SOP 19

Standard Operating Procedure for Calibration of Graduated Neck-Type Metal Provers (Volume Transfer Method)[1]

1 Introduction

1.1 Purpose of Test

This procedure is used to calibrate graduated neck type metal test measures and provers (20 L (5 gal) and larger) that are used in verification of petroleum, biodiesel, ethanol, milk, and/or water meters. Detailed measurement ranges, standards, equipment, and uncertainties for this SOP are generally compiled in a separate document in the laboratory.

1.2 Conformity Assessment

Standards that are calibrated for use in legal weights and measures applications should be evaluated for conformance to the appropriate specifications and tolerances that apply. Test measures or provers being calibrated should be evaluated using the checklist provided in NIST Handbook 105-3, Specifications and Tolerances for Graduated Neck Type Volumetric Field Standards, 2010. Alternatively, if requested by the customer, evaluation against OIML R 120 (2010), Standard capacity measures for testing measuring systems for liquids other than water, may be referenced. Where compliance is required by law, conformity evaluations should be conducted prior to performing calibrations. See Section 6.2 for reporting results.

1.3 Prerequisites

1.3.1 Verify that the unknown prover has been properly cleaned and vented, with all petroleum products removed prior to submission for calibration to ensure laboratory safety and compliance with environmental disposal requirements. The prover may be visually inspected to determine that residual liquid petroleum products are not present. Smell is not necessarily an adequate indicator of cleanliness.

1.3.2 Note: Many laboratories have a policy regarding cleanliness of submitted volumetric standards to minimize water contamination with flammable petroleum products.

1.3.3 Verify that valid current calibration certificates with measurement values and uncertainties are available for all the standards used in the test. All calibration values must have demonstrated metrological traceability to the

[1] Non-SI units are predominately in common use in State legal metrology laboratories, and/or the petroleum industry for many volumetric measurements, therefore non-SI units have been used to reflect the practical needs of the laboratories performing these measurements as appropriate.

international system of units (SI). Metrological traceability may be to the SI through a National Metrology Institute such as NIST.

1.3.4 Verify that the standards to be used have sufficiently small standard uncertainties for the intended level of calibration.

1.3.5 Verify the availability of an adequate supply of clean, preferably soft water (filtered and thermally equilibrated, as appropriate) water (GLP 10). Water does not need to be distilled or deionized for use in this procedure. The equations used in GLP 10 for the calculation of water density (air saturated) may be used without a significant impact on the measurement results.

1.3.6 Verify that the operator has had specific training and is proficient in SOP 17, SOP 19, SOP 20, SOP 31, GMP 3, and is familiar with the operating characteristics and conditioning of the standards used.

1.3.7 Verify that the laboratory facilities meet the following minimum conditions to make possible the expected uncertainty achievable with this procedure:

Table 1. Laboratory environmental conditions.

Procedure	Temperature	Relative Humidity
Volume Transfer	18 °C to 27 °C Stable to ± 2.0 °C / 1 h	35 % to 65 % Stable to ± 20 % / 4 h

1.4 Field Calibrations (Tests)

1.4.1 A “field” calibration is considered one in which a calibration is conducted in uncontrolled environments, such as out-of-doors. Calibrations conducted under field and laboratory conditions are not considered equivalent.

1.4.2 The care required for field calibrations includes proper safety, a clean and bubble-free water supply, measurement control programs, and a stable temperature environment shaded from direct sunshine to allow the prover, field standard, and clean test liquid (water) to reach an equilibrium temperature with minimal evaporation. Environmental conditions must be selected to be within stated laboratory conditions during the measurements. All data and appropriate environmental conditions must be documented regardless of test location.

1.4.3 An increased number of check standard verifications are required to ensure continued suitability of calibration values generated in field conditions as well as to verify the validity of any standards taken out of a secure laboratory environment once the standard(s) are returned to the laboratory.

2 Methodology

2.1 Scope, Precision, Accuracy

2.1.1 This procedure is applicable for the calibration of any size metal prover within the limitations of the standards available. The repeatability attainable depends on strict adherence to the procedure, the care in volumetric adjustments, and the number of transfers, in the case of multiple transfers. The accuracy depends on the standards used.

2.2 Summary

2.2.1 Water is delivered from calibrated volumetric standard(s) into the unknown test measure or prover being calibrated. Depending on the respective volumes, multiple transfers may be required. While these should be minimized, a maximum number of 15 transfers are permitted to ensure that final uncertainties and systematic errors are sufficiently small for the intended applications. The temperature of the calibration medium (water) cannot be considered constant during transfers; hence, the temperature of the water for each transfer must be measured. Because of the large volumes, the difference in thermal expansion of the respective vessels must be considered. Hand held test measures require a 30 s (± 5 s) pour followed by a 10 s drain, with the measure held at a 10° to 15° angle from vertical, during calibration and use. Provers are emptied by gravity drain, followed by a 30 s final drain after the cessation of flow.

2.3 Standards and Equipment

2.3.1 Calibrated volumetric standards of suitable sizes.

2.3.2 Calibrated flask(s) of suitable sizes to calibrate neck of prover.

2.3.3 A funnel for transferring water from the flask into the prover or test measure.

2.3.4 Meniscus reading device (See GMP 3).

2.3.5 Calibrated thermometer, with resolution and uncertainty less than 0.1 °C.

2.3.6 Timing device (calibration is not required; uncertainty of the measurement only needs to be less than 5 s for a 30 s pour time or drain time).

2.3.7 Sturdy platform, with appropriate safety conditions, with sufficient height to hold standard and to permit transfer of water from it to the prover by gravity flow.

2.3.8 Clean pipe or tubing (hoses) to facilitate transfer of water from the laboratory standard to prover. Pipe and hose lengths must be minimized to

reduce water retention errors. Care must be taken during wet-downs and runs to ensure complete drainage and consistent retention in all hoses or pipes.

2.4 Procedure

2.4.1 Cleanliness verification

Fill and drain both the standard and unknown test measure or prover to be calibrated and check for visual evidence of soiling and of improper drainage. If necessary, clean with non-foaming detergent and water and rinse thoroughly (see GMP 6).

2.4.2 Neck scale plate calibration

Neck scale plate calibrations are generally conducted only for new or damaged volumetric measures, those that have not been calibrated by the laboratory in the past, or those for which the calibration data is not available. See SOP 31 for the neck scale plate calibration procedure.

2.4.3 Body Calibration

2.4.3.1 Fill the standard with water and then transfer the water into the unknown prover establishing a wet down of the standard. Wait 30 s after the cessation of the main flow on the standard before closing the drain valve. Level the unknown prover, and drain or empty the water, following the applicable emptying and draining procedure based on the standard being calibrated. Hand held test measures require a 30 s (± 5 s) pour followed by a 10 s drain, with the measure held at a 10° to 15° angle from vertical, during calibration and use. Provers are emptied by gravity drain, followed by a 30 s final drain after the cessation of the main flow.

2.4.3.2 If a bottom zero is present, follow the guidance provided in SOP 21 for LPG provers as follows: When the liquid reaches the top of the lower gauge glass, close the valve and allow the water to drain from the interior of the prover into the lower neck for 30 s. Then bleed slowly with the bleed valve (4) until the bottom of the liquid meniscus reaches the zero graduation. (This step should be started during the 30 s drain period but should not be completed before the end of the drain period).

Alternatively, the prover may be completely drained with a 30 s drain time after the cessation of the main flow, and then refilled with a funnel and small volume of water to set the zero mark (which will add to the prover calibration uncertainty due to variable retention characteristics).

2.4.3.3 Run 1. Fill the standard and measure and record the temperature, t_1.

2.4.3.4 Adjust the standard prover to its reference mark or record the neck reading, and then discharge into the unknown prover. Wait 30 s after cessation of the main flow to attain specified drainage, and then close the delivery valve. Remove any hoses or pipes to prevent additional water transfer.

2.4.3.5 Repeat step 2.4.3.4 as many times as necessary (note the 15-drop limit) to fill the unknown prover to its nominal volume. Verify the level condition and record the temperature of water in the standard for each drop, t_1 to t_N.

2.4.3.6 Level the filled unknown prover. Check the prover level by placing a precision spirit or electronic digital level vertically on the neck on at least two locations, 90° apart around the circumference of the neck and adjust the orientation of the unknown measure until the neck is as close to vertical (plumb or perpendicular to the horizontal plane) as possible. Verify and adjust any mounted levels that are on the prover to agree (when present and when possible).

2.4.3.7 Read and record the scale plate (gauge) reading.

2.4.3.8 Measure the temperature of the water in the unknown prover, tx, and record. For test measures without thermometer wells, the temperature should be taken as close as possible to the center (vertically and horizontally) of the cylinder of the test measure main body (and not in the neck). For larger provers, and when thermometer wells are present, the average temperature, calculated from temperatures taken at multiple locations from within the unknown prover should be used. (Alternatively, if a prover has mounted thermometers, the internal temperature from multiple locations within the prover may be used).

2.4.3.9 Perform the calculations described in section 3 to determine the prover volume at the appropriate reference temperature.

2.4.3.10 Adjust the scale as needed. If adjusted, record the adjusted prover gauge reading for determining the "as left" value for Run 1. Run 2 will validate the setting. Alternatively, the average of Run 1 and Run 2 may be used with the adjustment made after Run 2. In that case, a validation run (Run 3) is required to ensure correct setting of the scale plate.

2.4.3.11 Run 2 - Repeat the process described from 2.4.3.3 to 2.4.3.9. Replicate runs of the test measure or prover (when the volume is corrected to the reference temperature) must pass the F-test, agree within ± 0.02 % of the test volume, or be within the control/action limits on the standard deviation or range charts (whichever is the most rigorous assessment). When calculating a 0.02 % agreement, it is calculated as the difference between Run 1 and Run 2, divided by the nominal volume, and then multiplied by 100.

Note: If excess disagreement between replicated measurements is observed, check all vessels for cleanliness, leaks, drain lines, additional valve, or damage, identifying and correcting any problems. Lack of measurement agreement may be due to prover condition, contamination, lack of cleanliness, excessive temperature changes, poor laboratory conditions, or poor field conditions, such as when calibration is conducted in an unstable environment. Repeatability problems must be corrected before calibration can be completed.

2.4.3.12 Seal the equipment as specified in the laboratory policy.

3 Calculations

The following calculations assume that the standard was calibrated using a reference temperature of 60 °F (15.56 °C) and that you are calibrating a field standard to a reference temperature of 60 °F (15.56 °C). Equations for situations where different reference temperatures are involved follows in Section 3.4.

3.1 Single Delivery

Calculate V_{X60}, the volume of the unknown prover at 60 °F, using the following equation:

$$V_{X60} = \frac{\rho_1 \left\{ \left(V_{S60} + \Delta_1 \right) \left[1 + \alpha \left(t_1 - 60\ ^\circ\mathrm{F} \right) \right] \right\}}{\rho_x \left[1 + \beta \left(t_x - 60\ ^\circ\mathrm{F} \right) \right]} \qquad \text{Eqn. (1)}$$

3.2 Multiple Deliveries

Calculate V_{X60}, the volume of the unknown prover at 60 °F, using the following equation:

$$V_{X60} = \frac{\rho_1\left\{\left(V_{S60}+\Delta_1\right)\left[1+\alpha\left(t_1-60\,°\text{F}\right)\right]\right\}+\rho_2\left\{\left(V_{S60}+\Delta_2\right)\left[1+\alpha\left(t_2-60\,°\text{F}\right)\right]\right\}+\ldots+\rho_N\left\{\left(V_{S60}+\Delta_N\right)\left[1+\alpha\left(t_N-60\,°\text{F}\right)\right]\right\}}{\rho_x\left[1+\beta\left(t_x-60\,°\text{F}\right)\right]}$$

Eqn. (2)

Table 2.Variables for V_{X60} equations.

Variables Used in Volume Equations	
V_{X60}	volume of the unknown vessel at 60 °F
V_{S60}	volume of the standard vessel at 60 °F
$\rho_1, \rho_2, \ldots, \rho_N$	density of the water in the standard prover where ρ_1 is the density of the water for the first delivery, ρ_2 is the density of the water for the second delivery, and so on until all N deliveries are completed
$\Delta_1, \Delta_2, \ldots, \Delta_N$	volume difference between water level and the reference mark on the standard where the subscripts *1, 2,..., N*, represent each delivery as above. If the water level is below the reference line, Δ is negative. If the water level is above the reference line, Δ is positive. If the water level is at the reference line, Δ is zero Note: units must match volume units for the standard. The Δ is zero for slicker-plate type standards.
$t_1, t_2, \ldots, t_N$	temperature of water for each delivery with the subscripts as above
α	coefficient of cubical expansion for the standard in units / ºF
β	coefficient of cubical expansion for the prover in units / ºF
t_x	temperature of the water in the filled unknown vessel in units ºF
ρ_x	density of the water in the unknown vessel in g/cm^3
Note: Values for the density of water should be calculated from the equations given in GLP 10. The cubical coefficient of the materials must match the unit assigned to the temperature measurement.	

3.3 Prover Error/Correction or Deviation from Nominal

3.3.1 The total calculated volume of the prover at its reference temperature should be reported on the calibration report. The SI unit of volume is m^3, so a conversion factor is to be included on the report in the notes section when other volume units are used.

3.3.2 The prover volume for an open neck prover equals the V_{X60} value minus the gauge reading that is the difference from the nominal volume (with matched units).

$$\text{Prover volume} = V_{X60} - \text{gauge reading} \qquad \text{Eqn. (3)}$$

$$\text{Prover error} = \text{Prover volume} - V_{Nom} \qquad \text{Eqn. (4)}$$

$$\text{Prover error} = V_{X60} - \text{gauge reading} - V_{Nom} \qquad \text{Eqn. (5)}$$

where: V_{Nom} = Nominal volume (taking care to match units).

3.3.3 V_{X60} is the calculated volume of water delivered from the standard that should be observed in the unknown prover. A positive prover error means that the prover is larger than nominal. A negative prover error means that the prover is smaller than nominal.

Example 1: If V_{X60} is 100.02 gal and gauge reading is 0.02 gal (above nominal); then the prover volume at nominal is 100.00 gal; and the prover error and correction are 0; and no adjustment is needed.

Example 2: If V_{X60} is 100.02 gal and gauge reading is -0.02 gal (below nominal); then the prover volume at nominal is 100.04 gal; the prover error is + 0.04 gal; and to adjust the prover, set the gauge to read 0.02 gal (the volume level will show a gauge reading of 0.02 gal, which is 4.62 in^3 or about 5 in^3, above nominal).

3.4 Alternative Reference Temperatures

3.4.1 Reference temperatures other than 60 ºF (15.56 ºC) may occasionally be used. Common reference temperatures for other liquids follow, however not all of them may be suitable for use with standards calibrated using this procedure:

Table 3. Common reference temperatures.

Commodity	Reference Temperature
Frozen food labeled by volume (e.g., fruit juice)	-18 ºC (0 ºF)
Beer	3.9 ºC (39.1 ºF)
Food that must be kept refrigerated (e.g., milk)	4.4 ºC (40 ºF)
Distilled spirits or petroleum	15.56 ºC (60 ºF)
Petroleum (International Reference)	15 ºC (59 ºF)
Compressed Natural Gas (CNG)	15 °C (60 ºF)
Wine	20 ºC (68 ºF)
Unrefrigerated liquids (e.g., sold unchilled, like soft drinks)	20 ºC (68 ºF)
Hydrogen (H_2)	21 ºC (70 ºF)
Petroleum (Hawaii)	26.67 ºC (80 ºF)

3.4.2 Equations for calculations when using alternative reference temperatures follow:

3.4.2.1 Single Delivery

Calculate V_{Xtref}, the volume of the unknown prover at its designated reference temperature (°F), using the following equation:

$$V_{Xtref} = \frac{\rho_1 \left\{ \left(V_{Stref} + \Delta_1 \right) \left[1 + \alpha \left(t_1 - \mathrm{t}_{\mathrm{ref\,S}} \right) \right] \right\}}{\rho_x \left[1 + \beta \left(t_x - \mathrm{t}_{\mathrm{ref\,X}} \right) \right]} \qquad \text{Eqn. (6)}$$

3.4.2.2 Multiple Deliveries

Calculate V_{Xtref}, the volume of the unknown prover at its designated reference temperature, using the following equation:

$$V_{XtrefX} = \frac{\rho_1 \left\{ \left(V_{StrefS} + \Delta_1 \right) \left[1 + \alpha_1 \left(t_1 - t_{ref\,S} \right) \right] \right\} + \rho_2 \left\{ \left(V_{StrefS} + \Delta_2 \right) \left[1 + \alpha_2 \left(t_2 - t_{ref\,S} \right) \right] \right\} + \ldots + \rho_N \left\{ \left(V_{StrefS} + \Delta_N \right) \left[1 + \alpha_N \left(t_N - t_{ref\,S} \right) \right] \right\}}{\rho_x \left[1 + \beta \left(t_x - t_{ref\,X} \right) \right]}$$

Eqn. (7)

Table 4 Variables for volume equations at alternative temperatures.

Symbols Used in Equations	
V_{XtrefX}	volume of the unknown vessel, V_X at its designated reference temperature, $t_{ref\,X}$
V_{StrefS}	volume of the standard vessel, V_S at its designated reference temperature, $t_{ref\,S}$
ρ_1, ρ_2, ρ_3	density of the water in the standard where ρ_1 is the density of the water for the first delivery, ρ_2 is the density of the water for the second delivery, and so on until all N deliveries are completed
$\Delta_1, \Delta_2, ..., \Delta_N$	volume difference between water level and the reference mark on the standard where the subscripts *1, 2,..., N,* represent each delivery as above. If the water level is below the reference line, Δ is negative. If the water level is above the reference line, Δ is positive. If the water level is at the reference line, Δ is zero. Note: units must match volume units for the standard. The Δ is zero for slicker-plate type standards.
$t_1, t_2, ..., t_N$	temperature of water for each delivery with the subscripts as above
α	coefficient of cubical expansion for the standard in its designated units
β	coefficient of cubical expansion for the prover in its designated units
t_x	temperature of the water in the filled unknown vessel in designated units
ρ_x	density of the water in the prover in g/cm^3
Notes: Values for the density of water should be calculated from the equations given in GLP 10. The cubical coefficient of the materials must match the unit assigned to the temperature measurement.	

3.5 Calculate the within process standard deviation, s_w, for the replicate runs. For two runs, the degrees of freedom will be one. This value is plotted on the standard deviation chart and may be used to incorporate an F-test as well.

3.6 The range of the replicated runs must repeat within 0.02 % of the volume, or the standard deviation must be less than applicable control/action limits on standard deviation charts, or the observed standard deviation must pass the F-test statistics (as applicable). Where the F-test is used, calculate the F statistic to compare the observed within process standard deviation, s_w, to the accepted (pooled) within process standard deviation for the measurement process. (See NISTIR 6969, Sections 8.4 and 8.9.2, for more information on pooling standard deviations and F-tests).

$$F = \frac{s^2_{w\,\text{Observed}}}{s^2_{w\,\text{Accepted}}} \qquad \text{Eqn. (8)}$$

The calculated F statistic must be less than the F value obtained from an F table at 95 % confidence level (Table 9.12, NISTIR 6969) to be acceptable. The F value is obtained from the F table for one degree of freedom for the numerator and the degrees of freedom for the denominator is equal to the number of degrees of freedom in the pooled within process standard deviation. If the data fails the

repeatability assessments and the source of the error cannot be determined conclusively and corrected, the measurement must be repeated. All values must be entered in the standard deviation chart or control chart, even if failing the repeatability assessment to ensure the variability of the accepted measurement process is representative of the process and not unduly reduced over time.

3.7 Calculate and report the mean volume of the volumetric standard at its applicable reference temperature.

If adjustments were made during replicate runs, report the "as found" volume or the mean of "as found" volumes and the "as left" volume or mean of "as left" volumes, as applicable, at the appropriate reference temperature. (Do not calculate a mean value by combining "as found" and "as left" values when adjustments are made).

4 Measurement Assurance

4.1 Duplicate the process with a suitable check standard. See SOP 17 or SOP 30. Plot the check standard volume and verify that it is within established limits. The mean of the check standard observations may be used to evaluate bias and drift over time when a reference value for the check standard is available. Check standard observations are used to calculate the standard deviation of the measurement process which contributes to the Type A uncertainty components.

4.1.1 A t-test may be incorporated to check the observed value against an accepted value.

$$t = \frac{\left(S_c - \overline{S_c}\right)}{s_p} \qquad \text{Eqn. (9)}$$

The t-statistic is evaluated using Eqn. 9 with a 95 % confidence level. All values must be entered in the control chart, even if failing this statistic to ensure the variability obtained for the process is truly representative of the process and not unduly reduced over time. The observed value of the check standard is compared to the accepted mean value of the check standard and divided by the standard deviation for the check standard observations over time. The limits for the t-test are based on applicable warning and action limits on the control chart (The applicable limits are shown in SOP 20 and based on the number of replicates).

4.2 A standard deviation chart is also used for measurement assurance through the evaluation of replicate measurements (See SOP 20). The standard deviation of each combination of Run 1 and Run 2 is calculated and the pooled standard deviation over time may be used to estimate the short-term variability in the measurement process. A standard deviation chart for unknown provers represents the variability in condition of test measures submitted for calibration as well as the short-term repeatability of the measurement process but does not monitor the stability of the reference standard or represent the variability or potential systematic errors associated with meniscus readings (See GMP 3). The range of the calculated measurement results must agree to within 0.02 % of the volume, or the standard deviation must be less than applicable control/action limits on standard deviation charts, or the observed standard deviation must pass the F-test statistics (as applicable).

For unknown standards that are adjusted, do not combine an "as found" value with an "as left" value for the two runs entered into the chart; use the adjusted value from Run 1 and the value from Run 2, both at the applicable reference temperature, when entering values in a standard deviation or range chart.

5 Assignment of Uncertainties

The limits of expanded uncertainty, U, include estimates of the standard uncertainty of the laboratory volumetric standards used, u_s, plus the standard deviation of the process, s_p, and the additional items noted below and in the uncertainty budget table, Table 5, at the 95 % level of confidence. See NISTIR 6969, SOP 29 for the complete standard operating procedure for calculating the uncertainty.

5.1 The standard uncertainty for the standard, u_s, is obtained from the calibration certificate. The combined standard uncertainty, u_c, is used and not the expanded uncertainty, U, therefore the reported uncertainty for the standard will usually need to be divided by the associated coverage factor k. See SOP 29 for the complete standard operating procedure for calculating the uncertainty when multiple deliveries or multiple standards are used to ensure correct handling of correlated uncertainties. Fifteen is the maximum recommended number of deliveries from a laboratory standard to a prover under test to minimize calibration uncertainties to the levels identified previously.

5.2 The standard deviation of the measurement process, s_p, is taken from a control chart for a check standard or from standard deviation charts from provers of similar size. See SOP 17, SOP 20 and NISTIR 6969, SOP 30. The larger of the value from the standard deviation over time for a check standard or from the standard deviation chart should be used in the uncertainty calculations. If a check standard is available, it is possible to evaluate the presence of bias in the measurement process. Where multiple staff members perform this calibration and obtain values for the check standard, the standard deviation for a check standard may represent variability and systematic errors associated with the meniscus reading. When a standard deviation chart is used alone (i.e., a check standard is not used), the repeatability represents

the process only and does not represent potential systematic differences in meniscus readings. In a laboratory with only one staff member performing calibration and entering data for a check standard, additional uncertainties for meniscus readings are needed per Section 5.3 and GMP 3.

5.3 Neck calibration uncertainty should be estimated based on the uncertainty of standards used, errors observed during calibration, ability to read the meniscus of all standards involved (see GMP 3) and the repeatability of the neck calibration (see SOP 31).

5.4 Other standard uncertainties usually included at this calibration level primarily include 1) uncertainties associated with the ability to read the meniscus, only part of which is included in the process variability due to parallax and visual capabilities (unless multiple staff are represented with a check standard that demonstrates variability is meniscus readings), and 2) uncertainties associated with temperature corrections that include values for the cubical coefficient of expansion for the prover under test, the accuracy and gradients associated with temperature measurements in test measures or provers. Additional factors that might be included are: round robin or proficiency testing data showing reproducibility, environmental variations over time, and bias or drift of the standard as noted in control charts.

5.5 To properly evaluate uncertainties and user requirements (tolerances), assessment of additional user uncertainties may be required by laboratory staff. Through proper use of documented laboratory and field procedures, additional uncertainty factors may be minimized to a level that does not contribute significantly to the previously described factors. Additional standard uncertainties in the calibration of field standards and their use in meter verification may include: how the prover level is established, how delivery and drain times are determined, the use of a proper "wetted-down" prior to calibration or use, whether gravity drain is used during calibration or whether the volume of water is eliminated by pumping, the cleanliness of the prover and calibration medium, prover retention characteristics related to inside surface, contamination or corrosion, and total drain times, and possible air entrapment in the water, and connecting pipes. Systematic errors may be observed between laboratory calibration practices where a gravity drain is used and field use where the pumping system is used.

5.6 Example components to be considered for an uncertainty budget table are shown in Table 5. Multiple values of some items may need to be considered (e.g., multiple drops from the standard, multiple meniscus readings, and multiple temperature readings).

Table 5. Example Uncertainty Budget Table.

Uncertainty Component Description	Symbol	Source	Typical Distribution
Uncertainty of the standard (5.1)	u_s	Calibration certificate(s); may be multiplied or added based on dependencies	Expanded divided by coverage factor
Accepted standard deviation of the process (5.2)	s_p	Control chart, standard deviation chart	Normal
Uncertainty or uncorrected error associated with a neck calibration (5.3)	u_n	SOP 31	Rectangular
Ability to read the Meniscus in S (5.4)	u_m	None if using a slicker-plate type standard; GMP 3	Triangular
Ability to read the Meniscus in X (5.4)	u_m	GMP 3	Triangular
Water temperature (S) (5.4)	u_{ts}	Consider accuracy, resolution, and gradients	Rectangular
Water temperature (X) (5.4)	u_{tx}	Consider accuracy, resolution, and gradients	Rectangular
Cubical Coefficient of Expansion (CCE) on S (5.4)	u_{CCE}	5 % to 10 % of the CCE (EURAMET CG-21)	Rectangular
Cubical Coefficient of Expansion (CCE) on X (5.4)	u_{CCE}	5 % to 10 % of the CCE (EURAMET CG-21)	Rectangular
Uncertainty of bias, drift, or variability of standards (5.2)	u_b	From control charts or calibration history of reference standards	Rectangular
Uncertainty of drain time (insignificant if closely following the procedure)	u_d	From experimental data	Normal

5.7 Uncertainty Evaluation

Where applicable, uncertainties for volume calibrations that are assessed for conformity must be less than the tolerances specified in Handbook 105-3 and used for decision rules.

6 Calibration Certificate

6.1 Report results as described in SOP 1, Preparation of Calibration Certificates, with the addition of the following:

"To Contain" or "To Deliver" prover volume, reference temperature, uncertainty, material, thermal coefficient of expansion (based on identification plate), construction, any identifying markings, tolerances (if appropriate), laboratory temperature, water temperature(s) at time of test, barometric pressure, relative humidity, and any out–of-tolerance conditions. Appendix B, Example Temperature Correction Chart may be provided as a supplement to the calibration report to encourage appropriate volumetric corrections of the provers during routine use.

6.2 Conformity Assessment

Evaluate compliance to applicable tolerances as needed or required by the customer or by legal metrology requirements. Compliance assessments must note the applicable documentary standard and which portions of the standard were or were not evaluated. The uncertainty for volume calibrations must be less than the tolerances published in the applicable documentary standards. For volume calibrations where the unknown standard can be adjusted, it is standard practice to adjust the standard or leave the scale plate in a position close enough to its nominal volume to ensure that the absolute value of the measurement result plus the uncertainty is less than the applicable tolerance. Where the unknown standard cannot be adjusted, and a portion of the uncertainty band from the error exceeds tolerance limits, it is not appropriate to state compliance with the tolerances unless additional decision rules are communicated with and agreed to by the end user. Correction values (measurement results) may need to be used by the end user in such cases.

7 Additional References:

Bean, V. E., Espina, P. I., Wright, J. D., Houser, J. F., Sheckels, S. D., and Johnson, A. N., NIST Calibration Services for Liquid Volume, NIST Special Publication 250-72, National Institute of Standards and Technology, Gaithersburg, MD, (2009).

EURAMET Calibration Guide 21, Guidelines on the Calibration of Standard Capacity Measures Using the Volumetric Method (Version 1.0, 04/2013).

Appendix A

Volume Transfer Data Sheet (page 1)

Laboratory data and conditions:

Vessel Owner		Operator	
Vessel Identification		Date	
Nominal Volume		Air Temperature	
Material		Relative Humidity	
Cubical Coefficient of Expansion		Standard deviation of the process, s_p from Control Chart	
Reference temperature of unknown prover		Standard deviation of the process, s_p from the Standard Deviation Chart	
Unknown prover graduations		Degrees of Freedom	
Applicable specifications and tolerances			

Volume standard(s) data:

Identification **(ID) (Note ID of Standards)**	**Nominal Volume**	**Volume/Correction**	**Expanded Unc: From Cal. Cert.**	**Unc: *k* factor**	**Cubical Coefficient of Expansion**
S					
S					
S					
S					

Run 1: Data for volumes delivered from the standards:

DROP #	**Reported Volume (gal)**	**Material (MS/SS)**	**Water Temp (°C) (Must be ≥ 0.5 °C and < 40 °C)**	**Gauge Delta (in^3)**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Appendix A
Volume Transfer Data Sheet (page 2)

Run 1: Data from the filled unknown field standard:

Material for the Unknown:		MS, SS, TP, PV
Final Gauge Reading:		in^3
Final Water Temperature:		°C

Run 2: Data for volumes delivered from the standards:

DROP #	Reported Volume (gal)	Material (MS/SS/)	Water Temp (°C) (Must be ≥ 0.5 °C and < 40 °C)	Gauge Delta (in^3)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Run 2: Data from the filled unknown field standard:

Material for the Unknown:		MS, SS, TP, PV
Final Gauge Reading:		in^3
Final Water Temperature:		°C

Appendix B

Example Temperature Correction Table[A]

Example for a 100 gallon prover and 60 °F reference temperature.				
	Mild Steel CCE: 1.86 x 10-5 / °F		Stainless Steel CCE: 2.65 x 10-5 / °F	
Temperature °F	in^3	gal	in^3	gal
-20	-34	-0.149	-49	-0.212
-15	-32	-0.139	-46	-0.199
-10	-30	-0.130	-43	-0.186
-5	-28	-0.121	-40	-0.172
0	-26	-0.112	-37	-0.159
5	-24	-0.102	-34	-0.146
10	-21	-0.093	-31	-0.133
15	-19	-0.084	-28	-0.119
20	-17	-0.074	-24	-0.106
25	-15	-0.065	-21	-0.093
30	-13	-0.056	-18	-0.079
35	-11	-0.047	-15	-0.066
40	-9	-0.037	-12	-0.053
45	-6	-0.028	-9	-0.040
50	-4	-0.019	-6	-0.026
55	-2	-0.009	-3	-0.013
60	0	0.000	0	0.000
65	2	0.009	3	0.013
70	4	0.019	6	0.026
75	6	0.028	9	0.040
80	9	0.037	12	0.053
85	11	0.046	15	0.066
90	13	0.056	18	0.080
95	15	0.065	21	0.093
100	17	0.074	24	0.106
105	19	0.084	28	0.119
110	21	0.093	31	0.133
115	24	0.102	34	0.146
120	26	0.112	37	0.159
CCE = coefficient of cubical expansion				

[A] Provide only the applicable coefficient of cubical expansion for the prover under test.