Enclosure 12

Cameron Document ER-1132NP, "Meter Factor Calculation and Accuracy Assessment for Hope Creek Nuclear Generating Station," Revision 2, (Non-Proprietary Version)

CAMERON
A Schlumberger Company

Measurement Systems

Caldon Ultrasonics
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Engineering Report No. 1132NP, Rev 2

Meter Factor Calculation and Accuracy Assessment for Hope Creek Nuclear Generating Station

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CAMERON
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Measurement Systems

Engineering Report No. ER-1132NP, 2

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ER-1132NP Rev 2, Meter Factor Calculation and Accuracy Assessment for Hope Creek Nuclear Generating Station

1.0 INTRODUCTION

1.1 Scope

This report documents calibration and uncertainty analysis of the Hope Creek Nuclear Generating Station flow element S/N 4511180010-001.

This report includes:

- Meter factor(s) and meter factor uncertainty
- Description of the hydraulic models
- Description of the tests conducted
- [ ]

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1.2 Background

The flow meter uses measurements of the fluid velocity projected onto acoustic paths to determine the volumetric and mass flow. The meter makes the transit time measurements of ultrasonic energy pulses that travel between transducers and combines these with the distance separating the transducers to calculate the velocity. The flow meter uses eight acoustic paths that are arranged as two crossing planes, each plane containing four chords (essentially two four path meters). The meter calculates volumetric flow by numerically integrating the fluid-velocity chord length product along the chords.

It is Cameron's practice to perform a calibration test in order to determine the meter calibration constant, or meter factor. The meter factor provides a small correction to the numerical integration to account for the specifics of the fluid velocity profile as well as any dimensional measurement effects. Further, for this calibration, parametric tests were performed to determine the sensitivity of the meter factor to upstream hydraulics. The parametric tests vary the model inlet conditions and/or piping components to vary the hydraulics.

The calibration test was performed at Alden Research Laboratories (Alden), an independent hydraulic laboratory. Alden can provide flow rates up to ~4500 m^3/hr (~20,000 gpm). For these hydraulic models, the piping pressure losses and cavitation limited the calibration flow rate to ~4,200 m^3/hr (~18,500 gpm).

During the calibration, reference flow rates were determined by Alden using a weigh tank, fill times, fluid temperature and barometric pressure measurements. All elements of the lab measurements including weigh tank scale, time measurements, thermometers and pressure gages, are traceable to NIST standards. In order to determine the meter factor, the flow meter outputs are compared against the reference flow rates.

The Hope Creek Nuclear Generating Station calibration test procedure was ALD-1164 Rev 2, which provided overall guidance for the test setup and test scope.

1.3 Report Summary

a. Table 1.1 provides the Hope Creek Nuclear Generating Station meter factors and uncertainties when calibrated in the installation model. Refer to Section 4.0 for a detailed summary.

Table 1.1 Calibration Summary

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b. [

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Table 1.2 [ ]

[ ]

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[1] This value is the weighted average of test data based on number of data points for each configuration. This number is slightly different than averaging the average of the tests, since the number of data points is not equal in all tests.

2.0 CALIBRATION TESTS

The objectives for the calibration tests were to:

- Determine the meter factor in a piping configuration that models the installation site,
- Determine the sensitivity of the meter factor to variations in the hydraulic model,
- [ ]

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2.1 Meter Seup

2.1.1 Setup

The meter was installed in accordance with portions of Cameron Engineering Field Procedure EFP-68. Specifically, the portions of EFP-68 accomplished:

- [
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-]

[ ]

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2.2 Installation Site Model

The hydraulic model configuration was designed as a hydraulic duplicate of the principle hydraulic features of the installation site (see Reference 1 for plant details). The model piping arrangement is shown in Figure 2.1 below. A photograph of the Alden Laboratories model is provided as Figure 2.2.

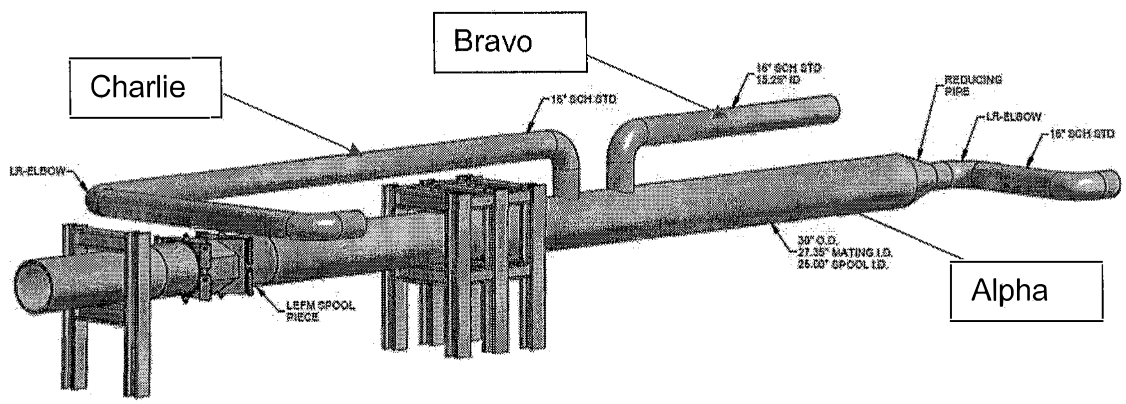

Figure 2.1 Hydraulic Model

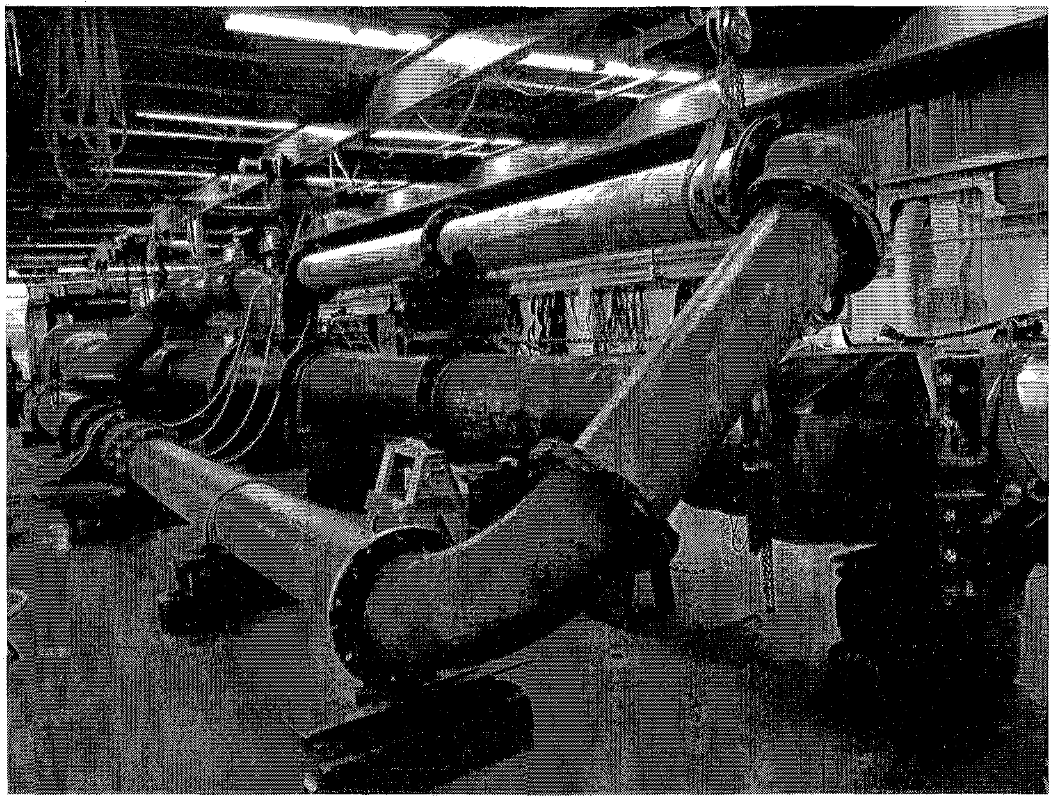

Figure 2.2 Header (Typical of all tests) – Hydraulic Model

2.3 Calibration Data and Parametric Tests

Reference 1 outlines the model tests and parametric tests performed. These parametric tests included variations in the flow distribution [ ]. With these parametric tests, installation uncertainty is addressed.

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The Hope Creek Nuclear Generating Station parametric tests and calibration numbers are described below in Table 2.1. The Hope Creek Nuclear Generating Station test data is shown in Appendix A – Calibration Data. All the tests are used to determine the average meter factor to be used at the plant.

Table 2.1 Test Summary

Loop	Test	Test No.	Used in Average MF	Comments

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Model test consisted of 25 weight tank runs over a range of different flow rates.

2.3.1 Test Collection Procedure

Weigh tank testing at a specific flow rate began by setting the proper flow in the flow loop using a remotely operated butterfly valve located downstream of the model. The flow meter data is collected using a serial connection to a laptop PC. The flow data is polled by the PC from the electronics at approximately 5-second intervals. The ported information contains a time stamp and volumetric flows, as well as signal data quality, and path velocity data. Velocity data for individual acoustic paths are recorded in order to evaluate the fluid velocity profile.

The test procedure at any given flow rate was as follows:

- Set the flow rate and allow flow to stabilize
- Alden personnel operate weigh tank run by moving the diverter valve.
- Cameron personnel separately record a start time and a stop time, as well as a complete datalog from the flow transmitter for each test run. This information is used to synchronize the ported data with the weigh tank data.

3.0 METER FACTOR CALCULATION

3.1 Meter Factor Definition

The meter factor accounts for (typically small) biases in the numerical integration due to the hydraulics, dimension measurements and acoustics of the application. The flow meter software multiplies the result of the multi-path numerical integration by the meter factor to obtain the flow rate. For the Alden tests, the meter factor was set at 1.000.

The meter factor is calculated by the following equation:

$$MF = \frac{Q_{Alden}}{Q_{meter}}$$

Where:

Q_{meter} = Volumetric flow rate from meter (with meter factor set to 1.000)
Q_{Alden} = Volumetric flow rate based on Alden weight tank

3.2 Test Results

Appendix A tabulates the results of the individual calibration runs. Each tab/subsection of Appendix A documents the different hydraulic configurations. All tables contain for each weigh tank run:

- Alden certified flow rate
- [ ]
- [ ]

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Table 3.1 below summarizes the data (including velocity profile data).

Figure 3.1 plots the meter factors vs Alden recorded flows for all the tests (note: for clarity only, the average meter factor at each flow rate is plotted).

Table 3.1 Meter Factors, Flatness Ratios (FR), and Swirl for Each Hydraulic Configuration[2]

Loop	Test No.	Used in Average MF	MF	FR	Swirl

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2 Note – [ ]

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3.3 Measured Velocity Profiles

Using the flow meter it is possible to measure and understand the actual hydraulic velocity profile. Appendix A has the velocity profiles observed during each model test. Figure 3.2 provides the velocity profile for the model test at each chord ("nominal" model only shown). The figures in Appendix A plot the velocity ratios (and differences between plans) for all the different model cases.

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Figure 3.2 Test A-1 (Model) Velocity Profile

3.3.1 Swirl Rate Definition

Swirl can be measured by the flow meter. Cameron quantifies swirl rate with a swirl rate calculation, as follows:

$$\text{Swirl Rate} = \text{Average}\left[\frac{V_1 - V_5}{2 \cdot y_S}, \frac{V_8 - V_4}{2 \cdot y_S}, \frac{V_2 - V_6}{2 \cdot y_L}, \frac{V_y - V_3}{2 \cdot y_L}\right]$$

Where:

V_1, V_4, V_5, V_8 = Normalized velocities measured along outside chords

V_2, V_3, V_6, V_7 = Normalized velocities measured along inside chords

y_S, y_L = Normalized chord location for short and long paths

Swirl rates less than 3% are low and are typically observed in models with only planar connections. Swirl rates greater than 3% are considered “swirling”. Swirl rates greater than 10% are considered to have strong swirl.

3.3.1.1 Swirl Rate Results

Figure 3.3 shown below summarizes the absolute value of swirl rate observed during the calibrations.

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Figure 3.3 Summary Swirl Rate for Tests

3.3.2 Flatness Ratio Definition

Cameron uses the flatness ratio (FR) to quantify how flat the velocity profile is. FR is defined as:

$$\mathrm{FR} = \left[\frac{V_1 + V_4 + V_5 + V_8}{V_2 + V_3 + V_6 + V_7}\right]$$

Where:

V_1, V_4, V_5, V_8 = velocities measured along outside chords (or short paths)

V_2, V_3, V_6, V_7 = velocities measured along inside chords (or long paths)

When a velocity profile is perfectly flat, then FR equals 1.0. When a velocity profile is laminar, then the FR equals approximately 0.38. The limits of 0.38 and 1.0 represent extremes. The FR is a function of Reynolds number but also is strongly influenced by the hydraulics upstream of the flow meter.

Typical feedwater applications have FR in the range of 0.78 to 0.95. Downstream of flow conditioners, the velocity profile tends to be pointier and the FR value is lower, 0.78 to 0.82. Downstream of elbows and tees, the velocity profile tends to be flatter and the FR value is higher, 0.85 to 0.95. The actual range at a given plant is dependent upon site upstream conditions (for example, hydraulic fittings such as tees, elbows, etc). The tests are summarized in Figure 3.4 below. For the Hope Creek Nuclear Generating Station the range of FR values is [ ].

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Figure 3.4 Summary of Flatness Ratios for Tests

3.4 Relationship between Flatness Ratio and Meter Factor

In 2002, Cameron published an analysis of velocity profiles observed in the field. In this analysis, an analytical relationship between the meter factor (MF) and the observed flatness ratio (FR) was computed. This relationship is based on integration of velocity profiles that were constructed using a power law representation. The power law velocity profile is described as follows:

$$u = (1 - r)^{1/n}$$

Where:

u	=	Velocity at any point in the pipe normalized with respect to the maximum velocity
r	=	Distance from the center of the pipe as a fraction of the pipe radius
n	=	Exponent term that changes the shape of the profile as a function of Reynolds number and pipe roughness

This approach has been applied in a fairly large number of studies due to its simple form and good match to actual velocity profiles.

The analysis calculated profiles with values of *n* of between 4 and 20. This range of *n* covers a very wide range of Reynolds Numbers, as it has been shown that $n = 6$ to $n = 15$ covers a Reynolds number range of 4,000 to 3,200,000 (Reference 13). The analysis has shown that MF for a 4-path Gaussian integration will have a linear relationship with FR. According to Reference 2, the relationship between MF and FR should be approximately as shown below in Figure 3.5.

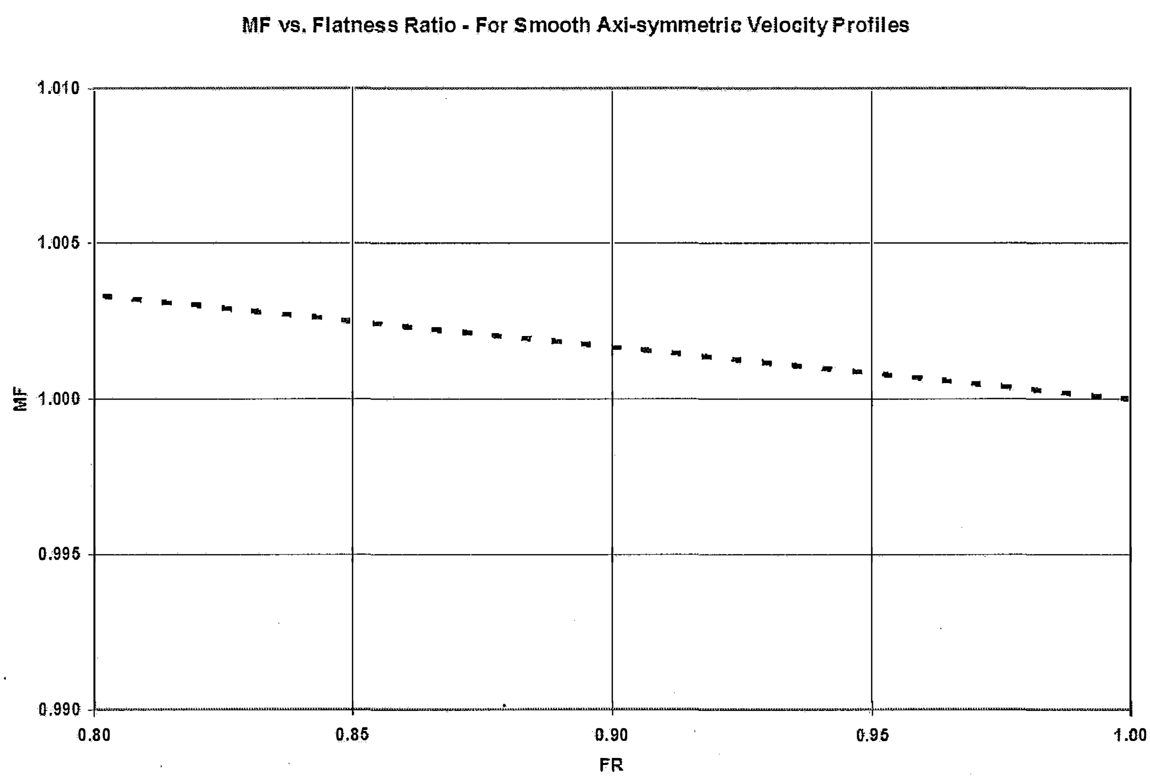

Figure 3.5 MF vs. FR for a 4-path Gaussian Integration of the Velocity Profile

The importance of this relationship is that the minor changes in the MF observed in the different hydraulics configurations are not merely unaccountable error terms due to hydraulics, but are predictable changes that can be confirmed analytically. For comparison, the average MFs for the loops are plotted in Figure 3.6 shown below (note that each meter has been offset such that the average MF lies on the "predict curve").

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Figure 3.6 MF vs. FR for Calibrations

4.0 METER FACTOR ACCURACY ASSESSMENT

This section documents the methodology for calculating the uncertainty or accuracy of the meter factor. This report was produced using a process and quality assurance consistent with the requirements of ASME PTC 19.1 and ANSI/NCSL Z540-2-1997 (see References 6, 10, 14, and 15). The approach to determining the uncertainty is to combine the random (Type A) and systematic (Type B) terms by the means of the RSS approach given that all the terms are independent, zero-centered and normally distributed.

First, the sensitivity of the calculated flow to each independent variable or input is determined. Once the sensitivities to the independent variables have been calculated, then the independent variables' uncertainties are calculated and multiplied with their sensitivity coefficient, such as calibration facility, timing errors, etc. The 95% confidence level uncertainty bounds are calculated for each element (uncertainty coverage for each term is 95%).

The evaluation of the sensitivity coefficients is performed by determining the independent variables in the mass flow (and volumetric flow) calculation. For example, if volume flow is a function of independent variables X_1, X_2, ..., X_n, as follows:

$$Q = f(X_1, X_2, \ldots, X_n)$$

The uncertainty effect of specific independent variables on the flow measurement is calculated by partial differentiation of the above equation. Expressing the result as a per unit sensitivity:

$$\frac{dQ}{Q} = \left[\frac{X_1}{Q}\frac{\partial Q}{\partial X_1}\right]\left(\frac{\Delta X_1}{X_1}\right) + \left[\frac{X_2}{Q}\frac{\partial Q}{\partial X_2}\right]\left(\frac{\Delta X_2}{X_2}\right) + \cdots + \left[\frac{X_n}{Q}\frac{\partial Q}{\partial X_n}\right]\left(\frac{\Delta X_n}{X_n}\right)$$

Where the terms in the brackets are the sensitivity coefficients for X_1, X_2, ..., X_n. The magnitudes and signs of each uncertainty for a given flow measurement are then bounded by 95% confidence intervals.

ASME PTC 19.1 demonstrates that by combining the independent uncertainty contributions as the root sum square, the overall uncertainty in volumetric flow is bounded by a 95% confidence level.

The allocation of uncertainties for meter factor for the flow meter (consistent with the Cameron Topical report) is shown in Table 4.1 below. Using the data in Table 4.1 and the root mean square summation technique indicated for combining independent uncertainties of relatively the same magnitude, the total uncertainty due to MF is computed.

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4.1 Facility Uncertainty

A facility uncertainty of] has been budgeted and this figure appears in Table 4.1 above.

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4.2 Measurement Uncertainty

Appendix B calculates the uncertainties in the volumetric flow measurement (excluding meter factor) of the flow meters used for this test. The results are summarized below in Table 4.2. [

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For this report, a typical flow of 18,500 gpm was used.

Table 4.2 Uncertainties in Volumetric Flow Measurements

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4.3 Extrapolation – Profile Variation Allowance

At the plant, it is likely that the hydraulic conditions will not equal those tested during the calibration. In particular, the plant's Reynolds numbers are higher than that achievable at the laboratory (approximately 20 million vs. ~2 million). Further, the plant may have a lower wall roughness than the test pipes used at the laboratory.

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The numerical calculation of meter factor is illustrated below.

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Figure 4.1 MF vs Reynolds Number (Reichardt Profile)

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Figure 4.2 FR vs. Reynolds Number (Reichardt Profile)

Using this analysis, a meter factor extrapolation of [ ].

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[ ]

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4.4 Modeling Sensitivity Uncertainty

For the Hope Creek Nuclear Generating Station test, 4 different models were tested. Using this population, the population statistics are calculated. This computation removes the mean meter factor from each meter factor test. Then these "normalized meter factors for all the tests are combined. For Hope Creek Nuclear Generating Station, a 95% confidence bound on the distribution was computed to be [ ].

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Alternatively, Cameron has elected to use its complete database of calibrations and hydraulic models to estimate the hydraulic variability. This approach is identical to that described in reference 17, except that today the database has a larger population of calibrated meters ([ ]

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4.5 Data Scatter – Mean Meter Factor Uncertainty

Each meter factor is computed as the average (mean) of the meter factor measurements made for that flow element. The uncertainty in mean meter factor addresses the 95% confidence limits on the uncertainty in that mean. Each set of data at a given flow rate is treated as a separate datum, since in fact the profile varies with flow rate (i.e., Reynolds Number) as shown in Section 3.2. Section 4.4 shows that meter factor is essentially independent of hydraulic configuration. Hence the precision with which the meter factor for a specific flow element is determined is enhanced by including all calibration data for that flow element. Accordingly the meter factor is determined as follows:

The calculation of the uncertainty of the mean proceeds as follows:

a. [

b.

c.

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Using the above methodology, the uncertainty in the mean meter factor is computed to be as follows:

- [ ]

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5.0 REFERENCES

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16. ISO “Guide to the Expression of Uncertainty in Measurement”
17. IGHEM Flow Paper 2008 Milan, Italy, “Accuracy Validation of Multiple Path Transit Time Flowmeters”
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Appendix A – Calibration Data

This Appendix contains the raw data for each test. The data includes the Alden calibration period flow, the average flow during the calibration, and the computed meter factor at each flow.

No attachment to follow as Appendix is Proprietary in its Entirety

Preparer: JP Reviewer: ___

Appendix B – Meter Uncertainty

B.1 – Inputs and Scaling

B.2 – Flow Uncertainty

B.3 – [ ]

B.4 – [ ]

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