TOPICAL REPORT EVALUATION

Report No.: NEDO 10859 (Non-proprietary)

Report Title: Steam Vent Clearing Phenomena and Structural Response of the BWR Torus

Report Date: April 1973 and Errata and Addenda Sheet, May 21, 1973.

Originating Organization: General Electric Company

Reviewed By: Operating Reactors Branch No. 2

SUMMARY OF TOPICAL REPORT

The report presents an analytical model that mathematically describes the process of relief valve opening, the clearing of the water out of the vent, and the subsequent pressure oscillations in the wetwell and the torus structural response due to the expanding air expelled from the vent. A parametric variation is performed which demonstrates the effect of such parameters as vent submergence, valve opening time, mass flow rate through the valve, and reactor pressure. In addition, analytical results are presented for the pressures generated in the suppression pool as a function of distance from the vent exit for single and multiple valve openings and for the resulting torus structure loads, deflections and stresses. The experimental data were derived from a series of nine tests performed on the Quad Cities Unit 2 plants.

The results of a test program consisting of five single valve tests and four multiple valve tests performed in October 1972 on the Quad Cities Unit 2 plant are reported. The instrumentation employed to determine the pressure response consisted of ten transducers in the torus at various distances from a vent exit, and one transducer on a vent pipe just above the water line. The values for the highest pressure amplitude (characteristically the second peak in the oscillations) are compared with the analytical predictions. Structural response instrumentation consisted of 7 displacement sensors and eleven strain gages, many of which failed during tests. The comparison of the data obtained from the tests with that obtained from the structural analytical model is of little significance based on the small amount of test data obtained from structural instrumentation.

SUMMARY OF REGULATORY EVALUATION

The analytical predictions shown in Figure 4-13 and 4-15 envelope the measurements of the maximum positive amplitudes of the pressure oscillations with the exception of the maximum negative amplitudes which frequently exceed the theoretical values for the single valve tests. All the measurements indicated show a substantial degree of scatter. It is significant to note that the multiple valve tests show a larger degree of scatter than the single valve tests.

The model generally represents a valid and sufficiently complete method of generating a pressure loading prediction for relief valve action; however, the analysis results presented in the report still

contain some unexplained anomalies. For example, a comparison between Figure 4-13 and Figure 4-15 indicates that at a distance of 5 ft. from the vent exit, the theory incorrectly would predict a higher positive pressure amplitude for single valve opening than for multiple valve opening. Furthermore, the limiting behavior of pressure in Figure 4-15 as the distance from the vent exit, goes to zero which does not appear to be correct since limiting behavior should approach that of Figure 4-13. It is expected that the phenomenon of pressure wave addition is also subject to substantial randomness which might well explain the scatter in Figure 4-15. Similarly, the starting conditions of each test would have to be reviewed to determine whether the initial conditions were identical. In view of the scatter in all the test results, it is our opinion that a determination of adequacy of the model to determine a universally applicable forcing function would have to be supported by larger data base to include other BWR/Mark I plants.

A suitable forcing function must also consider the projected number of valve openings over the life of the plant. Such a projection, necessary for determining the fatigue life of the plant, should include some correlation for including the attenuation from adjacent valves. The projection should be based on a breakdown over the anticipated number of occurrences; e.g., turbine trip, MIS, test requirement, etc. The figure in Section 5.3.4 that depicts less than five relief valve openings a year is considered unrealistic.

The analytical model of the entire torus-ring header system that uses bar members to represent torus segments is inadequate for dynamic analysis of the structure. This method of analytical modeling is not considered appropriate for determining stresses in such critical areas as the pipe penetrations. Stresses due to dynamic effects in the vicinity of pipe penetrations could not be calculated because the analytical model was not designed to yield detailed results in all torus bays. Furthermore, measured strain data which were used for comparison with analytical results are not reliable due to faulty instrumentation. On the basis of the above discussion, we find that the portion of the report concerning structural response and stress analysis is unacceptable and should not be used as a reference in future work relating to the Mark I structures.

REGULATORY POSITION

As emphasized above in our evaluation, the data base confirming the analytical mo for the forcing function is rather limited in view of the scatter that exists in the data. The verification of the model can therefore not be considered conclusive for application on other torus structure designs based on the Quad Cities tests alone. The model predicts certain anomalous results such as Figure which shows that the maximum column pressure does not increase with reduced valve opening time. Such a result would also need experimental verification.

The verification of the analytical model for the forcing function should be extended further by tests performed on other plants where the configuration and design of the relief valve vents and the torus are significantly different from the Quad Cities Unit 2 torus. Such testing would verify the model for variation in some of the parameters listed in Table 4-1. In addition, differences in the structural characteristics of the torus are expected to influence the pressure amplitudes that are measured in the suppression pool in view of the large deflections with which the torus shell responds to the pressure amplitudes.

Experimental stress analysis should be emphasized for the investigation of stress and strain conditions in the critical area. Strain and deflection measurements had not provided reliable data for analysis because of instrumentation malfunction. Therefore a test program should be established that provides a better experimental data base for stress and strain at pertinent and critical areas of the torus. In addition, effects of cumulative damage and usage factor due to previous tests and operations should be given consideration in determining the fatigue life of torus structures based on the steam vent clearing phenomena associated with operation of primary system relief valves.

SAFETY-RELIEF VALVE PHENOMENA

- PIPE CLEARING
- BUBBLE DYNAMICS (RAMSHEAD)
- BOUNDARY EFFECTS (")
- PRESSURE DECAY
- QUENCHER
- RAMSHEAD DATA

DETAILS OF
PIPE CLEARING MODEL

- ONE DIMENSIONAL TRANSIENT FLOW

CONSERVATION OF MASS:

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho v)}{\partial z} = 0$$

CONSERVATION OF MOMENTUM:

$$\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial z} + \frac{g_c}{\rho}\frac{\partial P}{\partial z} + \frac{f}{D}\frac{v|v|}{2} = 0$$

CONSERVATION OF ENERGY:

$$\frac{\partial h}{\partial t} + v\frac{\partial h}{\partial z} - \frac{1}{\rho}\left(\frac{\partial P}{\partial t} + v\frac{\partial P}{\partial z}\right) - \frac{f}{D}\frac{v^2|v|}{2g_c} = 0$$

- ASSUMPTIONS:

  - AIR AND STEAM BEHAVE AS IDEAL GASES
  - NO MIXING OF AIR AND STEAM
  - ADIABATIC FLOW WITH FRICTION (AIR AND STEAM)
  - FRICTION LOSSES NEGLIGIBLE FOR WATER

- BOUNDARY CONDITIONS:

  - RAMP-FLAT FLOW RATE FOR STEAM
  - ONE D EQUIVALENT MASS ADDED TO THE END OF PIPE
  - CHOKED FLOW OF AIR AFTER WATER IS EXPELLED

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DETAILS OF
BUBBLE DYNAMICS MODEL

1. CONSERVATION OF MASS

$$\frac{dM}{dt} = \dot{m}$$

- WHERE $\dot{m}$ IS 1/2 CHOKED FLOW RATE FOR EACH BUBBLE

$$\frac{dM}{dt} = 0 \qquad \text{WHEN ALL AIR IS DISCHARGED}$$

2. CONSERVATION OF ENERGY

$$\frac{dE}{dt} = \dot{m}_i h_i \eta - P\frac{dV}{dt}$$

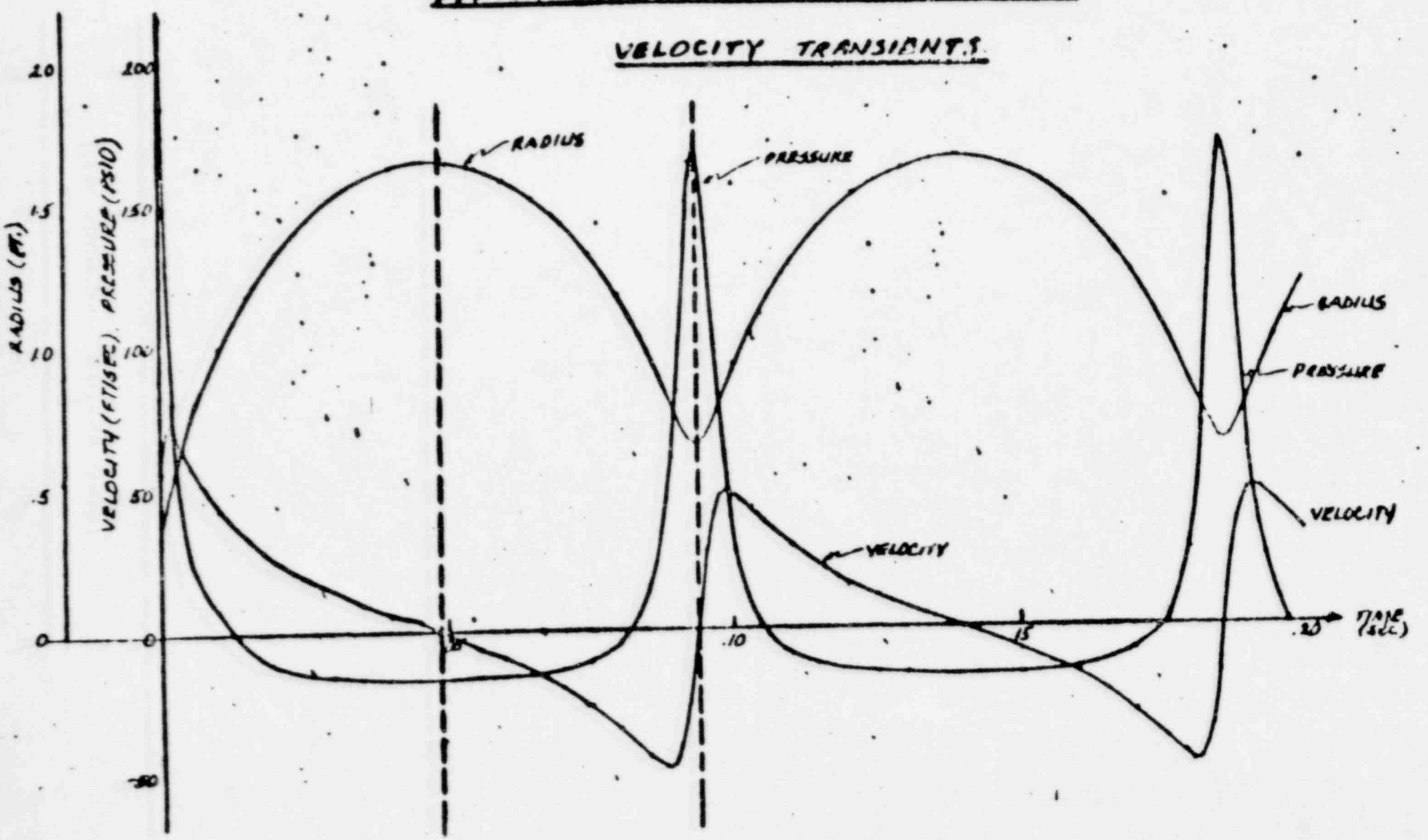
3. CONSERVATION OF MOMENTUM (RALEIGH'S EQUATION):

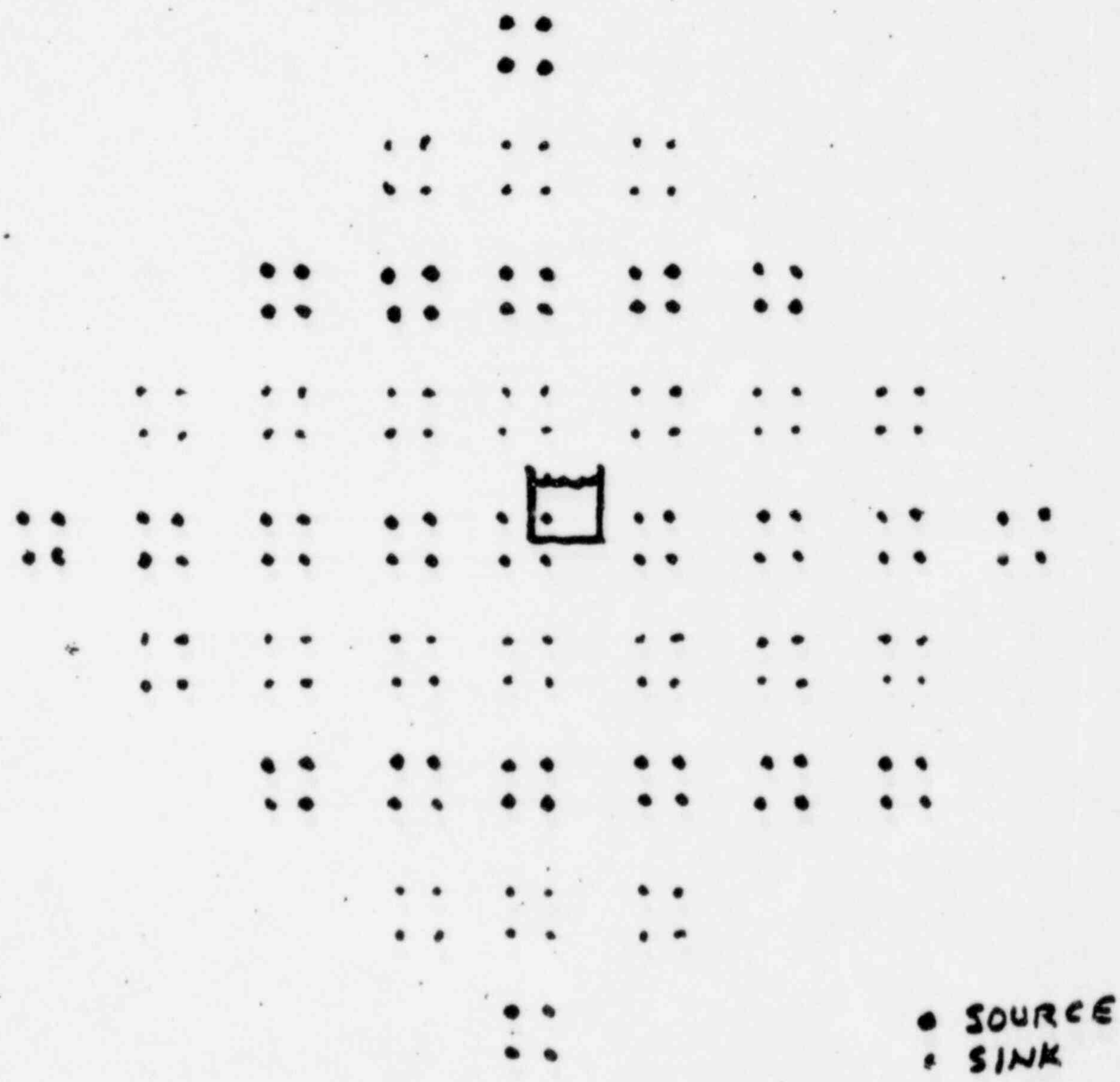
$$r\ddot{r} + \frac{3}{2}\dot{r}^2 = \frac{g_c}{\rho_L}(P - P_\infty)$$

4. EQUATION OF STATE

$$PV = MRT$$

TYPICAL BUBBLE PRESSURE, RADIUS AND VELOCITY TRANSIENTS





BOUNDARY EFFECTS

DETAILS OF
BUBBLE RISE MODEL

1. EQUATION OF MOTION OF C.G. OF BUBBLE

$$Z = Z_o + \frac{1}{2} g t^2 - (R_{MAX} - R_{MIN}) \cdot f \cdot t$$

WHERE f - FREQUENCY OF OSCILLATION

2. AS THE BUBBLE MOVES UP, THE PATTERN OF IMAGES IS MODIFIED ACCORDINGLY.

3. WHEN THE BUBBLE REACHES THE FREE SURFACE, ALL PRESSURE DIFFERENTIALS GO TO ZERO

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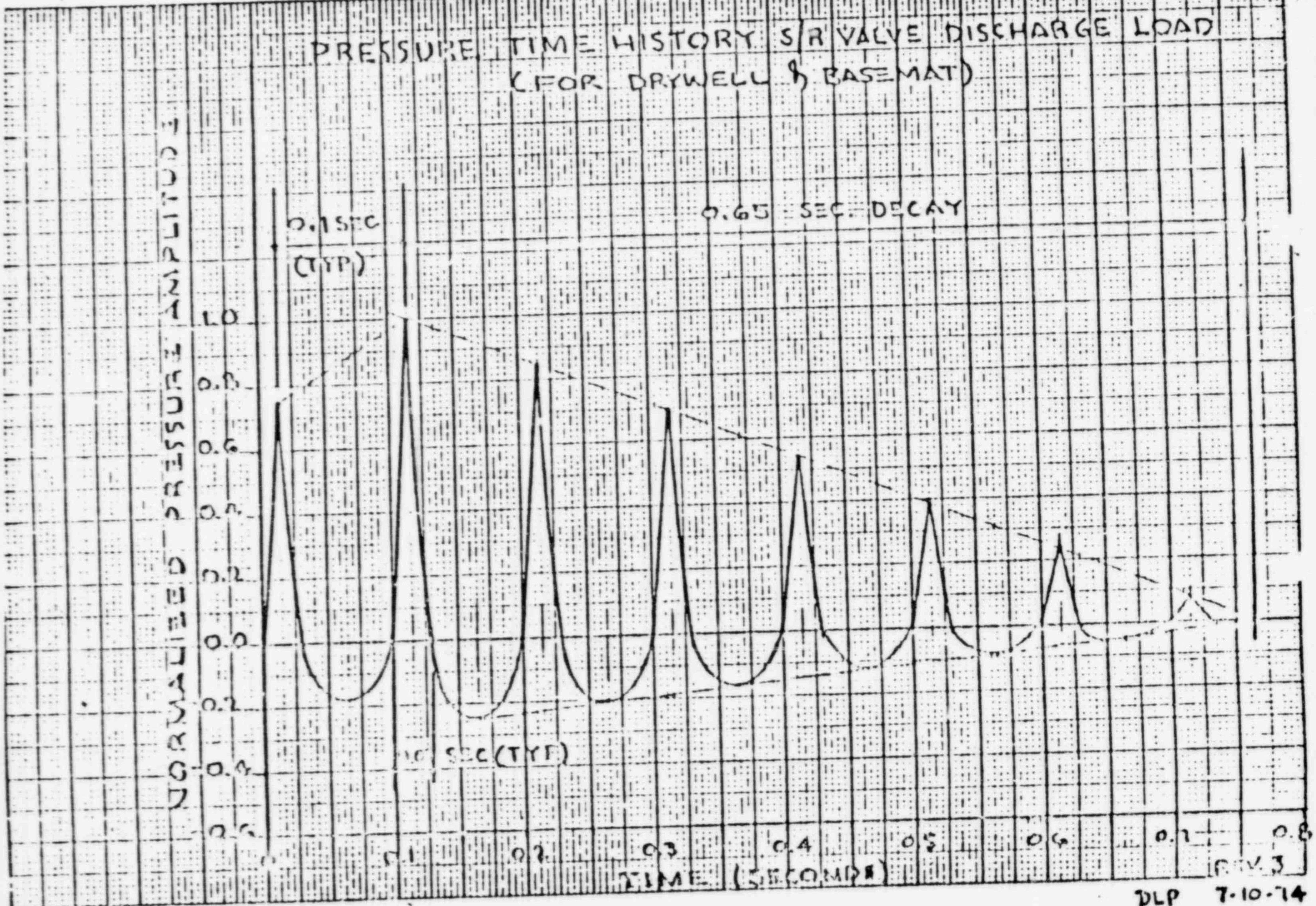
FIGURE 21



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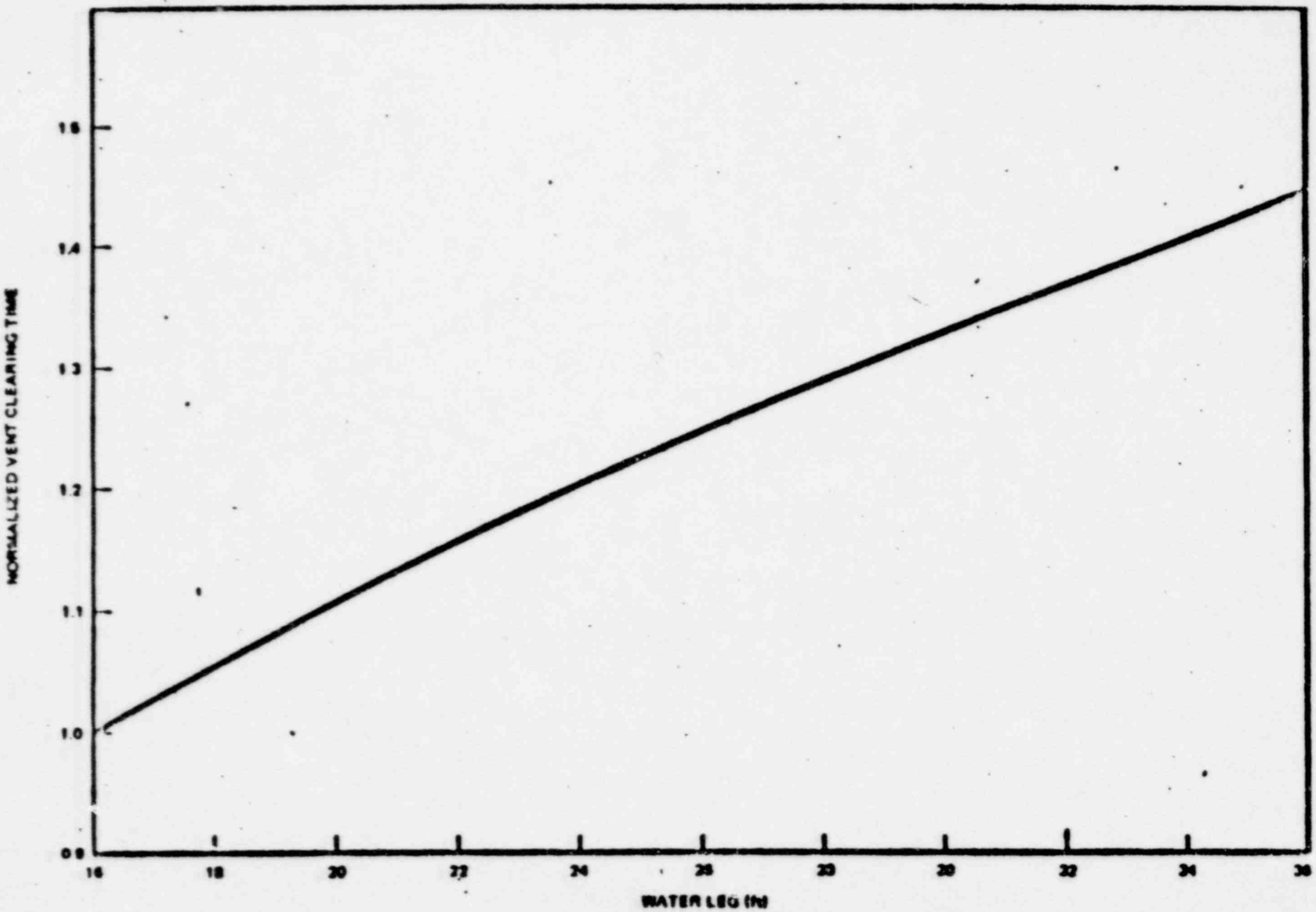

Figure A1-5. Effect of Water Leg on Vent Clearing Time

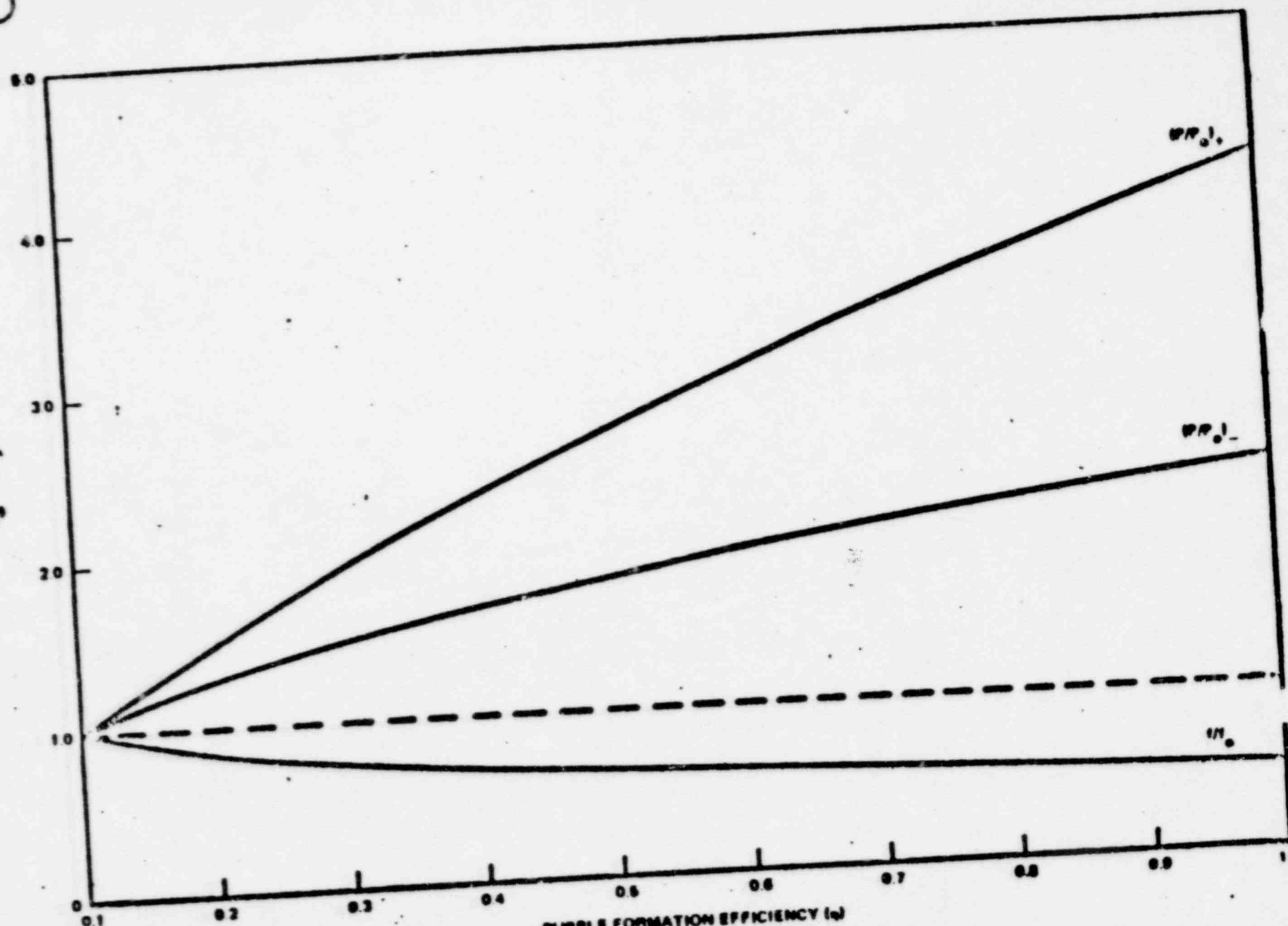

Figure A1-4. Effect of Bubble Formation Efficiency on Safety-Relief Valve Loads

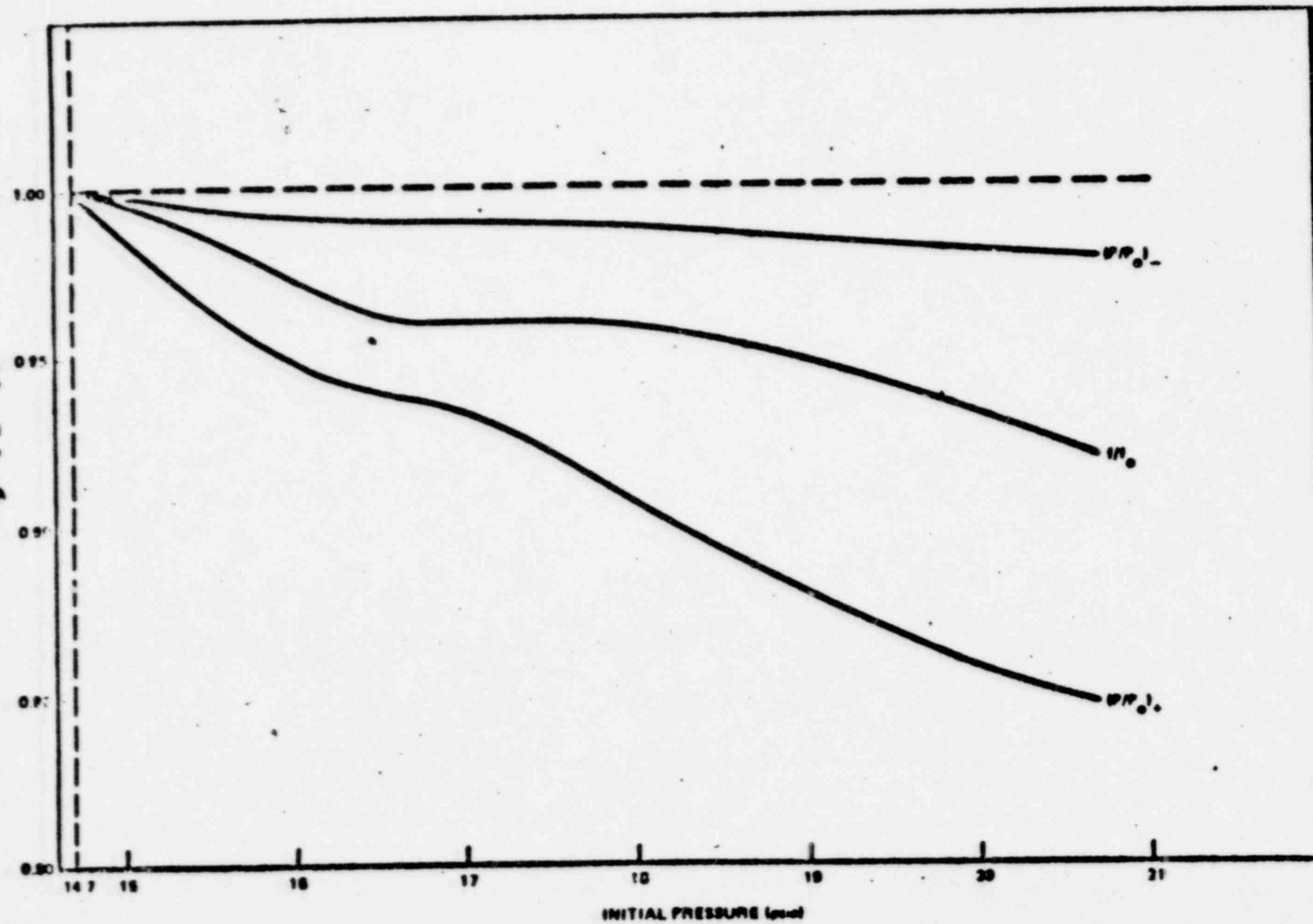

Figure A1-3. Effect of Initial Air Pressure on Safety-Relief Valve Loads

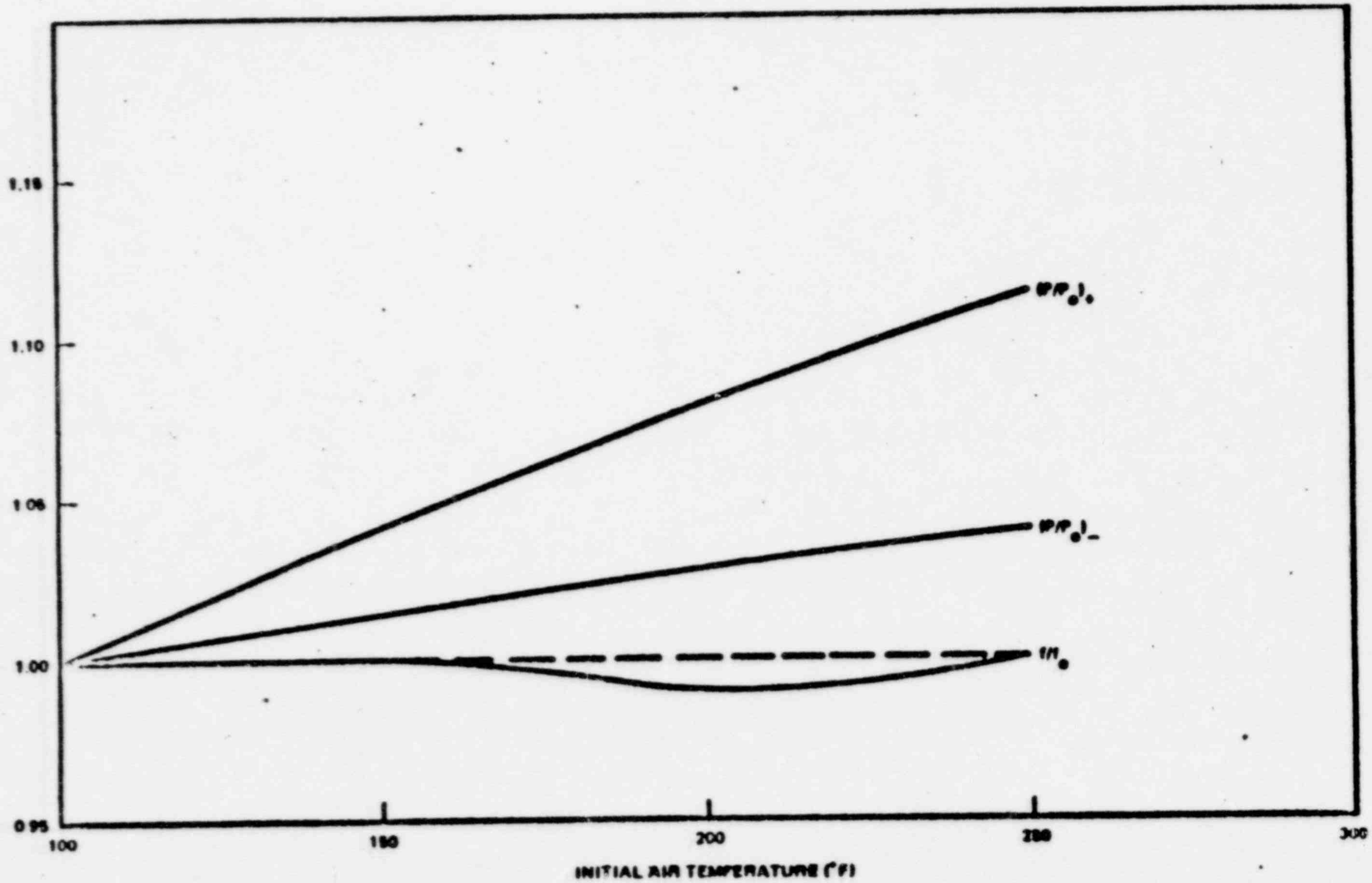

Figure A1-2. Effect of Initial Air Temperature on Safety-Relief Valve Loads

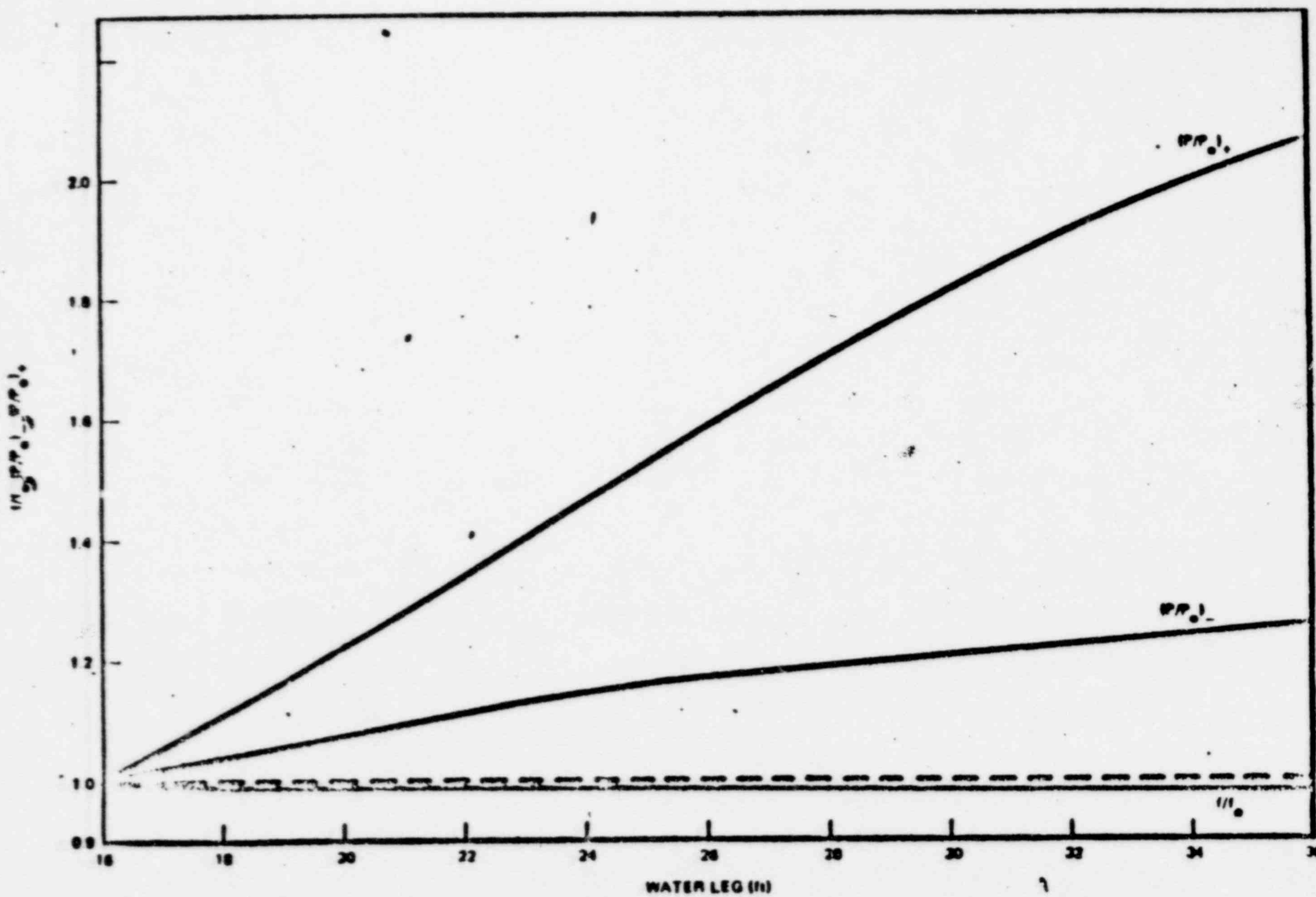

Figure A1-1. Effect of Water Leg on Safety-Relief Valve Loads

QUENCHER ARRANGEMENT

- ADVANTAGES:
  - LOWER AIR CLEARING LOADS
    - SMALLER BUBBLER
    - DISPERSION
    - BUBBLE INTERACTION
    - ENERGY DISSIPATION
  - SMOOTHER CONDENSATION
    - LARGER INTERFACE AREA
    - IMPROVED FLOW PATTERN
    - STABLE CONDENSATION AT HIGHER TEMPERATURE

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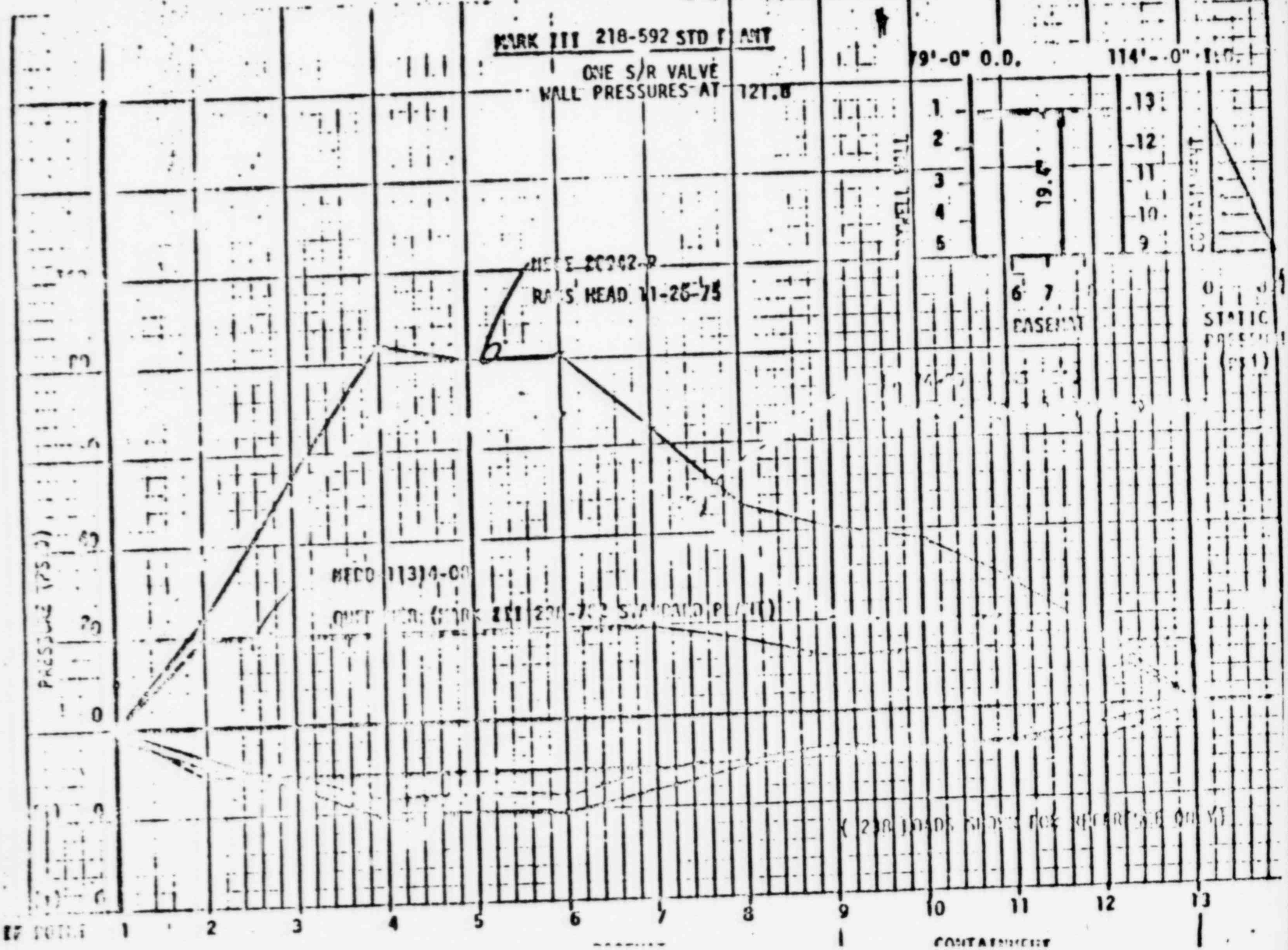
FIGURE 1


MARK III 218-592 STD PLANT
ONE S/R VALVE
WALL PRESSURES AT 121.8
79'-0" O.D.
114'-0" I.D.
19.6
BASEMAT
STATIC PRESSURE (PSI)
RAMS HEAD 11-26-75
NEDO 11314-08
PRESSURE (PSI)
CONTAINMENT

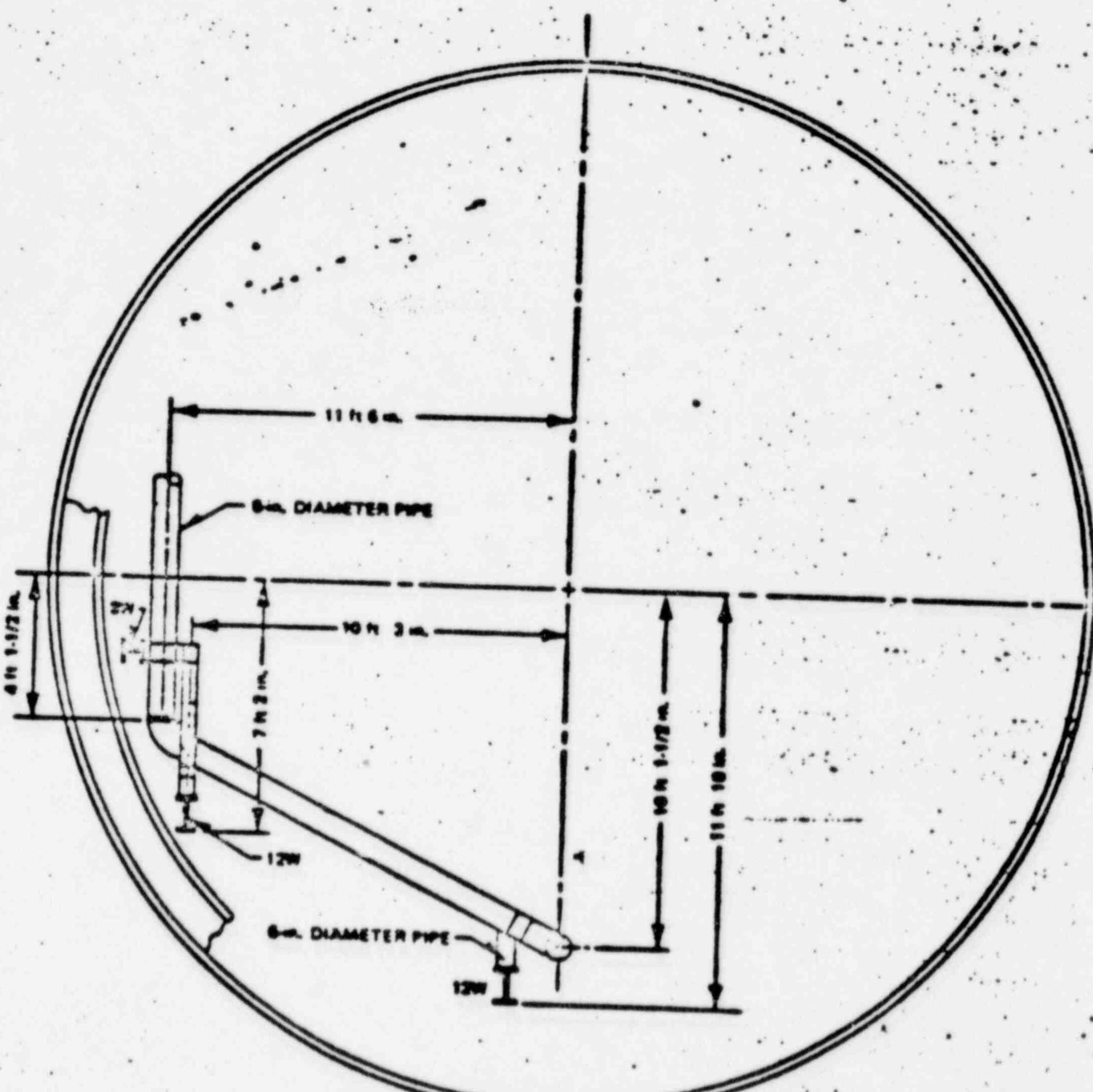


Figure 2-4. Typical Detail of Relief Valve Discharge Pipe Exit Within Torus

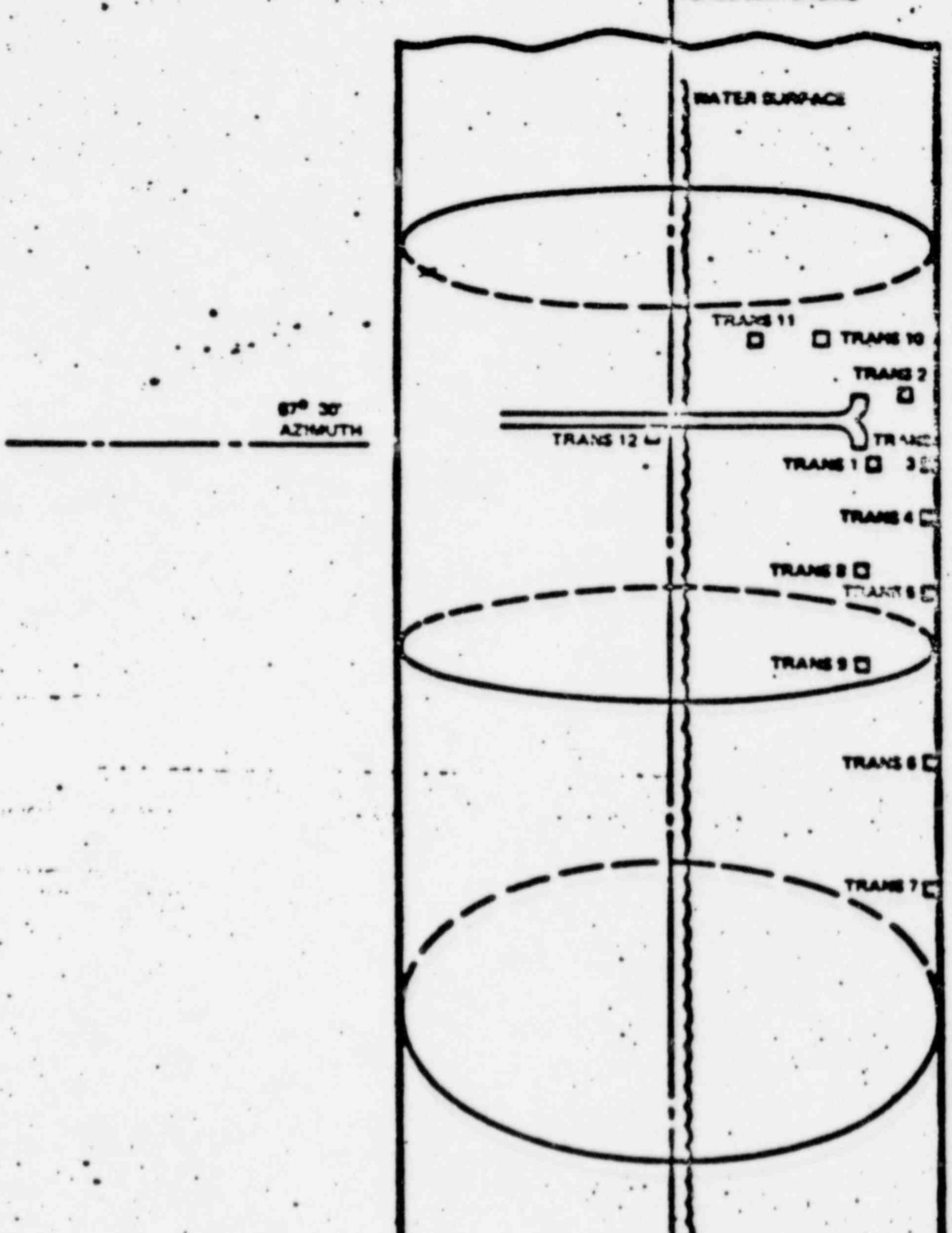


Figure 2-1. Pressure Transducer Locations

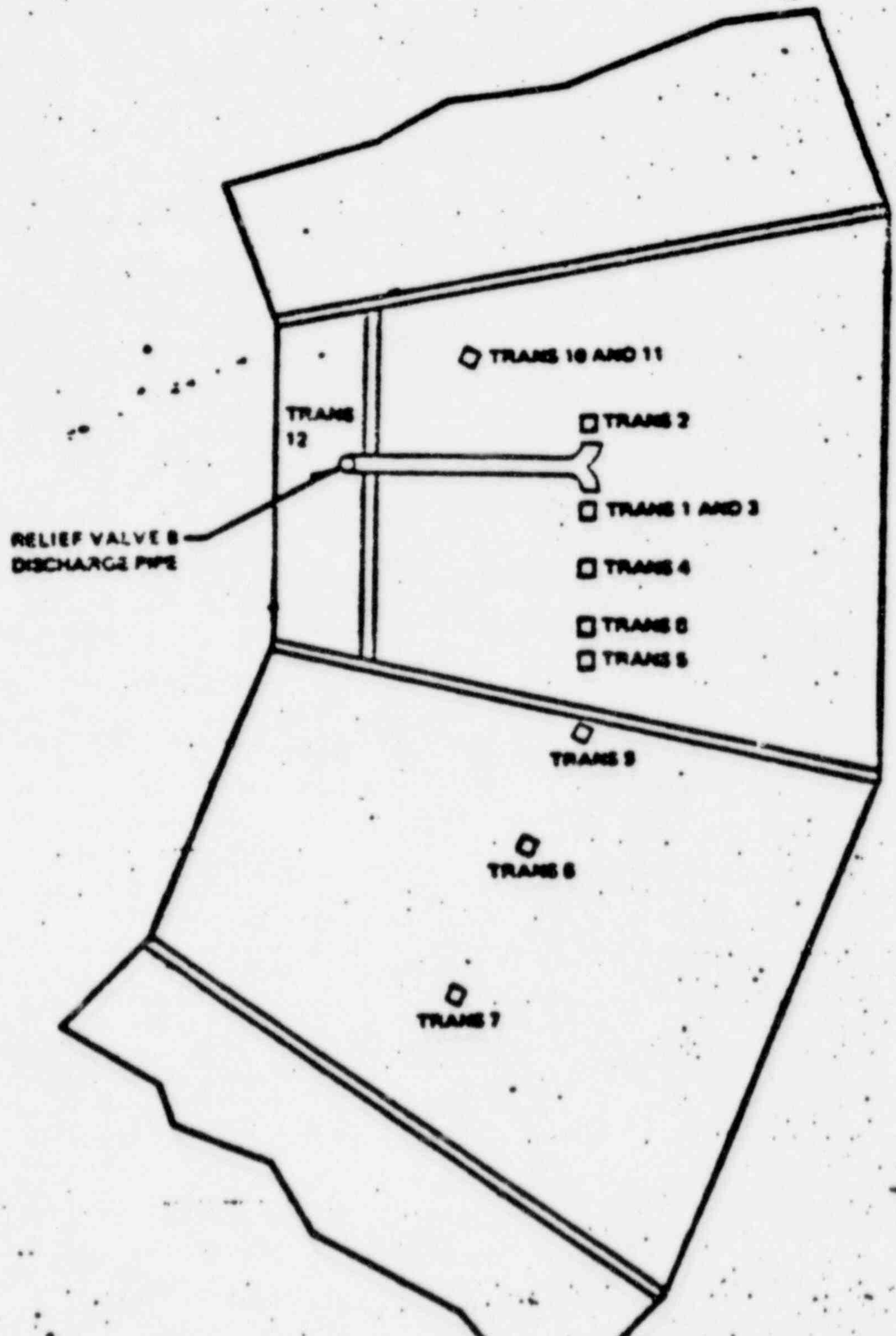


Figure 2-2. Pressure Transducer Locations

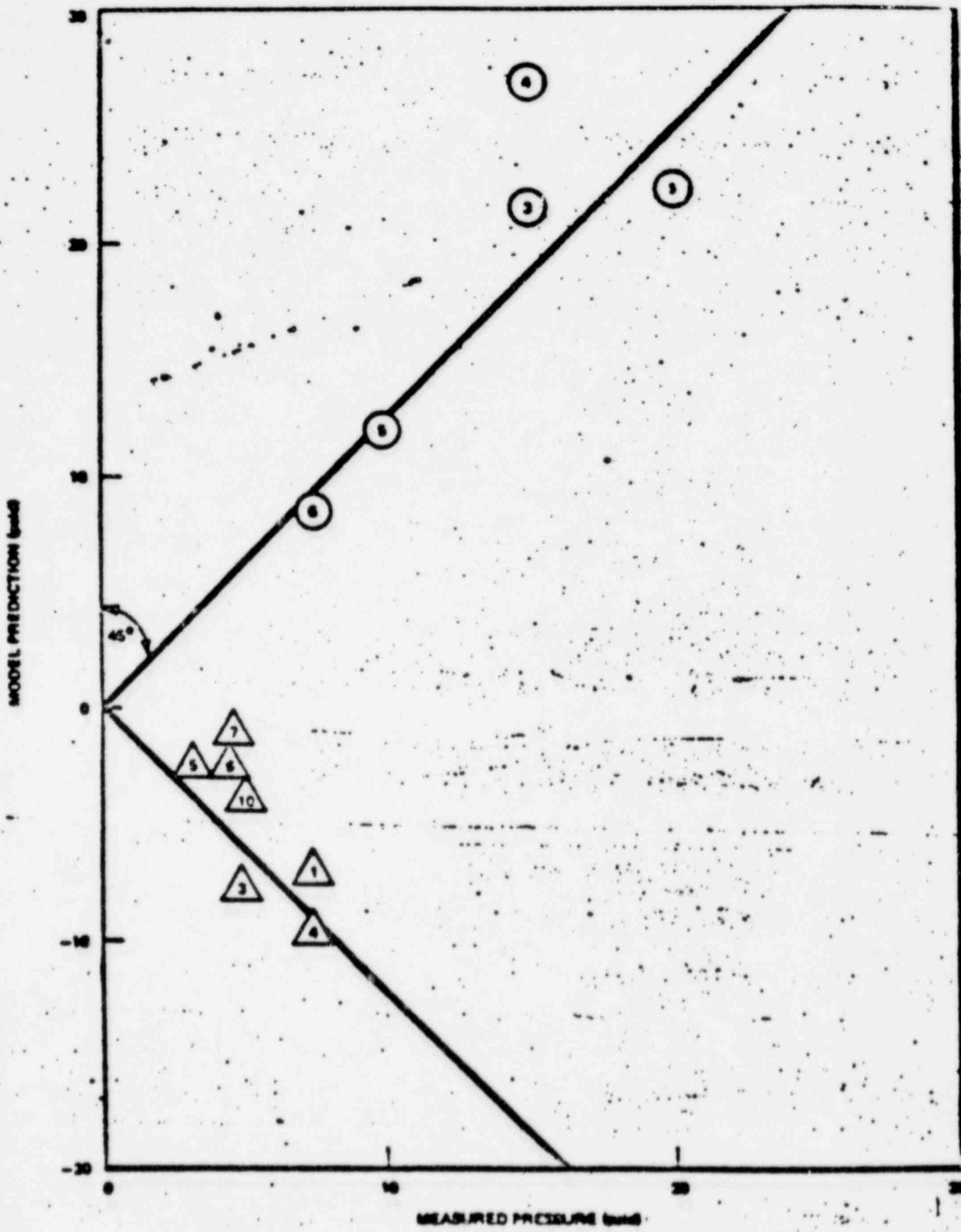


Figure 2-11. Comparison of Analysis and Data, All Five Valves, η = 0.1

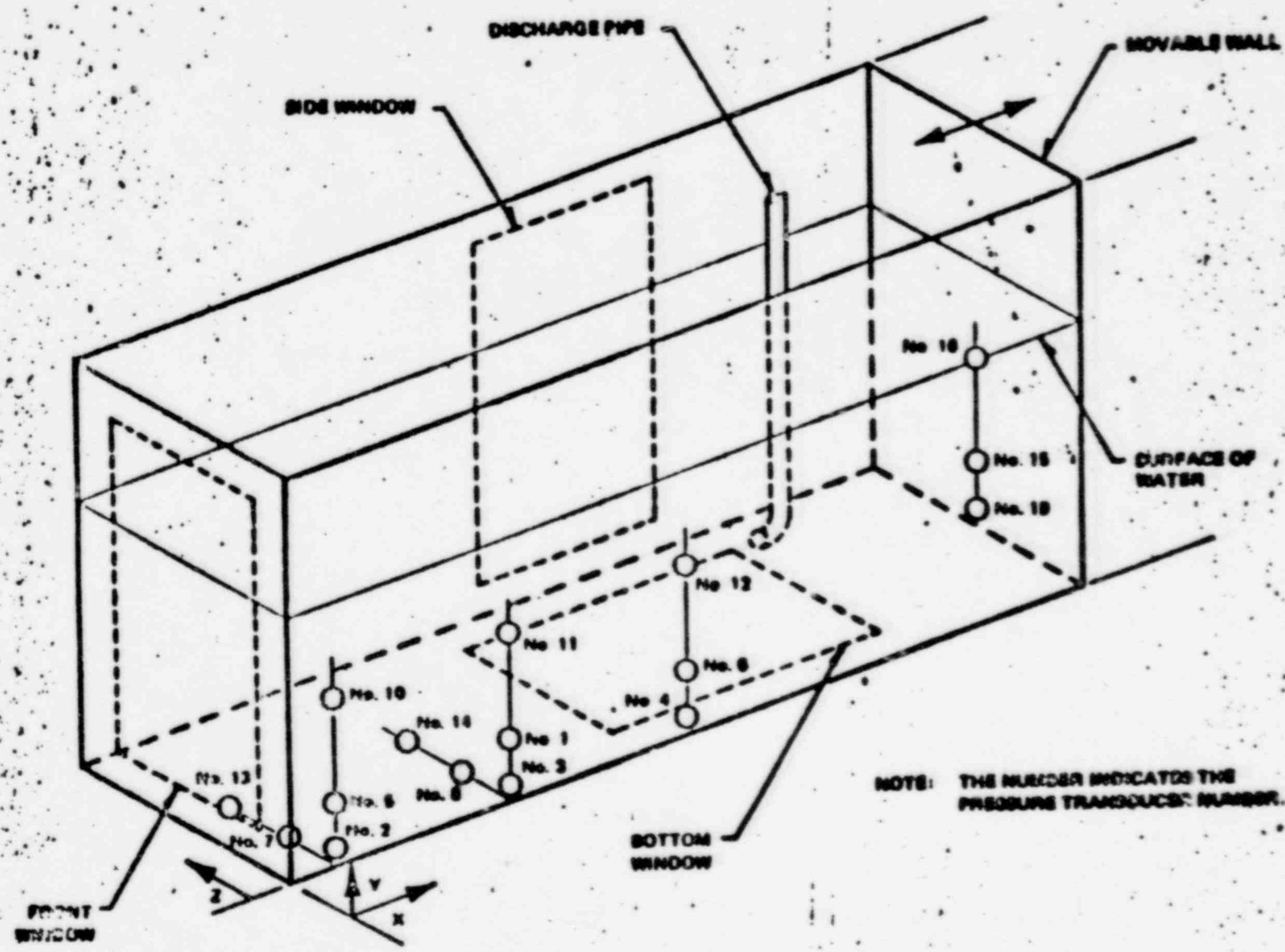


Figure 3-1, Location of Pressure Transducers

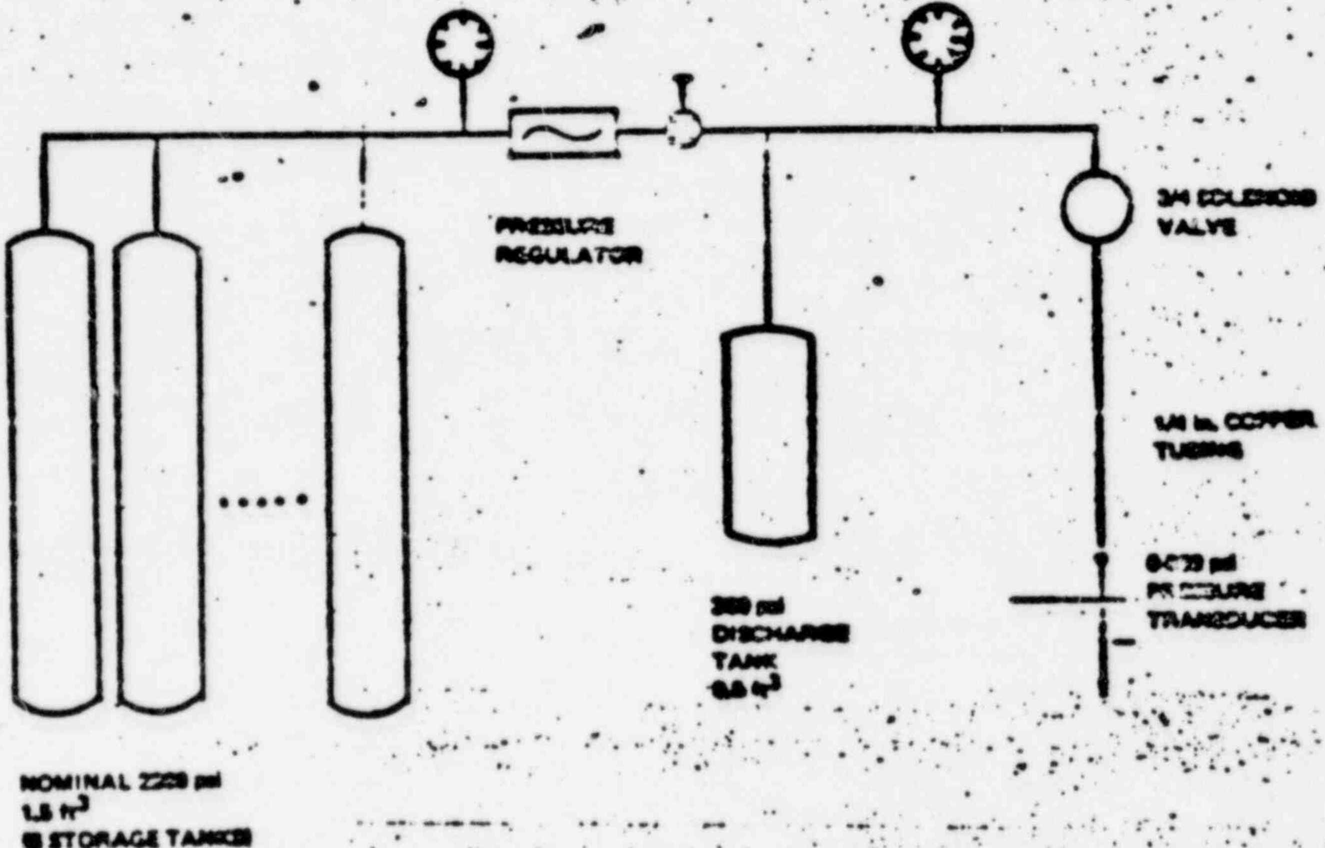


Figure 3-2. Discharge System Arrangement

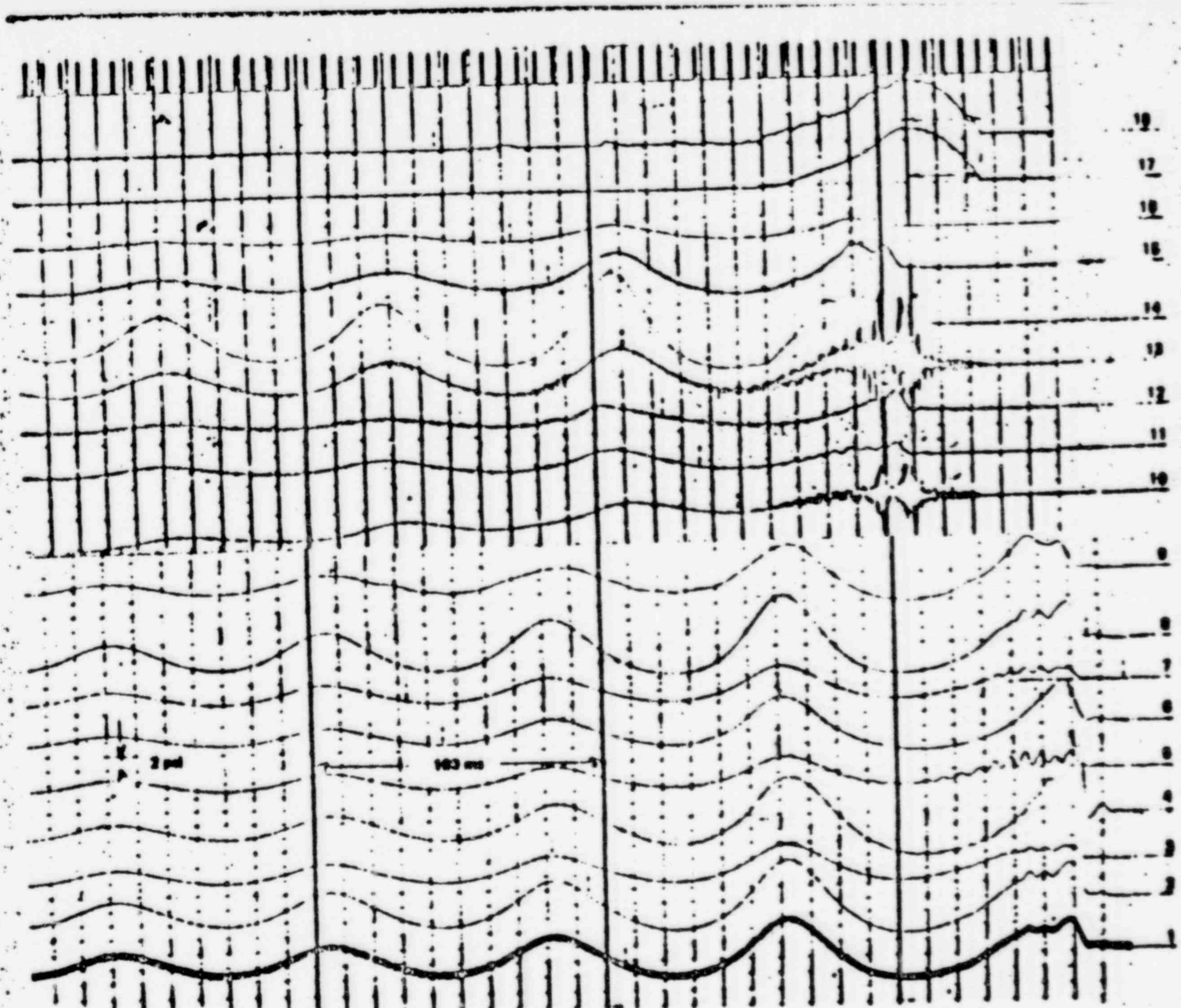


Figure 3-7. Run No. 2, Pool Depth = 30 in., Pool Length = 117 in.

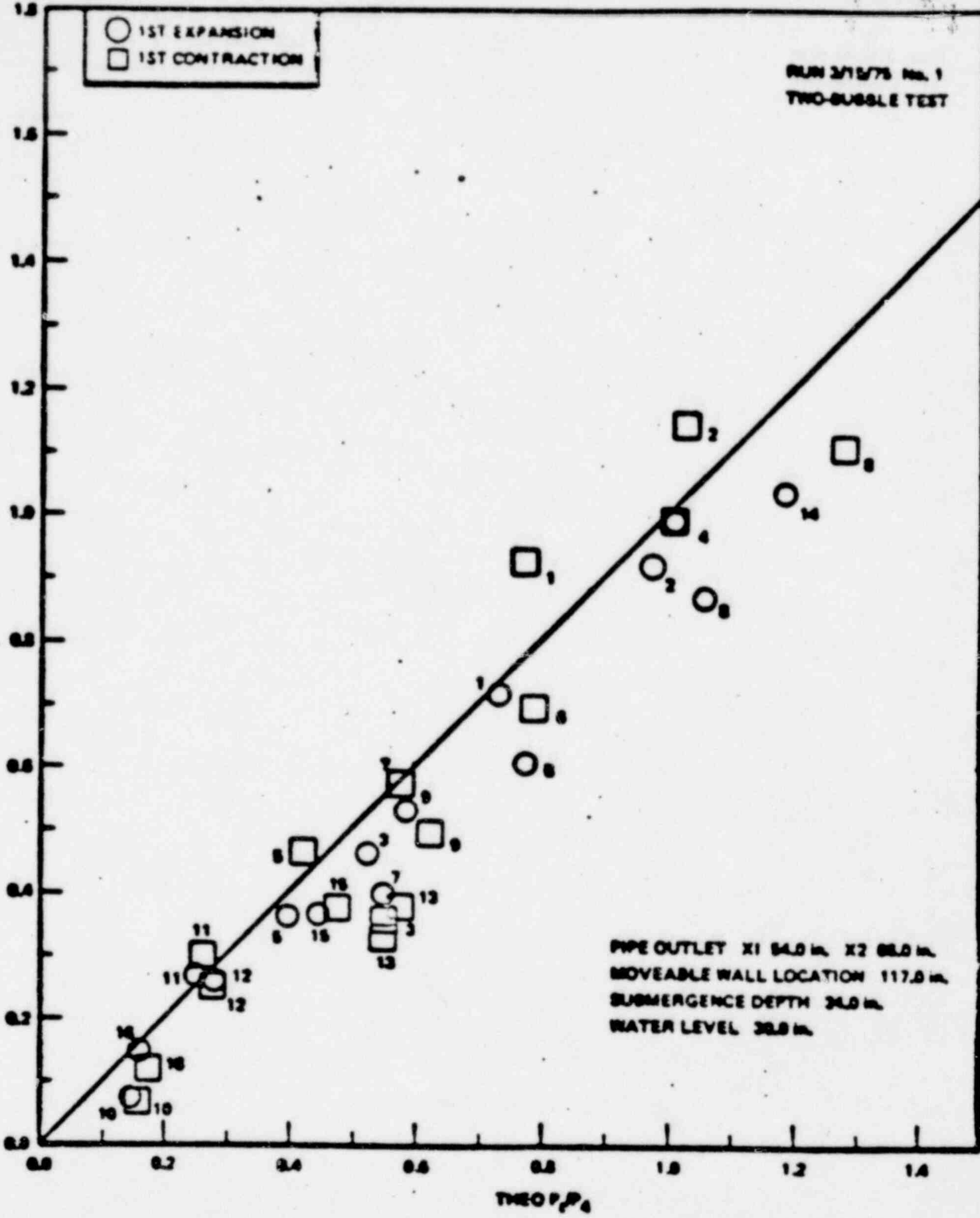


Figure 5-32 Comparison of Theory to Experiment in Pressure Ratio with Submergence 24 in., Water Level 30 in., and the Movable Wall at X = 117 in., with Two Bubbles Discharged Away from Each Other

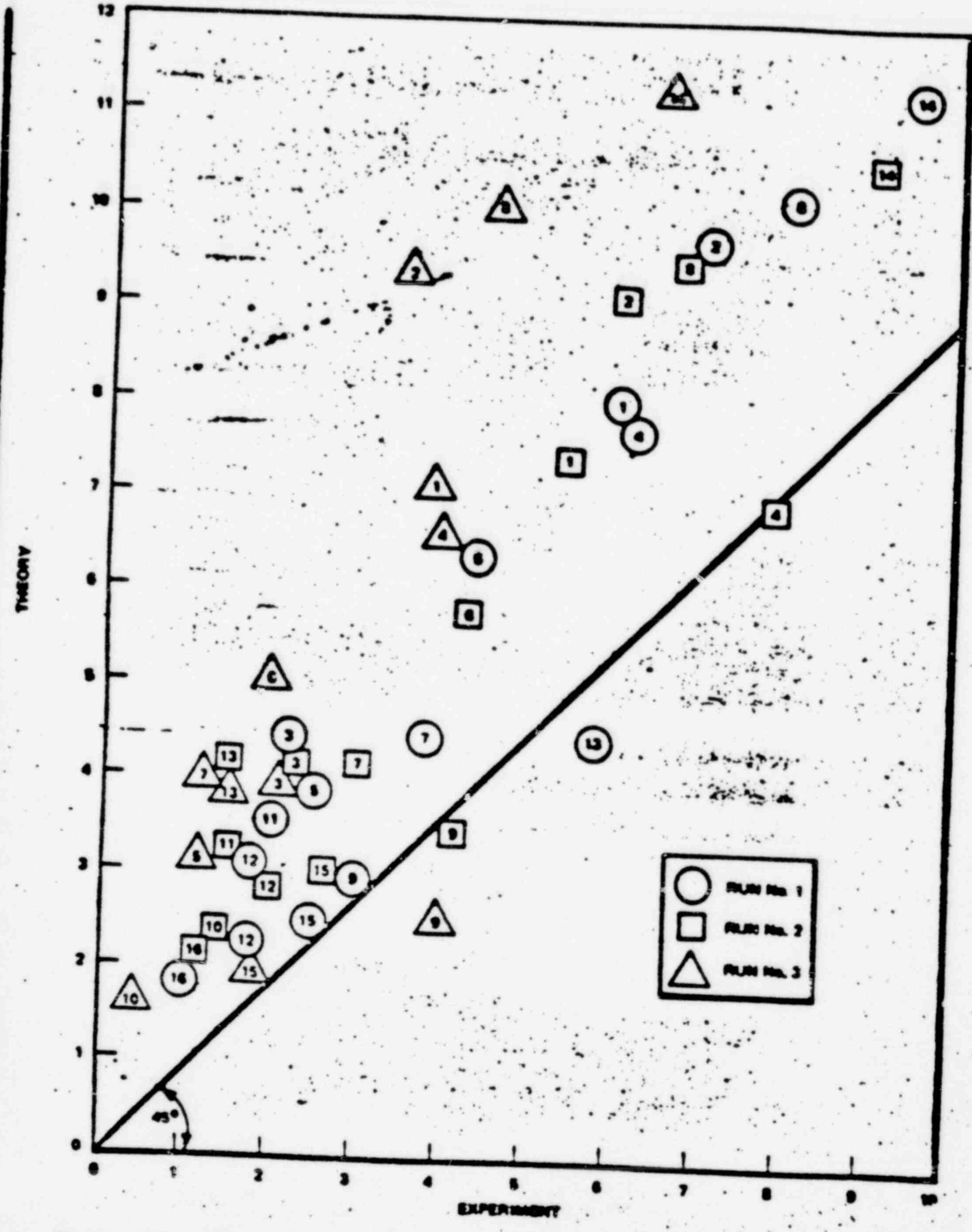


Figure 3-9. Comparison of Predicted Maximum Pressures with Test Data