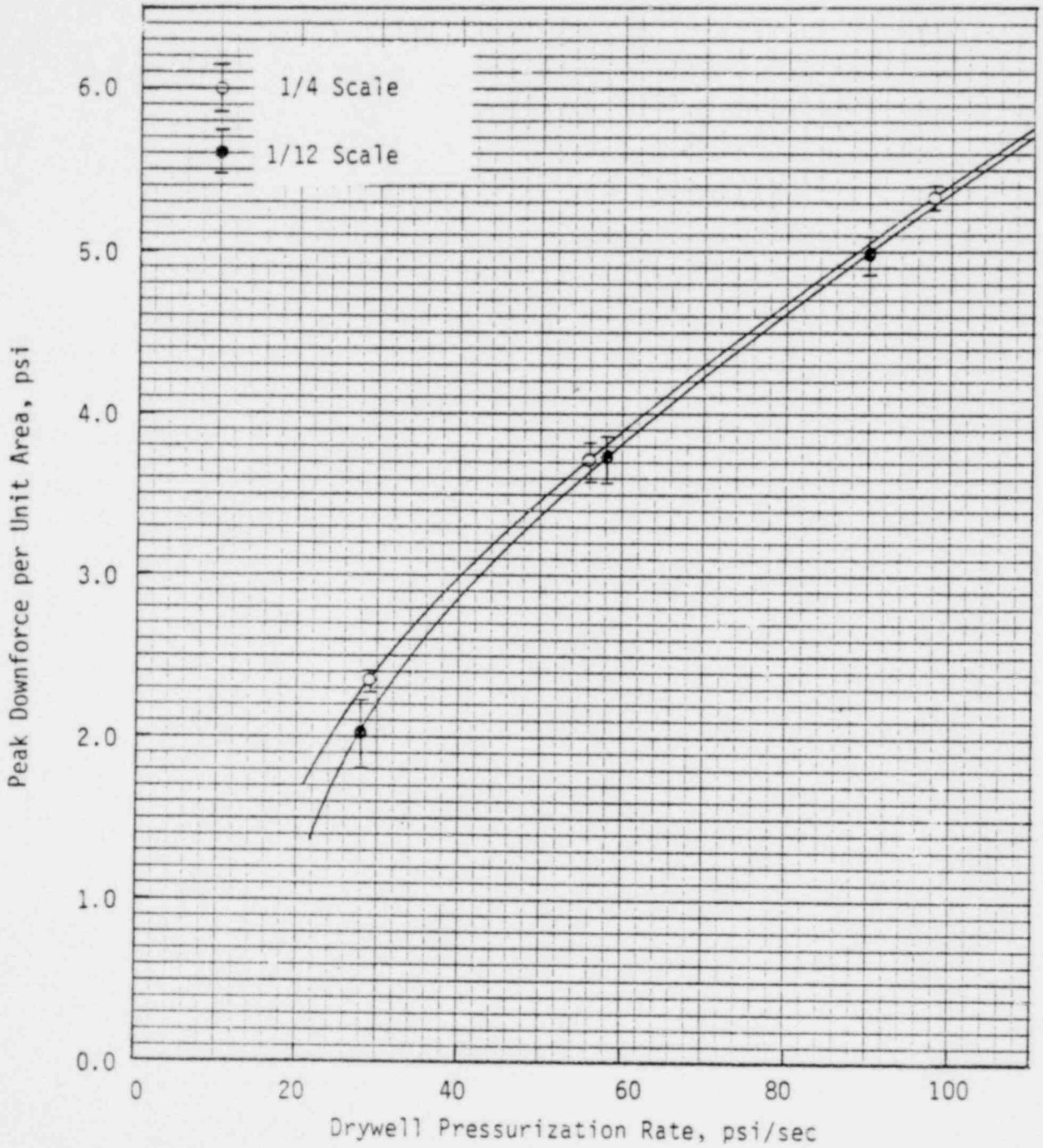

FIGURE 4-8. Comparison of Peak Downforces per Unit Area Between 1/4 Scale and 1/12 Scale (Full ΔP, 40" Downcomer Submergence)

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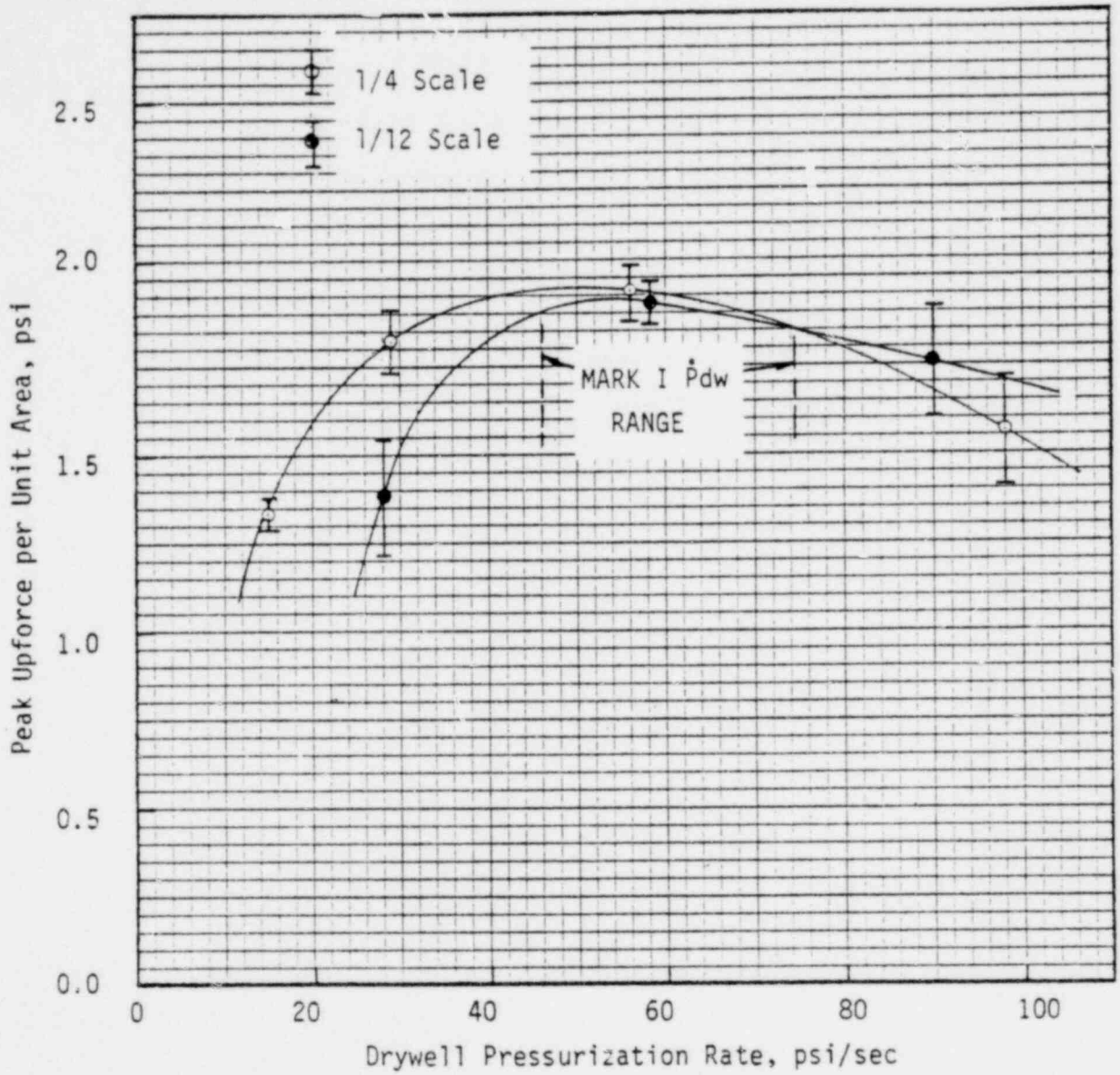
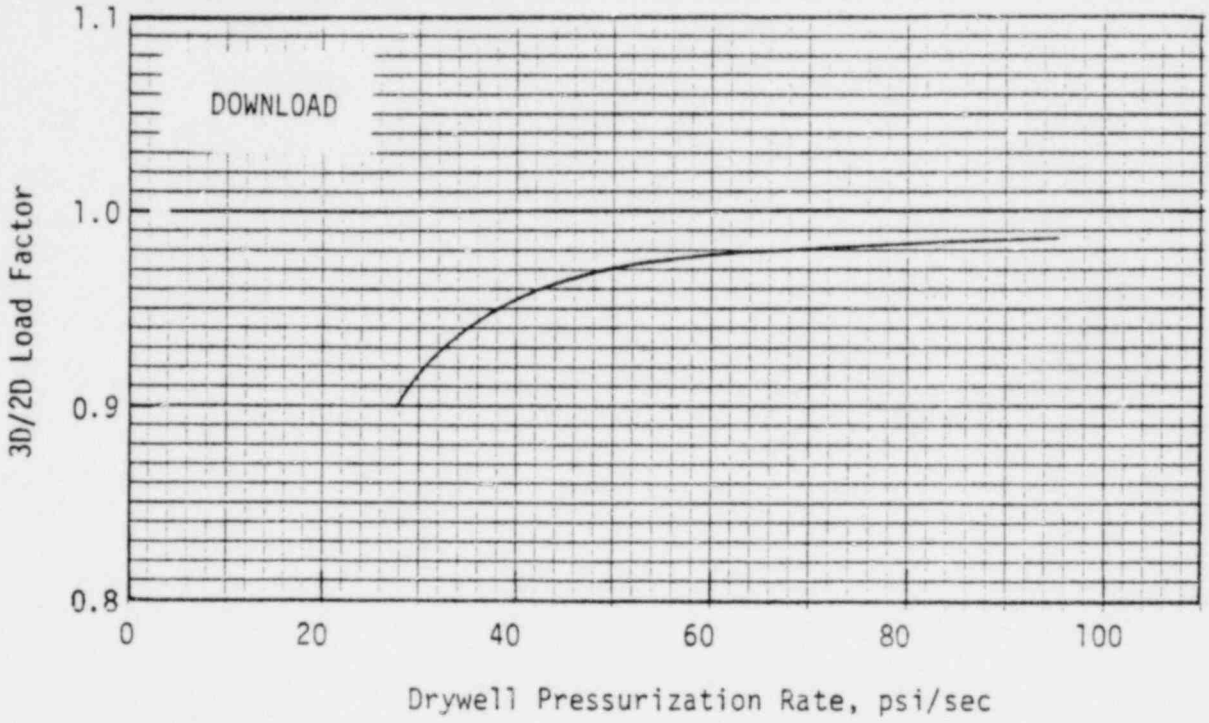


FIGURE 4-9. Comparison of Peak Upforces per Unit Area Between 1/4 Scale and 1/12 Scale (Full ΔP, 40" Downcomer Submergence)



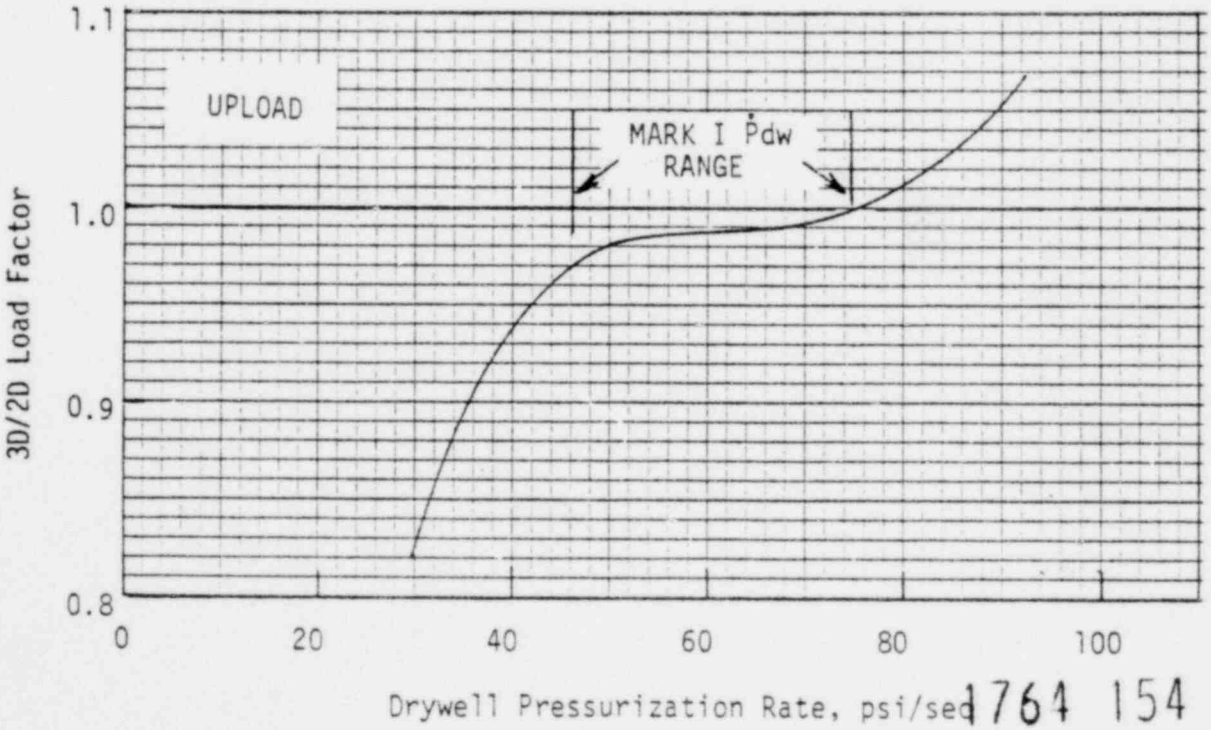


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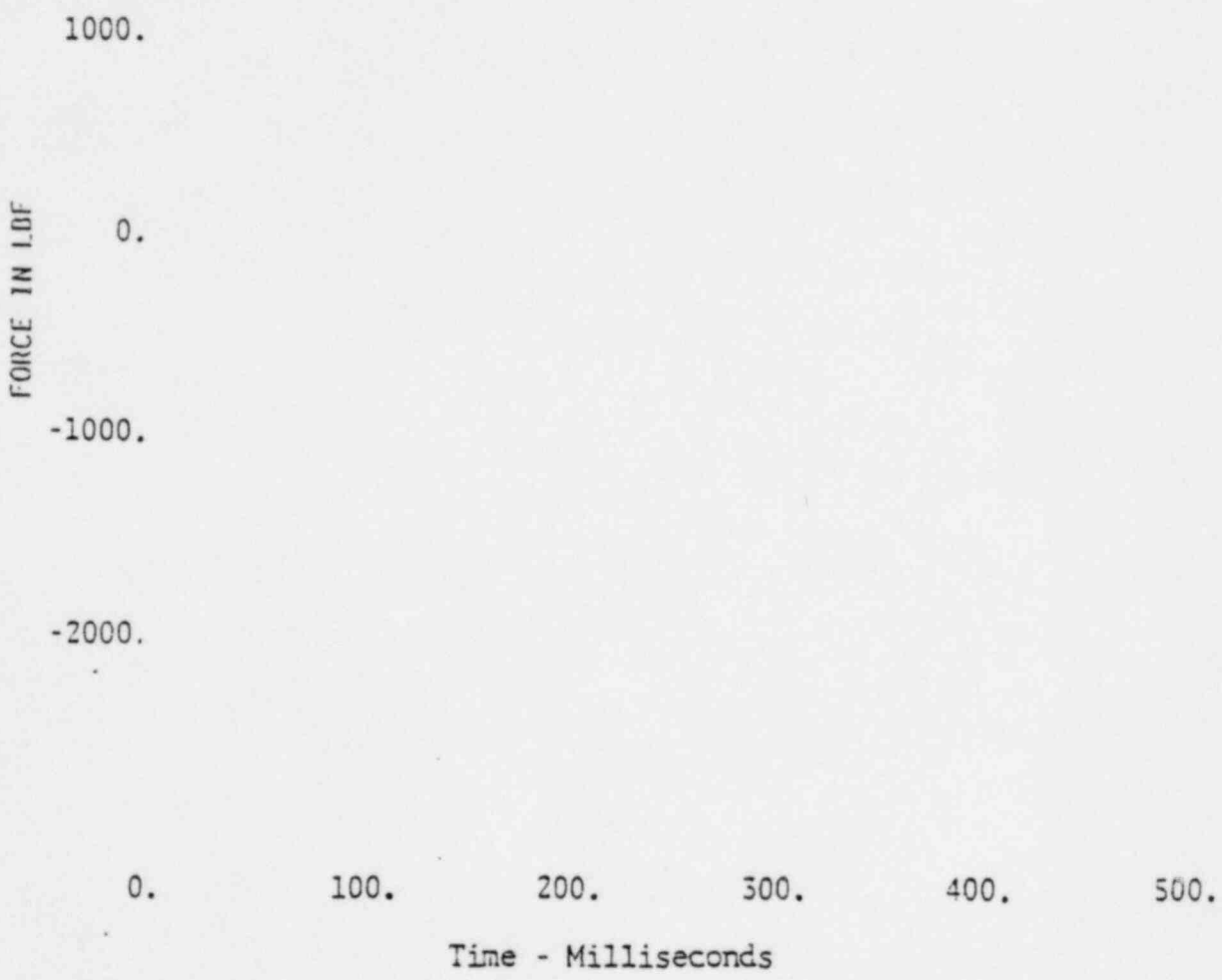
FIGURE 4-10 3D/2D Load Factors vs. Drywell Pressurization Rate - 1/12 Scale vs. 1/4 Scale (Full ΔP, 40" Downcomer Submergence)



$\dot{P}$ = Drywell Pressurization Rate
S = Downcomer Submergence
ΔP = Pressure Differential (Drywell-Wetwell)

Figure 4-11 Load Transient Comparison

*Proprietary information deleted

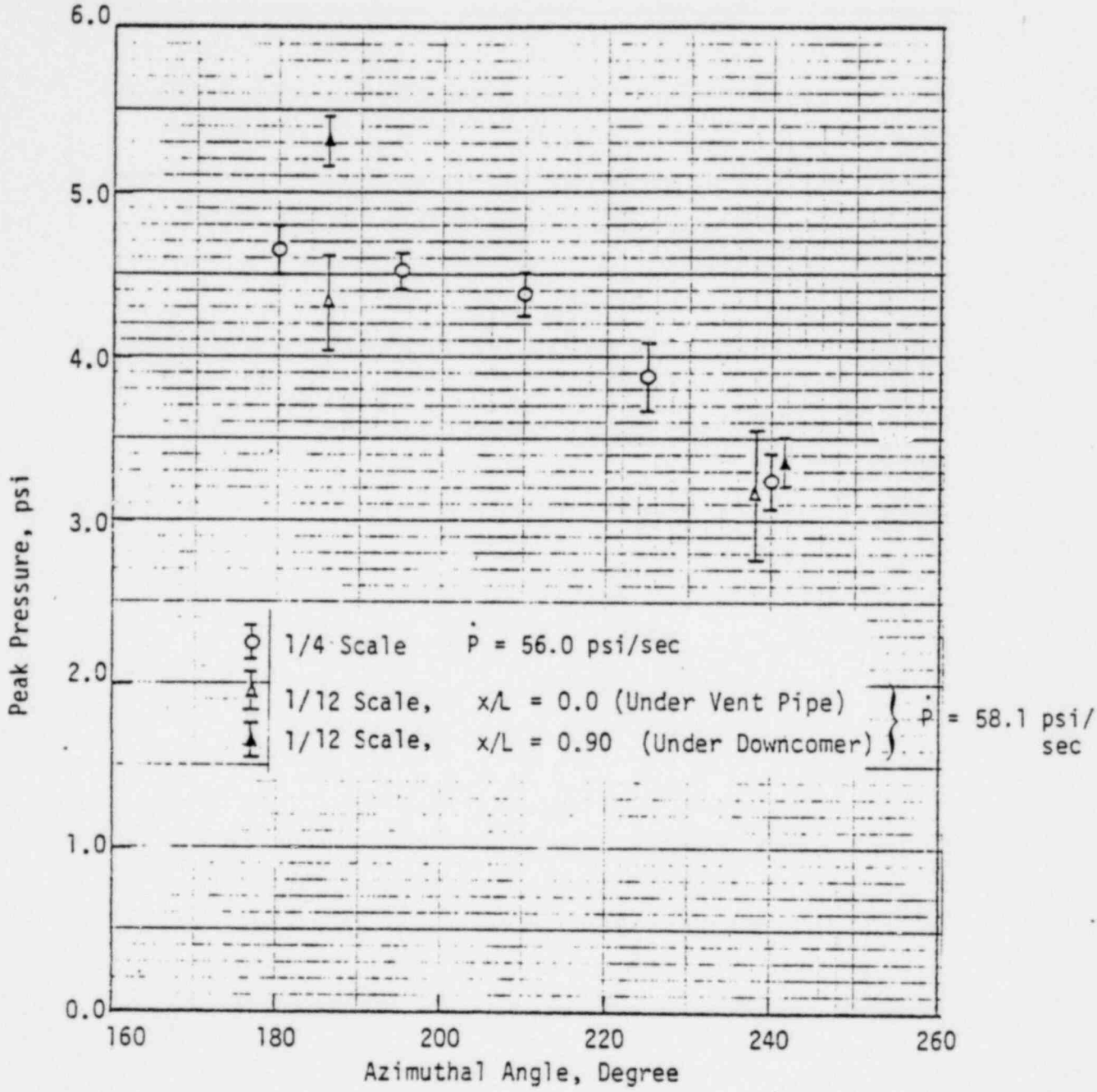


Figure 4-12 Azimuthal Peak Pressure Distribution--
1/4 Scale vs. 1/12 Scale
(Full ΔP, 40" Submergence)

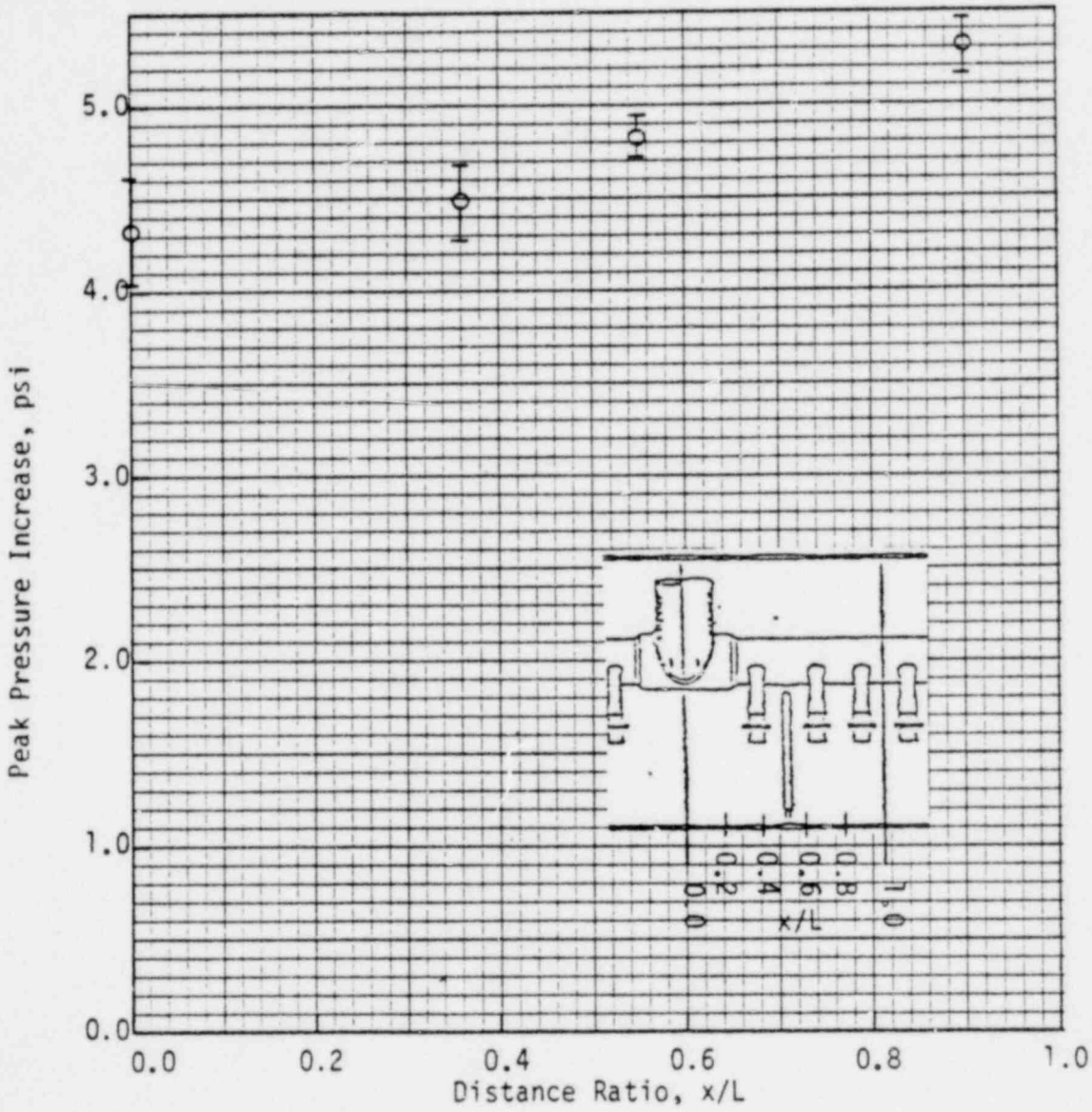


Figure 4-13 Axial Peak Pressure Increase Distribution at Bottom of the Torus (186°) - 1/12 Scale (Full ΔP, $\dot{P}$ = 58.1 psi/sec, 40" Submergence).

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5. CONCLUSIONS

1) Peak downloads from both facilities continuously increase linearly with drywell pressurization rate.

Peak uploads from both facilities increase with increasing drywell pressurization rate and then decline slightly at high drywell pressurization rates.

This trend in the upload is due to the breakthrough characteristics of the downcomer geometry evaluated. The Browns Ferry downcomers tested by GE and EPRI have a 45° bend about half way between the pool surface and the bottom of the vent header. High speed movies taken during testing show that when the pool reaches the downcomer bend the flow separates leaving a column of air above the bend which initiates breakthrough when the bubble reaches the elevation of the bend. At high drywell pressurization rates the duration of the download is longer but the bubble reaches the elevation of the downcomer bend earlier in the upload transient and initiates an early breakthrough.

2) The EPRI and GE download and upload data are in good agreement. Comparison of the peak download values versus $\dot{P}_{dw}$ for the 1/4 Scale and 1/12 Scale facilities shows that there is no net 3D/2D effect. Comparison of the peak upload values against $\dot{P}_{dw}$ shows that a 3D/2D effect of about 0.8 at low $\dot{P}_{dw}$ and increasing to about 1.0 at medium $\dot{P}_{dw}$ (< 75 psi/sec). The 3D loads were higher than the 2D loads at drywell pressurization rates much higher than that was calculated for actual plants.

3) Circumferential pressure distributions under downcomer vents show good agreement between the GE 1/4 Scale and the EPRI 1/12 Scale tests which further indicates no 3D/2D download effect.

6. REFERENCES

1. NEDO-23545 "Mark I Containment Program 1/4 Scale Pressure Suppression Pool Swell Test Program: LDR Load Tests - Generic Sensitivity Task 5.5.3, Series 1," June 1979.

2. EPRI-NP-906 "Three Dimensional Pool Swell Modeling of a Mark I Suppression System," EPRI-NP-906, October 1978.

3. NEDO-21627 "Mark I Containment Program 1/4 Scale Pressure Suppression Pool Swell Test Program: Scaling Evaluation, Task No. 5.5.1," January 1978.

4. NEDO-21943 "Mark I Containment Program 1/4 Scale Pressure Suppression Pool Swell Test Program: Download Oscillation Evaluation, Task No. 5.5.2," June 1979.

APPENDIX A
SCALING FACTORS

The subscale key parameters (measured and derived) are related to the full-scale parameters by the following factors (Ref. 3):

$$P_f = P_s \times S \qquad \text{(pressure)}$$

$$\dot{P}_f = \dot{P}_s \times \sqrt{S} \qquad \text{(pressurization rate)}$$

$$T_f = T_s \times \sqrt{S} \qquad \text{(time)}$$

$$F_f = F_s \times S^3 \qquad \text{(force)}$$

$$L_f = L_s \times S \qquad \text{(length)}$$

$$\left(\frac{fL}{D}\right)_{total} = \left(\frac{fL}{D}\right)_{vent\ system} + 1 \qquad \text{(total resistance)}$$

$$\left(\frac{fL}{D}\right)_{f_{total}} = \frac{1}{S} \left(\frac{fL}{D}\right)_{s_{total}} \qquad \text{(total resistance)}$$

where the subscripts f and s denote the full- and sub-scale values respectively, and S is the ratio of full to model scale dimensions.

The following table summarizes the parameter scaling factors.

	GE 1/4 Scale	EPRI 1/12 Scale
P_f	$4P_s$	$11.70\ P_s$
$\dot{P}_f$	$2\dot{P}_s$	$3.42\ \dot{P}_s$
T_f	$2T_s$	$3.42\ T_s$
F_f	$64F_s$	$1061.61\ F_s$
L_f	$4L_s$	$11.7\ L_s$
$\left(\frac{fL}{D}\right)_f$	$0.25\left(\frac{fL}{D}\right)_s$	$0.0855\left(\frac{fL}{D}\right)_s$

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SUMMARY

In this report comparisons of subscale pool swell test results from the General Electric 1/4 Scale two dimensional (2D) Test Facility and the Electric Power Research Institute 1/12 Scale three dimensional (3D) Test Facility are presented. The parameters compared include maximum upload, maximum download and peak pressure distribution. These comparisons lead to the conclusion that the 2D test facility yields maximum uploads and downloads which equal or exceed those measured in the 3D facility within the range of Mark I drywell pressurization rates.

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