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Project No.: 700
Our ref: LTR-NRC-06-32
May 26, 2006

Subject: Transmittal of ARL Venturi Calibration Report for Ft. Calhoun Nuclear Station

Reference: J. B. Nystrom (ARL), "Calibration of Two 16" Wall Tap Flow Nozzle Meter Runs Omaha Public Power District Purchase Order Number 0077262," ARL No. 080-05/C1160, Rev. 1, March 2005

During a recent CROSSFLOW Ultrasonic Flow Measurement System meeting, the Nuclear Regulatory Commission (NRC) staff requested a copy of the Alden Research Laboratory (ARL) venturi calibration report for the Ft. Calhoun Nuclear Station. Per your request, and with the concurrence of the Omaha Public Power District (OPPD), Westinghouse Electric Company LLC (Westinghouse) is transmitting herewith a copy of this report (Reference).

If you have any further questions regarding this matter, please do not hesitate to contact me at (412) 374-4643.

Very truly yours,

James A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Attachment: As stated

cc: A. G. Howe (NRC, w/o Attachment)
J. A. Nakoski (NRC, w/o Attachment)
G. S. Shukla (NRC, w/ Attachment)

D054

CALIBRATION OF
TWO 16" WALL TAP FLOW NOZZLE METER RUNS
OMAHA PUBLIC POWER DISTRICT
PURCHASE ORDER NUMBER 0077262
MARCH 2005 ARL NO. 080-05/C1160
Revision 1

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

Two 16" Wall Tap Flow Nozzle Meter Runs, Serial Numbers158458/FE1101/1395 and 158459 /1102/1398, were calibrated at the Alden Research Laboratory, Inc. (Alden) for Omaha Public Power District under their Purchase Order Number 00077262, using Alden's standard test procedures, QA-AGF-7-86, Revision 6. Flow element performance is presented as discharge coefficient, C, versus pipe Reynolds number, in both tabular and graphical format for two tap sets.

FLOW ELEMENT INSTALLATION

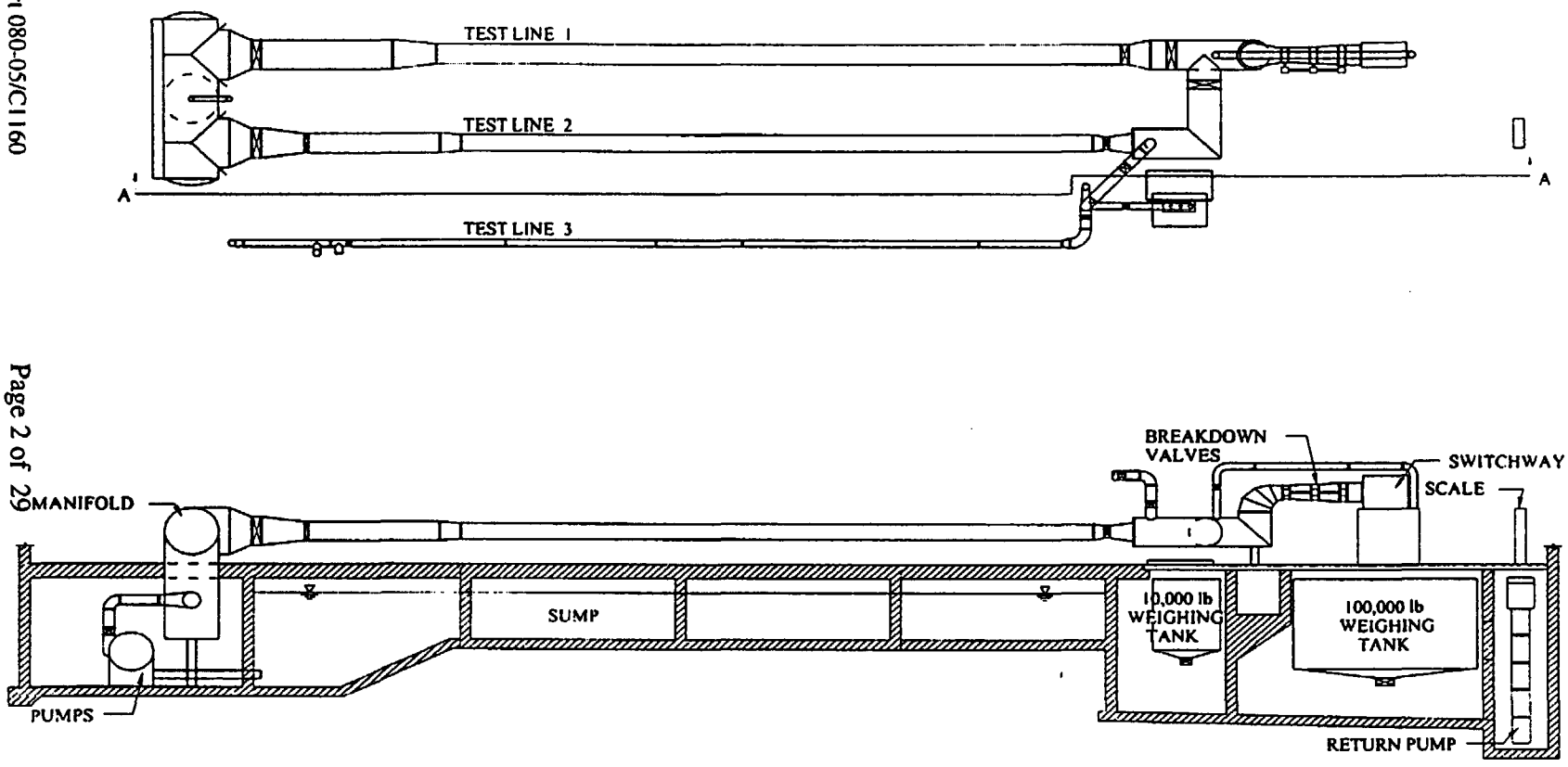
The flow meters were installed in Test Line 2 in the Allen Facility, which is shown in plan view on Figure 1. A pair of centrifugal pumps (300 horsepower each) provide a maximum head of about 150 ft and a maximum flow of about 44 ft^3/s. Water was provided from a heated 180,000 gallon sump under the test floor.

The detailed piping arrangements used for the calibrations, immediately upstream and downstream of the flow element, are shown in Figure 2, including all significant fittings and pipe lengths. 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. A specially fabricated elbow was included downstream of the meters to simulate field conditions

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.

Figure 1



SECTION A-A

Plan View of Allen High Reynolds Number Facility
Test Lines 1,2 and 3

ALDEN

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 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 tanks mounted on a scale having a capacity of 100,000 pounds with a resolution of 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, $\frac{ft^3}{sec}$

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 constant, as defined by Equation (3).

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

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).

$$R_D = \frac{q_a D}{a_p \gamma} \qquad (4)$$

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 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 results are presented in tabular and graphical format. The measured values of weight, time, and line temperature, which are 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 the discharge coefficient versus pipe Reynolds number for both tap sets. The discharge coefficient was measured over a test range of Reynolds numbers shown in the table below.

Serial Number	Tap Set	Pipe Reynolds Number	
		Minimum	Maximum
158459/FE1102/1398	FW147-FW148 & FW610-FW609	1,187,600	3,138,700
158458/FE1101/1395	FW145-FW146 & FW612-FW611	985,300	3,346,700

Mr. Neil Florentine of Westinghouse witnessed the tests.

As the operating Reynolds number exceeds the capability of the test facility, the discharge coefficient at operating conditions must be estimated. The extrapolation utilizes the ASME MFC-3M 1988 Equation (32) page 35 describing discharge coefficient versus pipe Reynolds number as shown by equation (5).

$$C = 0.9975 - 0.00653\left(\frac{10^6 \beta}{R_D}\right)^{0.5} \qquad (5)$$

The deviation of the measured coefficient from the equation value was calculated at each test Reynolds number. The average deviation was used calculate the discharge coefficient at any Reynolds number by equation (6).

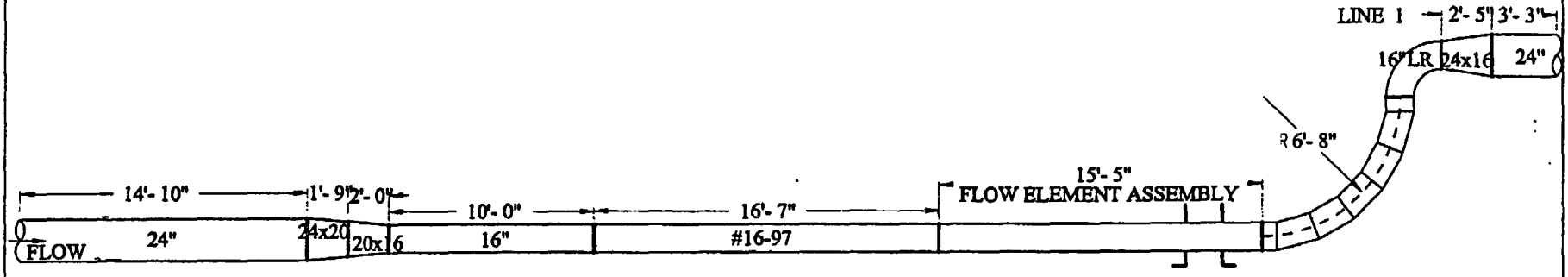
$$C = 0.9975 - 0.00653\left(\frac{10^6 \beta}{R_D}\right)^{0.5} + \Delta C_{ave} \qquad (6)$$

Tables are given indicating the measured coefficients versus Reynolds number, predicted coefficients, deviations, and average deviation over the test range. Plots of test data, predicted coefficients, and extrapolated coefficients are shown for each meter.

Analysis shown in the following tables an plot of uncertainty versus Reynolds number indicates that the flow measurement uncertainty is better than 0.15% at the 95% confidence level. Calibrations of

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).

Figure 2 Plan View Allen Facility Line 1 & 2



OMAHA PUBLIC POWER DISTRICT
Purchase Order Number: 00077262
16" PIPING ASSEMBLY
March, 2005

ALDEN

OMAHA PUBLIC POWER DISTRICT

Purchase Order Number: 00077262
16" FEEDWATER NOZZLE ASSEMBLY
Serial Number: 158458 FE1101/1395

CALIBRATION
DATE: March 23, 2005
PIPE DIAMETER = 13.9250
THROAT DIAMETER = 7.9710

TAP SET FW145 & FE146

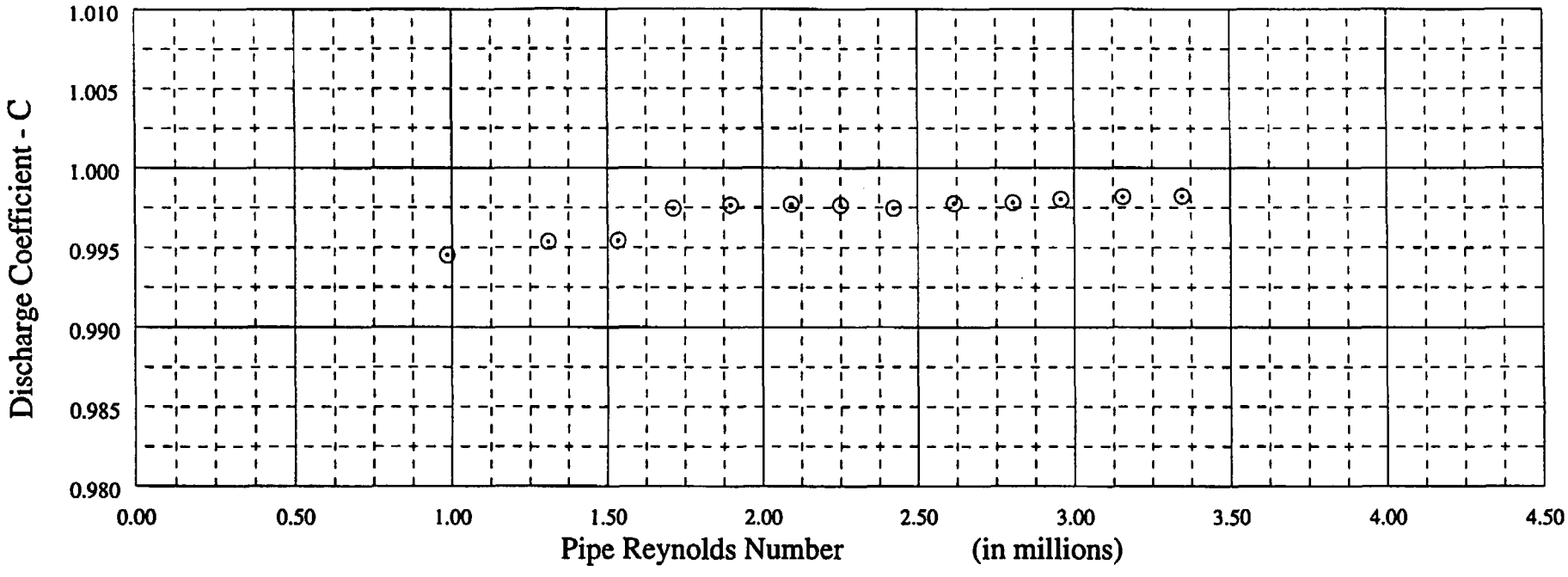
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^6	Coef
1	90	73	95441	118.952	3.834~	5804.5	19.411	1.7138	0.9975
2	90	73	95529	107.508	4.252~	6428.3	23.797	1.8980	0.9977
3	90	73	95387	97.236	4.748~	7096.6'	29.000	2.0928	0.9977
4	90	73	95589	90.512	5.187~	7639.9	33.614	2.2504	0.9977
5	90	73	95730	84.425	5.677~	8203.0	38.767	2.4220	0.9975
6	90	73	95630	78.141	6.283~	8853.6	45.131	2.6171	0.9978
7	90	73	95816	73.214	6.900~	9468.2	51.610	2.8049	0.9978
8	90	73	95768	69.466	7.437~	9974.3	57.247	2.9580	0.9981
9	90	73	95782	65.255	8.163~	10619.8	64.878	3.1562	0.9982
10	91	73	96097	61.880	8.900~	11236.2	72.622	3.3467	0.9982
11	91	73	95287	133.852	7.847~	5150.7	15.346	1.5341	0.9955
12	91	73	95190	207.972	4.420~	3311.6	6.355	0.9853	0.9945
13	91	73	95232	156.811	6.255~	4394.1	11.170	1.3088	0.9954

~ 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: S.V.K.

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 = $\frac{a\sqrt{2g}}{\sqrt{1 - \beta^4}}$	=	2.9418
F_a =	Average Thermal Expansion Factor	=	1.0004
a =	Throat Area (ft^2)	=	0.3465
g =	Local Acceleration of Gravity (ft/sec^2)	=	32.1625
β =	Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.5724
	Pipe Diameter (Inches)	=	13.9250
	Throat Diameter (Inches)	=	7.9710

Dimensions By: OMAHA PUBLIC POWER DISTRICT

OMAHA PUBLIC POWER DISTRICT
Purchase Order Number: 00077262
16" FEEDWATER NOZZLE ASSEMBLY
Serial Number: 158458 FE1101/1395

March 23, 2005

TAP SET FW145 & FW146

Certified By:

ARL

Omaha Public Power District
PO # 00077262
16" Feedwater Flow Nozzle
Tap Numbers FW145&FW146

Test #	Pipe Reynolds # 1000000	Measured Coefficient	Predicted Coefficient	Translated Coefficient
1	0.9853	0.9945	0.9925	0.9958
2	1.3088	0.9954	0.9932	0.9964
3	1.5341	0.9955	0.9935	0.9968
4	1.7138	0.9975	0.9937	0.9970
5	1.898	0.9977	0.9939	0.9972
6	2.0928	0.9977	0.9941	0.9973
7	2.2504	0.9977	0.9942	0.9975
8	2.422	0.9975	0.9943	0.9976
9	2.6171	0.9978	0.9944	0.9977
10	2.8049	0.9978	0.9946	0.9978
11	2.958	0.9981	0.9946	0.9979
12	3.1562	0.9982	0.9947	0.9980
13	3.3467	0.9982	0.9948	0.9980
	5		0.9953	0.9985
	6		0.9955	0.9987
	7		0.9956	0.9989
	8		0.9958	0.9990
	9		0.9959	0.9991
	10		0.9959	0.9992
	11		0.9960	0.9993
	12		0.9961	0.9993
	13		0.9961	0.9994
	14		0.9962	0.9994

Average Deviation 0.0032

OMAHA PUBLIC POWER DISTRICT

Purchase Order Number: 00077262
16" FEEDWATER NOZZLE ASSEMBLY
Serial Number: 158458 FE1101/1395

CALIBRATION
DATE: March 23, 2005
PIPE DIAMETER = 13.9250
THROAT DIAMETER = 7.9710

TAP SET FW611 & FW612

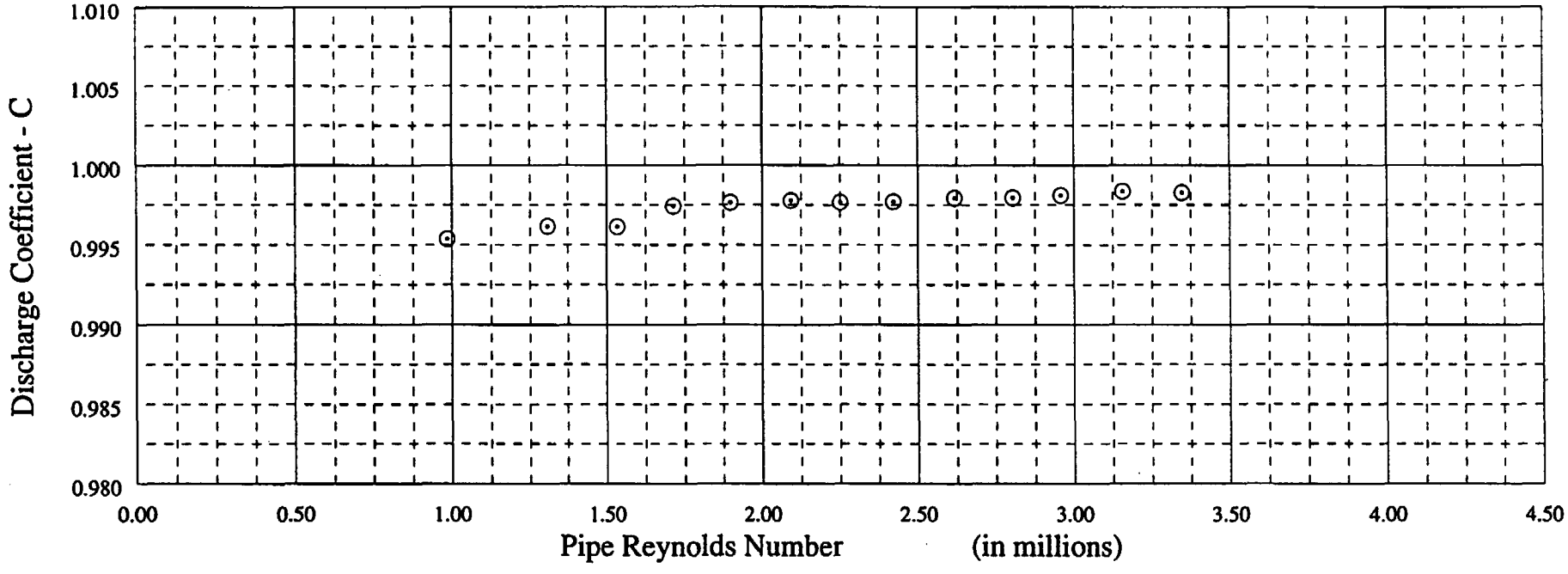
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^6	Coef
1	90	73	95441	118.952	3.859~	5804.5	19.412	1.7138	0.9974
2	90	73	95529	107.508	4.280~	6428.3	23.798	1.8980	0.9977
3	90	73	95387	97.236	4.778~	7096.6	28.996	2.0928	0.9978
4	90	73	95589	90.512	5.221~	7639.9	33.613	2.2504	0.9977
5	90	73	95730	84.425	5.714~	8203.0	38.748	2.4220	0.9977
6	90	73	95630	78.141	6.324~	8853.6	45.115	2.6171	0.9980
7	90	73	95816	73.214	6.946~	9468.2	51.596	2.8049	0.9980
8	90	73	95768	69.466	7.487~	9974.3	57.240	2.9580	0.9981
9	90	73	95782	65.255	8.217~	10619.8	64.856	3.1562	0.9984
10	91	73	96097	61.880	8.960~	11236.2	72.615	3.3467	0.9983
11	91	73	95287	133.852	7.879~	5150.7	15.325	1.5341	0.9961
12	91	73	95190	207.972	4.440~	3311.6	6.345	0.9853	0.9954
13	91	73	95232	156.811	6.281~	4394.1	11.152	1.3088	0.9962

~ 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: S.V.K.

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 = $\frac{a\sqrt{2g}}{\sqrt{1 - \beta^4}}$	=	2.9418
F_a =	Average Thermal Expansion Factor	=	1.0004
a =	Throat Area (ft^2)	=	0.3465
g =	Local Acceleration of Gravity (ft/sec^2)	=	32.1625
ß =	Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.5724
	Pipe Diameter (Inches)	=	13.9250
	Throat Diameter (Inches)	=	7.9710

Dimensions By: OMAHA PUBLIC POWER DISTRICT

OMAHA PUBLIC POWER DISTRICT
Purchase Order Number: 00077262
16" FEEDWATER NOZZLE ASSEMBLY
Serial Number: 158458 FE1101/1395

March 23, 2005

TAP SET FW611 & FW612

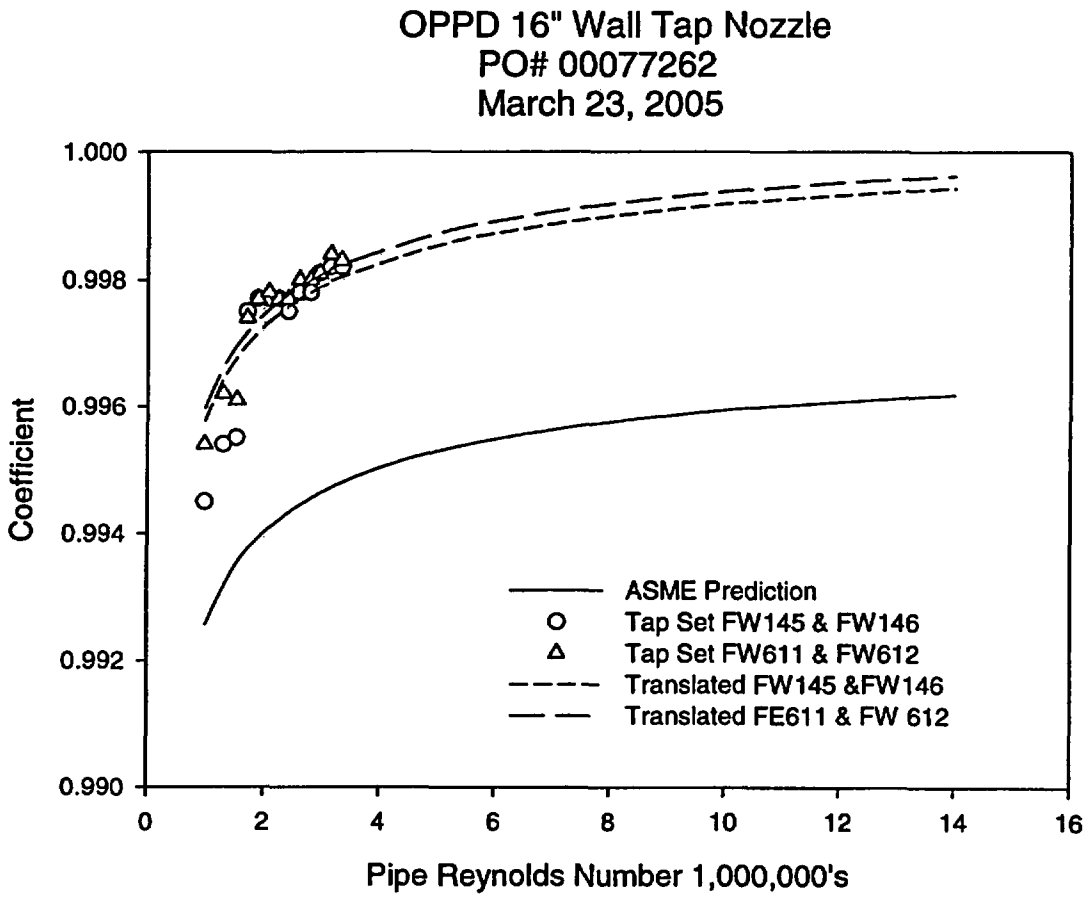
Certified By:

ARL

Omaha Public Power District
PO # 00077262
16" Feedwater Flow Nozzle
Tap Numbers FW612&FW611

Test #	Pipe Reynolds # 1000000	Measured Coefficient	Predicted Coefficient	Translated Coefficient
1	0.9853	0.9954	0.9925	0.99597
2	1.3088	0.9962	0.9932	0.99662
3	1.5341	0.9961	0.9935	0.99695
4	1.7138	0.9974	0.9937	0.99717
5	1.898	0.9977	0.9939	0.99736
6	2.0928	0.9978	0.9941	0.99753
7	2.2504	0.9977	0.9942	0.99765
8	2.422	0.9977	0.9943	0.99777
9	2.6171	0.9980	0.9944	0.99789
10	2.8049	0.9980	0.9946	0.99799
11	2.958	0.9981	0.9946	0.99807
12	3.1562	0.9984	0.9947	0.99816
13	3.3467	0.9983	0.9948	0.99824
	5		0.9953	0.99873
	6		0.9955	0.99892
	7		0.9956	0.99907
	8		0.9958	0.99919
	9		0.9959	0.99929
	10		0.9959	0.99938
	11		0.9960	0.99945
	12		0.9961	0.99952
	13		0.9961	0.99957
	14		0.9962	0.99962

Average Deviation 0.0034


OPPD 16" Wall Tap Nozzle
PO# 00077262
March 23, 2005
1.000
0.998
0.996
0.994
0.992
0.990
Coefficient
0
2
4
6
8
10
12
14
16
Pipe Reynolds Number 1,000,000's
ASME Prediction
Tap Set FW145 & FW146
Tap Set FW611 & FW612
Translated FW145 &FW146
Translated FE611 & FW 612

OMAHA PUBLIC POWER DISTRICT

Purchase Order Number: 00077262
16" FEEDWATER NOZZLE ASSEMBLY
Serial Number: 158459 FE1102/1398

CALIBRATION
DATE: March 23, 2005
PIPE DIAMETER = 13.9380
THROAT DIAMETER = 7.9700

TAP SET FW147 & FW148

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 10^6	Coef
1	88	67	96155	64.066	8.468~	10854.7	68.052	3.1387	0.9967
2	88	67	96109	66.521	7.992~	10448.9	63.055	3.0179	0.9968
3	88	67	95904	70.657	7.287~	9816.5	55.650	2.8385	0.9968
4	88	67	95818	74.258	6.777~	9332.3	50.303	2.7017	0.9967
5	88	67	95736	79.880	6.121~	8668.0	43.407	2.5094	0.9966
6	88	67	95878	85.033	5.646~	8155.0	38.430	2.3636	0.9965
7	88	67	95632	91.380	5.139~	7569.1	33.101	2.1963	0.9966
8	89	67	95427	98.804	4.676~	6985.7	28.240	2.0318	0.9958
9	89	67	95549	110.002	4.160~	6282.5	22.829	1.8251	0.9960
10	89	67	95371	124.072	8.824~	5559.7	17.902	1.6170	0.9954
11	89	67	95421	143.510	7.110~	4809.3	13.408	1.4004	0.9949
12	89	67	95260	169.140	5.667~	4073.7	9.625	1.1876	0.9947

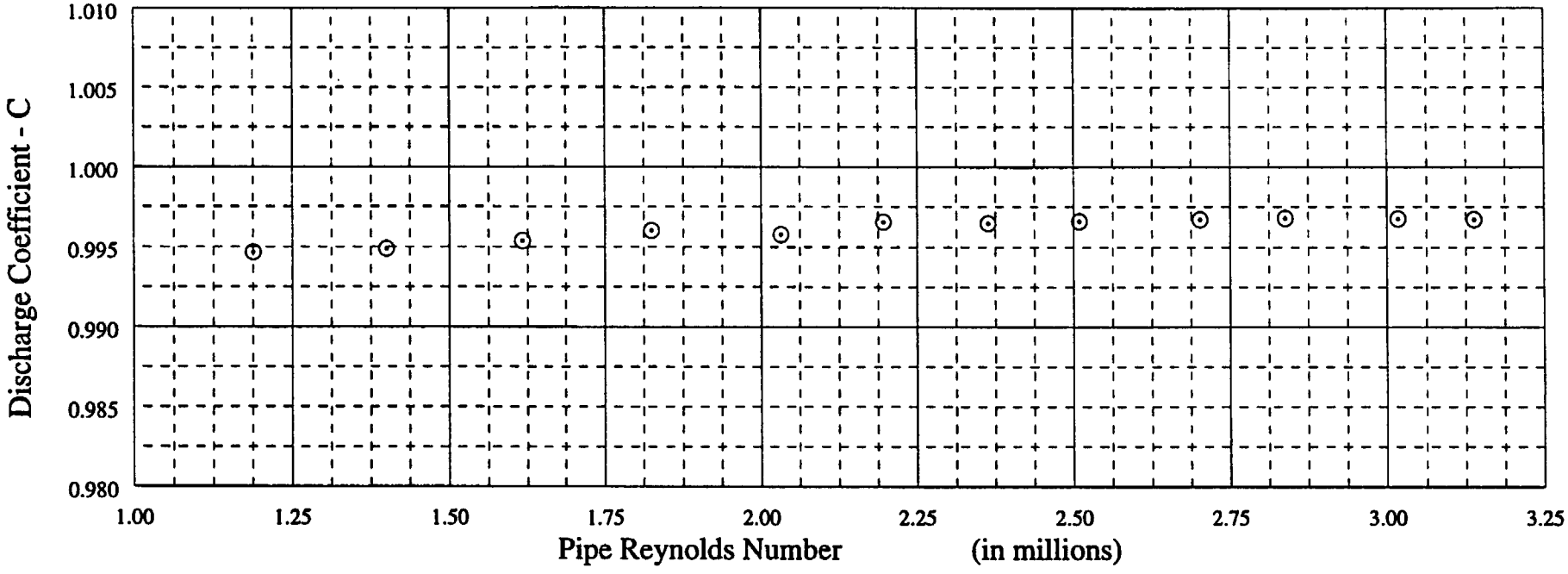
~ dp transmitter volts

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: S.V.K.

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 = $\frac{a\sqrt{2g}}{\sqrt{1 - \beta^4}}$	=	2.9403
F_a =	Average Thermal Expansion Factor	=	1.0003
a =	Throat Area (ft^2)	=	0.3465
g =	Local Acceleration of Gravity (ft/sec^2)	=	32.1625
ß =	Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.5718
	Pipe Diameter (Inches)	=	13.9380
	Throat Diameter (Inches)	=	7.9700

Dimensions By: OMAHA PUBLIC POWER DISTRICT

OMAHA PUBLIC POWER DISTRICT
Purchase Order Number: 00077262
16" FEEDWATER NOZZLE ASSEMBLY
Serial Number: 158459 FE1102/1398

March 23, 2005

TAP SET FW147 & FW148

Certified By:

Omaha Public Power District
PO # 00077262
16" Feedwater Flow Nozzle
Tap Numbers FW147&FW148

Test #	Pipe Reynolds # 1000000	Measured Coefficient	Predicted Coefficient	Translated Coefficient
1	1.1876	0.9947	0.9930	0.9950
2	1.4004	0.9949	0.9933	0.9954
3	1.617	0.9954	0.9936	0.9957
4	1.8251	0.9960	0.9938	0.9959
5	2.0318	0.9958	0.9940	0.9961
6	2.1963	0.9966	0.9942	0.9962
7	2.3636	0.9965	0.9943	0.9964
8	2.5094	0.9966	0.9944	0.9964
9	2.7017	0.9967	0.9945	0.9966
10	2.8385	0.9968	0.9946	0.9966
11	3.0179	0.9968	0.9947	0.9967
12	3.1387	0.9967	0.9947	0.9968
	4		0.9950	0.9971
	5		0.9953	0.9974
	6		0.9955	0.9975
	7		0.9956	0.9977
	8		0.9958	0.9978
	9		0.9959	0.9979
	10		0.9959	0.9980
	11		0.9960	0.9981
	12		0.9961	0.9981
	13		0.9961	0.9982
	14		0.9962	0.9982

Average Deviation 0.0021

OMAHA PUBLIC POWER DISTRICT

Purchase Order Number: 00077262
16" FEEDWATER NOZZLE ASSEMBLY
Serial Number: 158459 FE1102/1398

CALIBRATION
DATE: March 23, 2005
PIPE DIAMETER = 13.9380
THROAT DIAMETER = 7.9700

TAP SET FW609 & FW610

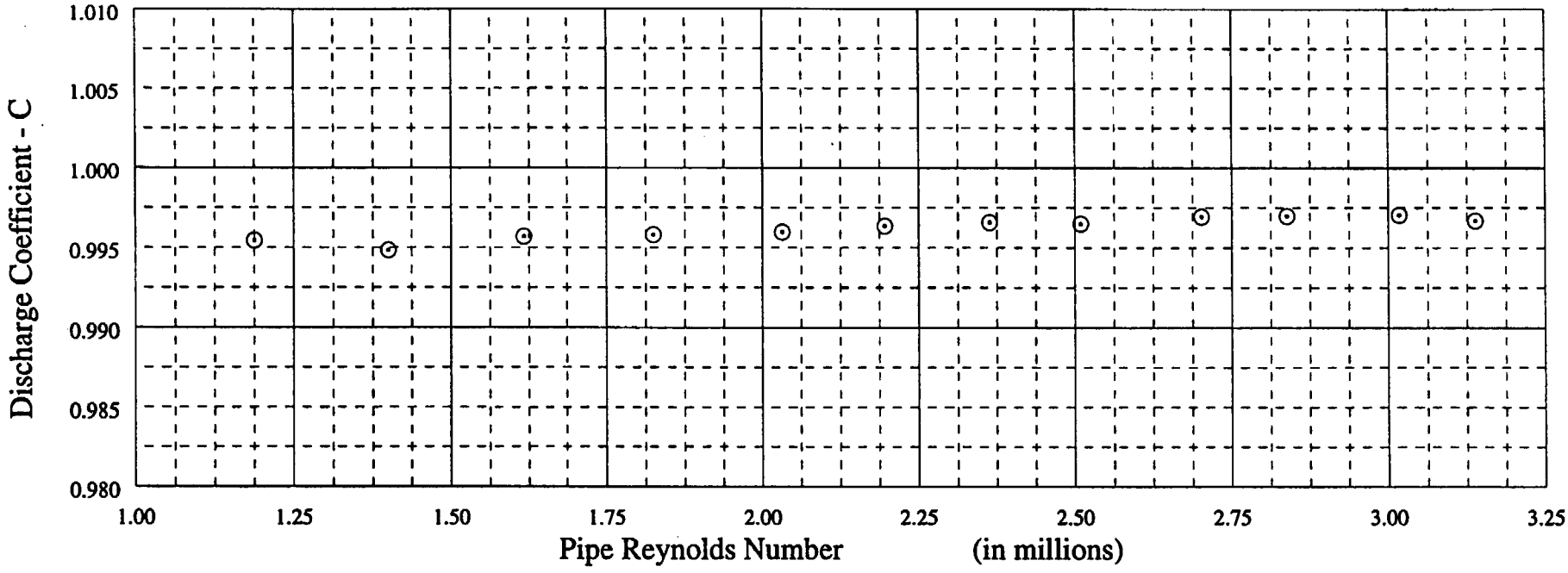
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^6	Coef
1	88	67	96155	64.066	8.527~	10854.7	68.059	3.1387	0.9967
2	88	67	96109	66.521	8.043~	10448.9	63.020	3.0179	0.9971
3	88	67	95904	70.657	7.334~	9816.5	55.630	2.8385	0.9970
4	88	67	95818	74.258	6.821~	9332.3	50.281	2.7017	0.9969
5	88	67	95736	79.880	6.162~	8668.0	43.416	2.5094	0.9965
6	88	67	95878	85.033	5.683~	8155.0	38.422	2.3636	0.9966
7	88	67	95632	91.380	5.174~	7569.1	33.115	2.1963	0.9964
8	89	67	95427	98.804	4.705~	6985.7	28.228	2.0318	0.9960
9	89	67	95549	110.002	4.188~	6282.5	22.839	1.8251	0.9958
10	89	67	95371	124.072	8.864~	5559.7	17.890	1.6170	0.9957
11	89	67	95421	143.510	7.148~	4809.3	13.410	1.4004	0.9948
12	89	67	95260	169.140	5.692~	4073.7	9.610	1.1876	0.9954

~ 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: S.V.K.

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 = $\frac{a\sqrt{2g}}{\sqrt{1 - \beta^4}}$	=	2.9403
F_a =	Average Thermal Expansion Factor	=	1.0003
a =	Throat Area (ft^2)	=	0.3465
g =	Local Acceleration of Gravity (ft/sec^2)	=	32.1625
ß =	Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.5718
	Pipe Diameter (Inches)	=	13.9380
	Throat Diameter (Inches)	=	7.9700

Dimensions By: OMAHA PUBLIC POWER DISTRICT

OMAHA PUBLIC POWER DISTRICT
Purchase Order Number: 00077262
16" FEEDWATER NOZZLE ASSEMBLY
Serial Number: 158459 FE1102/1398

March 23, 2005

TAP SET FW 609 & FW610

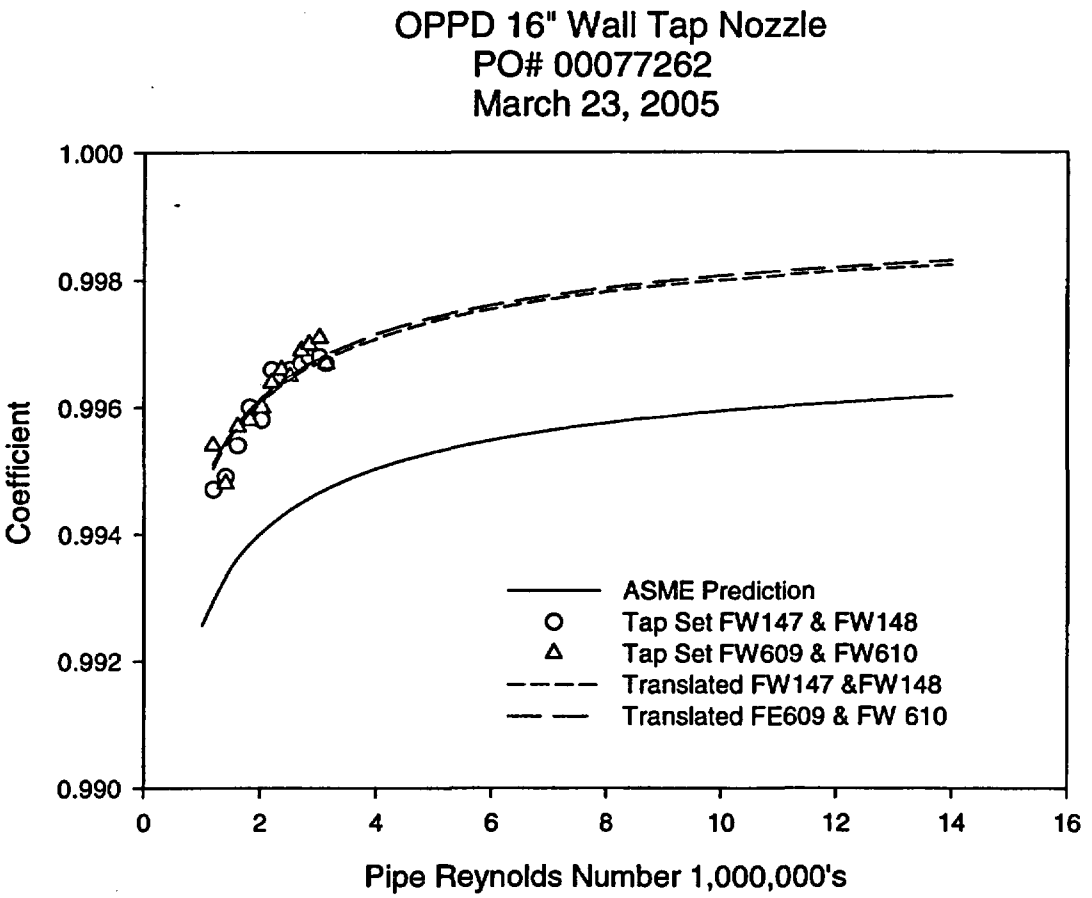
Certified By:

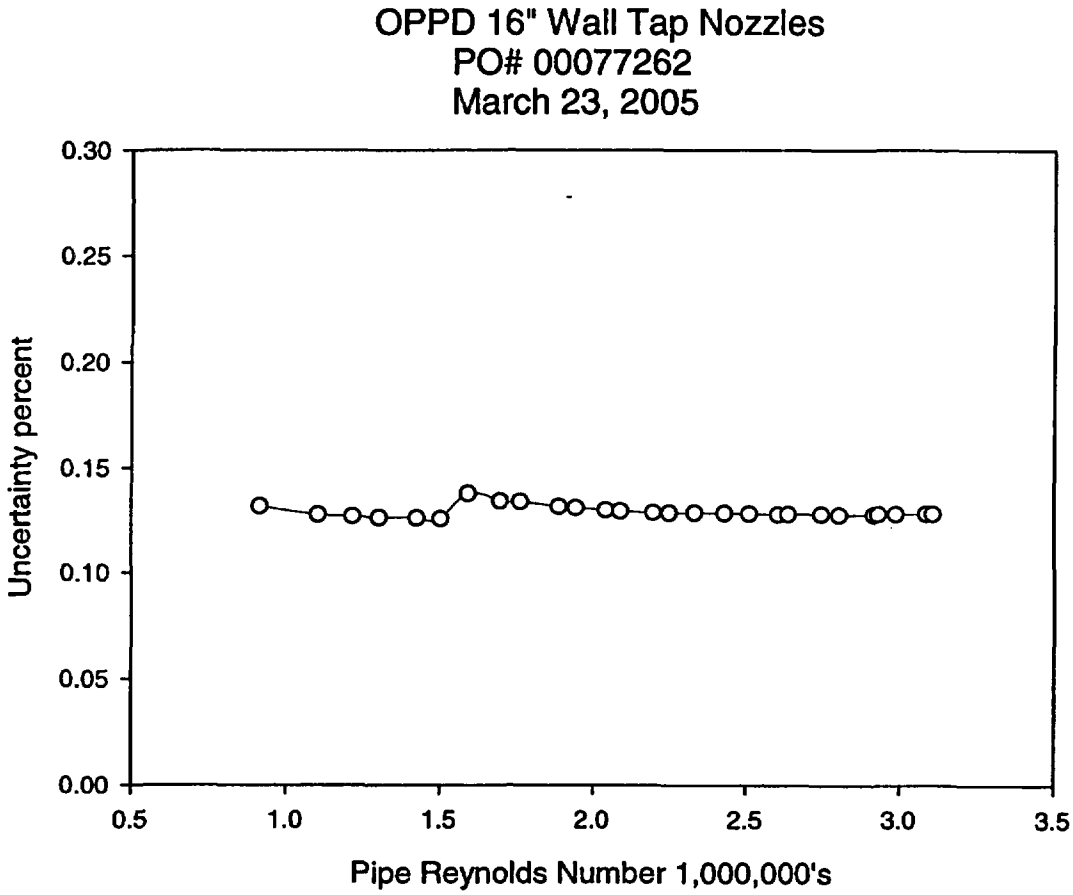
ARL

Omaha Public Power District
PO # 00077262
16" Feedwater Flow Nozzle
Tap Numbers FW610 & FW609

Test #	Pipe Reynolds # 1000000	Measured Coefficient	Predicted Coefficient	Translated Coefficient
1	1.1876	0.9954	0.9930	0.9951
2	1.4004	0.9948	0.9933	0.9955
3	1.617	0.9957	0.9936	0.9957
4	1.8251	0.9958	0.9938	0.9960
5	2.0318	0.9960	0.9940	0.9962
6	2.1963	0.9964	0.9942	0.9963
7	2.3636	0.9966	0.9943	0.9964
8	2.5094	0.9965	0.9944	0.9965
9	2.7017	0.9969	0.9945	0.9966
10	2.8385	0.9970	0.9946	0.9967
11	3.0179	0.9971	0.9947	0.9968
12	3.1387	0.9967	0.9947	0.9968
0	4		0.9950	0.9972
0	5		0.9953	0.9974
0	6		0.9955	0.9976
0	7		0.9956	0.9978
0	8		0.9958	0.9979
0	9		0.9959	0.9980
0	10		0.9959	0.9981
0	11		0.9960	0.9981
0	12		0.9961	0.9982
0	13		0.9961	0.9983
0	14		0.9962	0.9983

Average Deviation 0.0021


OPPD 16" Wall Tap Nozzle
PO# 00077262
March 23, 2005
1.000
0.998
0.996
0.994
0.992
0.990
Coefficient
0
2
4
6
8
10
12
14
16
Pipe Reynolds Number 1,000,000's
ASME Prediction
Tap Set FW147 & FW148
Tap Set FW609 & FW610
Translated FW147 &FW148
Translated FE609 & FW 610


OPPD 16" Wall Tap Nozzles
PO# 00077262
March 23, 2005
Uncertainty percent
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Pipe Reynolds Number 1,000,000's

Uncertainty Calculation
Omaha Public Power District
16" Wall Tap Nozzle

Toledo 100,000 lb
Table 1
Mass 96155

	Type B	Type A
Calibration	42.50	na
Buoyancy	8.52	na
Reading	na	2.00
Hysteresis	na	6.00
Ageing	11.06	na
Leakage	2.00	na
Standard Uncertainty (lb)	45.22	
Standard Uncertainty (%)	0.0470	

Table 2
Time 64.066

	Type B	Type A
Time Standard	0.00019	na
Resolution	na	0.001
Trigger	0.0019	0.002
Standard Uncertainty (sec)	0.0029	
Standard Uncertainty (%)	0.0046	

Table 3
Density
Percent at 88.2

	Type B	Type A
Temperature	0.017	0.009
Impurities	0.01	na
Standard Uncertainty (%)	0.0219	

Omaha Public Power District
16" Wall Tap Nozzle

Table 4
Overall Flow

Mass	0.047
Time	0.005
Diverter	0.025
Density	0.022
Standard Uncertainty (%)	0.058
Combined Uncertainty	0.116

Table 5
Differential Pressure
Percent of Reading

	Type B	Type A
Calibration	0.040	na
Span and Zero	0.015	na
Fluctuations	na	0.020
Temperature Correction	0.036	0.018
Thermal Gradients	0.019	na
Standard Uncertainty (%)	0.059	
Sensitivity	0.500	

Table 6
Discharge Coefficient

	Type B
Flow	0.058
Differential Head	0.029
Thermal Expansion	0.002
Local Gravity	0.0008
Meter Dimensions	0.014
Standard Uncertainty (%)	0.066
Combined Uncertainty	0.133

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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).

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

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