

OWNER

Measurement Uncertainty Analysis

Calculation



Document No.: [REDACTED] MEA-CAL-002

Rev. A, Issued for Review

Date: September 29, 2026

Project: [REDACTED] [REDACTED]



TORUS

[REDACTED], [REDACTED] County, [REDACTED]

ISSUE SUMMARY AND APPROVAL

This page records each issue of MEA-CAL-002. The preparer, reviewer and approver sign for each revision.

Rev.	Date	Issue purpose	Description
A	2026-09-29	Issued for Review	First issue

Contributors

Rev.	Discipline	Prepared by	Reviewed by	Approved by
A	Measurement			

CONTENTS

1.	OBJECTIVE.....	1
2.	METHODOLOGY	1
3.	DESIGN INPUTS.....	1
4.	ASSUMPTIONS.....	2
5.	REFERENCES	2
6.	CALCULATION.....	3
	6.1. METER.....	3
	6.2. PRESSURE AND TEMPERATURE.....	3
	6.3. COMPOSITION	4
	6.4. COMBINED RESULT AT C5	5
	6.5. MONTE CARLO CHECK.....	7
7.	RESULTS AND CONCLUSIONS	7

FIGURES AND TABLES

Figure 6-1. Contributions to Volume Uncertainty at C5.....	6
Figure 6-2. Contributions to Energy Uncertainty at C5	6
Figure 6-3. Monte Carlo Distribution of Volume and Energy Error at C5.....	7
Table 3-1: Design Inputs.....	2



Table 6-1: Meter Uncertainty (Relative) 3

Table 6-2: Pressure and Temperature Uncertainty (C5) 3

Table 6-3: Composition Standard Uncertainty (mol %).....4

Table 6-4: Composition Sensitivity Coefficients at C5 (% per mol %) 4

Table 6-5: Monte Carlo and Linear Results 7

Table 7-1: Expanded Uncertainty against Targets (\$k\$ = 2).....8

1. OBJECTIVE

This calculation estimates the expanded uncertainty, at 95 % confidence, of the custody volume at base conditions and of the delivered energy for the ultrasonic metering system at the . It compares the results with the targets in the Basis of Design, ± 0.5 % on volume and ± 0.6 % on energy, at normal operation (case C2) and at the governing velocity case (C5), and reports the turndown case (C3) for information.

2. METHODOLOGY

The uncertainty is propagated through the measurement equation with the law of propagation of uncertainty of the GUM (JCGM 100) as applied by ISO 5168 and API MPMS Chapter 13. The ultrasonic meter measures actual volume at flowing conditions; the flow computer converts it to base conditions and multiplies by the heating value:

AGA 9 and API MPMS 21.1, volume at base conditions

$$Q_b = Q_f \frac{P_f}{P_b} \frac{T_b}{T_f} \frac{Z_b}{Z_f}, \quad E = Q_b \cdot HHV$$

Each input was given a standard uncertainty from its stated distribution: a rectangular half-width a gives $a/\sqrt{3}$, an expanded uncertainty U at $k = 2$ gives $U/2$, and a GPA 2261 repeatability limit r gives $r/2.77$. Sensitivity coefficients were obtained numerically with the GERG-2008 equation of state. Pressure and temperature coefficients therefore include the change in Z_f , which at these conditions nearly doubles the temperature sensitivity compared with an ideal gas.

Composition errors affect both Z_b/Z_f and the heating value, in the same direction for the heavy components. TORUS handled this correlation by perturbing each measured component, renormalizing, and taking the coefficient of the product $(Z_b/Z_f) \cdot HHV$ directly. The combined standard uncertainty is the root-sum-square of the contributions, and the expanded uncertainty is $U = 2u_c$.

A Monte Carlo propagation (JCGM 101) with 200,000 trials checked the linear result. It samples every input from its distribution, renormalizes the sampled composition, and evaluates Z_f and Z_b with an independent GERG-2008 implementation. A separate check re-derived all sensitivity coefficients with that second implementation and a different differencing scheme; the combined uncertainties agree to four decimal places.

3. DESIGN INPUTS

Table 3-1 lists the inputs. The instrument and laboratory figures are typical values for the class of equipment specified; they will be replaced by the selected vendors' data.

Table 3-1: Design Inputs

Input	Value	Source
C2 meter conditions	1,056.8 psia, 69.6 °F, Z_f 0.83233	MEA-CAL-001
C5 meter conditions	901.1 psia, 59.2 °F, Z_f 0.84299	MEA-CAL-001
C3 meter conditions	1,014.0 psia, 60.0 °F, Z_f 0.82586	MEA-CAL-001
Gas composition	Design gas; Z_b 0.99743, HHV 1,103.7 Btu/scf	GEN-DB-001, Section 5.1
Flow laboratory capability	0.23 % at $k = 2$	Typical, HOLD H-15
Meter repeatability	0.1 % at 95 %	AGA Report No. 9
Pressure transmitter	Absolute, 0 to 1,500 psia span, 0.025 % of span, calibrated every 6 months	MEA-DS-010
Temperature loop	4-wire Pt100 with matched constants, verified against a reference in the test well	MEA-DS-010
Gas chromatograph	GPA 2261 method, GPA 2198-type standard, hourly averaged composition	MEA-DS-003

4. ASSUMPTIONS

- Inputs are independent except the composition effects, which are propagated through a combined coefficient. The transmitters on the two runs are calibrated independently.
- The installation term of ± 0.15 % assumes the laboratory installs upstream piping representative of the station header. *Verification required at flow calibration.*
- The drift term of ± 0.10 % assumes series verification at least quarterly with agreement within 0.3 %, and speed-of-sound checks within the limits of MEA-CAL-003.
- Laboratory, meter, transmitter and chromatograph figures are typical. *Verification required (HOLD H-15).*

5. REFERENCES

- JCGM 100:2008, Evaluation of measurement data, Guide to the expression of uncertainty in measurement.
- JCGM 101:2008, Propagation of distributions using a Monte Carlo method.
- ISO 5168:2005, Measurement of fluid flow, Procedures for the evaluation of uncertainties.
- API MPMS Chapter 13.1 (2017), Statistical Concepts and Procedures in Measurement.
- AGA Report No. 9 (2022); AGA Report No. 8 Parts 1 and 2 (2017).
- GPA 2261-20, GPA 2198-16, GPA 2145-16 and GPA 2172-19.

7. API MPMS Chapter 21.1 (2013).

8. GEN-DB-001, Basis of Design; MEA-CAL-001, Ultrasonic Meter Sizing; MEA-CAL-003, AGA 8 and AGA 10 Comparison.

6. CALCULATION

6.1. METER

Table 6-1 builds the meter term. The laboratory capability is the largest single part, which is why MEA-SPC-001 requires a laboratory capability of 0.25 % or better.

Table 6-1: Meter Uncertainty (Relative)

Source	Value	Distribution	Standard uncertainty (%)
Flow laboratory capability	0.23 %	Normal, $k = 2$	0.1150
Calibration curve residual after multipoint correction	± 0.05 %	Rectangular	0.0289
Field repeatability and reproducibility	0.10 %	Normal, $k = 2$	0.0500
Installation, laboratory to field	± 0.15 %	Rectangular	0.0866
Drift between verifications	± 0.10 %	Rectangular	0.0577
Meter body pressure and temperature correction	± 0.03 %	Rectangular	0.0173
Meter, C2 and C5			0.1664
Operation between q_{min} and q_t (C3 only)	± 0.30 %	Rectangular	0.1732
Meter, C3			0.2402

6.2. PRESSURE AND TEMPERATURE

Table 6-2 builds the pressure and temperature terms. Absolute transmitters are specified; a gauge transmitter with a fixed barometric pressure would add 0.0075 % at C5 for no benefit.

Table 6-2: Pressure and Temperature Uncertainty (C5)

Source	Half-width or U	Standard uncertainty
Deadweight tester, 0.015 % of reading, $k = 2$	0.135 psi	0.068 psi
Transmitter accuracy, 0.025 % of 1,500 psi	0.375 psi	0.217 psi
Ambient temperature effect	0.25 psi	0.144 psi
Stability over 6 months	0.20 psi	0.115 psi
Tap location and static head	0.10 psi	0.058 psi
Pressure		0.298 psi (0.033 %)
Reference thermometer, $k = 2$	0.10 °F	0.050 °F

Source	Half-width or U	Standard uncertainty
Loop after calibration	0.20 °F	0.115 °F
Installation: conduction and stratification	0.30 °F	0.173 °F
Stability	0.10 °F	0.058 °F
Temperature		0.222 °F

The sensitivities at C5 are:

$$\frac{P}{Q_b} \frac{\partial Q_b}{\partial P} = 1.176, \quad \frac{1}{Q_b} \frac{\partial Q_b}{\partial T} = -0.337 \text{ } \%/^{\circ}\text{F}$$

Of the temperature coefficient, 0.193 %/°F is the ideal-gas term $1/T$ and 0.145 %/°F comes from the rise of Z_f with temperature. A 1 °F error is therefore 0.34 % of volume and a 1 psi error is 0.13 %.

6.3. COMPOSITION

The chromatograph standard uncertainty of each component combines repeatability from GPA 2261, the certified uncertainty of the calibration standard, and ± 0.3 % relative response linearity. Table 6-3 shows the result for the design gas, and Table 6-4 the sensitivity coefficients at C5.

Table 6-3: Composition Standard Uncertainty (mol %)

Component	Mole %	Repeatability	Calibration standard	Linearity	Combined
Methane	88.50	0.0361	0.0442		0.0571
Ethane	6.00	0.0289	0.0150	0.0104	0.0342
Propane	2.20	0.0253	0.0055	0.0038	0.0261
i-Butane	0.40	0.0144	0.0020	0.0007	0.0146
n-Butane	0.50	0.0144	0.0025	0.0009	0.0147
i-Pentane	0.12	0.0144	0.0006	0.0002	0.0145
n-Pentane	0.10	0.0144	0.0005	0.0002	0.0145
Hexanes plus	0.10	0.0144	0.0005	0.0002	0.0145
Nitrogen	1.20	0.0253	0.0030	0.0021	0.0255
Carbon dioxide	0.88	0.0144	0.0044	0.0015	0.0152

Note 1: Methane is taken by normalization, so no linearity term applies.

Table 6-4: Composition Sensitivity Coefficients at C5 (% per mol %)

Component	On Z_b/Z_f	On HHV	On $(Z_b/Z_f) \cdot HHV$
Methane	-0.054	-0.081	-0.135
Ethane	+0.361	+0.616	+0.977
Propane	+0.687	+1.300	+1.987

Component	On Z_b/Z_f	On HHV	On $(Z_b/Z_f) \cdot HHV$
i-Butane	+0.946	+1.973	+2.920
n-Butane	+0.990	+1.984	+2.975
i-Pentane	+1.259	+2.659	+3.918
n-Pentane	+1.305	+2.669	+3.974
Hexanes plus	+1.573	+3.355	+4.928
Nitrogen	-0.273	-1.005	-1.278
Carbon dioxide	+0.133	-1.003	-0.870

The composition contribution at C5 is 0.046 % on volume and 0.143 % on energy. Treating the volume and heating value effects as independent would give 0.108 %, which understates the energy term because a heavy-component error moves both in the same direction.

6.4. COMBINED RESULT AT C5

API MPMS 13.1; JCGM 100, law of propagation

$$u_c(Q_b) = \sqrt{0.1664^2 + 0.0389^2 + 0.0748^2 + 0.0500^2 + 0.0463^2 + 0.0115^2 + 0.0029^2} = 0.199 \%$$

$$U(Q_b) = 2 \times 0.199 = 0.40 \%$$

For energy, the correlated composition term (0.143 %) replaces the volume composition term, and the heating value data (0.030 %), the hourly update of heating value (0.058 %) and sample representativeness (0.050 %) are added:

$$u_c(E) = 0.254 \%, \quad U(E) = 0.51 \%$$

Figure 6-1 and Figure 6-2 show where the uncertainty comes from. The calibrated meter is 70 % of the volume variance, and temperature is second at 14 %. For energy the chromatograph composition rises to 32 %, second only to the meter.

Figure 6-1. Contributions to Volume Uncertainty at C5

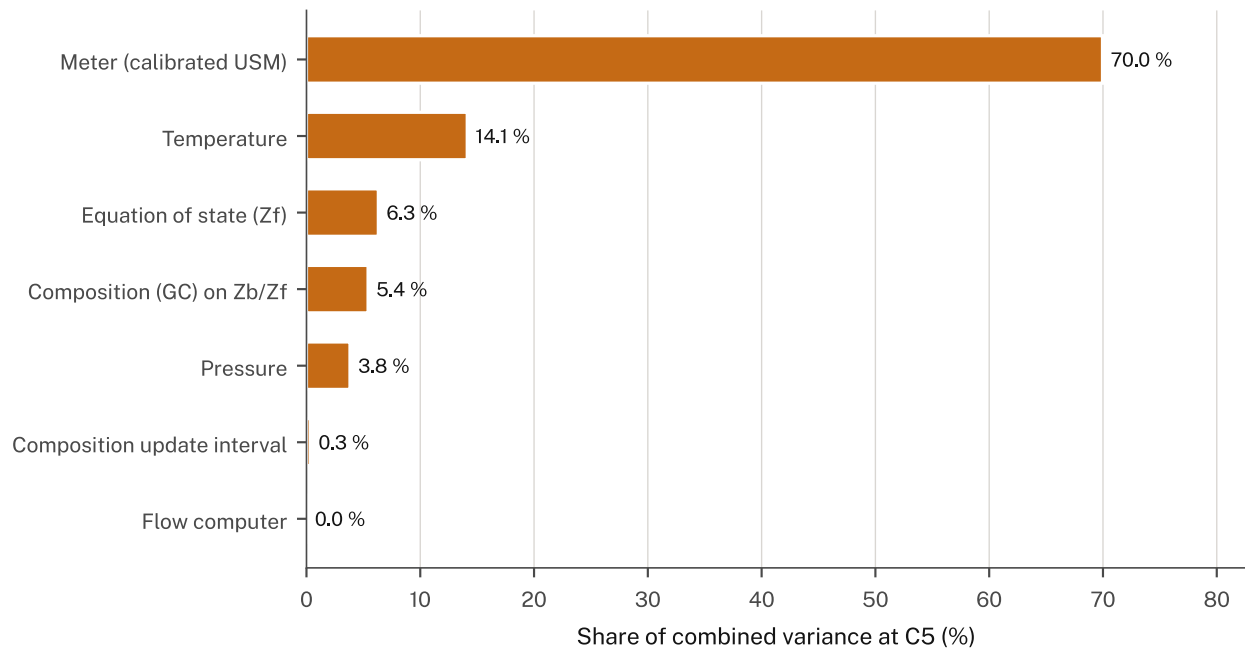
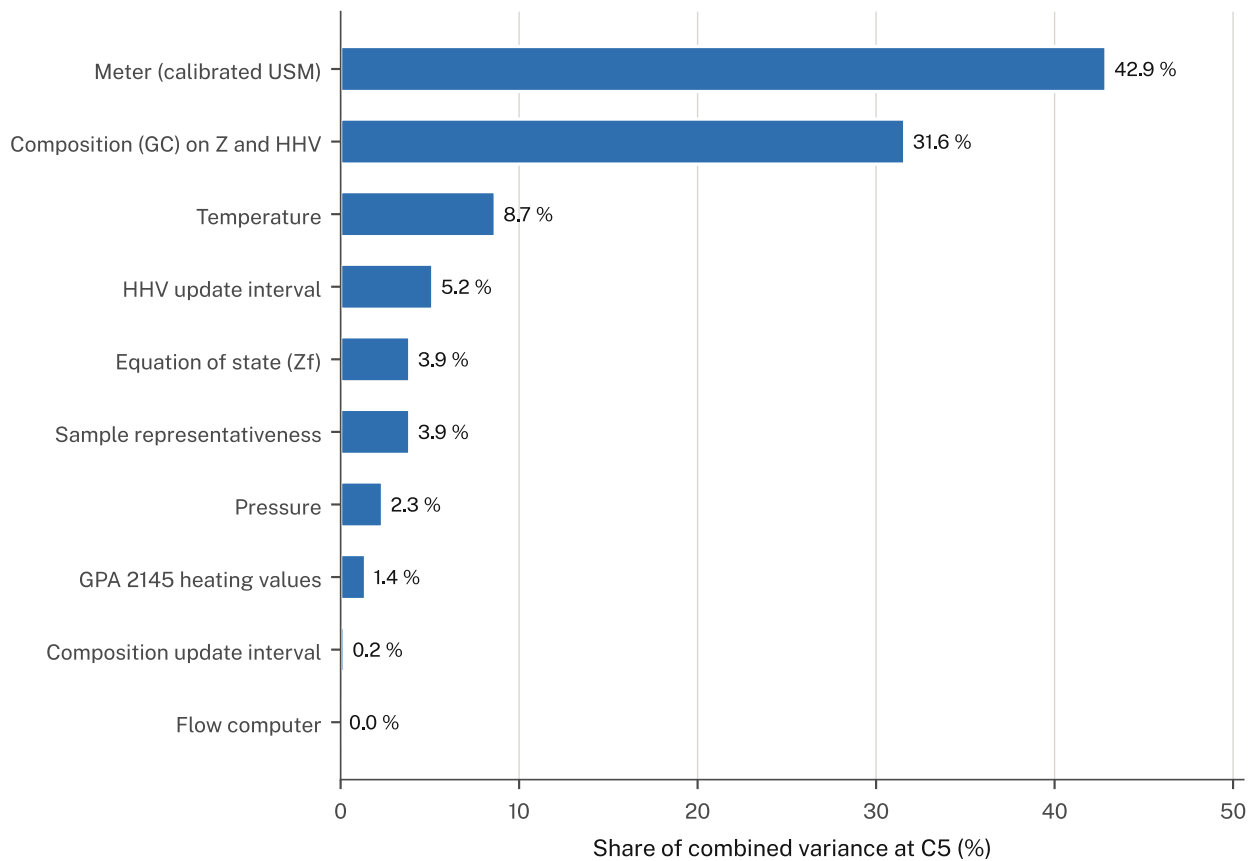


Figure 6-2. Contributions to Energy Uncertainty at C5



6.5. MONTE CARLO CHECK

Figure 6-3 shows the distribution of 200,000 trials at C5. The standard deviations agree with the linear combined uncertainties within 0.3 %, the mean error is zero within 0.0002 %, and the 95 % coverage intervals are ± 0.39 % on volume and ± 0.50 % on energy. The rectangular inputs make the distribution slightly flatter than normal, so the Monte Carlo interval is 0.01 percentage point narrower than $2u_c$. The linear result is therefore valid and is reported.

Figure 6-3. Monte Carlo Distribution of Volume and Energy Error at C5

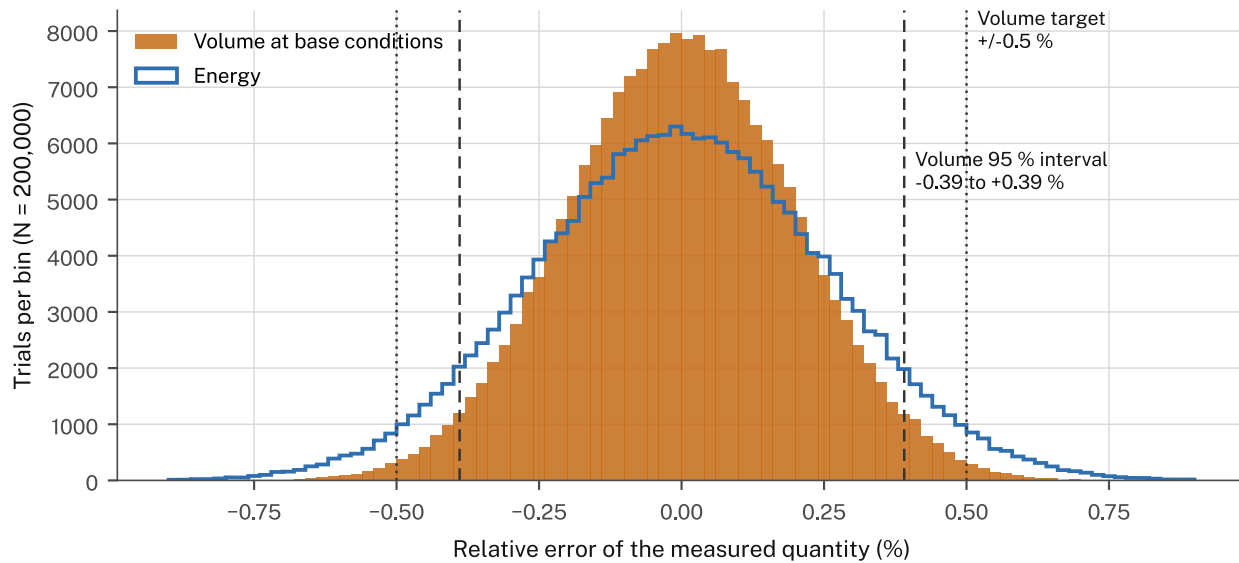


Table 6-5 compares the two methods at both cases.

Table 6-5: Monte Carlo and Linear Results

Case	Quantity	Monte Carlo std. dev. (%)	Linear u_c (%)	Monte Carlo 95 % half-width (%)	Linear U (%)
C2	Volume	0.200	0.200	0.39	0.40
C2	Energy	0.257	0.257	0.50	0.51
C5	Volume	0.200	0.199	0.39	0.40
C5	Energy	0.255	0.254	0.50	0.51

7. RESULTS AND CONCLUSIONS

Table 7-1 summarizes the results against the targets.

Table 7-1: Expanded Uncertainty against Targets ($k = 2$)

Case	Flow (MMSCFD)	Volume (%)	Volume target (%)	Energy (%)	Energy target (%)
C2	90	0.40	0.50	0.51	0.60
C5	120	0.40	0.50	0.51	0.60
C3	10	0.53	Not applicable	0.62	Not applicable

1. The system meets the targets with 0.10 and 0.09 percentage points of margin at C2 and C5.
2. The targets apply from 20 to 120 MMSCFD. Below 20 MMSCFD the meter operates under its transition flow rate and the expected figures are $\pm 0.53\%$ on volume and $\pm 0.62\%$ on energy. The Interconnect Agreement will state the applicable range (HOLD H-01).
3. The flow laboratory capability governs the meter term. A 0.25% capability gives 0.41% on volume and 0.52% on energy at C5; a 0.30% capability gives 0.44% and 0.54% . MEA-SPC-001 therefore requires 0.25% or better.
4. Temperature is the second largest volume term. If the meter tube were left bare and the installation term grew to $\pm 1.0^\circ\text{F}$, the volume uncertainty at C5 would be 0.54% , above the target. The insulated and shaded tube, the test thermowell and quarterly temperature verification are required for that reason.
5. Composition is the second largest energy term. The calibration standard will be kept close to the pipeline composition and the chromatograph verified with an independent standard (MEA-PRC-002).

The next step is to replace the typical instrument and laboratory figures with the selected vendors' data and rerun the budget (HOLD H-15).