Documentation for

BLM Uncertainty Calculator©

version 1.0

May 14, 2007

BLM Uncertainty Calculator, version 1.0
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BLM Uncertainty Calculator, version 1.0

Program Documentation

May 14, 2007

I. PROGRAM INSTRUCTIONS

A. General Instructions for Use

1. Data Entry

The input screens for this program are designed to be self explanatory and easy to use. A few general rules can be applied to make data entry easier. Data should be entered starting with the first tab (“Location/Prim. Device”), then progress to the second, third, and fourth tabs. On each tab, data should be entered from left to right and then top to bottom. Based on the data you enter, the program decides what subsequent fields are relevant to the meter you are describing. Other fields are “loaded” with selections based on previous data entries.

If a field is “enabled” (i.e. not grayed out), it requires some form of data entry. This may be a selection from a drop-down list or entry into a text box. Failure to fill in all enabled fields will result in a program error message. One exception to this is the calculation of calibration tolerances. This calculation only requires that the enabled fields on the second tab (“Secondary Device”) be filled in.

If you are analyzing an orifice meter, you must also enter a meter installation, with a defined upstream disturbance and relevant dimensions. To get into the installation dialog, hit the “Installation” button on the first tab, then hit OK when you are done.

2. Analysis

When all required fields have been entered, select the “Graph” button. At this point, any data entry errors will be displayed. These must be fixed in order for the program to run. Assuming there were no errors, the “Graph” button will display an “operating envelope” of differential and static pressure combinations that result in an overall measurement uncertainty of ±3%, or better. As you move the cursor inside of the graph area, a display of differential pressure, static pressure, and overall measurement uncertainty for the current cursor position is given at the bottom of the graph.

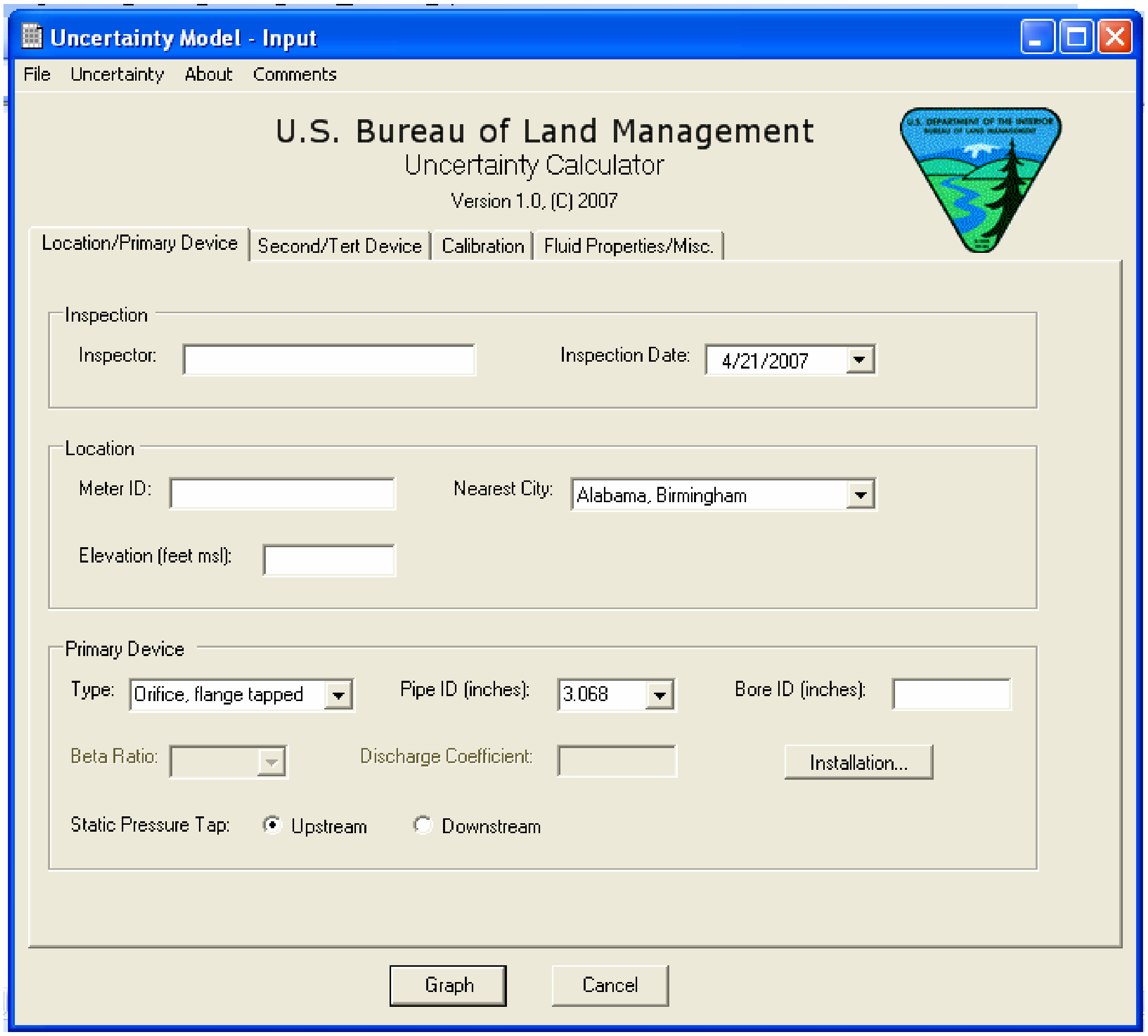
You can select a specific point on the graph in one of two ways. The simplest way is to move the cursor to the point you would like analyzed, and hit the left mouse button. Doing this will create a point on the graph. Another way is to enter a differential pressure and a static pressure in the text boxes at the bottom of the window, then hit the “Plot” button.

The “Details” tab provides a complete breakdown of uncertainty sources for the point you selected. The “Input” tab shows the data that you entered.
Once the operating envelope is displayed, you can choose to display Reynolds number limits (both high and low) and the differential to static pressure ratio limits for the primary device you selected. The default for these limits is to display them. Because BLM currently exempts meters measuring 100 Mcf/day or less for meeting uncertainty limits, there is also a menu selection to plot the 100 Mcf/day limit. All of these display options can be accessed from the “View” menu.

Under the “File” menu, you can print the information on one or more of the tabs and you can also save the tab information in several graphical formats. The active tab is the graphic that will be saved.

B. Data Entry Fields

<u>Tab 1 - Location/Primary Device </u>(see Figure 1)



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Inspection
Inspector:
Inspection Date: 4/21/2007

Location
Meter ID:
Nearest City: Alabama, Birmingham
Elevation (feet msl):

Primary Device
Type: Orifice, flange tapped
Pipe ID (inches): 3.068
Bore ID (inches):
Beta Ratio:
Discharge Coefficient:
Static Pressure Tap: ● Upstream ○ Downstream

Figure 1

Inspector: Inspector is any alpha numeric string and is the only enabled field which is not mandatory to fill out. If filled out, the Inspector field will appear on printed and saved program outputs.

Inspection Date: Selecting this field will bring up a calendar from which the date of inspection can be entered. The default value is today's date. The inspection date will appear on printed and saved program outputs.

Meter ID: The meter ID is any alpha numeric string. There are no real limits as to the length of the string, but strings greater than 20 characters will cause formatting problems on the output display. The only purpose of this entry is to provide a title for the operating envelope. Entry into this field is required by the program.

Nearest City: You should select the city nearest to the location of the meter you are describing. If there are no cities that are in the vicinity, please contact the program author (restabro@ca.blm.gov) and request that cities relevant to your location be added.

The purpose of the "Nearest City" entry along with the "Calibration Frequency", and "Location" fields, is to determine the amount of ambient temperature change that the secondary device is likely to experience. Ambient temperature change is one of the most significant variables to influence measurement uncertainty. It is also one of the most difficult to quantify. This program attempts to use objective and observable parameters to estimate the ambient temperature change experienced by the transducers. For a detailed discussion on how the ambient temperature shift is determined, see the Appendix.

Elevation: Elevation is a numeric entry field for the elevation of the meter, in feet above mean sea level (msl). The elevation is used to determine the bias in the value of atmospheric pressure that is assumed when converting gauge pressure transducer readings to absolute pressure. For absolute pressure transducers, it is used to determine the bias in the assumed value of atmospheric pressure during calibration. [Note: if atmospheric pressure is based on a pressure established in a contract, there will be no bias or uncertainty added.]

Primary Device Type: The Primary Device entry is a pick list of the primary devices that are currently allowed by BLM on a national basis. The flange-tapped orifice has blanket approval per Onshore Order Number 5. The BLM has also issued Washington Office Instruction Memorandum (IM) 2007-022, which establishes national policy to approve McCrometer Wafer V-Cones with specific Conditions of Approval. Note that the use of the Wafer V-Cone still requires the approval of a variance from Onshore Order 5.

The uncertainty calculation will include the discharge coefficient uncertainty of the primary device selected along with Reynolds number and differential to static pressure ratio limits, as applicable.

Pipe ID: The internal diameter of the pipe can be selected from the pick list or can be entered manually. Pipe diameter is used to calculate flow rate for the 100 Mcf/day limit and is used to calculate Reynolds number. It is also a parameter in determining primary device uncertainty. For Wafer V-Cones, only the pipe diameters that correspond to approved nominal meter sizes will be allowed.

Bore ID: This field will only be enabled when an orifice plate is selected from the Primary Device Type field. It is a text entry box for the bore diameter of an orifice plate. Bore diameter is used to calculate Reynolds number, flow rate, and orifice bore uncertainty. Uncertainty for orifice bore diameters less than 0.45" are currently undefined by API 14.3, therefore, these bore sizes will not be accepted by the uncertainty calculator.

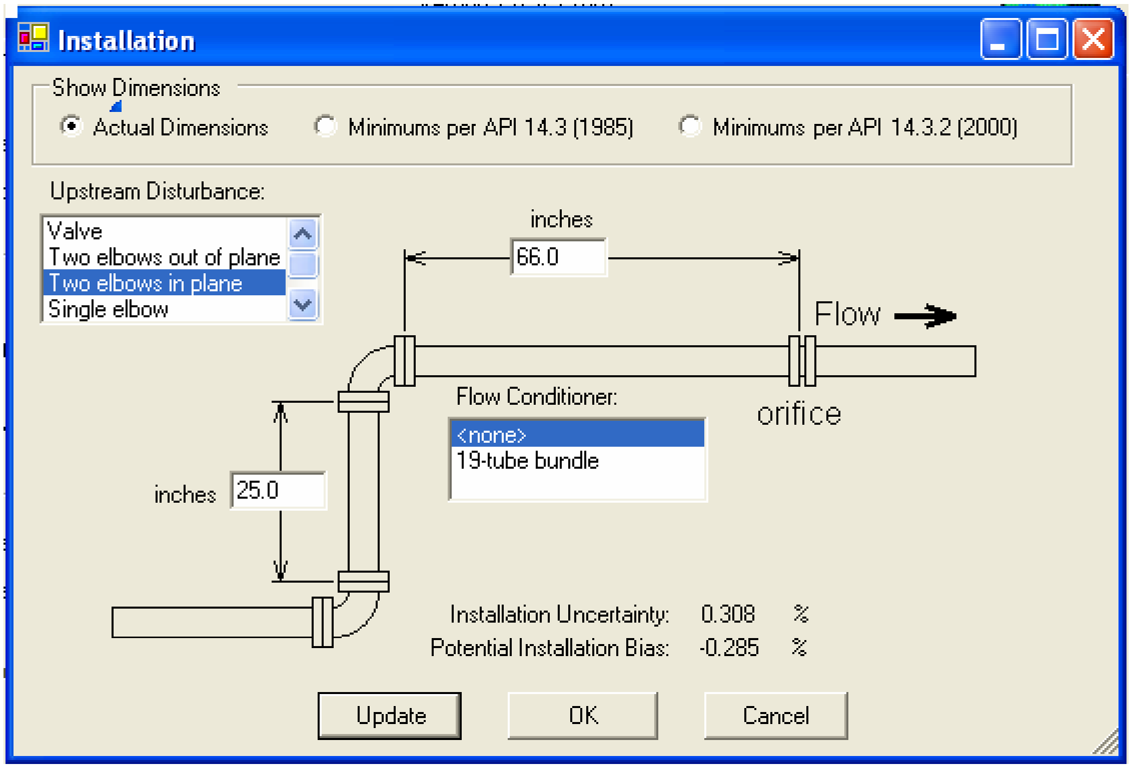
Beta Ratio: If you select the Wafer V-Cone as the primary device, this field will be enabled. You can select the Beta ratio from a pick list of nominal Beta ratios that are available from the manufacturer, or you can enter a specific Beta ratio from the sizing sheet that comes with each Wafer V-Cone. If you enter a Beta ratio it must be within 0.02 of one of the nominal sizes in the pick list. The Beta ratio is used to calculate flow rate, Reynolds number, and to reference the uncertainty and operating limits for that device. Only the nominal Beta ratios that have been reviewed by BLM will be allowed.

Discharge Coefficient: If you select the Wafer V-Cone as the primary device, this field will be enabled. This is a text entry box and requires a specific discharge coefficient to be entered. Only discharge coefficients of 0.8 or greater are allowed. The discharge coefficient can be found on the sizing sheet that comes with each Wafer V-Cone and is used to calculate Reynolds number and flow rate.

Installation (Figure 2): This button is only enabled for orifice plates and displays another dialog box that is used to input the installation dimensions of the primary device. You must enter a pipe size and a bore size to get into the installation screen.

Along the top of the installation dialog are 3 radio buttons. If you are going to manually enter the dimensions of an orifice installation, the "Actual Dimensions" radio button must be selected. Selecting the "Minimums per API 14.3 (1985)" or "Minimums per API 14.3.2 (2000)" radio buttons will auto-fill the dimensions between the upstream disturbance and the orifice or the tube bundle and the orifice per the API standard selected. However, if a double-elbow configuration is selected, you must enter the dimension of the elbow spacing first. For configurations that are not listed in the API standards, a message to that effect will appear.

There is a pick list in the upper right portion of the window to select an upstream disturbance and there is also a pick list to select whether or not there is a 19-tube bundle



Show Dimensions

● Actual Dimensions ○ Minimums per API 14.3 (1985) ○ Minimums per API 14.3.2 (2000)

Upstream Disturbance:

- Valve
- Two elbows out of plane
- Two elbows in plane
- Single elbow

inches 66.0

inches 25.0

Flow Conditioner:

- <none>
- 19-tube bundle

Installation Uncertainty: 0.308 %

Potential Installation Bias: -0.285 %

Figure 2

between the disturbance and the orifice. Other types of flow conditioners are not addressed in this version of the uncertainty calculator.

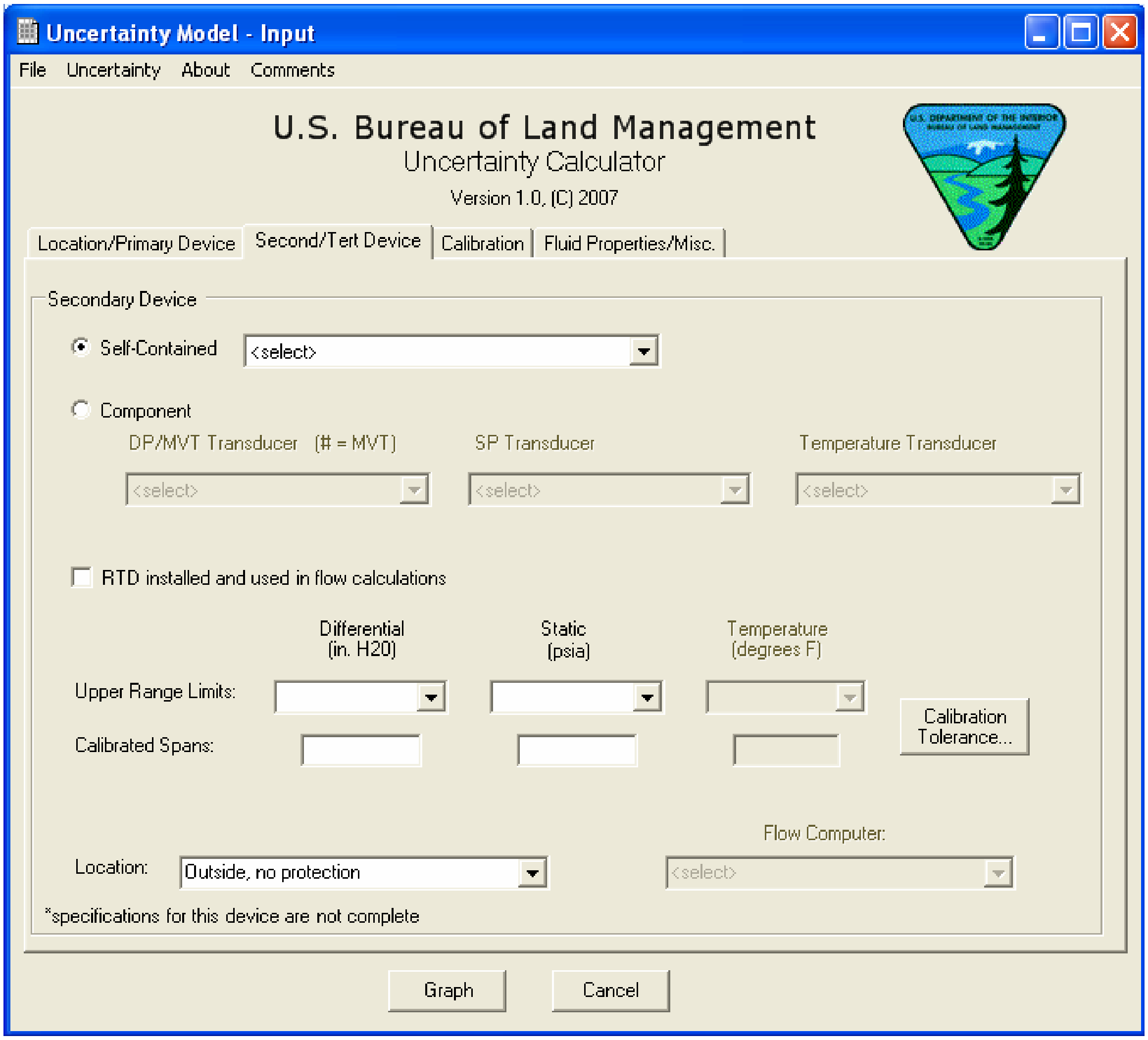
When you are finished entering the orifice installation, you can hit either the <Update> button or the <OK> button. Both buttons will calculate installation uncertainty and potential bias for the installation you selected. The <OK> button will also exit the dialog and return you to the main data entry screen. The <Cancel> button will reset the installation to the default values and exit back to the main data entry screen.

Installation data is mandatory for orifice plates.

Static Tap Location: Select either Upstream or Downstream. The only function of the static tap location is in the calculation of flow rate and Reynolds number. Uncertainty is not dependent on the tap location.

<u>Tab 2 – Secondary/Tert. Device</u> (Figure 3)

Self-Contained/Component Type: These radio buttons are used to select a general category of secondary device. "Self-Contained" units are those that house the transducers and flow computer all in one box. The real significance of selecting a "Self-Contained" type is that one manufacturer/model number will access the specifications for the differential pressure, static pressure, and temperature transducers. Examples include Totalflow, Bristol Babcock, and the Emerson FloBoss 503.



● Self-Contained <select>

○ Component

☐ RTD installed and used in flow calculations

Location: Outside, no protection

*specifications for this device are not complete

Figure 3

In contrast to self-contained units are component units (sometimes referred to as “remote” units). Component units are assembled from different makes and models of transducers and transmitters, therefore, each device must be individually identified to access the proper specifications.

A number of devices can be either self-contained or stand alone. The NuFlo Scanner 1150 and the Thermo Fisher AutoPILOT, for example, can be purchased with locally-mounted transmitters, in which case they are considered self-contained units. They can also be purchased without locally-mounted transmitters and used as a stand alone flow computer. If the computer and transmitters appear as one package and are listed in the “Self-Contained” pick list, it will act as a self-contained unit.

The program has attempted to use the most common manufacturer names in the pick lists. However, name changes occur frequently in the gas measurement industry and the manufacturer name may not always match what you observe in the field. As of the date of this documentation, the following manufacturer names all refer to the same equipment:

- Emerson owns Rosemount and Fisher; what's listed as an Emerson FloBoss, for example, may also be called a Fisher FloBoss.
- Emerson recently bought Bristol Babcock, but so far, the Bristol Babcock name is still used for the TeleFlow and TeleFlow +
- Cameron now owns NuFlo who bought Halliburton (flow measurement division) who acquired Barton. What's listed as a "NuFlo Scanner" may also appear in the field as a "Barton Scanner".
- ThermoFisher used to be called ThermoFlow Automation, so the "Thermo Fisher AutoPILOT, for example, may appear in the field as the "ThermoFlow Automation AutoPILOT".

Generally, the product name has not changed; however, the manufacturer name given in the pick lists may not match the manufacturer seen in the field.

Self-Contained: If the Self-Contained radio button is pushed, you can select a make and model from the pick list. All fields pertaining to component units will be disabled. Once selected, the program references all relevant manufacturer specifications for that make and model. In addition, the available transducer ranges will be loaded into the Upper Range Limit pick lists. For the time being, manufacturer specifications are taken at face value. However, to be used by the program, the manufacturer must have supplied specifications for the following:

- Reference accuracy (linearity, hysterisis, and repeatability)
- Ambient temperature effects
- Static pressure effects (DP units only)
- Stability

Some manufacturers also provide specifications for vibration, radio frequency interference, and toggle effects. Until these specifications become more universal, they will not used by the uncertainty calculator.

If the manufacturer specifications do not include at least the items listed above, an error message will appear when you hit the <Graph> button.

Note: If you are aware of equipment that is not included on any of the pick lists, please notify the program author (restabro@ca.blm.gov).

Component: The Component radio button describes a general category of flow computer, where the differential pressure, static pressure, and temperature transducers are individually selected along with a flow computer. Selecting this option will require separate entries of each device.

DP Transducer: When the Component radio button is selected, a differential pressure transducer can be selected from the pick list. Once a selection is made, the program references the manufacturer specifications for that device. As with the Self Contained systems, transducers must have specifications that include reference accuracy, ambient temperature affects, static pressure effects, and stability, to be used by the program. Transducers without these specifications are shown with an “*” after their name. Selection of a device with a “*” will generate an error message when you hit the <Graph> button.

A “#” symbol after the transducer make and model indicates that the transducer is a multi-variable transducer (MVT) that also contains static pressure and temperature sensors in the same unit. Because the selection of a single MVT will also dictate the specifications of the static pressure and temperature transducers, these fields are disabled.

SP Transducer: When a component system is chosen, and the selected DP transducer is not an MVT, you must select the make and model of the SP transducer from the pick list.

Temperature Transducer: For non-MVT component systems, this pick list contains commonly used temperature transducers. Since not all flow meters measure flowing temperature there is also an option to select <none>. If flowing temperature is not measured, you will be asked to enter an assumed fixed temperature on Tab 4.

RTD installed and used in flow calculations: This checkbox is enabled if you have selected a Self Contained unit or an MVT with a Component unit. Although self contained flow computers and MVTs have the capability to measure flowing temperature with an RTD (Resistance Temperature Device), some meter installations do not include an RTD. In addition, the mere fact that an RTD is installed does not mean that the measured temperature is used in the flow calculations. In some flow computers the measured flowing temperature can be disregarded, and a fixed temperature is used instead. This checkbox should be checked only if you are sure that the measured flowing temperature is used in the flow calculations. If this box is not checked, you will be prompted to enter the value of the assumed flowing temperature on Tab 4.

Upper Range Limits: After selecting the make and model of the secondary device you are analyzing, the available ranges for the differential, static, and temperature transducers will be loaded into the respective pick lists. From each pick list, select the range of the device that you are analyzing. This range represents the upper range limit, or maximum value that this device is designed to measure. The default unit of measure for the differential pressure device is inches of water; for the static pressure device, it is either psia or psig; and, for the temperature device, it is degrees Fahrenheit. Some upper range limits are given in other units such as millimeters of mercury (mmHg) or kiloPascals (kPa). If the units of measure for the device are different from the default, they will appear along with upper range limit.

On some transducers, a range code will also appear with the upper range limit to help you identify the range that you have. For example, a Rosemount 1151 DP comes in 3 ranges: 3, 4, and 5. A range 3 has an upper range limit of 30”, therefore, this range appears in the pick list as ‘3: 30”’. The range code is generally part of the model number.

For the static pressure transducer, the unit-of-measure label will indicate whether the device measures absolute pressure (psia) or gauge pressure (psig).

Calibrated Span: Many transducers allow some degree of turndown for the span of the transducer. For example, a Honeywell ST3000 STD624, has an upper range limit of 400”. This is the maximum differential pressure it is designed to measure. However, the span, or measurement range, can be adjusted anywhere from 0-400” to 0-25”. This corresponds to a turndown ratio of 16:1.

The calibrated span is a text-box entry that defaults to the upper range limit. The minimum allowable span for that make, model, and range of device is listed below the text box. You can enter any value into these windows, although an error will appear if the value you entered is greater than the upper range limit or less than the minimum span.

Calibration Tolerance: This button will display a window showing the calibration tolerances for the differential and static pressure transducers, the temperature transducer, and the maximum allowable low-flow cut off for the differential pressure transducer. All values shown in this box are required by Wyoming NTL (Notice to Lessees) 2004-1 and California NTL 2007-1, both of which conform to the “model NTL” described in Washington Office Instruction Memorandum WO IM 2006-233. Per the NTLs, the calibration tolerance for the differential and static pressure transducers equals the reference accuracy of the device, stated in actual units of measure. For example, the stated reference accuracy for a Totalflow 6410 is ±0.2% of span (with no turndown), for both the differential and static pressure. If the upper range value of the differential pressure transducer is 100”, and the span has not been turned down (i.e. 100”), then the calibration tolerance of the differential pressure transducer is 0.2% of 100”, or 0.2”.

The calibration tolerance for the temperature transducer is ±2˚F. The maximum allowable value for the low-flow cutoff in WY NTL 2004-1 is 1.5 times the reference accuracy of the differential pressure transducer, or 0.5”, whichever is less. For the above example, the maximum allowable low-flow cutoff would be 1.5 x 0.2”, or 0.3”. However, the maximum allowable cutoff in CA NTL 2007-1 and in the “model NTL” is fixed at 0.5”.

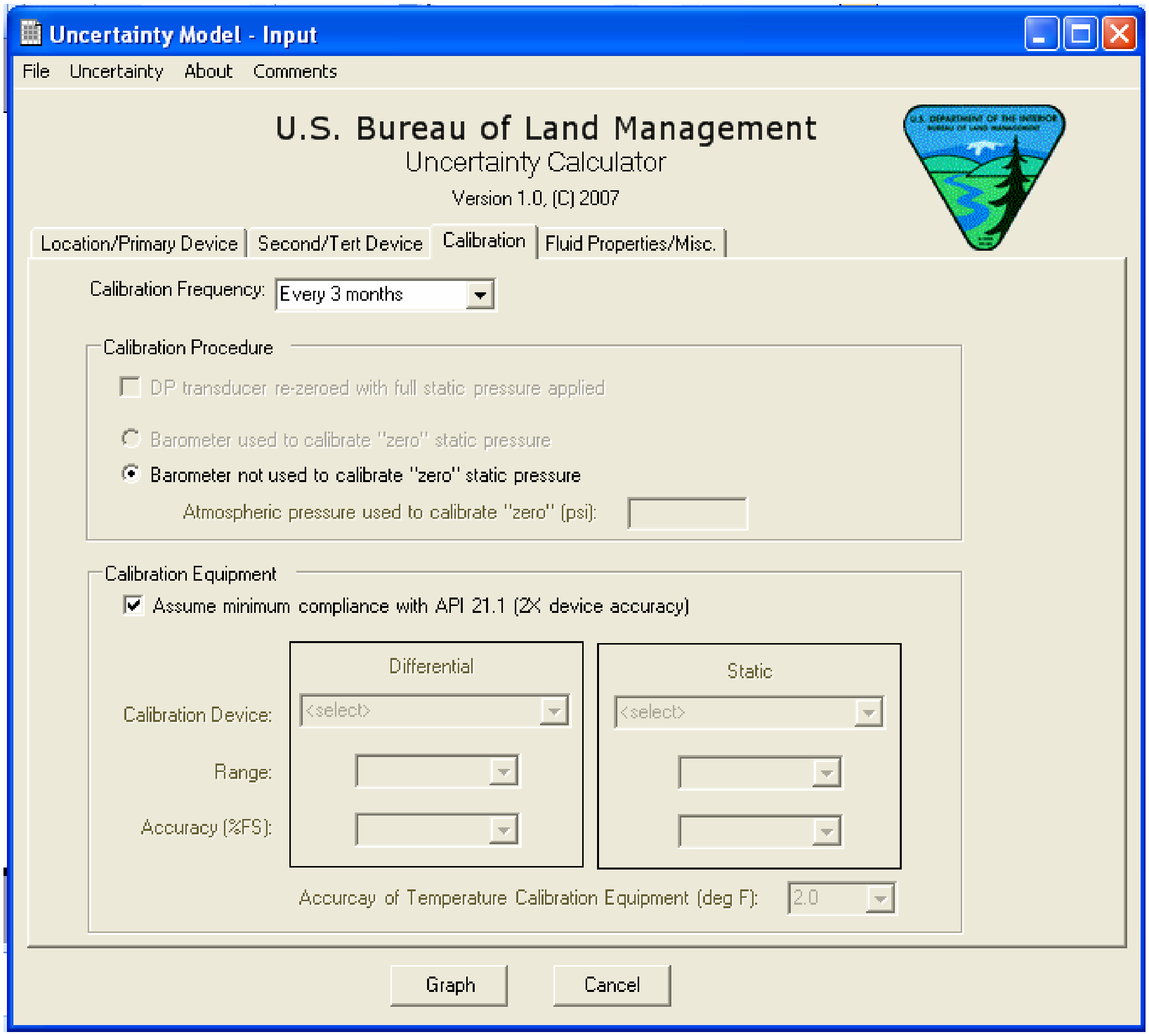
In order to obtain the calibration tolerances and low flow cutoff limit, you must enter the make, model, range, and calibrated span of each device.

Location: This is a pick-list describing the mounting location of the transducers. There are 5 choices, each providing a modification to the ambient temperature shift determined when selecting the nearest city and calibration frequency (see Appendix). Select the location that best describes the transducers you are analyzing.

Flow Computer: For the time being, this pick list of stand-alone flow computers is for reference only. If you are analyzing what appears to be a self contained unit, but you can’t find it in the self contained pick list, try selecting a component system, then look through the flow computer pick list. If you find it there, it is a component system and not a self contained unit.

Regardless of what flow computer, or tertiary device is selected, an uncertainty of ±0.1% is included in the determination of overall measurement uncertainty, per the requirements of API 21.1.7.6. When more defined standards for flow computer performance are developed, the performance of each computer will be referenced when a selection is made.

Tab 3 – Calibration (see Figure 4)



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Calibration Frequency: Every 3 months

Calibration Procedure

☐ DP transducer re-zeroed with full static pressure applied

○ Barometer used to calibrate "zero" static pressure

● Barometer not used to calibrate "zero" static pressure

Atmospheric pressure used to calibrate "zero" (psi):

Calibration Equipment

☑ Assume minimum compliance with API 21.1 (2X device accuracy)

	Differential	Static
Calibration Device:	<select>	<select>
Range:		
Accuracy (%FS):		

Accurcay of Temperature Calibration Equipment (deg F): 2.0

Calibration Frequency: This field is a pick list of commonly used calibration frequencies. Select the frequency that most closely fits the actual calibration schedule. The calibration frequency is used along with city and transducer location to determine the amount of ambient temperature shift experienced by the meter (see Appendix).

DP transducer re-zeroed with full static pressure applied: Some differential pressure transducers (Rosemount single variable models and some Yokogawa models) specify that zero-static pressure effects can be calibrated out by re-zeroing the transducer after full static pressure is applied. If this field is enabled, then the specifications allow for this correction. By checking the check box, zero static pressure effects are eliminated or reduced per the manufacturer's specifications. The check box should only be checked if re-zeroing the differential pressure transducer with full static pressure applied is part of the calibration procedure.

Barometer used to calibrate "zero" static pressure: This radio-button field will be enabled if an absolute pressure transducer was selected. To verify or calibrate the "zero" point of an absolute pressure transducer, it is first vented to atmosphere. The reading of the transducer is then compared to atmospheric pressure. If the transducer is verified against an actual measurement of atmospheric pressure using a barometer, this radio button should be pushed. In this case, no additional uncertainty due to assumptions of atmospheric pressure is added to the calculation of overall measurement uncertainty.

Barometer not used to calibrate "zero" static pressure: If, instead of using a barometer to set the "zero" point of an absolute pressure transducer, a fixed or calculated value is used, push this radio button. Calculated values of atmospheric pressure represent average values. Actual atmospheric pressure can vary by as much as 0.2 psi from the calculated average due to weather systems in the area. Therefore, if this radio button is pushed, an additional 0.2 psi of uncertainty is added to the static pressure uncertainty calculation. [Note: see "Fixed pressure is a contractual value" under Tab 4, for exceptions.]

Atmospheric pressure used to calibrate "zero" (psi): If you selected the radio button for not using a barometer, this field will be enabled. Enter the value used for atmospheric pressure during calibration and verification. The uncertainty calculator includes differences between the value entered and the "true" value based on elevation in the determination of overall measurement uncertainty. [Note: see "Fixed pressure is a contractual value" under Tab 4, for exceptions.]

Assume minimum compliance with API 21.1 (2X device accuracy): API 21.1.8.6 requires that the calibration equipment must be at least twice as accurate as the equipment being calibrated. By checking this box, it is assumed that this requirement has been met. If you want to use the actual accuracies of the calibration equipment, do not check this box. It is important to note that this requirement refers to the accuracies converted to actual units of measure and not to the percentage of full span that is typically given by manufacturers.

Note: Use caution when checking this check box. The use of calibration equipment that does not meet the API requirement is one of the most significant contributors to overall measurement uncertainty.

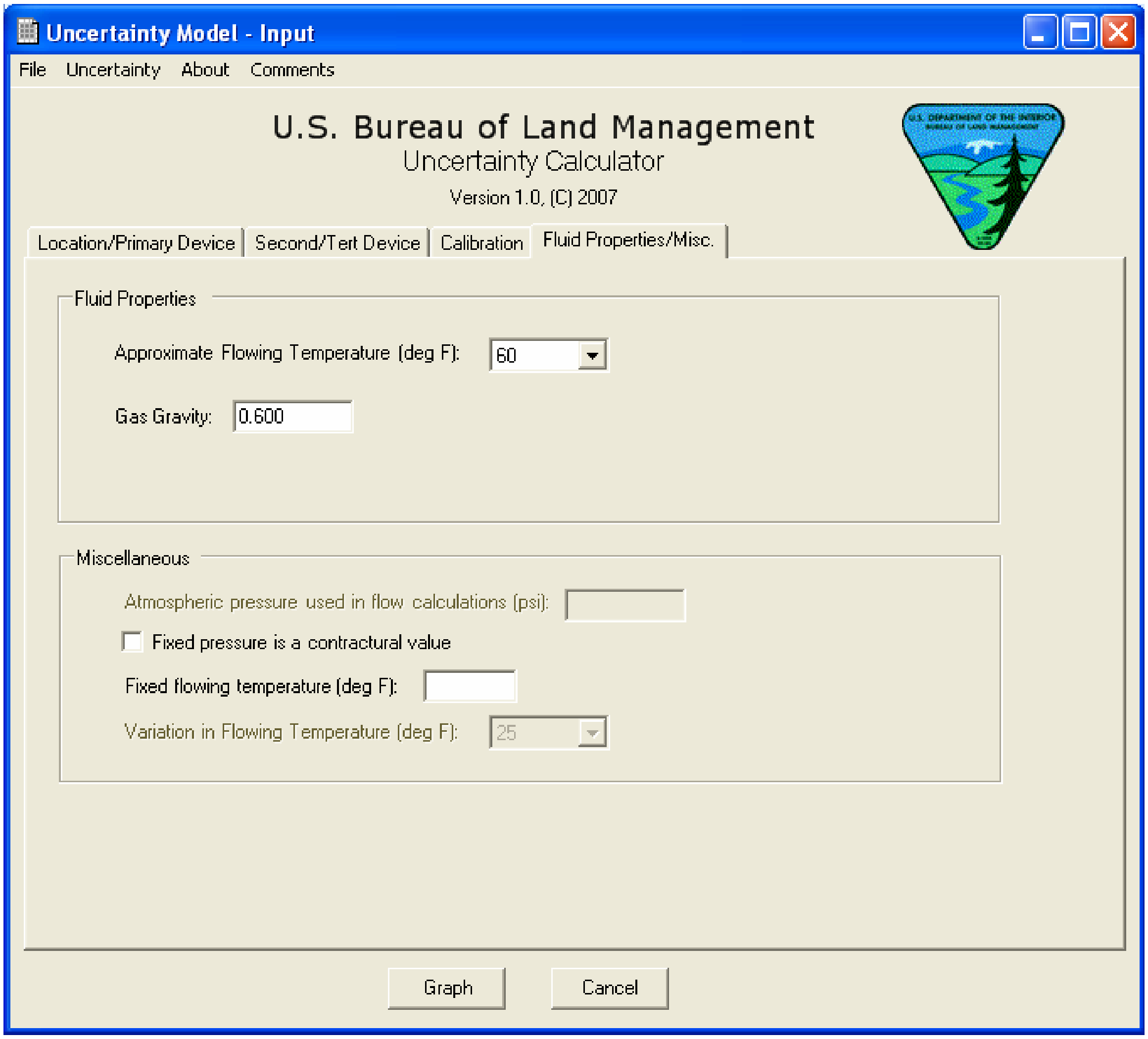
Calibration Device: This is a pick list of calibration gauges for differential pressure as well as static pressure. Select the make and model of the gauges used. Once selected, available ranges and accuracies will be loaded into their respective fields.

Range: Select the range of the device from the pick list.

Accuracy: Some calibration gauges come in a variety of accuracies. Select the rated accuracy of the device from the pick list.

Accuracy of temperature calibration equipment (deg F): If you are not assuming that the calibration equipment, including the temperature calibration device, complies with the requirements of API 21.1, this drop down menu item will be enabled. Select the accuracy, in degrees Fahrenheit that comes closest to the accuracy of the device being used. Most off-the-shelf digital thermometers have a stated accuracy of ±3˚F. If documentation of the device accuracy is not available, it is recommended that you use this as a default value.

<u>Tab 4 – Fluid Properties/Miscellaneous</u> (Figure 5)



Fluid Properties

Approximate Flowing Temperature (deg F): 60

Gas Gravity: 0.600

Miscellaneous

Atmospheric pressure used in flow calculations (psi):

☐ Fixed pressure is a contractural value

Fixed flowing temperature (deg F):

Variation in Flowing Temperature (deg F): 25

Approximate Flowing Temperature (deg F): From the pick list, select the flowing temperature that most closely represents the average flowing temperature at the meter you are analyzing. If there are wide seasonal fluctuations in flowing temperature, then the uncertainty calculation may have to be done seasonally. Because lower temperatures result in more uncertainty, you can also enter a temperature at the lower end of normal; if the meter meets the uncertainty standard using a low temperature, then it will also meet the uncertainty standard at higher temperatures.

Flowing temperature is used to calculate flow rate and also to determine the uncertainty of the temperature measurement.

Gas Gravity: This is a text box entry of specific gravity or relative density of the gas. At this point, the gravity field is only used in the calculation of gas flow rate. The uncertainty calculator does not include any uncertainty associated with the determination of gas gravity.

Atmospheric pressure used in flow calculations (psi): If you selected a gauge pressure transducer for static pressure, this field will be enabled. Enter the value of atmospheric pressure used by the flow computer in the flow rate calculations. Because this is a fixed value representing the average atmospheric pressure, variations of actual atmospheric pressure due to weather systems will add 0.2 psi to the uncertainty of static pressure. In addition, differences between the value you enter and the "true" atmospheric pressure based on the elevation that you entered will be included in the calculation of overall measurement uncertainty. [Note: see "Fixed pressure is a contractual value" under Tab 4, for exceptions.]

Fixed pressure is a contractual value: Check this box if the value of atmospheric pressure you entered, either to calibrate an absolute pressure transducer or which is added to the gauge pressure, is based on your gas contract. Because Onshore Order 5 allows for contractual values of atmospheric pressure to be used in lieu of calculated or measured atmospheric pressure, checking of this box will eliminate all uncertainty associated with the using a fixed value of atmospheric pressure.

Fixed flowing temperature (deg F): If you did not check the box labeled "RTD installed and used in flow calculations" (Tab 2), then this text box will be enabled. Enter the fixed temperature that is used by the flow computer. Both the temperature variation and the difference between the fixed temperature and "Approximate Flowing Temperature" will be included in the calculation of overall measurement uncertainty.

Variation in Flowing Temperature (deg F): If you did not check the box labeled "RTD installed and used in flow calculations" (Tab 2), then this text box will be enabled. Using the pick list provided, enter the approximate difference between the highest and lowest flowing temperature. If this is not known, you will have to make your best estimation.

C. Graph -> Program Output

Once all applicable data has been entered, hit the <Graph> button to analyze and display the operating envelope for the meter you described.

Operating Envelope

The <Graph> button will generate an operating envelope as a function of static pressure (x-axis) and differential pressure (y-axis). All areas within the green box indicate an overall meter station uncertainty of ±3%, or better [Note: if you want to analyze the meter at a different level of uncertainty, select the "Uncertainty" menu item in the data entry screen and select the uncertainty level that you want displayed. If you are not using BLM's standard of ±3%, the envelope will be a different color.]

As you move the cursor around inside the graph area, values of differential pressure, static pressure, and overall measurement uncertainty appear along the bottom of the graph.

There are four additional items that can be displayed on the graph, which are found under the "View" menu option:

→"100 Mcf/day limit" plots a line that represents combinations of static and differential pressure that result in a flow rate of 100 Mcf/day. Per Onshore Order 5, meters measuring 100 Mcf/day or less on a monthly basis do not have to meet the ±3% uncertainty requirement. Therefore, a meter operating outside of the green area, but below the 100 Mcf/day line is still in compliance with BLM requirements. The default is to not display this line.

→"Reynolds number high limit" eliminates portions of the operating envelope that exceed the upper Reynolds number limit for the primary device selected, and will show up on the graph as red. As with flow rate, the calculator determines the Reynolds number as a function of static and differential pressure. Because orifice plates have no practical upper bound on Reynolds number, this feature only applies to the Wafer V-Cone as determined from the API 22.2 testing. BLM will not allow operation of the meter outside of the Reynolds number limits tested if it results in potential bias, regardless of the flow rate. The default is to display this.

→"Reynolds number lower limit" eliminates portions of the operating envelope that are below the lower Reynolds number limit for the primary device selected, and will show up on the graph as red. For orifice plates, the lower Reynolds number limit is 4,000. For Wafer V-Cones, the lower Reynolds number limit was determined from the API 22.2 testing. BLM will not allow operation of the meter outside of the Reynolds number limits tested if it results in potential bias, regardless of the flow rate. The default is to display this.

→"DP/P limit" eliminates portions of the operating envelope that exceed the DP/P limit for the primary device selected, and displays these areas in yellow. For orifice plates, the limit is 0.2 (dimensionless). For Wafer V-Cones, the maximum DP/P limit was determined from the API 22.2 testing. BLM may allow operation of the meter above the DP/P limit, for meters measuring 100 Mcf/day or less, if there is no evidence of bias as a result. The default is to display this.

Details – Selecting a Point to Analyze

The details tab shows a complete breakdown of uncertainty sources for a specific differential pressure and static pressure that are selected on the operating envelope. There are two ways to select a point. The simplest way is to move the cursor to any desired position within the graph and click the left mouse button. This will display a point on the graph at the location you clicked. The display of differential pressure, static pressure, and overall uncertainty will continue to reflect the mouse position as you move the cursor inside the graph area. However, as soon as you move the mouse to a location outside the graph area, the values of the point you selected will be displayed along the bottom.

Another way to select a point to analyze is to manually enter the differential and static pressures in the text boxes at the bottom, then hit <Plot>. If you move the cursor outside of the text box area prior to hitting the <Plot> button, values you have already entered may change in response to the cursor position. However, as soon as you bring the cursor back into the text box area, the values you entered will reappear.

Once you have selected a point, you can click on the "Details Tab" to view the detailed breakdown of uncertainty sources.

Note: The selection of a specific point to analyze can be difficult, especially in a meter that experiences fluctuating flow. For relatively constant flowing wells, observed values of instantaneous differential and static pressure are usually adequate. However, for fluctuating wells, such as those on plunger lift, it is recommended that you use flow-weighted averages taken over a day or more. These values can be obtained by retrieving the hourly or daily quantity transaction records (volume statements) from the flow computer. Because BLM's requirement is "±3% for the majority of the flowing period", flow-weighted averages of differential and static pressure provide a much better representation of "for the majority of the flowing period" than instantaneous values do.

Input

The Input tab provides a complete list of the data that you input.

File Save and Print Options

Once you have created the operating envelope, the results of all three output tabs (operating envelope, details, and input) can be printed and saved. Both the save and print functions can be found under the "File" menu option. If you select "Save As…", a File Save dialog box will appear. The active tab will be saved in a graphic format that you select (jpeg, GIF, or bitmap). Note: GIF or bitmap provide better quality for most applications.

The “Print What >” menu selection lets you select which tabs you want printed. The “Print…” selection displays a standard Print dialog box.

D. Data Entry Errors

Prior to performing the uncertainty calculations and displaying the results, the uncertainty calculator performs a careful analysis to ensure the entered data are valid. Any errors will be displayed in a dialog box, and are generally self-explanatory. There are three common data entry errors that may require further explanation:

```
(34) No fixed flowing temperature entered
```

This error appears if you did not check the option “RTD installed and used in flow calculations” (self-contained or MVT), or you selected “<none>” for the temperature transducer in a component system. In either case where flowing temperature is not measured, you must enter the fixed temperature (Tab 4) that is assumed in the flow calculations.

```
(28) No atmospheric pressure entered
```

If you selected a device that measures gauge pressure, then you must enter the assumed atmospheric pressure (Tab 4) that is used by the flow computer to convert from gauge pressure to absolute pressure.

```
(31) No atmospheric pressure for 'zero' static entered
```

If you selected a device that measures absolute pressure, and you did not select the option that the ‘zero’ point is calibrated or verified using a barometer, then you must enter the assumed atmospheric pressure (Tab 3) that represents the ‘zero’ point.

II. CALCULATIONS

All uncertainty calculations are done in accordance with established industry procedures such as those found in API 14.3.1. In general, the uncertainty of each variable in the flow equation is multiplied by a sensitivity coefficient, squared, and summed. Overall measurement uncertainty is the square root of the sum. This methodology results in a 2-sigma (95% confidence) level.

Given the flow equation:

$$Q_v = 7709.61 d^2 \frac{C_d}{\sqrt{(1-\beta^4)}} Y \sqrt{\frac{1}{G_r}} \sqrt{\frac{Z_s}{Z_f}} \sqrt{\frac{h_w P_f}{T_f}};$$

the uncertainty of the flow rate (Q_v) is a combination of the following individual sources of uncertainty:

C_d: discharge coefficient of the primary device
d: diameter of the throat (or equivalent diameter for devices such as Wafer V-Cones)
D: inside diameter of the pipe
Y: gas expansion factor
T_f: flowing temperature of the gas
P_f: flowing pressure of the gas
h_w: differential pressure
Z_f : supercompressibility of the gas
G_r: gas gravity, or relative density

Note that the uncertainty of the Beta ratio (β) is accounted for by including uncertainty for throat diameter, d, and pipe diameter, D. Because the pressure and temperature base are defined values, there is no uncertainty associated with them. The flow computer itself adds an additional calculation uncertainty (±0.1%) not shown above.

The sensitivity coefficients associated with each variable are shown in Table 1.

Overall measurement uncertainty (U_m) is calculated with the following equation:

$$U_m = \sqrt{\sum_{i=0}^{i=9} (U_i X_i)^2}$$

Uncertainty, U	Description	Sensitivity Coefficient, X
U_0	C_d	1.0
U_1	d (inches)	$\frac{2}{(1-\beta^4)}$
U_2	D (inches)	$\frac{2\beta^4}{(1-\beta^4)}$
U_3	Y	1.0
U_4	P_f (psia)	.5
U_5	h_w (in H_20)	.5
U_6	T_f (˚R)	.5
U_7	G_r	.5
U_8	Z_f	.5
U_9	Q_v (flow computer)	1.0

Table 1 – Uncertainty sources and sensitivity coefficients

Discharge Coefficient, C_d

Flange Tapped Orifice Plate

For flange tapped orifice plates, the discharge coefficient uncertainty is calculated as follows:

$$U_{Cd} = \sqrt{U_{RG}^2 + B^2 + U_B^2}$$

where:

U_{Cd} = overall discharge coefficient uncertainty, %
U_{RG} = uncertainty in the Reader-Harris Gallagher (RG) equation, %
B = potential bias in Cd resulting from the installation entered, %
U_B = the scatter of the potential bias resulting from the installation entered, %

The uncertainty of the RG equation (U_{RG}) is the 2-sigma difference between the RG equation and the data used to derive it, and is calculated per API 14.3.1.12.4.1 (1991):

$$U_{Cd} = \left(0.5600 - 0.2550\beta^2 + 1.9316\beta^8\right)\left(1 + 1.7895\left[\frac{4000}{\mathrm{Re}_D}\right]^{0.8}\right) \qquad \beta>0.175$$

$$U_{Cd} = \left(0.7000 - 1.0550\beta\right)\left(1 + 1.7895\left[\frac{4000}{\mathrm{Re}_D}\right]^{0.8}\right) \qquad \beta\leq 0.175$$

These equations are only valid for orifice bores greater than 0.45 inches.

The data used in the development of the R-G equation came from lab tests using fully developed flow profiles and do not include the effects of various real-world installations upstream of the orifice.

Installation effects are characterized by numerous additional lab tests which were compiled into a single set of graphs by the Colorado Engineering Experiment Station, Inc. (CEESI), under contract with BLM. For each specific installation, the change in discharge coefficient from the R-G equation (bias, B) was plotted as a function of Beta ratio and dimensionless length between the disturbance and the orifice. Data for 19-tube flow bundles were also obtained and similar graphs of bias as a function of Beta ratio and dimensionless length between the exit of the tube bundle and the orifice were developed. The curve fit for each graph is included in the uncertainty calculator although some interpolation and extrapolation between installations, Beta ratios, and dimensionless lengths are made.

For each graph developed by CEESI, the 2-sigma scatter (U_B) between the graph and the data used to build the graph was also determined and is used in the uncertainty calculator. Again, some interpolation and extrapolation of the scatter is made.

Wafer V-Cone

For the Wafer V-Cone, the discharge coefficient uncertainty is determined directly from the API 22.2 testing that was used in preparation of IM 2007-022. To determine the Wafer V-Cone uncertainty, BLM included not only data from the baseline testing, but also from all the installation effect testing that was deemed to be statistically similar to the baseline testing. Therefore, the discharge coefficient uncertainty determined from the 22.2 testing includes installation effects and no further adjustments to the discharge coefficient uncertainty are necessary .

Throat Diameter, d

As with internal meter tube ID, the uncertainty calculator assumes that the orifice bore is as out of round as allowed under API 14.3.2.4.3. The specification requires a deviation between any individual measurement and the mean diameter, of ±0.0005 inches per inch of diameter (±0.05%). From this specification, the uncertainty of the bore ID is determined as follows (see API 14.3.1.12.4.4):

$$U_d = \pm\sqrt{\frac{4\times(0.05\%)^2}{3}} = \pm 0.0577\%$$

where:

U_d = uncertainty of bore diameter, %

Pipe Diameter, D

The uncertainty calculator assumes that the meter tube is as out-of-round as the specification in 14.3.2.5.1.3.1 allows. Since the specification requires a tolerance of ±0.25% between each of four required measurements and the mean diameter, the root sum square of the maximum allowable error is used (see API 14.3.1.12.4.5):

$$U_D = \pm\sqrt{\frac{4\times(0.25)^2}{3}} = \pm 0.289\%$$

where:

U_D = uncertainty of internal pipe diameter, %

Gas Expansion Factor, Y

Uncertainty of the gas expansion factor is given by the following equation (API 14.3.1.12.4.2):

$$U_Y = 4\left(\frac{h_w}{27.707P_f}\right)$$

Differential and Flowing Pressure, h_w and P_f

The uncertainty of both the differential and static pressure in the flow equation comes from the manufacturer's specification for the respective transducers. Both transducers have a number of uncertainty effects in common, which are described below.

Reference Accuracy (A_r, % of span): The accuracy at laboratory reference conditions (constant temperature, no vibration, no radio frequency interference) including the effects of linearity, repeatability, and hysterisis. Reference accuracy is given as percent of span, percent of upper range limit, or a combination of the two. To be used in the equations given below, the specification must be converted to percent of span.

Ambient Temperature Effects (E_{amb}, % of span): The effect on reference accuracy that a change in ambient temperature from the calibration condition has. It is usually given as percent of upper range limit, span, or a combination of the two, per a given amount of ambient temperature change. To be used in the equations given below, it must be converted to percent of span and adjusted for the actual temperature shift that the transducer experiences as determined in Appendix A.

Ambient Temperature Effects – Reading (E_{amb-r}, % of reading): Some transducers also give the uncertainty effect due to changes in ambient temperature as a percent of reading per a given amount of ambient temperature change. The specification given must be adjusted for the actual temperature shift that the transducer experiences as determined in Appendix A.

Vibration Effects (E_{vib}, % of span): The effect of vibration on reference accuracy, usually given as a percent of upper range limit per a vibration frequency and/or amplitude. Because the inclusion of this specification is not universal, it is currently not used in the calculation of differential or static pressure uncertainty.

Radio Frequency Interference (E_{rfi}, % of span): The effect of radio frequencies on reference accuracy, usually given as a percent of upper range limit for a given radio frequency strength and frequency. Because the inclusion of this specification is not universal, it is currently not used in the calculation of differential or static pressure uncertainty.

Stability (E_{stab}, % of span): This is not a well understood specification, but it generally references the effect of time on reference accuracy. It is typically expressed as a percent of span or upper range limit over a given amount of time. However, according to several manufacturers, stability is not a time-dependent function, and the affect of stability could occur regardless of how much time passes after calibration. Therefore, the stability specification is included as stated, with no pro-ration to account for the amount of time that has passed between calibrations.

Calibration Equipment Accuracy (E_{cal}, % of span): The accuracy of the calibration equipment will affect the reference accuracy of the transducer. API 21.1.8.6 requires that the calibration equipment be at least twice as accurate as the equipment being calibrated. The accuracy of the calibration equipment must be expressed in terms of the percent of span of the transducer being calibrated.

Flowing Pressure, P_f

In addition to the uncertainty effects listed above, the flowing pressure uncertainty also includes the following:

Atmospheric Pressure (E_{atm}, psi): If a fixed atmospheric pressure is used to calibrate the 'zero' point of an absolute pressure transducer or is assumed in the flow equation using gauge pressure, then two additional sources of uncertainty might be introduced. The first is from changes in atmospheric pressure due to weather systems. These changes can alter the atmospheric pressure by as much as ±0.2 psi from a fixed atmospheric pressure based on elevation. The second source is from errors between the value being used for fixed atmospheric pressure and what the fixed atmospheric pressure should be based on elevation using the following equation:

$$P_{atm} = 14.73 - \frac{0.496 \times E}{1000}$$

Where:

P_{atm} = atmospheric pressure, psi
E = elevation, feet msl

For example, if the elevation of a meter is 4500' msl, and a fixed atmospheric pressure is used to calibrate the 'zero' point of an absolute pressure transducer, then the value of the fixed atmospheric pressure should be 12.50 psi. If a value of 13.0 is used by the calibrator, this introduces a 0.50 psi error. Although this is technically a bias, the uncertainty calculator treats it as a source of uncertainty. The total uncertainty due to the use of a fixed atmospheric pressure is given by the following equation:

$$E_{atm} = \pm\sqrt{0.2^2 + (P_{atm} - P_{act})^2}$$

Where P act is the actual value of atmospheric pressure used (psi).

Note: If the check box "Fixed atmospheric pressure is a contract value" is checked, E_{atm} will be set to zero.

To calculate the uncertainty of flowing pressure (P_f), the following equation is used:

$$U_{Pf} = \pm U_{SPx} \times \frac{Span}{\mathrm{Re}ading}$$

where:

U_{pf} = uncertainty of flowing pressure, %
U_{SPx} = uncertainty of the static pressure transducer, % span

The uncertainty of the static pressure transducer (U_{SPx}) is a combination of the effects listed above:

$$U_{SPx} = \pm\sqrt{A_r^{\,2} + E_{cal}^{\,2} + \left(E_{amb} + E_{amb-r}\frac{\mathrm{Re}ading}{Span}\right)^2 + E_{stab}^{\,2} + \left(\frac{100E_{atm}}{Span}\right)^2}$$

Sample Calculation

Given the following transducer and operating conditions, determine the overall static pressure uncertainty:

Transducer:	Rosemount 1151GP-Smart
URL:	1000 psi (range 8)
Calibrated Span:	200 psi
Reading:	120 psi
Calibration Equipment:	Assume 21.1 compliant (2X device accuracy)
Ambient Temperature Shift:	82˚F
Meter Elevation:	1450' MSL
Fixed Atmospheric Press:	13.5 psi; not specified by contract

Manufacturer Specifications:

Reference Accuracy (A_r): 0.1% of span
Temperature Effect (E_{amb}): Total Error = ±(0.2% URL + 0.18% span) per 100˚F
Temperature Effect – Reading (E_{amb-r}): none given
Stability (E_{stab}): ±0.1% of URL for 2 years

Calculations:

First, specifications for ambient temperature effect, calibration equipment, and stability must be converted to percent of span:

E_{amb} = ±(0.2% of 1000 psi + 0.18% of 200 psi) per 100˚F

= ±(2 psi + 0.36 psi) per 100˚F = ±2.36 psi per 100˚F
= ±2.36 psi x 100 / 200 psi = 1.18% of span per 100˚F
= ±1.18% of span per 100˚F x (82˚F/100˚F)
= 0.9676% of span

E_{cal} = ±0.1% ÷ 2
= ±0.05% of span

E_{stab} = ±0.1% URL = ±0.1% of 1000 = ±1 psi
= ±1 psi x 100 / 200
= ±0.5% of span

$$P_{atm} = 14.73 - \frac{0.496 \times 1450}{1000}$$

= 14.01 psi

$$E_{atm} = \pm\sqrt{0.2^2 + (14.01 - 13.5)^2}$$

= ±0.5486 psi

$$U_{SPx} = \pm\sqrt{0.1^2 + 0.05^2 + 0.9676^2 + 0.5^2 + \left(\frac{100 \times 0.5486}{200}\right)^2}$$

U_{SPx} = ±1.1287% of span

Finally, the uncertainty in flowing pressure (P_f) is calculated by converting the percent of span into a percent of reading:

$$U_{Pf} = \pm 1.1287 \times \frac{200}{120}$$

U_{Pf} = ±1.8812%

Differential Pressure, h_w

In addition to the uncertainty effects that are common to both the differential and static pressure, differential pressure transducers are also affected by the following.

Static Pressure Effects (E_{SP}, % of span): Differential pressure accuracy is affected by the static pressure that is acting on it. The specification for static pressure effects adjust the reference accuracy for these effects and are typically given as a percent of span or upper range limit per a given amount of static pressure applied. Some transducer manufacturers specify a reduced effect if the transducer is re-zeroed with full static pressure applied.

Static Pressure Effects – Reading (E_{SP-r}, % of reading): Some transducers also give the uncertainty effect due to static pressure as a percent of reading per a given amount of static pressure applied.

To calculate the uncertainty of differential pressure (h_w), the following equation is used:

$$U_{hw} = \pm U_{DPx} \times \frac{Span}{\mathrm{Re}ading}$$

where:

U_{hw}= uncertainty of differential pressure, %
U_{DPx} = uncertainty of the differential pressure transducer, % span

The uncertainty of the differential pressure transducer (U_{DPx}) is a combination of the effects listed above, combined as follows:

$$U_{DPx} = \pm\sqrt{A_r^{\,2} + E_{cal}^{\,2} + \left(E_{amb} + E_{amb-r}\frac{\mathrm{Re}ading}{Span}\right)^2 + \left(E_{SP} + E_{SP-r}\frac{\mathrm{Re}ading}{Span}\right)^2 + E_{stab}^{\,2}}$$

Sample Calculation

Given the following transducer and operating conditions, determine the overall static pressure uncertainty:

Transducer:	Totalflow XFC6410
URL:	400 inH$_2$O
Calibrated Span:	400 inH$_2$O
Reading:	25 inH$_2$O
Static Pressure:	734 psig
Calibration Equipment:	Ashcroft ATE-100, AQS-2 module, 30 psig, ±0.025% of full range accuracy
Ambient Temperature Shift:	118˚F

Manufacturer Specifications:

Reference Accuracy: ±0.05% of span
Temperature Effect (E_{amb}): ±0.15% URL per 160˚F
Temperature Effect – Reading (E_{amb-r}): ±0.125% of reading per 160˚F
Static Pressure Effect (E_{SP}): ±0.03% of URL per 1500 psi
Static Pressure Effect – Reading (E_{SP-r}): ±0.1% of reading per 1500 psi
Stability (E_{stab}): ±0.1% of URL for 12 months

Calculations:

First, specifications for ambient temperature effect, calibration equipment, static pressure effect, and stability must be converted to percent of span:

E_{cal} = ±0.025% of (30 psi x 27.707) = ±0.2078 inH_2O
= ±0.2078 inH_2O x 100/400 inH_2O
= ±0.05195% of span (note that this is not in compliance with API 21.1)

E_{amb} = ±0.15% of 400 inH_2O per 160˚F
= ±0.6 inH_2O per 160˚F
= ±0.6 inH_2O x 100 / 400 inH_2O = 0.15% of span per 160˚F
= ±0.15% of span per 160˚F x (118˚F/160˚F)
= ±0.1116% of span

E_{SP} = ±0.03% of URL per 1500 psi
= ± 0.03% of 400 inH_2O per 1500 psi
= ±0.12 inH_2O per 1500 psi
= ±0.12 inH_2O x (734 psi/1500 psi) = ±0.0587 inH_2O
= ±0.0587 inH_2O x 100 / 400 inH_2O
= ±0.0147% of span

$E_{SP\text{-}r}$ = ±0.1% of reading per 1500 psi
= ±0.1% 25 inH_2O per 1500 psi x (734 psi / 1500 psi)
= 0.0489%

E_{stab} = ±0.1% URL = ±0.1% of 400 inH_2O = ±1 inH_2O
= ±1 inH_2O x 100 / 400 inH_2O
= ±0.1% of span

$$U_{DPx} = \pm\sqrt{0.05^2 + 0.05195^2 + 0.1116^2 + \left(0.0147 + 0.0489\frac{25}{400}\right)^2 + 0.1^2}$$

U_{DPx} = ±0.1672% of span

Finally, the uncertainty in differential pressure (h_w) is calculated by converting the percent of span into a percent of reading:

$$U_{hw} = \pm 0.1672 \times \frac{400}{25}$$

U_{hw} = ±2.6757%

Flowing Temperature, T_f

The flowing temperature comes from the RTD and the temperature transducer. The uncertainty of flowing temperature is calculated from the manufacturer's specifications for the RTD and flowing temperature transducer. Components of flowing temperature uncertainty are as follows:

Reference Accuracy (A_r): The accuracy at laboratory reference conditions (constant temperature, no vibration, no radio frequency interference) including the effects of linearity, repeatability, and hysterisis. Reference accuracy is typically given as a constant in degrees Fahrenheit.

Ambient Temperature Effects (E_{amb}): The effect on reference accuracy that a change in ambient temperature has. It is usually given as a constant in degrees Fahrenheit, per a given amount of ambient temperature change as determined in Appendix A.

Ambient Temperature Effects – Reading (E_{amb-r}): Some transducers also give the uncertainty effect due to changes in ambient temperature as a percent of reading per a given amount of ambient temperature change as determined in Appendix A.

Stability (E_{stab}): This is not a well understood specification, but it generally references the effect of time on reference accuracy. It is typically expressed as a constant in degrees Fahrenheit over a given amount of time. However, according to several manufacturers, stability is not a time-dependent function, and the affect of stability could occur regardless of how much time passes after calibration.

Calibration Equipment Accuracy (E_{cal}): The accuracy of the calibration equipment will affect the reference accuracy of the transducer. API 21.1.8.6 requires that the test equipment be twice as accurate as the equipment being calibrated. In addition, API requires that during a verification, the transducer readout only has to be within 0.5˚F of the test thermometer, regardless of the transducer accuracy.

To calculate the uncertainty of flowing temperature (T_f), the following equation is used:

$$U_{Tf} = U_{Tfx} \times \frac{100}{\mathrm{Re}ading(°R)}$$

where:

U_{Tf} = uncertainty of temperature, %
U_{Tfx} = uncertainty of the temperature transducer and RTD, ˚R

The uncertainty of the flowing temperature transducer (U_{Tfx}) is a combination of the effects listed above, combined as follows:

$$U_{Tfx} = \sqrt{A_r^{\,2} + E_{cal}^{\,2} + \left(E_{amb}^{\,2} + E_{amb-r}\frac{\mathrm{Re}\,ading}{Span} \right)^2 + E_{stab}^{\,2}}$$

Gas Gravity, G_r

Uncertainty in the value of gas gravity due to changes in gas gravity between samples, sampling accuracy, and accuracy of analysis are not yet included in the calculation of overall measurement uncertainty.

Supercompressibililty, Z_f

It is assumed that the calculation of supercompressibililty, per AGA 8, carries an uncertainty of ±0.1%, as shown in “Region 1” of AGA 8, Figure 1. Region 1 represents pressures from 0 to 1750 psia and temperatures from 17 to 143˚F. These ranges encompass the vast majority of pressures and temperatures common to meters administered by BLM.

APPENDIX A – Determination of ambient temperature change

Ambient temperature shift is determined from three input variables: the nearest city, the calibration frequency, and the physical location of the transducers.

A. Nearest City/Calibration Frequency

The temperature shift due to the nearest city and calibration frequency was determined using a rigorous statistical analysis described below.

For each city in the pick list, a statistical analysis has been performed to develop an ambient temperature change as a function of calibration frequency (see Table A-1). When a calibration is performed, the transducer will (hopefully) read accurately for the ambient temperature at which the calibration was performed. As the ambient temperature changes from the temperature during calibration, it is likely that the transducer readings will drift as a result of the temperature change. Most manufacturers specify the amount of drift that is likely to occur (transducers that do have specifications for ambient temperature effects will not be included in the pick lists).

The longer between calibrations, the more extreme the ambient temperature changes will be. For example, assume that an outdoor-mounted transducer is calibrated quarterly: once in the summer, once in the fall, once in the winter, and once in the spring. It is probable that the summer calibration will be done when the temperatures are relatively warm. The transducer will still experience daily fluctuations in ambient temperature, but by the time the temperatures start to drop off in the fall, another calibration will be performed, likely at a cooler temperature. When the winter extreme temperatures arrive, another calibration will be done at a colder temperature.

In contrast to the above example, now assume a similar transducer is calibrated on an annual schedule. One calibration is performed at some point in the year, at a particular temperature. That transducer will now experience everything from the maximum daily temperatures in the summer to the lowest winter time temperatures in the early morning hours. Therefore, in general statistical terms, the more often a meter is calibrated, the lower the temperature extremes it will experience because the meter is periodically reset to match the temperatures of the season.

The statistical method used to determine ambient temperature shift results in a 2-sigma, or 95% confidence level. In other words, if the ambient temperature shift for the city and calibration frequency is 50˚F, this means that there is a 95% probability that the actual temperature shift experienced by the secondary device is 50˚F or less. All inputs into the uncertainty model are based on 2-sigma probability.

	Calibration Frequency, months							
City	**1**	**2**	**3**	**4**	**6**	**8**	**12**	**24**
Birmingham, AL	46	50	55	60	69	73	73	73
Anchorage, AK	37	44	52	60	72	78	78	78
Fairbanks, AK	56	67	81	94	117	127	127	127
Bakersfield, CA	48	51	56	61	68	72	72	72
Sacramento, CA	46	48	51	55	59	61	61	61
Canon City, CO	58	62	66	71	78	80	80	80
Cortez, CO	56	60	66	72	82	87	87	87
Craig, CO	56	62	68	75	85	89	89	89
Durango, CO	54	58	63	69	77	80	80	80
Glenwood Springs, CO	56	60	66	72	80	84	84	84
Grand Junction, CO	51	57	64	71	82	87	87	87
Gunnison, CO	62	67	73	80	91	97	97	97
Meeker, CO	60	64	70	76	86	91	91	91
Rangely, CO	56	62	71	79	92	98	98	98
Wichita, KS	50	56	64	72	84	90	90	90
Baton Rouge, LA	43	46	50	54	61	65	65	65
Monroe, LA	47	51	56	61	69	73	73	73
New Orleans, LA	36	40	44	48	56	59	59	59
Shreveport, LA	45	49	54	59	68	72	72	72
Boston, MA	40	46	53	60	72	78	78	78
Kansas City, MO	48	54	57	70	83	89	89	89
Billings, MT	58	63	69	76	86	91	91	91
Great Falls, MT	60	64	70	75	84	89	89	89
Miles City, MT	60	67	76	85	78	102	102	102
Albuquerque, NM	51	55	60	66	76	81	81	81
Artesia, NM	62	65	69	74	82	87	87	87
Carlsbad, NM	57	60	65	70	78	82	82	82
Cuba, NM	64	67	72	76	84	88	88	88
Farmington, NM	53	58	63	70	80	85	85	85
Gallup, NM	65	68	73	78	86	90	90	90
Hobbs, NM	54	57	62	67	76	79	79	79
Roswell, NM	56	60	65	70	79	84	84	84
Dickinson, ND	61	67	75	83	96	103	103	103
Williston, ND	60	67	76	85	100	107	107	107
Oklahoma City, OK	49	54	60	67	77	82	82	82
Tulsa, OK	48	54	60	67	78	83	83	83
Corpus Christi, TX	40	42	45	48	54	57	57	57
Dallax, TX	45	49	55	61	71	75	75	75
Houston, TX	41	44	48	52	59	62	62	62
Midland, TX	53	57	62	67	76	80	80	80
Shamrock, TX	55	59	65	71	82	86	86	86
Moab, UT	58	63	70	77	89	95	95	95
Vernal, UT	56	62	69	76	88	93	93	93
Big Piney, WY	62	67	73	80	91	96	96	96
Buffalo, WY	57	62	69	75	86	91	91	91
Casper, WY	59	64	70	77	87	93	93	93
Cheyenne, WY	55	59	64	70	79	83	83	83
Cody, WY	57	61	67	73	81	86	85	86
Evanstan, WY	53	58	64	70	81	85	85	85

	Calibration Frequency, months							
City	1	2	3	4	6	8	12	24
Gillette, WY	57	62	68	75	86	92	92	92
Kemmerrer, WY	58	63	70	76	86	90	90	90
Labarge, WY	64	69	76	83	93	97	97	97
Newcastle, WY	58	63	70	77	88	94	94	94
Rock Springs, WY	50	56	64	71	83	89	89	89
Worland, WY	61	67	75	84	97	103	103	103

Table A-1 – Ambient temperature shifts of selected cities (˚F)

To determine the ambient temperature shift for each city, the following procedure was used. First, a minimum of 10 consecutive years of daily high/low temperatures were obtained for the cities listed. The data for each city comes from the National Climatic Data Center. A program was developed that rolls through the data at different intervals of time representing different calibration frequencies.

For example, to determine the ambient temperature shift for a quarterly calibration frequency (90 days), the program will first assume that the calibration was performed on the first day of the 10 years of data, at a temperature determined as follows:

$$T_{cal} = 0.7 \times T_{\max} + 0.3 \times T_{\min}$$

where:

T_{cal} = calibration temperature
T_{max} = the maximum temperature recorded for the day of calibration
T_{min} = the minimum temperature recorded for the day of calibration

The average difference between the calibration temperature and the next 90 days of high/low temperatures is then obtained. The program then rolls forward one day and repeats the calculation. In equation form, the average change in ambient temperature is determined as follows:

$$\Delta T_{avg} = \frac{\sum_{j=1}^{j=n} \sum_{i=j}^{i=j+CF} \left\| \left(T_{cal,j} - T_{\max,i} \right) \right\| + \left\| \left(T_{cal,j} - T_{\min,i} \right) \right\|}{n \times 2 \times CF}$$

Where:

CF = calibration frequency, days
n = number of iterations (3650 days – CF + 1)

j = day on which the “calibration” is performed
i = each day after which the “calibration” is performed
$T_{cal,j}$ = calibration temperature for day j, ˚F
$T_{max,i}$ = maximum temperature on day i, ˚F
$T_{min,i}$ = minimum temperature on day i, ˚F

In addition to calculating the average temperature difference between the calibration temperature and the daily high and low temperatures, the standard deviation is also calculated. Because the uncertainty calculator is a 2-sigma model, each individual source of uncertainty comprising the overall uncertainty is also calculated at 2-sigma. To determine the actual temperature shift used for a particular city, the following equation is used:

$$\Delta T_{amb} = \Delta T_{avg} + 2\sigma$$

For cities that have multiple weather stations, the statistical procedure was run for each weather station and the results averaged. Typically, the temperature-shift agreement between multiple weather stations for the same city was within 3˚F.

B. Location

The ambient temperature shift for a particular city and calibration frequency is then modified by location of the transducer selected on Tab 2 of the data entry screen. The modification is described in Table A-2.

Selection	Result (ΔT)
Inside a temperature controlled building	= 10˚F
Inside a heated meter house	$= \Delta T_{amb} \times 0.5$
Inside an unheated meter house	$= \Delta T_{amb} \times 0.95$
Outside, but protected from the sun	$= \Delta T_{amb}$
Outside, no protection	$= \Delta T_{amb} + 25$˚F

Table A-2 – Location modifiers

Some assumptions were used when developing these temperature modifiers. It was assumed that even in a “temperature controlled building”, the temperature is not constant. There may be variations between day and night or seasonally. It was assumed that a fixed temperature shift of 10˚F was a fair representation.

A heated meter house typically takes two forms. Some installations in colder climates use pipeline gas (usually taken downstream of the meter) to run a small heater placed inside the meter house. In other cases, the transducers are installed inside a heater-treater building. In either case, the heat provides some mitigation of temperature shift, especially in colder weather. It is assumed, therefore, that the outside ambient temperature shift is reduced by half (50%) because of the heat inside the meter house.

Transducers installed inside an unheated meter house would essentially experience the same ambient temperature shift they would if mounted outside. However, it was assumed that the heat capacity of the air and equipment inside the meter house would reduce the ambient temperature shift by 5%.

If the transducers are mounted outside, but protected from the sun, the meter will experience the full effect of ambient temperature changes. If the transducers are exposed to the sun, the radiant heat energy (insolation) will increase the transducer core temperature above the ambient temperature in the day time. At night, radiant heat transfer to the night sky will reduce the transducer core temperature below ambient temperature. Based on a preliminary study done by the Colorado Engineering Experiment Station, Inc. (CEESI), the amount of temperature gain in the day time is about 20˚F, and -5˚F in the nighttime, for a total temperature shift gain of 25˚F.