HYDRAULIC MODEL STUDY OF HIGH PRESSURE CORE SPRAY PUMP SUCTION TO EVALUATE THE FORMATION OF AIR DRAWING VORTICES AND AIR WITHDRAWAL FOR CLINTON NUCLEAR POWER STATION

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Submitted to

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ABSTRACT

At the request of the Clinton Power Station, Clinton, Illinois, a hydraulic model of the Reactor Core Isolation Cooling (RCIC) Tank at the Clinton Nuclear Power Station was constructed and tested at Alden Research Laboratory, Inc. (Alden) to determine the minimum submergences required to avoid air-drawing vortices and/or air entrainment at the High Pressure Core Spray (HPCS) pump suction nozzle for a range of flows and falling water levels.

The model was constructed using a geometric scale of 1:3.051. Testing included transient water level conditions simulating the field conditions for selected flows without return flow to the tank over a desired range of flows (corresponding to prototype flows of 3,000 to 5,500 gpm) and initial water levels giving submergences of 4 ft above the suction nozzles in the model (prototype submergences of 12 ft).

Testing of the original Clinton HPCS suction configuration yielded the following results. No air drawing vortices were observed for any of the flows tested. Air entrainment for all conditions tested was due to a localized draw down of the water level in the vicinity of the suction nozzle as the water level in the tank approached the top of the suction nozzle. At simulated prototype flows of 5,500 gpm, the submergence at the onset of air entrainment ranged from 4.17 to 4.8 inches prototype and the localized draw down could first be observed when the water levels were approximately 0.7 inches (prototype) higher than those at the onset of air entrainment. At simulated prototype flows of 3,000 gpm, the onset of air entrainment ranged from 2.56 to 2.75 inches prototype and the localized draw down could first be observed when the water levels were approximately 0.6 inches (prototype) higher than those at the onset of air entrainment. At a simulated prototype flow of 4,250 gpm, the submergence at the onset of air entrainment was 3.73 inches prototype.

HYDRAULIC MODEL STUDY OF HIGH PRESSURE CORE SPRAY PUMP SUCTION TO EVALUATE THE FORMATION OF AIR DRAWING VORTICES AND AIR WITHDRAWAL FOR CLINTON NUCLEAR POWER STATION

1.0 INTRODUCTION

At the request of the Clinton Nuclear Power Station, Clinton, Illinois, a hydraulic model of the Reactor Core Isolation Cooling (RCIC) Tank at the Clinton Nuclear Power Station was constructed and tested at Alden Research Laboratory, Inc. (Alden) to determine the minimum submergences required to avoid air-drawing vortices and/or air entrainment at the High Pressure Core Spray (HPCS) pump suction nozzle for a range of flows and falling water levels.

The RCIC tank is a circular tank with an ID of 29' - 11.25". The 16" suction nozzle has an ID of 14.86" and its centerline is 26.75" from the tank floor. The nozzle exits the tank 34.6 degrees from normal to the tank, thus, the nozzle entrance is elliptical in shape. The Clinton Tank and Nozzle geometries are shown in Figures 1 through 5. The suction flows vary depending on the operating cases from 3,000 gpm to 5,500 gpm.

The hydraulic model study allowed evaluation of vortex formation and air withdrawal, if any, over the range of operating water levels.

The Clinton model was constructed using a geometric scale of 1:3.051. The model tank had an I.D. of 9.813 ft and was approximately 6 ft deep. The tank was fitted with a removable floor and had a finished depth of approximately 5.5 ft, which allowed simulation of water levels corresponding to as high as about 16 ft in the plant. However, only lower water levels were tested, as air-entrainment due to air-drawing vortices or other anticipated conditions is likely to occur at lower water levels. Downstream piping geometry just outside the tank is unlikely to influence the flow patterns at the suction nozzle entrance, if a straight pipe of 5 pipe diameters or more is available immediately after the suction pipe exits the tank. In the Clinton plant, about 20 pipe diameters of straight piping is available. Hence, in the model, even though the 16 inch outlet pipe geometry within the tank was fully simulated, outside the tank it was only necessary to simulate approximately 5 pipe diameters of horizontal straight piping. Additionally, two nozzles internal to the tank (Nozzle K and Nozzle N2) were also modeled due to their close proximity to the suction nozzle which could influence the flow patterns and consequently vortex formation. These nozzles were modeled as obstructions to the flow only. The Clinton test setup is shown in Figures 6 and 7.

Tests were conducted such that air-drawing vortices and/or air entrainment due to outflow through the suction nozzle could be investigated over a desired range of flows and initial water levels and with a desired rate of drop of the water level.

2.0 MODEL SIMILITUDE

2.1 Free Surface Flow

Models involving a free surface are constructed and operated using Froude similarity since the flow process is controlled by gravity and inertial forces. The Froude number, representing the ratio of inertial to gravitational forces, can be defined for pump intakes as,

$$F = \frac{u}{\sqrt{gd}} \tag{1}$$

where

u	=	average axial velocity at the intake
g	=	gravitational acceleration
d	=	intake diameter (or diameter of a circle having equivalent area to the Elliptical entrance of the nozzle as with the Clinton nozzle)

The model Froude number, F_m, was therefore, made equal to the prototype Froude number F_p to satisfy the required scaling criteria.

$$F_m = F_p \tag{2}$$

Where F_m and F_p denote model and prototype Froude numbers. Dividing both sides of equation (2) by F_p gives

$$F_r = 1 \tag{3}$$

Where Fr denotes the ratio between model and prototype Froude numbers,

Substituting Equation (1) into Equation (2) and defining the length ratio by Equation (4), results in the velocity scale ratio given in Equation (5).

$$L_m / L_p = L_r \tag{4}$$

where L_r is the length scale ratio,

$$V_r = (L_r)^{0.5} \tag{5}$$

The flow ratio, Q_r, may be written as

$$Q_r = A_r V_r \tag{6}$$

Where A_r is the area ratio

Substituting Equation (5) into Equation (6), and noting that A can be dimensionally expressed as L^2, yields

$$Q_r = L_r^{5/2} \tag{7}$$

In modeling of a pump intake to study the formation of vortices, it is important to select a reasonably large geometric scale to achieve large Reynolds numbers so as to minimize viscous scale effects and to reproduce the flow pattern in the vicinity of the intake [Anwar, 1978].

2.2 Similarity of Vortices

The fluid motions involving vortex formation in pump intakes have been studied by several investigators. It can be shown by principles of dimensional analysis that the dynamic similarity of fluid motion that could cause vortices at an intake is governed by the following dimensionless parameters:

$$\frac{ud}{\Gamma}, \frac{u}{\sqrt{gd}}, \frac{d}{s}, \frac{ud}{\nu}, \text{ and } \frac{u^2 d}{\sigma/\rho}$$

$$\frac{u}{\sqrt{gd}} = \text{Froude number,}$$

$$\frac{ud}{\nu} = \text{Reynolds number,}$$

of which,

and,

$$\frac{u^2 d}{\sigma/\rho} = \text{Weber number.}$$

where

u	=	average axial velocity at the intake
Γ	=	circulation contributing to vortexing

d	=	diameter of the intake
S	=	submergence at the intake
ν	=	kinematic viscosity of water
g	=	acceleration due to gravity
σ	=	surface tension of water air interface
ρ	=	water density

The influence of viscous effects is defined by the Reynolds number, and surface tension effects are indicated by the Weber number. As strong air-core type vortices, if present in the model, would have to be eliminated by a modified design, the main concern for interpretation of model performance involves the similarity of weaker vortices. If the influence of viscous forces and surface tension on vortexing is negligible, dynamic similarity is obtained by equating the parameters ud / Γ, $u / \sqrt{gd}$, and d/s in model and prototype. A Froude model satisfies this condition, provided the approach flow pattern in the vicinity of the intake, which governs the circulation, Γ, is properly simulated.

Alden has conducted considerable research on scaling free surface and submerged vortices. From a study of horizontal outlets for a depressed sump conducted for containment sumps for Nuclear Power plants [NUREG/CR-2760, 1982 and Padmanabhan and Hecker, 1984], it was determined that no scale effect on vortex strength, frequency, or air withdrawal existed for pipe Reynolds numbers above 7×10^4.

Daggett and Keulegan [1974] indicated that an inlet Reynolds number of 3×10^4 is sufficient to obtain a good model to prototype correlation of vortices. Anwar [1978], using a radial Reynolds number, indicated that viscous forces become negligible at Reynolds numbers of 3×10^4.

Surface tension effects have been shown to be negligible for Weber numbers, W, greater than 120 [Jain et. al., 1978]. The Hydraulic Institute Standards (HI Standards) uses a safety factor of 2 for these values to ensure minimum scale effects for test conditions based on Froude similitude.

Based on the above considerations, the HI Standards recommends that the model scale be chosen such that the model Reynolds and Weber numbers are at least 6×10^4 and 240, respectively.

Considering the recommendations from various studies described above, the model scale for the present study has been chosen so that the Reynolds and Weber numbers for the model with the Froude scaled flows would be well above 7×10^4 and 240, respectively, so that no significant viscous and surface tension scale effects would be present in the model.

2.3 Similitude of Self Aerated Flows

Air entrainment is possible due to draw down as the transient water level in the tank approaches the top of the suction nozzle and the flow is at the verge of changing from closed conduit flow in the suction nozzle to free surface flow in the suction nozzle. This phenomenon of air being drawn from the free surface in the tank into the pipe during the draw down falls under the class of flows known as self-aerated flows similar to free surface flows involving air entrainment in drop shafts, hydraulic jumps and free surface vortices. The modeling of self aerated turbulent flows is based on Froude Similitude, as the gravity and inertial forces are the predominant forces, [Characteristics of Self-Aerated Free Surface Flows, by N.S. Rao and H.E. Kobus]. Hence, the Froude similitude that is needed for simulation of vortices is also sufficient for simulation of self-aerated flow resulting from sudden drawdown under transient conditions.

2.4 Model Scale Selection

The selected model geometric scale of 1:3.051 for the Clinton HPCS pump suction nozzle provided a model nozzle pipe of 4.875" I.D. The chosen scale allowed the use of commercially available plexiglass pipe. With the proposed geometric scale, both the Reynolds and Weber numbers in the model were high enough to assume that the model (operated based on Froude similitude and with model water temperatures between 51.8°F and 53.6°F) is free of any significant viscous and surface tension scale effects throughout the range of flows tested. The minimum Reynolds and Weber numbers in the model throughout the range of flows tested and water temperatures was 8.6 x 10^4 and 1,180, respectively.

With the selected model geometric scale mentioned above, the length, velocity, flow, and time scales in the model is as follows:

Scaled Parameter	Clinton Model
Length Scale $L_r = L_m / L_p$	1 /3.051
Velocity Scale $V_r = V_m / V_p = (L_r)^{1/2}$	1 / 1.747
Flow Scale $Q_r = Q_m / Q_p = (L_r)^{5/2}$	1 / 16.259
Time Scale $T_r = T_m / T_p = (L_r)^{1/2}$	1 / 1.747

2.5 Effect of Other Model Parameters on Vortex Formation

2.5.1 Test Liquid

All models used water as the test liquid, as in the prototype. For the flows of interest the prototype Reynolds and Weber numbers are above 7 x 10^4 and 240, respectively, and hence, as discussed in Section 2.2, any viscous or surface tension effects on vortexing would be negligible. Hence, the vortexing phenomenon in the prototype would be governed by the Froude number and submergence, which are independent of fluid properties. As discussed in Section 2.3, with the selected model scale, no significant viscous or surface tension effects on vortexing is expected in the model using water as the test liquid. The Froude number and submergence would control vortexing phenomenon in the model as in the prototype.

2.5.2 Acceleration Due to Gravity (g)

The value of g at the model location is 32.16 ft/sec^2. For calculation purposes, a rounded off value of 32.2 ft/sec^2 is used. As all the tests of results are made non-dimensional using the Froude number, the results can be used with the exact value of the Froude number for the prototype calculated with the correct g in the field.

2.5.3 Tank Air Pressure

A constant tank air pressure (atmospheric) was used in the model. The prototype tank is vented to atmospheric, hence, a constant tank air pressure (atmospheric) would also occur in the prototype during the transient water level drop. Any slight difference in atmospheric pressure between the model and prototype locations would not affect vortex phenomena, as the submergence at the outlet pipe is actually the difference in pressure between the water surface and the pipe invert, which is independent of the air pressure at the tanks. Submergence and Froude number control the vortexing phenomena.

2.5.4 Water Temperature

The kinematic viscosity and surface tension of water change with temperature, and hence, would impact the Reynolds (Re) and Weber (W) numbers, respectively. However, above certain threshold values of Re and W (about 7×10^4 and 240, respectively, as discussed in the similitude section of the report), vortex formation and severity of vortices are not significantly affected by Re and W. The model scale has been chosen such that at the model flows, Re and W are above the threshold values with model water temperatures between 51.8°F and 53.6°F. As the Re and W values in the field (at corresponding water temperatures and flows in the field), are much higher than those in the model, vortex formation and vortex severities predicted by the model are applicable in the field for the water temperature ranges anticipated in the field.

3.0 MODEL DESCRIPTION

As mentioned previously, the model was designed and constructed using a geometric scale of 1:3.051 to simulate the Clinton RCIC tank from the floor to a height of approximately 16 ft (prototype). The 16 inch outlet pipe geometry within the tank and outside the tank to include approximately 5 pipe diameters of horizontal piping were simulated in the model. Additionally, Nozzle K and Nozzle N2 were also simulated as flow obstructions in the model. Several additional nozzles and obstructions located in the tank were not modeled since their location was sufficiently far away so as not to affect the flow patterns near the suction nozzle of interest. Photographs of the Clinton model nozzle geometries are shown in Figures 8 and 9.

As shown in Figures 6 and 7, the model was provided with a flow loop. The flow loop included a laboratory sump to draw water from the tank and return piping to return the flow to a laboratory sump. An orifice flow meter calibrated at Alden was used for flow measurements and model flows were set using appropriate valves and a Variable Frequency Drive. Photographs of the model flow loop are shown in Figure 10.

A Tap located on the side wall of the model RCIC tank was used to read water levels in the tank with a differential pressure transducer, one side of which was connected to a known fixed water column. The location of this tap was located approximately 90 degrees from the suction nozzle as in the prototype.

A rectangular acrylic box, enclosing the model outlet pipe, was installed at a selected location to facilitate the viewing and video documentation of air entrainment. This box, when filled with water, allowed compensation for the refraction due to the curvature of the pipe and provided a good viewing and video taping location for air bubble identification. The viewing box is shown in Figure 11.

4.0 INSTRUMENTATION AND MEASURING TECHNIQUES

4.1 Flow

All flows were measured with a standard ASME orifice meter installed in the outflow piping downstream of the suction nozzle. The differential head from the orifice meter was measured using a differential pressure cell. A computer data acquisition system using TESTPOINT software was used to record flows during testing. The orifice meter and differential pressure cells were calibrated at the Alden calibration facility, and the calibration curves are given in Appendix A, including calibration of the pressure cells. DP cells were calibrated in conjunction with the computer data acquisition system. The accuracy of the flow measurement is estimated at ±2% of the units of measure (GPM). It should be noted that while the calibration report in Appendix A includes calibration for 2, 3 and 6 inch orifice meters, only the 6 inch meter was used for this study.

For Clinton testing, a DP cell with a range of a 0-72 inches (cell # 0697) was used to measure the meter deflection of the 6 inch orifice meter. The 6 inch meter was used to measure target flows of 3,000 to 5,500 gpm prototype (184.5 to 338.3 gpm model) for which the meter deflection range for the target flows was 8.85 to 29.77 inches. The accuracy of the DP cell was ±0.25% of the DP cell span.

4.2 Free Surface Vortices

In order to systematically evaluate the strength of free surface vortices, Alden uses a vortex strength scale of Type 1 to Type 6, as shown in Figure 12, where Type 1 is a surface swirl and Type 6 is an open air-core vortex to the outlet. Vortex types were identified in the model by visual observations with the help of dye tracers. As the tests were under transient conditions and limited time was available to identify vortices, vortex identification was qualitative and limited air-bubble drawing or air core vortices (Types 5 and 6).

4.3 Water Level

Water levels were tracked using a DP cell with a range of a 0-72 inches (cell # 0626), stilling well and vernier point gauge, and were measured with an accuracy of ±0.25% of the DP cell span. The differential pressure cell used to track the water level was also calibrated at the Alden calibration facility and the calibration data are given in Appendix A. Also, as with the flow measurements, a computer data acquisition system using TESTPOINT software was used to record water levels during testing.

5.0 TEST PLAN

The test plan included transient water level tests with no return flow in the model. The test matrix for the Clinton HPCS suction nozzle study is shown in Table 1. The test matrix consisted of 7 tests with no return flow to the tank. Tests for Clinton covered flows ranging from 3,000 to 5,500 gpm (prototype) and the initial water depths tested covered initial submergences corresponding to about 12 ft above the suction nozzle entrance in the plant.

Vortex and air entrainment observations were made under transient conditions (as the water level dropped). For each test, a video recording of any vortices in the tank and air-entrainment in the suction nozzles were obtained. The scope of testing was the same for all tests.

6.0 TEST PROCEDURE

Copies of the step by step test procedures for Clinton testing are given in Appendix B of the report. A brief description is given below.

The tank was first filled with water approximately to the desired initial water level using a laboratory fill pump. All differential pressure cells for flow meter differential pressure and water level measurements were purged and checked and the computer data acquisition system was initiated.

Separate video cameras were set up at the tank and at the view box to record the onset of air entraining vortices or air entrainment. The test number and water level were entered and the time clocks in the computer and video system were synchronized.

The pump in the flow loop was started and the pump speed was adjusted until the flow was set to the desired flow, as indicated by the computer (flow meter computer data acquisition), and the return flow was returned to the laboratory sump. The test was now initiated with the computer acquiring and storing data and start the video recording system with the timer on, recording the various flow phenomena of interest.

With continuous video recording, and flow and water level monitoring with the computer, any air bubbles drawn in the suction nozzles were noted.

The test was ended as soon as the flow could no longer be maintained. The pump was shut down and the flow loop was prepared for the next test.

7.0 RESULTS

The results discussed below are based on the test data supported by visual observations and video documentation of air drawing free surface vortex types in the tank and air entrainment observations in the outlet pipe (view box location) for the plant configuration.

To represent the data in terms of non-dimensional variables, the following are defined:

$$\text{Froude number, } F = U / (gd)^{0.5} \tag{8}$$

where

u	=	average model velocity at the suction nozzle entrance
g	=	gravitational acceleration
d	=	suction nozzle entrance diameter (or diameter of a circle having equivalent

area to the elliptical entrance of the nozzle as with the Clinton nozzles.

The test matrix for the Clinton HPCS suction nozzle study is shown in Table 1 and a summary of the test data is shown in Table 2. As mentioned previously, the test matrix consisted of 7 tests with no return flow to the tank. Tests covered specified flows ranging from 3,000 to 5,500 gpm (prototype) and the initial water depths tested covered initial submergences corresponding to about 12 ft (prototype) above the suction nozzle entrance in the plant.

The submergence datum reference is shown on Figure 7. Average model flows were calculated using the recorded flow rates from approximately 1 foot of submergence to the onset of air entrainment. Froude number calculations were made using model velocities calculated from average model flows.

Three tests simulating prototype flows of 5,500 gpm were conducted (Tests 1a through 1c). No actual air drawing vortices were observed, however, air was entrained into the suction nozzle due to a localized draw down of the water level in the vicinity of the suction nozzle as the water level in the tank approached the top of the suction nozzle. The submergence at the onset of air entrainment was 4.65, 4.17 and 4.8 inches prototype for test 1a, 1b, and 1c, respectively. For test simulating prototype flows of 5,500 gpm, the localized draw down could first be observed when the water levels were approximately 0.7 inches (prototype) higher than those at the onset of air entrainment.

Three tests (Tests 2a through 2c) were also conducted simulating prototype flows of 3,000 gpm. As with testing at the higher flows, no actual air drawing vortices were observed. Observed air entrainment in the suction nozzle was due to a localized draw down of the water level in the vicinity of the suction nozzle as the water level in the tank approached the top of the suction nozzle. The submergence at the onset of air entrainment was 2.60, 2.56 and 2.75 inches prototype for test 2a, 2b, and 2c, respectively. For test simulating prototype flows of 3,000 gpm, the localized draw down could first be observed when the water levels were approximately 0.6 inches (prototype) higher than those at the onset of air entrainment.

One test (Test 3) was also conducted at an intermediate flow of 4,250 gpm prototype. Results were similar to previous test in that no actual air drawing vortices were observed. Air entrainment in the suction nozzle was due to a localized draw down of the water level in the vicinity of the suction nozzle as the water level in the tank approached the top of the suction nozzle. The onset of air entrainment occurred at a submergence of 3.73 inches prototype.

8.0 CONCLUSIONS

The hydraulic model study of the existing High Pressure Core Spray Suction at the Clinton Nuclear Power Station led to the following conclusions.

1. No air drawing vortices were observed for any of the flows tested.

2. Air entrainment for all conditions tested was due to a localized draw down of the water level in the vicinity of the suction nozzle as the water level in the tank approached the top of the suction nozzle.

3. For the three tests conducted at simulated prototype flows of 5,500 gpm (Tests 1a through 1c) the onset of air entrainment occurred at submergences of 4.65, 4.17 and 4.80 inches prototype, respectively. The localized draw down could first be observed when the water levels were approximately 0.7 inches (prototype) higher than those at the onset of air entrainment.

4. For the three tests conducted at simulated prototype flows of 3,000 gpm (Tests 2a through 2c) the onset of air entrainment occurred at submergences of 2.60, 2.56 and 2.70 inches prototype, respectively. The localized draw down could first be observed when the water levels were approximately 0.6 inches (prototype) higher than those at the onset of air entrainment.

5. At the intermediate flow of 4,250 gpm prototype, the onset of air entrainment occurred at a submergence of 3.73 inches prototype.

9.0 REFERENCES

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TABLES

Table 1
Clinton HPCS Suction Test Matrix

Test No.	Prototype Flow (gpm)	Scaled Model Flow (gpm)	Initial Model Water Level (in)
1a	5500	338.3	48
1b	5500	338.3	48
1c	5500	338.3	48
2a	3000	184.5	48
2b	3000	184.5	48
2c	3000	184.5	48
3	4250	261.4	48

Note: Water level is measured from the top of the suction nozzle.

Table 2
Clinton HPCS Suction
Test Summary

Test No.	Target Prototype Flow (gpm)	Target Model Flow (gpm)	Avg. Model Flow (gpm)	Initial Water Level (Model in)	S, Submergence at Onset of Air Entrainment (Model in)	S, Submergence at Onset of Air Entrainment (Prototype in)	Model Froude No. Using Avg. Model Flow	Prototype Froude No. Using Target Prototype Flow
1a	5500	338.3	340.8	48	1.52	4.65	1.28	1.27
1b	5500	338.3	340.8	48	1.37	4.17	1.28	1.27
1c	5500	338.3	341.8	48	1.57	4.80	1.28	1.27
2a	3000	184.5	185.4	48	0.85	2.60	0.70	0.69
2b	3000	184.5	186.4	48	0.84	2.56	0.70	0.69
2c	3000	184.5	186.0	48	0.90	2.75	0.70	0.69
3	4250	261.4	262.7	48	1.22	3.73	0.99	0.98

Note: S = Submergence from Top I.D. of Suction Nozzle Pipe

FIGURES

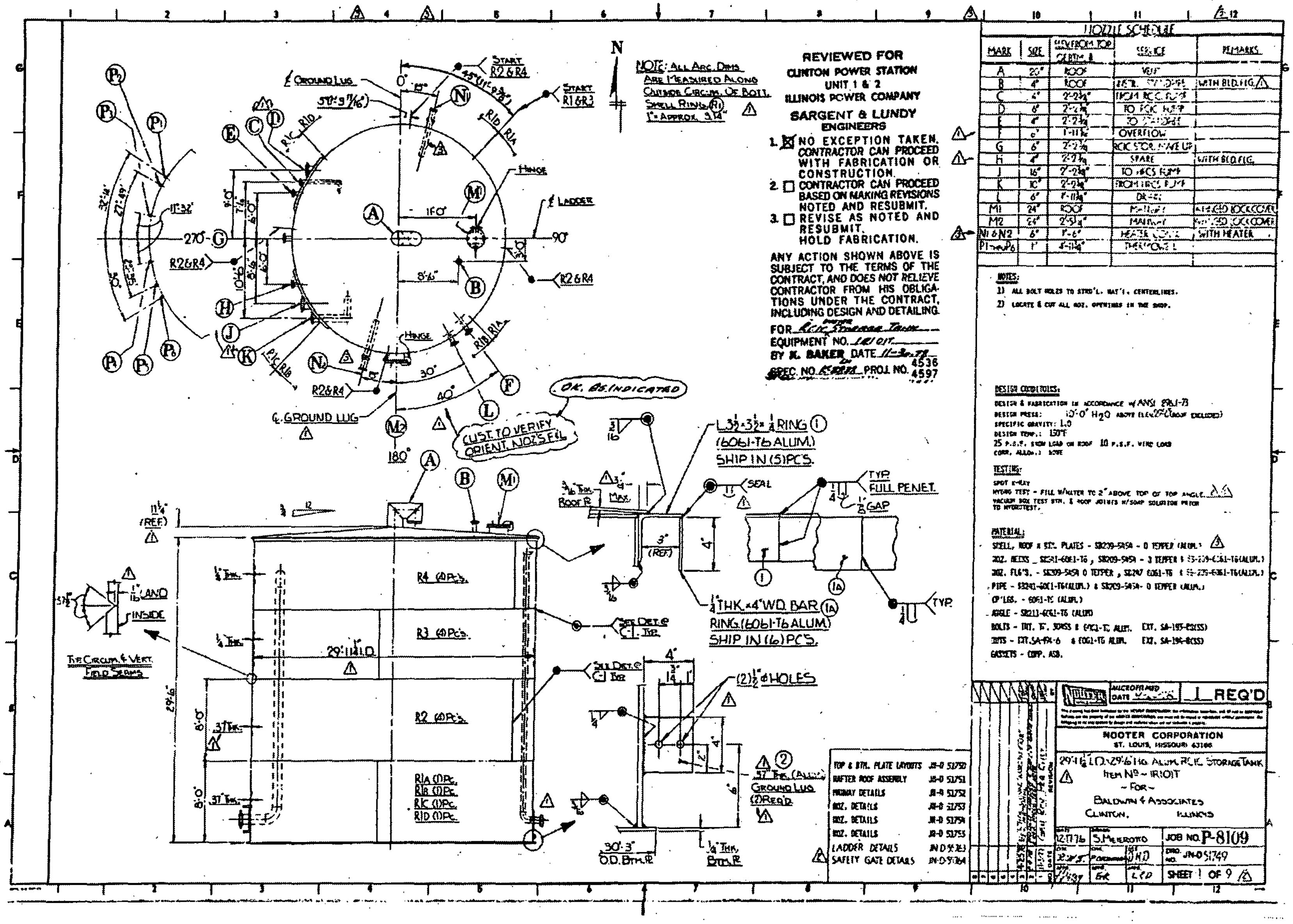

Figure 1: Clinton Nuclear Power Station RCIC Storage Tank Details

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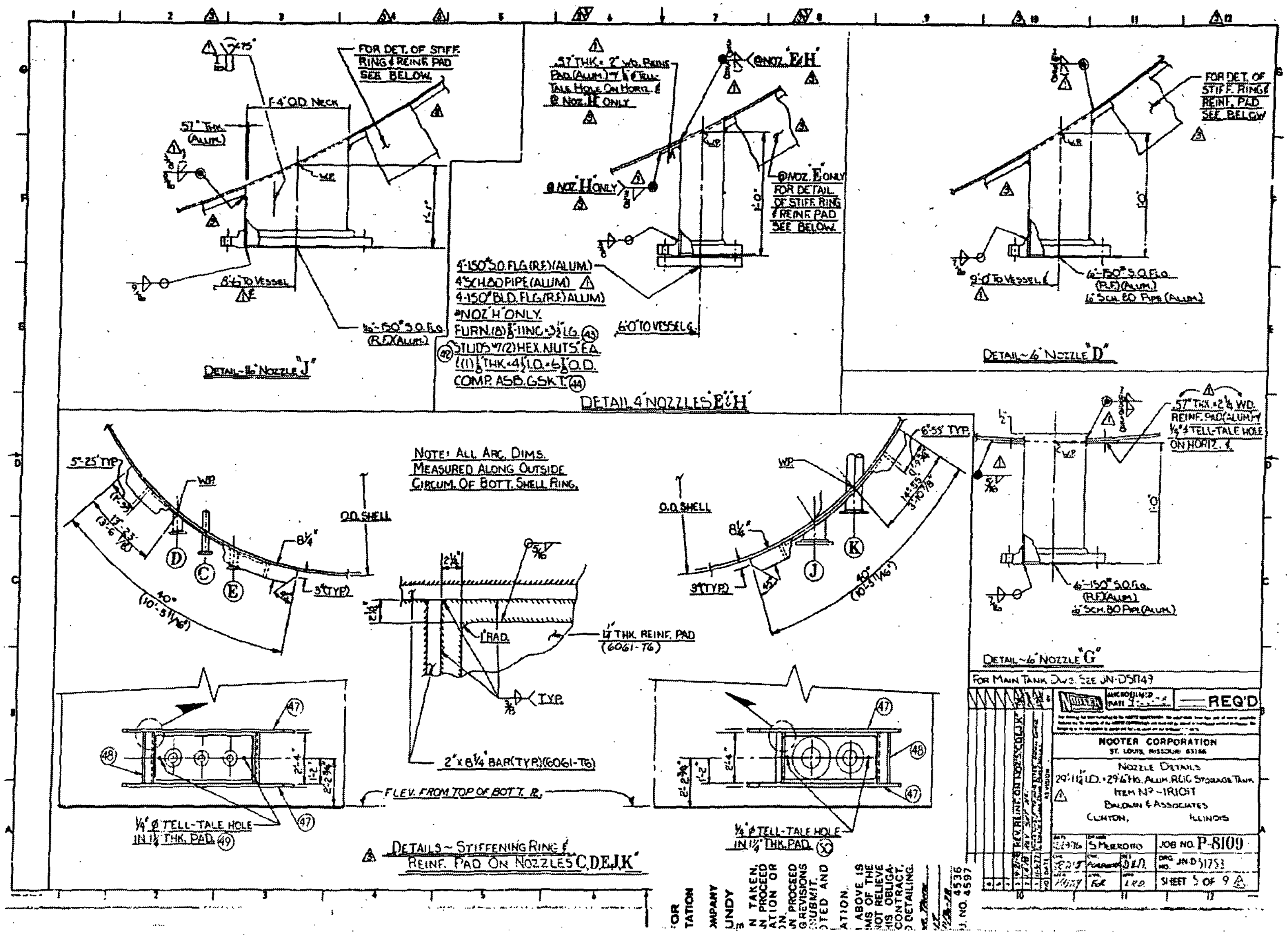

Figure 2: Clinton Nuclear Power Station RCIC Storage Tank; Nozzle Details

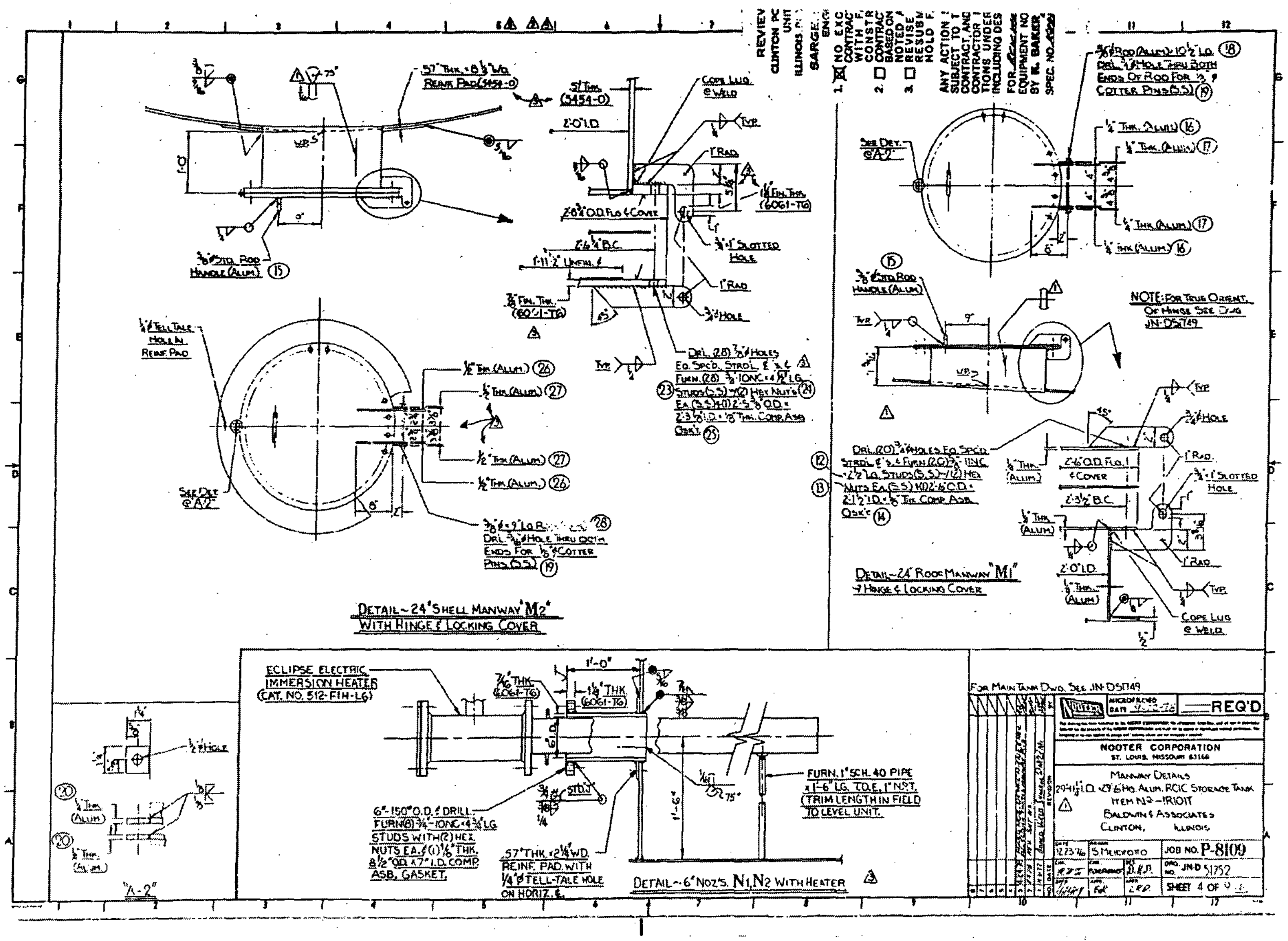

Figure 3: Clinton Nuclear Power Station RCIC Storage Tank; Nozzle Details

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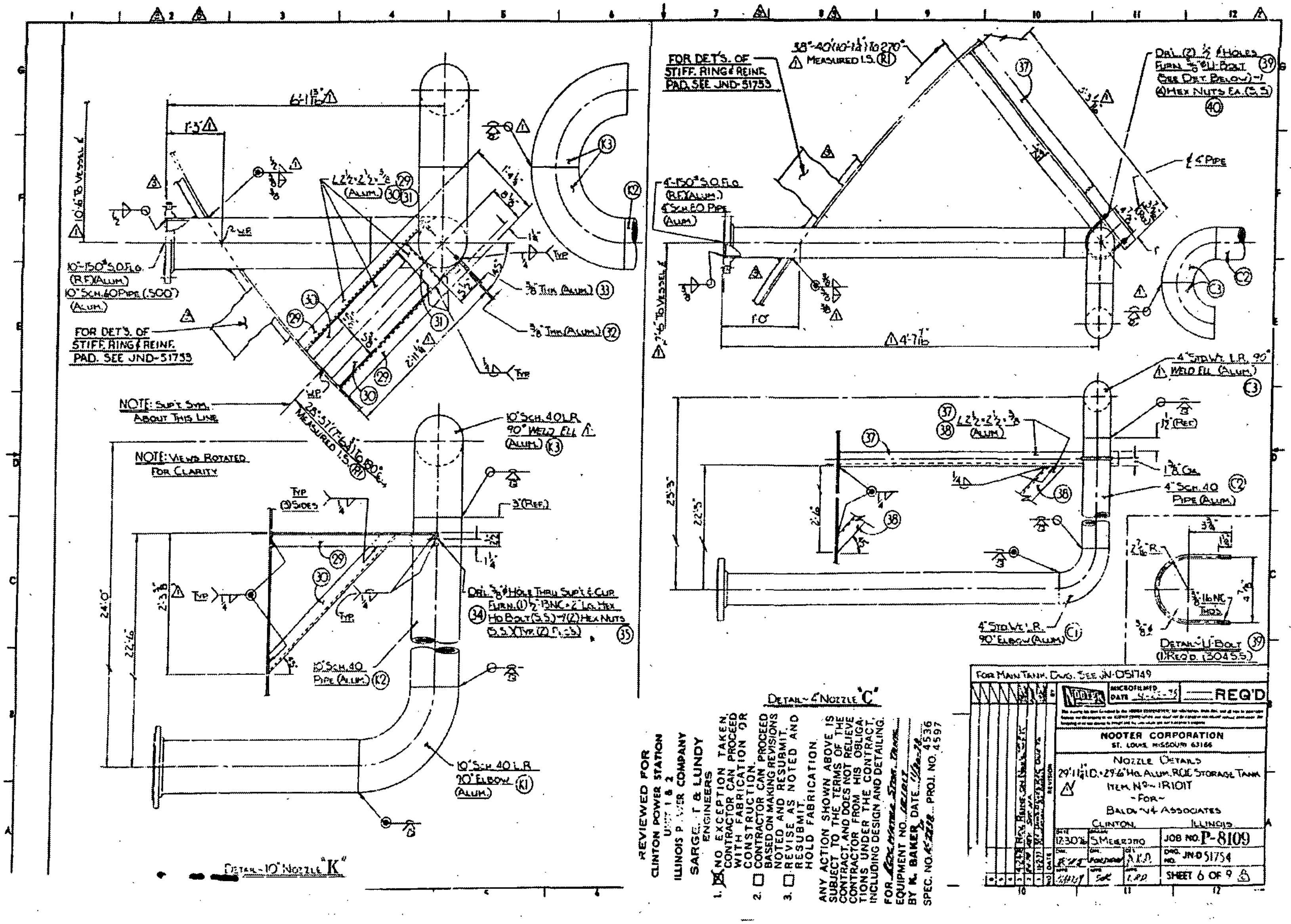

Figure 4: Clinton Nuclear Power Station RCIC Storage Tank; Nozzle Details

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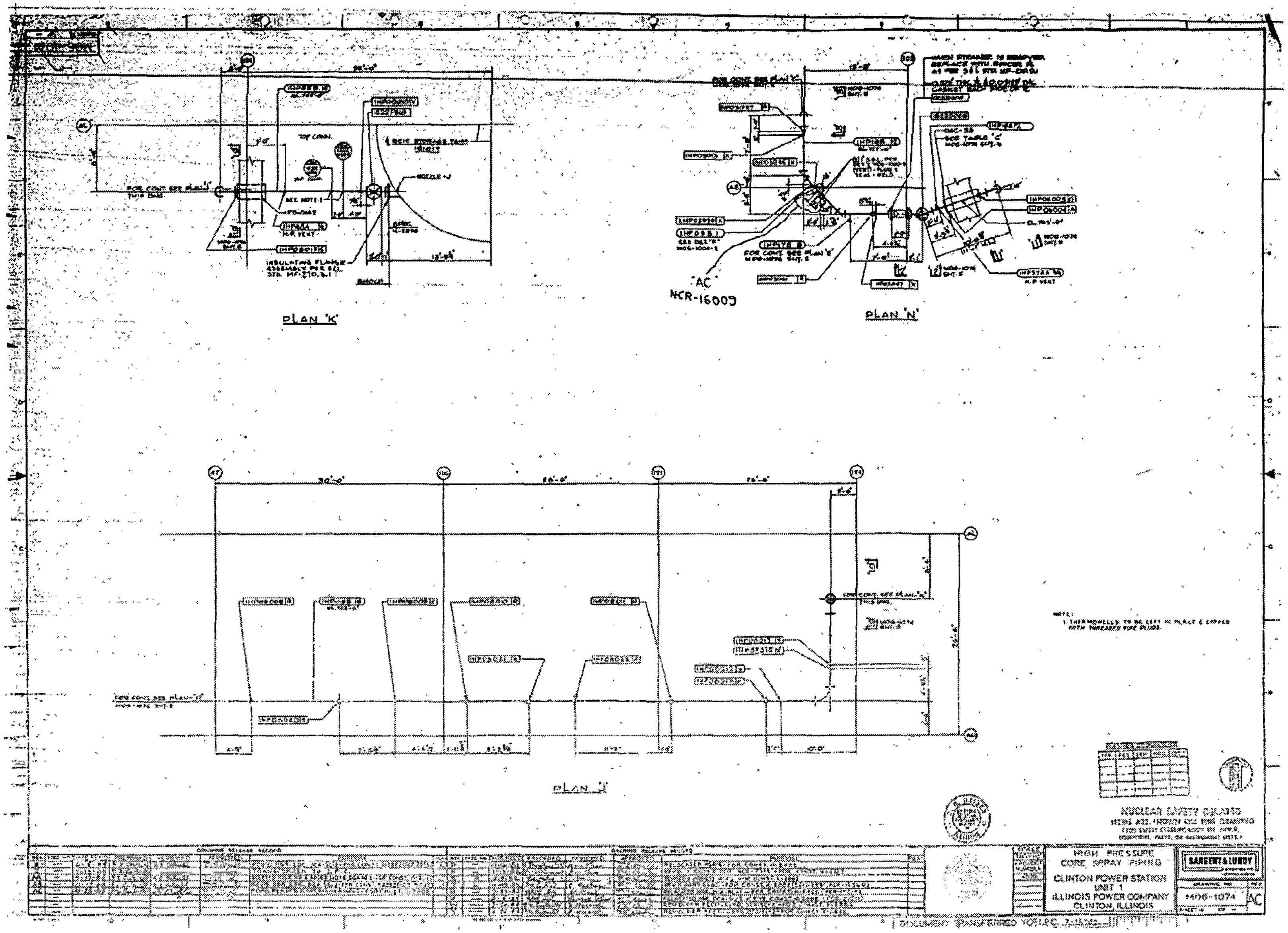

Figure 5: Clinton Nuclear Power Station RCIC Storage Tank; HPCS Piping

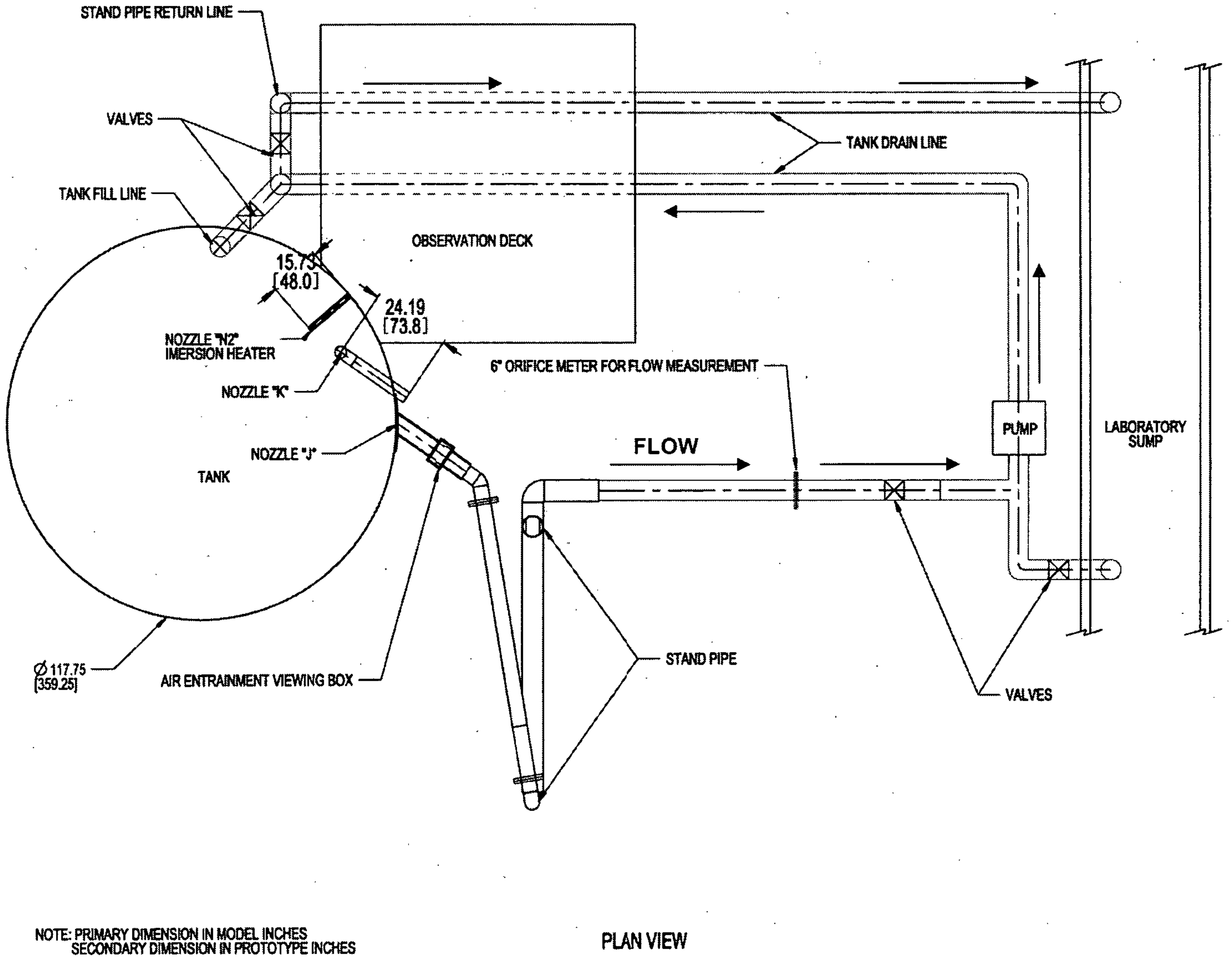

Figure 6: Clinton HPCS Suction Vortex Study Test Loop Setup: Plan

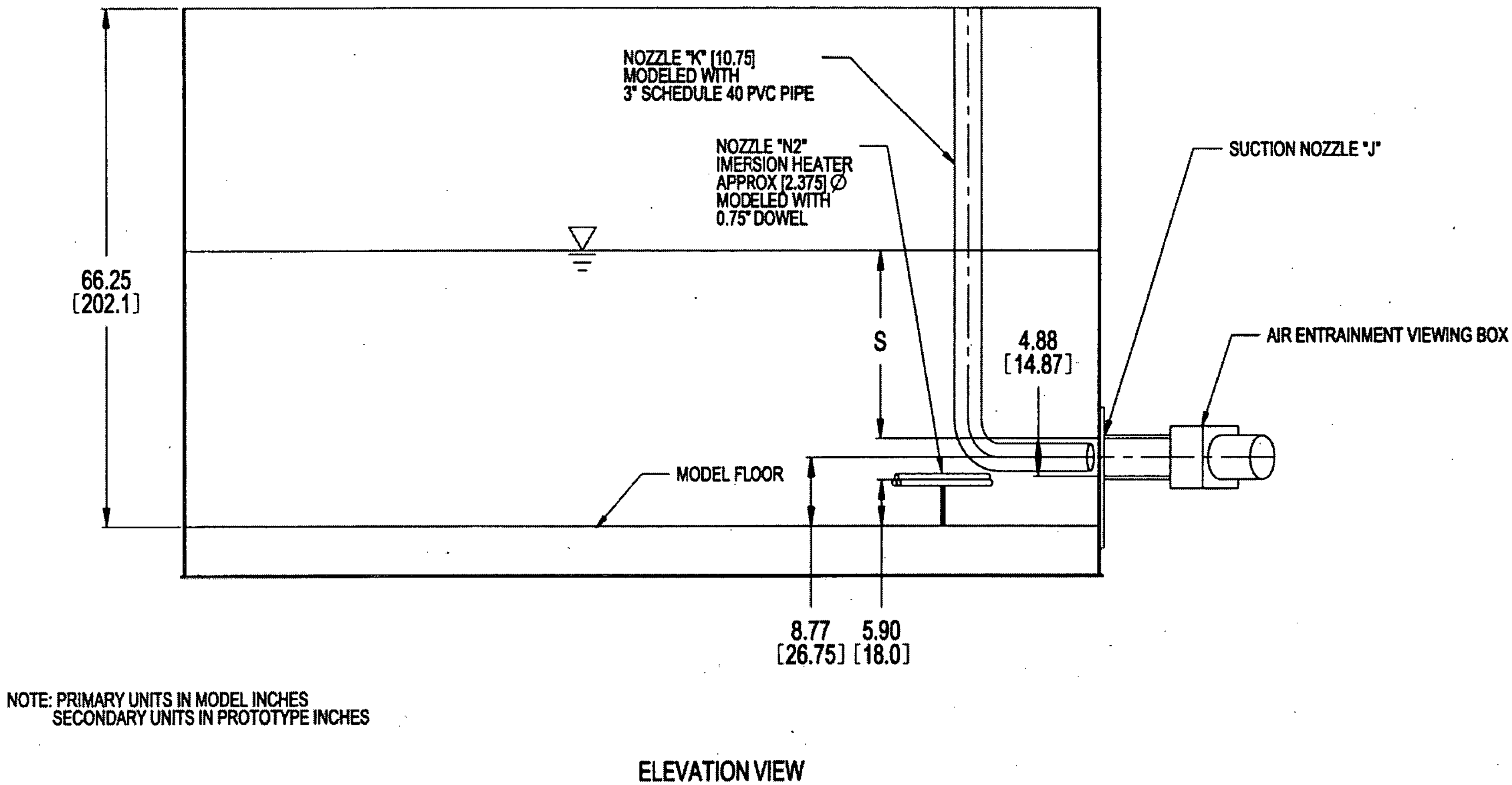

Figure 7: Clinton HPCS Suction Vortex Study Tank and Suction Nozzle Setup: Elevation

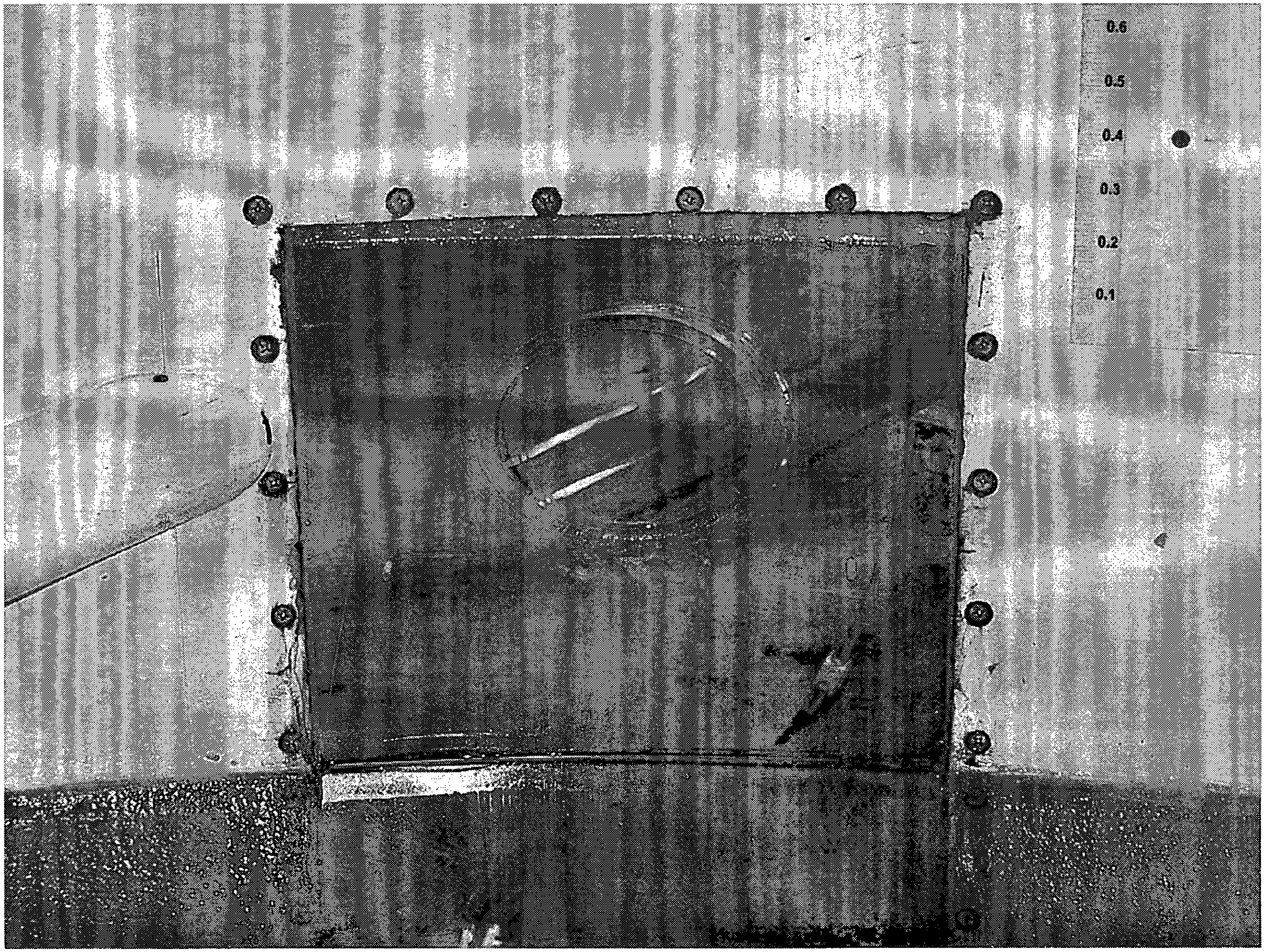

Figure 8: Clinton HPCS Suction Vortex Study; Model Nozzle J

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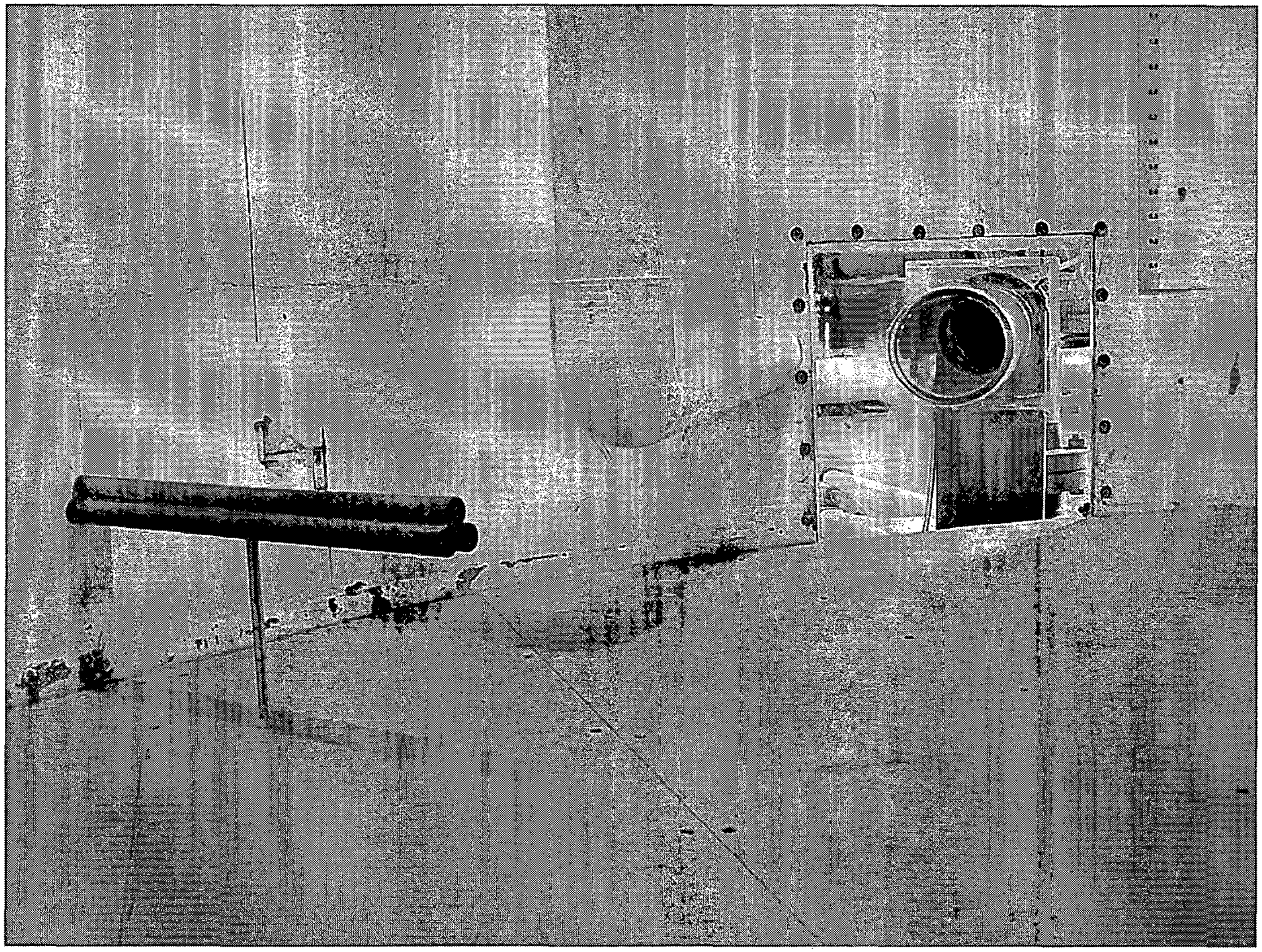


Figure 9: Clinton HPCS Suction Vortex Study; Model Nozzles N2, K and J

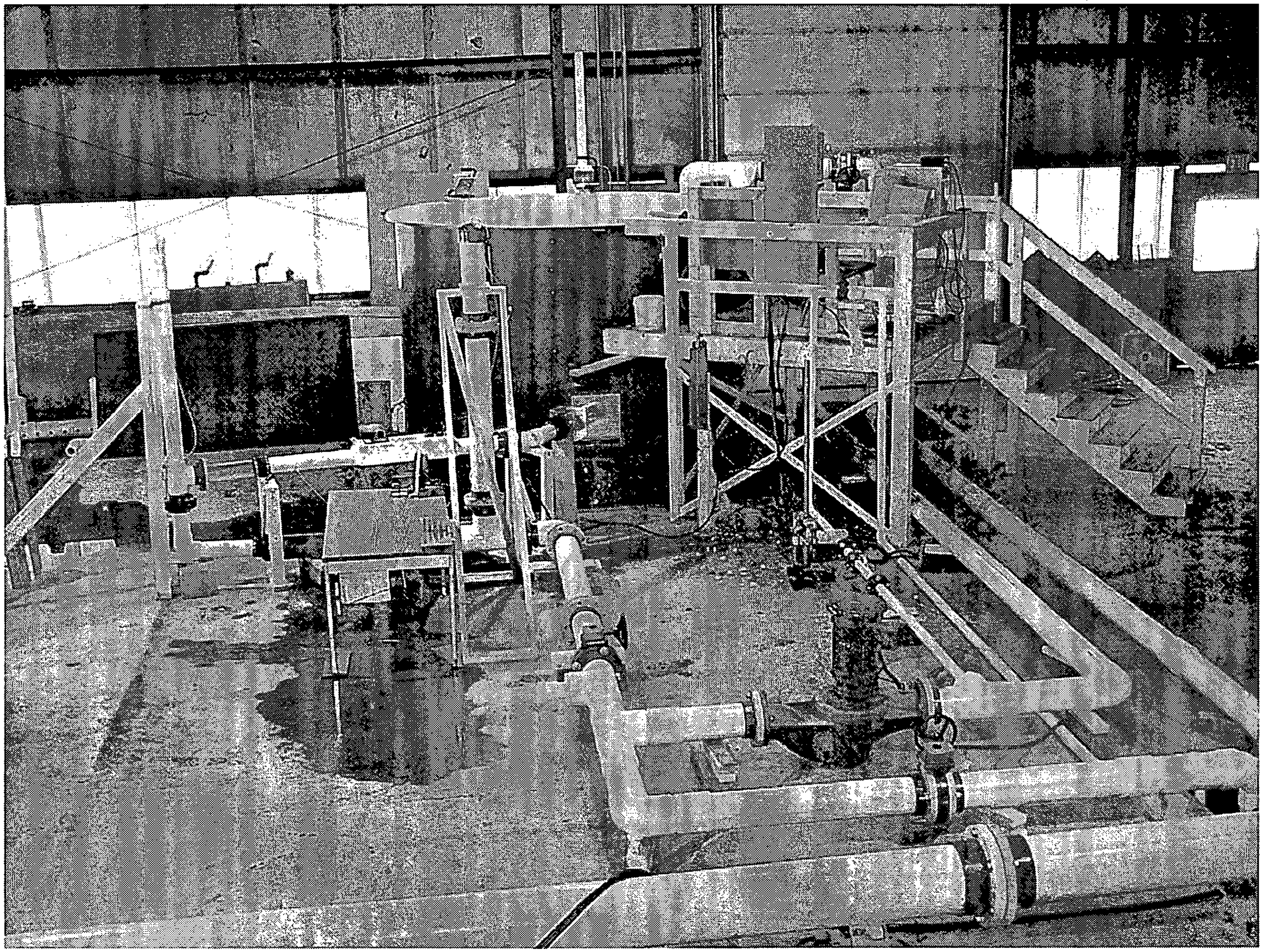


Figure 10: Clinton HPCS Suction Vortex Study; Model Flow Loop

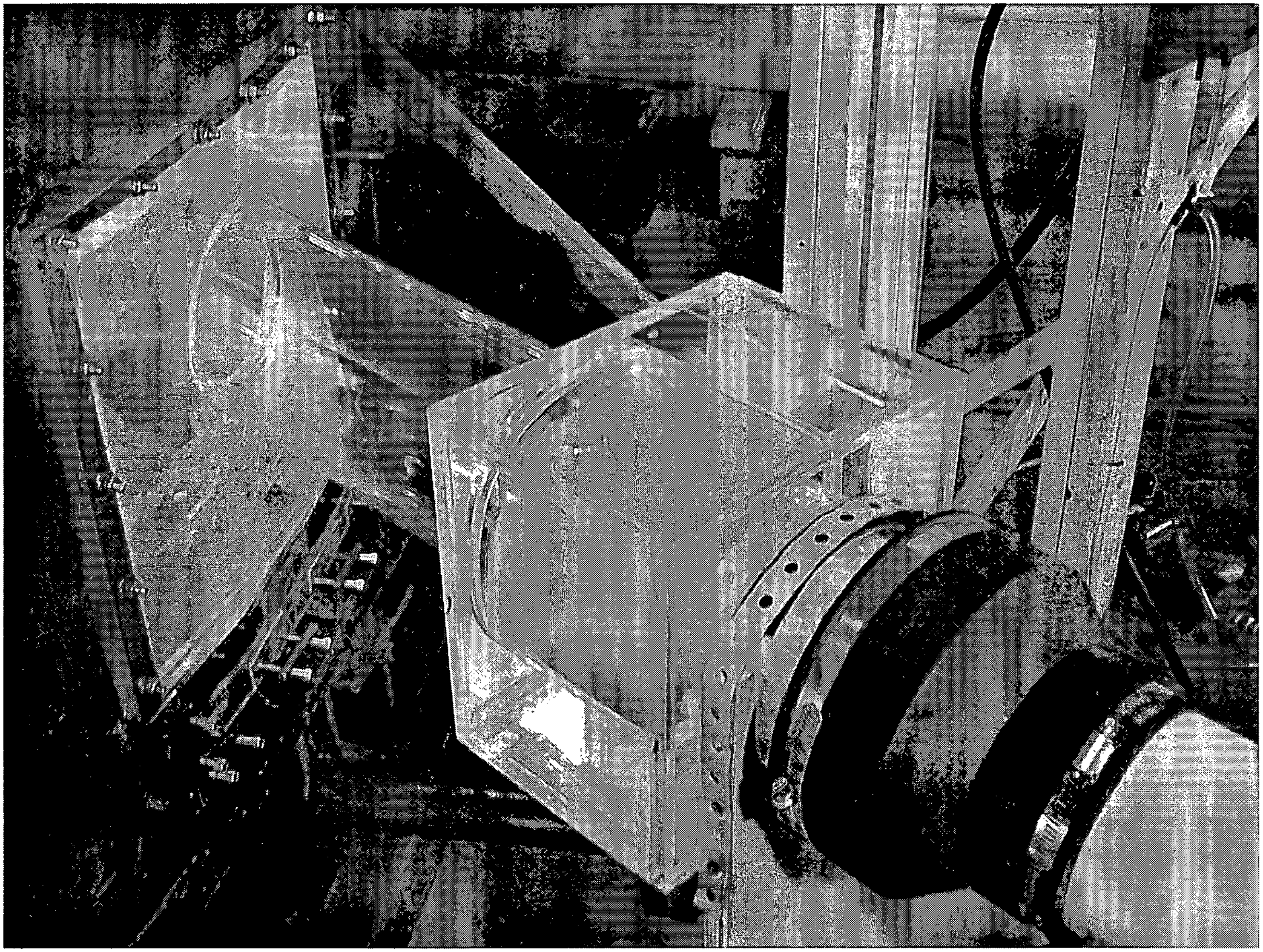
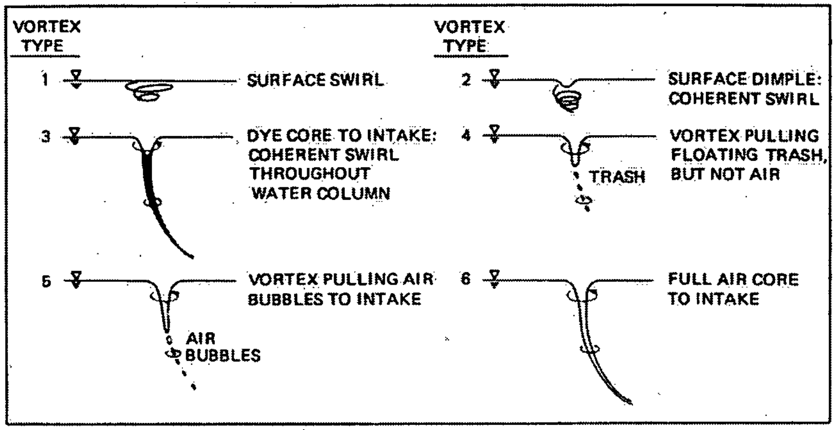
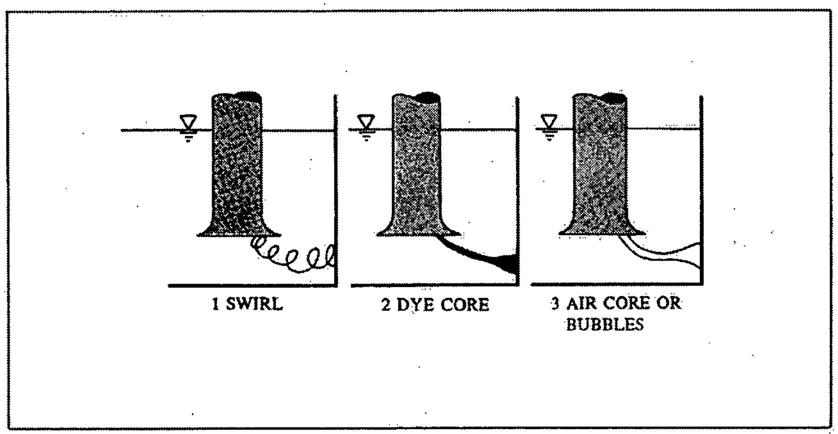


Figure 11: Air Entrainment Viewing Box



a. FREE-SURFACE VORTICES



b. SUBSURFACE VORTICES

Figure 12: Alden Vortex Classification

APPENDIX A

FLOW METER AND PRESSURE CELL CALIBRATION DATA

CALIBRATION OF

THREE ORIFICE FLOW SECTIONS

ALDEN JOB MCO/VORTEX

AUGUST 2006 REPORT NO. 2006-164/C0

CERTIFIED BY

James B. Nystrom

ALDEN RESEARCH LABORATORY, INC.

30 SHREWSBURY STREET

HOLDEN, MASSACHUSETTS 01520

All Client supplied information and calibration results are considered proprietary and confidential to the Client. If a third party is a witness are during calibrations or if the Client requests transmittal of data to a third party, Alden considers that the Client has waived confidentiality for the Witness.

In the event the Client distributes any report issued by Alden outside its own organization, such report shall be used in its entirety, unless Alden approves a summary or abridgment for distribution.

No advertising or publicity containing any reference to Alden or any employee, either directly or by implication, shall be made use of by Client without Alden's written approval.

INTRODUCTION

Three Orifice Flow Meters were calibrated at Alden Research Laboratory, Inc. for Alden Job MCO/VORTEX using Alden's standard test procedures, QA-AGF-7-86, Revision 6.1. Flow element performance is presented as discharge coefficient, C, versus Reynolds number, in both tabular and graphical format.

FLOW ELEMENT INSTALLATION

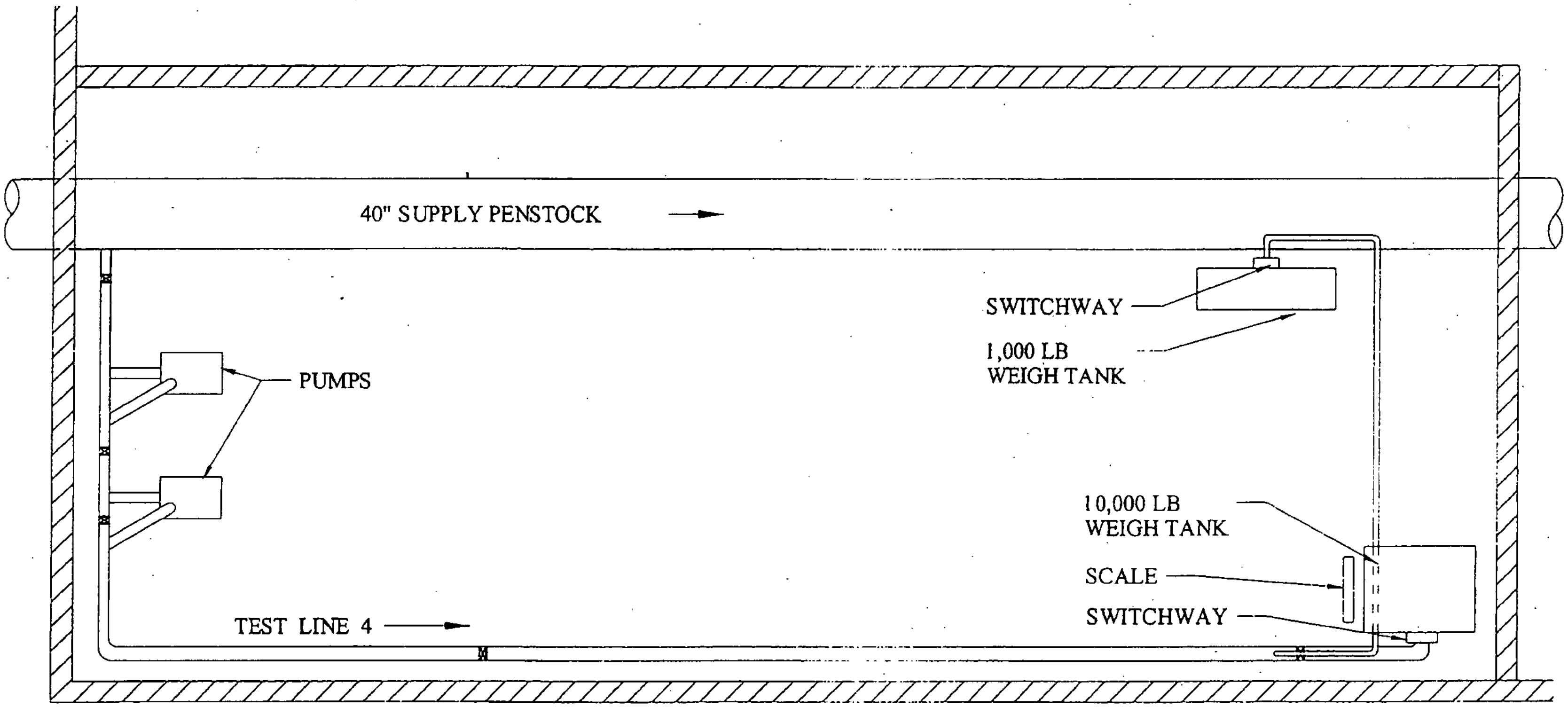
The flow elements were installed in Test Line 4 in the Hooper Facility, which is shown in plan view on Figure 1. A 25 horsepower centrifugal pump, rated at head of 150 ft at a flow of about 2 ft^3/s, drew water from the laboratory penstock. The penstock supplies water from the Laboratory Pond at a head of about 18 ft.

Careful attention was given to align the flow element with the test line piping, and to assure no gaskets between flanged sections protruded into the flow. Vents were provided at critical locations of the test line to purge the system of air.

TEST PROCEDURE

The test technician verified proper installation of the flow element in the test line prior to introducing water into the system to equalize test line piping and primary element temperature to water temperature. After attaining thermal equilibrium, the test line downstream control valve was then closed and vent valves in the test line were opened to remove air from the system. With the line flow shut off, the flow meter output was checked for zero flow indication. Prior to the test run, the control valve was set to produce the desired flow, while the flow was directed to waste. Sufficient time was allowed to stabilize both the flow and the instrument readings, after which the weigh tank discharge

Figure 1



Hooper Low Reynolds Number Facility

Test Line 4

ALDEN

valve was closed and the weigh tank scale indicator and the electric timer were both zeroed. To begin the test run, flow was diverted into the weigh tank, which automatically started the timer.

At the start of the water collection a computer based data acquisition system was activated to read the meter output, such that the meter output was averaged while the weigh tank was filling. At the end of the run, flow was diverted away from the weigh tank and the timer and data acquisition system were stopped to terminate the test run. The weight of water in the tank, elapsed time, water temperature, and average meter output were recorded on a data sheet. The data were entered into the computer to determine the flow and the results were plotted so that each test run was evaluated before the next run began. The control valve was then adjusted to the next flow and the procedure repeated.

FLOW MEASUREMENT METHOD

Flow was measured by the gravimetric method using a tank mounted on scales having a capacity of 10,000 pounds with a resolution of 0.2 lbs. Water passing through the flow element was diverted into the tank with a hydraulically operated knife edge passing through a rectangular jet produced by a diverter head box. A Hewlett-Packard 10 MHz Frequency Counter with a resolution 0.001 sec was started upon flow diversion into the tank by an optical switch, which is positioned at the center of the jet. The timer was stopped upon flow diversion back to waste and the elapsed diversion time was recorded. A thermistor thermometer measured water temperature to allow calculation of water density. Volumetric flow was calculated by Equation (1).

$$q_a = \frac{W}{T\rho_w B_c} \tag{1}$$

where q_a = actual flow, $\frac{ft^3}{sec}$

W = mass of water collected, lb_m

T = time, sec

ρ_w = water density, $\frac{lb_m}{ft^3}$

B_c = buoyancy correction, $1-\frac{\rho_a}{\rho_w}$

ρ_a = air density, $\frac{lb_m}{ft^3}$

The buoyancy correction includes air density calculated by perfect gas laws with the standard barometric pressure, a relative humidity of 75%, and measured air temperature. The weigh tank is periodically calibrated to full scale by the step method using 10,000 lb_m of cast iron weights, whose calibration is traceable to NIST. Flow calculations are computerized to assure consistency. Weigh tank calibration data and water density as a function of temperature, are stored on disk file. Data were recorded manually and on disk file for later review and reporting.

DISCHARGE COEFFICIENT CALCULATIONS

Discharge coefficient, C, is defined by Equation (2) and plotted versus pipe or throat Reynolds number. The discharge coefficient relates the theoretical flow to the actual flow.

$$C = \frac{q_a}{q_{th}} = \frac{q_a}{F_a K_m \sqrt{\Delta h}} \qquad (2)$$

where C = discharge coefficient, dimensionless

q_{th} = theoretical flow,

F_a = thermal expansion factor, dimensionless

Δh = differential head, ft at line temperature

K_m = meter constant, $\frac{ft^{2.5}}{sec}$

The theoretical proportionality constant, K_M, between flow and square root of differential head is a function of the meter throat area, the ratio of throat to pipe diameter, and the local gravitational

$$K_m = \frac{a_t\sqrt{2g_l}}{\sqrt{1-\beta^4}} \tag{3}$$

constant, as defined by Equation (3).

where a_t = throat area, $\frac{\pi d^2}{4}$, ft^2

d = throat diameter, ft

g_l = local gravitational constant, $32.1625 \frac{ft}{sec^2}$ at Alden

β = ratio of throat to pipe diameter, $\frac{d}{D}$, dimensionless

D = pipe diameter, ft

The effect of fluid properties, viscosity and density, on the discharge coefficient is determined by Reynolds number, the ratio of inertia to viscous forces. Pipe Reynolds number, R_D, is determined by Equation (4).

$$R_D = \frac{q_a D}{a_p \gamma} \tag{4}$$

where a_p = pipe area, $\frac{\pi D^2}{4}$, ft^2

γ = kinematic viscosity, $\frac{ft^2}{sec}$

FLOW METER SIGNAL RECORDING

The secondary element, which converts the primary element signal into engineering units, was one of several "Smart" differential pressure transmitters having ranges of 25" W.C.,250" W.C., 1000" W.C. and 100 psid. Each transmitter was calibrated with a pneumatic or a hydraulic dead weight tester having an accuracy of 0.02% of reading. Transmitter signals were recorded by a PC based data acquisition system having a 16 bit A to D board. Transmitter calibrations were conducted with the PC system such that an end to end calibration was achieved. Transmitter output was read simultaneously with the diversion of flow into the weigh tank at a rate of about 34 Hz for each test run (flow) and averaged to obtain a precise differential head. For primary elements with multiple tap sets, individual transmitters were provided for each tap set and all transmitters were read simultaneously. Average transmitter reading was converted to feet of flowing water using a linear regression analysis of the calibration data and line water temperatures to calculate appropriate specific weight.

TEST RESULTS

The calibration results are presented in individual tables and graphs for each of the three Orifice Flow Sections. The measured values of weight, time and line temperature, which were used to calculate the listed flow, are shown in the tables. The average transmitter reading used to calculate the differential head in feet of water at line temperature is also shown in the tables. Flow meter performance is given as discharge coefficient versus pipe Reynolds number.

Analysis indicates that the flow measurement uncertainty is within 0.25% of the true value for each test run. Calibrations of the test instrumentation (temperature, time, weight, and length measurements) are traceable to the National Institute of Standards and Technology (formerly the National Bureau of Standards) and ALDEN's Quality Assurance Program is designed to meet ANSI/NCSL Z540-1-1994 "Calibration Laboratories and Test Equipment-General Requirements" (supercedes MIL-STD-45662A).

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ALDEN

Purchase Order Number: MCO/VORTEX
2" ORIFICE METER
Serial Number: 2"

CALIBRATION
DATE: June 27, 2006
PIPE DIAMETER = 2.0670
THROAT DIAMETER = 1.1350

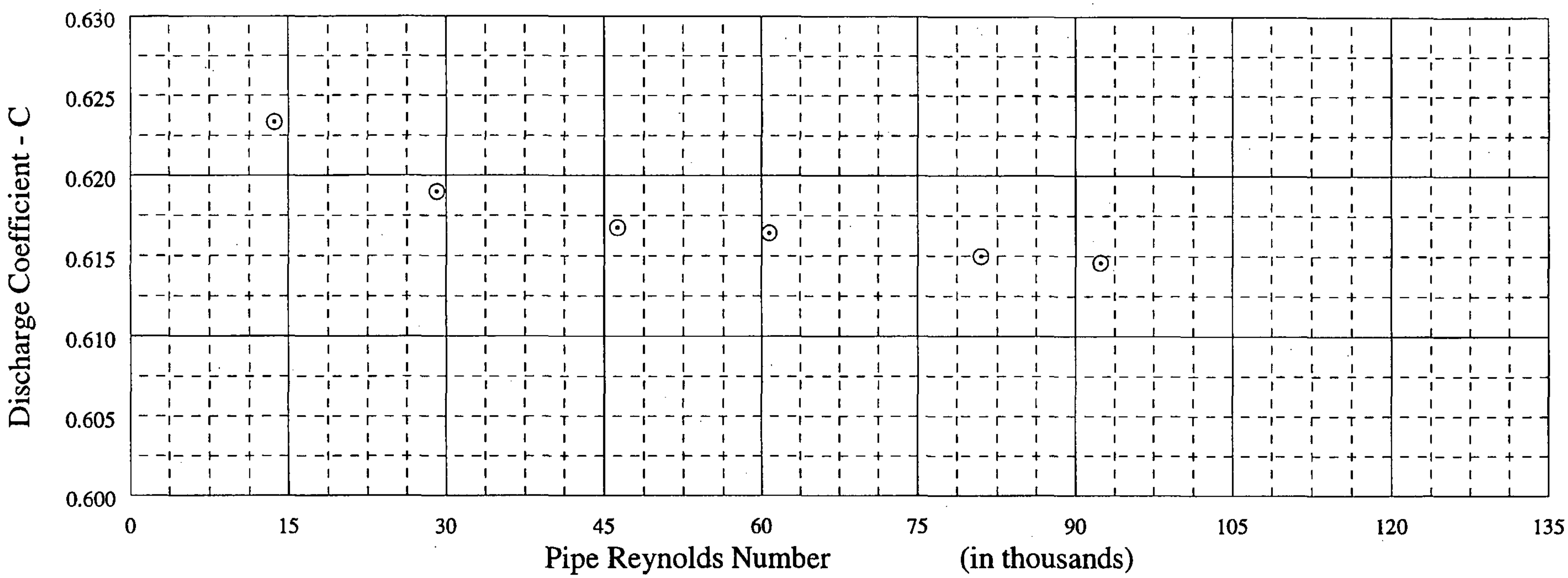
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^4	Coef
1	69	73	367	298.245	3.110~	8.863	0.287	1.3642	0.6233
2	69	73	754	287.497	7.109~	18.91	1.327	2.9116	0.6190
3	69	73	715	171.653	3.299~	30.04	3.373	4.6247	0.6168
4	69	73	2037	279.607	5.987~	52.53	10.372	8.0977	0.6150
5	69	73	2031	244.486	7.193~	59.92	13.510	9.2360	0.6146
6	69	73	2032	371.910	4.233~	39.40	5.806	6.0727	0.6164

~ dp transmitter volts

The data reported on herein was obtained by measuring equipment the calibration of which is traceable to NIST , following the installation and test procedures referenced in this report, resulting in a flow measurement uncertainty of +/- 0.25% or less.

CALIBRATED BY: PSS, THL

CERTIFIED BY:



$$q_a = C F_a K_M \sqrt{\Delta h}$$

q_a =	Actual Flow (ft^3/sec)		
C =	Discharge Coefficient (Dimensionless)		
Δh =	Pressure Differential (Feet of Water at Run Temperature)		
K_M =	Meter Constant = $\dfrac{a\sqrt{2g}}{\sqrt{1 - \beta^4}}$	=	0.0591
F_a =	Average Thermal Expansion Factor	=	1.0000
a =	Throat Area (ft^2)	=	0.0070
g =	Local Acceleration of Gravity (ft/sec^2)	=	32.1625
ß =	Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.5491
	Pipe Diameter (Inches)	=	2.0670
	Throat Diameter (Inches)	=	1.1350

Dimensions By: ALDEN

ALDEN
Purchase Order Number: MCO/VORTEX
2" ORIFICE METER
Serial Number: 2"
June 27, 2006

Certified By:

ARL

ALDEN

Purchase Order Number: MCO/VORTEX
3" ORIFICE METER
Serial Number: 3"

CALIBRATION
DATE: June 28, 2006
PIPE DIAMETER = 3.0680
THROAT DIAMETER = 1.8750

Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^5	Coef
5	69	72	2051	74.562	9.253~	198.3	18.875	2.0574	0.6137
2	69	72	2046	93.730	6.556~	157.4	11.853	1.6419	0.6147
3	70	72	2043	112.559	5.141~	130.8	8.170	1.3666	0.6154
4	70	72	2035	142.729	3.934~	102.8	5.027	1.0739	0.6165
5	70	72	2035	193.847	3.044~	75.71	2.711	0.7905	0.6180
6	70	72	2030	297.103	6.404~	49.28	1.144	0.5147	0.6194
7	70	72	2028	673.633	2.846~	21.71	0.219	0.2267	0.6240

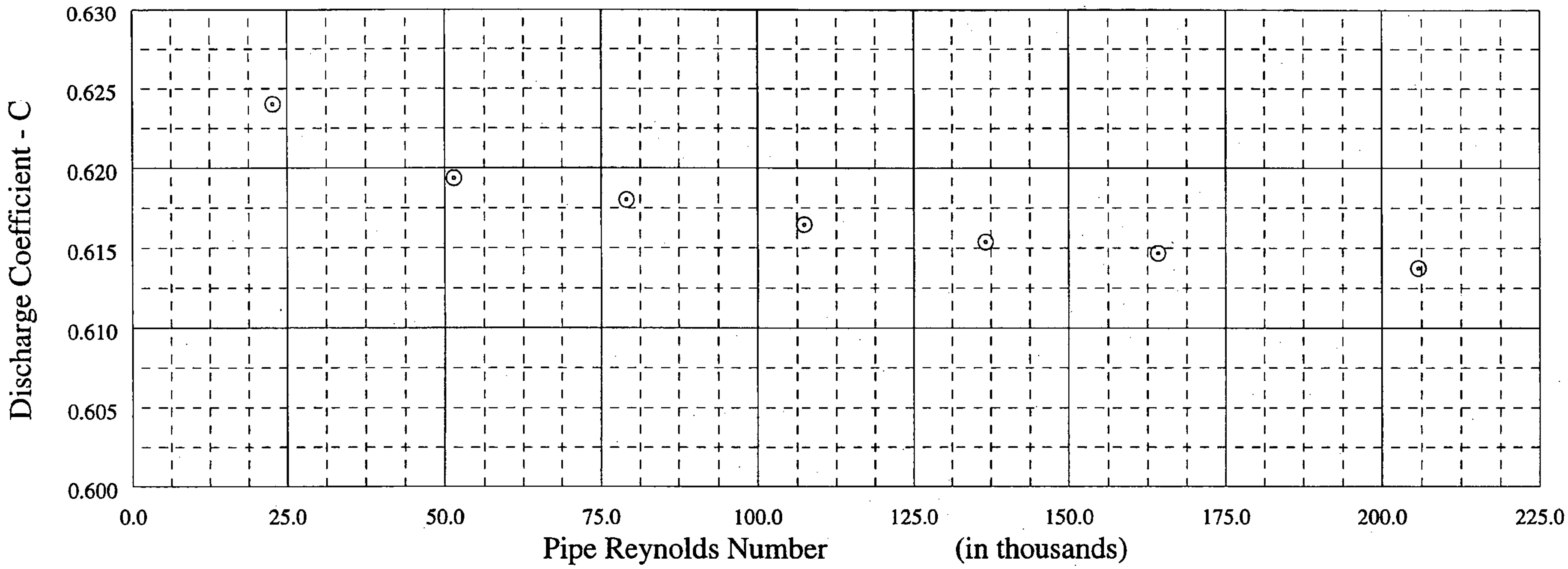
~ dp transmitter volts

The data reported on herein was obtained by measuring equipment the calibration of which is traceable to NIST , following the installation and test procedures referenced in this report, resulting in a flow measurement uncertainty of +/- 0.25% or less.

CALIBRATED BY: PSS

CERTIFIED BY:

ARL



$$q_a = C F_a K_M \sqrt{\Delta h}$$

q_a =	Actual Flow (ft^3/sec)		
C =	Discharge Coefficient (Dimensionless)		
Δh =	Pressure Differential (Feet of Water at Run Temperature)		
K_M =	Meter Constant = $\dfrac{a\sqrt{2g}}{\sqrt{1 - \beta^4}}$	=	0.1658
F_a =	Average Thermal Expansion Factor	=	1.0000
a =	Throat Area (ft^2)	=	0.0192
g =	Local Acceleration of Gravity (ft/sec^2)	=	32.1625
ß =	Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.6111
	Pipe Diameter (Inches)	=	3.0680
	Throat Diameter (Inches)	=	1.8750

Dimensions By: ARL

ALDEN
Purchase Order Number: MCO/VORTEX
3" ORIFICE METER
Serial Number: 3"
June 28, 2006

Certified By:

ARL

ALDEN

Purchase Order Number: MCO/VORTEX
6" ORIFICE METER
Serial Number: 6"

CALIBRATION
DATE: June 28, 2006
PIPE DIAMETER = 6.0650
THROAT DIAMETER = 4.0000

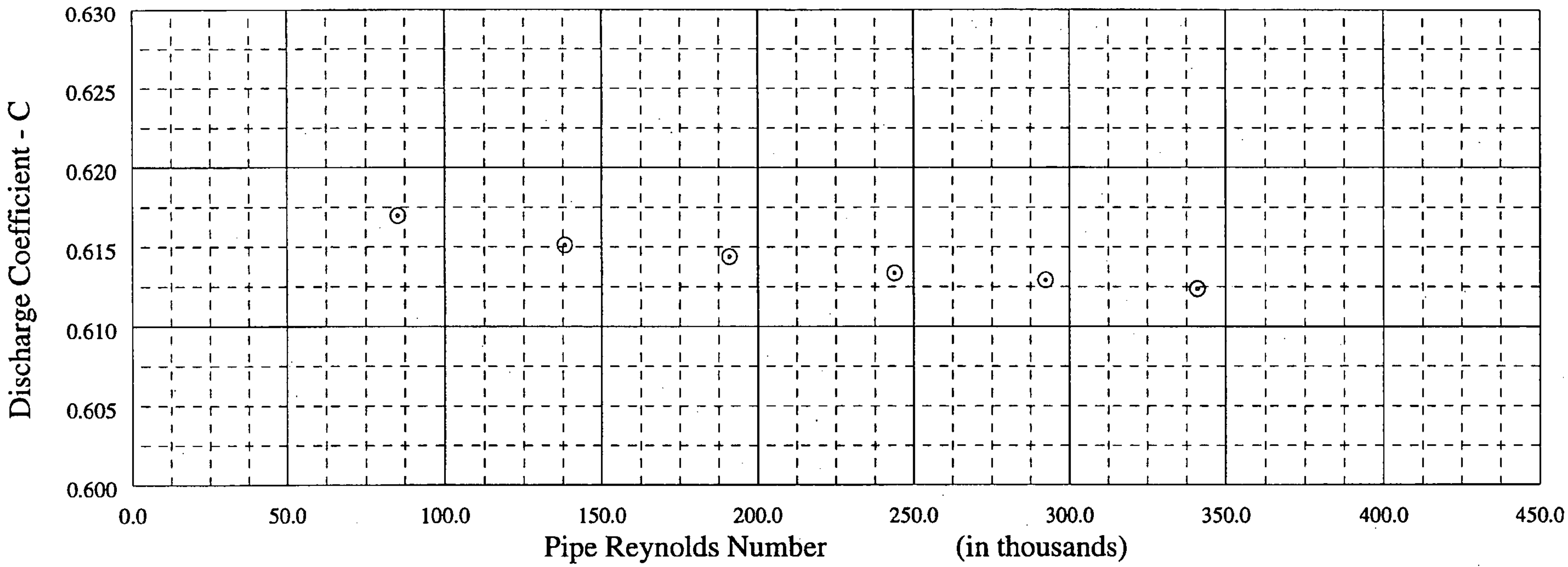
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^5	Coef
1	5	72	8083	90.954	5.461~	641.0	9.003	3.4093	0.6124
2	71	72	8071	107.291	4.476~	542.6	6.440	2.9228	0.6129
3	72	72	8067	129.524	3.696~	449.3	4.409	2.4386	0.6134
4	72	72	8059	165.143	3.039~	352.0	2.697	1.9106	0.6144
5	72	72	6053	171.550	7.414~	254.5	1.407	1.3815	0.6151
6	72	72	4041	185.239	4.060~	157.3	0.534	0.8530	0.6170

~ dp transmitter volts

The data reported on herein was obtained by measuring equipment the calibration of which is traceable to NIST , following the installation and test procedures referenced in this report, resulting in a flow measurement uncertainty of +/- 0.25% or less.

CALIBRATED BY: PSS

CERTIFIED BY:



$$q_a = C F_a K_M \sqrt{\Delta h}$$

q_a =	Actual Flow (ft^3/sec)		
C =	Discharge Coefficient (Dimensionless)		
Δh =	Pressure Differential (Feet of Water at Run Temperature)		
K_M =	Meter Constant = $\dfrac{a\sqrt{2g}}{\sqrt{1 - \beta^4}}$	=	0.7773
F_a =	Average Thermal Expansion Factor	=	1.0000
a =	Throat Area (ft^2)	=	0.0873
g =	Local Acceleration of Gravity (ft/sec^2)	=	32.1625
ß =	Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.6595
	Pipe Diameter (Inches)	=	6.0650
	Throat Diameter (Inches)	=	4.0000

Dimensions By: ARL

ALDEN
Purchase Order Number: MCO/VORTEX
6" ORIFICE METER
Serial Number: 6"
June 28, 2006

Certified By: [signature]

ARL

Thermal Expansion Factor

The dimensions of a differential producing flow meter are affected by the operating temperature, requiring a Thermal Expansion Factor (F_a) to be included in the calculations. The calculation requires the temperature at which the meter dimensions were measured be known. If this information is not available, an ambient temperature of 68°F is assumed. The Thermal Expansion Factor is calculated according to the American Society of Mechanical Engineers Standard ASME MFC-3M-1989, Equation 17 (pg 11).

$$F_a = 1 + \frac{2}{\left(1-\beta^4\right)}\left(\alpha_{PE} - \beta^4_{meas}\,\alpha_p\right)\left(t - t_{meas}\right)$$

where

	β	=	ratio of throat diameter to pipe diameter, dimensionless
	α_{PE}	=	thermal expansion factor of primary element, °F
	α_p	=	thermal expansion factor of pipe, °F
	t	=	temperature of flowing fluid, °F
	t_{meas}	=	temperature of measurements, °F

Thermal expansion factors, α, excerpted from MFC-3M-1989, are listed in the Table below for six typically used materials at three temperatures. Linear interpolation is used to determine the coefficients at flowing temperature.

Thermal Expansion Factors x 10^{-6}

Material	-50°F	70°F	200°F
Carbon Steel (low chrome)	5.80	6.07	6.38
Intermediate Steel (5 to 9 Cr-Mo)	5.45	5.73	6.04
Austenitic stainless steels	8.90	9.11	9.34
Straight chromium stainless steel	5.00	5.24	5.50
Monel (67Ni-30Cu)	7.15	7.48	7.84
Bronze	9.15	9.57	10.03

WATER DENSITY

Temperature Fahrenheit	Density lb_m / ft^3	Temperature Fahrenheit	Density lb_m / ft^3	Temperature Fahrenheit	Density lb_m / ft^3
32	62.4179	62	62.3549	92	62.0903
33	62.4201	63	62.3489	93	62.0788
34	62.4220	64	62.3427	94	62.0671
35	62.4235	65	62.3363	95	62.0552
36	62.4246	66	62.3296	96	62.0432
37	62.4255	67	62.3228	97	62.0311
38	62.4260	68	62.3157	98	62.0188
39	62.4262	69	62.3084	99	62.0063
40	62.4261	70	62.3010	100	61.9937
41	62.4257	71	62.2933	101	61.9810
42	62.4250	72	62.2855	102	61.9681
43	62.4240	73	62.2774	103	61.9551
44	62.4227	74	62.2692	104	61.9419
45	62.4211	75	62.2608	105	61.9286
46	62.4193	76	62.2522	106	61.9151
47	62.4171	77	62.2434	107	61.9015
48	62.4147	78	62.2344	108	61.8878
49	62.4121	79	62.2252	109	61.8739
50	62.4092	80	62.2159	110	61.8599
51	62.4060	81	62.2063	111	61.8458
52	62.4025	82	62.1966	112	61.8315
53	62.3988	83	62.1868	113	61.8172
54	62.3949	84	62.1767	114	61.8027
55	62.3907	85	62.1665	115	61.7880
56	62.3863	86	62.1561	116	61.7733
57	62.3816	87	62.1456	117	61.7584
58	62.3768	88	62.1348	118	61.7434
59	62.3716	89	62.1239	119	61.7284
60	62.3663	90	62.1129	120	61.7132
61	62.3607	91	62.1017	121	61.6978

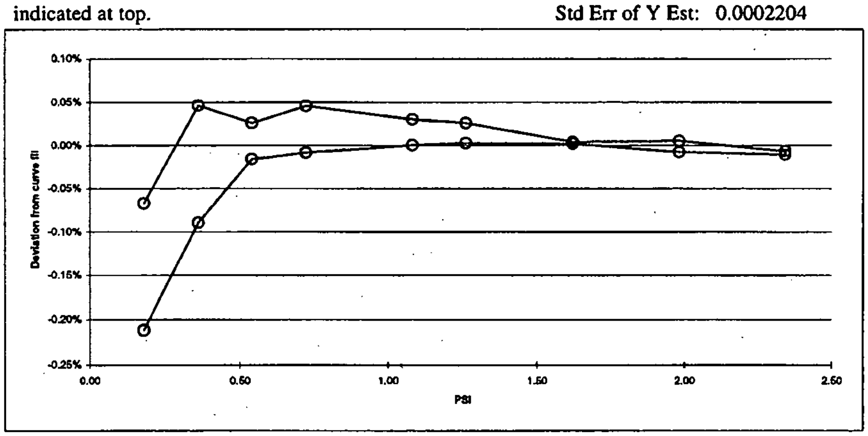
Calibration of Pressure Transmitter

Calibrated By: **THL**
Cell No.: **697**
Date: **11/14/2006**
Temp.: **61**
A-D Board No.: **642**
Using Pneumatic DWT No.: **550**

	Weight Id												Tester	Reading	Calculated	Percent	Approx.
	1	2	3	4	5	6	7	8	9	10	11	12	PSI	Volts	PSI	Error	inches
1													0.0000	1.9582			
2													0.1803	2.5116	0.1801	-0.07%	5.0
3	1												0.3605	3.0658	0.3607	0.05%	10.0
4		1											0.5408	3.619	0.5409	0.03%	14.9
5	1	1											0.7211	4.1729	0.7214	0.05%	19.9
6	1	1	1										1.0816	5.2795	1.0819	0.03%	29.9
7		1	1	1									1.2618	5.8328	1.2622	0.03%	34.8
8		1	1	1	1								1.6224	6.9386	1.6224	0.00%	44.8
9											1		1.9829	8.0453	1.9830	0.01%	54.7
10		1									1		2.3434	9.1511	2.3432	-0.01%	64.7
11		1									1		2.3434	9.1508	2.3431	-0.01%	64.7
12											1		1.9829	8.0445	1.9827	-0.01%	54.7
13		1	1	1	1								1.6224	6.9385	1.6224	0.00%	44.8
14		1	1	1									1.2618	5.8319	1.2619	0.00%	34.8
15	1	1	1										1.0816	5.2785	1.0816	0.00%	29.9
16	1	1											0.7211	4.1717	0.7210	-0.01%	19.9
17		1											0.5408	3.6183	0.5407	-0.02%	14.9
18	1												0.3605	3.0643	0.3602	-0.09%	10.0
19													0.1803	2.5108	0.1799	-0.21%	5.0
20													0.0000	1.9577	-0.0003		

Regression Coeffs.
Slope: **0.325792**
Intercept: **-0.638112**
Std Err of Y Est: 0.0002204

Note: Zeroes not included in regression.
Note: Pressures correct only for temperature indicated at top.



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Reviewed:

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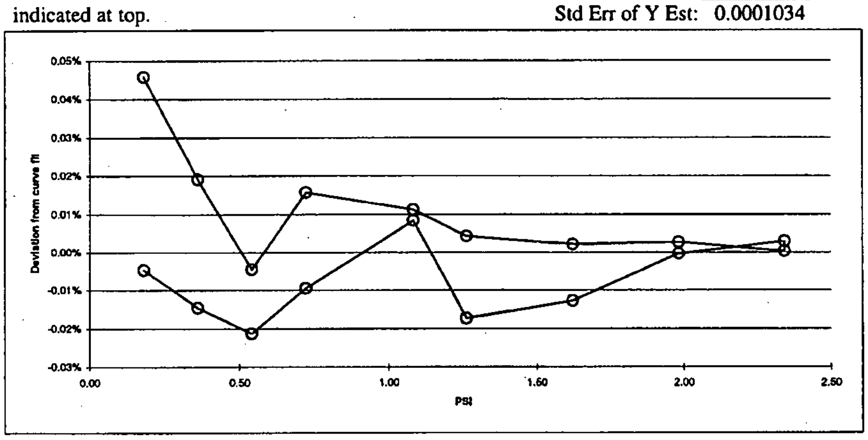
Calibration of Pressure Transmitter

Calibrated By: **THL**
Cell No.: **626**
Date: **11/14/2006**
Temp.: **61**
A-D Board No.: **642**
Using Pneumatic DWT No.: **550**

	Weight Id												Tester	Reading	Calculated	Percent	Approx.
	1	2	3	4	5	6	7	8	9	10	11	12	PSI	Volts	PSI	Error	inches
1													0.0000	1.9971			
2													0.1803	2.5921	0.1803	0.00%	5.0
3	1												0.3605	3.1871	0.3605	-0.01%	10.0
4		1											0.5408	3.782	0.5407	-0.02%	14.9
5	1	1											0.7211	4.3773	0.7210	-0.01%	19.9
6	1	1	1										1.0816	5.5681	1.0817	0.01%	29.9
7		1	1	1									1.2618	6.1622	1.2616	-0.02%	34.8
8		1	1	1	1								1.6224	7.3525	1.6222	-0.01%	44.8
9											1		1.9829	8.5434	1.9829	0.00%	54.7
10		1									1		2.3434	9.7339	2.3435	0.00%	64.7
11		1									1		2.3434	9.7337	2.3434	0.00%	64.7
12											1		1.9829	8.5436	1.9829	0.00%	54.7
13		1	1	1	1								1.6224	7.3533	1.6224	0.00%	44.8
14		1	1	1									1.2618	6.1631	1.2619	0.00%	34.8
15	1	1	1										1.0816	5.5682	1.0817	0.01%	29.9
16	1	1											0.7211	4.3779	0.7212	0.02%	19.9
17		1											0.5408	3.7823	0.5408	0.00%	14.9
18	1												0.3605	3.1875	0.3606	0.02%	10.0
19													0.1803	2.5924	0.1804	0.05%	5.0
20													0.0000	1.9969	0.0000		

Regression Coeffs.
Slope: **0.302893**
Intercept: **-0.604871**
Std Err of Y Est: 0.0001034

Note: Zeroes not included in regression.
Note: Pressures correct only for temperature indicated at top.



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APPENDIX B

TEST PLAN

TEST PLAN

CLINTON NUCLEAR POWER STATION
HIGH PRESSURE CORE SPRAY PUMP
SUCTION VORTEX/AIR ENTRAINMENT STUDY

December 5th, 2006

Prepared By
Alden Research Laboratory, Inc
Holden, MA

Prepared by: Martin M. Wosnik

Reviewed by: Andrew E. Johansson

Approved by:

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Clinton Nuclear Power Station Pump Intake Model CNS/Vortex		002	1	12/5//2006

RECORD OF REVISION

Revision No.	Date	Description
001	12/1/06	Removal of Gas Volume Fraction meter and Pressure Transmitter from Table 1 Measurement Equipment.
001	12/1/06	Change Figure 1 & 2 (Flow Loop).
002	12/5/06	Change item vii under test plan.
002	12/5/06	Change item xii under test plan.
002	12/5/06	Change item xiv under test plan.
002	12/5/06	Change tests under Table 2 Test Matrix.

TABLE OF CONTENTS

1. PURPOSE

The purpose of this test is to conduct a physical hydraulic model study of the High Pressure Core Spray (HPCS) tank and suction nozzle of Clinton Nuclear Power Station (CNPS) to evaluate the potential for vortexing/air-entrainment as the tank drains and the water level is lowered to reach specified minimum submergences at specified flow rates.

2. SCOPE

The testing will consist of only one phase, which will use the pre-modification design with a horizontal suction nozzle to evaluate vortexing/air-entrainment. 4 tests, covering prototype (plant) flow rates from 3,000 gpm to 5,500 gpm will be performed. All testing will be conducted under transient flow conditions at Froude-scaled flow and submergence.

The flow modeling will be performed at the facilities of Alden Research Laboratory, Inc. (Alden) in Holden, Massachusetts by Alden personnel. Selected tests will be witnessed by personnel from Clinton Nuclear Power Station.

3. MEASUREMENT EQUIPMENT

The measurement equipment required to perform the test program is summarized in Table 1. The accuracy and/or calibration requirements of each piece of equipment are also listed.

Table 1
Measurement Equipment

EQUIPMENT	PURPOSE	ACCURACY
ASME Orifice Flow Meter	Measure outflow through modeled pump suction nozzles	+/- 2% of measured flow
Differential Pressure Cell	Monitor orifice meter differential head	+/- 0.25% of dp cell span
Differential Pressure Cell	Monitor water level	+/- 0.25% of dp cell span
Stilling Well	Set reference water levels	0.001 ft
Thermometer	Monitor water temperature	+/- 0.5 °F over a 32 °F to 80 °F range
Three (3) digital video cameras with timers	Monitor and record vortex activity and air entrainment	N/A
Data Acquisition Computer	To record output of differential pressure cells which monitor orifice meter differential head and water level.	N/A

4. TEST SETUP

The test setup will accommodate a hydraulic model of Clinton Nuclear Power Station HPCS Tank and Suction Nozzle, as well as measurement equipment and instrumentation, piping, pump and controller, valves, and a platform for operating and viewing. The geometric scale factor for the hydraulic model will be 1:3.05. Plan and elevation schematics of the test setup for the model are shown in Figures 1 and 2.

5. TEST PROCEDURE

The following test procedure has been prepared for the Clinton Nuclear Power Station test program. The procedures may be modified based on preliminary results once the test program begins. Any changes to the test procedure will be communicated to Exelon/AmerGen for approval and will be formally submitted as a revision to the test procedure.

a. Clinton HPCS Tank and Suction Nozzle Test Procedure

i. Fill the tank with water approximately to the initial water level listed in Table 2 using a laboratory fill pump.
ii. Purge all differential pressure cells used to measure flow meter differential pressure and water level so that any air bubbles are removed..
iii. Ensure Plexiglas view box is filled with water
iv. Ensure that the data acquisition system clock and the clocks of the video cameras are synchronized.
v. Open and/or close appropriate valves of physical model flow setup for draining of tank/no return flow.
vi. Start computer data acquisition system. Enter appropriate log data including, but not limited to, date, test number, target flow rate and initial water level in the Alden lab data book. Check that zero flow is indicated with no flow in the loop.
vii. Record the date and test number on the labels of the three videocassettes and load them into the cameras.
viii. Position one video camera to record the water surface in the tank in the vicinity of the outlet pipe entrance where vortex formation is expected.
ix. Position the second video camera to record a side view of air bubbles in the outlet piping at the Plexiglas view box location.
x. Position the third video camera to record a top view of air bubbles in the outlet piping at the Plexiglas view box location.
xi. Read the water level and add/take away water until desired initial water level in the tank is achieved (Table 2).
xii. Start recording data from the data acquisition system and start the video cameras. The start of video recording can be delayed based on engineering judgment.

xiii. Start the pump in the flow loop
xiv. Adjust the flow using the variable frequency drive (VFD) and/or control valve until the flow is set to the desired value (given in Table 2) as indicated by the computer (flow meter data acquisition). Flow will be set to within + 2% of the desired flow.
xv. Monitor the tank water surface (to observe onset of air-drawing vorticies) and flow in the outlet pipe to identify at what water level air entrainment begins.
xvi. Stop the test by shutting down the pump, closing the bypass valve, and saving the acquired data.
xvii. Repeat steps i through xvii for the next test series.

Table 2
Clinton HPCS Tank and Suction Nozzle Test Matrix

Test No.	Prototype Flow [gpm]	Scaled Flow [gpm]	Scaled Flow [cfs]	Flow Returned to Tank [gpm]	Initial Water Level* [in]
1a	5500	338.3	0.754	0	48
1b	5500	338.3	0.754	0	48
1c	5500	338.3	0.754	0	48
2a	3000	184.5	0.411	0	48
2b	3000	184.5	0.411	0	48
2c	3000	184.5	0.411	0	48
3	4250	261.4	0.582	0	48

* Initial water level from top of suction nozzle.

Additional runs to be determined based on results of tests 1 through 4.

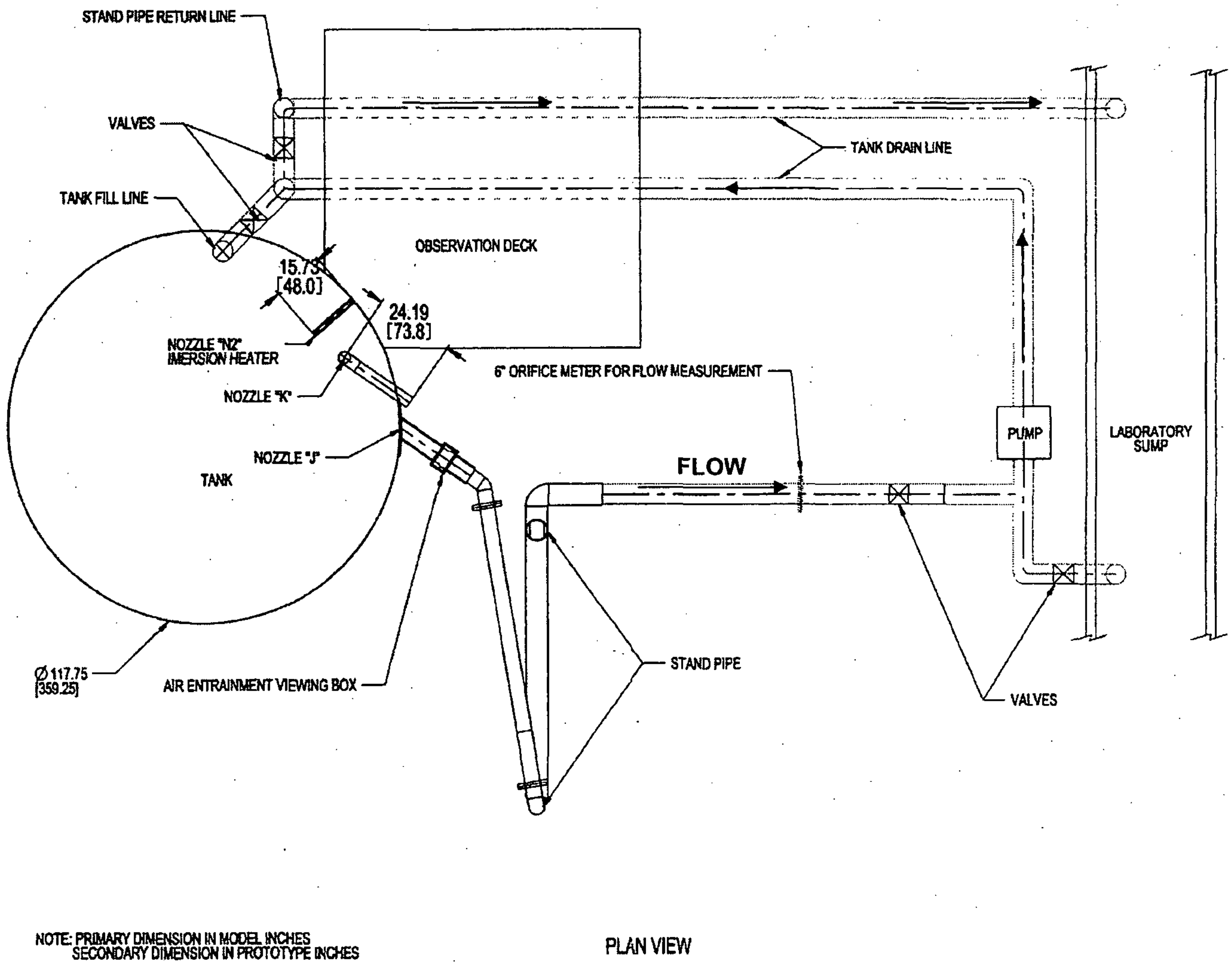

Figure 1: Clinton HPCS Tank and Suction Nozzle Air Entrainment/Vortex Study Test Loop Setup: Plan.

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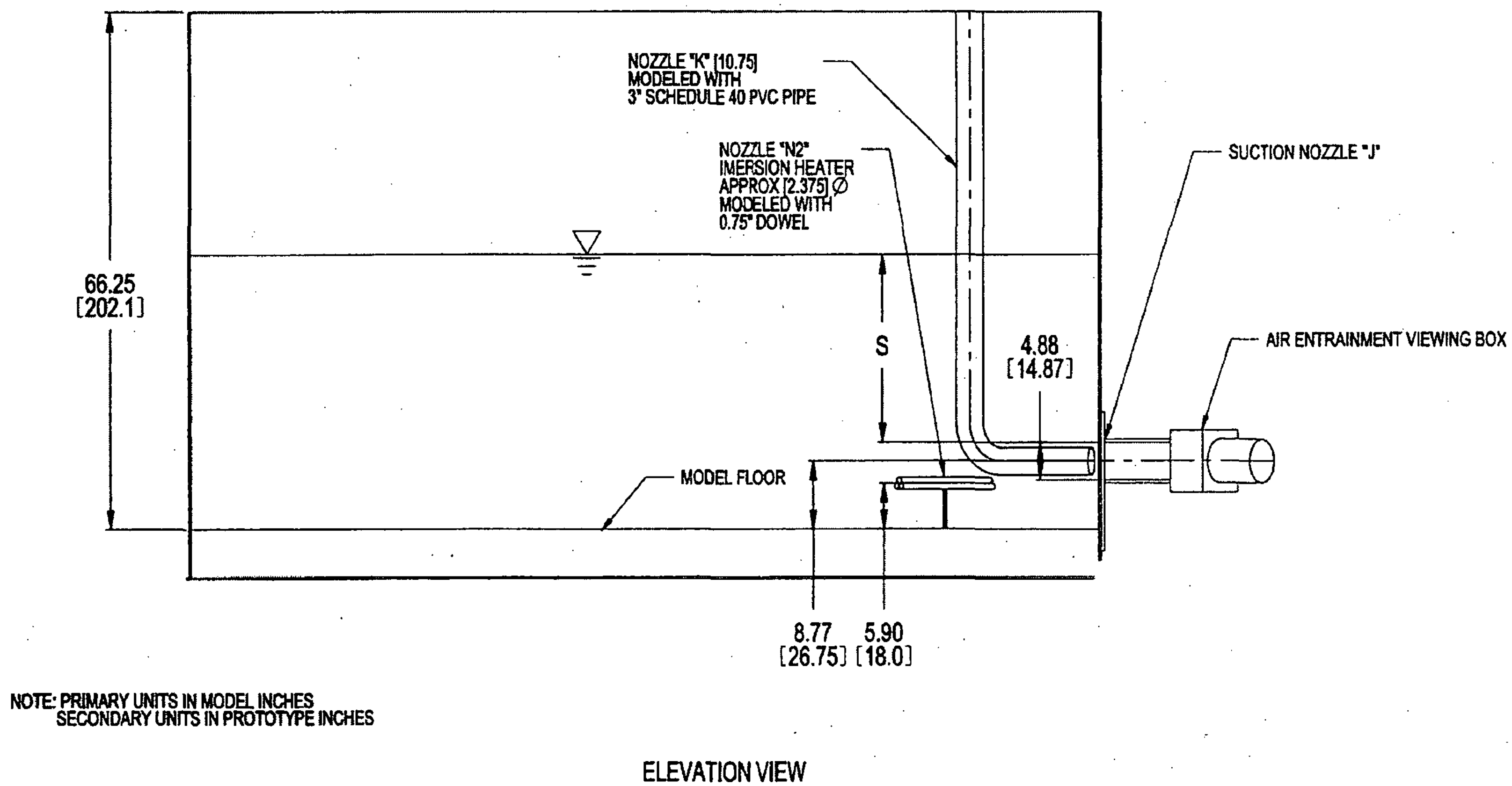

Figure 2: HPCS Tank and Suction Nozzle Air Entrainment/Vortex Study Test Loop Setup: Elevation.

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MPR
ASSOCIATES INC.
ENGINEERS

December 13, 2006
DRN 0065-0036-01

Mr. Robert Kerestes
Clinton Power Station
Amergen Energy
RR#3 Box 228
Clinton, IL 61727

Subject: Independent Third Party Review of Hydraulic Model Study of High Pressure Core Spray Pump Suction

Dear Mr. Kerestes:

Per your request, the purpose of this letter is to perform an independent third party review of the Hydraulic Model Study of the High Pressure Core Spray Pump Suction conducted for Exelon by Alden Research Laboratory (Alden). The scope of this review includes the test plan, scaling calculations, and final test report for the testing performed at Alden on December 5, 2006. Our observations and recommendations are provided below.

MPR reviewed the scaling calculations, model similitude, and test configuration. The geometric scale model used to perform the test was appropriately sized based on the actual configuration at Clinton. The geometric scale of 3.051 appropriately accounted for the velocity, flow, and other parameters for Froude similitude.

The test report states that two nozzles internal to the tank (Nozzle K and Nozzle N2) were also modeled due to their close proximity to the suction nozzle. These nozzles were modeled as obstructions to the flow only. The tank drawing (JND 51749) shows several additional nozzles in the tank.

Recommendation #1: MPR recommends that you confirm that the geometry of these additional nozzles does not impact the flow in the tank. Also, confirm that no other nozzles provide suction or discharge to the tank during the operation of the HPCS pump at Clinton to ensure that the flow field simulated in the test at Alden is representative of actual plant conditions when the pump is running.

The test included the use of several measurement devices which have associated uncertainties (Section 4.0 of the test report). Additionally, multiple runs at the same flow rates were conducted with varying results. The most critical result of the testing is the submergence value (S), documented in the results section and listed in Table 2 of the test report.

Recommendation #2: Analysis will be required to determine using the test data if the air ingested in the piping can reach the pump before recirculation alignment is complete. MPR recommends that Clinton Power Station should perform a statistical analysis of the data recorded in the test before using the submergence values to address the uncertainty in the test results.

The suction flows for the testing varied from 3000 gpm to 5500 gpm (prototype). Three runs were conducted at 3000 gpm (prototype), three runs at 5500 gpm (prototype) and one run at 4250 gpm (prototype). Because multiple runs were performed at the 3000 gpm and 5500 gpm (prototype) flowrates but not at the 4250 gpm (prototype) flowrate, they provide more assurance of the validity of the results than the 4250 gpm (prototype) run.

Recommendation #3: In addition to the 5500 gpm and 4200 gpm flow rates, a 4200 gpm flow rate was also tested at Alden. The purpose of this run was to ensure that the submergence for this flow was between the measured submergences for the other two flow rates. The test for 4250 gpm was not repeated since only a single run confirmed the expected result. Although, the results of the test were as expected, we recommend that this data point should not be used in analysis unless the test at 4250 gpm is repeated to obtain more readings.

An MPR representative witnessed the testing at Alden on December 5, 2006. The testing was conducted according to the test plan. Conclusions #1 and #2 in Section 8.0 of the test report are consistent with the observations noted by the MPR representative during the testing.

In reviewing the test report, MPR identified two “typos”. In Section 2.2, the definition of submergence states: “Bottom of nozzle for McGuire & Catawba, centerline of suction nozzle for Oconee”. The fourth sentence of the first paragraph of Section 5.0 states: “Tests for Clinton covered flows from ranging from…”

Recommendation #4: MPR recommends that these typos be corrected.

If you have any questions or comments about our independent third party review of this testing, please do not hesitate to call me or Peter Carlone.

Sincerely,

Amol Limaye

cc: E. Schweitzer