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Contribution from Kjell Eivind Frøysa, NORCE

Live Uncertainty
- how accurate is your flow measurement?

NFOGM Fagdag – March 19, 2026

Updated NOD regulations for fiscal metering 2023 (Måleforskriften)

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§ 10. *Målestørrelser og usikkerhetsgrenser*

(1) Målinger av mengder produsert petroleum skal oppfylle kravene til målestørrelser og usikkerhetsgrenser i tabell 1. For allokeringsmålinger kan rettighetshaver definere andre usikkerhetsgrenser for målestørrelser enn de som er angitt i tabell 1, dersom det kan dokumenteres at oppfyllelse av angitte usikkerhetsgrenser ikke er teknisk mulig eller vil føre til urimelig høye kostnader.

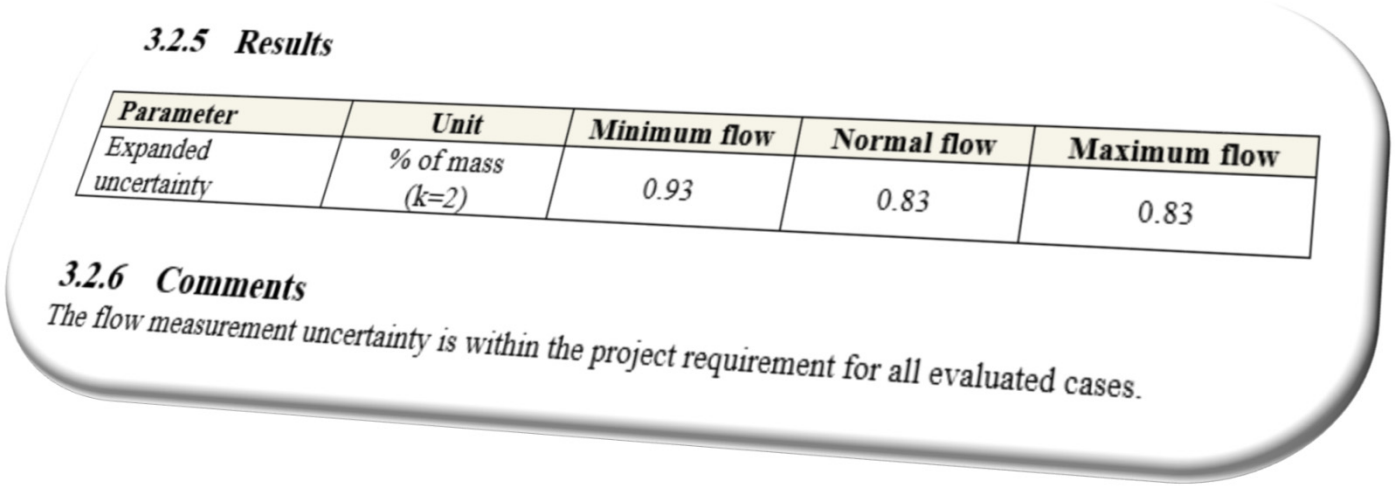
Tabell 1 (Krav til målinger av mengder produsert petroleum)

Type måling:	***Målestørrelse***	***Usikkerhetsgrense***
Leverings-måling	Netto mengde (standard volum eller masse) olje i en leveranse eller i en måleperiode på en måned	0,30 %
	Mengde (standard volum, masse eller energi) gass i en måleperiode på en måned	1,0 %
	Mengde (masse eller energi) LNG i en leveranse	0,5 %
Allokerings-måling	Netto mengde (standard volum eller masse) olje i en måleperiode på inntil en måned	0,5 %
	Mengde (standard volum eller masse) gass i en måleperiode på inntil en måned	1,5 %

Uncertainty - Traditional Calculation Method

- Offline calculation in project phase (before start-up) for 1 to 3 process cases
- **No uncertainty calculation or evaluation during operation**

What is the flow measurement uncertainty during operation?



3.2.5 Results

Parameter	Unit	Minimum flow	Normal flow	Maximum flow
Expanded uncertainty	% of mass (k=2)	0.93	0.83	0.83

3.2.6 Comments

The flow measurement uncertainty is within the project requirement for all evaluated cases.

Updated NOD regulations for fiscal metering 2023 (Måleforskriften)

Requirements for measurement uncertainty

Section 15:

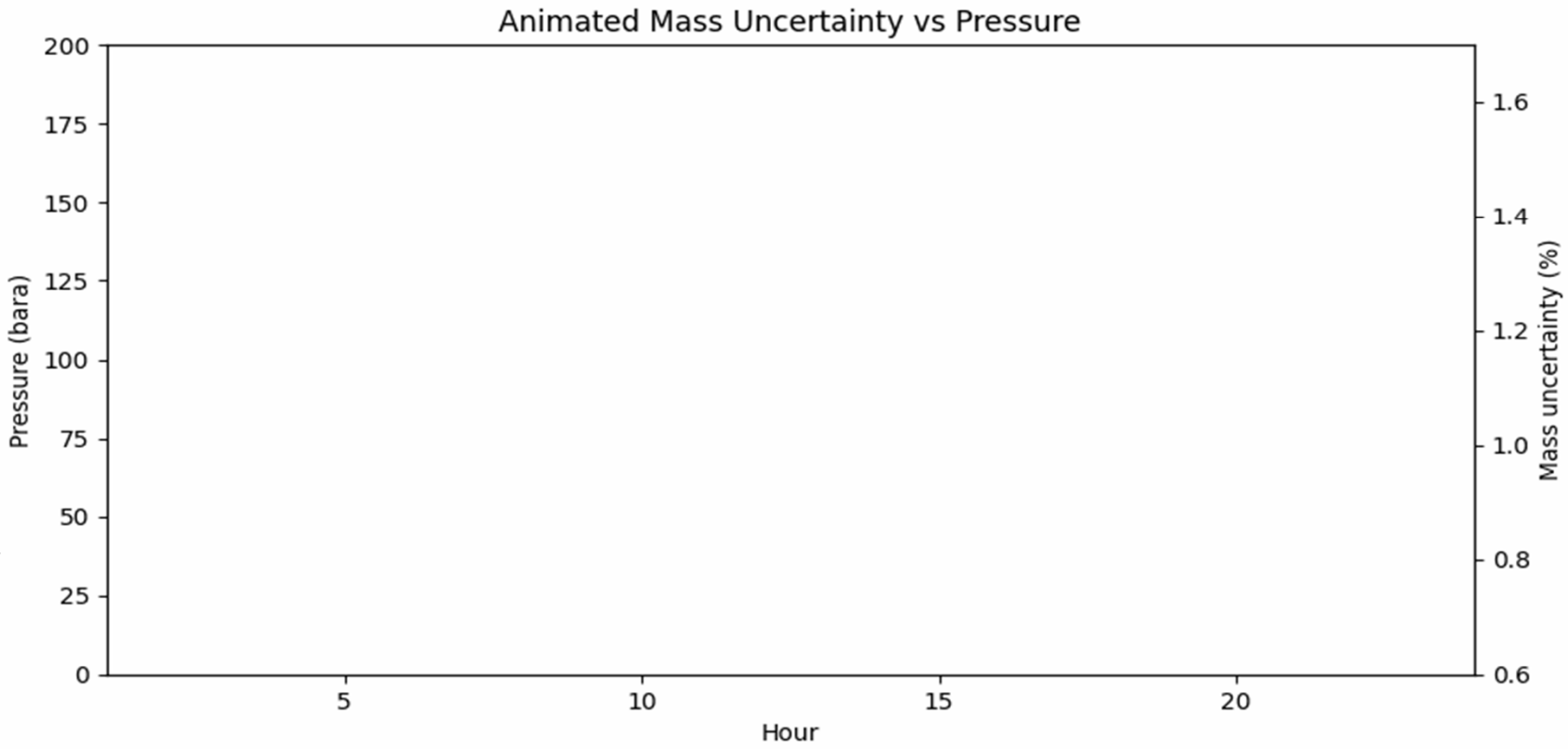
- The licensee shall establish and **maintain uncertainty budgets** to demonstrate compliance with uncertainty limit requirements in Section 10.

Measurement uncertainty is NOT STATIC!

Gas export station (example)

Pressure

Mass flow uncertainty



Project example using NFOGM uncertainty tool, AI animated

Measurement uncertainty is NOT STATIC!

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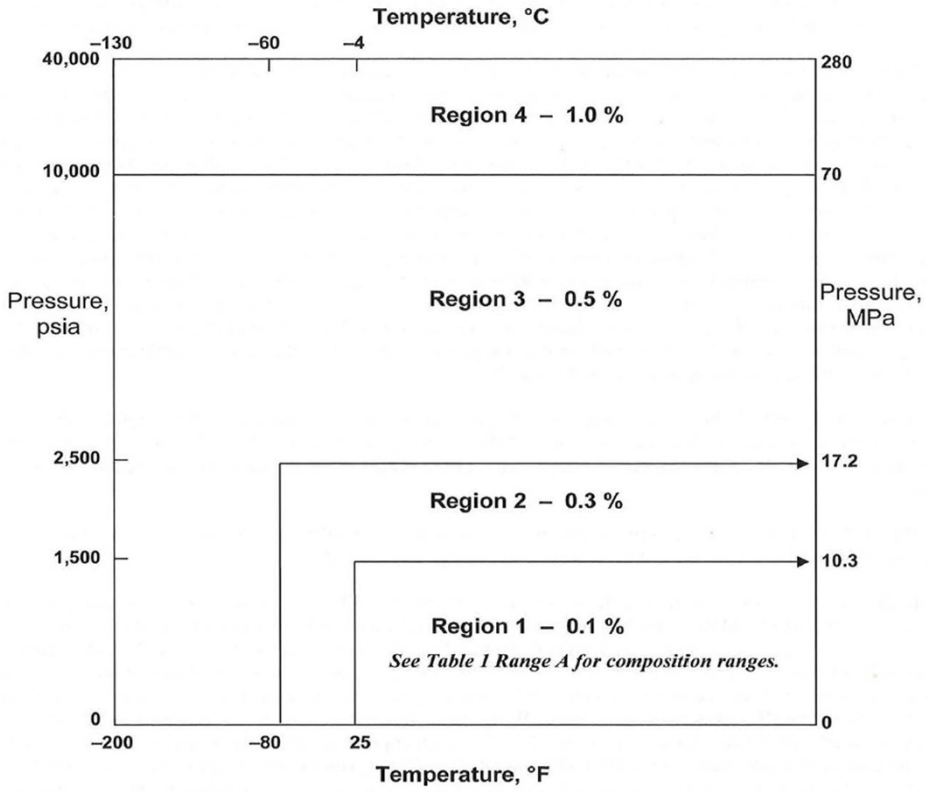
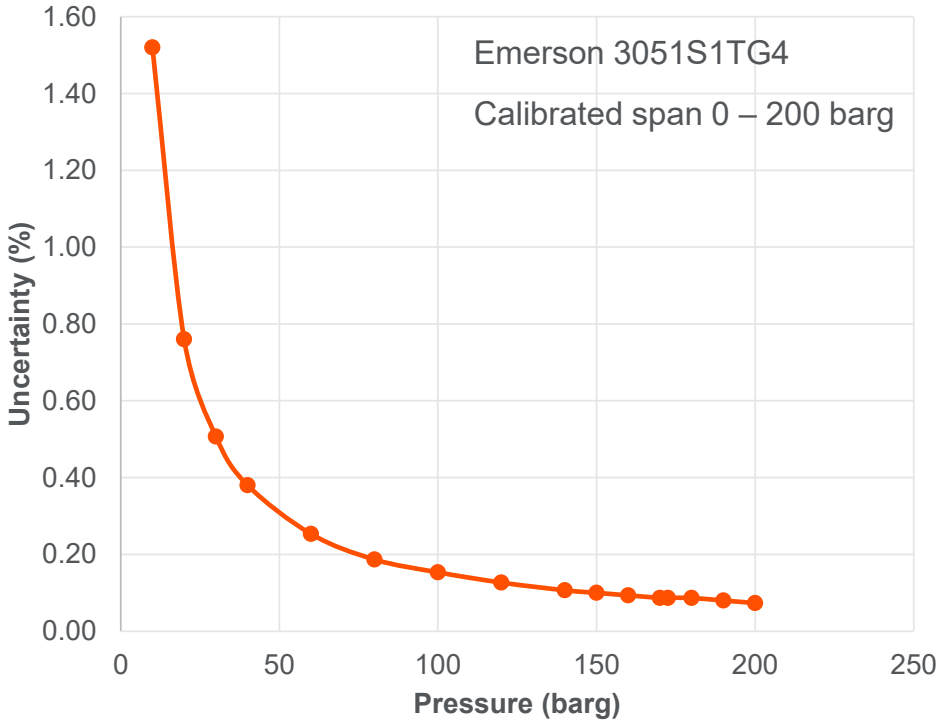
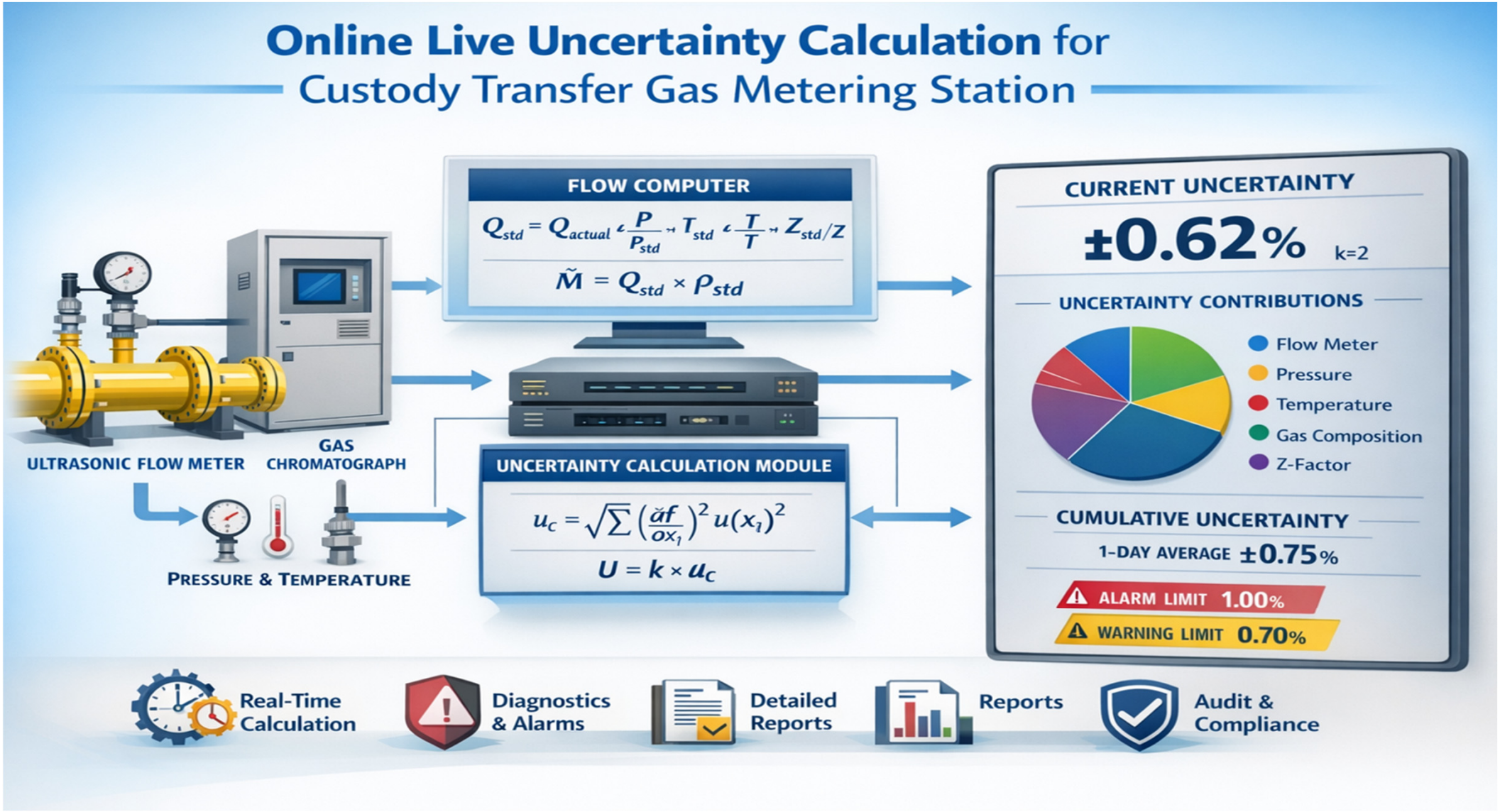
Density calculation uncertainty



Source: AGA 8_2017 Figure 1

Pressure uncertainty





Source: AI generated

Live Uncertainty Calculation

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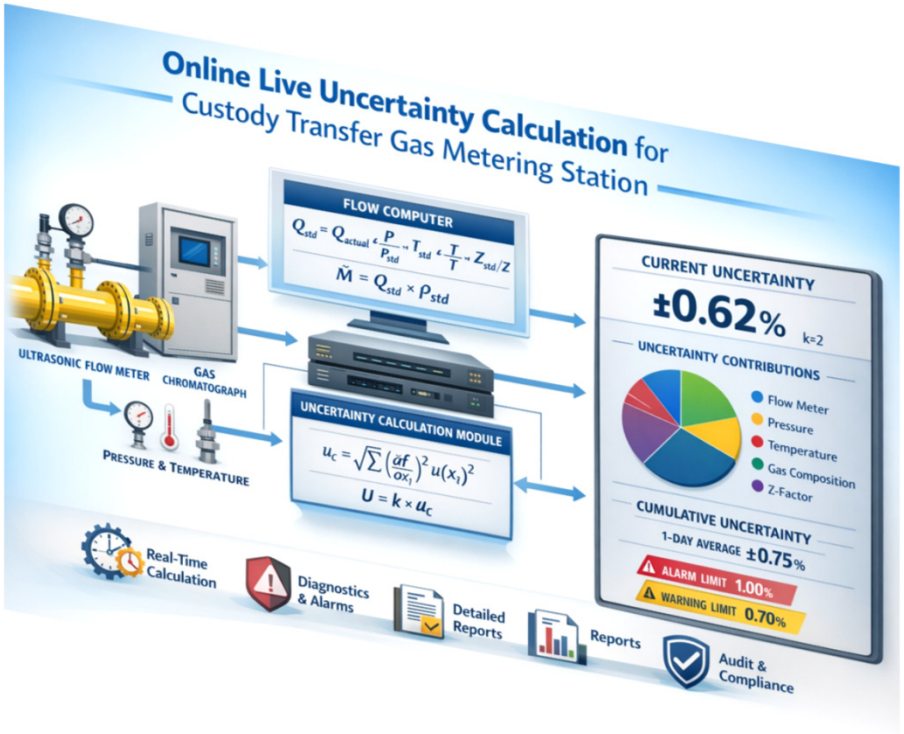
Features

- Online uncertainty of:
  - **Mass**
  - **Standard volume**
  - **Energy**
- Uncertainty of mass, standard volume and energy reported on **hourly, daily, monthly** and **batch reports**
- **No need for regular external evaluation or re-calculation of uncertainty budget**



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Live Uncertainty – Output Data

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2024.12.01 11:00 **Hourly Report from 2024.12.01 10:00 to 2024.12.01 11:00** Page 1 of 2

Production Previous Hour

Stream	Mass [t]	Ref. Volume [kSm³]	Volume [m³]	Energy [GJ]
1	34.560	39.304	604.505	1739.892
2	34.560	39.304	604.505	1739.889
3	34.560	39.304	604.505	1739.890
Total	**103.680**	**117.912**	**1813.514**	**5219.672**
Uncertainty (k=2)	**0.861**	**0.811**		**43.010**
Relative uncertainty (k=2)	**0.83%**	**0.69%**		**0.82%**

Live Uncertainty – Plans and Partners

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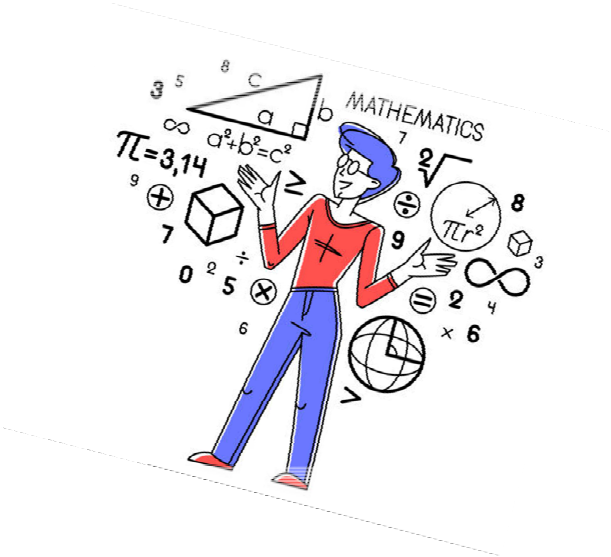
Functional design specification for live uncertainty calculation on gas metering station (USM / GC)

Implementation of live uncertainty calculation on gas metering station

Specification and implementation for oil metering stations

- Co-operation with Kjell Eivind Frøysa, NORCE
- Collaboration with working group with representatives from oil/gas companies



Live Uncertainty – Fiscal Gas Metering

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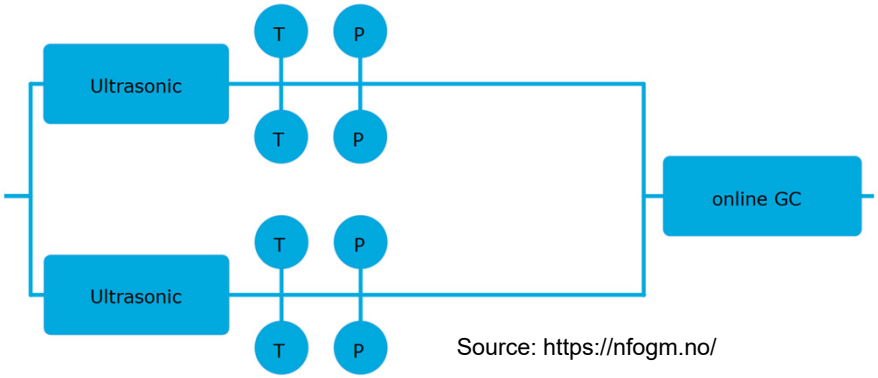
Metering configurations included

- 1 x USM, 1xGC, 1xPT, 1xTT
- 2 x USM (series), 2xGC, 2xPT, 2xTT
- 2 x 100% USM (parallel), 2xPT and 2xTT in each stream, 2xGC
- 3 x 50% USM (parallel), 2xPT and 2xTT in each stream, 2xGC

- Average or single pressure measurement
- Average or single temperature measurement
- Average or single gas chromatography
- AGA-8 DC1992 and GERG 2008 actual density calculation
- ISO 6976-1995 and ISO 6976-2016 standard density and energy calculation



Source: https://nfogm.no/

Live Uncertainty – Calculation Principles

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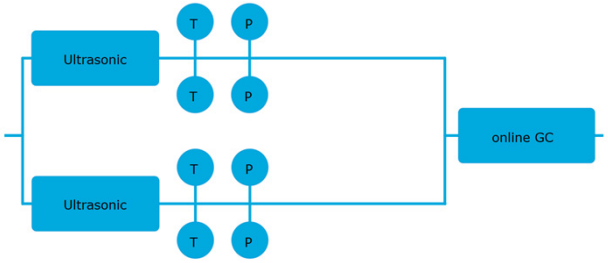
Standard volume flow rate:

$$q_{v0} = \frac{PT_0Z_0}{P_0TZ}q_v = \left(\frac{T_0}{P_0}\right)\left(\frac{P}{T}\right)\left(\frac{Z_0}{Z}\right)q_v$$



Standard volume flow rate **uncertainty**:

$$u^2(q_{v0}) = \left(\frac{\partial f}{\partial q_v}u(q_v)\right)^2 + \left(\frac{\partial f}{\partial P}u(P)\right)^2 + \left(\frac{\partial f}{\partial T}u(T)\right)^2 + \left(\frac{\partial f}{\partial \phi_1}u(\phi_1)\right)^2 + \cdots + \left(\frac{\partial f}{\partial \phi_{10}}u(\phi_{10})\right)^2 + \left(q_{v0}\frac{u_{model}(Z)}{Z}\right)^2 + \left(q_{v0}\frac{u_{model}(Z_0)}{Z_0}\right)^2$$

Flow (USM)	Pressure (PT)	Temperature (TT)	Gas composition (GC)	Compressibility Line conditions (AGA-8)	Compressibility Std. conditions (ISO 6976)

$$U(q_{v0}) = 2 * \sqrt{u^2(q_{v0})}$$ Expanded uncertainty, k = 2, approx. 95% confidence

Live Uncertainty – Input Data

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Input data for uncertainty calculations

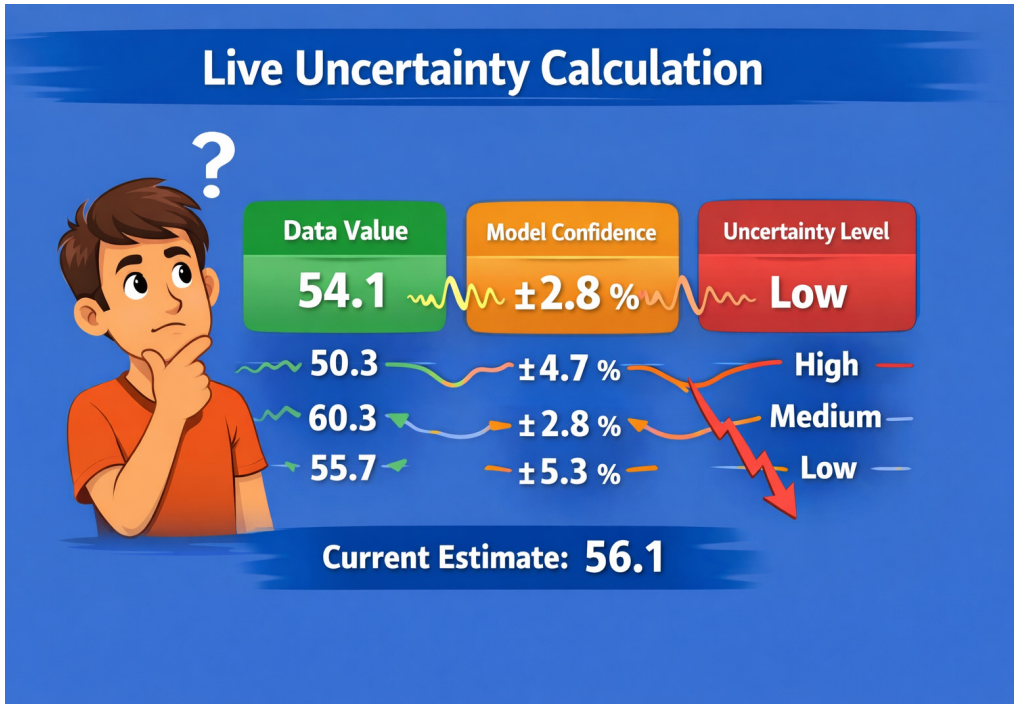
- **Data from the measurement system**
  - Hourly accumulated actual volume, standard volume, mass and energy per line
  - Hourly flow weighted pressure, temperature per line
  - Hourly flow weighted gas composition

- **Manually entered uncertainty data**
  - Ultrasonic flowmeters
  - Pressure meters
  - Temperature meters
  - Gas chromatographs

Live Uncertainty – How Live?

Discussion points

- How “live” should it be?
- Detailed or “overall” uncertainty inputs for flow, pressure, temperature?
- Handling of fallback values?
- Handling of flow rates outside calibrated range?
- Drift calculation / calibration date?



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Live Uncertainty – Pressure Input Parameters

NFOGM pressure transmitter - “Overall Input Level”

Line Conditions A, Pressure

☑ Overall Input Level

Input Variable	Uncertainty	Unit	Confidence
Uncertainty	0.3	%	95% (norm)

NFOGM pressure transmitter - “Detailed Input Level”

Line Conditions A, Pressure

☐ Overall Input Level

Properties and Constants

Max Calibrated Static Pressure	120	barg
Min Calibrated Static Pressure	50	barg
Upper Range Limit	138	barg
Time Between Calibrations	12	Months
Ambient Temp At Calibration	20	°C

Input Variable	Uncertainty	Unit	Confidence
Transmitter	0.05	%Span	99% (norm)
Stability	0.1	%URL/yr	95% (norm)
RFI Effects	0.1	%Span	99% (norm)
Ambient temp. effect	0.03	%Span/28C	99% (norm)
Atmospheric pressure	0.09	bar	99% (norm)
Misc.	0	bar	95% (norm)

Live Uncertainty – PT & TT Input parameters

Pressure transmitter – Input parameters

Uncertainty of pressure transmitter (bar, k=2)	Uncertainty of fallback pressure (bar, k=2)
0.13	1

Note: Pressure uncertainty input in bar instead of %

Temperature transmitter – Input parameters

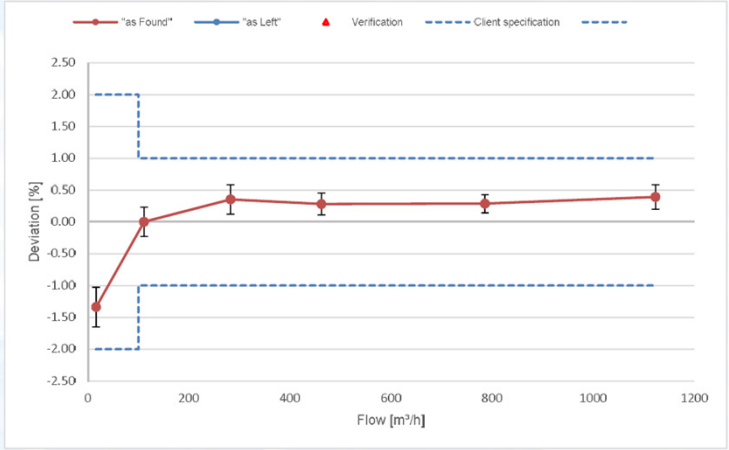
Uncertainty of temperature transmitter (degC, k=2)	Uncertainty of fallback temperature (degC, k=2)
0.15	0.5

Live Uncertainty – USM Input Parameters

Ultrasonic flow meter – input parameters

Test point	Flow rate (m3/h)	Deviation (%)	Uncertainty from repeatability during calibration, $u_{mut/dut}$ (%, k=1)	Overall calibration uncertainty, U_{TOT} (%, k=2)
1	16.541	-0.94	0.16	0.37
2	111.62	0.32	0.06	0.21
3	282.59	0.47	0.07	0.21
4	462.79	0.38	0.02	0.17
5	766.79	0.43	0.04	0.19
6	1123.9	0.49	0.05	0.19
7				
8				
9				
10				

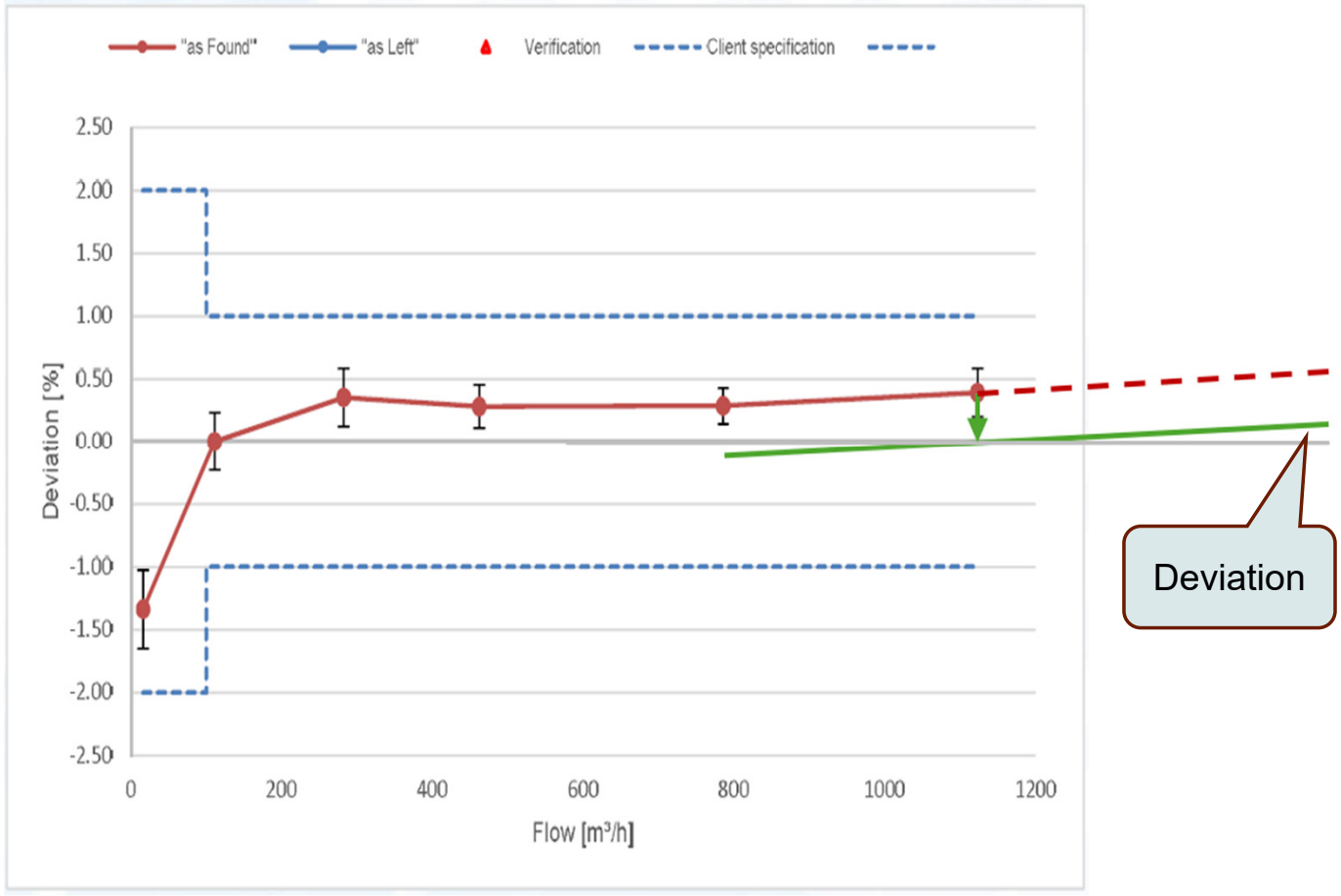
Uncertainty from repeatability during operation (%, k=2)	Uncertainty from field installation effects (%, k=2)
0.1	0.25



Calibration Result

Calibration / Verification Test run	Applied Reference Standard	Number of repeats [-]	Q [m³/h]	$v_{gas,mut}$ [m/s]	Observed deviation [%]	Deviation After Adj. [%]	u_{mut} [%]	U_{tot} [%]
Calibration	10	5	16.541	0.30	-0.94		0.16	0.37
Calibration	10	5	111.62	2.02	0.32		0.06	0.21
Calibration	10	6	282.59	5.11	0.47		0.07	0.21
Calibration	8	5	462.79	8.37	0.38		0.02	0.17
Calibration	8	5	766.79	14.24	0.43		0.04	0.19
Calibration	8	5	1123.9	20.34	0.49		0.05	0.19

Live Uncertainty – USM Input Parameters



Flow rate outside calibrated range

Q > Qcalmax

- Deviation (%) follows slope of two highest calibrated flow rates

Q < Qcalmin

- Deviation in flow rate (m3/h) for lowest calibration point constant for lower measured flow rates
- Limited to +/- 100%

Live Uncertainty – GC Input Parameters

Gas chromatograph – Input parameters

Component	Calibration gas composition (% mol)	Calibration gas uncertainty (% mol, k=2)	GC uncertainty from repeatability (% mol, k=2)	GC uncertainty from linearity (% mol, k=2)	GC uncertainty of fallback value (% mol, k=2)
C1	83.8390	0.02600	0.0047	0.0408	0.5
C2	8.8490	0.02200	0.0021	0.0173	0.2
C3	4.0700	0.01200	0.0030	0.0147	0.1
iC4	0.6547	0.00200	0.0005	0.0013	0.1
nC4	0.6557	0.00200	0.0004	0.0011	0.1
neoC5	0.0000	0.0000	0.0000	0.0000	0.1
iC5	0.0763	0.00048	0.0009	0.0003	0.1
nC5	0.0565	0.00038	0.0009	0.0002	0.1
C6+	0.0501	0.00060	0.0009	0.0001	0.05
N2	0.3134	0.00140	0.0001	0.0025	0.1
CO2	1.4333	0.00270	0.0008	0.0062	0.1

Composition entered on GC

From calibration gas certificate

From NORSOK I-106 GC Test

User entered

Live Uncertainty – Features

Included functions

- Reporting
  - Production report including uncertainties for mass, standard volume and energy (hourly, daily and monthly)
  - Detailed uncertainty report (hourly, daily and monthly)
  - Uncertainty parameter report
- Trending
- Alarming
- Audit trail

2024.12.01 11:00 **Hourly Report from 2024.12.01 10:00 to 2024.12.01 11:00** Page 1 of 2

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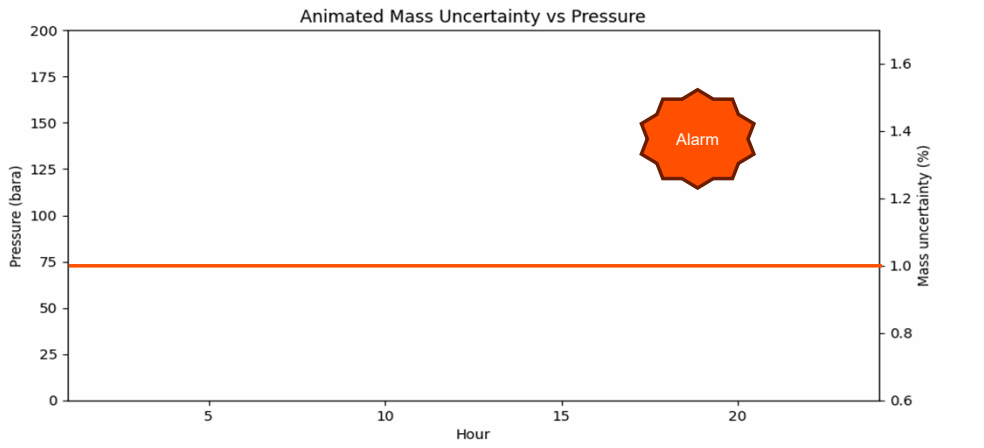

Live Uncertainty – Detailed Uncertainty Report

Example

Date	Hour from	Hour to
2024.12.01	10:00	11:00

Uncertainty Contributions Previous Hour

Mass Uncertainty (%, k=2)

Stream	Flow	Pressure	Temperature	Composition	Model	Total
1	0.xx	0.xx	0.xx	0.xx	0.xx	0.xx
2	0.xx	0.xx	0.xx	0.xx	0.xx	0.xx
3	0.xx	0.xx	0.xx	0.xx	0.xx	0.xx
Total						**0.83**

Reference Volume Uncertainty (%, k=2)

Stream	Flow	Pressure	Temperature	Composition	Model	Total
1	0.xx	0.xx	0.xx	0.xx	0.xx	0.xx
2	0.xx	0.xx	0.xx	0.xx	0.xx	0.xx
3	0.xx	0.xx	0.xx	0.xx	0.xx	0.xx
Total						**0.69**

Energy Uncertainty (%, k=2)

Stream	Flow	Pressure	Temperature	Composition	Model	Total
1	0.xx	0.xx	0.xx	0.xx	0.xx	0.xx
2	0.xx	0.xx	0.xx	0.xx	0.xx	0.xx
3	0.xx	0.xx	0.xx	0.xx	0.xx	0.xx
Total						**0.82**

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Thank you for listening!

Questions / comments?